

Faculty of Engineering

Engineering Properties of Solid and Laminated Glulam of *Acacia mangium* superbulk Planted in Sarawak

Nur Syahina binti Yahya

Doctor of Philosophy
2024

Engineering Properties of Solid and Laminated Glulam of *Acacia mangium* superbulk Planted in Sarawak

Nur Syahina binti Yahya

A thesis submitted

In fulfillment of the requirements for the degree of Doctor of Philosophy

(Civil and Structural Engineering)

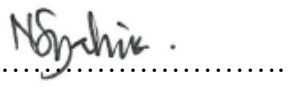
Faculty of Engineering

UNIVERSITI MALAYSIA SARAWAK

2024

DECLARATION

I declare that the work in this thesis entitled "Engineering Properties of Solid and Laminated Glulam of *Acacia mangium* superbulk Planted in Sarawak" was carried out in accordance with the regulations of Universiti Malaysia Sarawak. Expect where due acknowledgements have been made, the work is that of the author alone. The thesis has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.



……

Signature

Name: Nur Syahina binti Yahya

Matric No.: 15010149

Faculty of Engineering

Universiti Malaysia Sarawak

Date: 12th January 2024

ACKNOWLEDGEMENTS

With grateful and praise to Al-Mighty Allah S.W.T. with His companion, guidance, and Allah's wishes that this research has been completed successfully. The author would like to extend her gratitude to her supervisor Dr. Gaddafi bin Haji Ismaili, the most dedicated and supportive mentor. Your full attention and integrity in accomplishing this study are muchly appreciated. The author would like to express her sincere appreciation and thankfulness also to her co-supervisor, Dr. Haji Iskanda bin Haji Openg, for the support and advice. Much appreciation is given to the late Dr. Alik Duju who passed away on 26 July 2023, our expert from Applied Forest Science and Industry Development Division (AFSID) at Sarawak Forestry Corporation (SFC), who gave the author the best opportunity to conduct the research at SFC, may God blessed your soul. Not forgotten other SFC staff, including Mr. Nungah Liang, Mr. Willies Chin, Mr. Wong, Mr. Ibrahim, Mr. Teng Xin Yao, Mr. Simon, and Mr. Lai Jiew Kok, who assisted her in preparing samples, running the experiments, and even sharing their priceless experiences and knowledge. Utmost appreciation and thanks to Mr. Takeda on behalf of Daiken Plantation Bintulu Sdn. Bhd. for preparing logs samples for the research. The author would also likes to thank all plantation and sawmill staff from Samling Timber Sdn. Bhd. lead by Mr. Lionel Liew for his undivided support and contribution during sample preparation. Sincere gratitude to the all staffs of Civil Engineering Department, Faculty of Engineering and Centre of Graduate Studies, Universiti Malaysia Sarawak for assisting and giving the author opportunities to further her PhD studies. Thanks also to the Ministry of Higher Education (MoHE) MyBrain15 MyPhD for providing scholarships for the author's first three years of study. Finally, the author would like to express special thanks to her beloved husband, Mr. Mohd. Irshad Syafiq bin Azemi, daughter, Zarith Maryam binti Mohd. Irshad Syafiq, son, Luth Mateen bin Mohd. Irshad

Syafiq, father, Mr. Yahya bin Seman, mother, Madam Paridah binti Mustapha, brothers, Mr. Mohammad Zeirie bin Yahya and Mr. Mohammad Ruzaidie bin Yahya, sisters, Madam Nur Ezathul Faridza binti Yahya and Madam Nur Syahida binti Yahya and her younger brother, Mr. Mohammad Azwan bin Yahya, other family members, family in-laws, friends, and colleagues. Thank you for all the prayers, support, and sacrifices.

ABSTRACT

The slow growth rate of primer species has had an impact on the quantity available to meet market demand. To address this issue, a study was conducted to fully employ fast-growing timber as the principal resource in order to ensure that demand for timber logs remains stable. The purpose of this research was to study the engineering properties of *Acacia mangium* superbulk, a fast-growing timber species that planted in Daiken Plantation Bintulu, Sarawak with age groups of 7, 10 and 13 years old at air-dry moisture content. The small-clear samples were prepared in the form of solid and laminated (same age groups and different age groups) and set into untreated and treated for both solid and laminated sample products. The type of preservative and adhesive glue that have been used are *Copper Chrome Arsenic* (CCA) and *Phenol-resorcinol Formaldehyde* (PRF), respectively. The mechanical strength testing conducted are modulus of rupture (MOR), modulus of elasticity (MOE), compression parallel to grain and shear parallel to grain. This study also established the end-user applications in the timber industry based on density, hardwood category, strength grouping and hazard class. From the study, the maximum strength value of solid untreated is obtained by 10 years old, which is recorded the MOR, MOE, compression parallel to grain and shear parallel to grain are 115.11 N/mm^2, 14945 N/mm^2, 57.57 N/mm^2 and 14.24 N/mm^2, respectively. Besides that, the maximum strength value of solid treated is also obtained by 10 years old, which is recorded 118.76 N/mm^2, 15020 N/mm^2, 57.82 N/mm^2 and 13.67 N/mm^2 for MOR, MOE, compression parallel to grain and shear parallel to grain, respectively. For laminated samples, there is no significant difference in strength from laminated untreated products 10 // 10 years old when compared to solid untreated 10 years old, and the percentage differences obtained by MOR, MOE, compression parallel to grain and shear parallel to grain are 2.45%, 0.31%, 3.58% and 3.37%, respectively. Meanwhile,

the strength properties between laminated treated products 10 // 13 years old and solid treated 10 years old do not have any significant difference, and the percentage differences obtained by MOR, MOE, compression parallel to grain and shear parallel to grain are 3.37%, 0.06%, 3.91% and 1.17%, respectively. The treatment by CCA preservative shows the *Acacia mangium* superbulk is classified as moderately difficult to treat and hazard class of H4 (±14 litre/m^3). The density of *Acacia mangium* superbulk at air- dry condition is 0.61 g/cm^3 and its categorised as light hardwood. Moreover, the *Acacia mangium* superbulk is classified as Group B based on compression strength and Group A based on basic grading. The end-user utilisations of *Acacia mangium* superbulk are recommended for structural components, roofing, staircase, flooring, walling, door, window, and decorative panelling.

Keywords: fast-growing timber, small-clear, laminated glulam, modulus of rupture, modulus of elasticity, compression parallel to grain, shear parallel to grain, *Copper Chrome Arsenic* (CCA), *Phenol-resorcinol Formaldehyde* (PRF)

Sifat Kejuruteraan Pepejal dan Glulam Berlamina* Acacia mangium superbulk *yang ditanam di Sarawak

ABSTRAK

Kadar pertumbuhan perlahan species primer telah memberi kesan kepada kuantiti yang tersedia untuk memenuhi permintaan pasaran. Untuk menangani isu ini, satu kajian telah dijalankan untuk menggunakan sepenuhnya kayu yang tumbuh cepat sebagai sumber utama bagi memastikan permintaan terhadap kayu balak kekal stabil. Tujuan penyelidikan ini adalah untuk mengkaji sifat kejuruteraan Acacia mangium superbulk, *species kayu yang cepat tumbuh yang ditanam di* Daiken Plantation Bintulu, Sarawak *dengan kumpulan umur 7, 10, dan 13 tahun pada kandungan lembapan kering udara. Sampel-sampel ini disediakan dalam bentuk pepejal, berlamina (produk berlamina dengan kumpulan umur yang sama dan produk berlamina dengan kumpulan umur yang berbeza) dan juga disediakan dalam keadaan tidak dirawat dan dirawat. Bahan kimia yang digunakan untuk proses merawat sampel ialah* Copper Chrome Arsenic (CCA) *dan bahan gam yang digunakan untuk proses lamina ialah* Phenol-resornicol Formaldehdye (PRF). *Ujian-ujian mekanikal yang dijalankan ke atas sampel kayu adalah modulus pecah, modulus keanjalan, mampatan ira selari dan ricih ira selari. Kajian ini juga menetapkan aplikasi penggunaan kayu dalam industri kayu berdasarkan kepada ketumpatan kayu, kategori kayu keras, kumpulan kekuatan kayu dan kelas bahaya. Daripada kajian ini, nilai kekuatan maksimum sampel pepejal yang tidak dirawat adalah diperoleh daripada kumpulan umur 10 tahun yang masing – masing mencatatkan modulus pecah, modulus keanjalan, mampatan ira selari dan ricih ira selari sebanyak 115.11 N/mm^2, 14945 N/mm^2, 57.57 N/mm^2 dan 14.24 N/mm^2. Selain itu, nilai kekuatan maksimum bagi sampel pepejal yang dirawat juga diperoleh daripada kumpulan umur 10 tahun dengan mencatatkan nilai masing-masing iaitu 118.76*

N/mm^2, 15020 N/mm^2, 57.82 N/mm^2 dan 13.67 N/mm^2 untuk modulus pecah, modulus keanjalan, mampatan ira selari dan ricih ira selari. Untuk sampel berlamina, tiada perbezaan sifat kekuatan yang signifikan diantara sampel tidak dirawat yang berumur 10 // 10 tahun dengan sampel pepejal yang tidak dirawat yang berumur 10 tahun dan peratusan perbezaan kekuatan tersebut ialah 2.45%, 0.31%, 3.58% dan 3.37% masing-masing untuk modulus pecah, modulus keanjalan, mampatan ira selari dan ricih ira selari. Sementara itu, sifat kekuatan diantara sampel produk berlamina dirawat yang berumur 10 // 13 tahun dan sampel pepejal dirawat yang berumur 10 tahun juga tidak mempunyai perbezaan yang signifikan, dan perbezaan peratusan yang diperoleh oleh modulus pecah, modulus keanjalan, mampatan ira selari dan ricih ira selari adalah 3.37%, 0.06%, 3.91% dan 1.17%. Disamping itu, rawatan yang menggunakan CCA menunjukkan Acacia mangium superbulk *diklasifikasikan sebagai kelas agak sukar dirawat dan kelas bahaya H4 (± 14 liter/m^3). Ketumpatan* Acacia mangium superbulk *dalam keadaan udara kering adalah 0.61 g/cm^3 dan dikategorikan sebagai kayu keras ringan. Pokok* Acacia mangium superbulk *dikelaskan dalam kumpulan kekuatan B berdasarkan kekuatan mampatan dan kumpulan A berdasarkan gred asas. Penggunaan* Acacia mangium superbulk *di dalam industri perkayuan disyorkan untuk digunakan sebagai komponen struktur, atap, tangga, lantai, dinding, pintu, tingkap dan panel hiasan.*

Kata kunci: *kayu cepat tumbuh, pepejal, glulam berlamina, modulus pecah, modulus keanjalan, mampatan ira selari dan ricih ira selari*, Copper Chrome Arsenic (CCA), Phenol-resorcinol Formaldehyde (PRF)

TABLE OF CONTENTS

		Page
DECLARATION		i
ACKNOWLEDGEMENTS		ii
ABSTRACT		iv
ABSTRAK		vi
TABLE OF CONTENTS		ix
LIST OF TABLES		xiii
LIST OF FIGURES		xxvi
LIST OF ABBREVIATION		xli
CHAPTER 1: INTRODUCTION		1
1.1	Background	1
1.2	Problem Statement	3
1.3	Objectives of Study	5
1.4	Chapter Outline	6
CHAPTER 2: LITERATURE REVIEW		7
2.1	Background	7
2.2	*Acacia mangium*	9
2.3	Physical Properties of *Acacia mangium*	13
2.4	Mechanical Properties of *Acacia mangium*	18
2.5	Strength Group	20
2.6	Treatment of *Acacia mangium*	23
2.7	Lamination of Acacia mangium	27

2.8 Decay and Damage Protection 31

2.9 The Applications of *Acacia mangium* 37

CHAPTER 3: METHODOLOGY 40

3.1 Background 40

3.2 E-numeration and Selection of Trees 40

3.3 Preparation of Sample 48

3.4 Physical Testing 58

3.5 Mechanical Testing 61

3.5.1 Static Bending 63

3.5.2 Compression Parallel to Grain 65

3.5.3 Shear Parallel to Grain 66

3.6 Treatability 68

3.7 Lamination 73

3.7.1 Tree's Pairing 78

3.8 Method to Rank the Strength Differences 79

3.9 Method of Analysis 79

CHAPTER 4: RESULTS, ANALYSIS AND DISCUSSIONS 81

4.1 Background 81

4.2 Solid-untreated of *Acacia mangium* superbulk 83

4.2.1 Moisture Content 83

4.2.2 Density 86

4.2.3 Basic Density 88

4.2.4 Static Bending 90

4.2.5 Compression Parallel to Grain 99

4.2.6 Shear Parallel to Grain 105

4.3 Solid-treated of *Acacia mangium* superbulk 113

4.3.1 Moisture Content 114

4.3.2 Density 114

4.3.3 Static Bending 118

4.3.4 Compression Parallel to Grain 126

4.3.5 Shear Parallel to Grain 132

4.4 Laminated-untreated Products of *Acacia mangium* superbulk 142

4.4.1 Moisture Content 143

4.4.2 Density 147

4.4.3 Basic Density 150

4.4.4 Static Bending by the Same Age Groups 155

4.4.5 Static Bending by the Different Age Groups 163

4.4.6 Compression Parallel to Grain by the Same Age Groups 171

4.4.7 Compression Parallel to Grain by the Different Age Groups 177

4.4.8 Shear Parallel to Grain by the Same Age Groups 182

4.4.9 Shear Parallel to Grain by the Different Age Groups 189

4.5 Laminated-treated Products of *Acacia mangium* superbulk 194

4.5.1 Moisture Content 194

4.5.2 Density 195

4.5.3 Static Bending by the Same Age Groups 202

4.5.4 Static Bending by the Different Age Groups 213

4.5.5 Compression Parallel to Grain by the Same Age Groups 223

4.5.6 Compression Parallel to Grain by the Different Age Groups 230

4.5.7 Shear Parallel to Grain in Tangential Direction by the Same Age Groups 236

4.5.8 Shear Parallel to Grain in Tangential Direction by the Different Age Groups 242

4.6 Treatability Retention of *Acacia mangium* superbulk 248

4.6.1 Solid 248

4.6.2 Laminated 252

4.7 Summary of Results 257

4.8 Factors Affecting Mechanical Strength Properties 260

4.8.1 Effect of Physical Properties 260

4.8.2 Effect of Maturity 264

4.8.3 Effect of Miscellaneous 265

4.9 Treatability Evaluation and Hazard Classification 266

CHAPTER 5: UTILISATION OF ACACIA MANGIUM SUPERBULK 271

5.1 Background 271

5.2 Percentage Difference of Mechanical Strength Properties to the Reference Point 271

5.3 Strength Grouping 275

5.3.1 Strength Grouping Based on Compression Parallel to Grain (Burgess, 1958) 275

5.3.2 Strength Grouping Based on Basic Grade (Air-dry Condition) (Chik, 1988) 276

5.4 The Recommendation for End-user Applications 277

CHAPTER 6: CONCLUSION AND RECOMMENDATION 283

6.1 Conclusions 283

6.2 Recommendations 287

REFERENCES 289

APPENDICES 306

LIST OF TABLES

		Page
Table 2.1	Classification of Malaysian Hardwood (Malaysia Timber Industry Board, 2019c)	8
Table 2.2	Growth characteristics of *Acacia mangium* superbulk at Different Ages (Adam et al., 2012)	14
Table 2.3	Mechanical Properties of *Acacia mangium* and *Acacia mangium* superbulk from Prior Study	19
Table 2.4	Dry-grade Stress for Various Strength Groups of Timber	20
Table 2.5	Strength Grouping (Burgess, 1958; Ashaari, 2017)	20
Table 2.6	Probability Values for Determination of Basic Stresses (Chik, 1988a)	21
Table 2.7	Factors of Safety for Determining Basic Stresses (Chik, 1988a)	21
Table 2.8	Strength Ratio (Pun et al., 1997)	22
Table 2.9	Strength Groups Based on Basic Grade (Air-dry Condition) (Chik, 1988a)	23
Table 2.10	Treatability Classification (Malaysian Standard, 2006)	24
Table 2.11	Hazard Class Selection Guide Extracted from Malaysian Standard (2003) and Malaysian Standard (2006)	25
Table 2.12	Treatability Retention of *Acacia mangium* (Lai and Sammy, 2014)	26
Table 2.13	Treatability Retention of *Acacia mangium* (Salmiah et al., 2011)	26
Table 2.14	Mechanical Properties of Lamination of *Acacia mangium* (Suryono, 2015)	31
Table 2.15	Strength Groups of Timber and Applications, (Malaysia Timber	38

	Industry Board, 2019b)	
Table 2.16	Density Groups of Hardwood and its Applications (Sulaiman and Lim, 2004)	39
Table 3.1	Description of Locality and Plot Area of 7, 10, and 13 Years Old	43
Table 3.2	Summary of the Inventoried Trees	44
Table 3.3	Grouping and Batches of *Acacia mangium* superbulk Plot 1	45
Table 3.4	Grouping and Batches of *Acacia mangium* superbulk Plot 2	46
Table 3.5	Grouping and Batches of *Acacia mangium* superbulk Plot 3	47
Table 3.6	Tree's Pairing for Lamination	78
Table 4.1	Moisture Content (Solid-untreated) of *Acacia mangium* superbulk	84
Table 4.2	One-way ANOVA Moisture Content (Solid-untreated) of *Acacia mangium* superbulk	84
Table 4.3	DMRT of Moisture Content (Solid-untreated) of *Acacia mangium* superbulk	85
Table 4.4	DMRT of Moisture Content (Solid-untreated) of *Acacia mangium* superbulk	86
Table 4.5	One-way ANOVA Density (Solid-untreated) of *Acacia mangium* superbulk	87
Table 4.6	DMRT of Density (Solid-untreated) of *Acacia mangium* superbulk	87
Table 4.7	One-way ANOVA of Basic Density (Solid-untreated) of *Acacia mangium* superbulk	89
Table 4.8	DMRT of Basic Density (Solid-untreated) of *Acacia mangium* superbulk	89
Table 4.9	One-way ANOVA of MOR and MOE (Solid-untreated) of *Acacia*	92

mangium superbulk

Table 4.10 DMRT of MOR (Solid-untreated) of *Acacia mangium* superbulk 93

Table 4.11 DMRT of MOE (Solid-untreated) of *Acacia mangium* superbulk 93

Table 4.12 Maximum Load of Static Bending (Solid-untreated) of *Acacia mangium* superbulk 94

Table 4.13 Comparison of Static Bending between *Acacia mangium* and *Acacia mangium* superbulk (Solid-untreated) 98

Table 4.14 One-way ANOVA of Compression Parallel to Grain (Solid-untreated) of *Acacia mangium* superbulk 101

Table 4.15 DMRT of Compression Parallel to Grain (Solid-untreated) of *Acacia mangium* superbulk 101

Table 4.16 Maximum Load of Compression Parallel to Grain (Solid-untreated) of *Acacia mangium* superbulk 102

Table 4.17 Comparison of Compression Parallel to Grain between *Acacia mangium* and *Acacia mangium* superbulk (Solid-untreated) 104

Table 4.18 One-way ANOVA of Shear Parallel to Grain (Solid-untreated) of *Acacia mangium* superbulk 108

Table 4.19 DMRT of Shear Parallel to Grain in Radial Plane (Solid-untreated) of *Acacia mangium* superbulk 108

Table 4.20 DMRT of Shear Parallel to Grain in Tangential Plane (Solid-untreated) of *Acacia mangium* superbulk 109

Table 4.21 Maximum Load of Shear Parallel to Grain (Solid-untreated) of *Acacia mangium* superbulk 109

Table 4.22 Density Before and After Treatment (Solid-treated) of 115

Acacia mangium superbulk

Table 4.23 One-way ANOVA of Density Before Treatment (Solid-treated) of *Acacia mangium* superbulk 116

Table 4.24 DMRT of Density Before Treatment (Solid-treated) of *Acacia mangium* superbulk 116

Table 4.25 One-way ANOVA of Density After Treatment (Solid-treated) of *Acacia mangium* superbulk 117

Table 4.26 DMRT of Density After Treatment (Solid-treated) of *Acacia mangium* superbulk 117

Table 4.27 One-way ANOVA of MOR and MOE (Solid-treated) of *Acacia mangium* superbulk 120

Table 4.28 DMRT of MOR (Solid-treated) of *Acacia mangium* superbulk 120

Table 4.29 DMRT of MOE (Solid-treated) of *Acacia mangium* superbulk 120

Table 4.30 Maximum Load of Static Bending (Solid-treated) of *Acacia mangium* superbulk 121

Table 4.31 One-way ANOVA of Compression Parallel to Grain (Solid-treated) of *Acacia mangium* superbulk 128

Table 4.32 DMRT of Compression Parallel to Grain (Solid-treated) of *Acacia mangium* superbulk 128

Table 4.33 Maximum Load of Compression Parallel to Grain (Solid-treated) of *Acacia mangium* superbulk 129

Table 4.34 One-way ANOVA of Shear Parallel to Grain (Solid-treated) of *Acacia mangium* superbulk 134

Table 4.35 DMRT of Shear Parallel to Grain in Radial Plane (Solid- 135

treated) of *Acacia mangium* superbulk

Table 4.36 DMRT of Shear Parallel to Grain in Tangential Plane (Solid-treated) of *Acacia mangium* superbulk 135

Table 4.37 Maximum Load of Shear Parallel to Grain (Solid-treated) of *Acacia mangium* superbulk 136

Table 4.38 Moisture Content of the Same Age Groups of *Acacia mangium* superbulk (Laminated-untreated Products) 144

Table 4.39 One-way ANOVA of Moisture Content by the Same Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk 144

Table 4.40 DMRT of Moisture Content by the Same Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk 145

Table 4.41 Moisture Content of the Different Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk 145

Table 4.42 One-way ANOVA of Moisture Content by the Different Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk 146

Table 4.43 DMRT of Moisture Content by the Different Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk 146

Table 4.44 One-way ANOVA of Moisture Content by the Same Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk 148

Table 4.45 DMRT of Density by the Same Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk 148

Table 4.46 One-way ANOVA of Density by the Different Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk 150

Table 4.47 DMRT of Density by the Different Age Groups (Laminated- 150

	untreated Products) of *Acacia mangium* superbulk	
Table 4.48	One-way ANOVA of Basic Density by the Same Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk	152
Table 4.49	DMRT of Basic Density by the Same Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk	152
Table 4.50	One-way ANOVA of Basic Density by the Different Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk	154
Table 4.51	DMRT of Basic Density by the Different Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk	154
Table 4.52	One-way ANOVA of MOR and MOE by the Same Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk	157
Table 4.53	DMRT of MOR by the Same Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk	158
Table 4.54	DMRT of MOE by the Same Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk	158
Table 4.55	Maximum Load of Static Bending by the Same Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk	158
Table 4.56	One-way ANOVA of MOR and MOE by the Different Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk	166
Table 4.57	DMRT of MOR by the Different Age Groups (Laminated-Untreated Products) of *Acacia mangium* superbulk	167
Table 4.58	DMRT of MOE by the Different Age Groups (Laminated-Untreated Products) of *Acacia mangium* superbulk	167
Table 4.59	Maximum Load of Static Bending by the Different Age Groups	167

(Laminated-untreated Products) of *Acacia mangium* superbulk

Table 4.60 One-way ANOVA of Compression Parallel to Grain by the Same Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk 173

Table 4.61 DMRT of Compression Parallel to Grain by the Same Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk 173

Table 4.62 Maximum Load of Compression Parallel to Grain by the Same Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk 174

Table 4.63 One-way ANOVA of Compression Parallel to Grain by the Same Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk 178

Table 4.64 DMRT of Compression Parallel to Grain by the Same Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk 179

Table 4.65 Maximum Load of Compression Parallel to Grain by the Same Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk 180

Table 4.66 One-way ANOVA of Shear Strength by the Same Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk 184

Table 4.67 DMRT of Shear Strength by the Same Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk 185

Table 4.68 Maximum Load of Shear Strength by the Same Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk 186

Table 4.69 One-way ANOVA of Shear Strength by the Different Age Groups 191

(Laminated-untreated Products) of *Acacia mangium* superbulk

Table 4.70 DMRT of Shear Strength by the Different Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk 192

Table 4.71 Maximum Load of Shear Strength by the Different Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk 192

Table 4.72 One-way ANOVA of Density Before Treatment by the Same Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk 196

Table 4.73 DMRT of Density Before Treatment by the Same Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk 197

Table 4.74 One-way ANOVA of Density After Treatment by the Same Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk 198

Table 4.75 DMRT of Density After Treatment by the Same Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk 198

Table 4.76 One-way ANOVA of Density Before Treatment by the Different Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk 200

Table 4.77 DMRT of Density Before Treatment by the Different Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk 200

Table 4.78 One-way ANOVA of Density After Treatment by the Different Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk 202

Table 4.79 DMRT of Density After Treatment by the Different Age Groups 202

(Laminated-treated Products) of *Acacia mangium* superbulk

Table 4.80 One-way ANOVA of MOR and MOE by the Same Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk 205

Table 4.81 DMRT of MOR by the Same Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk 205

Table 4.82 DMRT of MOE by the Same Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk 206

Table 4.83 Maximum Load of Static Bending by the Same Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk 206

Table 4.84 One-way ANOVA of MOR and MOE by the Different Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk 215

Table 4.85 DMRT of MOR by the Different Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk 216

Table 4.86 DMRT of MOE by the Different Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk 216

Table 4.87 Maximum Load of Static Bending by the Different Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk 217

Table 4.88 One-way ANOVA of Compression Parallel to Grain by the Same Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk 225

Table 4.89 DMRT of Compression Parallel to Grain by the Same Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk 225

Table 4.90 Maximum Load of Compression Parallel to Grain by the Same Age Groups (Laminated-treated Products) of 226

Acacia mangium superbulk

Table 4.91 One-way ANOVA of Compression Parallel to Grain by the Different Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk 231

Table 4.92 DMRT of Compression Parallel to Grain by the Different Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk 232

Table 4.93 Maximum Load of Compression Parallel to Grain by the Different Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk 233

Table 4.94 One-way ANOVA of Shear Parallel to Grain in Tangential Direction by the Same Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk 237

Table 4.95 DMRT of Shear Parallel to Grain in Tangential Direction by the Same Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk 238

Table 4.96 Maximum Load of Shear Parallel to Grain in Tangential Direction by The Same Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk 238

Table 4.97 One-way ANOVA of Shear Parallel to Grain in Tangential Direction by the Different Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk 244

Table 4.98 DMRT of Shear Parallel to Grain in Tangential Direction by the Different Age Groups (Laminated-treated Products) of 244

Acacia mangium superbulk

Table 4.99 Maximum Load of Shear Parallel to Grain in Tangential Direction by the Different Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk 245

Table 4.100 Treatability Retention Level on Solid *Acacia mangium* superbulk 249

Table 4.101 Dry-salt Retention on Solid *Acacia mangium* superbulk 249

Table 4.102 One-way ANOVA of Treatability Retention on Solid *Acacia mangium* superbulk 250

Table 4.103 DMRT of Treatability Retention on Solid *Acacia mangium* superbulk 251

Table 4.104 Comparison of Treatability Retention between Solid *Acacia* and *Acacia mangium* superbulk 251

Table 4.105 Treatability Retention Level on Laminated Products by the Same Age Groups of *Acacia mangium* superbulk 252

Table 4.106 Dry-salt Retention on Laminated Products by the Same Age Groups *Acacia mangium* superbulk 253

Table 4.107 One-way ANOVA of Treatability Retention on Laminated Products by the Same Age Groups of *Acacia mangium* superbulk 254

Table 4.108 DMRT of Treatability Retention on Laminated Products by the Same Age Groups of *Acacia mangium* superbulk 254

Table 4.109 Treatability Retention Level on Laminated Products by the Different Age Groups of *Acacia mangium* superbulk 255

Table 4.110 Dry-salt Retention on Laminated Products by the Different Age Groups of *Acacia mangium* superbulk 255

Table 4.111 One-way ANOVA of Treatability Retention on Laminated Products 256

by the Different Age Groups of *Acacia mangium* superbulk

Table 4.112 DMRT of Treatability Retention on Laminated Products by the Different Age Groups of *Acacia mangium* superbulk 257

Table 4.113 Summary Results for Physical and Mechanical Properties of Untreated Samples of *Acacia mangium* superbulk 258

Table 4.114 Summary Results for Physical and Mechanical Properties of Treated Samples of *Acacia mangium* superbulk 259

Table 4.115 Summary Results for Treatability Evaluation of *Acacia mangium* superbulk 260

Table 4.116 Comparison of Mechanical Strength Between Solid and Laminated Products Based on Moisture Content 263

Table 4.117 Comparison of Mechanical Strength Between Untreated and Treated 269

Table 5.1 Percentage Difference (%Δ) of Mechanical Properties Between 10 Years Old Solid Untreated and Laminated Untreated *Acacia mangium* superbulk Products at Air-dry Condition 272

Table 5.2 Percentage Difference (%Δ) of Mechanical Properties Between 10 Years Old Solid Treated and Laminated Treated *Acacia mangium* superbulk Products at Air-dry Condition 274

Table 5.3 Strength Grouping based on Compression Strength at Green Condition 276

Table 5.4 Strength Grouping based on Compression Strength at Air-dry Condition 277

Table 5.5 The Application of *Acacia mangium* superbulk Based on Hardwood Category at Air-dry Condition 278

Table 5.6 Strength-Based Grouping Recommendation Application for Air-Dry 280

	Condition for Solid and Laminated *Acacia mangium* superbulk Products	
Table 5.7	The Recommendation of Application Based on Hazard Class	281
Table 5.8	The Recommendation Sample Products Based on Strength and CCA Retention	282

LIST OF FIGURES

		Page
Figure 2.1	Cross-section of wood (Wiedenfoeft, 2005)	8
Figure 2.2	Bark of young *Acacia mangium* tree (Krisnawati et al., 2011)	11
Figure 2.3	Bark of old *Acacia mangium* tree (Krisnawati et al., 2011)	11
Figure 2.4	Inflorescence of *Acacia mangium* (Krisnawati et al., 2011)	12
Figure 2.5	Mature blackish-brown *Acacia mangium* pods (Krisnawati et al., 2011)	12
Figure 2.6	Termite attack - Drywood termite (Ismaili, 2012)	32
Figure 2.7	Termite attack - Subterranean termite (Ismaili, 2012)	33
Figure 2.8	Termite attack - Powder post beetle (Bostrychid) (Ismaili, 2012)	33
Figure 2.9	Termite attack - Carpenter bee (Ismaili, 2012)	34
Figure 2.10	Fungi attack - Blue stain (Ismaili, 2012)	34
Figure 2.11	Fungi attack - Soft rot (Ismaili, 2012)	35
Figure 2.12	Fungi attack - Mould (Ismaili, 2012)	35
Figure 2.13	Marine Borer attack - Nausitora dunlopei Wright (Ismaili, 2012)	36
Figure 2.14	Marine Borer attack - Martesia striata Linneaus (Ismaili, 2012)	36
Figure 3.1	Flow chart of research work	42
Figure 3.2	Plot 1, *Acacia mangium* superbulk (7 Years Old)	46
Figure 3.3	Plot 2, *Acacia mangium* superbulk (10 Years Old)	47
Figure 3.4	Plot 3, *Acacia mangium* superbulk (13 Years Old)	48
Figure 3.5	Timber Logs of *Acacia mangium* superbulk	49
Figure 3.6	Transferring the *Acacia mangium* superbulk Logs	49
Figure 3.7	Cutting the *Acacia mangium* superbulk Logs into the Board	50

Figure 3.8	Marking the *Acacia mangium* superbulk Board	50
Figure 3.9	Bundles of Sample's Board	51
Figure 3.10	Bundles of Sample's Board are Moved to Drying Room	51
Figure 3.11	Sorting According to Tree Number	52
Figure 3.12	Sample's Board is Stacked to Air-drying Process	52
Figure 3.13	Bundle of Timber Transfer to the Working Area	53
Figure 3.14	Ripping Process on the Side of Board	53
Figure 3.15	Marking Process for Ripping Process	54
Figure 3.16	Ripping Process from Board to Sticks	54
Figure 3.17	Sticks Going Through Second Planning	55
Figure 3.18	Marking Process on Sample's Sticks	55
Figure 3.19	Marking on Sticks According to the Type of Tests	56
Figure 3.20	Example Defect of Splay Knot	56
Figure 3.21	Example Defect of Margin Knot	57
Figure 3.22	Cutting Process According to the Type of Test	57
Figure 3.23	MC Obtained by a Moisture Meter	59
Figure 3.24	Moisture Content Obtained by the Oven-dry Method	59
Figure 3.25	Flow Chart of Physical Test	61
Figure 3.26	Instron 5569 Universal Testing Machine	62
Figure 3.27	Dimensions of Mechanical Properties Test	62
Figure 3.28	Static Bending Test by Three-point Bending Method (Gaddafi, 2012)	63
Figure 3.29	Static Bending Set-up in Laboratory	64
Figure 3.30	Compression Parallel to Grain Test (Tan et al., 2010)	65
Figure 3.31	Shear Parallel to Grain Test (Tan et al., 2010)	66

Figure 3.32	Flow Chart of Mechanical Test	67
Figure 3.33	Timber Treatability Test Vacuum Desiccators Set-up (Tan et al., 2010)	69
Figure 3.34	Treatment Process Machine	69
Figure 3.35	Flow Chart of the Treatability Test	72
Figure 3.36	Preparation of PRF Glue	74
Figure 3.37	PRF Glue Mix-stir with Hardener	75
Figure 3.38	Applying the Glue on the Surface Sample's Planks	75
Figure 3.39	Press the Sample's Plank using Pressing Jig	76
Figure 3.40	Illustration of Preparing Sample	76
Figure 3.41	Flow Chart of Lamination Test	77
Figure 4.1	Density (Solid-untreated) of *Acacia mangium* superbulk	86
Figure 4.2	Basic Density (Solid-untreated) of *Acacia mangium* superbulk	88
Figure 4.3	MOR Against Age Groups (Solid-untreated) of *Acacia mangium* Superbulk	91
Figure 4.4	MOE Against Age Groups (Solid-untreated) of *Acacia mangium* Superbulk	91
Figure 4.5	MOR Against Basic Density for 7 Years Old (Solid-untreated) of *Acacia mangium* superbulk	95
Figure 4.6	MOE Against Basic Density for 7 Years Old (Solid-untreated) of *Acacia mangium* superbulk	95
Figure 4.7	MOR Against Basic Density for 10 Years Old (Solid-untreated) of *Acacia mangium* superbulk	96
Figure 4.8	MOE Against Basic Density for 10 Years Old (Solid-untreated) of	96

Acacia mangium superbulk

Figure 4.9 MOR Against Basic Density for 13 Years Old (Solid-untreated) of *Acacia mangium* superbulk 97

Figure 4.10 MOE Against Basic Density for 13 Years Old (Solid-untreated) of *Acacia mangium* superbulk 97

Figure 4.11 Compression Parallel to Grain Against Age Groups (Solid-untreated) of *Acacia mangium* superbulk 100

Figure 4.12 Compression Parallel to Grain Against Basic Density for 7 Years Old (Solid-untreated) of *Acacia mangium* superbulk 103

Figure 4.13 Compression Parallel to Grain Against Basic Density for 10 Years Old (Solid-untreated) of *Acacia mangium* superbulk 103

Figure 4.14 Compression Parallel to Grain Against Basic Density for 13 Years Old (Solid-untreated) of *Acacia mangium* superbulk 104

Figure 4.15 Shear Parallel to Grain Against Age Groups (Solid-untreated) of *Acacia mangium* superbulk 106

Figure 4.16 Shear Parallel to Grain Against Basic Density for 7 Years Old at Radial Plane (Solid-untreated) of *Acacia mangium* superbulk 110

Figure 4.17 Shear Parallel to Grain Against Basic Density for 7 Years Old at Tangential Plane (Solid-untreated) of *Acacia mangium* superbulk 111

Figure 4.18 Shear Parallel to Grain Against Basic Density for 10 Years Old at Radial Plane (Solid-untreated) of *Acacia mangium* superbulk 111

Figure 4.19 Shear Parallel to Grain Against Basic Density for 10 Years Old at Tangential Plane (Solid-untreated) of *Acacia mangium* superbulk 112

Figure 4.20 Shear Parallel to Grain Against Basic Density for 13 Years Old at 112

	Radial Plane (Solid-untreated) of *Acacia mangium* superbulk	
Figure 4.21	Shear Parallel to Grain Against Basic Density for 13 Years Old at Tangential Plane (Solid-untreated) of *Acacia mangium* superbulk	113
Figure 4.22	Density (Solid-before Treatment) of *Acacia mangium* superbulk	115
Figure 4.23	Density (Solid-before Treatment) of *Acacia mangium* superbulk	115
Figure 4.24	MOR Against Age Groups (Solid-treated) of *Acacia mangium* superbulk	119
Figure 4.25	MOE Against Age Groups (Solid-treated) of *Acacia mangium* superbulk	119
Figure 4.26	MOR Against Density for 7 Years Old (Solid-treated) of *Acacia mangium* superbulk	122
Figure 4.27	MOE Against Density for 7 Years Old (Solid-treated) of *Acacia mangium* superbulk	122
Figure 4.28	MOR Against Density for 10 Years Old (Solid-treated) of *Acacia mangium* superbulk	123
Figure 4.29	MOE Against Density for 10 Years Old (Solid-treated) of *Acacia mangium* superbulk	123
Figure 4.30	MOR Against Density for 13 Years Old (Solid-treated) of *Acacia mangium* superbulk	124
Figure 4.31	MOE Against Density for 13 Years Old (Solid-treated) of *Acacia mangium* superbulk	124
Figure 4.32	Comparison of MOR between Untreated and Treated of *Acacia mangium* superbulk	125
Figure 4.33	Comparison of MOE between Untreated and Treated of	125

Acacia mangium superbulk

Figure 4.34 Compression Parallel to Grain Against Age Groups (Solid-treated) of *Acacia mangium* superbulk 127

Figure 4.35 Compression Parallel to Grain Against Density for 7 Years Old (Solid-treated) of *Acacia mangium* superbulk 130

Figure 4.36 Compression Parallel to Grain Against Density for 10 Years Old (Solid-treated) of *Acacia mangium* superbulk 130

Figure 4.37 Compression Parallel to Grain Against Density for 13 Years Old (Solid-treated) of *Acacia mangium* superbulk 131

Figure 4.38 Comparison of Compression Parallel to Grain between Untreated and Treated (Solid-treated) of *Acacia mangium* superbulk 131

Figure 4.39 Shear Parallel to Grain Against Age Groups (Solid-treated) of *Acacia mangium* superbulk 133

Figure 4.40 Shear Parallel to Grain Against Density for 7 Years Old at Radial Plane (Solid-treated) of *Acacia mangium* superbulk 137

Figure 4.41 Shear Parallel to Grain Against Density for 7 Years Old at Tangential Plane (Solid-treated) of *Acacia mangium* superbulk 137

Figure 4.42 Shear Parallel to Grain Against Density for 10 Years Old at Radial Plane (Solid-treated) of *Acacia mangium* superbulk 138

Figure 4.43 Shear Parallel to Grain Against Density for 10 Years Old at Tangential Plane (Solid-treated) of *Acacia mangium* superbulk 138

Figure 4.44 Shear Parallel to Grain Against Density for 13 Years Old at Radial Plane (Solid-treated) of *Acacia mangium* superbulk 139

Figure 4.45 Shear Parallel to Grain Against Density for 13 Years Old at 141

	Tangential Plane (Solid-treated) of *Acacia mangium* superbulk	
Figure 4.46	Comparison of Shear Parallel to Grain between Untreated and Treated (Radial) of *Acacia mangium* superbulk	141
Figure 4.47	Comparison of Shear Parallel to Grain between Untreated and Treated (Tangential) of *Acacia mangium* superbulk	141
Figure 4.48	The Illustration of the Glue-laminated Sample Products (single-layer laminated) of *Acacia mangium* superbulk	142
Figure 4.49	Density of the Same Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk	147
Figure 4.50	Density of the Different Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk	149
Figure 4.51	Basic Density of the Same Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk	151
Figure 4.52	Basic Density of the Different Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk	153
Figure 4.53	MOR Against Age Groups, Same Age Groups (Laminated-Untreated Products) of *Acacia mangium* superbulk	156
Figure 4.54	MOE Against Age Groups, Same Age Groups (Laminated-Untreated Products) of *Acacia mangium* superbulk	156
Figure 4.55	MOR Against Basic Density for 7 // 7 Years Old (Laminated-Untreated Products) of *Acacia mangium* superbulk	159
Figure 4.56	MOE Against Basic Density for 7 // 7 Years Old (Laminated-Untreated Products) of *Acacia mangium* superbulk	160
Figure 4.57	MOR Against Basic Density for 10 // 10 Years Old (Laminated-	160

	untreated Products) of *Acacia mangium* superbulk	
Figure 4.58	MOR Against Basic Density for 10 // 10 Years Old (Laminated-untreated Products) of *Acacia mangium* superbulk	161
Figure 4.59	MOR Against Basic Density for 13 // 13 Years Old (Laminated-untreated Products) of *Acacia mangium* superbulk	161
Figure 4.60	MOE Against Basic Density for 13 // 13 Years Old (Laminated-untreated Products) of *Acacia mangium* superbulk	162
Figure 4.61	Comparison of MOR between Solid-untreated and Laminated-untreated Products of *Acacia mangium* superbulk	163
Figure 4.62	Comparison of MOE between Solid-untreated and Laminated-untreated Products of *Acacia mangium* superbulk	163
Figure 4.63	MOR Against Age Groups, Different Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk	164
Figure 4.64	MOE Against Age Groups, Different Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk	165
Figure 4.65	MOR Against Basic Density for 7 // 10 Years Old (Laminated-untreated Products) of *Acacia mangium* superbulk	168
Figure 4.66	MOE Against Basic Density for 7 // 10 Years Old (Laminated-untreated Products) of *Acacia mangium* superbulk	169
Figure 4.67	MOR Against Basic Density for 7 // 13 Years Old (Laminated-untreated Products) of *Acacia mangium* superbulk	169
Figure 4.68	MOE Against Basic Density for 7 // 13 Years Old (Laminated-untreated Products) of *Acacia mangium* superbulk	170
Figure 4.69	MOR Against Basic Density for 10 // 13 Years Old (Laminated-	170

	untreated Products) of *Acacia mangium* superbulk	
Figure 4.70	MOE Against Basic Density for 10 // 13 Years Old (Laminated-untreated Products) of *Acacia mangium* superbulk	171
Figure 4.71	Compression Parallel to Grain Against Age Groups, Same Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk	172
Figure 4.72	Compression Parallel to Grain Against Basic Density for 7 // 7 Years Old (Laminated-untreated Products) of *Acacia mangium* superbulk	175
Figure 4.73	Compression Parallel to Grain Against Basic Density for 10 // 10 Years Old (Laminated-untreated Products) of *Acacia mangium* superbulk	175
Figure 4.74	Compression Parallel to Grain Against Basic Density for 13 // 13 Years Old (Laminated-untreated Products) of *Acacia mangium* superbulk	176
Figure 4.75	Comparison of Compression Parallel to Grain between Solid-untreated and Laminated-untreated Products of *Acacia mangium* superbulk	177
Figure 4.76	Compression Parallel to Grain Against Age Groups, Different Age Groups (Laminated-untreated) of *Acacia mangium* superbulk	178
Figure 4.77	Compression Parallel to Grain Against Basic Density for 7 // 10 Years Old (Laminated-untreated Products) of *Acacia mangium* Superbulk	181
Figure 4.78	Compression Parallel to Grain Against Basic Density for 7 // 13	181

	Years Old (Laminated-untreated Products) of *Acacia mangium* superbulk	
Figure 4.79	Compression Parallel to Grain Against Basic Density for 10 // 13 Years Old (Laminated-untreated Products) of *Acacia mangium* superbulk	182
Figure 4.80	Shear Test on Laminate Sample	183
Figure 4.81	Shear Strength Against Age Groups, Same Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk	184
Figure 4.82	Shear Strength Against Basic Density for 7 // 7 Years Old (Laminated-untreated Products) of *Acacia mangium* superbulk	187
Figure 4.83	Shear Strength Against Basic Density for 10 // 10 Years Old (Laminated-untreated Products) of *Acacia mangium* superbulk	187
Figure 4.84	Shear Strength Against Basic Density for 13 // 13 Years Old (Laminated-untreated Products) of *Acacia mangium* superbulk	188
Figure 4.85	Comparison of Shear Parallel to Grain between Solid-untreated and Laminated-untreated Products of *Acacia mangium* superbulk	189
Figure 4.86	Shear Strength Against Age Groups, Different Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk	190
Figure 4.87	Shear Strength Against Basic Density for 7 // 10 Years Old (Laminated-untreated Products) of *Acacia mangium* superbulk	193
Figure 4.88	Shear Strength Against Basic Density for 7 // 13 Years Old (Laminated-untreated Products) of *Acacia mangium* superbulk	193
Figure 4.89	Shear Strength Against Basic Density for 10 // 13 Years Old (Laminated-untreated Products) of *Acacia mangium* superbulk	194

Figure 4.90	Density Before Treatment of the Same Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk	195
Figure 4.91	Density After Treatment of the Same Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk	197
Figure 4.92	Density Before Treatment of the Different Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk	199
Figure 4.93	Density After Treatment of the Different Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk	201
Figure 4.94	MOR Against Age Groups, Same Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk	204
Figure 4.95	MOE Against Age Groups, Same Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk	204
Figure 4.96	MOR Against Density for 7 // 7 Years Old (Laminated-treated Products) of *Acacia mangium* superbulk	207
Figure 4.97	MOE Against Density for 7 // 7 Years Old (Laminated-treated Products) of *Acacia mangium* superbulk	207
Figure 4.98	MOR Against Density for 10 // 10 Years Old (Laminated-treated Products) of *Acacia mangium* superbulk	208
Figure 4.99	MOE Against Density for 10 // 10 Years Old (Laminated-treated Products) of *Acacia mangium* superbulk	208
Figure 4.100	MOR Against Density for 13 // 13 Years Old (Laminated-treated Products) of *Acacia mangium* superbulk	209
Figure 4.101	MOE Against Density for 13 // 13 Years Old (Laminated-treated Products) of *Acacia mangium* superbulk	209

Figure 4.102	Comparison of MOR between Laminated-untreated Products and Laminated-treated Products by Same Age Groups of *Acacia mangium* superbulk	210
Figure 4.103	Comparison of MOE between Laminated-untreated Products and Laminated-treated Products by Same Age Groups of *Acacia mangium* superbulk	211
Figure 4.104	Comparison of MOR between Solid-treated and Laminated-treated Products of *Acacia mangium* superbulk	213
Figure 4.105	Comparison of MOE between Solid-treated and Laminated-treated Products of *Acacia mangium* superbulk	215
Figure 4.106	MOR Against Age Groups, Different Age Groups (Laminated-treated) Products of *Acacia mangium* superbulk	214
Figure 4.107	MOE Against Age Groups, Different Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk	214
Figure 4.108	MOR Against Density for 7 // 10 Years Old (Laminated-treated Products) of *Acacia mangium* superbulk	218
Figure 4.109	MOE Against Density for 7 // 10 Years Old (Laminated-treated Products) of *Acacia mangium* superbulk	219
Figure 4.110	MOR Against Density for 7 // 13 Years Old (Laminated-treated Products) of *Acacia mangium* superbulk	219
Figure 4.111	MOE Against Density for 7 // 13 Years Old (Laminated-treated Products) of *Acacia mangium* superbulk	220
Figure 4.112	MOR Against Density for 10 // 13 Years Old (Laminated-treated Products) of *Acacia mangium* superbulk	220

Figure 4.113	MOE Against Density for 10 // 13 Years Old (Laminated-treated Products) of *Acacia mangium* superbulk	221
Figure 4.114	Comparison of MOR between Laminated-untreated Products and Laminated-treated Products by Different Age Groups of *Acacia mangium* superbulk	221
Figure 4.115	Comparison of MOE between Laminated-untreated Products and Laminated-treated Products by Different Age Groups of *Acacia mangium* superbulk	223
Figure 4.116	Compression Parallel to Grain Against Age Groups, Same Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk	224
Figure 4.117	Compression Parallel to Grain Against Density for 7 // 7 Years Old (Laminated-treated Products) of *Acacia mangium* superbulk	227
Figure 4.118	Compression Parallel to Grain Against Density for 10 // 10 Years Old (Laminated-treated Products) of *Acacia mangium* superbulk	227
Figure 4.119	Compression Parallel to Grain Against Density for 13 // 13 Years Old (Laminated-treated Products) of *Acacia mangium* superbulk	228
Figure 4.120	Comparison of Compression Parallel to Grain between Laminated-untreated Products and Laminated-treated Products by Same Age Groups of *Acacia mangium* superbulk	229
Figure 4.121	Comparison of Compression Parallel to Grain between Solid- treated and Laminated-treated Products by Same Age Groups of	230

Acacia mangium superbulk

Figure 4.122 Compression Parallel to Grain Against Age Groups, Different Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk 231

Figure 4.123 Compression Parallel to Grain Against Density for 7 // 10 Years Old (Laminated-treated Products) of *Acacia mangium* superbulk 233

Figure 4.124 Compression Parallel to Grain Against Density for 7 // 13 Years Old (Laminated-treated Products) of *Acacia mangium* superbulk 234

Figure 4.125 Compression Parallel to Grain Against Density for 10 // 13 Years Old (Laminated-treated Products) of *Acacia mangium* superbulk 234

Figure 4.126 Comparison of Compression Parallel to Grain between Solid- treated and Laminated-treated Products by Different Age Groups of *Acacia mangium* superbulk 235

Figure 4.127 Shear Parallel to Grain in Tangential Direction Against Age Groups, Same Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk 236

Figure 4.128 Shear Parallel to Grain in Tangential Direction Against Density for 7 // 7 Years Old (Laminated-treated Products) of *Acacia mangium* superbulk 239

Figure 4.129 Shear Parallel to Grain in Tangential Direction Against Density for 10 // 10 Years Old (Laminated-treated Products) of *Acacia mangium* superbulk 240

Figure 4.130 Shear Parallel to Grain in Tangential Direction Against Density for 13 // 13 Years Old (Laminated-treated Products) of 240

Acacia mangium superbulk

Figure 4.131 Comparison of Shear Parallel to Grain in Tangential Direction between Laminated-untreated Products and Laminated-treated Products by Same Age Groups of *Acacia mangium* superbulk 241

Figure 4.132 Comparison of Shear Parallel to Grain in Tangential Direction Between Solid-treated and Laminated-treated Products by Same Age Groups of *Acacia mangium* superbulk 241

Figure 4.133 Shear Parallel to Grain in Tangential Direction Against Age Groups, Different Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk 243

Figure 4.134 Shear Parallel to Grain in Tangential Direction Against Density for 7 // 10 Years Old (Laminated-treated Products) of *Acacia mangium* superbulk 246

Figure 4.135 Shear Parallel to Grain in Tangential Direction Against Density for 7 // 13 Years Old (Laminated-treated Products) of *Acacia mangium* superbulk 246

Figure 4.136 Shear Parallel to Grain in Tangential Direction Against Density for 10 // 13 Years Old (Laminated-treated Products) of *Acacia mangium* superbulk 247

Figure 4.137 Comparison of Shear Parallel to Grain in Tangential Direction between Laminated-untreated Products and Laminated-treated Products by Different Age Groups of *Acacia mangium* superbulk 247

LIST OF ABBREVIATIONS

ANOVA	Analysis of Variance
ASTM	American Society for Testing and Materials
BS	British Standard
CCA	Copper Chrome Arsenic
CV	Coefficient of Variance
DBH	diameter breast height
DMRT	Duncan's Multiple Range Test
DT	Destructive Test
ITTO	International Tropical Timber Organization
JAS	Japanese Agricultural Standards
MC	Moisture Content
MOE	Modulus of Elasticity
MOR	Modulus of Rupture
MS	Malaysian Standard
MTIB	Malaysian Timber Industry Board
PRF	Phenol-resorcinol Formaldehyde
SD	Standard Deviation
SG	Strength Group

CHAPTER 1

INTRODUCTION

1.1 Background

Timber is a renewable natural resource and one of the oldest known construction materials. It is commonly used in many applications such as structural buildings, ship buildings, bridges, railroad ties, flooring, cabinets, furniture, and indoor equipment. In Malaysia, forestry remains a significant economic activity. Log production in Malaysia is mainly to accommodate the huge demand for utility timber for industrial purposes (Ismaili, 2015). According to Ismaili et al. (2011), Malaysia's timber industries nowadays have involved into cores of plywood and rise the major constituent of fibreboard, particleboard, interior construction timber, and other low-grade use.

Timber is one of the construction materials that is becoming popular as it is a renewable natural resource. Timber is versatile and strong, not just because of the practical quality of the material but also due to its natural aesthetic. According to Yahya and Ismaili (2015), timber is a fascinating material because of its complex structure and wide application on earth. Unlike the common materials used in construction, such as concrete and steel, their raw materials are non-renewable and less sustainable. Timber is also a fibre-composite material that tends to perform due to its physical and mechanical properties.

The competition from other types of downstream products and the increasing demand for timber products cause the industry to have a shortage in timber supply. It was led by the Malaysian Timber Industry Board (MTIB) and participated by several other government agencies with timber-based industries that have shown a seriously commitment to

establishing the National Forest Plantation Programme (NFPP). This programme aims to produce a minimum 30 cm diameter breast height (DBH) tree within the period of 15 years, and NFPP earmarked one million ha of land in Sarawak for planted forests by the year 2020 (Cheng & Le Clue, 2010)

Rationale, the most basic reason of launching this programme is to meet the current and future demand from the timber industry without disregarding the conservation of natural forest. In the production, a period of 15 years, focusing on a fast-growing timber plantation is the best effort to encounter the pressures that come up. Sarawak is estimated to have more than 2500 tree species in the forest and most of Sarawak's commercial timber species fall into the hardwood category (Ismaili et al., 2013). However, this category of hardwood no longer sustained to the market demand (Ismaili et al., 2013).

According to Malaysia Timber Industry Board (2019a), NFPP lists nine (9) fast-growing species such as *Hevea brasilensis* (Rubberwood-timber Latex Clone), *Acacia* spp. (*mangium* and hybrid) *Tectona grandis* (Teak), *Azadirachta* (Sentang), *Khaya* spp. (*Khaya ivorensis and senegalensis*), *Neolamarckia cadamba* (Kelampayan), *Paraserianthes falcataria* (Batai*), Octomeles sumatrana* (Binuang), and, *Giganchloa* spp. (Bamboo). Out of nine species, the programme is mainly focused on two species, which are Rubberwood-timber Latex Clone and Acacia spp. From this point of view, the Sarawak Government takes a proactive measure to make sure the timber industry is progressing continually. Adam et al. (2012) stated that the State Government's commitment to sustainable forest management and the establishment of large commercial forest plantations are among the proactive measures to ensure the timber industry is a sunrise industry. Thus, 72 percent of the total planted forest areas in Sarawak belong to fast-grown Acacia species (Ting & Teng, 2014).

1.2 Problem Statement

The proactive action to relieve pressures on natural forests is to fully utilize the fast-growing timber species. One of the most critical strategies which can help improve the forest plantation is focusing on the rotation type of the trees in ecosystem of forests in Malaysia, (Hamid & Abiri, 2021) so that, the fast-growing timber trees can be used in very short rotation plantation with the aim of improving genetic gain, nursery techniques, preparation, and establishment of site-specific species, and improving silviculture treatment in the forest lands in Malaysia.

Among the fast-growing timber species, *Acacia mangium* has been planted widely in East Malaysia, particularly in Sarawak, primarily for wood-based industries such as plywood and medium-density fibreboard (MDF) (Adam et al., 2012). *Acacia mangium* is one of the major fast-growing species introduced by the National Forest Plantation Programme (NFPP). Various studies have been done on this species in Sarawak. Although there is a potential for the promotion of this fast-grown timber in the country, future challenges lie in the proper understanding of the basic and working properties of different age groups with respect to their end-uses. Adam et al. (2012) reported that the *Acacia mangium* plantations are anticipated to play important roles in maintaining the commercial supply of logs, thus reducing timber demand from the natural forest.

There are various types of research done on *Acacia mangium*, but not much study on *Acacia mangium* superbulk participates. *Acacia mangium* superbulk or *Acacia* superbulk is also known as the second generation of *Acacia mangium*. It is improved and selected plus tree as a result of a tree improvement programme (Jusoh et al., 2014). Thus, it is obligatory to study the selected plus tree from origin *Acacia mangium*, as ‘Superbulk’ trees have

superior characteristics in comparison to the first-generation in terms of high growth rate, high volume, good stem form and resistance to heart rot (Jusoh et al., 2014).

Compared to the origin of *Acacia mangium*, this study also investigated their physical and mechanical properties, including density, drying, preservative treatment, working properties, natural and processing defects, lamination, durability, end- uses etc. Many plantations now use genetically improved materials whose characters and properties have been improved through many years of selected planting (Adam et al., 2012). Hence, the essentiality to accomplish this research can execute more information on Acacia spp.

The *Acacia mangium* is known as the most admired planted fast-growing species (Ismaili et al., 2011a; Ismaili et al., 2022a). As mentioned in the previous research by Ismaili (2015), the origin of *Acacia mangium* timber is very well-known for producing attractive furniture and cabinets, door frames, window parts, mouldings, and sliced veneers. Therefore, this research can establish a variety of end-use of *Acacia* spp. by using the second generation of *Acacia mangium*.

According to Ting and Teng (2014), *Acacia mangium* has a higher frequency of defects such as knots and lower recovery compared to some timbers from natural forests, so lamination is a useful method to improve the recovery rate as well as higher grade timber by cross-cutting to remove defects and joining shorter piece of timbers together to produce the required length and width.

Regarding the demand of supply in current and future industries, the lamination technique to produce timber products with a wider range of sizes and quality timbers, hence could also contribute to a higher intended recovery rate and optimise the usage of raw materials (Ting & Teng, 2014). The appearances of laminated timber products also attract

the end-user. The finishing layers of laminated timber products are proficient in drawing more consumers to the timber industry. The previous studies are mostly limited to evaluating the mechanical strength of finger-jointing, not laminated. Most of the studies focus on which adhesive is best bonded to the timber species. The previous studies are mostly experimented the cross-laminated timber multiple layers with finger- jointing.

The study conducted by Alik et al., (2015) on the solid of the small clear sample shows differences in strength properties compared with different age groups of 7, 10 and 13 years old. The study conducted by Alik et al., (2015) should be continued further to investigate several factors in which hypotheses can be made that can influence the physical and mechanical properties of timber where the result can be an improvement of the timber or vice-versa. These factors cover the age of the timber, the physical form of timber, either in solid or laminated, and the condition of timber, either untreated or treated timber.

1.3 Objectives of Study

The aim of the research is to study the engineering properties of solid and laminated glulam of *Acacia mangium* superbulk planted in Sarawak. *Acacia mangium* superbulk timber age group of 7, 10 and 13 years old are collected from Bintulu, Sarawak. Engineering strength properties include the tests on air-dry condition of solid small-clear and air-dry laminated small clear specimens. Both solid and laminated specimens are undergoing physical testing and mechanical testing. A lamination study has used *Phenol-resorcinol Formaldehyde* (PRF) as a standard adhesive used in the timber-making industry. The strength properties are also derived from the treatability retention level of *Copper Chrome Arsenic* (CCA) preservative. Several objectives of the study are described as follows.

i. To determine the engineering properties of solid, laminated, untreated and treated *Acacia mangium* superbulk at air-dry condition and in different age groups,

ii. To analyse the strength performance of laminated with age arrangement as compared with solid (as reference) of *Acacia mangium* superbulk at air-dry condition,

iii. To classify the treatability retention level and hazard class of *Acacia mangium* superbulk at air-dry condition in different age groups, and

iv. To develop the end-user utilisation strength table and to recommend the best-laminated age arrangement of *Acacia mangium* superbulk.

1.4 Chapters Outline

Chapter 1 prefaces the background, problem statement and objectives of the study. Briefly introduce the Government's action and policy to implement the forest plantation programme for fast-growing timber in Sarawak. Next, Chapter 2 summarizes the details of previous studies, either from journals, books, case studies, or any trusted sources as support references with the current findings. Explain the native origin of timber species and analysing the strength properties from previous studies. Then, Chapter 3 presents the methodology and analysis that was involved in this study. Including the figures and flowcharts for overall experiments. Meanwhile, Chapter 4 presents the results and analysing the recorded data along with supportive data and discussions. Furthermore, Chapter 5 emphasizes the results and focuses on end-user utilisation of timber species in the commercial timber engineering. Lastly, Chapter 6 draws the conclusion of the study and presents the recommendations for further research and study.

CHAPTER 2

LITERATURE REVIEW

2.1 Background

This chapter discusses the literature review from previous research and findings covering the research's scope. Mainly, the sub-chapters pioneered the influential facts and data that help to endorse the current findings. The information obtained from the literature is important to support the research findings and discussion.

Kho et al. (1999) mentioned that wood is a biological material made up of long cells that are intricately interconnected for efficient support and transport of nutrients down and water up the trunk of a tree. Wood is also a hygroscopic material, able to adjust its moisture content to the humidity level of the environment it is placed in. In other words, dry wood placed in a wet environment will pick up moisture, whereas wet wood placed in a dry environment will lose moisture.

Generally, timbers are grouped into hardwood and softwood. However, the terms are not entirely correct since some softwoods are harder than some hardwoods (Calvert, 2009). Ashaari (2017) stated that Malaysian timbers are classified into four categories: heavy hardwood, medium hardwood, light hardwood, and softwood. The weight and hardness of wood are attributed to the density of the cells, the amount of lignin in the cell walls, and the percentage of tiny air spaces or pores within the cell walls (Ashaari, 2017). Table 2.1 represents the classification of three hardwoods in Malaysia.

Table 2.1: Classification of Malaysian Hardwood (Malaysia Timber Industry Board, 2019c)

Classification	Density Range, kg/m^3 (at 15 % Moisture Content)
Heavy hardwood	800 - 1120
Medium hardwood	720 – 880
Light hardwood	400 - 720

Figure 2.1 illustrates the cross-section of wood, including outer bark (ob), inner bark (ib), vascular cambium (vc), pith (P), sapwood and heartwood. The outer part is dead bark, which is a layer of dead tissue that acts as protection for the trunk and branches. It helps to reduce water loss from the living cells of the tree. Meanwhile, the inner bark is a layer of living tissue where food materials produced by the leaves are conducted through the live bark to the branches, trunk, and roots of the tree. (McKenzie, 2000).

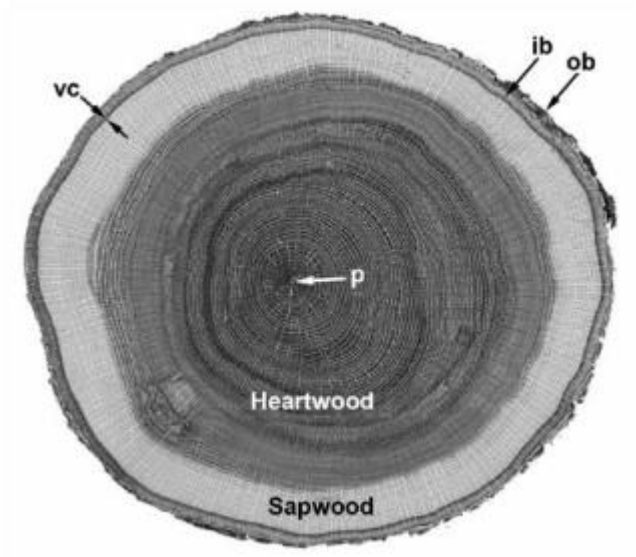


Figure 2.1: Cross-section of wood (Wiedenfoeft, 2005)

Another important element in tree growth is the vascular cambium. It is a single layer of living cells located between the inner bark and the wood in both softwoods and

hardwoods. These cells are responsible for increases in tree height and branch and root length, where the cells in the cambium reproduce by division and deposit identical new wood cells on the previous layer (Calvert, 2009).

Rajakaruna (2015) mentioned that sapwood is responsible for transferring water and nutrients from roots to leaves. It is less dense and lighter in colour. The sapwood is also susceptible to attack; hence, treatment is required. In other words, while a tree is young, the wood conducts water (or sap) up the tree, stores food for growth, and provides strength to the tree stem (Calvert, 2009). Later, as the tree grows in diameter, the cells toward the pith of the stem die. This core of dead cells around the pith is called heartwood (Calvert, 2009).

2.2 *Acacia mangium*

Acacia mangium is a species of the family *Leguminosae*, and it was first introduced into Sabah in 1967 as a fire-break species before it was introduced into Peninsular Malaysia through the Compensatory Forest Plantation Programme (CFPP) in 1982 (Lim et al., 2003). Sahri et al. (1998) mentioned that *Acacia mangium* is a sub-family of *Mimosoideae* that was native to north Queensland, Australia and also found in Papua New Guinea and the Molucas Islands of Indonesia. The common names for it include Black Wattle, Hickory Wattle and Mangium (Ismaili et al., 2011a; Ismaili et al., 2022a). Besides that, other common names of *Acacia mangium* are Brown Salwood, Sabah Salwood (Australia, England), Arr (Papua New Guinea), Maber (Philippines), Zamorano (Spain), and Kra Thin Epa (Thailand) (Krisnawati et al., 2011). Yamamoto et al. (2003) also stated that *Acacia mangium* occurs naturally in Queensland, Australia, Papua New Guinea, the Islands of Sula, Ceram, Aru, and Irian Jaya.

It was stated that the logs of *Acacia mangium*, when taken from well-pruned trees, can be quite straight (Lim et al., 2003). Sapwood is pale yellow to straw-coloured and distinct

from heartwood, which is light to dark brown. The planed surface is not particularly lustrous. Growth rings are indistinct or absent. The texture is fine to moderately coarse and even. Grain is usually straight, sometimes interlocked. *Acacia mangium* trees are generally large and can grow to a height of 30 m, with a straight-bole that may be more than half of the total tree height. (Krisnawati et al., 2011). In the study that has been done by Yang and Voon (2014), the sapwood of *Acacia mangium* is whitish to creamy yellow and sharply differentiated from the heartwood, which is light yellowish-brown with olive cast to light red-brown. The grain is straight to shallowly interlocked, sometimes sloping. Its texture is moderately fine and sometimes uneven. The flatsawn surface presents a faint, vague growth ring while showing a stripe figure on the quarter-sawn surface. (Yang & Voon, 2014).

As stated by Krisnawati et al. (2011), *Acacia mangium* wood is diffuse and porous. The sapwood of *Acacia mangium* is narrow and light-coloured. The grain is straight to shallowly interlocked; the texture is fine to medium and even. Its heartwood is medium-brown, hard, strong and durable in well-ventilated situations, although not in ground contact (Krisnawati et al., 2011). Moreover, according to Krisnawati et al. (2011) also stated that bark in young *Acacia mangium* trees (Figure 2.2) is smooth and greenish as fissures begin to develop at 2-3 years, while bark in older trees (Figure 2.3) is rough, hard and fissures near to base, and coloured brown to dark brown. It also has a mild flower with a sweet fragrance (Figure 2.4). After fertilisation, the flower develops into a green pod that darkens to blackish-brown at maturity (Krisnawati et al., 2011). They also specified that the seeds are black and shiny with shapes ranging from longitudinal, elliptical, and ovate to oblong with a size of 3-5 mm by 2-3 m (Figure 2.5). The seeds are attached to the pods by an orange to red folded funicle.



Figure 2.2: Bark of young *Acacia mangium* tree (Krisnawati et al., 2011)



Figure 2.3: Bark of old *Acacia mangium* tree (Krisnawati et al., 2011)



Figure 2.4: Inflorescence of *Acacia mangium* (Krisnawati et al., 2011)



Figure 2.5: Mature blackish-brown *Acacia mangium* pods (Krisnawati et al., 2011)

In the timber industry, *Acacia mangium* timber is very well known for producing attractive furniture and cabinets, door frames, window parts, mouldings and sliced veneers (Ismaili, 2015). Generally, according to Lim et al. (2003), Acacia trees are renowned for their robustness and adaptability, which makes them good plantation species. It is adapted to a wide range of soils in moist tropical lowlands (Ismaili, 2015). National Research Council

(1983) and Krisnawati et al. (2011) also described that *Acacia mangium*'s desirable properties include rapid growth, good wood quality and tolerance to a wide range of soils and environments.

The planting of *Acacia mangium* in Malaysia on a commercial basis in plantations was instituted in 1962. (Ismaili, 2015). In Sarawak, this species is most widely used in the reforestation and rehabilitation of abandoned shifting cultivation areas (Ismaili et al., 2011b; Ismaili et al., 2022b). Yamamoto et al. (2003) also mentioned their importance as plantation species, which could be attributed to rapid growth, rather good wood quality, tolerance to a range of soil types, and pH values. The study conducted by Ismaili (2005) revealed that all organic soils in Kuching, Sarawak, are highly acidic, with pH levels below 4.5.

The second generation of *Acacia mangium* is an improved and selected plus tree as a result of a tree improvement program. It is propagated from the seed of *Acacia mangium*, and the trees have gone through many years of tree improvement. The second-generation *Acacia mangium* trees have characteristics in comparison to the first-generation in terms of high growth rate, high volume, good stem form and resistance to heart rot (Jusoh et al., 2014).

2.3 Physical Properties of *Acacia mangium*

The *Acacia mangium* superbulk can reach the height and diameter breast height (DBH) of 22.90 m and 21.70 cm, respectively, at the age of 4 years old, whereas at the same age, first-generation *Acacia mangium* can only achieve a height of 16.80 m and DBH at 17.70 cm (Jusoh et al., 2014). However, the survival rate of *Acacia mangium* superbulk decreased with age, and after 9.83 years of planting, its survival rate was 57 % (Adam et al., 2012).

Research done by Adam et al. (2012) concluded that the diameter size of *Acacia mangium* superbulk increased with age, and 9.83 years old stand recorded a mean DBH of 23.40 cm and a maximum diameter of 34.5 cm. Although the diameter size increased, the number of remaining trees decreased with age. The results of the growth characteristics of *Acacia mangium* superbulk at different ages are tabulated in Table 2.2. The study is done on the plot area of 30 m x 30 m from Daiken Plantation Sdn. Bhd.

Table 2.2: Growth characteristics of *Acacia mangium* superbulk at Different Ages (Adam et al., 2012)

Age (Year)	**Survival Rate (%)**	**Maximum DBH (cm)**	**Mean DBH (cm)**	**Mean Basal area per tree (m^2)**	**Mean basal area per ha (m^2ha^{-1})**	**Basal area MAI ($m^2ha^{-1}y^{-1}$)**
4	79	22.80	16.13	0.0212	18.59	4.65
5.17	61	25.10	18.36	0.0275	18.61	3.60
6.17	68	26.60	18.80	0.0292	22.05	3.57
7	66	28.50	19.60	0.0322	23.62	3.37
8.41	63	31.20	21.30	0.0376	26.29	3.13
9.83	57	34.50	23.40	0.0448	28.39	2.89

*MAI: Mean annual increment

According to Calvert (2009), growth rate affects the density of softwood differently for different species, and generally, density values fall off more severely with very rapid growth than with very slow growth. However, the effect of growth rate on density is easier to predict for hardwoods.

Timber is a heterogeneous material. Thus, some physical testing must be conducted to reveal and confirm the timber strength group as identified by its density (Ismaili et al., 2015). Density is the amount of weight and volume of the wood, and it is also affected by the amount of moisture it contains. Density is an excellent indicator of wood strength; the

higher the density, the stronger the wood (Calvert, 2009). Ismaili et al. (2022) also specified that basic density could be adopted as a reliable strength indicator for the mechanical stress grading of Sarawak timbers.

Wood density provides a simple measurement of the total amount of solid-wood substances in a piece of wood, as mentioned by Ismaili et al. (2011b). In the study that was done by Ismaili et al. (2011b) on 23 years old of *Acacia mangium* from Sabal Reforestation, the mean value of basic density was 0.54 g/cm^3 with a coefficient of the percentage of 8.83 %. Thus, *Acacia mangium* is classified as light hardwood. As in prior Table 2.1, the density range for light hardwood is 400 to 720 kg/m^3. Meanwhile, based on the study that has been done by Yang and Voon (2014), the average basic density for 7, 10 and 13 years old is 442 kg/m^3, 517 kg/m^3 and 473 kg/m^3, respectively.

Yang and Voon (2014) also reported that the mean green density of 7, 10, and 13 years old of *Acacia mangium* is 1020 kg/m^3, 1048 kg/m^3 and 1037 kg/m^3, respectively. Meanwhile, the mean density for treatment samples of *Acacia mangium*, which is the density before the treatment process that had been reported by Lai and Sammy (2014), 586 kg/m^3, 593 kg/m^3 and 616 kg/m^3 for 7, 10, and 13 years old respectively which is under the 15 ± 2 % moisture content or air-dry condition.

The density or specific gravity of *Acacia mangium* varies depending on the origin of the wood. Air-dry conditions vary between 500 – 600 kg/m^3 (Sahri et al., 1998). Sahri et al. (1998) reported that *Acacia mangium* wood has a specific gravity of 0.56, and the plantation-grown timber recorded slightly lower values (0.40 – 0.45). *Acacia mangium* from the natural stands is normally about 0.60. However, Sahri et al. (1998) reported a slightly higher SG range from the plantation: 0.43 – 0.47 for 6 years old *Acacia mangium* grown in Sabah.

Research done by Krisnawati et al. (2011) shows that the wood density varies, ranging from 450 to 690 kg/m^3 at 15 % moisture content. The specific gravity of *Acacia mangium* grown in timber plantations is more commonly between 0.4 and 0.45, whereas that from natural stands is normally about 0.6 (Krisnawati et al., 2011).

Although the density of timber is relatively reflected in the strength of the timber, it should not be the definitive measurement of its strength. (Ismaili et al., 2015). It depends on the strength properties that are required. For example, the amount of deflection of wood in response to load (modulus of elasticity) is an important strength property, and the actual breaking strength of the piece (modulus of rupture) is also important (Calvert, 2009).

The moisture content of timber influences its mechanical properties (Alik & Liang, 2014). Timber will increase in strength as it dries, though this effect does not begin until the water within the cell has dried out (Ismaili, 2015). However, not every property of strength improves with the decrease in moisture content (Ismaili, 2015). The ability of species that can preserve a certain percentage of moisture content directly depends on their wood cells (Ismaili, 2015). Ismaili (2015) also stated that the strength and stability of timber are greatly influenced by its moisture contents, and the relationship between bending strength and modulus of elasticity can be affected by the way in which the timber is dried.

According to Loffer (2018), the acceptable moisture levels in wood depend on the final use of the wood, the type and thickness of the wood, and the average relative humidity in the environment where the wood is to be used. The acceptable moisture level for wood objects used indoors is generally 6% to 8% for wood flooring, 6% to 9% for furniture and 9% to 18% for construction (Loffer, 2018).

Wood is hygroscopic, which means it gains or loses moisture as the relative humidity

of the air surrounding it changes. As the humidity increases, the moisture content increases, causing the wood to expand. As the humidity decreases, the moisture content decreases, causing the wood to shrink. When the wood neither gains nor loses moisture, it means that the wood has reached its equilibrium moisture content (EMC) (Loffer, 2018). Wood with a higher moisture content dries more slowly than that with lower moisture content and is generally more susceptible to drying defects (Yamamoto et al., 2003).

Several factors affect the moisture content in timber, such as the characteristics of clones or the provenance of seeds and the amount of precipitation at plantation sites (Yamamoto et al., 2003). Larcher (2003) mentioned that wood in growing trees contains a considerable amount of moisture, which accounts for about 50% of the fresh weight. The natural air-drying process able to minimise the strength of the wood failures, such as various splits and cracks (Ismaili et al., 2022). In the air-dried activities, it was difficult to achieve moisture content in the vicinity of 15-19 % because some timber species tend to dry rapidly (Ismaili, 2015). *Acacia mangium* dried slowly and tended to distort. For pieces containing heart rot, collapse may occur. (Lim et al., 2003). Due to a large amount of water in stem wood, especially in the heartwood of *Acacia* species, drying time becomes much longer (Yamamoto et al., 2003). The highest moisture content found in the inner heartwood was 253 % for both *Acacia mangium* and *Acacia* hybrid. (Yamamoto et al., 2003). The moisture content of *Acacia mangium* from Malaysia was around 100-110 % in heartwood and 80-90% in sapwood (Yamamoto et al., 2003).

According to Yang and Voon (2014), the 10 years old had a slightly higher proportion of sapwood than those the 7-years old. The 13 years old of *Acacia mangium* had the lowest sapwood proportion. The average percentage of sapwood for 7, 10, and 13 years

old of *Acacia mangium* is 28.16 %, 29.31 % and 25.38 %, respectively. The amount of sapwood for the 3 age groups is considerably high. The average green moisture content for 7, 10, and 13 years old of *Acacia mangium* is 139 %, 108 % and 128%, respectively (Yang & Voon, 2014).

2.4 Mechanical Properties of *Acacia mangium*

Generally, strength refers to a timber's ability to resist and withstand different types of external forces. Ismaili et al. (2022), wood's strength properties are classified according to its moisture content, density, durability, and grain direction. The mechanical strength of timber is a measure of its ability to resist outside forces, such as elasticity, rupture, compression, and shear. These forces are being acted as a destructive test (DT) while investigated in the laboratory.

As stated by Alik and Liang (2014), the evaluation of the mechanical strength properties of wood is an important criterion for determining the strength grouping of the timber species, which is used for different end-use classifications and for establishing working stresses for structural designing. The strength of timber is dependent on the species and the effects of certain growth features (Mobolaji et al., 2022).

The following table introduces the extracted results of static bending testing of *Acacia mangium* and *Acacia mangium* superbulk from the prior study based on certain age groups, number of samples, size of specimen, condition, and origin (sample site collection).

Table 2.3: Mechanical Properties of *Acacia mangium* and *Acacia mangium* superbulk from Prior Study

Species	Age	Physical Properties	Mechanical Properties	Descriptions	Source
Acacia mangium	6	MC: 11.63 %	MOR: 62.23 N/mm^2 MOE: 5828.00 N/mm^2	Kiln-dried, small-clear	Serdang, Malaysia. (Sahri et al., 1998)
	7	MC: 18.29 %	MOR: 93.21 N/mm^2 MOE: 11456.00 N/mm^2 Compression: 47.06 N/mm^2 Shear (Radial): 13.28 N/mm^2 Shear (Tangential): 13.61 N/mm^2	Air-dried, small-clear, 60 samples each of age groups	Samarakan, Bintulu, Malaysia (Alik & Liang, 2014)
	7	Basic Density: 0.46 g/cm^3	MOR: 78.00 N/mm^2 MOE: 9992.00 N/mm^2	Air-dried, 2.5 x 2.5 x 10 cm	Borneo Seeds and Seedlings Sdn. Bhd. (Jusoh et al., 2014)
	10	MC: 18.42 %	MOR: 114.86 N/mm^2 MOE: 14819.00 N/mm^2 Compression: 56.01 N/mm^2 Shear (Radial): 15.22 N/mm^2 Shear (Tangential): 16.22 N/mm^2)	Air-dried, small-clear, 60 samples each of age groups	Samarakan, Bintulu, Malaysia (Alik & Liang, 2014)
	13	MC: 18.40 %	MOR: 95.10 N/mm^2 MOE: 11626.00 N/mm^2 Compression: 51.48 N/mm^2 Shear (Radial): 14.37 N/mm^2 Shear (Tangential): 15.32 N/mm^2	Air-dried, small-clear, 60 samples each of age groups	Samarakan, Bintulu, Malaysia (Alik & Liang, 2014)
	14	MC: 16.50 %	MOR: 117.90 N/mm^2 MOE: 12941.00 N/mm^2 Compression: 51.80 N/mm^2 Shear: 16.40 N/mm^2	-	FRIM, Kepong (Lim et al., 2003)
	20 – 25	MC: 18.70 % Basic Density: 0.52 g/cm^3	MOR: 95.96 N/mm^2 MOE: 12064.51 N/mm^2 Compression: 41.66 N/mm^2	Air-dried, small-clear	Sabal Reforestation Plot, Sarawak (Ismaili, 2015)
	*12	MC Green: 111.93 % Air-dry: 18.70 %	Compression Green: 37.32 N/mm^2 Air-dry: 41.66 N/mm^2	Green and air-dried	Sabal Forest Reserve, Sarawak (Ismaili, 2012)
Acacia mangium superbulk	7	Basic Density: 0.34 g/cm^3	MOR: 55.00 N/mm^2 MOE: 8185.00 N/mm^2 Compression: 50.00 N/mm^2	Air-dried, 2.5 x 2.5 x 10 cm	Borneo Seeds and Seedlings Sdn. Bhd. (Jusoh et al., 2014)

*: Reference in this study

2.5 Strength Group

According to Burgess (1958) and Ashaari (2017), the strength grouping of tropical hardwood timber can be classified into two, namely, strength groups (SG) 1 to 7, which corresponds to grade stresses as in Table 2.4, or strength group (SG) A to D which is solely on compression strength parallel to the grain as presented in Table 2.5.

Table 2.4: Dry-grade Stress for Various Strength Groups of Timber

Strength Group	Bending (MOR)	Tension Parallel to Grain	Compression		Modulus of Elasticity (MOE)
			Parallel to Grain	Perpendicular to Grain	
SG1	26.5	15.9	22.5	3.74	18800
SG2	18.3	11.0	18.5	3.05	16800
SG3	15.9	9.5	14.1	2.09	14300
SG4	13.2	7.9	11.1	1.65	11000
SG5	9.5	5.7	8.5	1.14	9100
SG6	8.9	5.3	6.9	1.02	7300
SG7	6.5	3.9	5.4	0.62	6600

*The grade stress is adopted from dry standard structural grade in Malaysian Standard (2001)

Table 2.5: Strength Grouping at Green Condition (Burgess, 1958; Ashaari, 2017)

Strength Group	Compression strength parallel to the grain (N/mm^2)
A	Greater than 55.2; extremely strong
B	41.4 – 55.2; very strong
C	27.6 – 41.4; moderately strong
D	Less than 27.6; weakest

*Determined using the test procedure described in American Society for Testing Materials (1983)

The grading of timber can be conducted by visual or mechanical methods. The importance of grading timber is assisting in determining the strength class of the timber.

However, the results obtained from small-clear specimens shall not be directly used. It needs to be calculated by using the probability values listed in Table 2.6 and multiplied with the safety factors as in Table 2.7.

According to Ismaili et al. (2011a) and Ismaili et al. (2016) the strength properties of some species can be compared and identified as its strength group classification of the species based on Malaysian Standard (2001). The strength groups can be classified into seven categories, namely SG1, SG2, SG3, SG4, SG5, SG6 and SG7.

Table 2.6: Probability Values for Determination of Basic Stresses (Chik, 1988a)

Property	Probability	Formula
Bending	1 in 100	$\bar{x}$- 2.33σ
Compression parallel to the grain	1 in 100	$\bar{x}$- 2.33σ
Shear parallel to the grain	1 in 100	$\bar{x}$- 2.33σ
Mean modulus of elasticity	-	$\bar{x}$
Minimum modulus of elasticity	1 in 100	$\bar{x}$- 2.33σ
Where, $\bar{x}$ = mean ultimate stress, σ = standard deviation		

Table 2.7: Factors of Safety for Determining Basic Stresses (Chik, 1988a)

Property	Factor of Safety
Bending	2.5
Compression parallel to the grain	1.5
Shear parallel to the grain	2.5
Mean modulus of elasticity	1.0
Minimum modulus of elasticity	1.0

For the air-dry conditions, the basic stress shall be determined by using following equations (Chik,1988):

$$\text{Basic stress (air-dry)} = \frac{S_3}{\text{Mean ultimate stress}} \text{ x Basic stress (green)} \qquad \text{Equation 2.1}$$

To estimate the ultimate stress at 19 % MC, its shall be calculated by using Madison's formula as follows:

$$\log S_3 = \log S_1 + \frac{(M_1 - M_3)}{(M_1 - M_2)} \log \frac{S_2}{S_1} \qquad \text{Equation 2.2}$$

where, S3: ultimate stress at 19 % MC

S1: ultimate stress at fibre saturation point (25 % MC) assumed to be equal to green stress

S2: ultimate stress from air-dry test

M1: 25 % MC from test, and

M2: Air-dry MC from test

M3: 19 % (Maximum MC for air-dry condition)

Hence, the result attained from green and air-dry basic stresses are multiplied by the strength ratio as in Table 2.8.

Table 2.8: Strength Ratio (Pun et al., 1997)

Property	**Select structural %**	**Standard structural %**	**Common structural %**
Bending, tension and compression parallel to grain	80	63	50
Shear parallel to grain	72	56	45
Modulus of elasticity	Same as the basic value for all grades		

The study by Chik (1980) listed the strength groups based on the basic grade of the air-dry condition, as stated in Table 2.9.

Table 2.9: Strength Groups Based on Basic Grade (Air-dry Condition) (Chik, 1988a)

Strength Properties	Strength Group (MPa)			
	A	B	C	D
Bending parallel to grain	>20	>17	>12	>7.6
Tension parallel to grain	>20	>17	>12	>7.6
Compression parallel to grain	>17	>14	>9.6	>6.5
Compression perpendicular to grain	>2	>1	>0.7	>0.4
Shear parallel to grain	>3	>2	>1.4	>1.4

From the study that has been done by Ismaili et al. (2011a), it was found that the strength group of *Acacia mangium* species is prone to be classified under SG5 as it is the lowest case between the strength group at the green and air-dry conditions. The result from the different studies also clarifies that *Acacia mangium* in air-dry conditions is classified under SG5 (Ismaili et al., 2015).

2.6 Treatment of *Acacia mangium*

Treatability varies among wood species, where particularly their heartwood, which generally resists preservative treatment more than sapwood (Lai & Sammy, 2014). *Acacia mangium* is susceptible to both fungal and insect attacks and, therefore, needs to be protected to prolong its service life (Lim et al., 2003). Among the conventional methods used to prolong the service life of wood materials is treated with preservatives, such as *Copper Chrome Arsenic (CCA),* creosote or boron (Ashaari, 2017). Meanwhile, the degree of

protection achieved depends on the preservative and treatment process used and the target penetration and retention of the chemicals (Lai & Sammy, 2014).

Based on Jenang and Inoue (1996), the penetration of preservatives is closely related to the permeability of wood. The difference in permeability between different species of timber is due to a combination of factors such as the nature of the cell wall, the presence of extractives and the size of cells which make up the wood (Jenang & Inoue, 1996).

The *Acacia mangium* is reported to be easily treated with preservatives. Satisfactory loading and penetration of preservatives even though the timber contains higher than normal moisture content (Lim et al., 2003). There are several factors that affect heartwood treatability, including the higher extractive content in heartwood, the increased rate of irreversible aspirated pits in the heartwood of softwoods, and the tyloses formation in the heartwood of hardwoods (Lai & Sammy, 2014).

Table 2.10: Treatability Classification (Malaysian Standard, 2006)

Permeability class	**Retention in wood (litre/m^3)**
Very easy	Over 320
Easy	240-320
Average	160-240
Moderately difficult	80-160
Difficult	Less than 80

Table 2.11: Hazard Class Selection Guide Extracted from Malaysian Standard (2003) and Malaysian Standard (2006)

Hazard Class	Exposure	Specific service conditions	Biological hazard	Typical uses	Minimum net dry salt retention (kg/m^3)	Minimum depth of penetration (mm)
H1	Inside, above ground	Completely protected from weather and well ventilated, and protected from termites	Insects other than termites (e.g. lyctid)	Framing, flooring, furniture, interior joinery	-	-
H2	Inside, above ground	Protected from wetting and leaching	Bores and termites	Framing, flooring, and similar, used in dry situations	5.6	3 or 5
H3	Outside, above ground	Subject to periodic moderate wetting and leaching	Moderate decay, borers and termites	Weather board, fascia, pergolas (above ground), window joinery, framing and decking	8	12
H4	Outside, in-ground	Subject to severe wetting and leaching	Severe decay, borers and termites	Fence posts, greenhouse, pergolas (in ground) and landscaping timbers	12	12
H5	Outside, in-ground contact with or fresh water	Subject to extreme wetting and leaching and/or where the critical use requires a higher degree of protection	Very severe decay, borers and termites	Retaining walls, piling, house stumps, building poles, cooling tower fill	16	25
H6	Marine waters	Subject to prolonged immersion in sea water	Marine wood borers and decay	Boat hulls, marine piles, jetty cross-bracing, landing steps and similar	32	25

The CCA preservative is used in this study since this type of preservative is widely used in the country's industry (Ismaili et al., 2022). The treatability assessment will be driven by the ability of the timber to penetrate the CCA preservative or, in other words, the maximum of timber to absorb the preservative solution, and in the treatment testing, the results of CCA retention will be classified according to treatability classification from Malaysian Standard (2006) (Table 2.10). Therefore, CCA retention will determine the dry salt retention and refer to the hazard class extracted from Malaysian Standard (2003) and Malaysian Standard (2006) (Table 2.11).

Therefore, the following tables introduce the extracted results of treatability retention of *Acacia mangium* spp. from the prior study based on a certain age group, number of samples, size of specimen, condition, and origin (sample site collection).

Table 2.12: Treatability Retention of *Acacia mangium* (Lai & Sammy, 2014)

Age groups: 7, 10, and 13 years old Number of Samples: 146 for all three age groups Conditions: 15±2% MC Size of specimen: 20 x 20 x 457 mm Origin: SPFSB Samarakan, Bintulu		
Age group (year)	Retention (litre/m^3)	Dry-salt Retention (kg/m^3)
7	143.8	14.38
10	147.1	14.71
13	129.1	12.91

Table 2.13: Treatability Retention of *Acacia mangium* (Salmiah et al., 2011a,b)

Age groups: 16 and 20 years old Number of Samples: 20 specimens for each of the age groups Conditions: 15±2% MC, Size of specimen: 20 x 20 x 457 mm Origin: 16-years-old logs from Ulu Sedili Forest Reserve Johor and 20-years-old logs from Kemasul Forest Reserve Pahang		
Age group (year)	Retention (litre/m^3)	Dry-salt Retention (kg/m^3)
16	166	16.60
20	173	17.30

The treatability retention results using the CCA preservative in Table 2.12 explained that when referring to Table 2.11, the results met the H4 (minimum 12 kg/m^3), which is for timber used outside in ground contact and subjected to severe (not extreme) wetting and leaching. This treatability process uses full-cell treatment, which comprises an initial vacuum of -85 kPa for 60 minutes, followed by 1400 kPa pressure for 120 minutes and a final vacuum of -85 kPa for 30 minutes.

Based on Table 2.13, Salmiah et al. (2011a,b) reported that 16 and 20 years old *Acacia mangium* stands from Peninsular Malaysia were averagely treatable (Table 2.10) classifications with uptake retentions of 166 litre/m^3 and 173 litres/m^3 and mean CCA dry-salt retention for both are >16 kg/m^3 respectively, hence, fulfil the Malaysian Standard (2003) hazard class H5 requirements. Permeability was not significantly different between these two age groups. By comparison, it is interesting to note that the older tree stands from Peninsular Malaysia achieved higher loading than their younger counterparts from Sarawak (Salmiah et al., 2011a,b; Lai & Sammy, 2014).

2.7 Lamination of *Acacia mangium*

Glued-laminated timber, like other engineered wood products, represents an efficient use of available timber (Wan Mohamad et al., 2014). Glued laminated (glulam) timber is a stacking sequence of several layers of timbers to be bonded with glue perfectly adjacent to layers (Sulistyawati et al., 2008). In other words, glulam is defined as a material that is made from suitably selected and prepared pieces. Glulam was developed in response to the increasing demand for high-quality timber at a time when it was becoming difficult to obtain it from forest resources. (Sulistyawati et al., 2008).

Sahari and Inoue (1996) stated that the most important feature of bonded-wood

products such as plywood and glulam is their bonding properties. Bonded-wood products such as plywood and glulam are superior to wood in many properties, such as greater stability, more uniformly distributed strength, availability in standard dimensions and ease of handling and installation (Sahari & Inoue, 1996).

Moreover, glued laminated has several advantages (Sulistyawati et al., 2008), including;

i. Size capability – to produce large structural elements is possible with small pieces.
ii. Architectural effects – a variety of architectural effects that are impossible or difficult with other materials can be obtained.
iii. Seasoning – the timber used in the manufacture of glulam must be seasoned or dried prior to use so the effect of checking and other drying effects is minimised.
iv. Variation of cross-section – glulam can be designed with varying cross-sections along their length as determined by strength and stiffness requirements.
v. Grades – a large quantity of lower-grade timber can be used within the less highly stressed laminations of the beam.

An adhesive can perfectly transfer and distribute stresses, thereby increasing the strength and stiffness of laminated (Sulistyawati et al., 2008). However, cause of the imperfect glueing process, the glulam is not monolithic, and it might be causing the decrease in mechanical properties of glulam (Sulistyawati et al., 2008). Insufficiently dried veneers or lumbers may affect the bond performance of the products (Sahari & Inoue, 1996) and test specifications from the Japanese Agricultural Standards (2003) for Glued Laminated Timber is moisture content ≤ 14 %. Based on the American Society for Testing Materials (1995), moisture content for bonding specimens was in the range of 12 % to 14 %.

The conditions in use naturally affect the performance of a glue bond. A glue joint should remain as strong as the wood under the service conditions to which the glued product is exposed for adequate performance. If it does not, it becomes the weakest link in the assembly and the point at which failure first will occur (Selbo, 1975). Sahri (1990) reported that the suitability of glues and glueing techniques to produce joints adequate for exterior service needs to be evaluated regularly. Many factors govern the choice of wood species and wood adhesives, but the most important one is the strength and integrity of the glue joint (Sahri, 1990).

In general, the serviceability of a glued wood assembly depends upon (Selbo, 1975);

i. The kind of wood and its preparation for use.
ii. The type and quality of the adhesive.
iii. Compatibility of the glueing process with the wood and adhesive used.
iv. Type of joint or assembly.
v. Moisture-excluding effectiveness of the finish or protective treatment applied to the glued product.

Three common types of adhesives that are commercially used for laminated wood are *Phenol-resorcinol formaldehyde (PRF), Emulsion polymer isocyanate (EPI)* and *Polyvinyl acetate (PVAc).* Among them, PRF is a popular adhesive for structural use (commonly used for glulam manufacturing). However, PRF requires a higher spreading rate than other adhesive types (Sikora et al., 2016).

According to Selbo (1975), *phenol-resorcinol* resins are modifications of straight *resorcinol* resin adhesives produced by polymerising the two resins *(phenol-formaldehyde* and *resorcinol-formaldehyde)*. The principal advantage of copolymer resins over straight

resorcinol resin is their significantly lower cost because the price of *phenol* is much lower than that of *resorcinol.* This cost advantage is apparently achieved without any significant losses in a joint performance. For wood glueing, the volume *of phenol-resorcinol* used now far exceeds that of straight *resorcinol*. Sikora et al. (2016) mentioned that PRF and EPI are, in principle, suitable for bonding finger joints as well as edge and surface bonding. However, EPI is not allowed for large finger joints. PRF is dark brown, which may be an issue in terms of aesthetic quality, and it contains formaldehyde.

Suryono (2015) stated that some of the advantages of wood laminated wood lamina fingers joint connection are in terms of size, architectural form, cross-section, drying, wood use more efficiency and environmentally friendly (Moody & Hernandez, 1997). Moreover, laminate is an effective way to use high-strength wood with laminated dimensions and has become a major structural element in many shapes and sizes (Council, 1991). Serrano (2002) mentioned that the advantages of using laminated wood are improving the properties of strength and stiffness, providing a choice of form geometries that are more diverse, allowing the adjustment of the quality of wood laminate and wood laminate connection finger joint level desires voltage and improve the dimensional accuracy of stability of shape. Sahri et al. (1998) reported that the glue joint strength of *Acacia mangium* timber was found to be satisfactory. The *Acacia mangium* timber can be laminated well (Lim et al., 2003).

Foremost, PRF adhesive is chosen on account of wet use compared to PVAc adhesive, which is for dry use only. On application for the outside environment, it is best to elect PRF adhesive due to its execution in wet circumambient and great in dry surroundings. Mohd Yusof et al. (2019) also mentioned that PRF is an in situ polymerized adhesive that possesses higher and more rigid crosslinked polymers and is found to be able to penetrate

the wood cell wall.

The following Table 2.14. represents the static bending and shear strength of 25 years old of *Acacia mangium* that has been used PVAc type of adhesive. The study done by Suryono (2015) found that MOR, MOE and shear strength are 95.71 N/mm^2, 11265.98 N/mm^2 and 8.21 N/mm^2, respectively, with the PVAc type of adhesive.

Table 2.14: Mechanical Properties of Lamination of *Acacia mangium* (Suryono, 2015)

Species: *Acacia mangium* Age groups: 25 years old Type of adhesive: PVAc Conditions: 12.34 – 12.82 % MC Size of specimen: 60x60x760 mm Origin: Separi Tenggarong Regency, East Kalimantan		
Static bending (N/mm^2)	MOR	95.71
	MOE	11265.98
Shear strength (N/mm^2)	8.21	

2.8 Decay and Damage Protection

Wood, in its diverse forms, is susceptible to decay and insect damage when exposed to warm, moist conditions owing to the presence of wood-destroying organisms. These organisms possess the capacity to eliminate or substantially diminish the efficacy of significant quantities of wood and other forest products. The occurrence of decay within a structural framework is deemed unacceptable, as it expeditiously diminishes strength, even in its incipient stages (Ismaili, 2012). Research estimates indicate that a mere 5% weight loss from decay can lead to strength losses as substantial as 50% (Winandy, 1994). Consequently, the paramount focus in wood preservation research is centered on efficaciously controlling and safeguarding wood against these deleterious organisms.

Microbiological attacks from wood-inhabiting fungi and, to a lesser extent, bacteria,

precipitate considerable timber loss. Wood preservation techniques must consider severe environmental conditions and behavioral factors, addressing wood-boring insects that pose threats to logs, stored timber, and in-service wood. Simultaneously, marine borers consistently present a hazard to piling, wharf timbers, and various other forms of wood exposed to marine conditions. Figure 2.6 until 2.14 provides comprehensive insights into various wood-destroying organisms that exert influence on the physical and mechanical properties of timber.



Figure 2.6: Termite attack - Drywood termite (Ismaili, 2012)



Figure 2.7: Termite attack - Subterranean termite (Ismaili, 2012)



Figure 2.8: Termite attack - Powder post beetle (Bostrychid) (Ismaili, 2012)



Figure 2.9: Termite attack - Carpenter bee (Ismaili, 2012)



Figure 2.10: Fungi attack - Blue stain (Ismaili, 2012)



Figure 2.11: Fungi attack - Soft rot (Ismaili, 2012)



Figure 2.12: Fungi attack - Mould (Ismaili, 2012)



Figure 2.13: Marine Borer attack - Nausitora dunlopei Wright (Ismaili, 2012)



Figure 2.14: Marine Borer attack - Martesia striata Linneaus (Ismaili, 2012)

In situations where warm and moist conditions are beyond control, the imperative utilization of naturally decay-resistant wood species or chemical treatments arises to counteract decay. Infestation by wood-boring insects can be managed through the

implementation of mechanical barriers, naturally durable species, or chemical treatments. The utilization of *Copper Chrome Arsenic* (CCA) as a chemical treatment to protect against wood decay persists in commercial and industrial products, such as construction materials and other aboveground building components, in several countries, including Malaysia (Lee at el., 2014). Nevertheless, exercising vigilance is paramount to mitigate the risk of environmental pollution associated with CCA usage. The recommended mixing ratio is using 10% CCA (Ling & Wong, 200).

2.9 The Application of *Acacia mangium*

Acacia mangium is a fast-growing species and has been used extensively to produce tannin, pulp and paper, timber, and fuel wood (Jenang et al., 1999). Krisnawati et al. (2011) also stated that *Acacia mangium* wood is suitable for pulp, paper, particle board, crates, and woodchips. It also has potential for sawn timber, moulding, furniture, and veneers. As it has a calorific value of 4800 – 4900 Kcal/kg, the wood can be used for firewood and charcoal. The leaves can serve as forage for livestock. Fallen branches and dead leaves can be used for fuel. Non-timber uses include adhesive and honey production. The sawdust provides a good-quality substrate for edible mushrooms (Krisnawati et al., 2011). *Acacia mangium* trees can also be used as fire breaks as trees with diameters of 7 cm or more are commonly fire-resistant (Krisnawati et al., 2011).

Acacia mangium is suitable for the manufacturer of furniture, turnery, wall panelling, veneer and plywood, composite panel products, fibre for medium density fibreboard (MDF) manufacture, tool handlers, interior finishing, and other general utility purposes (Lim et al., 2003). *Acacia mangium* timber makes attractive furniture and cabinets, door frames, window parts, mouldings, and sliced veneers (Sahri et al., 1998). In the long term, the application of

Acacia mangium timber for housing and other light structures will reduce the destruction of exotic natural tropical forests for a more sustainable human sphere (Firmanti et al., 2007).

Table 2.15: Strength Groups of Timber and Applications, (Malaysia Timber Industry Board, 2019b)

Application	Strength Group (Engku Abdul Rahman Chik, 1988a,b)	Strength Group (Malaysia Standard, 2011)
Structural Components		
Columns, beams, bearers, studs, joist, ties & struts	A & B	SG1, SG2, SG3 & SG4
Form work	A, B & C	SG1, SG2, SG3, SG4 & SG5
Roofing		
Rafters, ties, struts, purlins & bracing	A & B	SG1, SG2, SG3 & SG4
Battens	A, B & C	SG1, SG2, SG3, SG4 & SG5
Staircase		
Stringers, treads, trimmer beam & handrail	A & B	SG1, SG2, SG3 & SG4
Balustrades	A, B & C	SG1, SG2, SG3, SG4, SG5 & SG6
Flooring		
Floor boarding & parquetry	A & B	SG1, SG2, SG3 & SG4
Skirtings	A, B & C	SG1, SG2, SG3, SG4, SG5 & SG6
Walling		
Wall, partition, framing & external wall boarding	A, B & C	SG1, SG2, SG3, SG4, SG5 & SG6
Internal wall boarding, slate screens	A, B, C & D	SG1, SG2, SG3, SG4, SG5, SG6 & SG7
Facia boards	A & B	SG1, SG2, SG3 & SG4
Ceiling frames		
Cover battens to joint of ceiling sheets	A & B	SG1, SG2, SG3 & SG4
Ceiling strips and soffit battens	A, B & C	SG1, SG2, SG3, SG4, SG5 & SG6
Door & window frames		
Door, window and vent frames, including their stops and grounds	A & B	SG1, SG2, SG3 & SG4
Door leaves, window and vent sashes	A, B & C	SG1, SG2, SG3, SG4, SG5 & SG6
Furniture		
Built-in fittings, furniture generally and workshop furniture	A, B & C	SG1, SG2, SG3, SG4, SG5 & SG6
Science laboratory tops	A & B	SG1, SG2, SG3 & SG4
Beading fillets and edgings generally	A, B & C	SG1, SG2, SG3, SG4, SG5 & SG6

The strength groups and applications of timber are listed by Malaysia Timber Industry Board (2019b) as presented in Table 2.15. Sulaiman and Lim (2004) found that the application of timber in air-dry conditions can be classified according to its density groups of hardwood. The density groups of hardwood and its applications is presented in the Table 2.16.

Table 2.16: Density Groups of Hardwood and its Applications (Sulaiman & Lim, 2004)

Hardwood Category	**Density (g/cm^3)**	**Applications**
Heavy hardwood	0.88 – 1.12	Constructional timber
Medium hardwood	0.72 – 0.88	Moderately heavy to heavy construction purposes
Light hardwood	0.4 – 0.72	General utility timbers, excellent for high class joinery work, cabinet making, furniture, decorative panelling, etc.
Softwood	< 0.4	Decorative plywood and panelling

CHAPTER 3

METHODOLOGY

3.1 Background

In Chapter 3, the discussions are focused on the methodology for research on the fast-growing of *Acacia mangium* superbulk timber species. The elaboration in this chapter includes the enumeration and selection of *Acacia mangium* superbulk until the preparation of physical and mechanical testing as well as treatability and lamination work in order to determine its strength properties. The research work for this study can be summarised in the presented flow chart, as shown in Figure 3.1.

3.2 E-numeration and Selection of Trees

The collections of *Acacia mangium* superbulk are from Daiken Bintulu Plantation Sdn. Bhd. The procedure of sampling trees and allocation of logs are according to ITTO's Testing Methods for Plantation Grown Tropical Timbers (Tan et al., 2010), which is also referred to as ISO 4471 E (1982). The criteria for the selection of tree sampling plots are the group, locality of the plantation, terrain, and accessibility (Tan et al., 2010). Sahri et al. (1998) also stated that the selection of trees is based on criteria such as bole straightness, absence of excessive defects and good cylindrical form. The specification of good tree had been clearly mentioned in The Qur'an, Surah Ibrahim, Chapter 14, Verse 24 "Dost thou not see how Allah sets forth the similitude of a good word? *It is* like a good tree, whose root is firm and whose branches reach into heaven" (The Qur'an, 14:24). A total of three plots were recognised at three different locations and labelled as Plot 1, Plot 2 and Plot 3. The size of each established plot is 50 m x 50 m, equivalent to 0.25 ha, at a planting distance of 3 m x 3 m,

assuming all the trees survive, and each plot will have approximately 277 planted trees. The following table represents the location and plot area of trees 7, 10 and 13 years old of *Acacia mangium* superbulk.

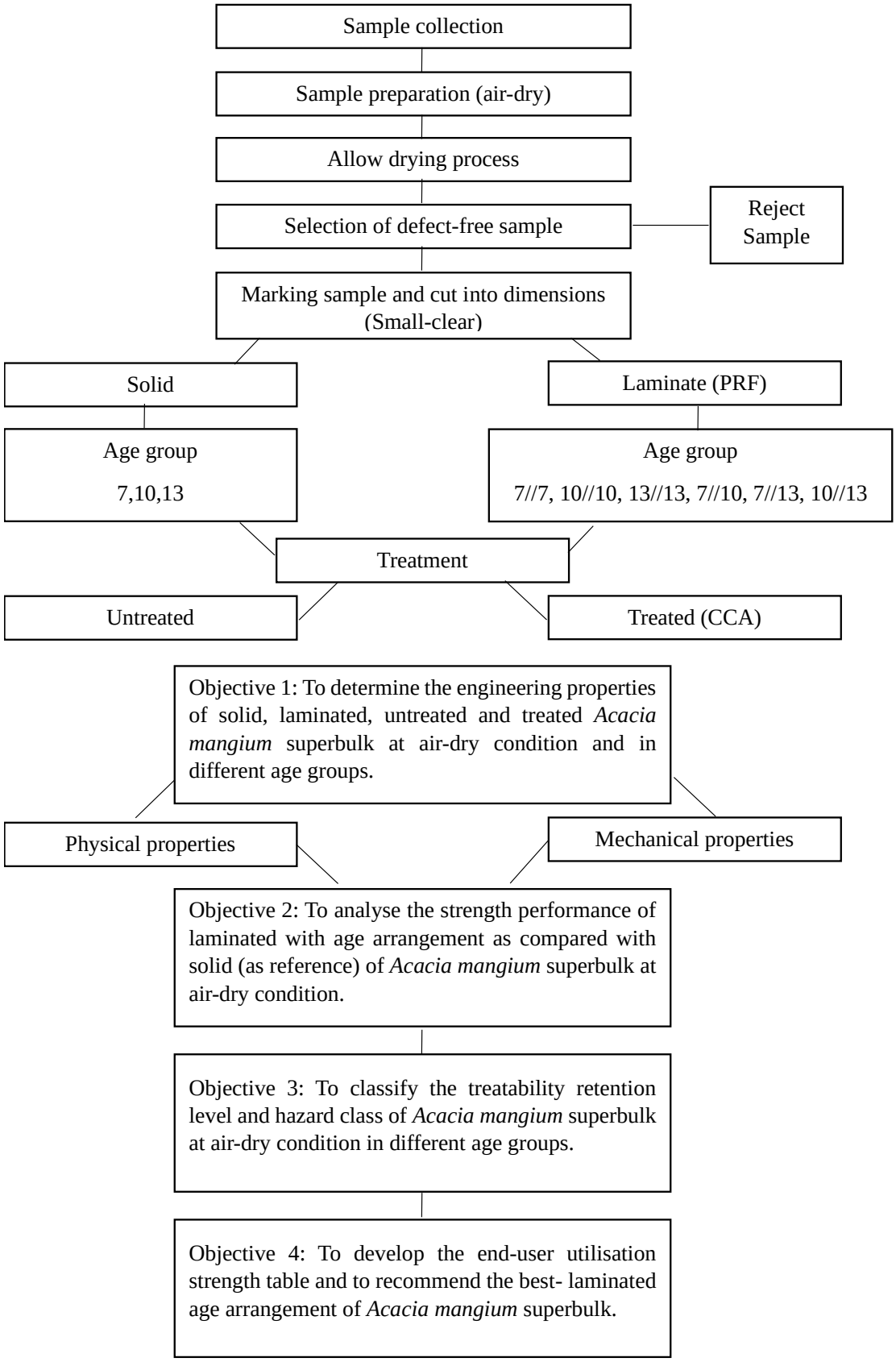


Figure 3.1: Flow chart of research work

Table 3.1: Description of Locality and Plot Area of 7, 10, and 13 Years Old

Plot	Age	Block No.	GPS Location	Elevation ≈	Remarks
Plot 1	7	41	N 03º18`18.3`` E 113º25`01.2``	97 m	On a steep slope, termites activity and some windblown or fallen trees
Plot 2	10	46	N 03º19`07.8`` E 113º26`42.8``	71 m	On a steep slope, termites' activity and some windblown or fallen trees
Plot 3	13	14	N 03º20`42.1`` E 113º26`57.4``	46 m	Flat land with trees infected by *Ceratocytis*

Table 3.1 prescribed plot 1, plot 2 and plot 3 with the ages of 7, 10 and 13 years old of *Acacia mangium* superbulk, respectively. Plot 1 at Block No. 41, with GPS location of N 03º18`18.3``E 113º25`01.2``, elevation approximately 97 m and on a steep slope, has termites' activity and some windblown or fallen trees. Meanwhile, Plot 2 is at Block No. 46 with a GPS location of N 03º19`07.8``E 113º26`42.8``, elevation of approximately 71 m and on a steep slope, has termite activity and has some windblown or fallen trees. Besides that, the third plot at Block No. 14 with GPS location of N 03º20`42.1``E 113º26`57.4``, elevation of approximately 46 m and on flat land with trees infected by *Ceratocytis*.

As mentioned by ITTO's Testing Methods for Plantation Grown Tropical Timbers (Tan et al., 2010), e-numerated trees mean all trees found in the plots which are still standing inclusive of healthy and unhealthy trees, whereas healthy trees are the trees with the full crown with no visual evidence of hollow pith, attacked by termites, decay at bole and main branches, stunted growth, dead trees, deformed boles, *Ceratocytis,* etc. and sample trees are healthy trees with diameter breast height (DBH) more than 18 cm.

The sampling plots were selected near to roadside for easy accessibility during collection. The trees in each plot were e-numerated, and the labelling of the trees was running

numbers from T328 to T369 for 7 years old trees, from T559 to T643 for 10 years old trees and from T142 to T225 for 13 years old trees. According to ITTO's Testing Methods for Plantation Grown Tropical Timbers (Tan et al., 2010), the selection for the sample trees when the mean DBH of e-numerated healthy trees are more than 22 cm, the minimum DBH over bark should be 18 cm and the sample trees also are healthy with no decays, termite and tree borers infestation and have a minimum bole length of 6 m from the root collar.

Table 3.2: Summary of the Inventoried Trees

Plot Number	Plot 1 (7 years old)	Plot 2 (10 years old)	Plot 3 (13 years old)	Total / Mean *
Total number of trees e-numerated in the plot	141	89	145	375
E-numerated healthy trees in the plot	87	61	67	215
E-numerated healthy trees-DBH range (cm)	15.7-33.3	18.3-47.0	15.8-37.6	15.7-47.0
E-numerated healthy trees-mean DBH (cm)	23.5	29.3	26.7	26.5*
No of sample trees selected with DBH > 18 cm	73	61	63	197
Sample trees – DBH range (cm)	18.4-33.3	18.3-47.0	19.0-37.6	18.3-47.0
Sample trees – mean DBH (cm)	24.8	29.3	27.3	27.1*

Table 3.2 describes the summary of inventoried trees for all plots. The total numbers of trees e-numerated in plots are 141, 89 and 145 trees for Plot 1, Plot 2 and Plot 3 that represent 7-, 10- and 13- years old, respectively. Meanwhile, from the total numbers of the trees e-numerated, the healthy trees in the plots recorded are 87, 61 and 67, respectively. The range of diameter breast height for all three plots is from 15.7 cm to 47.0 cm and gives the mean value of 26.5 cm from all three plots. From the e-numerated healthy trees in the plot,

the total numbers of selected trees with DBH more than 18 cm are 73, 61 and 63, respectively. Meanwhile, the DBH range for all three plots is from 18.3 cm to 47.0 cm, whereas the mean DBH of the three plots is 27.1 cm.

Table 3.3: Grouping and Batches of *Acacia mangium* superbulk Plot 1

Batch	Group 1		Group 2		Group 3		Group 4		Group 5		Group 6	
	Tree No	DBH	Tree No	DBH	Tree No	DBH	Tree No	DBH	Tree No	DBH	Tree No	DBH
	354	18.4	368	22.9	281	23.0	273	27.7	279	27.7		
	376	18.4	394	22.6	339	23.0	258	27.5	291	28.0		
	338	18.5	272	22.5	372	23.0	344	27.4	317	28.0		
7	315	18.8	360	22.5	302	23.1	297	27.2	362	28.2	334	33.3
5	259	19.0	319	22.2	365	23.5	333	27.0	330	28.5	348	33.3
3	280	19.0	369	22.2	347	23.8	304	26.8	264	29.0	352	33.0
1	335	19.0	276	22.0	267	23.9	356	26.0	367	29.0	377	32.1
2	240	19.0	375	21.6	320	240	391	25.3	286	29.1	381	31.5
4	386	19.2	300	21.3	388	24.0	328	25.2	278	29.2	265	31.3
6	329	19.3	261	21.0	355	24.5	393	25.1	313	29.2	299	30.8
8	295	19.5	331	21.0	379	24.5	296	25.0	383	29.2	271	30.5
	305	19.9	294	20.2	390	24.5	327	25.0	363	30.0		
	292	20.0	369	20.0	285	25.0	350	25.0	287	30.4		

*highlighted: selected tree

Subsequently, selected sample trees are grouped and batched according to their increasing DBH value. These are tabulated in Table 3.3. Based on Table 3.3, at least one tree is selected for each group, making a total of eight trees selected. The average DBH from all eight trees of 7 years old of superbulk species is 26.79 cm. Meanwhile, Figure 3.2 presents Plot 1's site at Daiken Plantation, Bintulu Sarawak.



Figure 3.2: Plot 1, *Acacia mangium* superbulk (7 Years Old)

Table 3.4: Grouping and Batches of *Acacia mangium* superbulk Plot 2

Batch	Group 1		Group 2		Group 3		Group 4		Group 5		Group 6	
	Tree No	DBH	Tree No	DBH	Tree No	DBH	Tree No	DBH	Tree No	DBH	Tree No	DBH
	609	18.3	586	25.4	639	25.5	569	33.0	631	33.0		
	566	18.6	558	25.3	599	25.6	575	33.0	603	33.4		
7	616	19.0	577	25.3	590	25.8	587	33.0	589	33.5	643	47.0
5	641	19.1	626	25.3	640	26.7	574	32.9	580	33.8	635	44.5
3	619	19.8	557	25.2	618	27.0	617	32.0	559	34.0	645	44.3
1	613	20.5	596	25.1	634	27.3	628	31.8	606	35.0	610	39.0
2	642	20.8	620	25.0	630	27.9	591	31.6	607	35.0	637	38.8
4	629	21.2	570	24.9	597	29.0	583	31.5	636	35.0	605	36.6
6	564	21.7	611	24.2	621	29.5	622	31.2	644	35.8	571	36.5
	565	23.1	612	24.1	608	29.9	568	31.0	576	36.4		
	582	23.1	563	23.2	595	30.0	581	30.5				

*highlighted: selected tree

Furthermore, Table 3.4 shows the grouping and batches of *Acacia mangium* superbulk plot 2, which plot for 10 years old. The selected trees are highlighted, and the mean of DBH is 29.91 cm. Figure 3.3 introduces the site of 10 years old superbulk plantation, which is plot number 2.



Figure 3.3: Plot 2, *Acacia mangium* superbulk (10 Years Old)

Table 3.5: Grouping and Batches of *Acacia mangium* superbulk Plot 3

Batch	Group 1		Group 2		Group 3		Group 4		Group 5		Group 6	
	Tree No	DBH	Tree No	DBH	Tree No	DBH	Tree No	DBH	Tree No	DBH	Tree No	DBH
	147	19.0	134	24.4	245	24.9	248	30.0	120	30.5		
	203	19.2	167	24.0	127	25.0	171	29.5	164	30.5		
7	219	19.2	176	24.0	148	25.0	252	29.4	225	30.5	161	37.6
5	207	20.0	230	24.0	256	25.0	131	29.0	240	30.6	253	36.9
3	178	20.1	172	23.5	151	25.4	146	29.0	235	31.0	195	35.2
1	242	20.9	257	23.4	189	25.6	227	28.9	114	32.0	206	35.0
2	224	21.0	118	23.3	184	25.8	168	28.8	231	32.0	113	34.8
4	117	22.1	142	23.3	132	26.5	255	28.7	119	32.9	212	34.5
6	125	22.2	140	23.2	163	26.6	254	28.6	185	32.9	213	34.0
8	211	22.7	115	23.1	116	26.9	144	27.8	123	33.0	223	34.0
	238	22.8	165	23.1	166	27.4	239	27.5	191	33.1		

*highlighted: selected tree

On the other hand, a grouping and batches for 13 years old superbulk species are

presented in Table 3.5 with highlighted trees selected. The mean DBH of 13 years old trees is 27.79 cm. Figure 3.4 shows the site of Plot 3.



Figure 3.4: Plot 3, *Acacia mangium* superbulk (13 Years Old)

3.3 Preparation of Sample

A total of 8 trees per plot or per age group proceed for further process cutting, ripping, drying, and testing. The cutting and ripping process was held at Samling Plywood Bintulu Sdn. Bhd. The logs are transported from Daiken's plantation site after all selected trees are cut down. Figure 3.5 shows the timber logs of *Acacia mangium* superbulk at the sawmill site.



Figure 3.5: Timber Logs of *Acacia mangium* superbulk

The logs are transferred to the processing machine to cut into the board to ease the mobilisation process from Bintulu to Kuching. Initially, the logs are cut to the size of the board with a thickness of ±30 mm and length of ±1.5 m. The following figures represent the processes that were held at the sawmill.



Figure 3.6: Transferring the *Acacia mangium* superbulk Logs



Figure 3.7: Cutting the *Acacia mangium* superbulk Logs into the Board



Figure 3.8: Marking the *Acacia mangium* superbulk Board

The samples were moved from Bintulu to Sarawak Forestry Corporation at Kuching. The sample boards are sorted and stacked from bundles of samples according to the age and number of the tree. It is necessary to stack it properly in order to allow samples to dry constantly, as the moisture content of the *Acacia mangium* superbulk species is really high, and it takes a year to dry. The following figures describe the process of sorting, stacking and drying.



Figure 3.9: Bundles of Sample's Board



Figure 3.10: Bundles of Sample's Board are Moved to Drying Room



Figure 3.11: Sorting According to Tree Number



Figure 3.12: Sample's Board is Stacked to the Air-drying Process

As the samples achieved the air-dry moisture content which is 18%, the boards were transferred to the working area of planning, ripping and cutting. The boards have planned both surface and the thickness reduced to ±23 mm. The sideboards are also being ripped to have a smooth face. Next, the boards are marked for the ripping process with a width size of ±20 mm and turned into sticks. After that, the sticks undergo second planning to achieve the

final thickness which is ±20 mm. The marking processes on the sticks, according to the tests, take place before the sticks go through the cutting process. Eliminating the defects on the sticks is also held during the marking process and is known as visual testing. The following figures clarify all the processes of getting the final dimension of the test sample.



Figure 3.13: Bundle of Timber Transfer to the Working Area



Figure 3.14: Ripping Process on the Side of Board



Figure 3.15: Marking Process for Ripping Process



Figure 3.16: Ripping Process from Board to Sticks



Figure 3.17: Sticks Going Through Second Planning

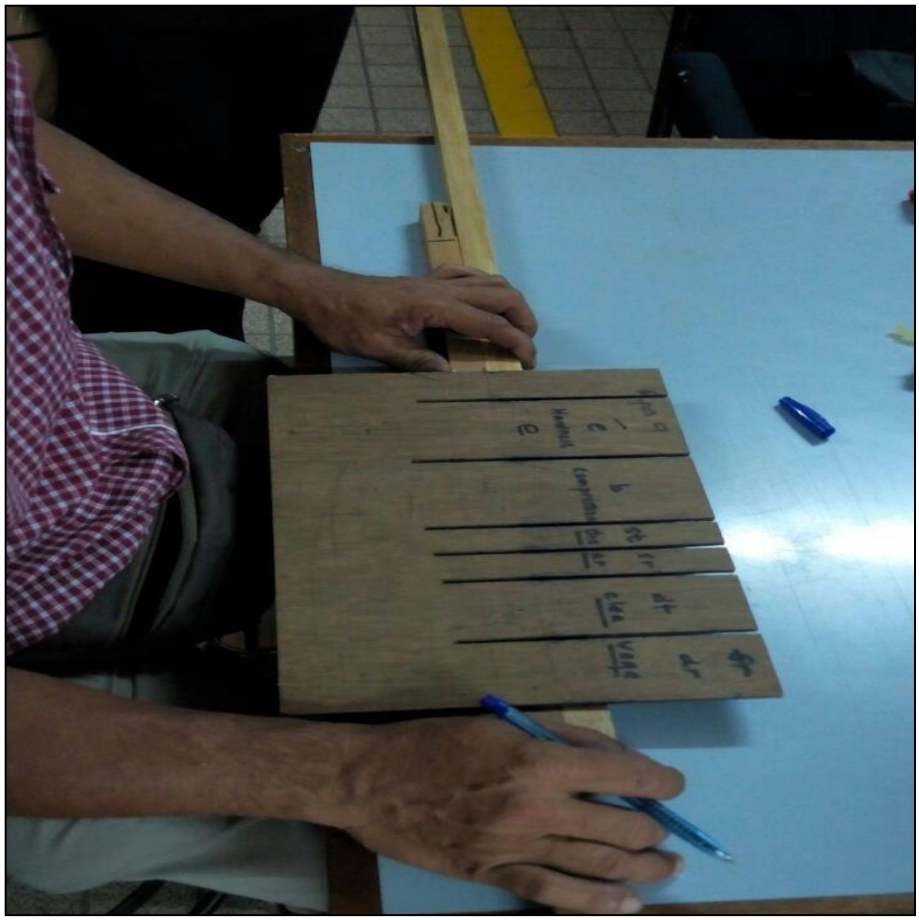


Figure 3.18: Marking Process on Sample's Sticks



Figure 3.19: Marking on Sticks According to the Type of Tests



Figure 3.20: Example Defect of Splay Knot



Figure 3.21: Example Defect of Margin Knot



Figure 3.22: Cutting Process According to the Type of Test

3.4 Physical Testing

The physical properties of timber include moisture content, density and basic density. The air-dry and condition moisture contents were in the vicinity of 12 – 19%, respectively. Moisture content (MC) refers to the percentage of differences between the initial weight of specimens and the oven-dry weight of specimens. On the other hand, the moisture content of samples also can be obtained by a moisture meter. The oven-dry weight was obtained by drying the specimen in an oven at 105 ºC until a constant weight was achieved. The result obtained represents the air-dry condition of the sample. A total of 576 specimens are tested, and the dimension of the specimen to determine moisture content is irrelevant. The following Equation 3.1 and figures refer to how to obtain the moisture content of the sample.

$$\text{MC } (\%) = \frac{W_1 - W_2}{W_2} \times 100 \qquad \text{Equation 3.1}$$

Where,

W_1: Initial weight (g), W_2: Oven-dry weight (g)

On the other hands, defining of density of the timber is required in order to determine the timber hardwood category and its applications. This density is also known as the existing density which is at air-dry condition and before the testing is being conduct. Thus, the density of the timber shall be identified by using Equation 3.2 as follow.

$$\text{Density } \left(\frac{g}{cm^3}\right) = \frac{W}{V} \qquad \text{Equation 3.2}$$

Where,

W: Weight of the sample, V: Volume of the sample





Figure 3.23: MC Obtained by a Moisture Meter







(i) Before oven-dry (ii) Oven at 105ºC (iii) After oven-dry

Figure 3.24: Moisture Content Obtained by the Oven-dry Method

Besides that, basic density is determined by dividing the oven-dry weight of the

specimen by the volume of the specimen. The means value of basic density when the specimen was at zero per cent moisture content and can be obtained by the following equation. A total of 576 specimens are tested and the dimension of the specimen to determine a basic density is irrelevant. The following Equation 3.3 represents the way to obtain a basic density.

$$\text{Basic Density } \left(\frac{g}{cm^3}\right) = \frac{W_2}{V} \qquad \text{Equation 3.3}$$

Where,

W2: Oven-dry weight of specimen (g), V: Volume of specimen (cm^3)

Thus, the following flow chart is introduced for overall physical test.

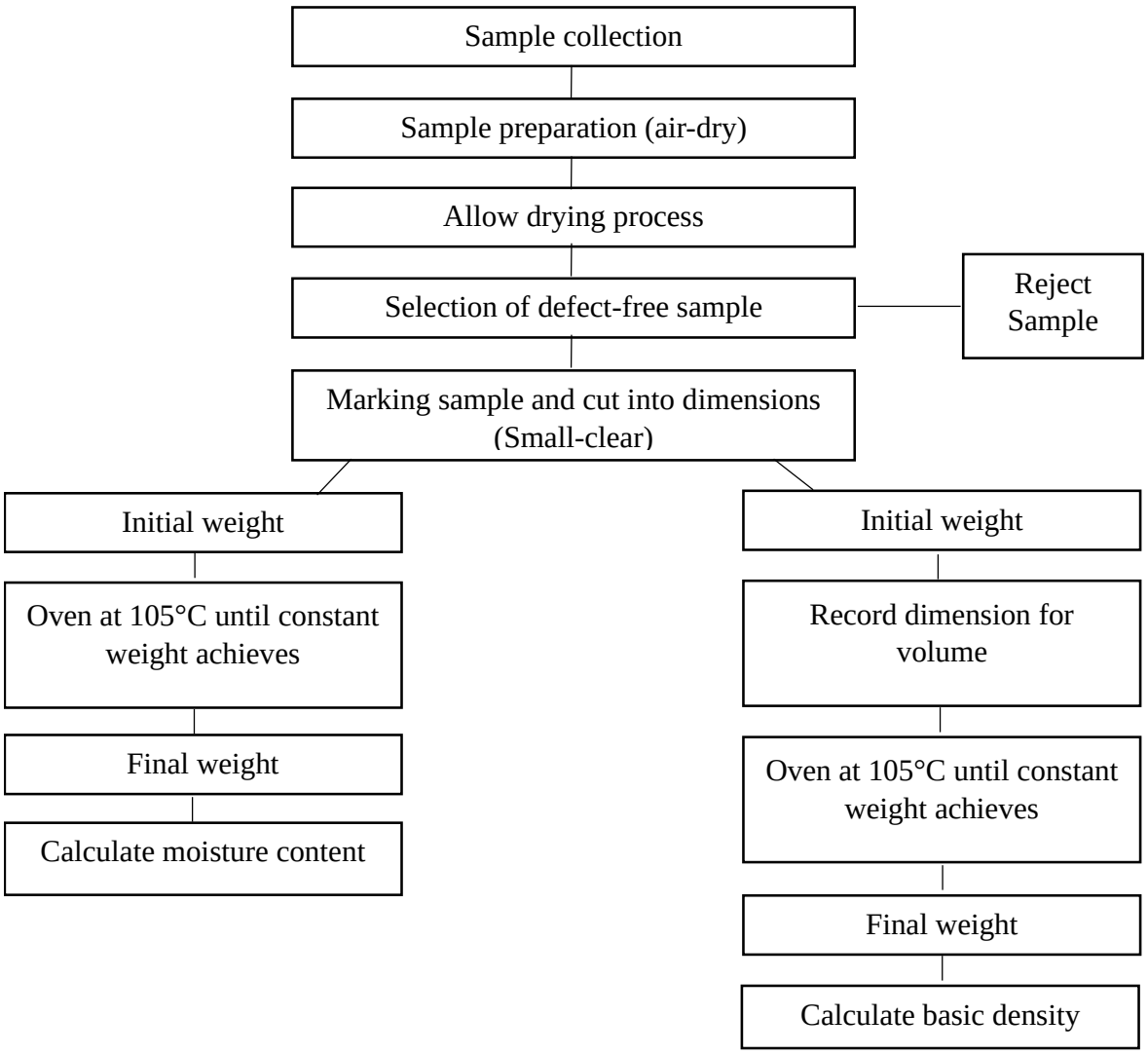


Figure 3.25: Flow Chart of Physical Test

3.5 Mechanical Testing

Mechanical testing involves static bending, compression parallel to grain and shear parallel to grain. Each test has a specific dimension of the specimen, and the test procedure was according to ITTO's Testing Methods for Plantation Grown Tropical Timbers (Tan et al., 2010), which was also adopted from BS 373 (1957).

In addition, it is necessary to observe the failure pattern after the test was done on the static bending test and compression test. All the mechanical tests were used mechanical testing machine Instron 5569 Universal Testing Machine as in the following figure.



Figure 3.26: Instron 5569 Universal Testing Machine

Thus, a flow chart is introduced on the whole mechanical test in Figure 3.32, and the overall dimensions of the three tests, as mentioned above, are illustrated in the following figure (Figure 3.27).

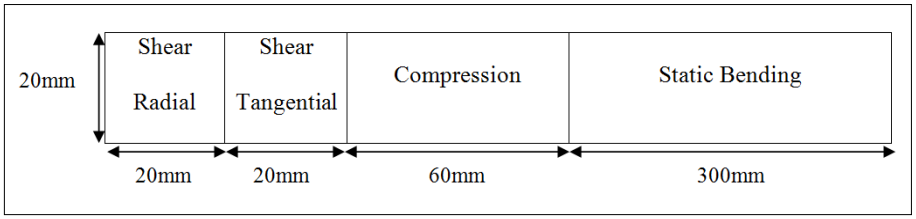


Figure 3.27: Dimensions of Mechanical Properties Test

3.5.1 Static Bending

Referring to ITTO's Testing Methods for Plantation Grown Tropical Timbers (Tan et al., 2010), the static bending test is carried out by the three-point bending method. The dimensions of the specimen should be 20 mm x 20 mm x 300 mm. The distance between the points of support of the specimen should be 280 mm. Besides that, a constant loading speed of 6.0 mm min^{-1}. The following figures illustrate the static bending by the three-point method and how it is set up in the laboratory.

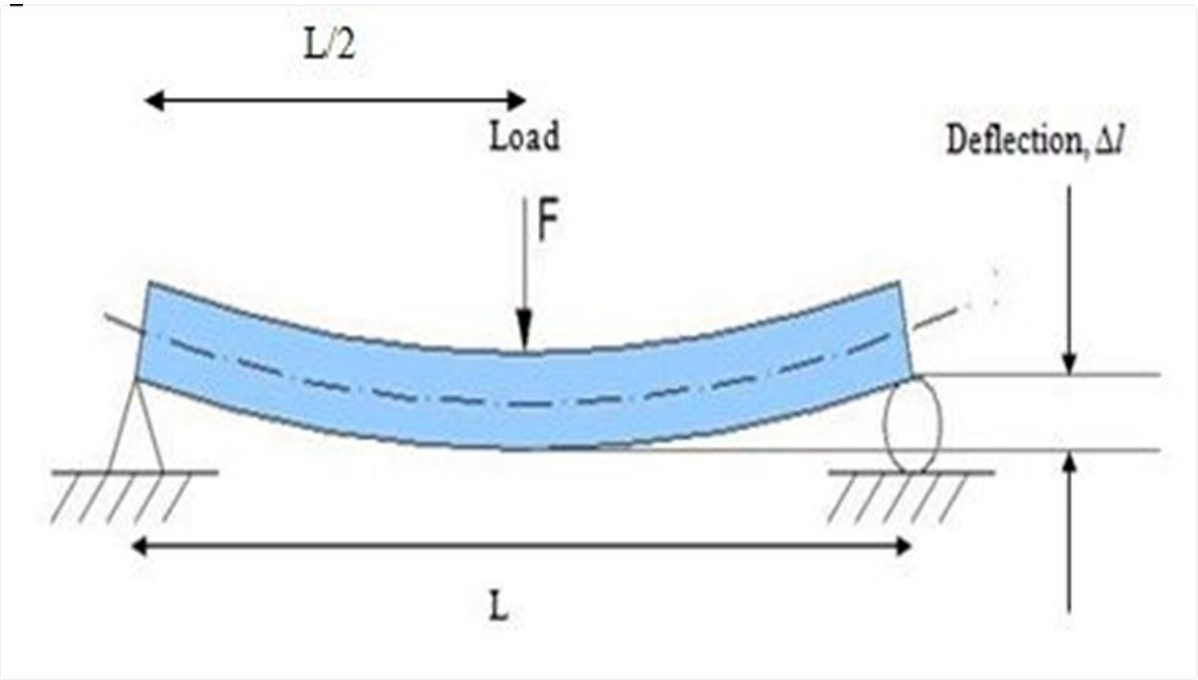


Figure 3.28: Static Bending Test by Three-point Bending Method (Ismaili, 2012)

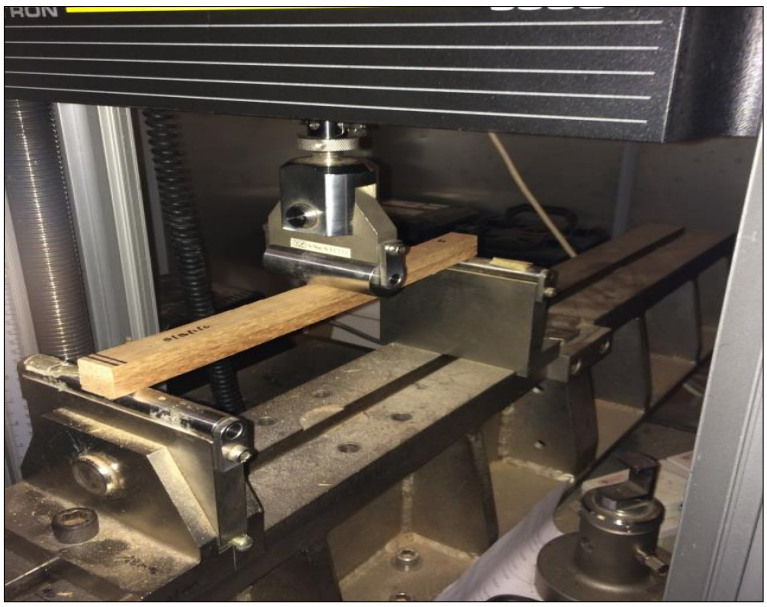


Figure 3.29: Static Bending Set-up in Laboratory

The static bending test has resulted in two main strength properties, which are the modulus of rupture (MOR) and modulus of elasticity (MOE). A total of 144 specimens are tested for three age groups, and MOR and MOE are calculated based on Equation 3.4 and Equation 3.5, respectively.

$$MOR=\frac{3}{2}\frac{FL}{WT^2} \qquad \text{Equation 3.4}$$

Where,

F: Maximum load (N), L: Span (mm), W: Width (mm), T: Depth (mm)

$$MOE=\frac{L^3}{4WT^3}\frac{\Delta F}{\Delta l} \qquad \text{Equation 3.5}$$

Where,

L: Span (mm), $\Delta F/\Delta l$: Slope of the graph (Nmm^{-1}), W: Width (mm), T: depth (mm)

3.5.2 Compression Parallel to Grain

The compression test resulted from the compression strength in Nmm^{-1}. According to ITTO's Testing Methods for Plantation Grown Tropical Timbers (Tan et al., 2010), the dimension of compression parallel to grain of the test specimen should be 20 mm x 20 mm x 60 mm, and the load should be applied parallel to the grain. To ensure the accuracy of results, the ends of the rectangular test specimen should be smooth and normal to the axis, and the top compression platen should be kept parallel to the bottom platen throughout the test in accordance with ITTO's Testing Methods for Plantation Grown Tropical Timbers (Tan et al., 2010). Meanwhile, the constant loading speed of 0.6 mm min^{-1} should be applied during the test. A total of 144 specimens are involved in this test. The following figure represents the compression parallel to grain test.

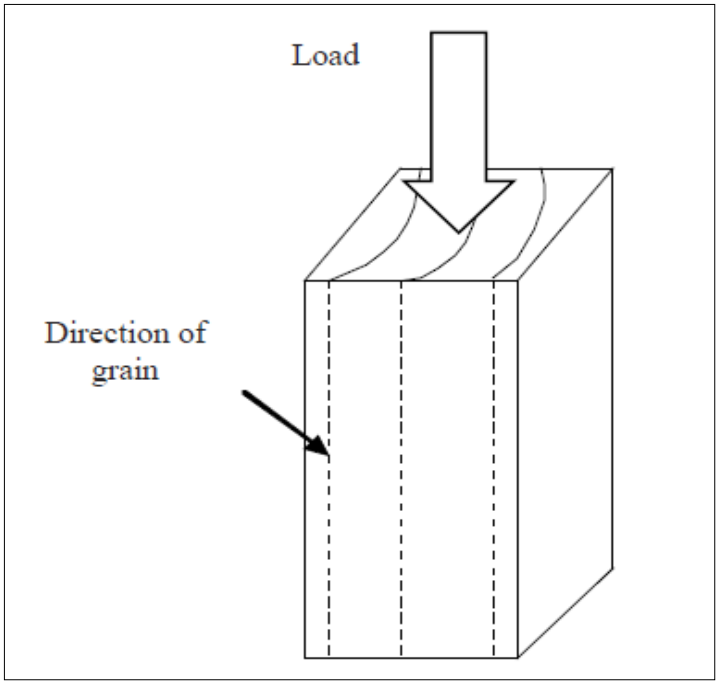


Figure 3.30: Compression Parallel to Grain Test (Tan et al., 2010)

Hence, compression strength at maximum load is obtained by the following Equation 3.6.

$$\text{Compression strength at maximum load} = \frac{F}{A} \qquad \text{Equation 3.6}$$

Where,

F: Maximum load (N), A: Cross-sectional area (mm^2)

3.5.3 Shear Parallel to Grain

As stated in ITTO's Testing Methods for Plantation Grown Tropical Timbers (Tan et al., 2010), the test is performed by introducing a shear failure along a plane parallel to the tangential direction of the grain and with the plane of shear failure parallel to the radial direction. Figure 3.31 describes the shear parallel to grain test. Meanwhile, a constant loading speed of 0.6 mm min^{-1} should be applied during the test. A total of 144 specimens are concerned in this test, and the dimension should be a cube with a 20 mm side.

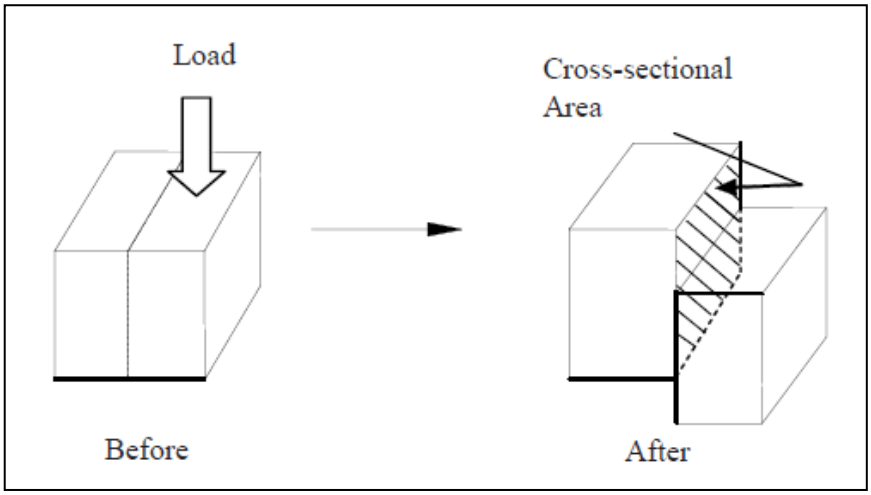


Figure 3.31: Shear Parallel to Grain Test (Tan et al., 2010)

Hence, shear stress at maximum load was obtained by the following expression.

$$\text{Shear stress at maximum load} = \frac{F}{A} \qquad \text{Equation 3.7}$$

Where,

F: Maximum load (N), A: Cross-sectional area (mm^2)

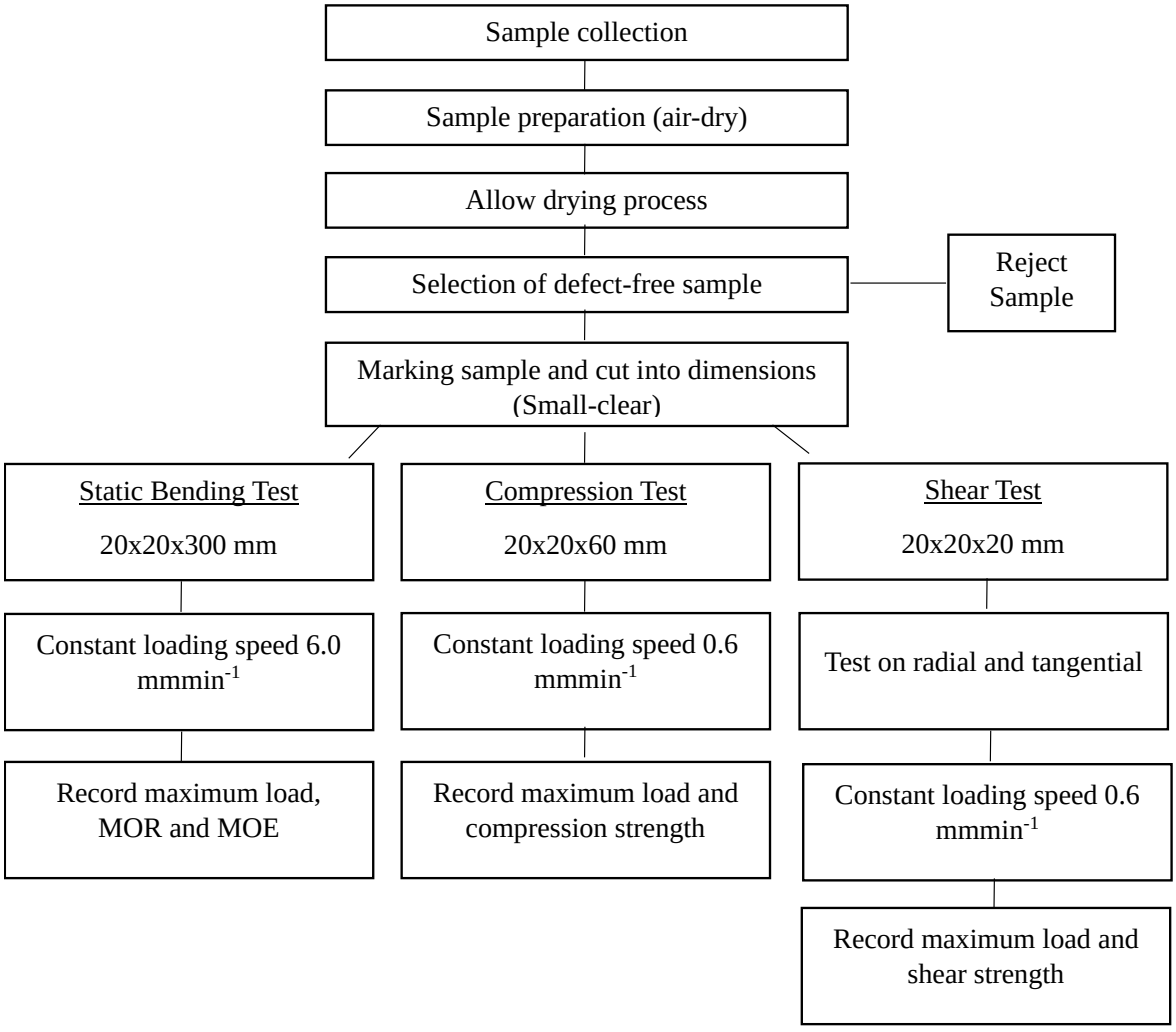


Figure 3.32: Flow Chart of Mechanical Test

3.6 Treatability

Treatability is the ability of the timber to absorb the preservative solution as much as possible. The testing methods are according to ITTO's Testing Methods for Plantation Grown Tropical Timbers (Tan et al., 2010), which is also referred to:

i. MS360:2006 Treatment of Timber with *Copper/Chrome/Arsenic* Wood Preservatives – Specification (Third Revision)
ii. MS1921:2006 Treatment of Roof, Ceiling and Timber Roof Components with *Copper Chrome Arsenic* Preservatives for Indoor Above Ground Use
iii. MS544:PART 10:2003 Code of Practice for Structural Use of Timber: Part 10: Preservative Treatment of Structural Timber
iv. AS/NZS 1605:2000 Methods for Sampling and Analysing Timber Preservatives and Preservative-treated Timber
v. AS1604,1-2000 Specification for Preservative Treatment Part 1: Sawn and Round Timber

Treatability processes were used with 10% *Copper Chrome Arsenic* (CCA) timber preservative solution and underwent a full-cell process. According to the work procedure by ITTO's Testing Methods for Plantation Grown Tropical Timbers (Tan et al., 2010), the full cell process is where a treatment process of timber is subjected to several treatment phases, namely an initial vacuum of -85 kPa for 60 minutes, followed by 1400 kPa pressure for 120 minutes and final vacuum of -85 kPa for 30 minutes. The figures below illustrate the timber treatability test vacuum desiccators' setup and treatability works in a laboratory.

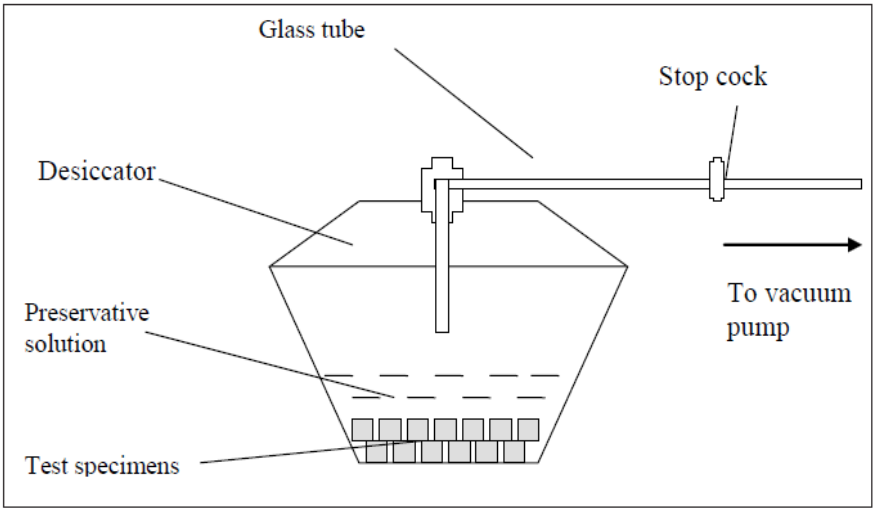


Figure 3.33: Timber Treatability Test Vacuum Desiccators Set-up (Tan et al., 2010)



Figure 3.34: Treatment Process Machine

Moreover, the treatability retention is evaluated by calculating differences in the weight of specimens before and after the treatment process and dividing by their volume. A total of 144 specimens for each test were used in the treatment process, and its dimensions are exactly similar to the dimensions for the static bending test, compression test and shear test. After the treatment, the same test procedure was applied to get the MOR, MOE,

compressive strength, and shear strength. The results are therefore compared with controlled results, and then failure patterns of the test are also identified.

On the other hand, treatability retention is therefore classified by treatability classification from MS 544 Part 10 (2003) and MS1921 (2006). Treatment of roof, ceiling and timber roof components with copper-chrome-arsenic preservatives for indoor above-ground use – specification. Hence, retention of the timber in litres per metre cubic is required to identify dry-salt retention and referred to hazard class selection from MS 544 Part 10 (2003) and MS1921 (2006). Equations 3.8 and 3.9 represent the treatability retention and dry-salt retention, respectively.

$$\text{Treatability retention } \left(\frac{\text{litre}}{\text{m}^3}\right) = \frac{W_2\text{-}W_1}{G \times V} \times 1000 \qquad \text{Equation 3.8}$$

Where,

Taking density of water = 1 g/m^3, W1: Weight before treatment (g), W2: Weight after treatment (g), G: specific gravity of timber preservative (Hydrometer reading = 1.05), V: Volume of the specimens (cm^3)

Dry salt retention

$$\left(\frac{\text{litre}}{\text{m}^3}\right) = \text{treatability retention} \times \%\text{ of CCA solution used} \qquad \text{Equation 3.9}$$

Where,

Treatability retention: Calculated in Equation 3.8

% of CCA solution used: 10 %

Furthermore, based on the value of retention, its treatability is classified as either very easy, easy, average, moderately difficult or difficult, according to Table 2.10 (Chapter 2 in this thesis). Meanwhile, the purpose of dry salt retention is to determine its hazard class and explain its type of exposure, specific service conditions, biological hazard, and typical uses. The hazard class is tabulated in Table 2.11 (Chapter 2 in this thesis). Last but not least, Figure 3.35 indicates the flow chart of the treatability process.

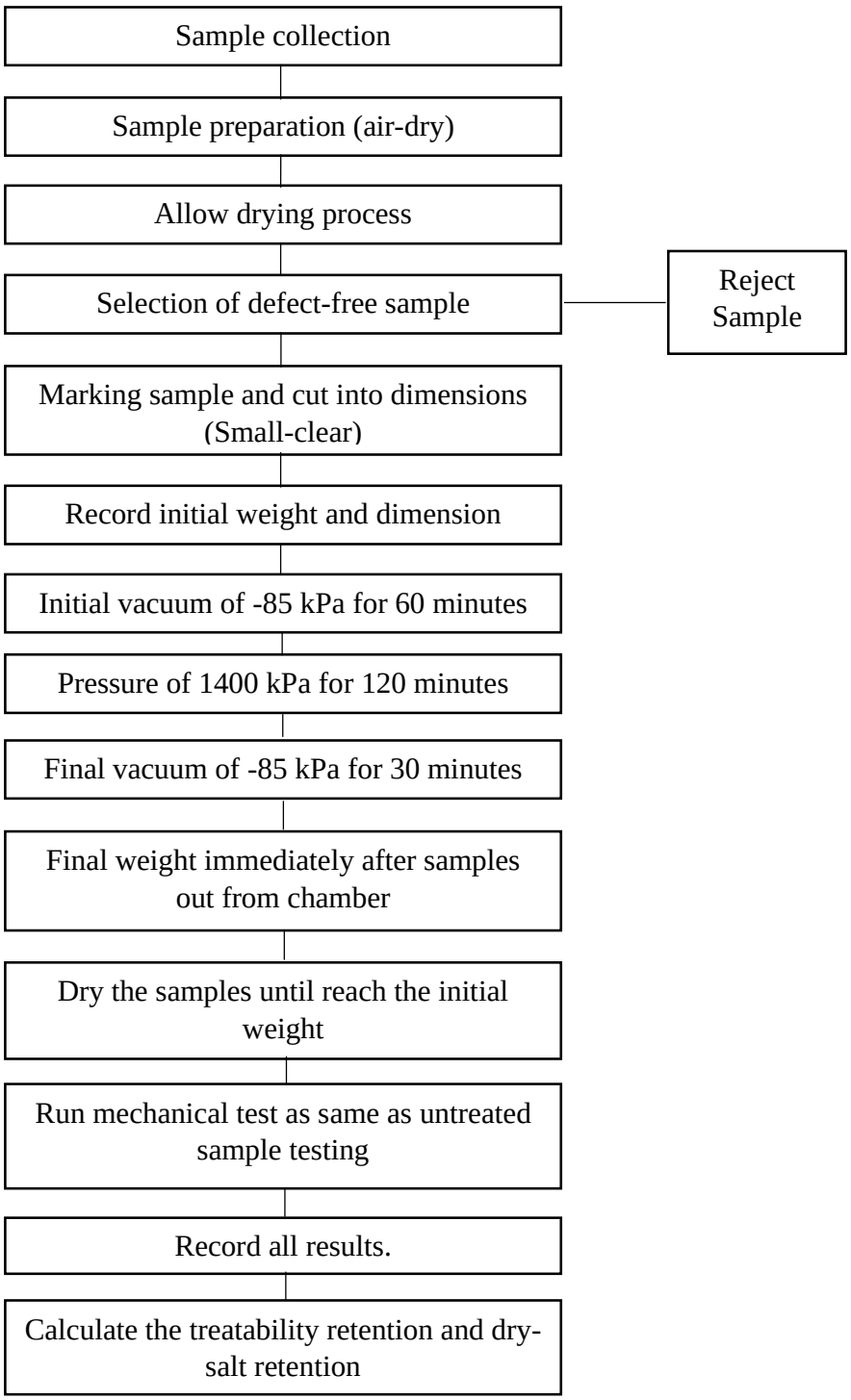


Figure 3.35: Flow Chart of the Treatability Test

3.7 Lamination

A total of 270 specimens from all age groups are involved in this experiment. The lamination process whereby requires adhesive bonds to join the samples. Basically, there are two types of adhesives which are adhesives for dry use and wet use. In this experiment, the wet use of *Phenol-resorcinol formaldehyde (PRF)* type of adhesive is chosen. The test procedures are according to ITTO's Testing Methods for Plantation Grown Tropical Timbers (Tan et al., 2010), which is also referred to as:

i. American Society for Testing and Materials (1999) Standard Specification for Adhesive Used for Laminate Joints in Non-structural Lumber Products

ii. Japanese Agricultural Standards (2003), MAFF, Notification No. 234 Japanese Agricultural Standard for Glued Laminated Timber

The PRF adhesive is prepared enough for the total of the samples. A total of 3 kg PRF was used together with a 15% hardener. Thus, 15% of 3 kg means 0.45 kg of hardener was used to cover up a total of samples. Applying adhesive should be done right after planning is done to ensure there is no dust and impurities lying on the surface of the planks. Meanwhile, as the planks meet the air-dry MC, the sample preparation starts with planning the timber's plank to the thickness of 10 mm and then applying PRF adhesive to one of the side surfaces of the plank. After that, combine two planks, press and leave it for a minimum of two days. The planks are cut into sticks, and from sticks, after the marking process is done, it is cut into dimensions whereby exactly the same as the untreated mechanical test specimens, which are static bending (20mm x 20mm x 300mm), compression (20mm x 20mm x 60mm) and shear (20mm x 20mm x 20mm). The mechanical testing on laminated

sample products was done in both situations, which are untreated and treated (CCA treatment). The adhesive and treatment used in this research are kept in constant variable, which means no experimental study specifically on adhesive and treatment properties will be conducted.

From this point of view, the modification in identifying the strength where the combination of pieces of wood, usually known as lamination takes place in a different age group. A different age group planks were glued together and hence underwent the same procedure from the origin lamina samples. The following figures indicate the preparation of PRF adhesive, applying PRF to the planed planks, planks compressed using the pressing jig and the illustration of preparing samples as well as a flow chart for the lamination process.



Figure 3.36: Preparation of PRF Glue



Figure 3.37: PRF Glue Mix-stir with Hardener



Figure 3.38: Applying the Glue on the Surface Sample's Planks



Figure 3.39: Press the Sample's Plank using Pressing Jig

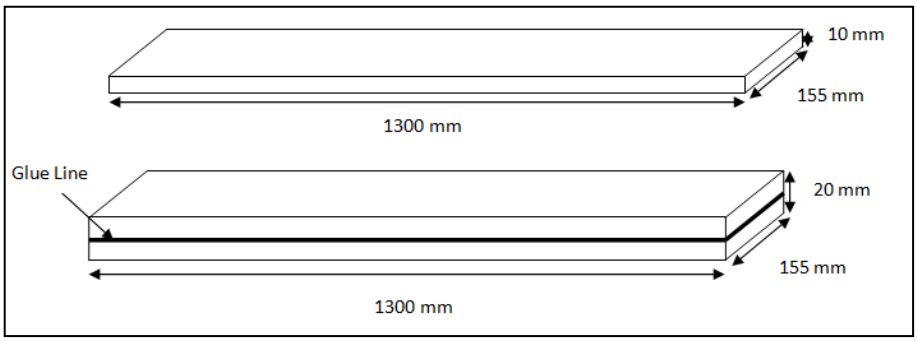


Figure 3.40: Illustration of Preparing Sample

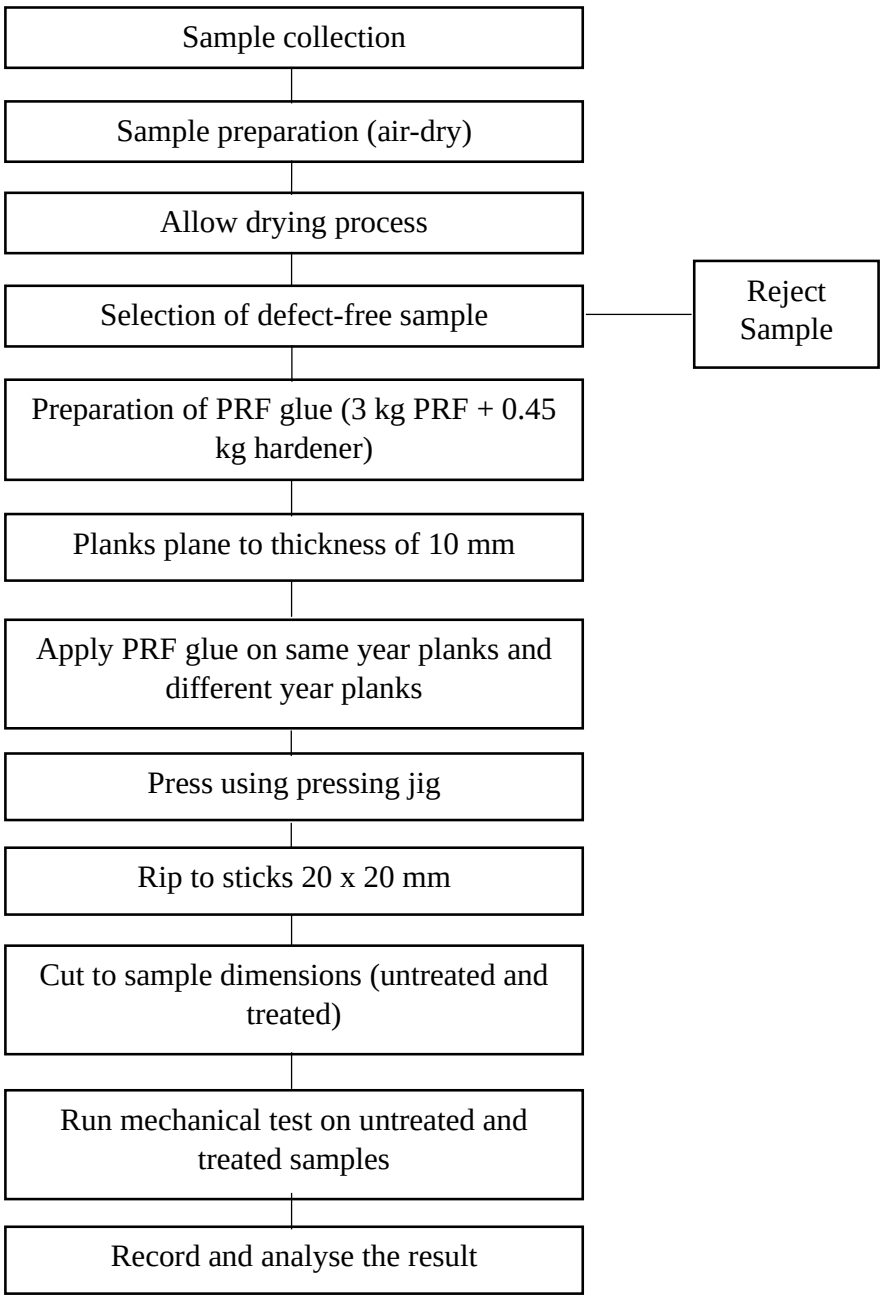


Figure 3.41: Flow Chart of Lamination Test

3.7.1 Tree's Pairing

This lamination testing consisted of two timber planks and applied an adhesive PRF type. The two timber planks are from different tree numbers. The different tree numbers are laminated together in order to investigate the strength behaviour of the timber in the same age group and in the different groups. Table 3.6 below indicates the tree pairing of superbulk species for the lamination process.

Table 3.6: Tree's Pairing for Lamination

	Age Groups (Year)	Tree Number
Same Age Group	7 // 7	328 / 347
		329 / 334
		348 / 367
		362 / 369
	10 // 10	559 / 620
		571 / 621
		626 / 642
		629 / 643
	13 // 13	142 / 163
		146 / 195
		206 / 211
		207 / 255
Different Age Group	7 // 10	348 / 559
		334 / 626
		362 / 571
		347 / 643
	7 // 13	328 / 225
		329 / 142
		367 / 207
		369 / 163
	10 // 13	620 / 146
		621 / 195
		629 / 206
		643 / 211

3.8 Method to Rank the Strength Differences

To rank the differences in strength from the best strength value (reference point) in the solid sample to the laminated sample products using The Garrett Ranking technique. Garrett's ranking technique was used to rank the preferences indicated by the respondents on different factors (Dhanavandan, 2016). Initially, the steps to set the ranking start with setting the percentage position by using the following formula.

Percent position = [100 (R-0.50] / N Equation 3.10

where R is the rank given for the variable by respondents, and N is the total number of variables ranked by respondents.

Thus, the per cent position obtained needs to refer to the Garrett Ranking Conversion Table (Appendix) to determine its score. The highest score is considered to the most important factor (Dhanavandan, 2016).

3.9 Method of Analysis

The methods used for analysing recorded data are simple regression analysis and one-way ANOVA analysis. According to Kumari and Yadav (2018), linear regression is a statistical procedure for calculating the value of a dependent variable from an independent variable, and it is a modelling technique where a dependent variable is predicted based on one or more independent variables. Regression analysis is a statistical technique for investigating and modelling the relationship between variables (Montgomery et al., 2021; Ismaili and Majid, 2007; Ismaili, 2007).

A one-way ANOVA (analysis of variance) compares the means of two or more groups for one dependent variable, and it is required when the study includes more than two groups (Ross & Wilson, 2017). The one-way ANOVA has certain assumptions. First, it assumed each sample had been selected independently from other samples, and second, the variance of the data in the different groups should be similar to the dependent variable. The final assumption is that each sample is from a normally distributed population (Connelly, 2021). The result of calculating this statistical test is called an F ratio, which is the ratio of how much variability within the groups (Bondmass, 2013). If the null hypothesis is true, there would be no difference between groups, and the ratio would be close to 1. Mishra et al. (2019) stated that the larger the value of F, the more likely it is the difference between the groups on the independent variable is real. Connelly (2021) reported that, if the p-value is significant (<0.05), then it can be concluded the groups' means varied from each other by a large enough amount for the difference to be significant.

CHAPTER 4

RESULTS, ANALYSIS AND DISCUSSIONS

4.1 Background

This chapter includes the recorded results of laboratory tests of *Acacia mangium* superbulk samples, its analysis, and discussions. These samples are made up of a total of eight trees. There are divided into two physical forms: solid (small-clear) form and glued-laminated form products. Each sample's form is prepared in two conditions: untreated and treated. All the samples that had been prepared separatly according to both forms and both conditions are undergoing physical testing and mechanical testing. Physical testing involves such moisture content (MC) and basic density, whereas mechanical testing takes place such as modulus of rupture (MOR), modulus of elasticity (MOE), compression parallel to grain and shear parallel to grain. Note that the shear parallel to grain test for solid form is experienced testing in two directions, which are radial plane and tangential plane; meanwhile, the shear test only has a single run-on direction for glue-laminated form. The recorded data is analysed by using mean analysis, the statistical model of simple linear regression, one-way ANOVA, post-hoc Duncan's Multiple Range Test (DMRT) and error bars at 95% confidence intervals.

Analysis using regression helps to determine the relationship between two or more variables and how the data fits the model of the analysis. It is also used to understand how the dependent variable changes when one of the independent variables varies and determine which of those variables has a mathematical impact. Meanwhile, a one-way ANOVA analysis with a probability of 0.05 is carried out to determine whether there is any statistically significant difference or not in the results corresponding to the particular test of all age

groups. Furthermore, the Duncan Multiple Range Test (DMRT) is the post-hoc test to determine the specific difference in mean values between the three age groups in this research. Meanwhile, the error bars at 95% confidence intervals ($p<0.05$) are used to analyse whether the comparison of the selected mean data set to other mean data sets has any significant difference. Moreover, the coefficient of variance (CV) is a statistical measure of the dispersion of data points in a data series around the mean. It is the ratio of the standard deviation (SD) to the mean of data and is generally expressed as a percentage. Habitually, the CV is interpreted as the lower the CV, the more precise the estimate. If the percentage of CV is more than 30 %, then the set of data analysed is unacceptable. Noted that the value (in parenthesis) is indicated in the CV.

This research is driven by the overarching goal of conducting a comprehensive strength analysis between solid and laminated products of *Acacia mangium* superbulk across various age groups. The primary objective is to pinpoint the optimal age group for laminated timber, emphasizing the identification of combinations that exhibit notable strength enhancements. Rigorous strength assessments will be carried out on both solid and laminated timber products, focusing on observing and ensuring strength stability. This evaluation will specifically consider the impact of durability treatment, adhering strictly to established safety standards. Furthermore, the research seeks to go beyond mere analysis by translating findings into actionable outcomes. The intention is to introduce innovative laminated timber products that are not only aligned with industry safety norms but also finely attuned to the prevailing conditions and diverse needs of end-users. This approach aims to bridge the gap between research outcomes and practical applications, offering tailored solutions that address real-world challenges and requirements.

4.2 Solid-untreated of *Acacia mangium* superbulk

The solid-untreated *Acacia mangium* superbulk was prepared from the three age groups of 7, 10 and 13 years old, which also controlled this study's samples also as. These solid-untreated samples undergo a few physical tests, such as moisture content test (MC) and basic density. Moisture content is determined by the percentage of differences between oven-dry weight and the initial weight of the sample. Meanwhile, the basic density of the timber is determined by oven-dry weight over the volume of the sample. The formulae for both physical properties are stated in Chapter 3. Furthermore, this form of the sample also experienced mechanical strength testing such as modulus of rupture (MOR), modulus of elasticity (MOE), compression parallel to grain and shear parallel to grain (radial plane and tangential plane).

4.2.1 Moisture Content

Moisture content obtained from all age groups is almost the same as all the samples are monitored consistently until they achieve the per cent moisture of air-dry. A total of 576 samples from all age groups are used, and the mean results are tabulated in Table 4.1. Moisture content is collected from all test samples, including static bending, compression, and shear (radial and tangential). Referring to that respective table, the mean moisture content of *Acacia mangium* superbulk was achieved for all three age groups of 7, 10 and 13-year-old samples at 18.73 %, 18.64 % and 18.84 %, respectively. The collected CVs from three age groups also show excellent statistics. The percentages of moisture content are acceptable in accordance with Alik and Kuroda (1996) stated that in the case of Sarawak timber, the air-dry moisture content is introduced in the range of 18 – 20 %. Further experiments on getting mechanical strength properties are only started when all samples

have reached air-dry MC. Note that the value (in parentheses) is indicated in the CV.

Table 4.1: Moisture Content (Solid-untreated) of *Acacia mangium* superbulk

Age Groups	Moisture Content (%)
7 Years Old	18.73 (5.27)
10 Years Old	18.64 (5.30)
13 Years Old	18.84 (5.04)

*(In parenthesis) are the coefficients of variances.

Table 4.2: One-way ANOVA Moisture Content (Solid- untreated) of *Acacia mangium* superbulk

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	3.88	2	1.94	2.04	0.13
Within Groups	546.00	573	0.95		
Total	549.88	575			

A statistical analysis of one-way ANOVA with a probability of 0.05 is performed to determine whether there is a statistically significant difference or not in the percentage of moisture content recorded by samples from all age groups. The result from the ANOVA analysis is presented in Table 4.2. The table shows no statistically significant difference in moisture content among all the samples since the significant value is higher than the probability of 0.05. Note that, in one-way ANOVA analysis, between-group represented how two or more groups are different, whereas within-group shows differences among subjects who are in the same group. Based on Table 4.2, the F value obtained is 2.04, where the F value is the value on the F distribution, where it is calculated by dividing two mean squares to determine the ratio of explained variance and whether the test is statistically significant or not.

Table 4.3: DMRT of Moisture Content (Solid-untreated) of *Acacia mangium* superbulk

Age Groups	N	Subset for alpha = 0.05
		1
10 Years Old	192	18.64
7 Years Old	192	18.73
13 Years Old	192	18.84
Sig.		0.06

The Duncan Multiple Range Test is selected to identify which age group varied in the mean percentage of moisture content from all age groups. Table 4.3 indicates the DMRT post-hoc test result of the mean moisture content. The table shows that the mean of moisture content obtained is placed in the same groups since there is no specific difference in the mean of moisture content between all age groups. The mean moisture content for all age groups attained from 192 samples by each age group was equivalent to each other.

In contrast, the mean moisture content of samples from *Acacia mangium* recorded by Yang and Voon (2014), the air-dry MC for the age groups of 7, 10, and 13 years old samples are 18.29 %, 18.42 % and 18.40 %, respectively. There is no massive difference in MC values for both species samples. The comparison of moisture content between both species is presented in Table 4.4. The mean air-dry moisture content resulting from both species is almost equivalent to each other. Hence, it has been proved that the moisture content of air-dry condition from current research is acceptable.

Table 4.4: Comparison of Moisture Content between *Acacia mangium* and *Acacia mangium* superbulk (Solid-untreated)

Age Groups	*Acacia mangium*	*Acacia mangium* superbulk
7 Years Old	18.29 %	18.73 %
10 Years Old	18.42 %	18.64 %
13 Years Old	18.40 %	18.84 %

4.2.2 Density

The three age groups of solid-untreated *Acacia mangium* superbulk are prepared under air-dry condition before undergoing mechanical testing. The air-dry density of the samples is being evaluated for the age groups of 7, 10, and 13 years old samples and presented in Figure 4.1. Based on Figure 4.1, the mean density and CV of the *Acacia mangium* superbulk at the air-dry condition for the age groups of 7, 10, and 13 years old samples are 0.62 g/cm^3 (10.96), 0.66 g/cm^3 (10.85) and 0.63 g/cm^3 (9.59), respectively. The coefficient of variances collected is in the best range. The density age groups of 7 and 13 years old samples are not significant to each other compared to the density of 10 years old samples, which is significantly different at 95% confidence intervals.

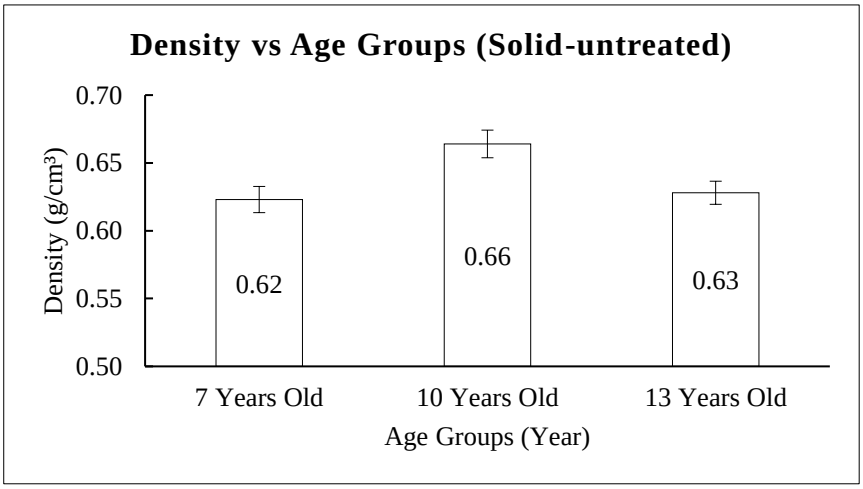


Figure 4.1: Density (Solid-untreated) of *Acacia mangium* superbulk

All the density results are being performed in the one-way ANOVA analysis. The outcome of that analysis is tabulated in Table 4.5. Based on the table, there is no statistically significant difference among all the densities results from all three age groups. The significant value obtained is 0.00, which is below 0.05 (probability level). Moreover, to determine which age group varied among densities results, the DMRT analysis is performed. The DMRT result is indicated in Table 4.6. Based on Table 4.6, the DMRT analysis results show that the density of 10 years old samples has a specific difference compared to the densities of the two age groups. The densities of 7 and 13-year-old samples do not have specific differences from each other.

Table 4.5: One-way ANOVA Density (Solid-untreated) of *Acacia mangium* superbulk

	Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	0.19	2	0.09	20.79	0.00
Within Groups	2.59	573	0.01		
Total	2.78	575			

Table 4.6: DMRT of Density (Solid-untreated) of *Acacia mangium* superbulk

Age Groups	**N**	**Subset for alpha = 0.05**	
		1	**2**
7 Years Old	192	0.62	
13 Years Old	192	0.63	
10 Years Old	192		0.66
Sig.		0.52	1.00

4.2.3 Basic Density

Basic density is determined by dividing the oven-dry weight of the specimen by the volume of the specimen. According to Ismaili et al. (2022) and Alik and Kuroda (1996), basic density can be adopted as a reliable strength indicator for the mechanical stress grading of Sarawak timbers. Note that the basic density is calculated using the formula stated in Chapter 3 (Equation 3.3). Thus, it is essential to determine the basic density as the results of basic density are conveyed the basic effect of the strength properties. Figure 4.2 is presented from the mean of 576 samples that were used for the basic density test.

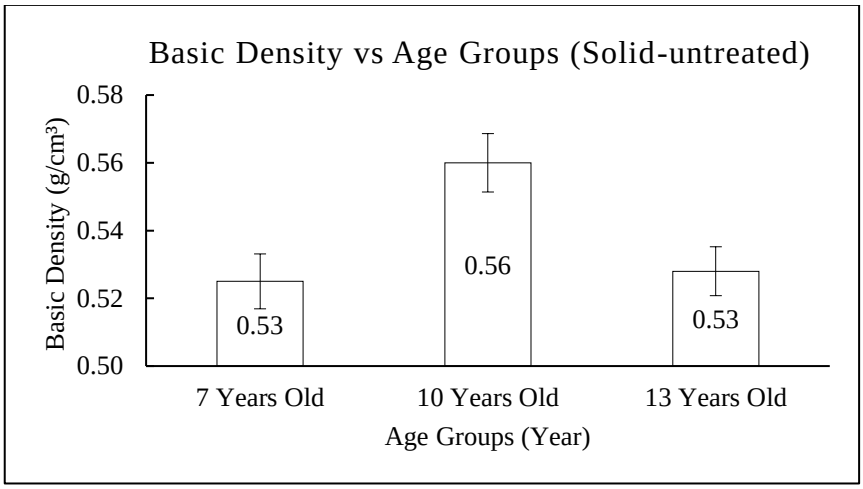


Figure 4.2: Basic Density (Solid-untreated) of *Acacia mangium* superbulk

Based on Figure 4.2, the mean and CV of basic density results obtained confirmed that the age group of 10 years old samples has the highest basic density, which is 0.56 g/cm^3 (10.89), followed by 13 years old samples at 0.53 g/cm^3 (9.66) and the lowest in the age group of 7 years old samples which recorded mean 0.53 g/cm^3 (10.92). The calculated CVs also are in the good range. At 95% confidence intervals, the mean basic density of 7 and 13 years old samples does not show a significant difference, whereas the mean basic density of 10 years old samples is significantly difference when compared to those three age groups

($p<0.05$).

Table 4.7: One-way ANOVA of Basic Density (Solid-untreated) of *Acacia mangium* superbulk

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0.14	2	0.07	22.23	0.00
Within Groups	1.83	573	0.00		
Total	1.97	575			

A statistical analysis of one-way ANOVA variance analysis with a probability of 0.05 and a number of 576 samples is performed in order to determine the statistically significant difference in basic density results for all age groups. Table 4.7 summarises the one-way ANOVA results of basic density for 7, 10, and 13-year-old samples of *Acacia mangium* superbulk. Table 4.7 shows a statistically significant difference in the basic density of all age groups since the p-value is < 0.05.

Table 4.8: DMRT of Basic Density (Solid-untreated) of *Acacia mangium* superbulk

Age Groups	N	Subset for alpha = 0.05	
		1	2
7 Years Old	192	0.53	
13 Years Old	192	0.53	
10 Years Old	192		0.56
Sig.		0.52	1.00

The Duncan Multiple Range Test (DMRT) was chosen to run the post-hoc test in order to determine which age group varied in mean basic density. DMRT was conducted to identify whether there are specific differences in mean basic density between age groups. Table 4.8 represents the Duncan Multiple Range Test comparison results on the mean basic

density of *Acacia mangium* superbulk. According to Table 4.8, all *Acacia mangium* superbulk age groups have specific differences in mean basic density. The age group of 10 years old samples has a specific difference in mean of basic density compared to the other two age groups. Meanwhile, the mean of basic density 13 years old samples and 7 years old samples does not have any specific difference among them, and they are placed under the same class.

4.2.4 Static Bending

An analysis of static bending of untreated specimen results is categorised into two parts, which are modulus of rupture (MOR) and modulus of elasticity (MOE) with respect to age groups and also modulus of rupture (MOR) and modulus of elasticity (MOE) respect to basic density.

i. MOR and MOE Respect to Age Groups

A total of 144 untreated small clear of *Acacia mangium* superbulk underwent a static bending test to determine the modulus of rupture (MOR) and modulus of elasticity (MOE). According to Alik and Kuroda (1996), MOR indicates a measure of the ultimate bending strength of timber for that size of the sample and that rate of bending, whereas MOE concerns a measure of stiffness or flexibility of a specimen in bending. The MOR and MOE results were obtained from the formulae as stated in Chapter 3 of this thesis. Figures 4.3 and 4.4 show the mean results for MOR and MOE obtained from all three age groups.

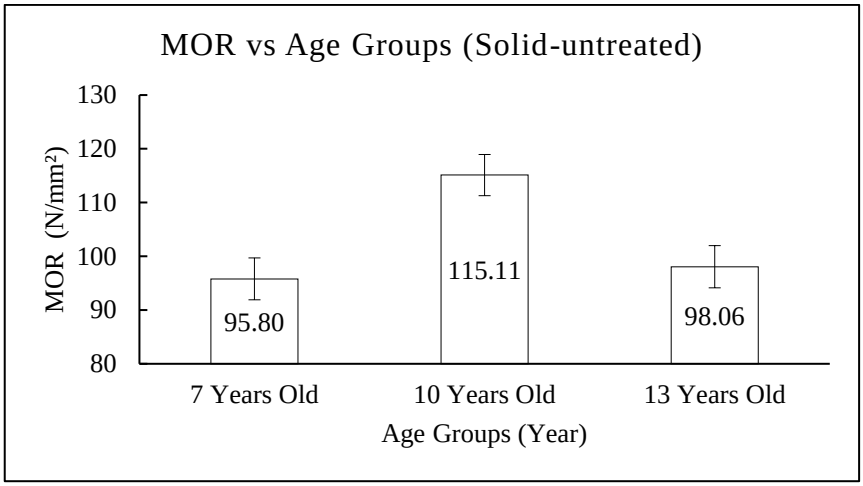


Figure 4.3: MOR Against Age Groups (Solid-untreated) of *Acacia mangium* superbulk

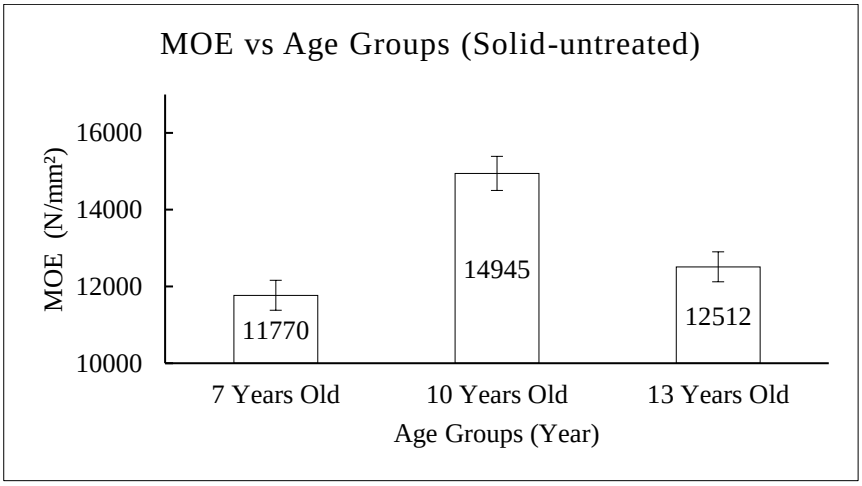


Figure 4.4: MOE Against Age Groups (Solid-untreated) of *Acacia mangium* superbulk

From data collected among three age groups, Figure 4.3 shows that the age group of 10 years old samples has the highest MOR mean with CV value, which is 115.11 N/mm^2 (11.77). Meanwhile, the lowest MOR, which is 95.80 N/mm^2 (14.37), is obtained by age groups of 7 years old samples and 13 years old samples marked in the middle among all age groups with mean and CV of MOR equal to 98.06 N/mm^2 (14.16). On the other hand, Figure 4.4 shows the most excellent MOE value among the three age groups is also from 10 years

old samples trees, which is 14945 N/mm^2 (10.51), followed by 13 years old samples, which is 12512 N/mm^2 (11.02). The smallest is 11770 N/mm^2 (11.72) from the age group of 7 years old samples. Moreover, all the CVs recorded by the data are classified under a good rating.

At 95% confidence intervals, there is no statistically significant difference in mean of 7 and 13 years old samples, and only 10 years old samples has a statistically significant difference when compared to those three age groups for MOR and MOE. Meanwhile, mean MOE from all age groups has significant differences when compared to each other. The analysis continues with a one-way ANOVA analysis of variance at 5% probability. It was presented in order to identify whether there is any statistically significant difference in the value of the modulus of rupture and modulus of elasticity of all age groups of species. Table 4.7 indicates the ANOVA results for modulus of rupture and modulus of elasticity of all age groups, with the total number of samples being 144.

Table 4.9: One-way ANOVA of MOR and MOE (Solid-untreated) of *Acacia mangium* superbulk

		Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
MOR	Between Groups	10703.47	2	5351.73	28.37	0.00
	Within Groups	26594.56	141	188.61		
	Total	37298.03	143			
MOE	Between Groups	264825389.26	2	132412694.63	63.35	0.00
	Within Groups	294729480.23	141	2090280.00		
	Total	559554869.49	143			

Table 4.9 shows that the F values of MOR and MOE are 28.37 and 63.35, respectively. The results show a statistically significant difference in both MOR and MOE values of all three age groups, where both significant values are $p<0.05$. To determine which

age group varied in mean modulus of rupture and mean modulus of elasticity, the Duncan Multiple Range Test (DMRT) was selected to perform the post-hoc test. DMRT is conducted to identify whether the differences between MOR and MOE between age groups are significant. Table 4.10 and Table 4.11 represent the results of Duncan Multiple Range Test comparison on the mean modulus of rupture and mean modulus of elasticity, with the number of samples in each age group is 48.

Table 4.10: DMRT of MOR (Solid-untreated) of *Acacia mangium* superbulk

Age Groups	**N**	**Subset for alpha = 0.05**	
		1	**2**
7 Years Old	48	95.80	
13 Years Old	48	98.06	
10 Years Old	48		115.11
Sig.		0.42	1.00

Table 4.11: DMRT of MOE (Solid-untreated) of *Acacia mangium* superbulk

Age Groups	**N**	**Subset for alpha = 0.05**		
		1	2	3
7 Years Old	48	11769.88		
13 Years Old	48		12512.02	
10 Years Old	48			14945.00
Sig.		1.00	1.00	1.00

Both Table 4.10 and Table 4.11 showed that the age group of 10 years old samples has a highest specific difference in mean of MOR and MOE. Table 4.10 presented that the age groups of 13 years old samples and 7 years old samples do not have any specific difference in mean MOR, whereas, in Table 4.11, mean MOE from age groups of 7 years

old samples and 13 years old samples have specific differences from each other.

From the static bending test, instead of MOR and MOE results, the recorded data also listed the maximum load that the timber samples can carry. Table 4.12 represents the maximum load in kN by each of the age groups, and it shows that the highest amount of loading that can be carried is 2.30 kN, which is from the age group of 10 years old samples, followed by 13 years old samples, which is 1.95 kN and 7 years old samples 1.92 kN. The maximum load of MOR and MOE can be obtained by calculating using the formula given, and the results have been tabulated in Table 4.12. The higher maximum load derived in Table 4.12 represent the higher MOR and MOE.

Table 4.12: Maximum Load of Static Bending (Solid-untreated) of *Acacia mangium* superbulk

Age Group (Year)	Maximum Load (kN)
7	1.92
10	2.30
13	1.95

ii. MOR and MOE Respect to Basic Density

The following figures represent the linear regression analysis of MOR and MOE against basic density for 7, 10 and 13 years old's samples.

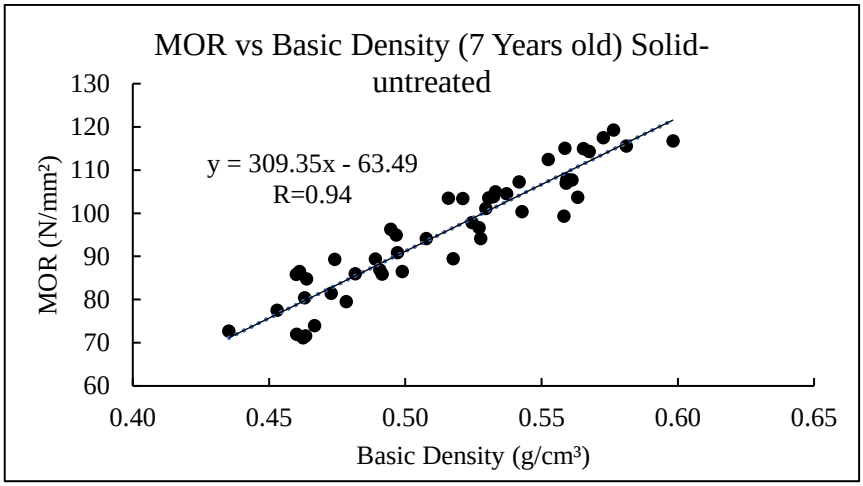


Figure 4.5: MOR Against Basic Density for 7 Years Old (Solid-untreated) of *Acacia mangium* superbulk

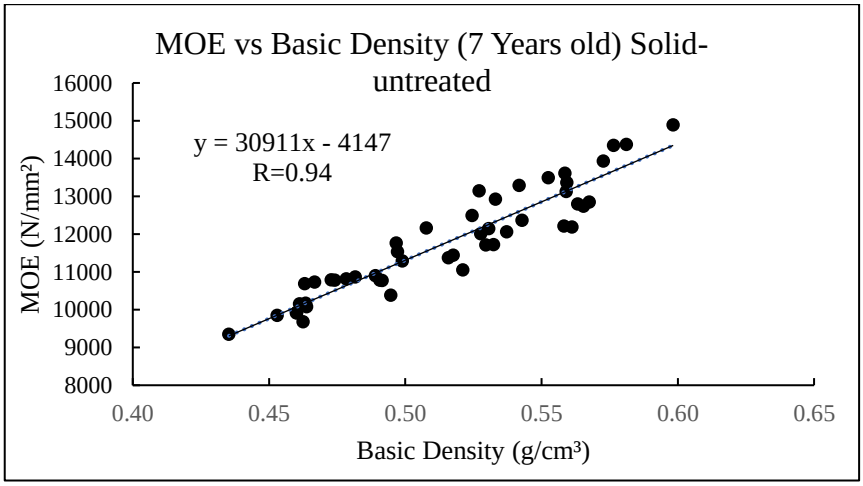


Figure 4.6: MOR Against Basic Density for 7 Years Old (Solid-untreated) of *Acacia mangium* superbulk

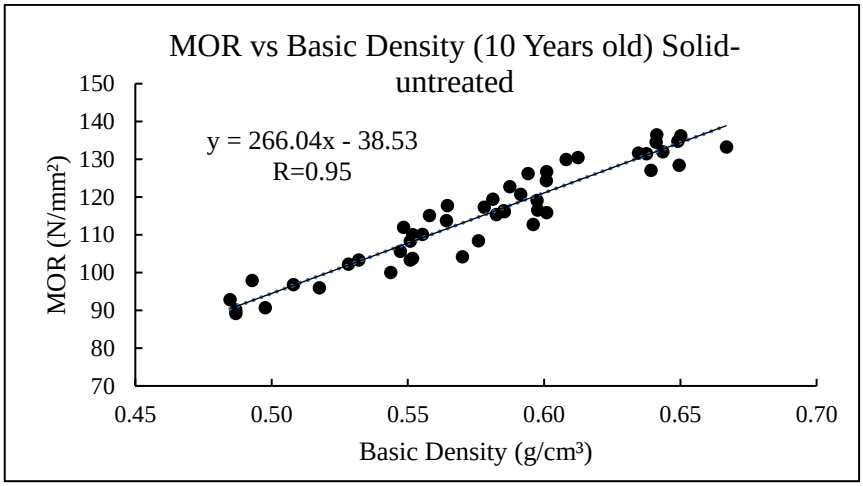


Figure 4.7: MOR Against Basic Density for 10 Years Old (Solid-untreated) of *Acacia mangium* superbulk

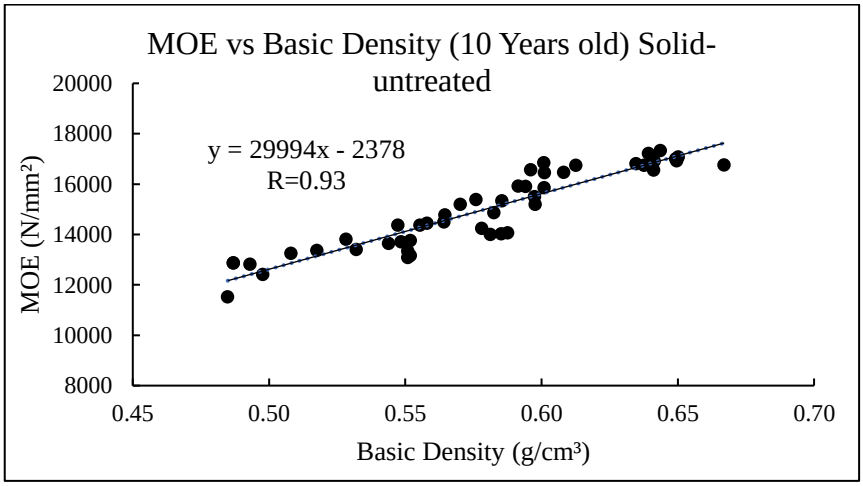


Figure 4.8: MOE Against Basic Density for 10 Years Old (Solid-untreated) of *Acacia mangium* superbulk

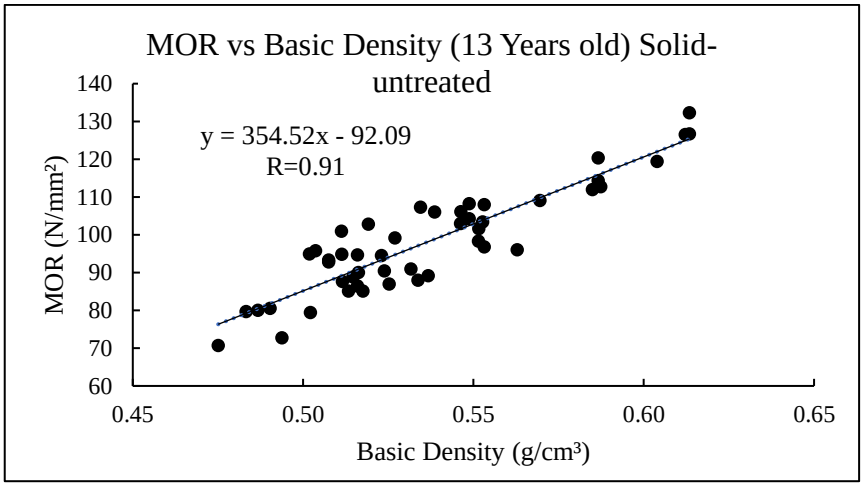


Figure 4.9: MOR Against Basic Density for 13 Years Old (Solid-untreated) of *Acacia mangium* superbulk

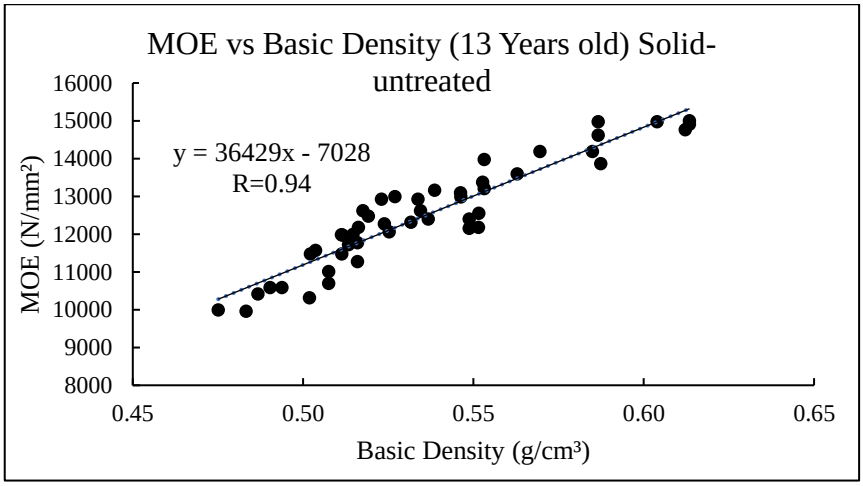


Figure 4.10: MOE Against Basic Density for 13 Years Old (Solid-untreated) of *Acacia mangium* superbulk

The correlation values, R-values that obtained from regression analysis of all MOR and MOE for 7, 10 and 13 years old showed a strong correlation between MOR or MOE and basic density (Figure 4.5 to Figure 4.10) since the R-values are very strong correlation as reported by Senthinathan (2019) that correlation value range 0.70 to 1.00 are very strongly considerable correlation. The correlation values obtained are 0.94 (MOR 7 years old), 0.94

(MOE 7 years old), 0.95 (MOR 10 years old), 0.93 (MOE 10 years old), 0.91 (MOR 13 years old) and 0.94 (MOE 13 years old). Therefore, it can be concluded that MOR and MOE strongly correlate with basic density for all age groups.

The static bending test of *Acacia mangium* superbulk that derives two important timber characteristics exhibits better strength results from the study conducted by Alik and Liang (2014) on *Acacia mangium*. The species of 'Superbulk' is mainly generated from the best-selected seed of *Acacia mangium*. Hence, it obviously should be given the improved strength properties, and this study proved it perfectly. The summary of all mean results of static bending for controlled specimens compared to the previous study of *Acacia mangium* is tabulated in Table 4.13.

Table 4.13: Comparison of Static Bending between *Acacia mangium* and *Acacia mangium* superbulk (Solid-untreated)

Species	***Acacia mangium* superbulk**			***Acacia mangium* (Alik & Liang, 2014)**		
Year	7	10	13	7	10	13
Modulus of Rupture (N/mm^2)	95.80	115.11	98.06	93.21	114.86	95.10
Modulus of Elasticity (N/mm^2)	11770	14945	12512	11456	14519	11626

In conclusion, compared with the previous study of *Acacia mangium* by Alik and Liang (2014), it is shown that MOR and MOE from *Acacia mangium* superbulk are higher than MOR and MOE from *Acacia mangium*. The highest MOR and MOE from both species are from the same age group, which is 10 years old samples. The MOR and MOE results for 10 years old *Acacia mangium* are 114.86 N/mm^2 and 14519 N/mm^2, respectively, compared

to the current study that obtained MOR and MOE are 115.11 N/mm^2 and 14945 N/mm^2, respectively. The second highest MOR and MOE of origin *Acacia* spp. are also from the age group of 13 years old samples, which are 95.10 N/mm^2 and 11626 N/mm^2, respectively, compared to improved *Acacia* spp. which is obtained MOR and MOE are 98.06 N/mm^2 and 12512 N/mm^2 respectively. Lastly, MOR 93.21 N/mm^2 and MOE 11456 N/mm^2 are the lowest coming from the age group of 7 years old of *Acacia mangium* compared to MOR 95.80 N/mm^2 and MOE 11770 N/mm^2 from the age group of 7 years old of *Acacia mangium* superbulk. Therefore, this comparison made more explicit evidence to express the enhancement of strength properties between the origin Acacia spp. and an improved *Acacia* spp.

4.2.5 Compression Parallel to Grain

An analysis of compression parallel to grain of untreated specimen results is categorised into two parts: compression parallel to grain with respect to age groups and compression parallel to grain with respect to basic density.

i. Compression Parallel to Grain

Compression strength is obtained where a maximum load in N/mm^2 is applied on a cross-sectional area. A total of 144 small clear specimens in air-dry conditions went through the experiment. Therefore, the recorded data is analysed using one-way ANOVA and Duncan Multiple Range Test concerning age groups. The scatter chart illustrated in Figure 4.11 represents the compression parallel to grain against age groups (7, 10 and 13 years old samples).

Figure 4.11 explains that the highest mean with CV compression strength for the

untreated specimen is 57.57 N/mm^2 (10.25), which is from the age group 10 years old *Acacia mangium* superbulk sample, followed by 13 years old samples that acquired mean and CV compression strength of 52.93 N/mm^2 (11.75). The lowest mean and CV compression strength is from 7 years old samples, with 49.18 N/mm^2 (9.97). All CVs also meet a good range of data. All three age groups have a statistically significant difference from each other at 95% confidence intervals.

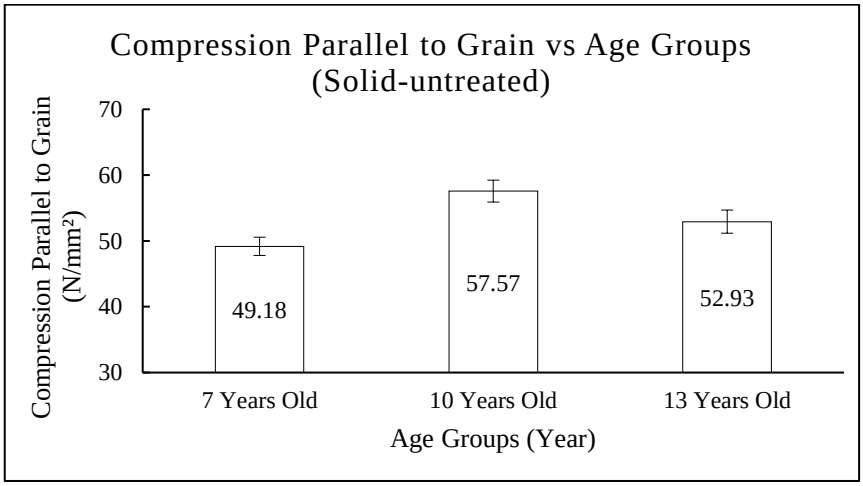


Figure 4.11: Compression Parallel to Grain Against Age Groups (Solid-untreated) of *Acacia mangium* superbulk

A one-way ANOVA analysis is carried out to determine whether there is any statistically significant difference or not in the results of compression strength of all age groups. The analysis of variance, one-way ANOVA with a probability of 0.05 and the total number of samples is 144, presented in Table 4.14. The table summarises that the F value, obtained by dividing two mean squares, gives the result of 26.12. Hence, the compression strength results of all age groups have a statistically significant difference among all results where the significant value attained is less than 0.05.

Table 4.14: One-way ANOVA of Compression Parallel to Grain (Solid-untreated) of *Acacia mangium* superbulk

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1696.92	2	848.46	26.12	0.00
Within Groups	4581.58	141	32.49		
Total	6278.50	143			

Based on Table 4.15, a post-hoc test of DMRT is presented to differentiate which age group varies in compression strength. DMRT is conducted to identify whether the differences in mean compression strength between age groups are significant or not. From that respective table, DMRT analysis signified that the mean compression strength of all groups is placed into every single group, meaning that, among the three age groups, there is a specific difference in mean compression strength for all age groups.

Table 4.15: DMRT of Compression Parallel to Grain (Solid-untreated) of *Acacia mangium* superbulk

Age Groups	N	Subset for alpha = 0.05		
		1	2	3
7 Years Old	48	49.18		
13 Years Old	48		52.93	
10 Years Old	48			57.57
Sig.		1.00	1.00	1.00

Establishing the maximum load that can be achieved from the compression testing on each sample is necessary. Therefore, the mean for all age groups is determined and tabulated in Table 4.16. Table 4.15 refers to the maximum load of compression strength in kN obtained by the age group of 7 years old samples, which is 2.05 kN, whereas 2.39 kN,

which is the highest maximum load, was attained by the age group of 10 years old samples. Meanwhile, the age group of 13 years old samples achieved the maximum load of compression strength is 2.19 kN.

Table 4.16: Maximum Load of Compression Parallel to Grain (Solid-untreated) of *Acacia mangium* superbulk

Age Group (Year)	Maximum Load (kN)
7	2.05
10	2.39
13	2.19

ii. Compression Parallel to Grain Respect to Basic Density

The analysis of results continues to another factor, which is compression parallel to grain with respect to the basic density of each age group. This analysis introduced the correlation between compression strength and basic density for a total of 144 specimens. A linear regression model is presented between the dependent and independent variables and gives the R values of that smooth line created. The relationship between the dependent variable (compression strength) and independent variable (basic density) of 7, 10, and 13 years old of *Acacia mangium* superbulk samples are displayed in Figure 4.12, Figure 4.13, and Figure 4.14, respectively.

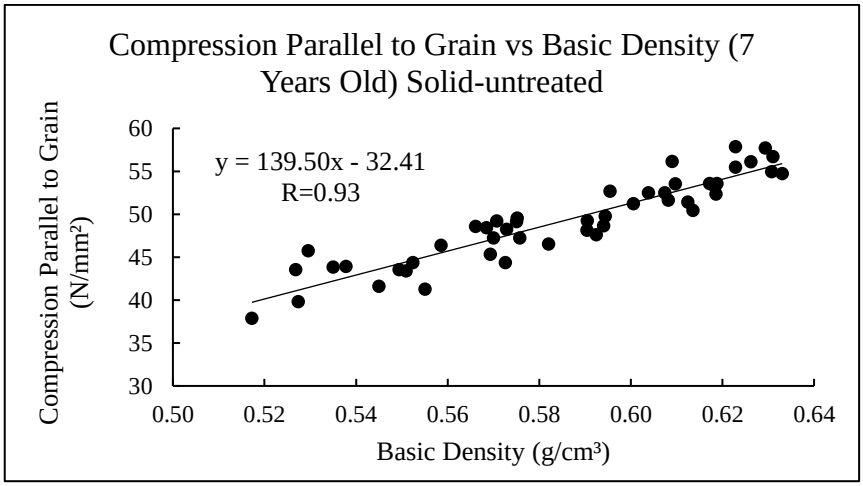


Figure 4.12: Compression Parallel to Grain Against Basic Density for 7 Years Old (Solid-untreated) of *Acacia mangium* superbulk

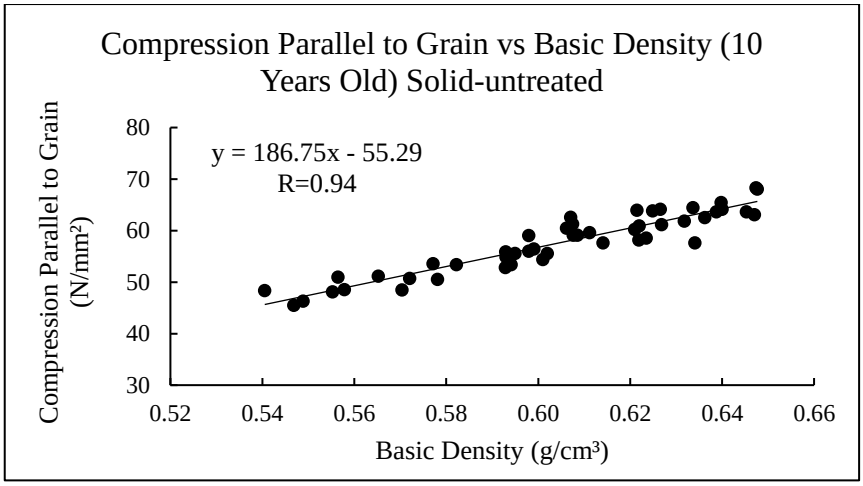


Figure 4.13: Compression Parallel to Grain Against Basic Density for 10 Years Old (Solid-untreated) of *Acacia mangium* superbulk

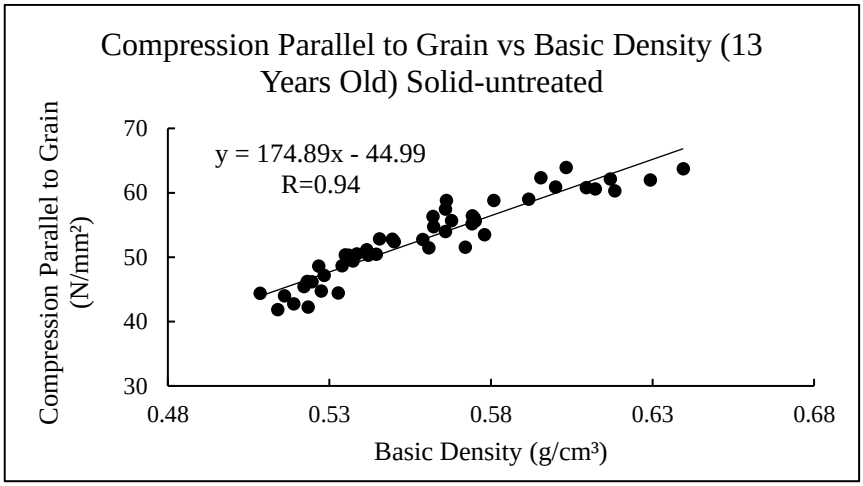


Figure 4.14: Compression Parallel to Grain Against Basic Density for 13 Years Old (Solid-untreated) of *Acacia mangium* superbulk

From the linear regression analysis for all three age groups, there is a very strong correlation obtained since the R-values collected are more than 0.90, which is 0.93 (7 years old), 0.94 (10 years old) and 0.94 (13 years old). This very strong correlation is verified by the Senthinathan (2019) study, where a correlation range from 0.70 to 1.00 is considered a very strong correlation. Meanwhile, the compression strength is another important key in the strength properties of timber. The strength properties of *Acacia mangium* superbulk propagated from the basis of *Acacia* spp. should exhibit better strength results. There was more apparent improvement in the strength of the superbulk when compared to the study conducted by Alik and Liang (2014) on the origin *Acacia* spp, as shown in Table 4.17.

Table 4.17: Comparison of Compression Parallel to Grain between *Acacia mangium* and *Acacia mangium* superbulk (Solid-untreated)

Species	***Acacia mangium* superbulk**			***Acacia mangium* (Alik &Liang, 2014)**		
Year	7	10	13	7	10	13
Compression Strength (N/mm^2)	49.18	57.57	52.93	47.06	56.01	51.48

Table 4.17 describes the differences in compression strength between the current and previous studies of *Acacia* species done by Alik and Liang (2014); it records the highest mean compression strength is 56.01 N/mm^2 compared to the present research on 'Superbulk' species is 57.57 N/mm^2, where the increment is about 1.56 N/mm^2. The highest compression strength from both species is the same, which is from the age group 10 years old of *Acacia* spp. Meanwhile, the second-lowest mean compression strength gained from both species is also from the same age group, which is 13 years old samples. The strength obtained from 13 years old of *Acacia mangium* superbulk and *Acacia mangium* is 52.93 N/mm^2 and 51.48 N/mm2, respectively. The difference between them is 1.45 N/mm^2. Like the current study, the previous study also recorded the lowest compression strength from the age group of 7 years old samples. The compression strength attained from both findings of *Acacia mangium* superbulk and *Acacia mangium* is 49.18 N/mm^2 and 47.06 N/mm^2, respectively. It rises about 2.12 N/mm^2 from base *Acacia mangium* to 'Superbulk'. Therefore, it is verified that *Acacia mangium* superbulk is better in compression strength compared to *Acacia mangium.*

4.2.6 Shear Parallel to Grain

An analysis of shear parallel to grain of untreated specimen results is categorised into two parts: shear parallel to grain with respect to age groups and shear strength with respect to basic density.

i. Shear Parallel to Grain Respect to Age Groups

Shear parallel to grain is obtained when maximum load is applied on the cross-sectional area of 20 mm x 20 mm. The experiment's formula and procedure are introduced in the previous chapter. Shear parallel to grain analysis includes two types of testing: test on the radial plane and test on the tangential plane. These two planes bring in different shear

strength values. A total of 144 small clear controlled specimens underwent the shear test. Figure 4.15 indicates the mean untreated shear parallel to grain between the radial and tangential planes concerning age groups.

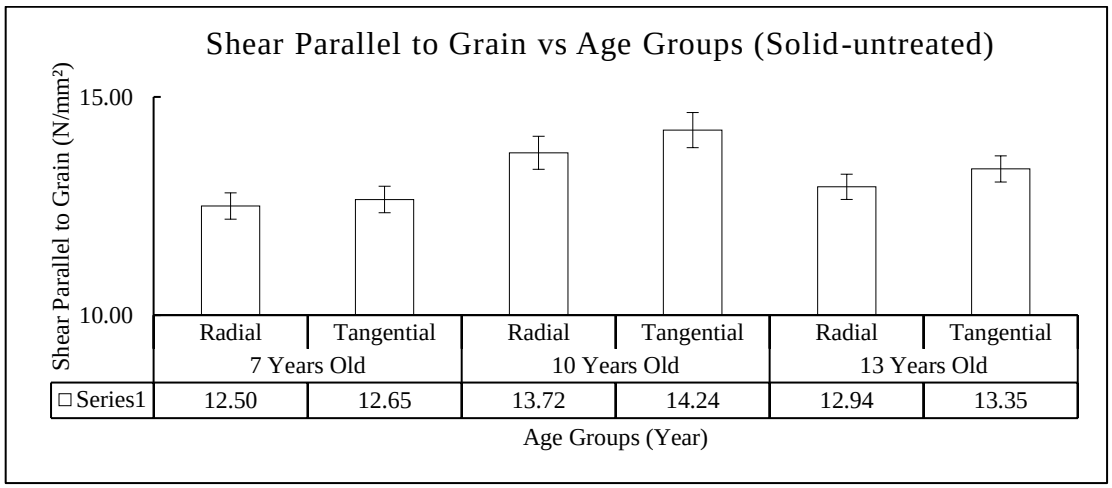


Figure 4.15: Shear Parallel to Grain Against Age Groups (Solid-untreated) of *Acacia mangium* superbulk

Figure 4.15 shows the mean results of untreated shear parallel to grain in radial and tangential plane concerning age groups of 7, 10, and 13 years old *Acacia mangium* superbulk samples. It is explained that the best shear strength between two planes is at the tangential plane. The highest mean with the CV of shear parallel to grain is from the age group of 10 years old samples that resulted in radial and tangential are 13.72 N/mm^2 (9.75) and 14.24 N/mm^2 (10.00), respectively. The difference between the radial and tangential plane results is increased by 0.52 N/mm^2. The second highest mean shear parallel to the grain is from 13 years old of the 'Superbulk' species. The radial and tangential mean results obtained are 12.94 (7.91) N/mm^2 and 13.35 (7.94) N/mm^2. The increment recorded from radial to tangential plane shear parallel to grain is 0.41 N/mm^2. Meanwhile, the lowest mean shear parallel to grain for untreated conditions is the age group of 7 years old samples, where

results reported that radial and tangential are 12.50 (8.53) N/mm^2 and 12.65 (8.49) N/mm^2, respectively. The tangential plane from 7 years old samples rises about 0.15 N/mm^2 compared to the radial plane. All CVs from the data are low, indicating excellent condition, and show a low level of dispersion around the mean.

At 95% confidence intervals, in the radial plane, there is no statistically significant difference between mean shear parallel to grain from 7 and 13 years old and only 10 years old samples have a statistically significant difference at $p < 0.05$. Meanwhile, all mean shear parallel to grain in the tangential plane from three age groups is significantly different to each other at 95% confidence intervals. However there are no statistically significant differences between radial and tangential direction within each age groups.

The statistical analysis of one-way ANOVA is carried out to determine whether there is a statistically significant difference in the result for all age groups or not. The one-way ANOVA analysis of variance is run with a probability of 0.05, and the total number of samples 144 is tabulated in Table 4.18. Based on the respective table, it is shown that shear parallel to grain in both the radial plane and the tangential plane has a statistically significant difference in shear parallel to grain result for all age groups since the significant value is equal to 0.00, which means below 0.05. Meanwhile, the F value is the F distribution from the ratio between two mean squares, proving the analysis is significantly different from each other. The F values obtained from both planes are 13.68 and 21.13, respectively.

Table 4.18: One-way ANOVA of Shear Parallel to Grain (Solid-untreated) of *Acacia mangium* superbulk

		Sum of Squares	df	Mean Square	F	Sig.
Radial	Between Groups	36.23	2	18.11	13.68	0.00
	Within Groups	186.66	141	1.32		
	Total	222.89	143			
Tangential	Between Groups	60.62	2	30.31	21.13	0.00
	Within Groups	202.32	141	1.44		
	Total	262.94	143			

The following tables, Table 4.19 and Table 4.20 represent the subsequent analysis chosen to determine which age group varies in mean shear parallel to grain for both planes. The selected analysis is post-hoc of the Duncan Multiple Range Test (DMRT). Based on Table 4.19, shear parallel to grain from the age group of 10 years old samples has specific differences from the other two age groups since it is placed in a single class. Meanwhile, in Table 4.20, all age groups have specific differences in mean shear parallel to grain. This is confirmed when all mean results are placed in a single class.

Table 4.19: DMRT of Shear Parallel to Grain in Radial Plane (Solid-untreated) of *Acacia mangium* superbulk

Age Groups	N	Subset for alpha = 0.05	
		1	2
7 Years Old	48	12.50	
13 Years Old	48	12.94	
10 Years Old	48		13.71
Sig.		0.07	1.00

Table 4.20: DMRT of Shear Parallel to Grain in Tangential Plane (Solid-untreated) of *Acacia mangium* superbulk

Age Groups	N	Subset for alpha = 0.05		
		1	2	3
7 Years Old	48	12.65		
13 Years Old	48		13.35	
10 Years Old	48			14.24
Sig.		1.00	1.00	1.00

This study also presents the maximum load in kN that each sample can carry. The mean of maximum load in radial and tangential obtained from each age group is presented in Table 4.21. Based on that respective table, it is shown that the most excellent maximum load is obtained by the age group of 10 years old samples, followed by 13 years old samples, and the lowest is 7 years old samples from both planes. The maximum loads obtained by those age groups in the radial plane are 5.77 kN, 5.34 kN and 5.18 kN, respectively, whereas in the tangential plane are 5.97 kN, 5.51 kN and 5.24 kN, respectively. In fact, the shear strength of timber is influenced by the maximum load, where the increment of shear strength results in an enormous maximum load. The formula for getting the shear strength is where the maximum load is divided by the cross-sectional area.

Table 4.21: Maximum Load of Shear Parallel to Grain (Solid-untreated) of *Acacia mangium* superbulk

Age Group (Year)	Maximum Load (kN)	
	Radial	Tangential
7	5.18	5.24
10	5.77	5.97
13	5.34	5.51

ii. Shear Parallel to Grain Respect to Basic Density

Recorded data from an untreated shear test continues to be analysed with another factor, basic density. Shear strength in radial and tangential planes is analysed by using linear regression with respect to basic density for each age group. A total of 144 specimens had undergone the shear test to fit the linear regression (R) model. The smooth line with R^2 and R-value is created from the relationship between the dependent variable (shear strength) and independent variable (basic density). The linear regression model for shear strength in the radial plane of each age group (7, 10, and 13 years old samples) of *Acacia mangium* superbulk against basic density are presented in Figures 4.16, 4.18 and 4.20, respectively, whereas Figures 4.17, Figure 4.19 and Figure 4.21 represent the shear strength in tangential plane of 7, 10 and 13 years old of 'Superbulk' species respectively.

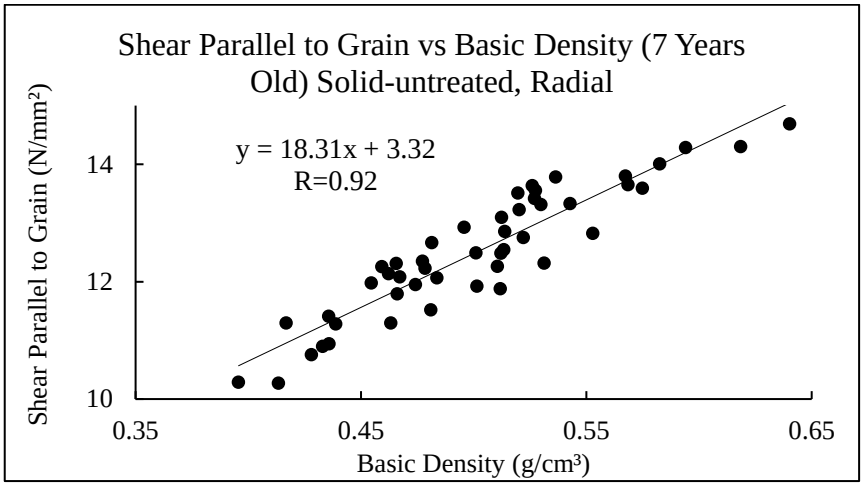


Figure 4.16: Shear Parallel to Grain Against Basic Density for 7 Years Old at Radial Plane (Solid-untreated) of *Acacia mangium* superbulk

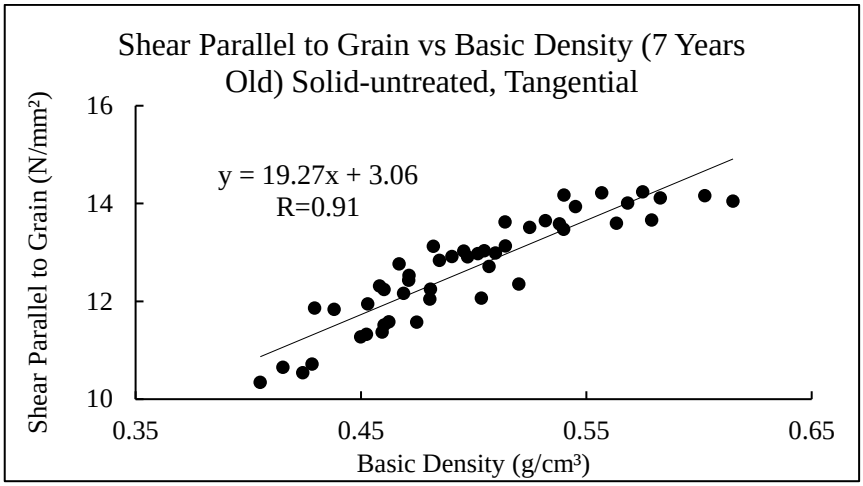


Figure 4.17: Shear Parallel to Grain Against Basic Density for 7 Years Old at Tangential Plane (Solid-untreated) of *Acacia mangium* superbulk

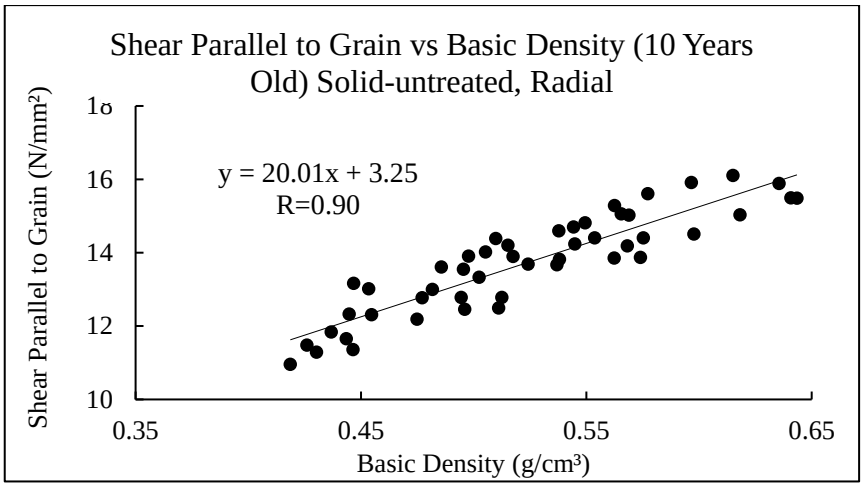


Figure 4.18: Shear Parallel to Grain Against Basic Density for 10 Years Old at Radial Plane (Solid-untreated) of *Acacia mangium* superbulk

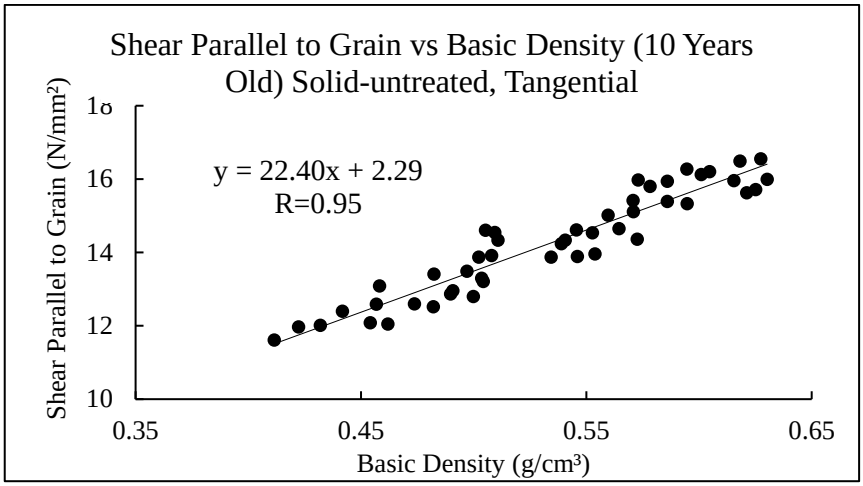


Figure 4.19: Shear Parallel to Grain Against Basic Density for 10 Years Old at Tangential Plane (Solid-untreated) of *Acacia mangium* superbulk

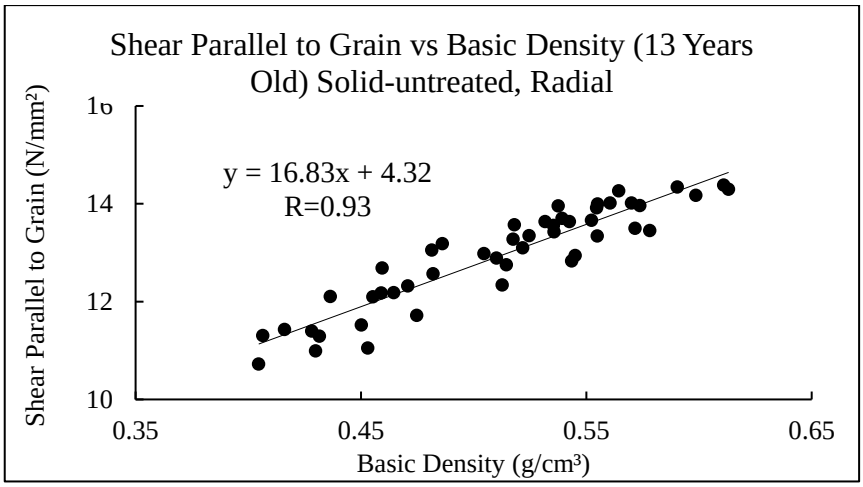


Figure 4.20: Shear Parallel to Grain Against Basic Density for 13 Years Old at Radial Plane (Solid-untreated) of *Acacia mangium* superbulk

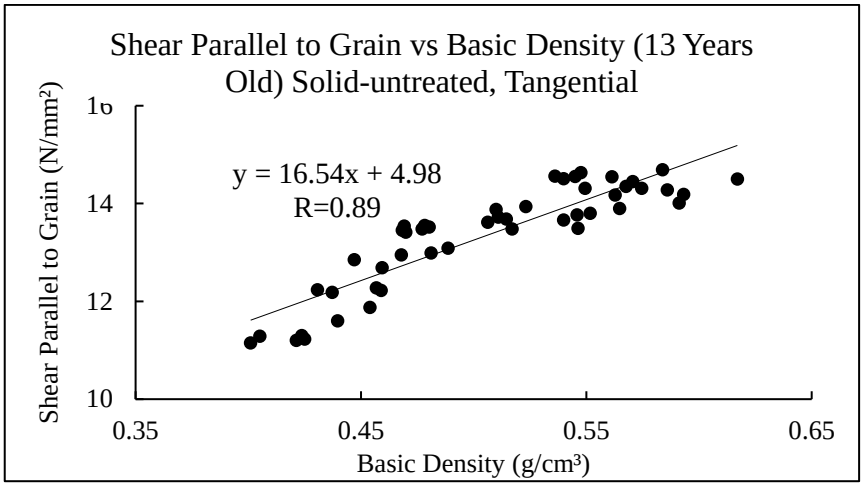


Figure 4.21: Shear Parallel to Grain Against Basic Density for 13 Years Old at Tangential Plane (Solid-untreated) of *Acacia mangium* superbulk

Figure 4.16 until Figure 4.21 present the linear regression analysis of shear strength at radial and tangential plane against basic density for all three age groups. From the analysis, the correlation values R-values obtained were in the range of 0.89 to 0.95. This shows that there is a very strong correlation between shear strength and basic density since the R-values are approaching 1.00. In other words, these analyses signified that the dependent variable (mechanical properties) is explicated wisely by the independent variable (basic density), where the greater the basic density, the greater the mechanical properties' strength value.

4.3 Solid-treated of *Acacia mangium* superbulk

The mechanical properties testing of the solid-treated samples is experienced with similar procedures as solid-untreated samples' testing, only the condition of the sample is different. The superbulk samples comprising 8 trees are treated with 10 % of *Copper Chrome Arsenic* (CCA). The technique of this treatment is well-presented in the methodology chapter. These treated samples also run for mechanical strength testing, such as MOR, MOE, compression parallel to grain and shear parallel to grain. Noted that, in parenthesis, is the

coefficient of variance (cv) in percentage units.

4.3.1 Moisture Content (MC)

The samples that will be treated need to achieve moisture content at air-dry, which is ±18 %, which is the same MC as the untreated samples.

4.3.2 Density

The density of the sample is obtained from the initial weight divided by the sample's volume. The density of the sample is g/cm^3. A total of 192 samples by each age group are involved in determining the density of the timber. Table 4.22 indicates the density of the *Acacia mangium* superbulk from 7, 10, and 13 years old samples before and after treatment. Based on Table 4.22, the densities of 7, 10 and 13 years old samples of 'Superbulk' species before the treatment process are 0.61 g/cm³, 0.63 g/cm³ and 0.61 g/cm³, respectively. Meanwhile, the densities after the treatment process are 0.76 g/cm³, 0.79 g/cm³ and 0.76 g/cm³ from age groups of 7, 10, and 13 years old samples, respectively. The CVs obtained show no more than 20.00, meaning the data collected was not too dispersed from the mean value. The percentage of average increment in timber density after the preservative is applied is 24.76 %. Rabbi et al. (2015) reported that the increment detected in some wood density from before and after the treatment process is 22.50 %. This study was done on some tropical wood in Bangladesh that also used a CCA type of preservative. The error bars analysis at 95% confidence intervals shows there is no statistically significant difference in the mean of density before and after treatment for all age groups, as shown in Figure 4.22 and Figure 4.23 respectively.

Table 4.22: Density Before and After Treatment (Solid-treated) of *Acacia mangium* superbulk

Age Groups (year)	Density Before Treatment (g/cm^3)	Density After Treatment (g/cm^3)
7	0.61 (13.82)	0.76 (11.52)
10	0.63 (14.11)	0.79 (12.17)
13	0.61 (14.76)	0.76 (12.12)

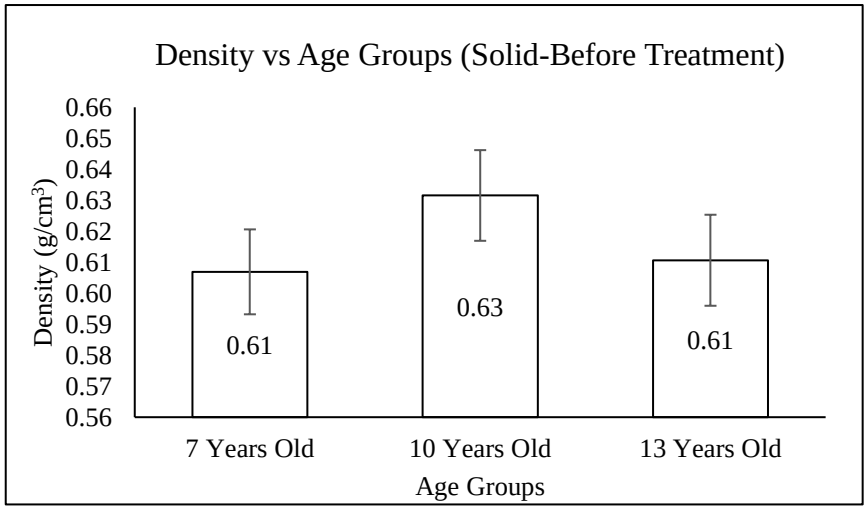


Figure 4.22: Density (Solid-Before Treatment) of *Acacia mangium* superbulk

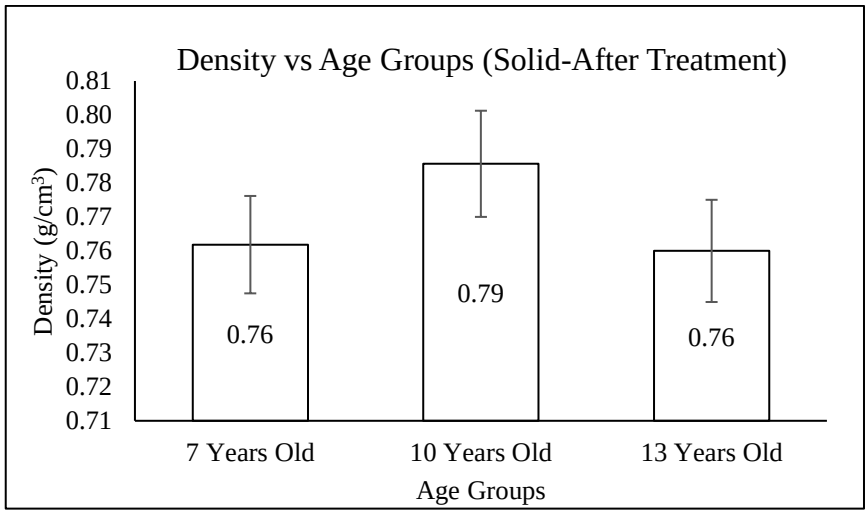


Figure 4.23: Density (Solid-After Treatment) of *Acacia mangium* superbulk

Table 4.23: One-way ANOVA of Density Before Treatment (Solid-treated) of *Acacia mangium* superbulk

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0.07	2	0.03	4.38	0.01
Within Groups	4.42	573	0.01		
Total	4.49	575			

The analysis proceeded to one-way ANOVA to determine whether the samples' density data were significant. Table 4.23 shows the result of one-way ANOVA analysis. At a probability level of 5%, the significant value obtained is 0.01, below the probability level. So, the density data from the three age groups are significant to each other.

The DMRT result is tabulated in Table 4.24. Referring to that respective table, it shows that the density from the age group of 10-year-old samples has a specific difference among the three densities because it is placed in a single class. The densities from 7 and 13 years old samples are not different from each other. In other words, there is no specific difference between them.

Table 4.24: DMRT of Density Before Treatment (Solid-treated) of *Acacia mangium* superbulk

Age Groups	N	Subset for alpha = 0.05	
		1	2
7 Years Old	192	0.61	
13 Years Old	192	0.61	
10 Years Old	192		0.63
Sig.		0.68	1.00

The one-way ANOVA analysis was carried out to obtain the density results after the treatment process to determine whether there was any significant difference. The result from the ANOVA analysis is tabulated in Table 4.25. From the table, the significant value obtained is 0.01, which means that there is a statistically significant difference among all the density results for all three age groups since the value is lower than 0.05. Meanwhile, Table 4.26 presents the DMRT analysis to identify which age group varied among the density of the three age groups. Based on the table, the density from 10 years old samples is a statistically significant difference when compared to the 7 and 13 years old samples.

Table 4.25: One-way ANOVA of Density After Treatment (Solid-treated) of *Acacia mangium* superbulk

	Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	0.08	2	0.04	4.64	0.01
Within Groups	4.83	573	0.01		
Total	4.92	575			

Table 4.26: DMRT of Density After Treatment (Solid-treated) of *Acacia mangium* superbulk

Age Groups	**N**	**Subset for alpha = 0.05**	
		1	**2**
13 Years Old	192	0.76	
7 Years Old	192	0.76	
10 Years Old	192		0.79
Sig.		0.84	1.00

4.3.3 Static Bending

A total of 144 small clear *Acacia mangium* superbulk specimens underwent the treatment process using a 10 % *Copper Chrome Arsenic* (CCA) timber preservative solution. After the full cell treatment process is done, the samples are ready to be tested using a similar procedure done on controlled samples accordingly. The following Figure 4.24 and Figure 4.25 interpret the mean results of MOR and MOE of static bending with respect to all age groups.

i. MOR and MOE Respect to Age Groups

Based on Figure 4.24 shows the mean MOR versus age groups for treated specimens. In comparison between all age groups, the highest mean with CV of MOR is 118.76 N/mm^2 (17.89) from the age group of 10 years old samples, followed by 13 years old samples, where the mean MOR obtains 99.16 N/mm^2 (19.94). The lowest mean MOR is 97.14 N/mm^2 (20.22) from 7 years old of the 'Superbulk' species. Besides that, refer to Figure 4.25, the highest mean MOE is 15020 N/mm2 (10.79), which is from the age group of 10 years samples. Meanwhile, the second highest mean MOE is from 13 years old of *Acacia mangium* superbulk that recorded an MOE of 12666 N/mm^2 (15.36). The lowest mean belongs to the age group of 7 years old samples with reported MOE results of 11834 N/mm^2 (15.09). Meanwhile, the CVs collected from all MOR and MOE data show good CV values with scattered data around the mean. The error bars analysis at 95% confidence intervals shows there is no statistically significant difference in the mean of MOR age groups 7 and 13 years old samples when compared to the mean MOR and MOE from the age group of 10 years old samples that has significant differences. Besides that, all the mean MOE from the three age groups have significant differences among them at $p < 0.05$.



Figure 4.24: MOR Against Age Groups (Solid-treated) of *Acacia mangium* superbulk

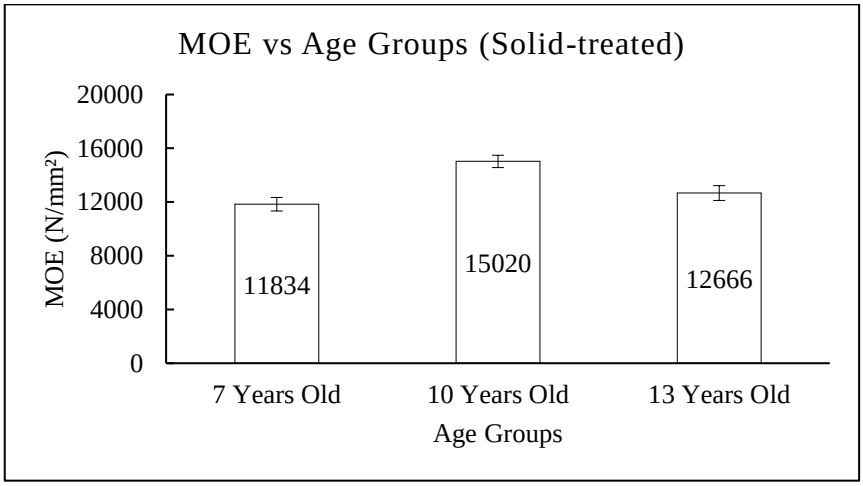


Figure 4.25: MOE Against Age Groups (Solid-treated) of *Acacia mangium* superbulk

Next, a one-way ANOVA analysis of variance and Duncan Multiple Range Test with a probability of 0.05 take place. Table 4.27 shows the summary of one-way ANOVA results of MOR and MOE for CCA treated specimens. The F values of MOR and MOE are 16.72 and 40.95, respectively. Note that the F value is the value on the F distribution, which is calculated by dividing two mean squares to determine the ratio of explained variance and whether the test is statistically significant. Both MOR and MOE data have a statistically

significant difference since the significant value attained is below 0.05 at the probability level.

Table 4.27: One-way ANOVA of MOR and MOE (Solid-treated) of *Acacia mangium* superbulk

		Sum of Squares	df	Mean Square	F	Sig.
MOR	Between Groups	13692.51	2	6846.25	16.72	0.00
	Within Groups	57725.50	141	409.40		
	Total	71418.01	143			
MOE	Between Groups	262146746.17	2	131073373.08	40.95	0.00
	Within Groups	451282169.77	141	3200582.76		
	Total	713428915.94	143			

Table 4.28: DMRT of MOR (Solid-treated) of *Acacia mangium* superbulk

Age Groups	N	Subset for alpha = 0.05	
		1	2
7 Years Old	48	97.14	
13 Years Old	48	99.16	
10 Years Old	48		118.76
Sig.		0.62	1.00

Table 4.29: DMRT of MOE (Solid-treated) of *Acacia mangium* superbulk

Age Groups	N	Subset for alpha = 0.05		
		1	2	3
7 Years Old	48	11834		
13 Years Old	48		12666	
10 Years Old	48			15020
Sig.		1.00	1.00	1.00

A post-hoc test of the Duncan Multiple Range Test (DMRT) is presented in Table 4.28 and Table 4.29. It differentiates which age group varies in mean MOR and mean MOE of CCA-treated specimens. DMRT is conducted in order to identify whether the differences in mean MOR and mean MOE between age groups are significant or not. Table 4.28 shows that the mean of MOR from the age group of 10-year-old samples has a specific difference compared to the other two age groups. Mean MOR age groups of 7 and 13 years old samples do not have specific differences from each other. Meanwhile, Table 4.29 presented the DMRT of MOE's means. The analysis of DMRT shows that all of the means by three age groups have specific differences from each other. The result of Duncan's analysis is categorising all three means under a single class.

Table 4.30: Maximum Load of Static Bending (Solid-treated) of *Acacia mangium* superbulk

Age Group (Year)	Maximum Load (kN)
7	1.92
10	2.34
13	1.98

Table 4.30 indicates the maximum load that static bending specimens can carry. The mean of the maximum load obtained from 48 samples in each age group derives from the results of static bending since both parameters (MOR and MOE) are achieved with the basic maximum load results. Based on Table 4.30, the maximum load attained by age groups of 7, 10 and 13 years old samples are 1.92 kN, 2.34 kN and 1.98 kN, respectively.

ii. MOR and MOE Respect to Basic Density

Figure 4.26 until Figure 4.31 presents the MOR and MOE against basic density in solid-treated conditions for the age group of 7, 10, and 13 years old samples.

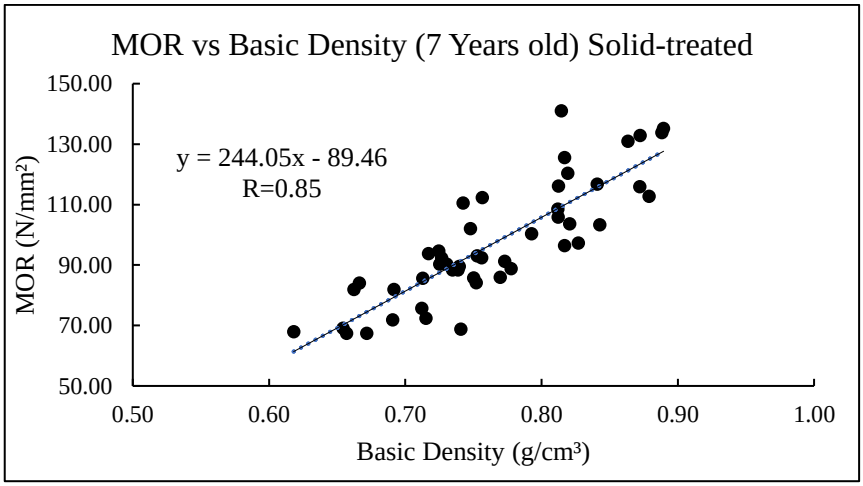


Figure 4.26: MOR Against Basic Density for 7 Years Old (Solid-treated) of *Acacia mangium* superbulk

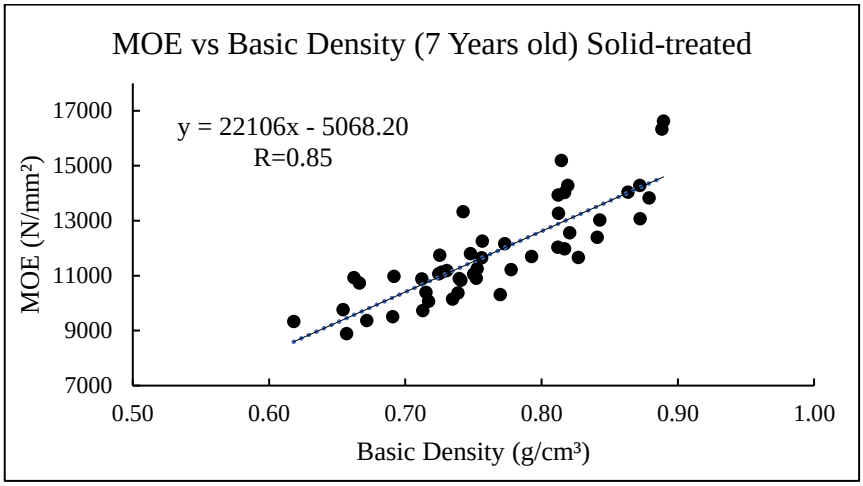


Figure 4.27: MOE Against Basic Density for 7 Years Old (Solid-treated) of *Acacia mangium* superbulk

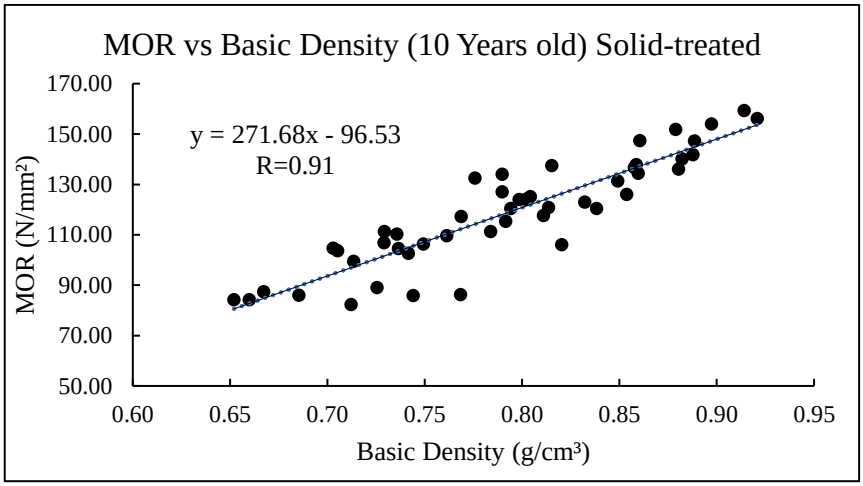


Figure 4.28: MOR Against Basic Density for 10 Years Old (Solid-treated) of *Acacia mangium* superbulk

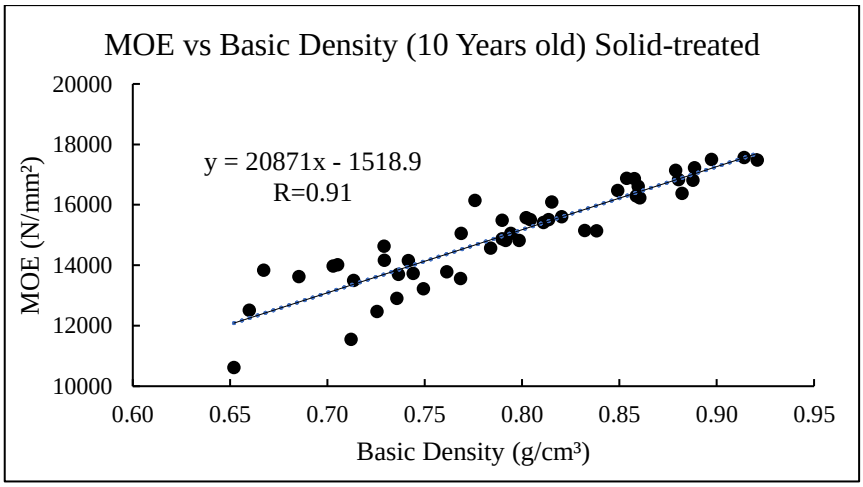


Figure 4.29: MOE Against Basic Density for 10 Years Old (Solid-treated) of *Acacia mangium* superbulk

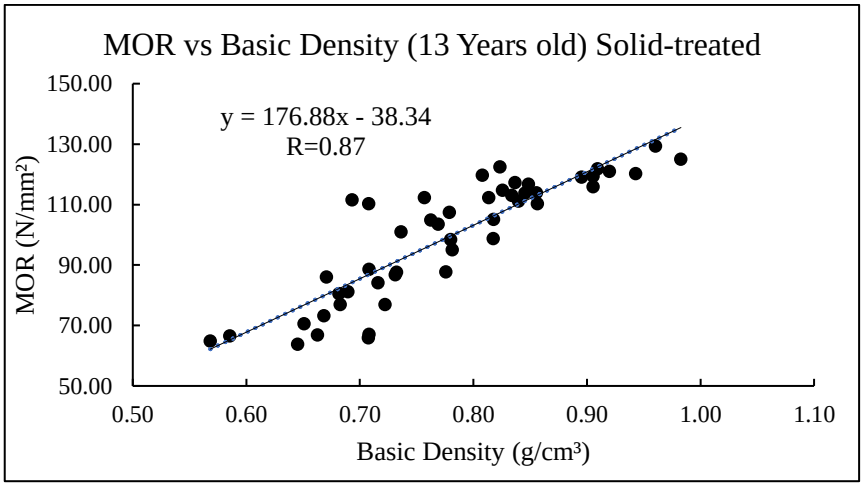


Figure 4.30: MOR Against Basic Density for 13 Years Old (Solid-treated) of *Acacia mangium* superbulk

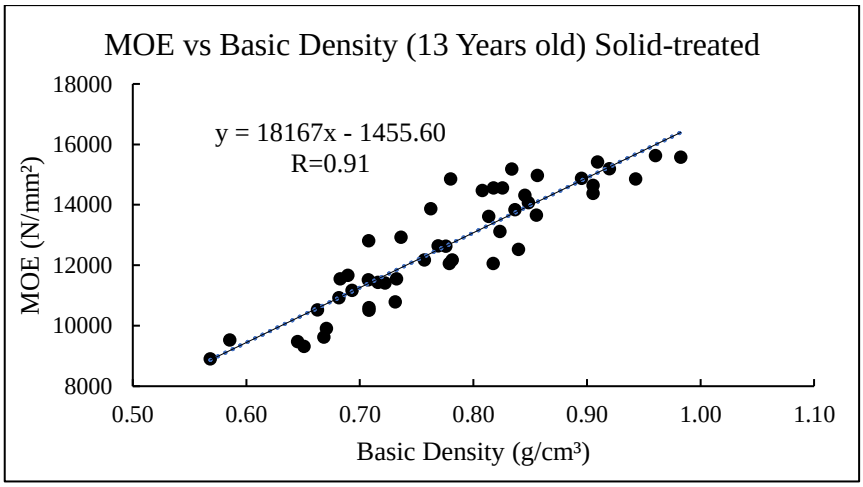


Figure 4.31: MOE Against Basic Density for 13 Years Old (Solid-treated) of *Acacia mangium* superbulk

From the linear regression analysis, it is shown that there is a very strong correlation between MOR or MOE and basic density. The R-values recorded are in the range of 0.85 to 0.91, and it is approaching 1.00. The analysis is said to have a very strong considerable correlation where the R-values obtained are in the range of 0.70 to 1.00, as reported by Senthilnathan (2019).

The mean MOR and MOE evaluation for untreated results reveals the rising strength value in treated results. The CCA chemical that penetrated the samples acts as a factor in improving the strength properties of the samples. Although the increasing scale by the year is the same for both untreated and treated specimens, but there is an increment in all treated results. The subsequent figures indicated the comparison between static bending mean results of the untreated specimen and treated specimen.

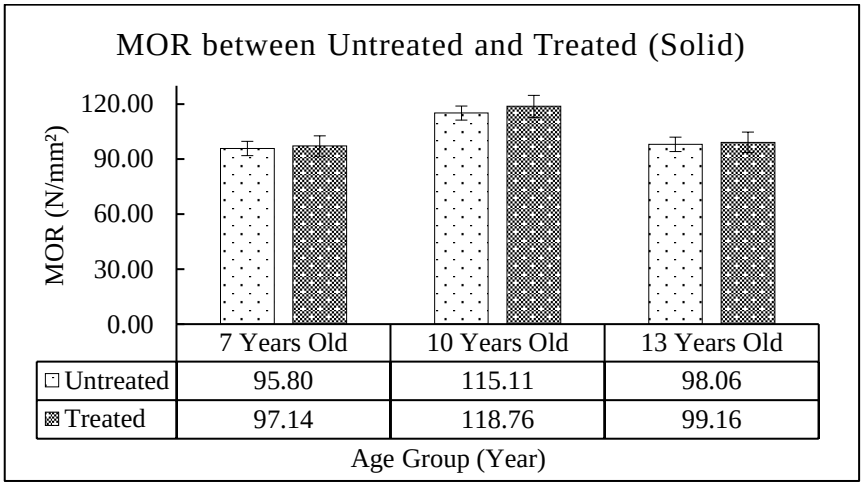


Figure 4.32: Comparison of MOR between Untreated and Treated (Solid) of *Acacia mangium* superbulk

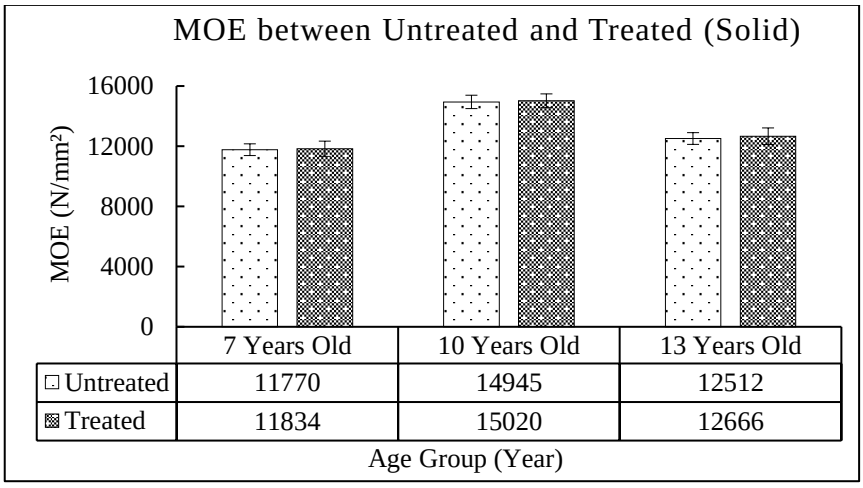


Figure 4.33: Comparison of MOE between Untreated and Treated (Solid) of *Acacia mangium* superbulk

Both figures introduce static bending results for untreated and treated conditions. MOR and MOE from both conditions record the highest strength in the age group of 10 years old samples, followed by 13 years old samples, and the lowest is 7 years old of 'Superbulk' species. Based on Figure 4.32, the MOR age group of 10 years old samples records a strength difference of about 3.65 N/mm^2 between untreated and treated results. Meanwhile, an increment of 1.10 N/mm^2 is noted from MOR values of 13 years old samples and 7 years old *Acacia mangium* superbulk marks down the differences of about 1.34 N/mm^2 between untreated and treated MOR results. Furthermore, refer to Figure 4.33, which shows the results of MOE from both conditions. The highest MOE obtained from the age group of 10 years old samples traced the increased strength value on treated conditions at about 75 N/mm^2. Whereas the middle age group of 13 years samples attained, the addition in MOE results from the untreated condition is about 154 N/mm^2, and the lowest MOE is from the age group of 7 years samples, rising about 64 N/mm^2. At 95% confidence intervals, the mean MOR and MOE of 7 and 13 years old for untreated and treated samples do not show a statistically significant differences, whereas the mean of 10 years old samples is statistically significant differences different when compared to those two age groups ($p< 0.05$). However, a comparison between untreated and treated mean MOR and MOE from each age group shows that there are no statistically significant differences.

4.3.4 Compression Parallel to Grain

A total of 144 specimens sized 20cm x 20cm x 60cm had gone through the treatment process using 10 % *Copper Chrome Arsenic* (CCA) timber preservative solution. After all the treatment processes are done, the compression parallel to grain test takes place according to a small clear test procedure by ITTO's Testing Methods for Plantation Grown Tropical

Timbers (Tan et al., 2010).

i. Compression Parallel to Grain Respect to Age Groups

The mean of compression parallel to grain strength by three age groups under treated conditions gained from the laboratory test is presented in Figure 4.34.

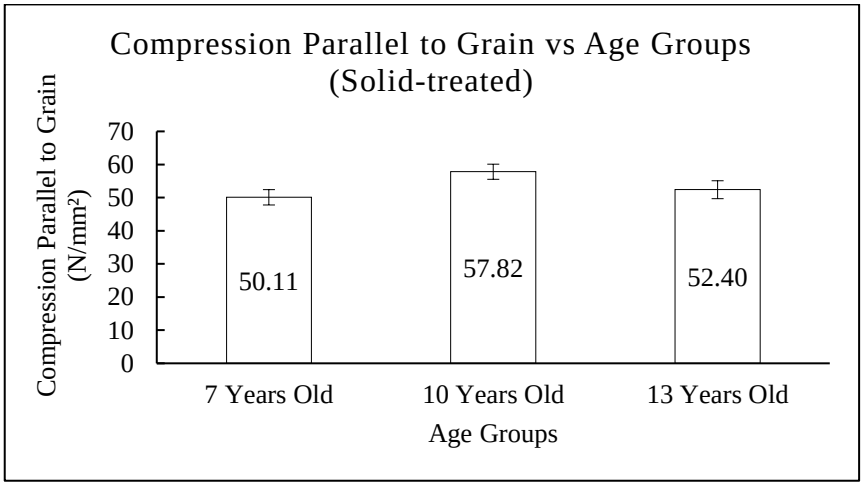


Figure 4.34: Compression Parallel to Grain Against Age Groups (Solid-treated) of *Acacia mangium* superbulk

Figure 4.34 represents the treatment condition's compression strength against the age groups of 7. 10, and 13 years old samples. Figure 4.34 shows that the age group of 10 years old samples of treated 'Superbulk' species is recorded as having the highest compression strength compared to the other two age groups. The highest mean compression strength with CV obtained was 57.82 (13.95) N/mm^2, followed by the age group of 13 years old samples of 52.40 (18.25) N/mm^2. Meanwhile, the lowest compression strength recorded was 50.11 (16.32) N/mm^{2,} which is from the age group of 7 years old samples. The coefficient of variances from all age groups is under a good range. Besides that, there is a statistically significant difference in mean compression parallel to grain from 10 years old samples, whereas the mean obtained from age groups 7 and 13 years old samples do not have any

statistically significant differences at 95% confidence intervals.

The summary of the analysis of variance one-way ANOVA with a probability of 0.05 is tabulated in Table 4.31. From Table 4.31, it is concluded that there are significant differences between all the compression strength results of all age groups since the significant value obtained is less than 0.05. One-way ANOVA also recorded the F value, which is 10.11.

Table 4.31: One-way ANOVA of Compression Parallel to Grain (Solid-treated) of *Acacia mangium* superbulk

	Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	1505.62	2	752.81	10.11	0.00
Within Groups	10501.89	141	74.48		
Total	12007.51	143			

Based on Table 4.32, it is shown that mean compression from the age group of 10 years old samples has a specific difference from the other two means. The mean from the age groups of 7 years old samples and 13 years old samples does not have any specific difference since both are placed into the same class; in other words, both means are just slightly different to each other, as shown in Table 4.32.

Table 4.32: DMRT of Compression Parallel to Grain (Solid-treated) of *Acacia mangium* superbulk

Age Groups	**N**	**Subset for alpha = 0.05**	
		1	**2**
7 Years Old	48	50.11	
13 Years Old	48	52.40	
10 Years Old	48		57.82
Sig.		0.20	1.00

It is necessary to list out the maximum load achieved by the compression test on 144 samples. The maximum loads are presented in Table 4.33. In fact, the maximum load is one of the parameters in getting the compression strength of the timber. By referring to Table 4.33, the maximum loads recorded from 7, 10 and 13 years old samples are 2.06 kN, 2.37 kN and 2.15 kN, respectively.

Table 4.33: Maximum Load of Compression Parallel to Grain (Solid-treated) *of Acacia mangium* superbulk

Age Group (Year)	Maximum Load (kN)
7	2.06
10	2.37
13	2.15

ii. Compression Parallel to Grain Respect to Basic Density

Further analysis on compression parallel to grain is performed in the linear regression model based on two variables: compression strength and density. The following Figure 4.35, Figure 4.36 and Figure 4.37 are present the compression parallel to grain versus basic density under treated conditions for age groups of 7, 10 and 13 years old of *Acacia mangium* superbulk species.

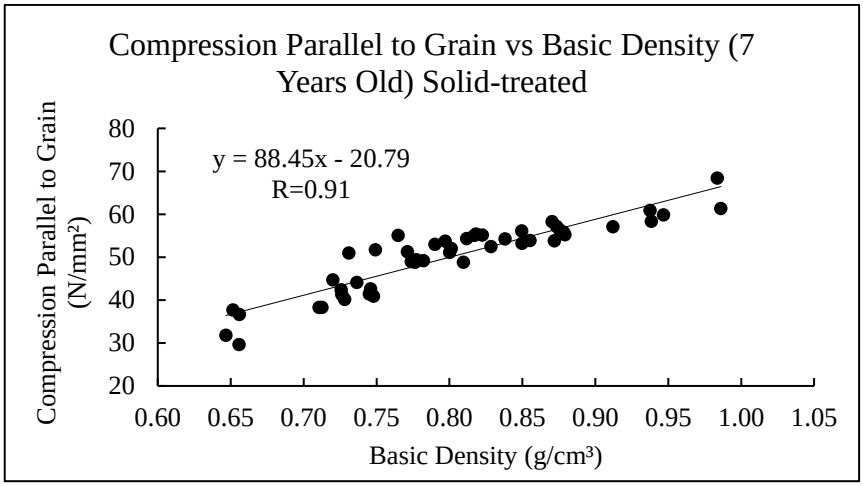


Figure 4.35: Compression Parallel to Grain Against Basic Density for 7 Years Old (Solid-treated) of *Acacia mangium* superbulk

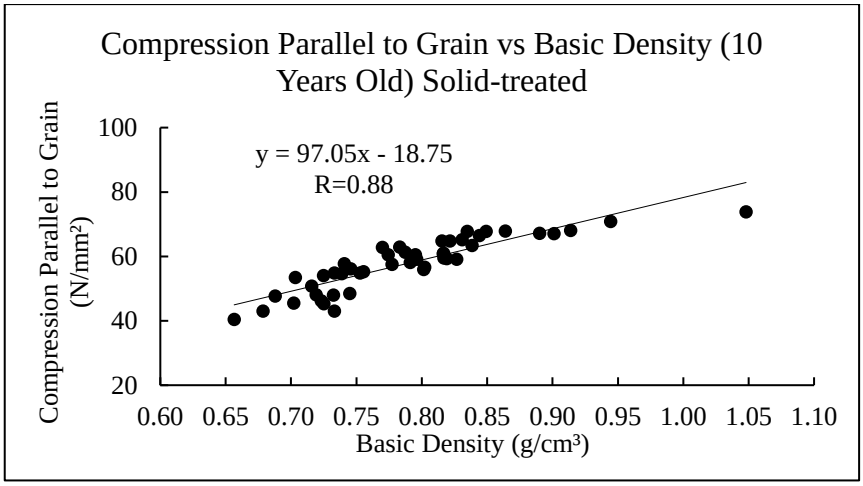


Figure 4.36: Compression Parallel to Grain Against Basic Density for 10 Years Old (Solid-treated) of *Acacia mangium* superbulk

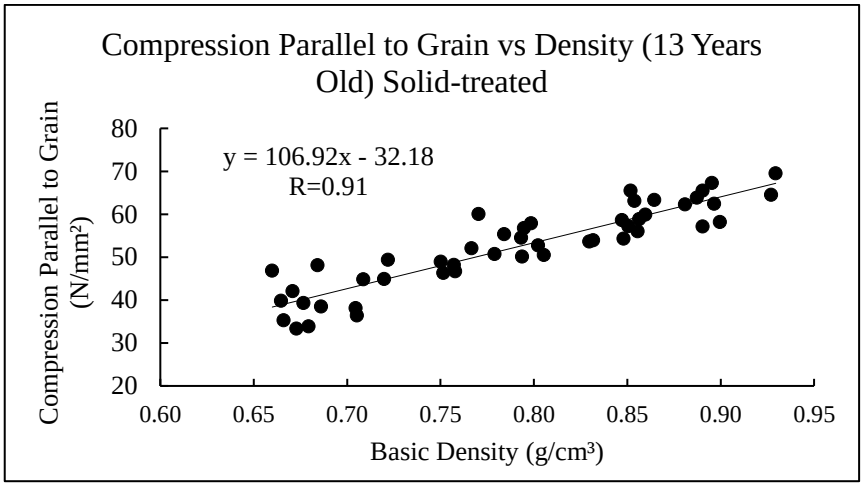


Figure 4.37: Compression Parallel to Grain Against Density for 13 Years Old (Solid-treated) of *Acacia mangium* superbulk

Based on linear regression analysis, compression parallel to grain against basic density showed a very strong correlation since the R-values obtained were 0.91 (7 years old), 0.88 (10 years old) and 0.91 (13 years old). All the R-values are approaching 1.00.

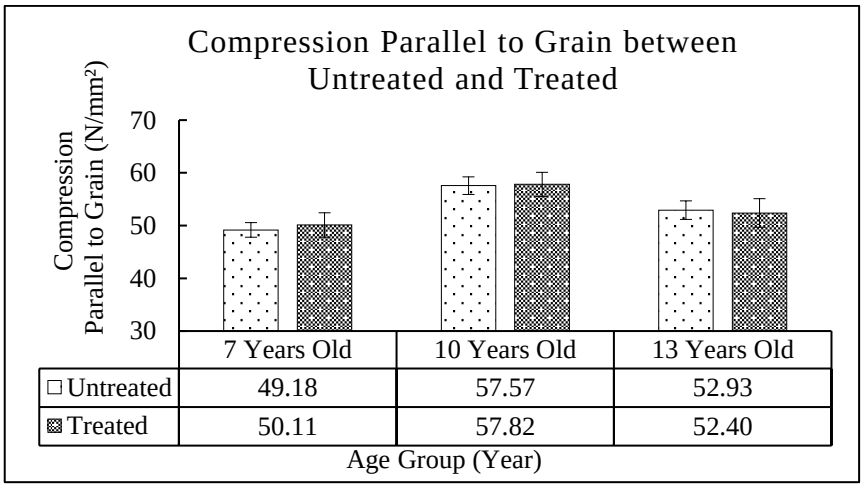


Figure 4.38: Comparison of Compression Parallel to Grain between Untreated and Treated (Solid-treated) of *Acacia mangium* superbulk

Figure 4.38 illustrates the comparison between untreated and treated compression strength results discussed earlier. Both conditions recorded the same greatest strength of age group which is 10 years old samples, followed by 13 years old samples, and the lowest is 7 years old samples. The observation shows an improvement in strength in treated samples compared to the untreated (solid) samples for all age groups. For age group 7 years old samples 'Superbulk' species, the compression strength from untreated to treated testing is increased by 0.93 N/mm^2. Meanwhile, the difference in mean compression strength between the untreated and treated age group of 10 years old samples is 0.25 N/mm^2. Moreover, an increment of 0.53 N/mm^2 from untreated to treated mean compression strength is attained by the age group of 13 years old samples. At 95% confidence intervals, the mean compression parallel to grain for untreated samples for all age groups shows a statistically significant difference and meanwhile treated samples for the age groups of 7 years old and 13 years old do not had statistically significant differences, whereas the mean of 10 years old samples had statistically significant difference when compared to those two age groups ($p < 0.05$). Comparison between untreated and treated compression parallel to grain samples for each age group shows there are no statistically significant differences.

4.3.5 Shear Parallel to Grain

A total of 288 cubic specimens with a size of 20 cm3 had to undergo a treatment process using 10% Copper Chrome A*rsenic* (CCA) timber preservative solution. Next, all the specimens underwent shear tests in radial and tangential planes based on ITTO's Testing Methods for Plantation Grown Tropical Timbers (Tan et al., 2010).

i. Shear Parallel to Grain Respect to Age Groups

All data from both planes are recorded by obtaining their mean result. The mean results for both planes are presented in Figure 4.39. Figure 4.39 shows the mean of shear strength from all age groups in radial and tangential planes for treated conditions. Both planes recorded the highest mean shear strength from the age group of 10 years old samples. The mean with CV shear strengths obtained is 13.55 (11.29) N/mm^2 from the radial plane and 13.67 (12.28) N/mm^2 from the tangential plane. Moreover, 13.12 (11.11) N/mm^2 and 13.19 (11.45) N/mm^2 are recorded in the age group of 13 years old samples' radial and tangential planes, respectively. The lowest mean shear strength is from the age group of 7 years old samples, which recorded a mean with CV results of about 12.76 (11.33) N/mm^2 (radial) and 12.85 (14.57) N/mm^2 (tangential). The percentages of CV (in parenthesis) show all the data are dispersed around the mean. At 95% confidence intervals, there is no statistically significant difference in the mean of shear parallel to grain for both radial and tangential planes from all three age groups.

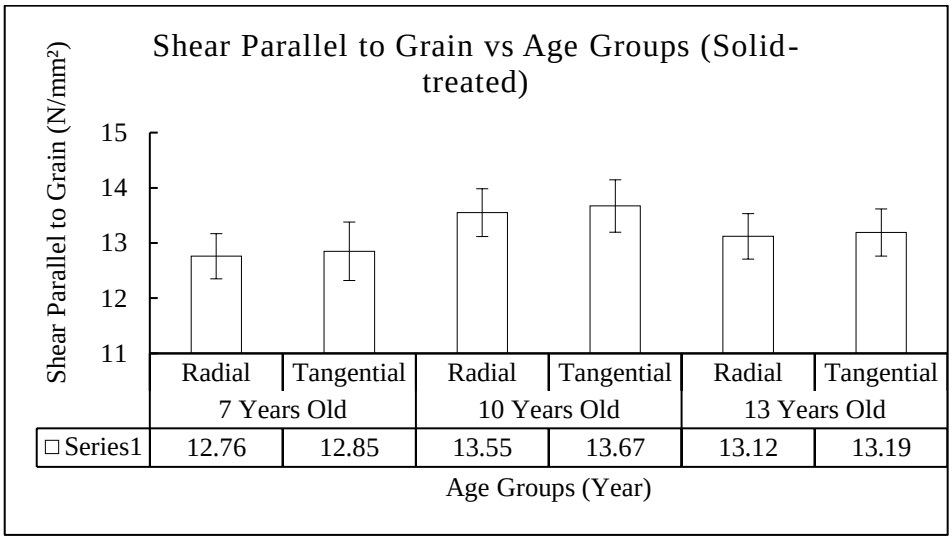


Figure 4.39: Shear Parallel to Grain Against Age Groups (Solid-treated) of *Acacia mangium* superbulk

To determine whether there are any significant differences in shear strength results among all age groups. A statistical analysis of one-way ANOVA analysis of variance is performed to determine the significant differences in shear strength results of all age groups. Table 4.34 represents the result of a one-way ANOVA analysis of shear strength among age groups.

Table 4.34: One-way ANOVA of Shear Parallel to Grain (Solid-treated) of *Acacia mangium* superbulk

		Sum of Squares	df	Mean Square	F	Sig.
Radial	Between Groups	14.92	2	7.46	3.42	0.04
	Within Groups	307.95	141	2.18		
	Total	322.88	143			
Tangential	Between Groups	16.58	2	8.29	2.89	0.06
	Within Groups	404.45	141	2.87		
	Total	421.03	143			

Table 4.34 shows the one-way ANOVA analysis of variance results of shear strength for all age groups of 'Superbulk' species. This analysis of variance is done by a probability of 0.05. Only the radial plane has a statistically significant difference among all results since its significant value is less than 0.05.

The Duncan Multiple Range Test (DMRT) is selected to perform the analysis to identify the significant differences in mean shear strength of three age groups. This analysis will determine which age group varies among them. Table 4.35 and Table 4.36 represent the DMRT results from post-hoc analysis for shear strength in both planes between age groups.

Table 4.35: DMRT of Shear Parallel to Grain in Radial Plane (Solid-treated) of *Acacia mangium* superbulk

Age Groups	N	Subset for alpha = 0.05	
		1	2
7 Years Old	48	12.76	
13 Years Old	48	13.12	13.12
10 Years Old	48		13.55
Sig.		0.24	0.15

Table 4.36: DMRT of Shear Parallel to Grain in Tangential Plane (Solid-treated) of *Acacia mangium* superbulk

Age Groups	N	Subset for alpha = 0.05	
		1	2
7 Years Old	48	12.84	
13 Years Old	48	13.19	13.19
10 Years Old	48		13.67
Sig.		0.32	0.17

Based on both tables, the mean from the age group of 13 years old samples does not have any specific differences with the mean age group of 7 years old samples and 10 years old samples. Therefore, the mean age group of 13 years old samples is placed in both classes. Meanwhile, both tables also presented that there are specific differences between the mean age group of 7 years old samples and 10 years old samples since their means are placed in a separate class.

Table 4.37: Maximum Load of Shear Parallel to Grain (Solid-treated) of *Acacia mangium* superbulk

Age Group (Year)	Maximum Load (kN)	
	Radial	Tangential
7	5.28	5.31
10	5.61	5.64
13	5.44	5.42

The maximum load of shear strength obtained by all planes by age groups are presented in Table 4.37. Based on Table 4.37, the maximum load attained by radial planes for age groups of 7, 10 and 13 years old samples are 5.28 kN, 5.61 kN and 5.44 kN, respectively. Meanwhile, in the tangential plane age groups of 7, 10, and 13 years old samples, the maximum loads recorded are 5.31 kN, 5.64 kN and 5.42 kN, respectively.

ii. Shear Parallel to Grain Respect to Basic Density

The following figures (Figure 4.40 until Figure 4.45) represent the linear regression analysis of shear parallel to grain and basic density for all age groups at the radial and tangential planes. All analyses obtained R-values in the range of 0.86 to 0.95, and it can be concluded that there is a very strong correlation between these two variables since their R-values are nearly 1.00.

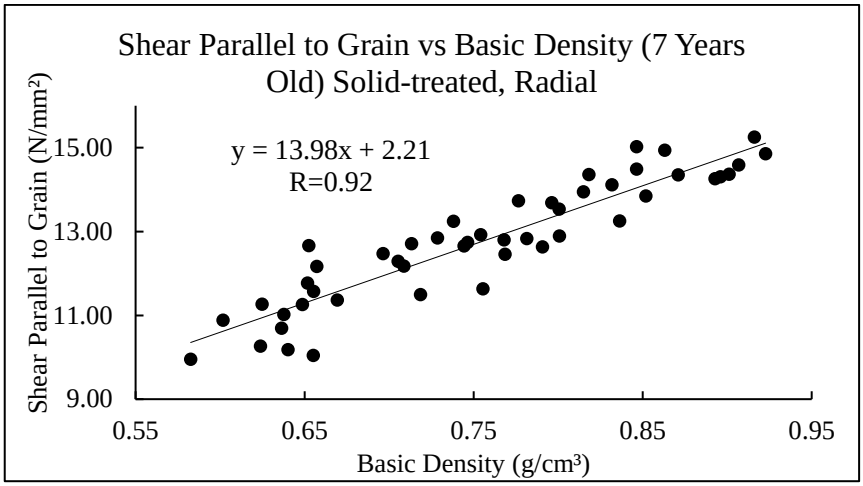


Figure 4.40: Shear Parallel to Grain Against Basic Density for 7 Years Old at Radial Plane (Solid-treated) of *Acacia mangium* superbulk

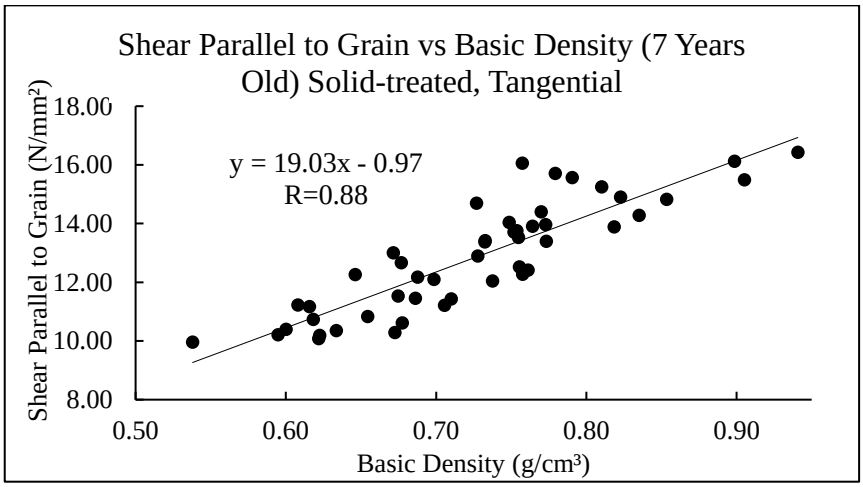


Figure 4.41: Shear Parallel to Grain Against Basic Density for 7 Years Old at Tangential Plane (Solid-treated) of *Acacia mangium* superbulk

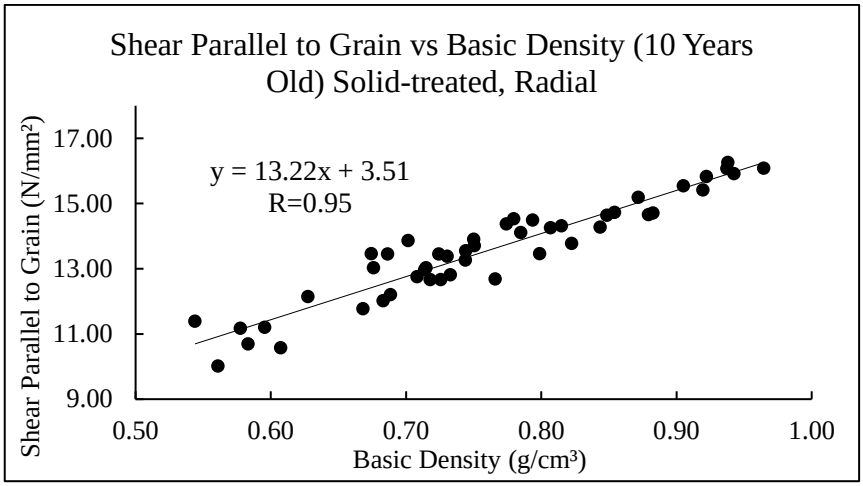


Figure 4.42: Shear Parallel to Grain Against Basic Density for 10 Years Old at Radial Plane (Solid-treated) of *Acacia mangium* superbulk

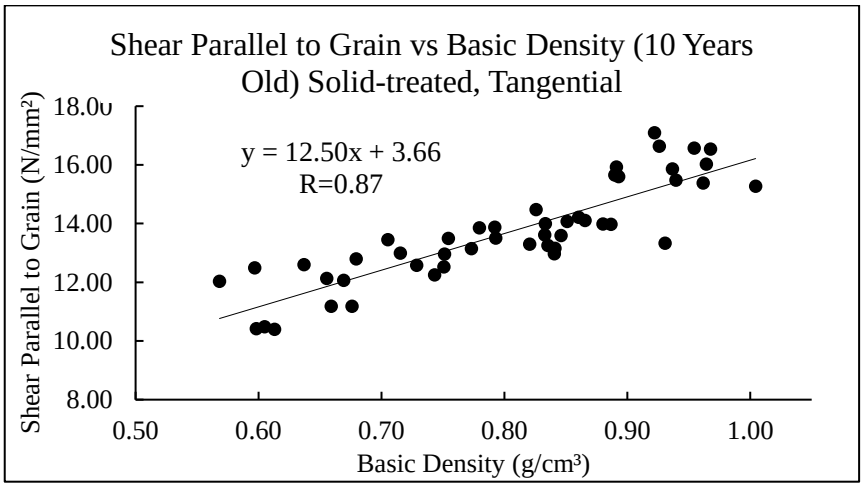


Figure 4.43: Shear Parallel to Grain Against Basic Density for 10 Years Old at Tangential Plane (Solid-treated) of *Acacia mangium* superbulk

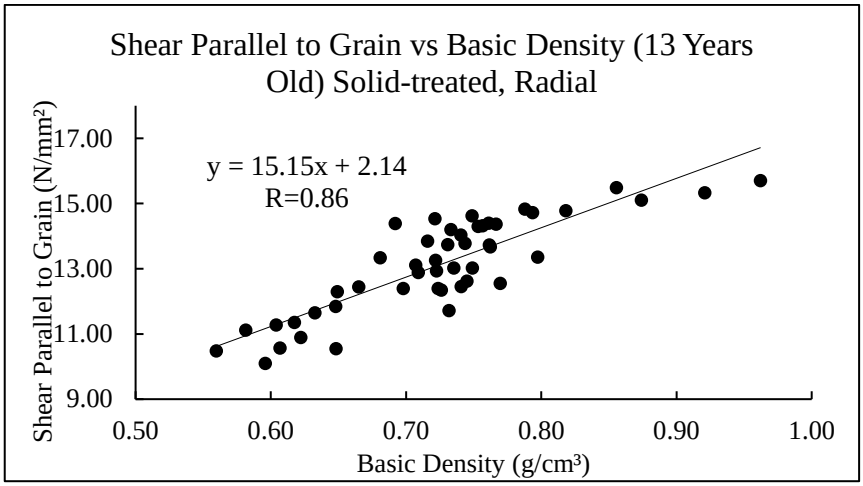


Figure 4.44: Shear Parallel to Grain Against Basic Density for 13 Years Old at Radial Plane *Acacia mangium* superbulk (Solid-treated)

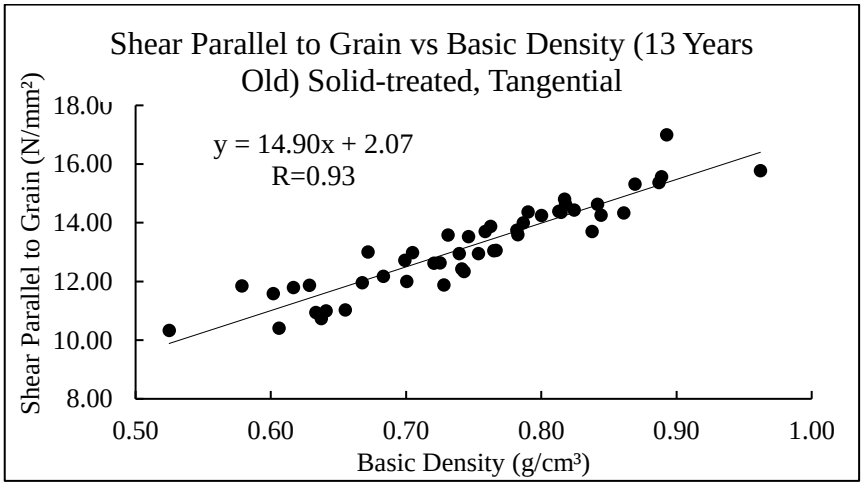


Figure 4.45: Shear Parallel to Grain Against Basic Density for 13 Years Old at Tangential Plane *Acacia mangium* superbulk (Solid-treated)

In further analysis of shear strength results, evaluating the shear strength of the treated sample compared with the untreated sample is necessary. This can validate which conditions affect the strength behaviour on small clear solid timber. Both results are explained in Figure 4.46 and Figure 4.47 to describe the distinction of shear strength between controlled specimens and treated specimens with CCA preservative for radial and tangential planes.

Based on Figure 4.46, the shear parallel to grain strength on a radial plane from the age group of 7-year-old samples shows an increment of 0.26 N/mm2 from untreated to treated conditions. Meanwhile, the age group of 10 years old of 'Superbulk' species recorded a reduction in shear parallel to grain strength on the radial plane of about 0.17 N/mm^2 from untreated to treated conditions. There are about 0.18 N/mm^2 increments from untreated to treated of shear strength on the radial plane in the age group of 13 years old samples.

Figure 4.47 indicates the comparison of shear parallel to grain by three age groups on a tangential plane between untreated and treated conditions of solid samples. Referring to Figure 4.47, the difference mean values of shear strength from untreated to treated are about 0.20 N/mm^2, 0.57 N/mm^2 and 0.16 N/mm^2 in the age groups of 7, 10, and 13 years old samples, respectively. At 95% confidence intervals, the mean shear parallel to grain parallel to grain in radial direction for untreated samples for the age groups of 7 years old and 13 years old as shown in Figure 4.46 do not have statistically significant differences, whereas the mean of 10 years old samples had statistically significant differences when compared to those two age groups ($p < 0.05$). However, shear parallel to grain in radial direction treated samples for all age groups had no statistically significant differences. Comparisons between untreated and treated samples within the age groups also show no statistically significant differences ($p > 0.05$). Figure 4.47 shows that mean shear parallel to grain in tangential direction untreated samples show statistically significant differences for all age groups and for treated samples for all age groups show no statistically significant differences ($p > 0.05$). Comparisons between untreated and treated shear parallel to grain in tangential direction samples within the age groups also show no statistically significant differences ($p > 0.05$). From this study, however, most treated samples experienced an increment of mean value in shear strength, and this clarified that the treatment method applied to the timber species

enhanced the strength performances of the timber.

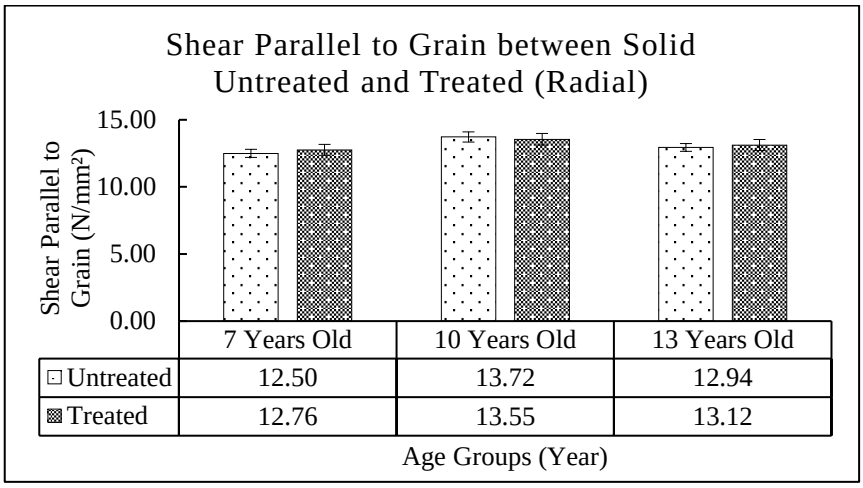


Figure 4.46: Comparison of Shear Parallel to Grain between Solid Untreated and Treated (Radial) of *Acacia mangium* superbulk

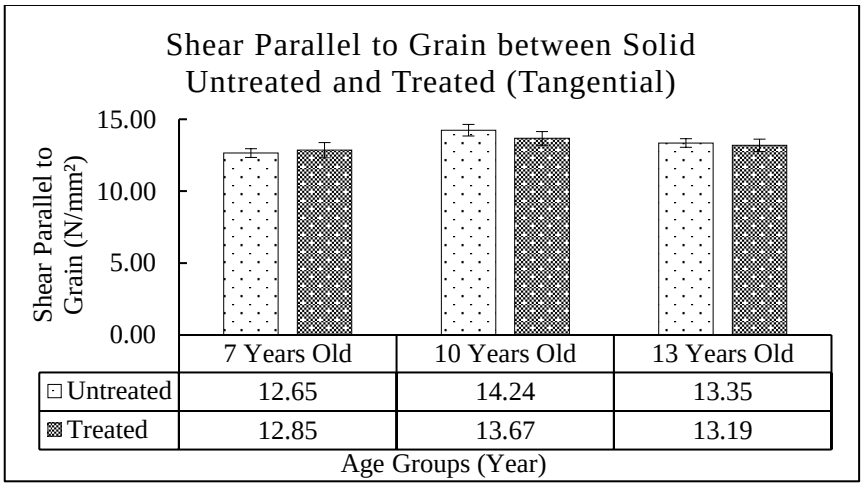


Figure 4.47: Comparison of Shear Parallel to Grain between Solid Untreated and Treated (Tangential) of *Acacia mangium* superbulk

4.4 Laminated-untreated Products of *Acacia mangium* superbulk

Lamination includes the process of glueing the timber specimens with a selected adhesive type, which is *Phenol-resorcinol formaldehyde* (PRF), mainly for wet-use purposes. The testing procedures are also according to ITTO's Testing Methods for Plantation Grown Tropical Timbers (Tan et al., 2010), which is similar to solid small clear specimens. The lamination work (single-layer laminated products) is done into two types of arrangement of specimens, laminated products with the same age group of timber and laminated products with the different age groups of timber. The illustration of the glue-laminated sample products is presented in Figure 4.48.

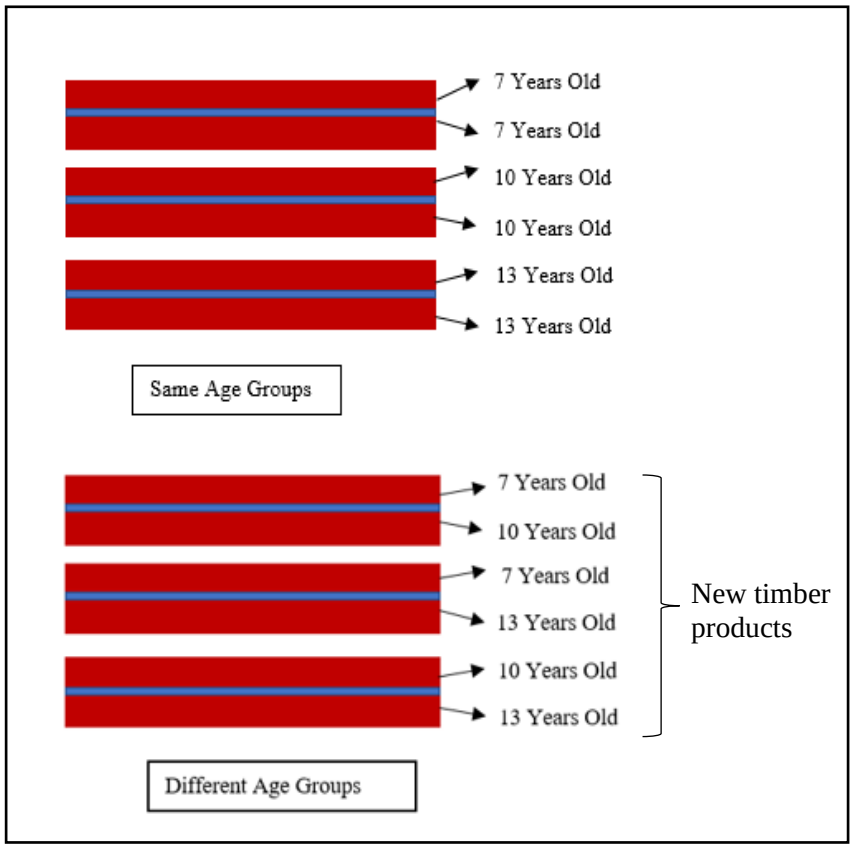


Figure 4.48: The Illustration of the Glue-laminated Sample Products (single-layer laminated) of *Acacia mangium* superbulk

The tests involved are static bending, compression, and shear in two conditions, which are tested on untreated and treated conditions to observe any changes that occur. The air-dry *Acacia mangium* superbulk specimens had undergone all the tests, and the recorded data had been analysed with linear regression, one-way ANOVA and post-hoc Duncan Multiple Range Test (DMRT), which is identical to the analysis that had been done in the previous sub-chapter.

4.4.1 Moisture Content

According to ITTO's Testing Methods for Plantation Grown Tropical Timbers (Tan et al., (2010) and the JIS Z 2101 (1994), the minimum moisture content for bonded wood is ≤ 14 %. Insufficiently dried veneers or lumbers may affect the bond performance of the products (Sahari and Inoue, 1996). It is important to monitor the moisture content wisely before running the tests.

i. Moisture Content by Same Age Groups

All three age groups are monitored to achieve an equivalent moisture content among them. A total of 270 specimens are under monitoring, and the mean moisture content is tabulated in Table 4.38. That respective table shows that all three age groups have moisture content equivalent to each other. The moisture content obtained was 12.15 %, 11.97 % and 12.07 % from 7 // 7, 10 // 10 and 13 // 13 years old samples 'Superbulk' species, respectively.

Table 4.38: Moisture Content of the Same Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk

Age Groups	Moisture Content (%)
7 // 7 years old samples	12.15
10 // 10 years old samples	11.97
13 // 13 years old samples	12.07

*//:lamination

Table 4.39: One-way ANOVA of Moisture Content by the Same Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1.39	2	0.70	1.58	0.21
Within Groups	117.28	267	0.44		
Total	118.67	269			

A one-way ANOVA analysis of variance is carried out to determine whether there is any statistically significant difference or not among all moisture content results by 270 samples. The result of the ANOVA analysis is well indicated in Table 4.39. The table shows there is no statistically significant difference among all the moisture content results since the significant value obtained is 0.21, which is greater than the probability level of 0.05.

A post-hoc test of the Duncan Multiple Range Test (DMRT) was chosen to determine which age group differed in the mean moisture content. This post-hoc test is run at a 0.05 probability level, and the number of samples (N) equals 90 from each age group. Based on Table 4.40, it is revealed that all means of moisture content by all age groups are categorised as one class. This is because the mean results of moisture content are approximate to each

other. This means that there is no specific difference in mean results among them.

Table 4.40: DMRT of Moisture Content by the Same Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk

Age Groups	N	Subset for alpha = 0.05
		1
10 // 10 Years Old	90	11.97
13 // 13 Years Old	90	12.07
7 // 7 Years Old	90	12.15
Sig.		0.10

*//:lamination

ii. Moisture Content by Different Age Groups

A total of 270 laminate specimens for different age groups are also undergoing moisture content testing. At first, all the moisture content results are calculated using mean analysis. The mean moisture content by three different age groups is tabulated in Table 4.41. Based on the table, the moisture content gained from three different age groups is recorded as 12.83 % for age groups of 7 // 10 years old samples, 12.47 % for 7 // 13 years old samples and 12.35 % for 10 // 13 years old samples.

Table 4.41: Moisture Content of the Different Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk

Age Groups	Moisture Content (%)
7 // 10 years old samples	12.83
7 // 13 years old samples	12.47
10 // 13 years old samples	12.35

*//:lamination

ANOVA analysis is run at a 95 % confidence level, and the results are presented in

Table 4.42. The table shows that the significance value attained is 0.017, below the 0.05 significance level. Thus, it is stated that moisture content results among all three different age groups are significant to each other.

Table 4.42: One-way ANOVA of Moisture Content by the Different Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk

	Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	8.22	2	4.11	4.14	0.02
Within Groups	265.31	267	0.10		
Total	273.52	269			

To determine the best specific difference among those three means of moisture content, a Duncan Multiple Range Post-hoc test is performed with the alpha of 0.05, and N is 90 for each age group. DMRT test results are reported in Table 4.43. DMRT test results showed that moisture content for the laminated sample products age groups of 7 // 10 years old of the 'Superbulk' species varied from the other two age groups. Meanwhile, laminated sample products age groups of 7 // 13 years old samples and 10 // 13 years old samples are ranked in the same class since both means do not have any specific difference from each other.

Table 4.43: DMRT of Moisture Content by the Different Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk

Age Groups	**N**	**Subset for alpha = 0.05**	
		1	**2**
10 // 13 Years Old	90	12.35	
7 // 13 Years Old	90	12.47	
7 // 10 Years Old	90		12.83
Sig.		0.36	1.00

*//:lamination

4.4.2 Density

The density of the laminated sample products at 12-14 % moisture content is determined by weight at that current MC over the volume of the samples. Both laminated sample products by the same age groups and laminated products by different age groups are evaluated using the same procedure.

i. Density by the Same Age Groups

Figure 4.49 presents the density of the same age group of *Acacia mangium* superbulk. Based on Figure 4.49, the highest mean density with the coefficient of variance (CV) of the laminated sample products is obtained in the age group of 10 years old samples recorded at an amount of 0.59 g/cm^3 (8.63). The mean densities with CV attained by the laminated age group of 7 years old samples and 13 years old samples are 0.58 g/cm^3 (7.35) and 0.58 g/cm^3 (7.19), respectively. Besides that, there is no statistically significant difference for all mean density from all age groups at 95% of confidence intervals.

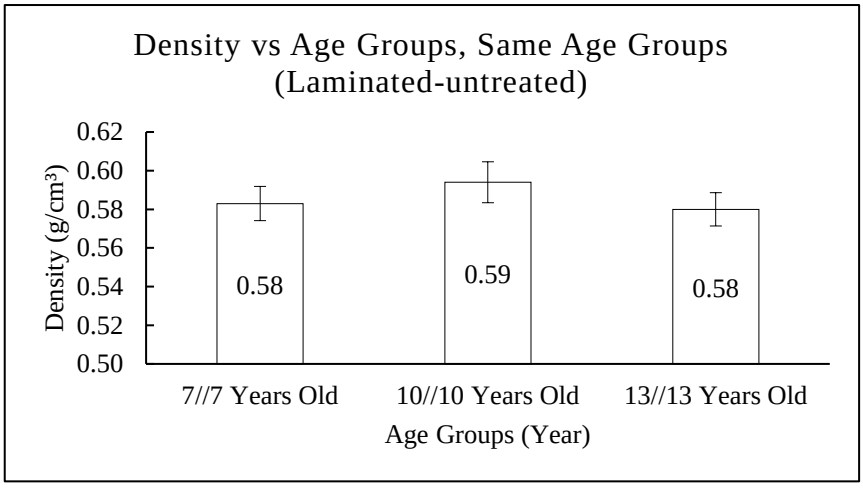


Figure 4.49: Density of the Same Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk

The one-way ANOVA analysis shows there is no statistically significant difference among all the densities results by three age groups. The significant value obtained is 0.10, which is greater than the probability level of 0.05. The details of the result are tabulated in Table 4.44. On the other hand, DMRT analysis also presented that there is no specific difference among the three densities. In other words, the three densities from age groups of 7 // 7, 10 // 10 and 13 // 13 years old samples have not differed too much.

Table 4.44: One-way ANOVA of Density by the Same Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk

	Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	0.01	2	0.01	2.29	0.10
Within Groups	0.56	267	0.00		
Total	0.57	269			

Table 4.45: DMRT of Density by the Same Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk

Age Groups	**N**	**Subset for alpha = 0.05**
		1
13 // 13 Years Old	90	0.58
7 // 7 Years Old	90	0.58
10 // 10 Years Old	90	0.59
Sig.		0.05

*//:lamination

ii. Density by the Different Age Groups

The mean densities recorded by the laminated products of different age groups are presented in Figure 4.50. Based on Figure 4.50, the mean density with the coefficient of variance (CV) value of the laminated-untreated products age groups of 7 // 10 years old

samples is 0.61 g/cm^3 (8.77). Meanwhile, the age groups of 7 // 13 years old samples were recorded with 0.59 g/cm^3 (9.20), and the 10 // 13 years old samples were recorded with 0.62 g/cm^3 (10.08). The error bars at $p < 0.05$ showed that there is a statistically significant difference in the mean density age groups of 7 // 13 years old samples, whereas 7 // 10 and 10 // 13 are not statistically significant differences to each other.

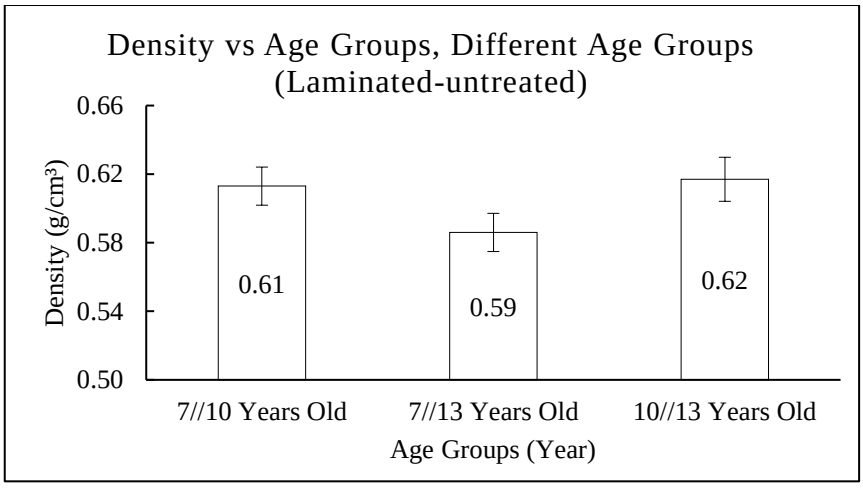


Figure 4.50: Density of the Different Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk

The outcomes from the one-way ANOVA analysis tabulated in Table 4.46 show that the significant value recorded is 0.00, below the probability value of 0.06. Therefore, the density data from all the age groups are significant to each other. Meanwhile, the DMRT analysis is also performed, and the result shows that the density of laminated age groups products of 7 // 13 years old samples has statistically significant differences from the other two age groups, as indicated in Table 4.47.

Table 4.46: One-way ANOVA of Density by the Different Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0.05	2	0.03	8.15	0.00
Within Groups	0.86	267	0.00		
Total	0.91	269			

Table 4.47: DMRT of Density by the Different Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk

Age Groups	N	Subset for alpha = 0.05	
		1	2
7 // 13 Years Old	90	0.59	
7 // 10 Years Old	90		0.61
10 // 13 Years Old	90		0.62
Sig.		1.00	0.65

*//:lamination

4.4.3 Basic Density

The analysis of the basic density of laminated sample products is also carried out since it strongly correlates to the strength properties. Basic density is determined by dividing the oven-dry weight of the specimen by the volume of the specimen. According to Alik and Kuroda (1996), basic density can be adopted as a reliable strength indicator for the mechanical stress grading of Sarawak timbers. Thus, it is important to determine the basic density as the results of basic density are conveyed the basic effect of the strength properties. Noted that the value (in parenthesis) is indicated as the Coefficient of Variance (CV).

i. Basic Density by the Same Age Groups

A total of 270 specimens undergo a basic density test. Figure 4.51 represents the mean basic density recorded for all three Superbulk species age groups.

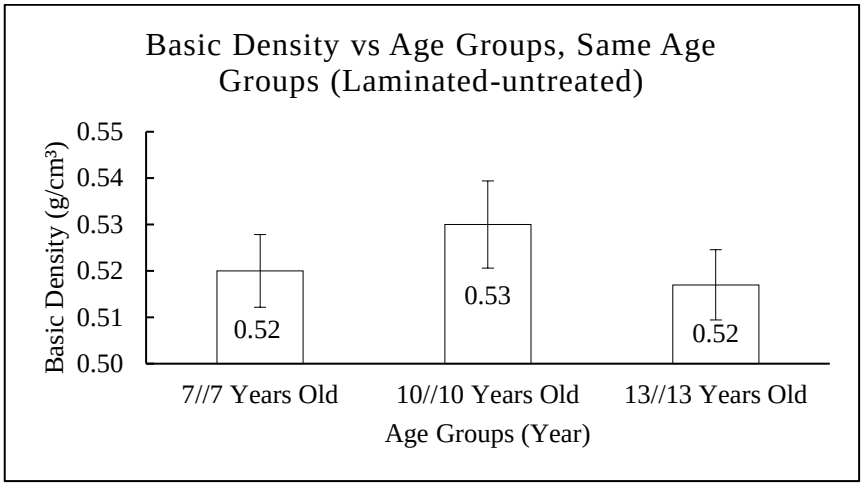


Figure 4.51: Basic Density of the Same Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk

Based on Figure 4.51, the basic density with CV attained is 0.52 g/cm^3 (7.30), 0.53 g/cm^3 (8.57) and 0.52 g/cm^3 (7.08) for the laminated age group of 7 // 7 years old samples, 10 // 10 years old samples and 13 // 13 years old of 'Superbulk' species respectively. The highest basic density is obtained by the laminated age group of 10 // 10 years old samples, followed by the laminated age group of 7 // 7 years old samples, and the lowest is the laminated age group of 13 // 13 years old samples. Meanwhile, at 95% confidence intervals, there is no statistically significant difference for all age groups at $p>0.05$. The basic densities will be analysed with mechanical strength properties such as static bending, compression strength and shear strength. The linear regression model analysis introduces the correlation between basic density and mechanical strength properties. These analyses will be presented in the following sub-chapter.

Table 4.48: One-way ANOVA of Basic Density by the Same Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	0.01	2	0.00	2.74	0.07
Within Groups	0.43	267	0.00		
Total	0.44	269			

Table 4.48 shows the summary result of the one-way ANOVA of the basic density of all age groups. The one-way ANOVA analysis is run with a significant level of 0.05 with 270 samples. The result obtained was 0.07, which is higher than 0.05, meaning there is no statistically significant difference in basic density among all the test specimens.

Table 4.49: DMRT of Basic Density by the Same Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk

Age Groups	N	Subset for alpha = 0.05	
		1	2
13 // 13 Years Old	90	0.52	
7 // 7 Years Old	90	0.52	0.52
10 // 10 Years Old	90		0.53
Sig.		0.66	0.08

*//:lamination

To determine which age groups are varied in the mean of basic density for all age groups, the Duncan Multiple Range Test (DMRT) is performed. Results from the post-hoc test of DMRT are presented in Table 4.49. By referring to that respective table, it is shown there is no specific difference in basic density of laminated age group 7 // 7 years old samples with the laminated age group of 10 // 10 and laminated age group of 13 // 13 years old of 'Superbulk' species since it is placed in both classes. Compared to the basic density of

laminated 13 // 13 years old samples and 10 // 10 years old samples age group, there is a specific difference between both basic densities because there are placed in different classes.

ii. Basic Density by the Different Age Groups

Mean analysis with 95 % significant basic density for laminated products of different age groups can be observed in Figure 4.52. Based on Figure 4.52, it is shown that the mean with CV basic densities of 0.54 (8.83) g/cm^3, 0.52 (9.07) g/cm^3 and 0.55 (10.21) g/cm^3 are indicated the age group's pairing of 7 // 10 years old samples, 7 // 13 years old samples and 10 // 13 years old samples respectively. The error bars at $p<0.05$ confidence intervals analysed that there is a statistically significant difference in mean basic density from age groups 7 // 13 years old samples when compared to mean basic density from age groups 7 // 10 years old samples and 10 // 13 years old samples.

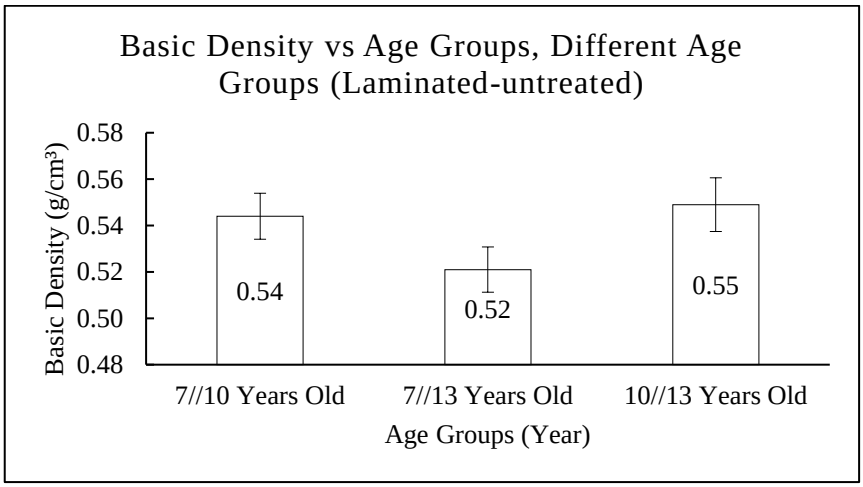


Figure 4.52: Basic Density of the Different Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk

The analysis of one-way ANOVA is performed at a 95 % confidence level, and the analysis finding is indicated in Table 4.50. Based on Table 4.50, the results from ANOVA analysis show a significant value of 0.00, meaning that there is a statistically significant

difference among all basic densities of laminated dissimilar age groups of 'Superbulk' species.

Table 4.50: One-way ANOVA of Basic Density by the Different Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk

	Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	0.04	2	0.02	7.95	0.00
Within Groups	0.69	267	0.00		
Total	0.73	269			

Table 4.51: DMRT of Basic Density by the Different Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk

Age Groups	**N**	**Subset for alpha = 0.05**	
		1	**2**
7 // 13 Years Old	90	0.52	
7 // 10 Years Old	90		0.54
10 // 13 Years Old	90		0.55
Sig.		1.00	0.50

*//:lamination

DMRT takes place in obtaining which age group is varied, and the mean of basic density is tabulated in Table 4.51. Based on Table 4.51, the basic density of laminated age groups products of 7 // 13 years old samples is specific different from the other two age groups. It is clearly explained because the basic density of laminated age group 7 // 10 and laminated 10 // 13 samples are shared in the same class, whereas the basic density of laminated 7 // 13 years old samples is alone.

4.4.4 Static Bending by the Same Age Groups

An analysis of static bending of laminated products by the same age groups specimen results is categorised into two parts, which are modulus of rupture (MOR) and modulus of elasticity (MOE) with respect to age groups and modulus of rupture (MOR) and modulus of elasticity (MOE) respect to basic density. Note that the value (in parenthesis) is indicated as the coefficient of variance (CV).

i. MOR and MOE Respect to Age Groups

According to Alik and Kuroda (1996), MOR indicates a measure of the ultimate bending strength of timber for that size of the sample and that rate of bending, whereas MOE is concerning a measure of stiffness or flexibility of a specimen in bending. Both strength properties are analysed using a linear regression model, one-way ANOVA, and the Duncan Multiple Range Test (DMRT). Before that, the mean analysis of the static bending test result is done. The mean of MOR and MOE are obtained from 90 specimens, and the mean results are presented in Figure 4.53 and Figure 4.54, respectively.

Figure 4.53 shows the mean and coefficient of variance (CV) MOR of laminated products same-age groups for untreated specimens. The highest MOR obtained by the age group of 10 // 10 years old samples with recorded MOR is 117.93 N/mm^2 (10.48). The lowest MOR attained is 99.41 N/mm^2 (12.19) which is from the age group of 7 // 7 years old samples, whereas, in the middle of that, is 105.36 N/mm^2 (14.01) recorded from 13 // 13 years old *Acacia mangium* superbulk. Besides that, Figure 4.54 shows the highest MOE is 14991 N/mm^2 (9.32) recorded by the laminated age group of 10 // 10 years old samples, followed by 12603 (9.81) N/mm^2 obtained by the laminated age group of 13 // 13 years old samples. The lowest MOE mean results from the laminated age group of 7 // 7 years old

samples, which is 12022 N/mm^2 (10.43).

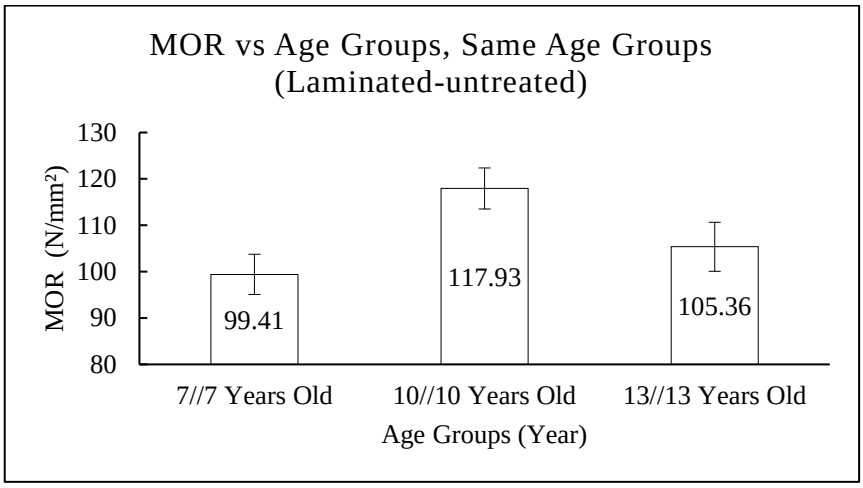


Figure 4.53: MOR Against Age Groups, Same Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk

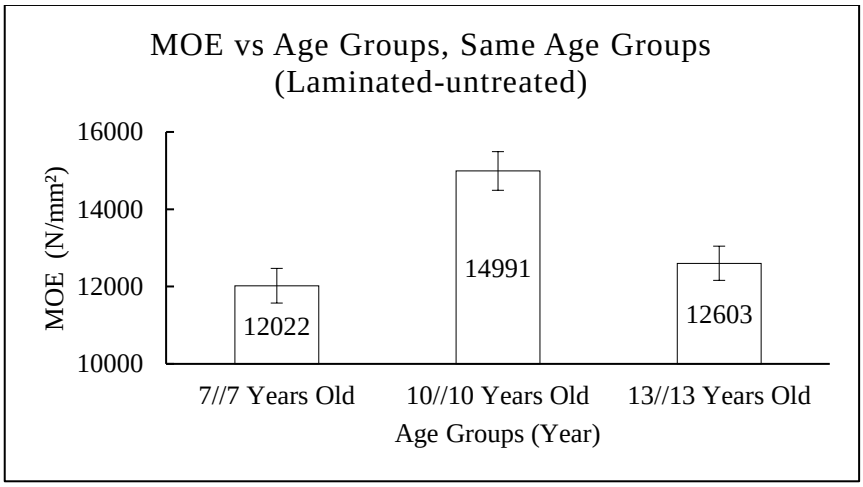


Figure 4.54: MOE Against Age Groups, Same Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk

There is a statistically significant difference in the mean MOR age group of 10 // 10 years old samples when compared with the mean MOR age group of 7 // 7 years old samples and 13 // 13 years old samples at 95% confidence intervals. Meanwhile, the mean MOE age group of 10 // 10 years old samples was also had a statistically significant difference when

compared to the mean MOE from the age group of 7 // 7 years old samples and 13 // 13 years old samples at $p<0.05$ confidence intervals.

The ANOVA analysis with a probability of 0.05 is tabulated in Table 4.52. From that respective table, with the total number of the sample (n = 90), both results, MOR and MOE, have a statistically significant difference between them since the significant value obtained is 0.000, which is below the probability level of 0.05.

Table 4.52: One-way ANOVA of MOR and MOE by the Same Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk

		Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
MOR	Between Groups	5366.19	2	2683.10	15.55	0.00
	Within Groups	15009.45	87	172.52		
	Total	20375.65	89			
MOE	Between Groups	148482617.13	2	74241308.57	44.07	0.00
	Within Groups	146570252.76	87	1684715.55		
	Total	295052869.89	89			

In order to determine which age group is varied in the mean of modulus of rupture and modulus of elasticity, a post-hoc test of Duncan Multiple Range Test is performed. The results for the respective post-hoc tests are presented in Table 4.53 and Table 4.54. Table 4.53 shows that the MOR from the laminated age group of 10 // 10 years old samples has a specific difference compared to the other two laminated products age groups . It is proven since the MOR from the age group of 10 // 10 years old samples is categorised under a single class. Meanwhile, Table 4.54 shows a specific difference in MOE for the laminated age group of 10 // 10 years compared to the laminated age group of 7 // 7 and 13 // 13 years old samples. The table shows that the laminated age group of 7 // 7 and 13 // 13 years old samples

are grouped into the same class because both do not have any specific difference.

Table 4.53: DMRT of MOR by the Same Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk

Age Groups	N	Subset for alpha = 0.05	
		1	2
7 // 7 Years Old	30	99.41	
13 // 13 Years Old	30	105.36	
10 // 10 Years Old	30		117.93
Sig.		0.08	1.00

*//:lamination

Table 4.54: DMRT of MOE by the Same Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk

Age Groups	N	Subset for alpha = 0.05	
		1	2
7 // 7 Years Old	30	12022.20	
13 // 13 Years Old	30	12603.27	
10 // 10 Years Old	30		14990.56
Sig.		0.09	1.00

*//:lamination

Table 4.55: Maximum Load of Static Bending by the Same Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk

Age Group (Year)	Maximum Load (kN)
7 // 7	1.91
10 // 10	2.28
13 // 13	2.04

*//:lamination

Table 4.55 specifies the maximum load that laminated static bending specimens can carry. Maximum load, therefore, will be derived from the results of MOR and MOE from

the static bending experimental. Based on Table 4.55, laminated products by the same year, 7 // 7 has a maximum load equal to 1.91 kN, whereas laminated years 10 // 10 and 13 // 13 have a maximum load equal to 2.28 kN and 2.04 kN, respectively.

ii. MOR and MOE Respect to Basic Density

The further analysis of linear regression for all data takes place. The linear regression model is run for each age group. The best straight line is created from the regression model, and the result with regression value will determine the accuracy of the data fit the model by the two variables involved. The variables include the dependent variable, MOR or MOE, and the independent variable, basic density. Figure 4.55 and Figure 4.56 indicate the MOR and MOE with respect to the basic density age group of 7 // 7 years old samples, respectively. From the analysis, the R-values obtained are 0.95 and 0.96 collected from MOR and MOE Laminated-untreated products of 7 // 7 years old, respectively. This shows that there is a very strong correlation between MOR or MOE and basic density since the R-values obtained are nearly 1.00.

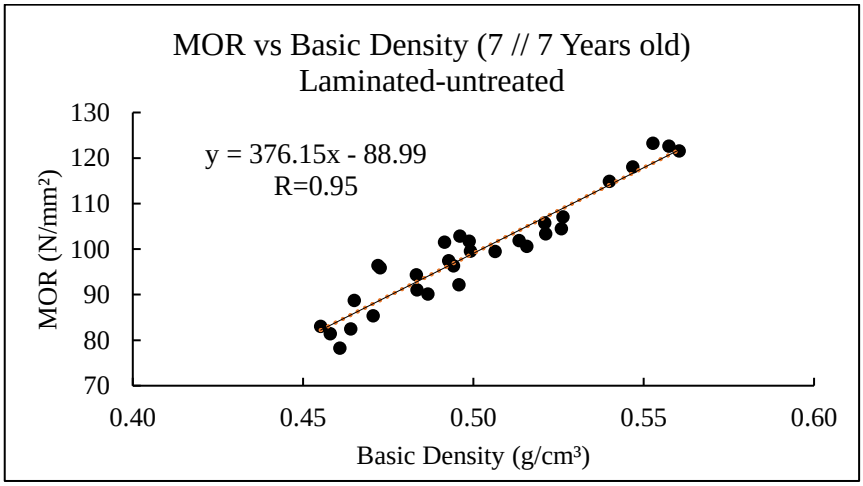


Figure 4.55: MOR Against Basic Density for 7 // 7 Years Old (Laminated-untreated Products) of *Acacia mangium* superbulk

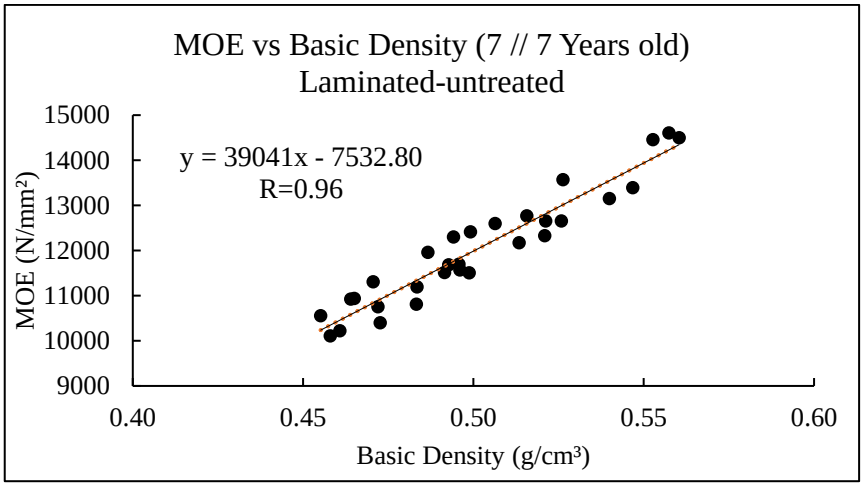


Figure 4.56: MOE Against Basic Density for 7 // 7 Years Old (Laminated-untreated Products) of *Acacia mangium* superbulk

Figures 4.57 and 4.58 present the linear regression analysis of MOR and MOE against basic density for 10 // 10 years. From the analysis, the R-values recorded are both 0.96 for MOR and MOE against basic density 10 // 10 years old. This shows a very strong correlation between those two variables since their R-values are approaching 1.00.

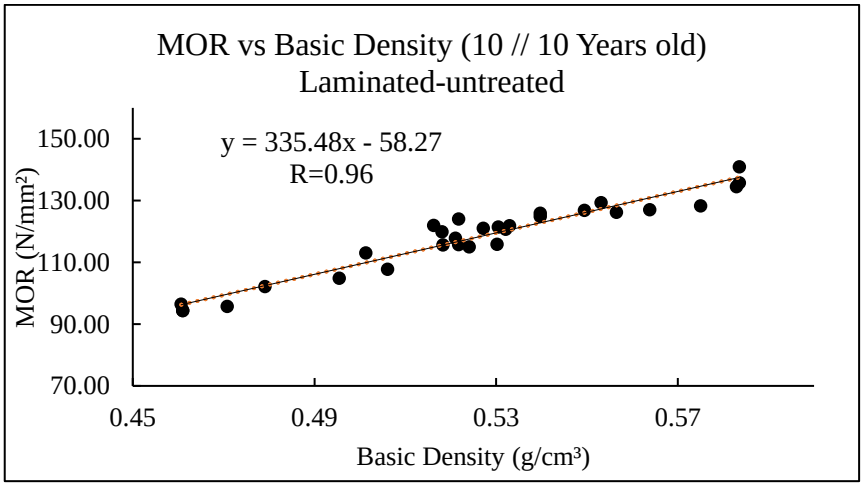


Figure 4.57: MOR Against Basic Density for 10 // 10 Years Old (Laminated-untreated Products) of *Acacia mangium* superbulk

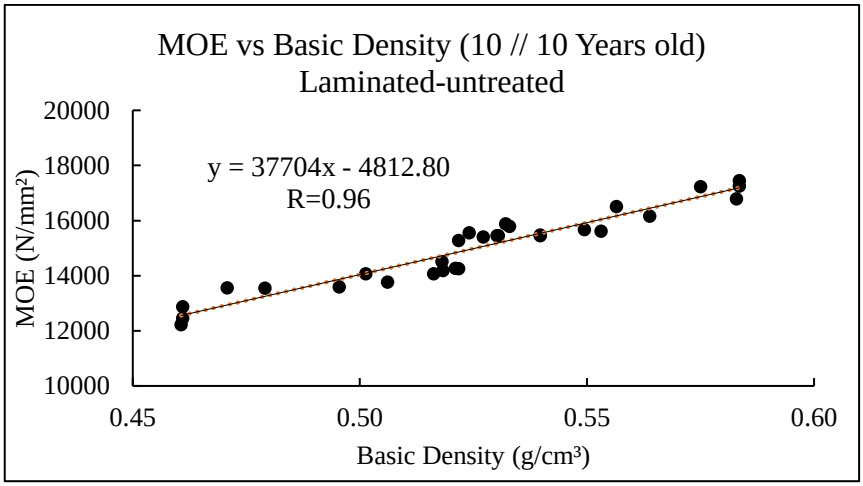


Figure 4.58: MOE Against Basic Density for 10 // 10 Years Old (Laminated-untreated Products) of *Acacia mangium* superbulk

The linear regression analysis between MOR and MOE against basic density for 13 // 13 years is presented in Figure 4.59 and Figure 4.60. From the analysis, the R values obtained are 0.98 and 0.96 for MOR and MOE against basic density 13 // 13 years old, respectively. From the R-values, it can be concluded that there is a very strong correlation between the two variables since the R-values obtained are only slightly less than 1.00.

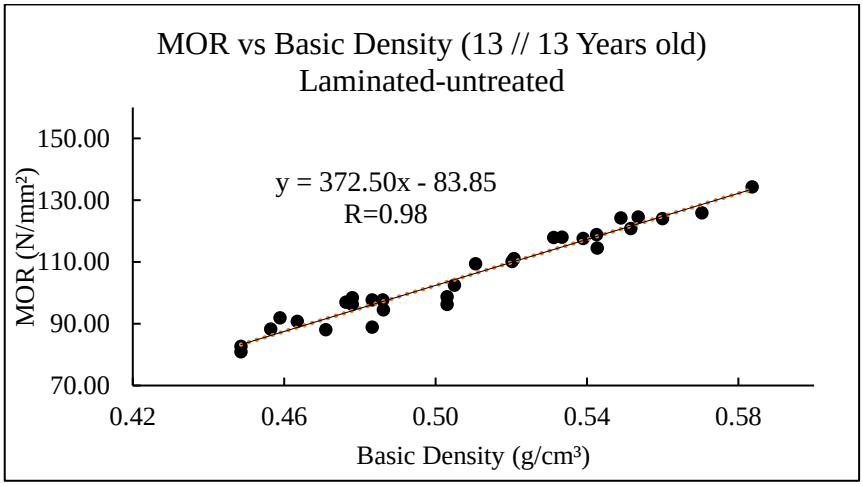


Figure 4.59: MOR Against Basic Density for 13 // 13 Years Old (Laminated-untreated Products) of *Acacia mangium* superbulk

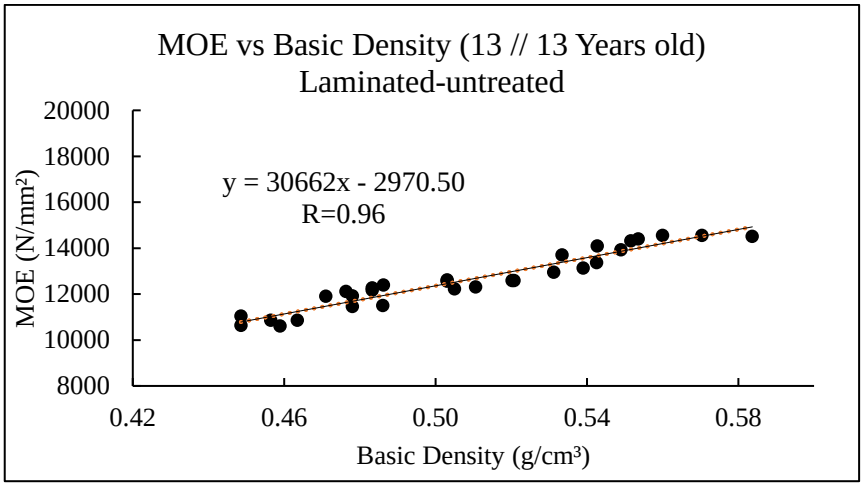


Figure 4.60: MOE Against Basic Density for 13 // 13 Years Old (Laminated-untreated Products) of *Acacia mangium* superbulk

Figure 4.61 and Figure 4.62 indicate the comparison of mean MOR and MOE when compared to solid-untreated results. Based on Figure 4.61, it is shown that there are increments in MOR from solid-untreated to laminated-untreated products results. The increases recorded in the MOR age group of 7 // 7, 10 // 10 and 13 // 13 years old samples are 3.61 N/mm^2, 2.82 N/mm^2 and 7.30 N/mm^2, respectively. Meanwhile, in Figure 4.62, the increment recorded in MOE from solid-untreated to laminated-untreated products are 252 N/mm^2, 45 N/mm^2 and 91 N/mm^2 for the age group of 7, 10 and 13 years old samples, respectively. At 95% confidence intervals, the mean MOR and MOE for solid and laminated untreated samples show only 10 // 10 years old sample products had statistically significant differences when compared to those two age groups ($p < 0.05$). Comparisons between solid and laminated untreated samples within the age groups also show no statistically significant differences ($p > 0.05$) for all age groups.

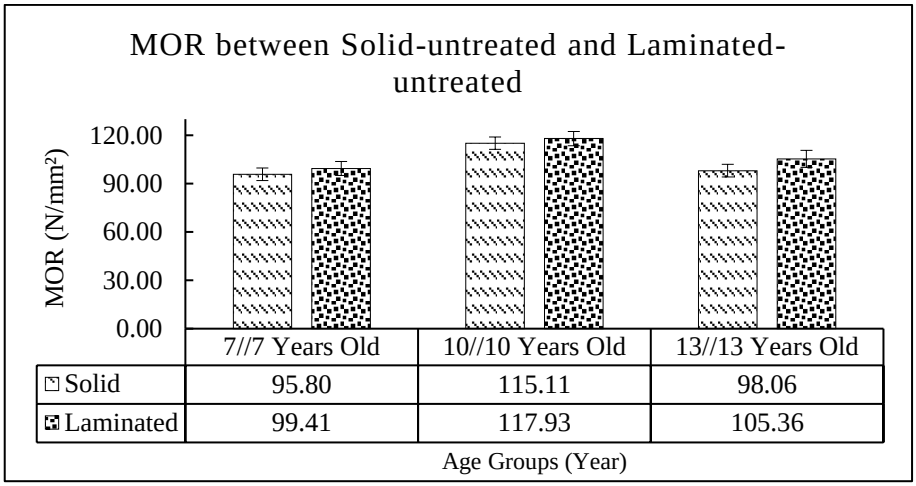


Figure 4.61: Comparison of MOR between Solid-untreated and Laminated-untreated Products of *Acacia mangium* superbulk

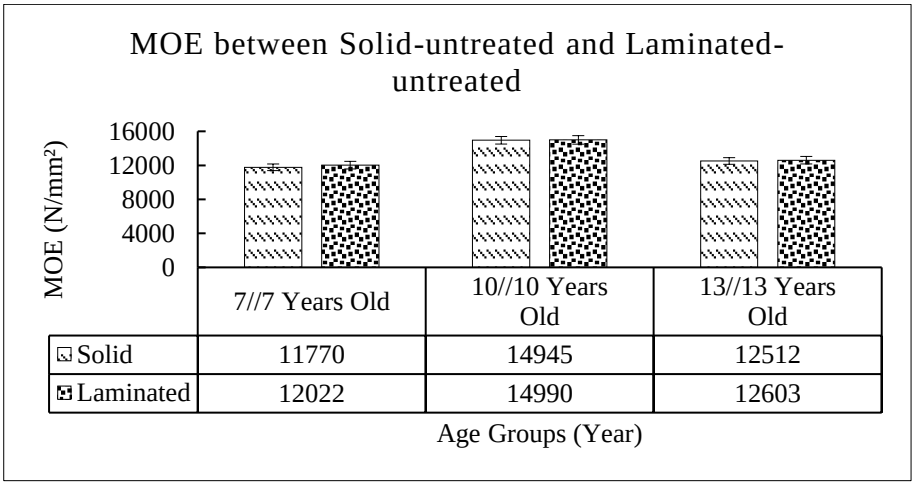


Figure 4.62: Comparison of MOE between Solid-untreated and Laminated-untreated Products of *Acacia mangium* superbulk

4.4.5 Static Bending by the Different Age Groups

An analysis of static bending of laminated-untreated products by the different age groups specimen results are obtained from the modulus of rupture (MOR), and modulus of elasticity (MOE) with respect to age groups and also modulus of rupture (MOR) and modulus of elasticity (MOE) respect to basic density. Note that the value (in parenthesis) is indicated as the coefficient of variance (CV).

i. MOR and MOE Respect to Age Groups

Static bending tests for laminated specimens of different age groups are provided as solid samples in small clear specimens. With sizes of 20 mm x 20 mm x 300 mm, these specimens are laminated with two layers of different age groups of *Acacia mangium* superbulk. The mean of the static bending test with respect to different age groups is analysed for both laminated-untreated products MOR and MOE. These two analyses are presented in Figure 4.63 and Figure 4.64 at a 95 % significant level, respectively.

Based on Figure 4.63, the mean of MOR for all laminated specimens is revealed to be the highest from the laminated age groups products of 10 // 13 years old samples, which are reported with 110.19 N/mm^2 (13.52). Meanwhile, laminated age groups products of 7 // 13 years old samples marked the lowest, which gained 101.15 N/mm2 (17.18), then laminated age groups products of 7 // 10 years old samples obtained MOR equal to 107.50 N/mm^2 (25.44). The CVs collected show that all the data are acceptable since the values recorded are below 30. No statistically significant difference exists among all mean MOR from all age groups at 95% confidence intervals.

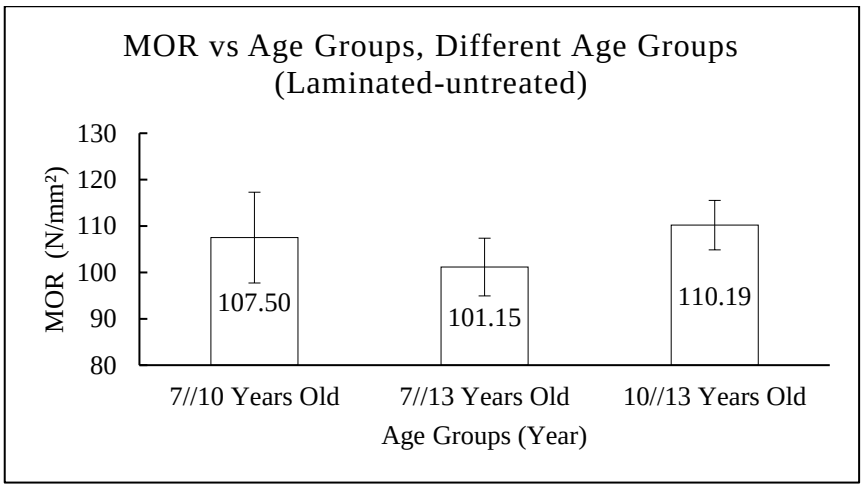


Figure 4.63: MOR Against Age Groups, Different Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk

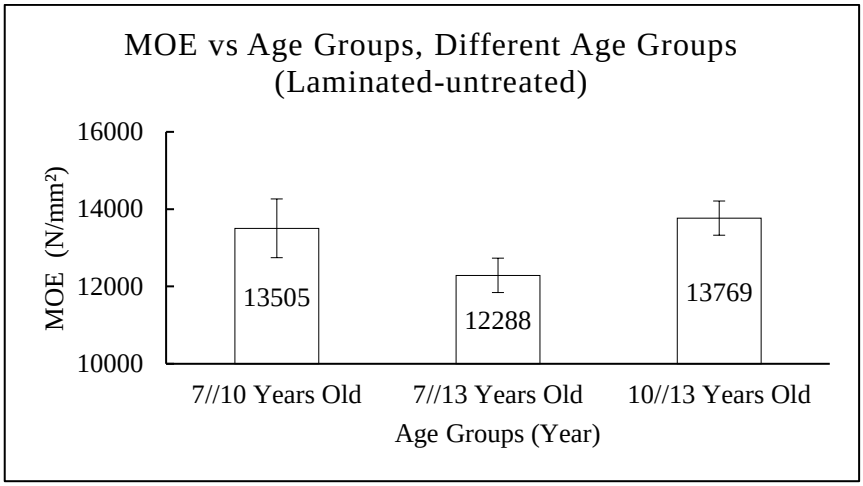


Figure 4.64: MOE Against Age Groups, Different Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk

The mean of MOE by all laminated in different age groups is displayed in Figure 4.64. From the analysis, the highest MOE obtained is 13769 (8.98) N/mm^2 which is from laminated age groups products of 10 // 13 years old samples, whereas the lowest is 12288 N/mm^2 (10.12) which is gained by laminated age groups products of 7 // 13 years old samples, while, the mean of MOE from laminated age groups products of 7 // 10 years old samples recorded 13505 N/mm^2 (15.72). Hence, based on the CVs attained, the MOE data from all the age groups are good as it is not dispersed too much away from the mean. There is a statistically significant difference in mean MOE only between the age groups of 7 // 13 years old with 10 // 13 years old samples at $p<0.05$.

All the MOR and MOE results are sorted out to analyse the variance using one-way ANOVA analysis to determine whether there is any statistically significant difference or not among all the results. The output from the one-way ANOVA analysis is interpreted in Table 4.56, which shows that the F distributions obtained for MOR and MOE are 1.52 and 7.40, respectively. Thus, the significant value attained from the F distributions for MOR and MOE

is 0.22 and 0.00, respectively. The MOE results are significantly different since the significant value is below the probability level of 0.05. Meanwhile, one-way ANOVA analysis for MOR results found no statistically significant difference among all results because the significant value obtained was higher than the probability level.

Table 4.56: One-way ANOVA of MOR and MOE by the Different Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk

		Sum of Squares	df	Mean Square	F	Sig.
MOR	Between Groups	1292.57	2	2683.10	1.52	0.22
	Within Groups	36889.15	87	172.52		
	Total	38181.72	89			
MOE	Between Groups	37418295.80	2	18709147.90	7.40	0.00
	Within Groups	219927432.30	87	2527901.52		
	Total	257345728.10	89			

The mean for both MOR and MOE are evaluated using the DMRT post-hoc test to analyse the specific difference in both means of MOR and MOE for all age groups. The DMRT results for mean MOR and MOE are indicated in Table 4.57 and Table 4.58, respectively. Based on Table 4.57, the mean of MOR results for all untreated laminated products age groups is close to each other, and all the means are categorised into one class. The analysis shows that there is no specific difference among them.

From the Duncan Multiple Range Post-hoc Test results in Table 4.58, it is observed that the mean of MOE from laminated age groups products of 7 with 13 years old samples has specific differences compared to the other two age groups. The mean of MOE from laminated products-untreated 7 // 10 years old samples and 10 // 13 years old samples are reported with no specific difference, so they share the same class.

Table 4.57: DMRT of MOR by the Different Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk

Age Groups	N	Subset for alpha = 0.05
		1
7 // 13 Years Old	30	101.15
7 // 10 Years Old	30	107.50
10 // 13 Years Old	30	110.19
Sig.		0.11

*//:lamination

Table 4.58: DMRT of MOE by the Different Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk

Age Groups	N	Subset for alpha = 0.05	
		1	2
7 // 13 Years Old	30	12288.03	
7 // 10 Years Old	30		13504.73
10 // 13 Years Old	30		13768.53
Sig.		1.00	0.52

*//:lamination

Table 4.59: Maximum Load of Static Bending by the Different Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk

Age Group (Year)	Maximum Load (kN)
7 // 10	2.06
7 // 13	1.92
10 // 13	2.12

*//:lamination

The static bending test also listed out the maximum load that all the test specimens from all age groups can carry. The maximum load in kN for all three age groups are presented in Table 4.59. From the table, the highest maximum load is 2.12 kN, resulting from the

laminated age groups products of 10 with 13 years old samples. Meanwhile, the lowest maximum load that can be applied is 1.92 kN which is gained from laminated products 7 with 13 years old samples, whereas 2.06 kN is the maximum load obtained from laminated products 7 with 13 years old samples.

ii. MOR and MOE Respect to Basic Density

An analysis continues with MOR and MOE with respect to basic density. The following charts indicate the MOR and MOE against basic density for laminated-untreated products 7 with 10 years old samples, 7 with 13 years old samples, and 10 with 13 years old samples, respectively.

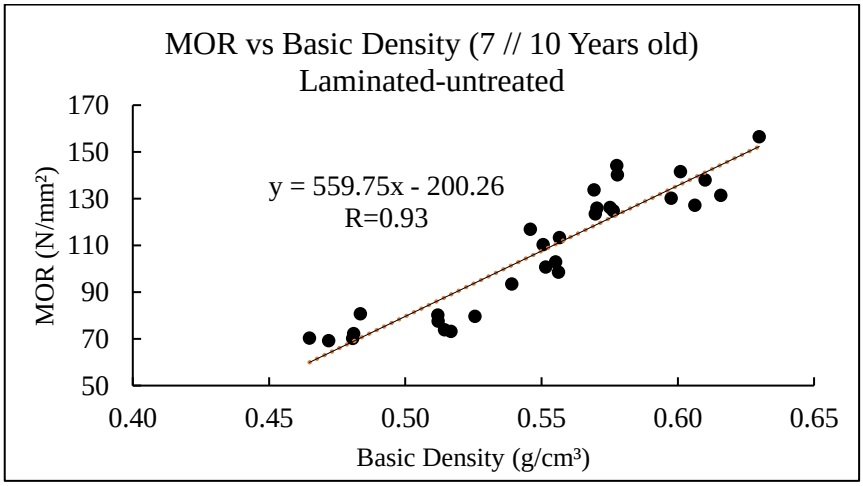


Figure 4.65: MOR Against Basic Density for 7 // 10 Years Old (Laminated-untreated Products) of *Acacia mangium* superbulk

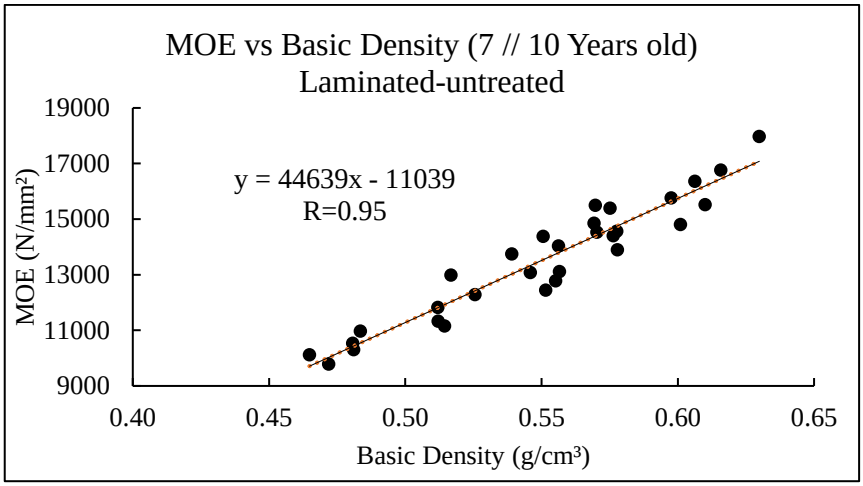


Figure 4.66: MOE Against Basic Density for 7 // 10 Years Old (Laminated-untreated Products) of *Acacia mangium* superbulk

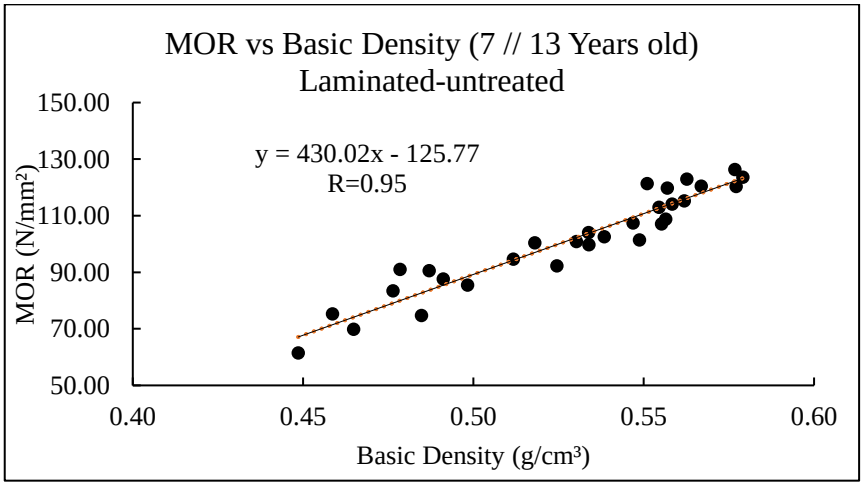


Figure 4.67: MOR Against Basic Density for 7 // 13 Years Old (Laminated-untreated Products) of *Acacia mangium* superbulk

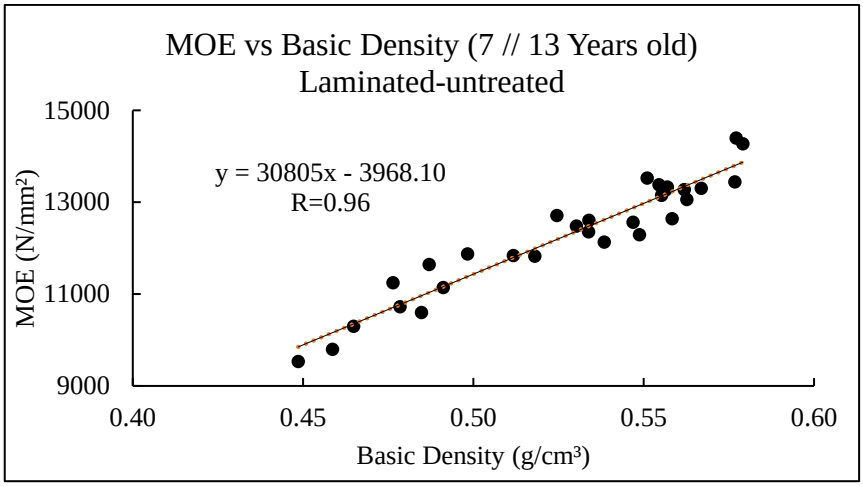


Figure 4.68: MOE Against Basic Density for 7 // 13 Years Old (Laminated-untreated Products) of *Acacia mangium* superbulk

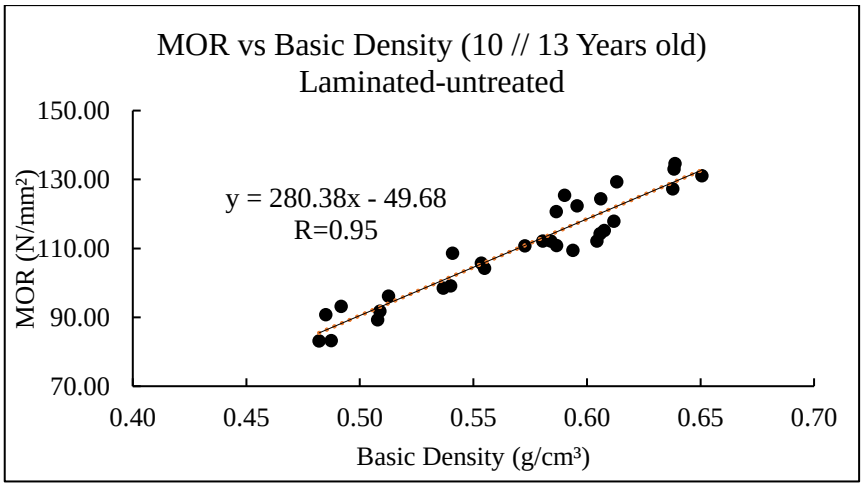


Figure 4.69: MOR Against Basic Density for 10 // 13 Years Old (Laminated-untreated Products) of *Acacia mangium* superbulk

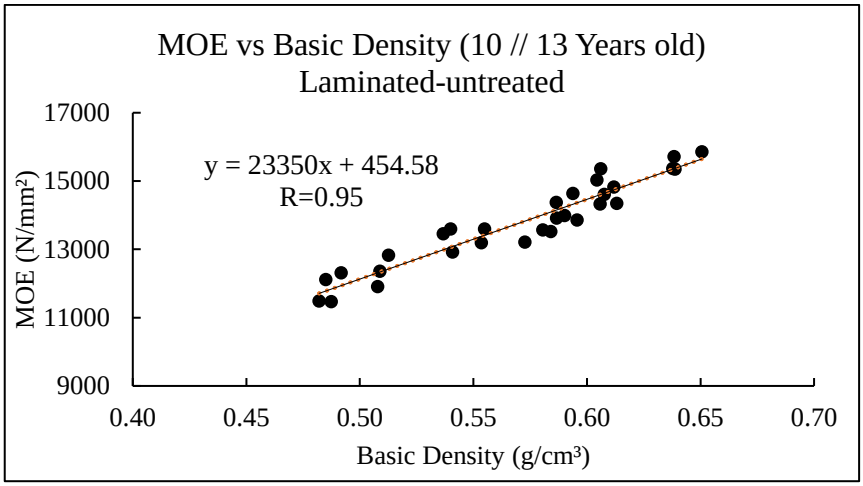


Figure 4.70: MOE Against Basic Density for 10 // 13 Years Old (Laminated-untreated Products) of *Acacia mangium* superbulk

From the linear regression analysis, the R-values obtained from MOR and MOE of laminated-untreated products by different age groups are in the range of 0.93 to 0.96. Thus, this is concluded that there is a very strong correlation between MOR or MOE and basic density since the R-values recorded are approaching 1.00.

4.4.6 Compression Parallel to Grain by the Same Age Groups

The analysis compression parallel to grain of the laminated-untreated products specimen from the same age group will be analysed with respect to age groups and basic density.

i. Compression Parallel to Grain Respect to Age Groups

A total of 90 laminated specimens sized 20 mm x 20 mm x 60 mm undergo testing according to a small clear test procedure by ITTO's Testing Methods for Plantation Grown Tropical Timbers (Tan et al., 2010). Figure 4.71 presents the analysis of mean compressive strength from laminated products-untreated with respect to age groups. Figure 4.71 shows that the highest compressive strength is obtained by the laminated age group of 10 // 10 years

old samples with a value of 59.63 N/mm^2 (12.99), followed by the age group of 13 // 13 years old with 54.61 N/mm^2 (15.49). The lowest compression strength was recorded by the 7 // 7 age group with 52.56 N/mm^2 (9.75). The error bars at 95% confidence intervals were analysed to show that there is a statistically significant difference in mean compression parallel to grain only between the age group of 10 // 10 years old samples with the age group of 7 // 7 years old samples and 13 // 13 years old samples had no statistically significant difference.

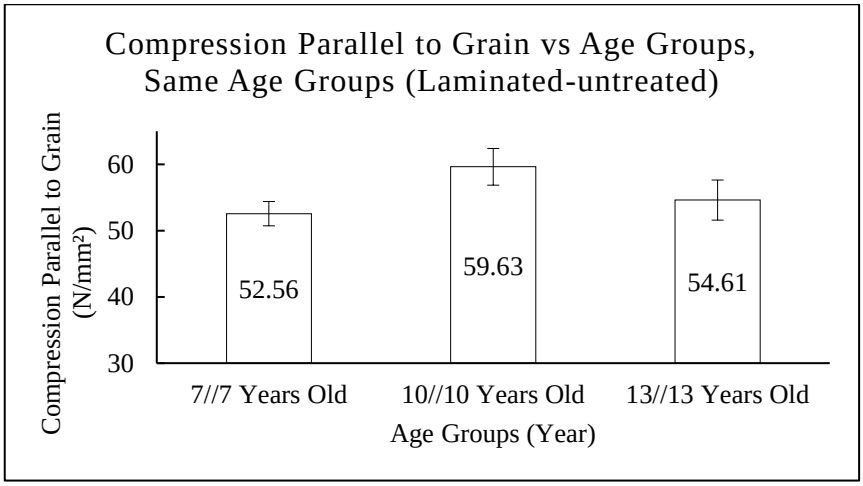


Figure 4.71: Compression Parallel to Grain Against Age Groups, Same Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk

Meanwhile, an analysis of one-way ANOVA is carried out to determine whether there are any significant differences among all results of compressive strength. With the total number of samples (n = 90) of all age groups, the one-way ANOVA comes out with the result tabulated in Table 4.60. Based on Table 4.60, it is shown that compression test results for all age groups have significant differences since the significant value obtained was 0.001, which is below the probability level of 0.05.

Table 4.60: One-way ANOVA of Compression Parallel to Grain by the Same Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	794.02	2	397.01	7.55	0.00
Within Groups	4575.69	87	52.59		
Total	5369.72	89			

Table 4.61: DMRT of Compression Parallel to Grain by the Same Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk

Age Groups	N	Subset for alpha = 0.05	
		1	2
7 // 7 Years Old	30	52.56	
13 // 13 Years Old	30	54.61	
10 // 10 Years Old	30		59.63
Sig.		0.28	1.00

*//:lamination

To determine which lamination years couples varied in mean compression test results, a post-hoc Duncan Multiple Range Test is selected. The result from the DMRT test is presented in Table 4.61. It is shown that the lamination from the age group of 10 years old samples has a specific difference in mean compressive strength than the other two age groups; thus, it is placed in a single class. Meanwhile, the lamination age group of 13 years old samples and 7 years old samples does not have any specific difference in the mean of compressive strength, and they share the same class.

The compression strength of the timber is obtained from the maximum load applied to the cross-sectional area of the 20 cm x 20 cm x 60 cm specimen. The mean maximum load attained by all age groups is presented in Table 4.62. Table 4.62 shows the highest

maximum load recorded from the age group of 10 // 10 with a value of 2.42 kN, followed by the age group of 13 // 13 with 2.15 kN. The lamination age group of 7 // 7 years old samples obtained the lowest maximum load with the result of 2.15 kN.

Table 4.62: Maximum Load of Compression Parallel to Grain by the Same Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk

Age Group (Year)	Maximum Load (kN)
7 // 7	2.15
10 // 10	2.42
13 // 13	2.24

*//:lamination

ii. Compression Parallel to Grain Respect to Basic Density

It is necessary to analyse the compression strength for each age group with respect to basic density. As mentioned, basic density has a strong correlation to mechanical strength properties. Hence, this consequent analysis is done via linear regression model analysis with regression value derived from two variables: compression strength (dependent) in N/mm^2 and basic density (independent) in g/cm^3. Figures 4.72, 4.73 and 4.74 present the linear regression analysis for compression parallel to grain against the basic density of laminated-untreated products for 7 // 7, 10 // 10 and 13 // 13 years old, respectively. From the analysis, all the R-values obtained are 0.96, which shows that there is a strong correlation between those two variables since their R-values are approaching 1.00.

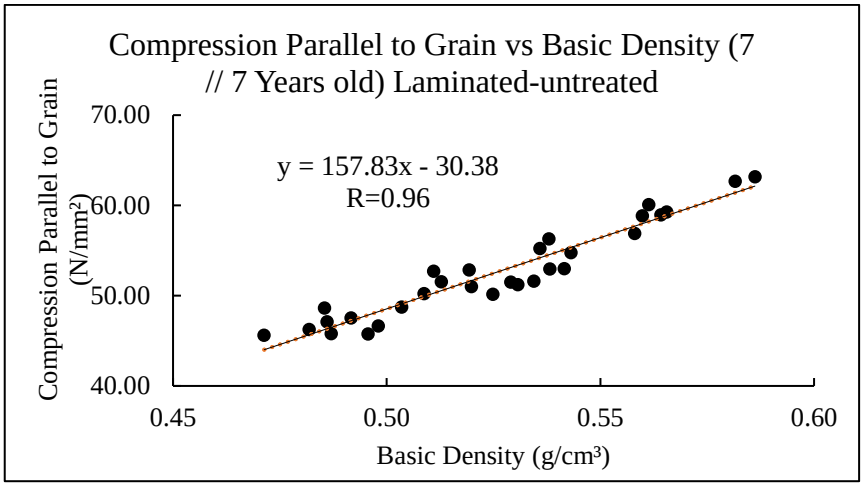


Figure 4.72: Compression Parallel to Grain Against Basic Density for 7 // 7 Years Old (Laminated-untreated Products) of *Acacia mangium* superbulk

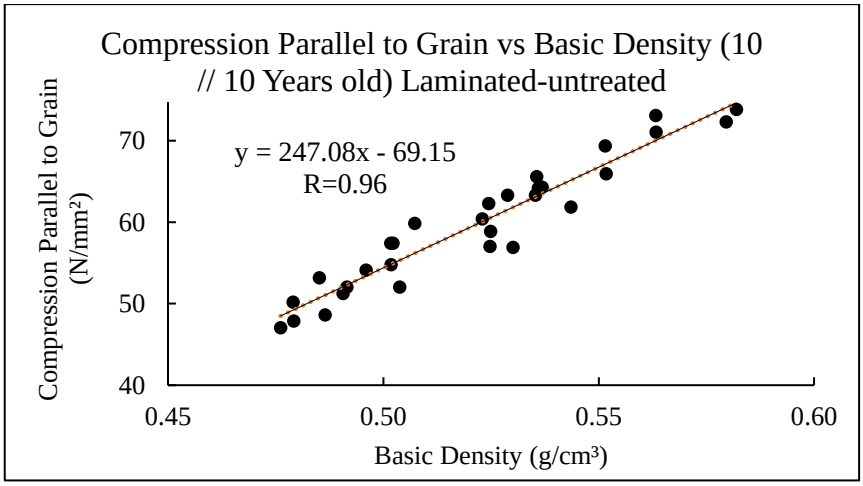


Figure 4.73: Compression Parallel to Grain Against Basic Density for 10 // 10 Years Old (Laminated-untreated Products) of *Acacia mangium* superbulk

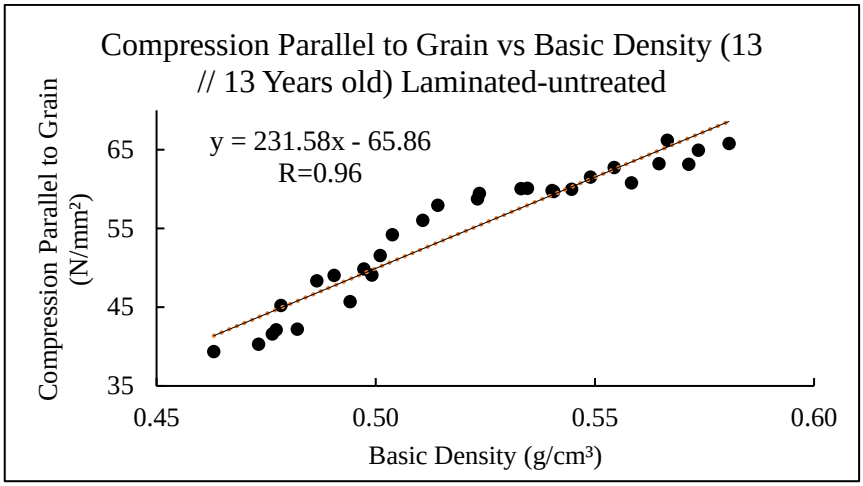


Figure 4.74: Compression Parallel to Grain Against Basic Density for 13 // 13 Years Old (Laminated-untreated Products) of *Acacia mangium* superbulk

There should be a difference in compression results when comparing solid-untreated results and laminated-untreated products results. Roughly, it is introduced that there is an increment in the laminate-untreated results compared to that of solid-untreated results. The comparison is well presented in Figure 4.75. The differences in the mean of compression strength for the laminated age group of 7, 10, and 13 years old of 'Superbulk' timber species from solid are 3.38 N/mm^2, 2.06 N/mm^2 and 1.68 N/mm^2, respectively. Analising using 95% confidence intervals shows that mean compression parallel to grain solid untreated samples for all age groups have statistically significant differences, meanwhile, for laminated sample products, only 7 // 7 years old with 10 // 10 years old have statistically significant differences, while 13 // 13 years old does not has a statistically significant difference. There are no statistically significant differences when solid and laminated untreated samples are compared within the age groups ($p > 0.05$).

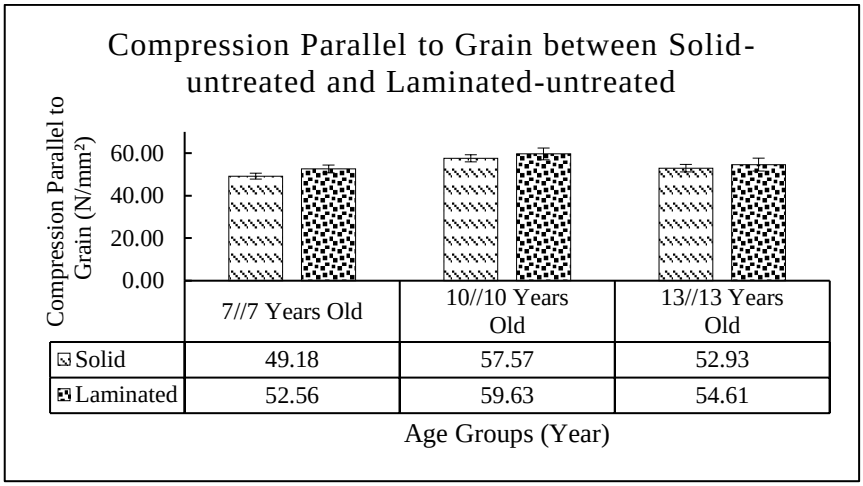


Figure 4.75: Comparison of Compression Parallel to Grain between Solid-untreated and Laminated-untreated Products of *Acacia mangium* superbulk

4.4.7 Compression Parallel to Grain by the Different Age Groups

An analysis of compression parallel to grain of different age groups laminated-untreated products specimen results are categorised into two parts: compression strength with respect to age groups and compression strength with respect to basic density.

i. Compression Parallel to Grain Respect to Age Groups

A 20 mm x 20 mm x 60 mm is laminated products by using different year planks and running the compression test similar to the previous testing. The compression strength is recorded from a total of 30 specimens from each age group. All the recorded results are being analysed identically to other analyses, which are via mean analysis, linear regression analysis, one-way ANOVA analysis, and also Duncan Multiple Range Test analysis at 95 % significance. Thus, Figure 4.76 indicates the mean of compression strength against age groups for laminated-untreated products laminates of different years.

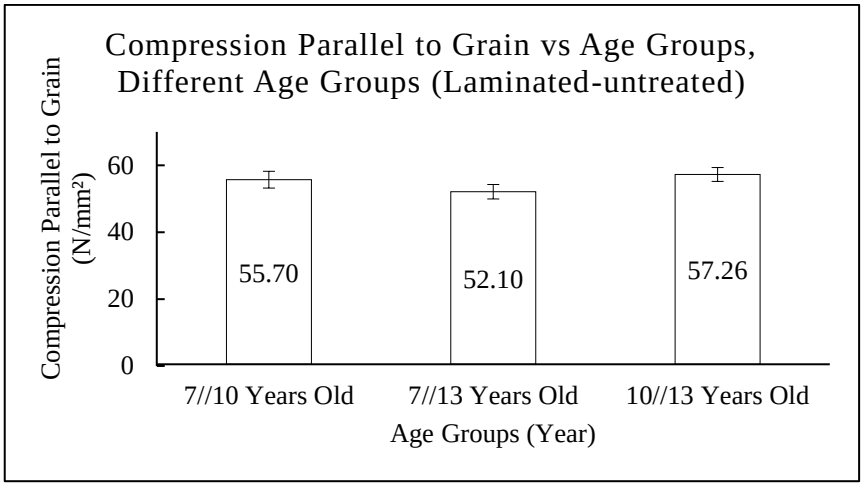


Figure 4.76: Compression Parallel to Grain Against Age Groups, Different Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk

Based on Figure 4.76, from the mean analysis, the highest mean with CV of compression strength is marked by the laminated age groups products of 10 // 13 years old samples, which is 57.26 N/mm^2 (10.14). Besides that, the lowest mean of compression strength is recorded in the laminated age groups products of 7 // 13 years old samples with 52.10 (11.60) N/mm^2, while laminated age groups products of 7 // 10 years old samples acquired a mean of 55.70 (12.58) N/mm^2. The collected CVs also showed good values, meaning all the compression strength results are dispersed around the means. There is a stataistically significant difference in mean compression parallel to grain only between the age groups of 7 // 13 years old with 10 // 13 years old samples at 95% confidence intervals.

Table 4.63: One-way ANOVA of Compression Parallel to Grain by the Different Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk

	Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	420.87	2	210.44	5.30	0.01
Within Groups	3459.14	87	39.76		
Total	3880.02	89			

Secondly, all the compression strength results are analysed by using analysis of variance one-way ANOVA in order to determine whether there is any statistically significant difference among all the compression strength results. The one-way ANOVA analysis is tabulated in Table 4.63. A one-way ANOVA analysis yielded a significant value of 0.01 from the table. It is clearly stated that there is a statistically significant difference among all the compression strength results since the significant value obtained was below the probability level of 0.05.

Table 4.64: DMRT of Compression Parallel to Grain by the Different Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk

Age Groups	N	Subset for alpha = 0.05	
		1	2
7 // 13 years old	30	52.10	
7 // 10 years old	30		55.70
10 // 13 years	30		57.26
Sig.		1.00	0.34

*//:lamination

The DMRT test is selected to identify whether there is any significance or not among all means by all three age groups, and this analysis is presented in Table 4.64. Table 4.64 shows that the mean compression strength of laminated age groups products of 7 with 13 years old samples has specific different compared to the other two means. The mean results from the laminated age groups products of 7 // 10 years old samples and 10 // 13 years old samples were reported to have no specific difference since they are placed in the same class.

Table 4.65: Maximum Load of Compression Parallel to Grain by the Different Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk

Age Group (Year)	Maximum Load (kN)
7 // 10	2.25
7 // 13	2.10
10 // 13	2.30

*//:lamination

The maximum load obtained by compression strength by laminated-untreated products at different age groups is tabulated in Table 4.65. Table 4.65 reported that the maximum load achieved is 2.30 kN from the laminated age groups products of 10 with 13 years old samples, whereas only 2.10 kN is recorded from laminated age groups products of 7 with 13 years old samples, which is the lowest maximum load. Meanwhile, laminated age groups products of 7 with 10 years old samples attained a maximum load of 2.25 kN.

ii. Compression Parallel to Grain Respect to Basic Density

Further analysis was carried out using linear regression to analyse compression strength when respect to basic density. This analysis will determine the regression value from the relationship between two variables: the dependent variable (compression strength) and the independent variable (basic density). Therefore, the following figures show the compression strength against basic density for laminated age groups products of 7 // 10, 7 // 13 and 10 // 13 years old samples, respectively.

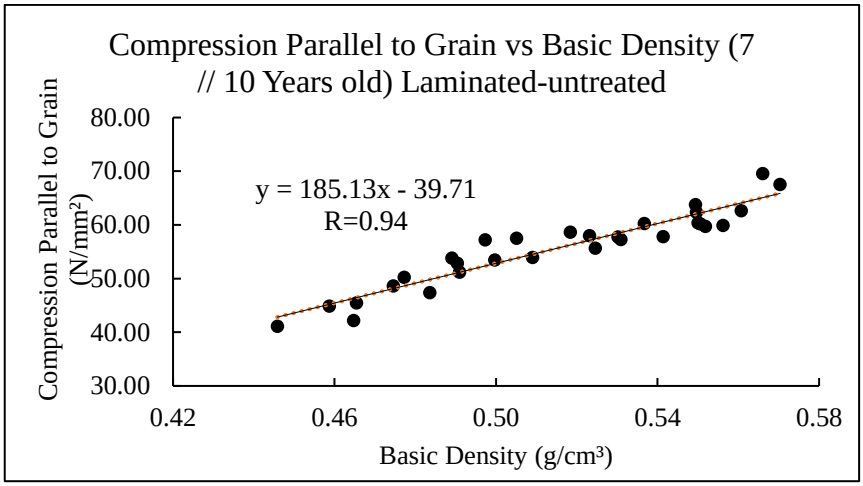


Figure 4.77: Compression Parallel to Grain Against Basic Density for 7 // 10 Years Old (Laminated-untreated Products) of *Acacia mangium* superbulk

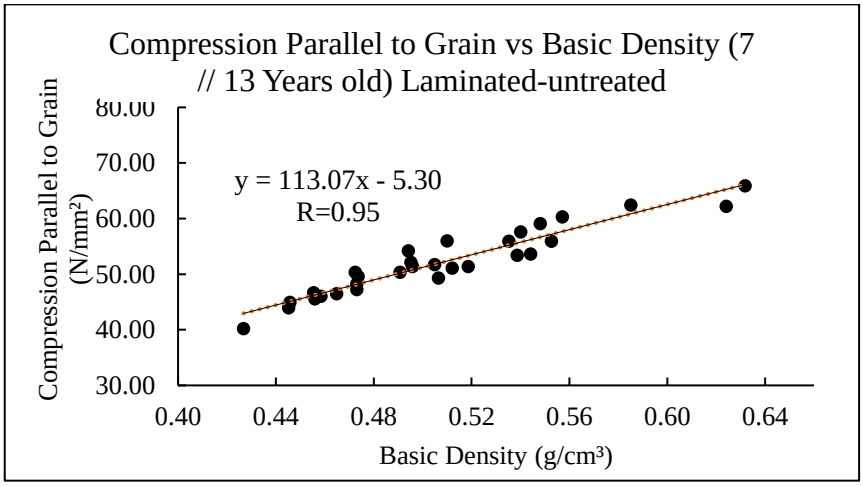


Figure 4.78: Compression Parallel to Grain Against Basic Density for 7//13 Years Old (Laminated-untreated Products) of *Acacia mangium* superbulk

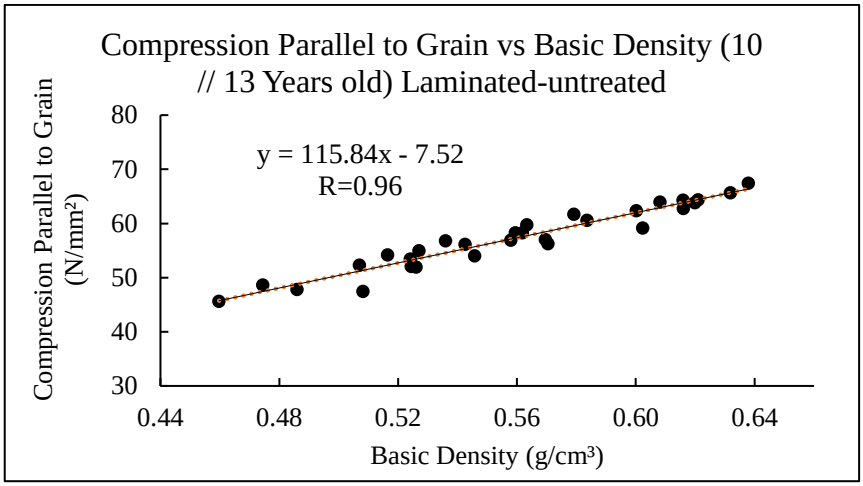


Figure 4.79: Compression Parallel to Grain Against Basic Density for 10 // 13 Years Old (Laminated-untreated Products) of *Acacia mangium* superbulk

From the linear regression analysis, the R-values obtained are 0.94 (7 // 10 years old), 0.95 (7 // 13 years old) and 0.96 (10 // 13 years old). It is concluded that there is a very strong correlation between compression parallel to grain against basic density since its R-values are approaching 1.00.

4.4.8 Shear Parallel to Grain in Tangential Direction by the Same Age Groups

An analysis of the shear strength of the same-year laminated specimen under untreated results is conducted with respect to age groups and basic density. The shear test results are recorded only on one plane compared to solid, tested on the radial and tangential planes. The overview of the test sample is illustrated in Figure 4.80.

Figure 4.80 shows the loading applied perpendicular to the glue line, which is on tangential planes. This laminated shear testing is only done on the tangential plane, as the previous testing was on solid; the study obtained the maximum strength at loading applied on a tangential plane, not on the radial plane. Thus, the study only needs shear strength on tangential results to compare solid and laminated results.

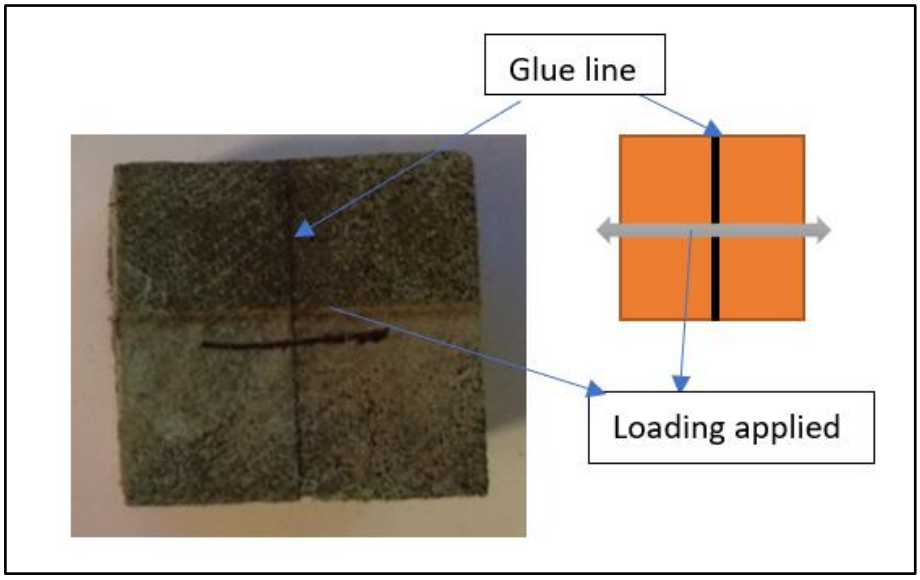


Figure 4.80: Shear Test on Laminate Sample

i. Shear Parallel to Grain in Tangential Direction Respect to Age Groups

Some 90 laminate shear samples undergo the test per ITTO's Testing Methods for Plantation Grown Tropical Timbers (Tan et al., 2010). The shear strength was recorded and analysed in the mean by age group. The mean shear strength of lamination specimens is presented in Figure 4.80. Based on the respective figure, at 95% significance, the highest laminate shear strength obtained is 13.76 N/mm^2 (7.32), which is conquered by the laminated age group of 10 // 10 years old samples. Meanwhile, the lowest mean shear strength of laminate samples is obtained by the age group of 7 // 7 years old of 'Superbulk' species with a value of 12.64 N/mm^2 (11.29), whereas laminated specimens by the age group of 13 // 13 years old samples gained the mean shear strength of 12.81 (13.74) N/mm^2. There is a statistically significant difference in mean shear parallel to grain only between the age group of 10 // 10 years old with the age group of 7 // 7 years old samples at 95% confidence intervals.

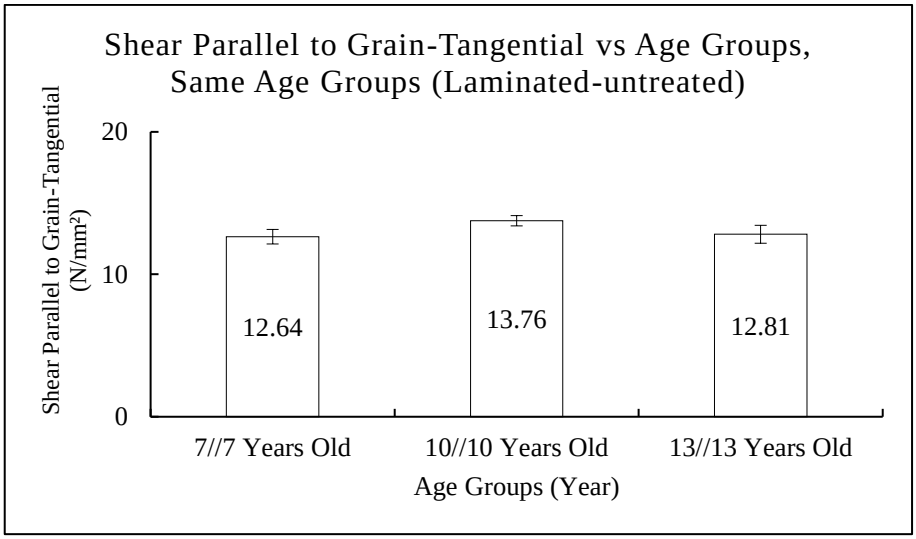


Figure 4.81: Shear Parallel to Grain in Tangential Direction Against Age Groups, Same Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk

Table 4.66: One-way ANOVA of Shear Parallel to Grain in Tangential Direction by the Same Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk

	Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	21.87	2	10.93	5.34	0.01
Within Groups	178.28	87	2.05		
Total	200.15	89			

The further analysis of one-way ANOVA analysis of variance is run at a 0.05 probability level in order to determine whether there are any significant differences or not among all shear strength results by all age groups. Table 4.66 indicates the one-way ANOVA result by all shear strength results among age groups. In Table 4.66, the significant value attained was 0.01, and the F distribution obtained is 5.34, derived from the ratio of two mean squares. Thus, it is described that the shear strength of all age groups is significantly different to each other since the significant value from ANOVA analysis was lower than 0.05.

Table 4.67: DMRT of Shear Parallel to Grain in Tangential Direction by the Same Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk

Age Groups	N	Subset for alpha = 0.05	
		1	2
7 // 7 years old	30	12.64	
13 // 13 years old	30	12.81	
10 // 10 years old	30		13.76
Sig.		0.06	1.00

A post-hoc analysis of the Duncan Multiple Range Test (DMRT) determines which age groups vary in the mean shear strength in untreated conditions. The result of the DMRT analysis is presented in Table 4.67. Based on that respective table, with a total of 30 samples, it is shown that mean shear strength from the age group of 10 // 10 years old samples has a specific difference and is placed under a single class. Compared to the other two age groups, their mean values do not have specific differences since those values correspond to each other. Thus, both mean values from the age group of 7 // 7 years old samples and 13 // 13 years old samples are categorised under the same class.

The maximum load from the shear test (laminated-untreated products) for all age groups are tabulated in Table 4.68. Table 4.68 shows that the maximum load attained by the laminated age group of 7 // 7, 10 // 10 and 13 // 13 years old samples are 5.22 kN, 5.60 kN and 5.21 kN, respectively. In fact, the value of the maximum load is applied to the cross-sectional area of the shear's cubic specimens and derives the shear strength result in N/mm^2.

Table 4.68: Maximum Load of Shear Parallel to Grain in Tangential Direction by the Same Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk

Age Group (Year)	Maximum Load (kN)
7 // 7	5.22
10 // 10	5.60
13 // 13	5.21

*//:lamination

ii. Shear Parallel to Grain in Tangential Direction Respect to Basic Density

Further analysis with the same age group of laminated-untreated products shear strength results is evaluated with respect to basic density by using linear regression analysis, R. This analysis will introduce the relationship between two variables: shear strength results and basic density. The correlation between those variables is specified by the regression value obtained from the straight line created in the regression model. The regression model for shear strength versus basic density from the laminated-untreated products age group of 7 // 7, 10 // 10 and 13 // 13 years old of *Acacia mangium* superbulk are presented in Figure 4.82, Figure 4.83, and Figure 4.84, respectively.

Based on Figure 4.82, the linear regression model is formed by shear strength results with respect to basic density from the age group of laminated 7 // 7 years old samples. The R-value obtained is 0.91. Thus, dependent and independent variables have a very strong correlation since the R-value obtained is nearly 1.00.

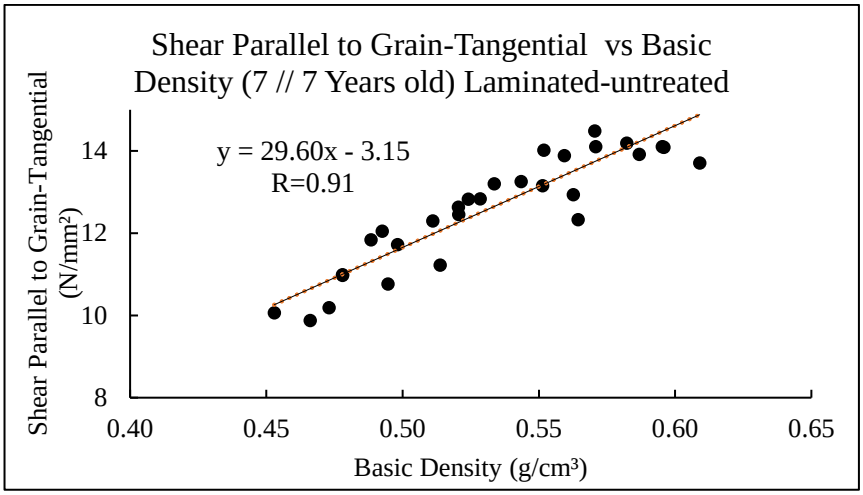


Figure 4.82: Shear Parallel to Grain in Tangential Direction Against Basic Density for 7 // 7 Years Old (Laminated-untreated Products) of *Acacia mangium* superbulk

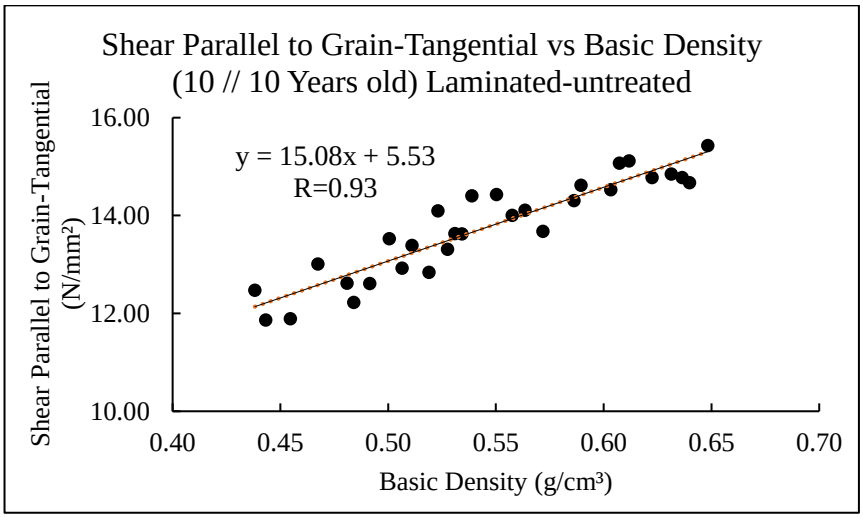


Figure 4.83: Shear Parallel to Grain in Tangential Direction Against Basic Density for 10 // 10 Years Old (Laminated-untreated Products) of *Acacia mangium* superbulk

By referring to Figure 4.83, from linear regression analysis for the laminated age group of 10 // 10 years old of the 'Superbulk' species presented, the analysis revealed that the R-value obtained is 0.93, which is near 1.00. Thus, this analysis concludes that there is a very strong correlation between shear strength and basic density since the regression value is close to 1.00.

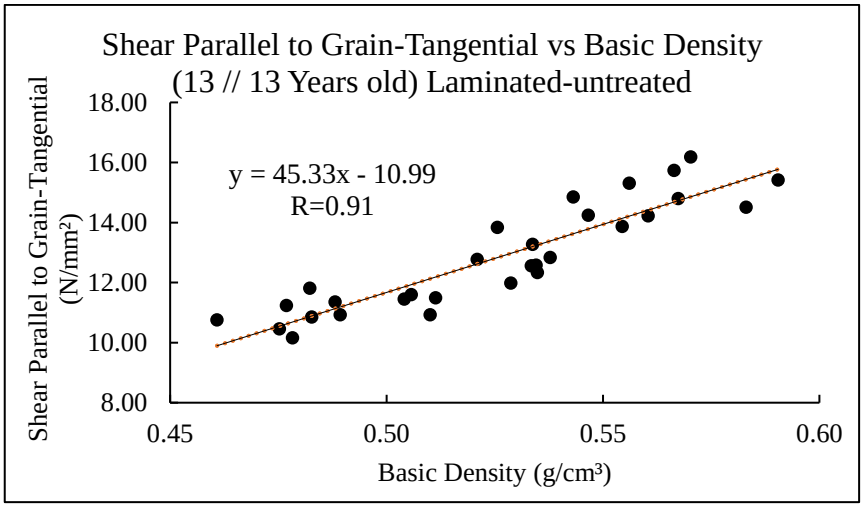


Figure 4.84: Shear Parallel to Grain in Tangential Direction Against Basic Density for 13 // 13 Years Old (Laminated-untreated Products) of *Acacia mangium* superbulk

A best straight line is also constructed from two variables known as shear strength and basic density of laminated age group of 13 // 13 years old samples of 'Superbulk' species as stated in Figure 4.84. The R-value attained by the laminated-untreated products age group of 13 // 13 years old samples is 0.91. Therefore, it can be concluded that there is a robust relationship between those two variables, as shear strength will increase when basic density increases.

There should be a difference in compression results when comparing solid-untreated results and laminated-untreated products results. Roughly, it is introduced that there is an increment in the laminate-untreated results compared to that of solid-untreated results. The comparison is well presented in Figure 4.85. The differences in the mean of shear strength between solid and laminated age groups products of 7, 10, and 13 years old of 'Superbulk' timber species are 0.01 N/mm^2, 0.48 N/mm^2 and 0.54 N/mm^2, respectively. Analysing using 95% confidence intervals shows that mean shear parallel to grain in tangential direction solid untreated samples for all age groups have statistically significant differences, meanwhile,

for laminated sample products, only 7 // 7 years old with 10 // 10 years old have statistically significant differences, while 13 // 13 years old does not has a statistically significant difference. There are no statistically significant differences when solid and laminated untreated samples are compared within the age groups ($p > 0.05$).

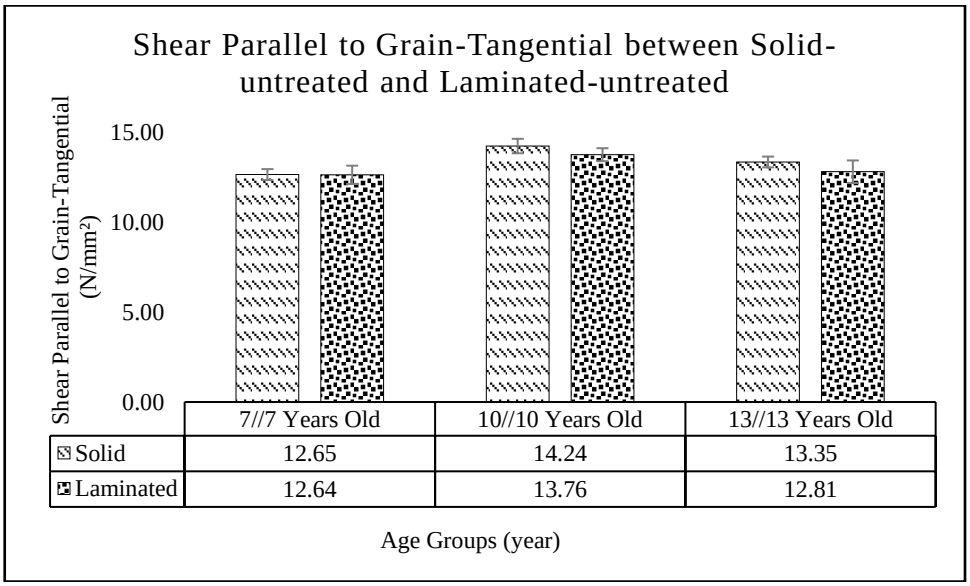


Figure 4.85: Comparison of Shear Parallel to Grain in Tangential Direction between Solid-untreated and Laminated-untreated Products of *Acacia mangium* superbulk

4.4.9 Shear Parallel to Grain in Tangential Direction by the Different Age Groups

The analysis of shear strength of the different age groups of the laminated specimen under untreated results is analysed with respect to age groups and basic density. As mentioned in subtopic 4.4.8, the shear test results are recorded only on one plane compared to solid tested on the radial plane and tangential plane. Figure 4.86 overview the results of the test sample.

i. Shear Parallel to Grain in Tangential Direction Respect to Age Groups

A total of 90 specimens with the size of 20 mm x 20 mm x 20 mm are prepared for

the shear strength test. All the recorded results are analysed via mean analysis, linear regression analysis, one-way ANOVA analysis, and Duncan Multiple Range Test (DMRT) analysis. All the analysis is run at a 95 % significant level. Thus, the following figure shows the mean shear strength versus age groups for different-year laminated-untreated products condition.

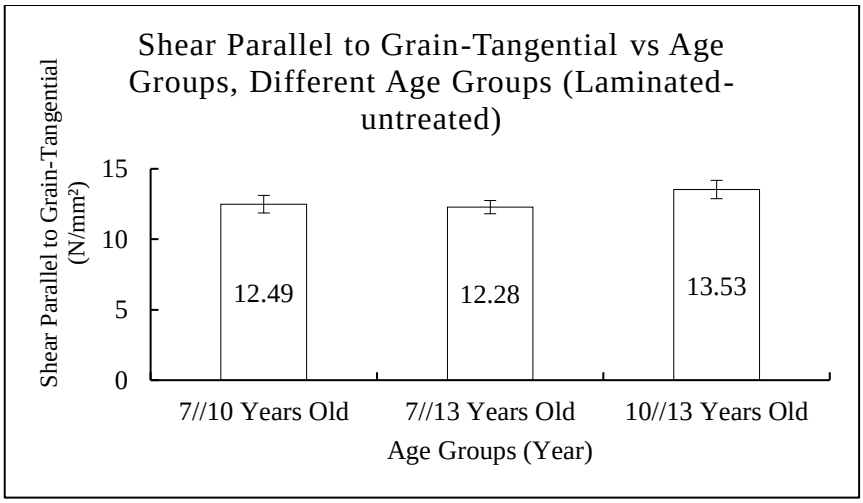


Figure 4.86: Shear Parallel to Grain in Tangential Direction Against Age Groups, Different Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk

Based on Figure 4.86, the highest mean with the coefficient of variation (CV) of shear strength gained is 13.53 N/mm^2 (13.45), which is from the laminated age group products of 10 with 13 year old samples. The second highest mean of shear strength is 12.49 N/mm^2 (13.99) which is attained by laminated age group products of 7 with 10 years old samples. Then, the lowest is 12.28 N/mm^2 (10.70), recorded by laminated age groups products of 7 with 13 years old samples. The results obtained from all age groups are acceptable since the CV values obtained are below 20 and are not dispersed far from the means. There is a statistically significant difference in mean shear parallel to grain only between the age groups of 10 // 13 years old samples with 7 // 13 years old samples at $p<0.05$,

and there is no statistically significant difference in mean shear parallel to grain for the age groups of 7 // 10 years old samples.

Table 4.69: One-way ANOVA of Shear Parallel to Grain in Tangential Direction by the Different Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk

	Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	27.14	2	13.57	5.03	0.01
Within Groups	234.78	87	2.70		
Total	261.92	89			

In order to determine whether there is any statistically significant difference or not among all the shear strength results, an analysis of variance one-way ANOVA is performed. The result from the analysis is tabulated in Table 4.69. Table 4.69 shows that the F distribution obtained is 5.03. Hence, the significant value attained is 0.01, clearly showing that all the shear strength results are significantly different since the significant value achieved from the ANOVA analysis is below 0.05.

The DMRT post-hoc test is run to determine whether there is any statistically significant difference or not among all three means of shear strength. The outcome of the DMRT analysis is presented in Table 4.70. Based on the table, the mean shear strength from the laminated age groups products of 10 with 13 years old samples has specific different among all the means since it is placed in a single class. Compared to the other two means, they share the same class because they are not having specific difference to each other.

Table 4.70: DMRT of Shear Parallel to Grain in Tangential Direction by the Different Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk

Age Groups	N	Subset for alpha = 0.05	
		1	2
7 // 13 years old	30	12.28	
7 // 10 years old	30	12.49	
10 // 13 years old	30		13.53
Sig.		0.62	1.00

*//:lamination

Table 4.71: Maximum Load of Shear Parallel to Grain in Tangential Direction by the Different Age Groups (Laminated-untreated Products) of *Acacia mangium* superbulk

Age Group (Year)	Maximum Load (kN)
7 // 10	5.10
7 // 13	5.03
10 // 13	5.57

*//:lamination

Table 4.71 indicates the maximum load of laminated-untreated products shear strength by different age groups. The highest maximum load recorded is 5.57 kN which is obtained by laminated age groups products of 10 // 13 years old samples, followed by 5.10 kN attained by laminated age groups products of 7 // 10 years old samples. While the lowest is 5.03 kN, gained by the laminated age groups products of 7 // 13 years old samples.

ii. Shear Parallel to Grain in Tangential Direction Respect to Basic Density

Figure 4.87, 4.88 and 4.89 are presented the linear regression analysis between shear parallel to grain against basic density for 7 // 10 years old, 7 // 13 years old and 10 // 13 years old, respectively. Based on those figures, the R-values obtained are 0.92, 0.91 and 0.91 for 7 // 10 years old, 7 // 13 years old and 10 // 13 years old, respectively. This is concluded that

there is very strong correlation between shear parallel to grain and basic density since the R-values recorded are approaching to 1.00.

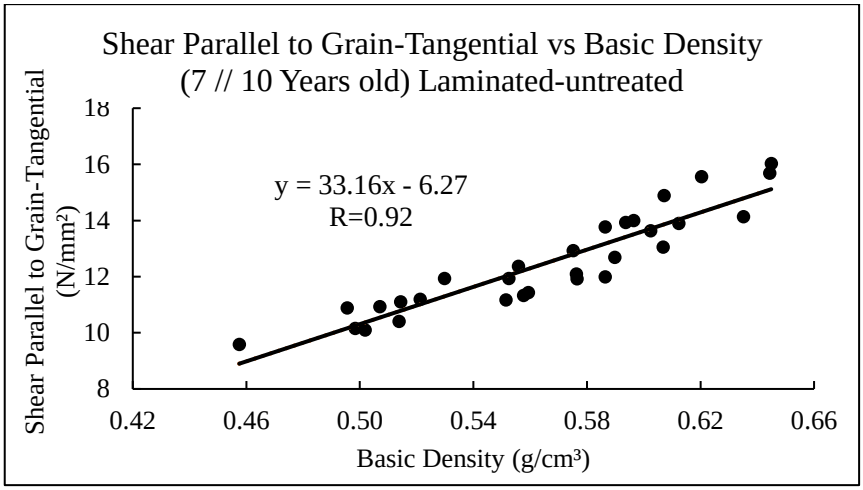


Figure 4.87: Shear Parallel to Grain in Tangential Direction Against Basic Density for 7 // 10 Years Old (Laminated-untreated Products) of *Acacia mangium* superbulk

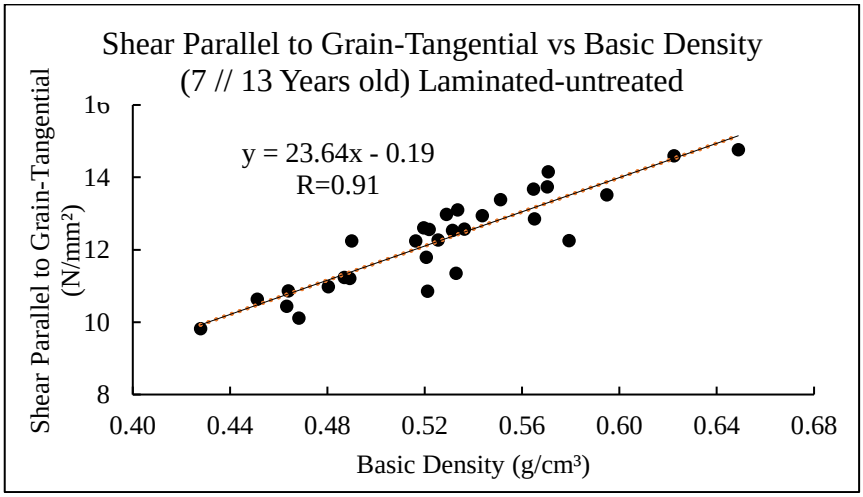


Figure 4.88: Shear Parallel to Grain in Tangential Direction Against Basic Density for 7 // 13 Years Old (Laminated-untreated Products) of *Acacia mangium* superbulk

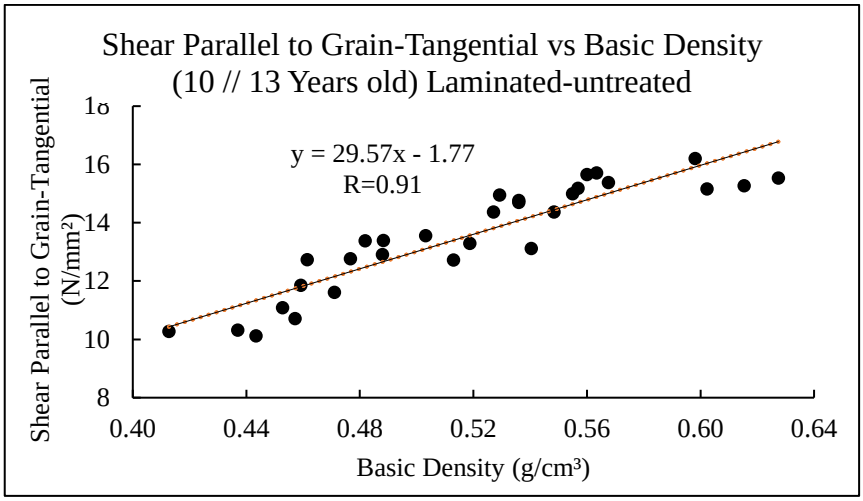


Figure 4.89: Shear Parallel to Grain in Tangential Direction Against Basic Density for 10 // 13 Years Old (Laminated-untreated Products) of *Acacia mangium* superbulk

4.5 Laminated-treated Products of *Acacia mangium* superbulk

The analysis of laminated-treated products samples is done on the 'Superbulk' samples with dimensions that are the same as the laminated-untreated products samples. Only the condition of the sample is different. The laminated sample products are treated with 10 % of *Copper Chrome Arsenic* (CCA) accordingly to the procedures and methods stated in Chapter 3. These treated samples also run for mechanical strength testing, such as MOR, MOE, compression parallel to grain and shear strength, which is the same as the previous untreated samples. Noted that, in parenthesis, is the coefficient of variance (CV) in percentage unit.

4.5.1 Moisture Content

According to ITTO's Testing Methods for Plantation Grown Tropical Timbers (Tan et al., 2010) and the JIS Z2101 (1994), the minimum moisture content for bonded wood is ≤ 14 %. Insufficiently dried veneers or lumbers may affect the bond performance of the products (Sahari & Inoue, 1996). Therefore, monitoring the moisture content before running

the tests is important.

4.5.2 Density

The density of the treated samples is obtained from the sample's initial weight divided by the sample's volume, which is stated in Chapter 3. The density of the sample is g/cm^3. The density of the treated samples was also investigated to evaluate the difference in density between before and after treatment.

i. Density by the Same Age Groups

There is a total of 270 samples laminated products by the same age groups involved in determining the density of the timber. Figure 4.90 is presented the density of laminated-treated products products by the same age groups of *Acacia mangium* superbulk for the age group of 7 // 7, 10 // 10 and 13 // 13 years old samples before the treatment process was applied.

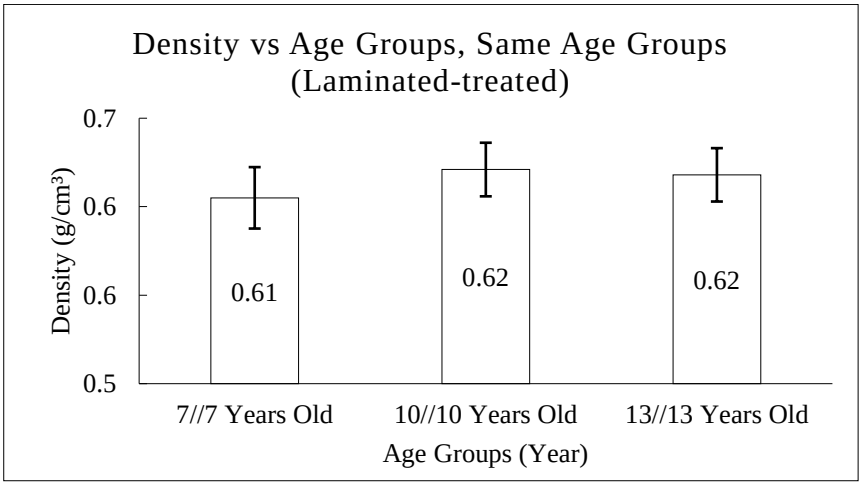


Figure 4.90: Density Before Treatment of the Same Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk

Based on Figure 4.90, the mean density with CV obtained by the laminated age group of 7 // 7 years old samples is 0.61 g/cm^3 (13.88). Meanwhile, the density of the laminated age group of 10 // 10 years old samples is 0.62 g/cm^3 (11.80). The laminated age group of 13 // 13 years old 'Superbulk' species attained a density of 0.62 g/cm^3 (11.81). All the means from the three age groups do not have any statistically significant difference from each other at $p<0.05$ confidence intervals. Furthermore, the coefficient of variances recorded is in the good range since their values are below 20. Thus, it is clarified that all the density results are distributed around the mean.

The analysis proceeded to a one-way ANOVA analysis of variance, whereby the analysis will determine whether there is any significantly different or not among all the density results by the laminated-treated products of the same age groups. The result from the ANOVA analysis is tabulated in Table 4.72. From the result of ANOVA analysis at 5 % probability, all the density results of laminated-treated products are significantly different since their significant value is 0.34 > 0.05.

Table 4.72: One-way ANOVA of Density Before Treatment by the Same Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk

	Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	0.01	2	0.01	1.08	0.34
Within Groups	1.58	267	0.01		
Total	1.59	269			

Table 4.73: DMRT of Density Before Treatment by the Same Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk

Age Groups	N	Subset for alpha = 0.05
		1
7 // 7 Years Old	90	0.61
13 // 13 Years Old	90	0.62
10 // 10 Years Old	90	0.62
Sig.		0.19

*//:lamination

Moreover, in order to determine which age group is varied in the mean of density, the Duncan Multiple Range Test (DMRT) is performed. The DMRT results are presented in Table 4.73. Based on the table, the DMRT analysis showed there is no specific difference in all three densities since their densities are close to each other. Clearly, the timber species' density should not differ for each age group.

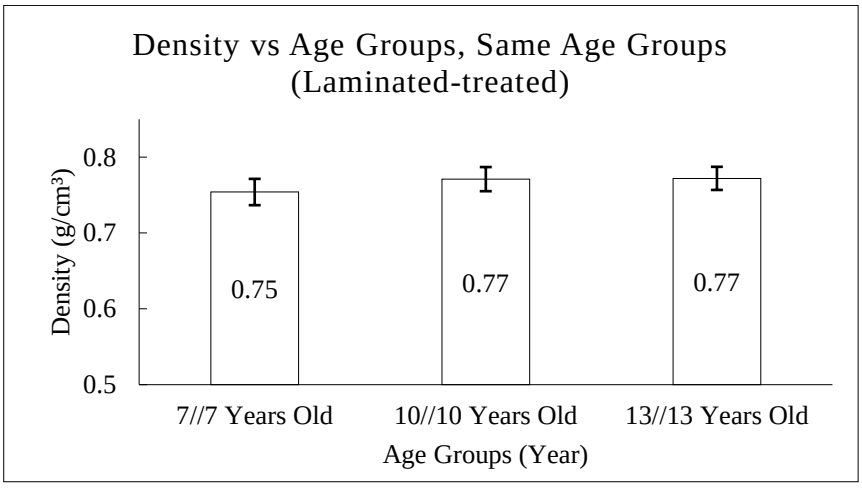


Figure 4.91: Density After Treatment of the Same Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk

Figure 4.91 indicates the density after laminated-treated products treatment by the same age groups. Based on Figure 4.91, the densities of laminated-treated products after treatment process are 0.75 g/cm^3 (11.14), 0.77 g/cm^3 (9.99) and 0.77 g/cm^3 (9.57) from

laminated products age group of 7 // 7, 10 // 10 and 13 // 13 years old samples respectively. There is also no statistically significant difference in the mean density among the three age groups after treatment. The coefficient of variance also shows the best values.

Table 4.74: One-way ANOVA of Density After Treatment by the Same Age Groups (Laminated-treated Products) of *Acacia mangium* Superbulk

	Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	0.02	2	0.01	1.53	0.22
Within Groups	1.64	267	0.01		
Total	1.66	269			

Table 4.75: DMRT of Density After Treatment by the Same Age Groups (Laminated-treated Products) of *Acacia mangium* Superbulk

Age Groups	**N**	**Subset for alpha = 0.05**
		1
7 // 7 Years Old	90	0.75
10 // 10 Years Old	90	0.77
13 // 13 Years Old	90	0.77
Sig.		0.14

*//:lamination

The one-way ANOVA analysis of variance is run in order to determine whether there is any statistically significant difference or not among all density results by the same age groups. The analysis indicated in Table 4.74 shows that there is no statistically significant difference among them since their significant value is greater than 0.05. The Duncan Multiple Range Test (Table 4.75) also presented that none among the three age groups having a specific difference to each other. Their densities are close to each other.

ii. Density by the Different Age Groups

There are 90 samples evaluated for density study from each of the laminated's pair that is made up of three age groups, which are age groups 7 // 10 years old, 7 // 13 years old and 10 // 13 years old of superbulk species. The mean density in g/cm^3 for these three laminated products age groups is presented in Figure 4.91. Based on Figure 4.92, the densities acquired after the preservative apply are 0.60 g/cm^3 (10.91), 0.61 g/cm^3 (11.33) and 0.64 g/cm^3 (9.24) from laminated products different age groups of 7 // 10 years old, 7 // 13 years old and 10 // 13 years old samples respectively. The error bars at $p<0.05$ confidence intervals showed there is a statistically significant difference of density from laminated age groups products of 10 // 13 years old compared to mean density from laminated age groups products of 7 // 10 years old and laminated age groups products of 7 // 13 years old samples. The coefficient of variance of the data that has been obtained also showed a good range.

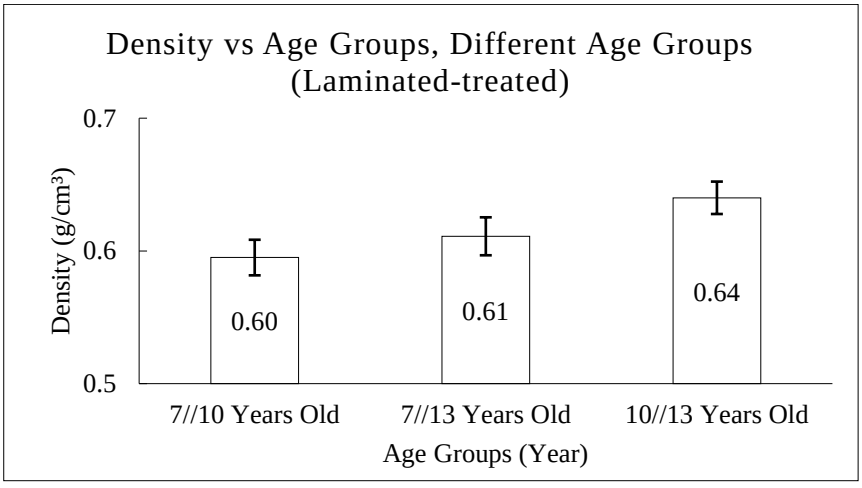


Figure 4.92: Density Before Treatment of the Different Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk

The analysis of one-way ANOVA is carried out to evaluate whether there is any statistically significant difference or not among the density results from all three laminated

products age groups . The result from the analysis is tabulated in Table 4.76. Based on Table 4.76, the statistically significant difference collected at the 5 % probability error level is 0.00, which means there is a statistically significant difference among the density results since the significant value obtained is below the probability error level.

Table 4.76: One-way ANOVA of Density Before Treatment by the Different Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk

	Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	0.09	2	0.05	10.98	0.00
Within Groups	1.11	267	0.00		
Total	1.20	269			

Table 4.77: DMRT of Density Before Treatment by the Different Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk

Age Groups	**N**	**Subset for alpha = 0.05**	
		1	**2**
7 // 10 Years Old	90	0.60	
7 // 13 Years Old	90	0.61	
10 // 13 Years Old	90		0.64
Sig.		0.10	1.00

*//:lamination

In order to establish which laminated pairing varied among the mean of density, the Duncan Multiple Range Test (DMRT) is run. The result of the analysis is tabulated in Table 4.77. Table 4.77 shows that the mean density from laminated age groups products of 10 // 13 years old samples has specific differences among the three laminated products age groups . Therefore, it has been placed in a single class. Compared to laminated age groups products of 7 // 10 years old and laminated age groups products of 7 // 13 years old samples that have

been grouped since their densities are close to each other, in other words, there is no difference between these two means of densities.

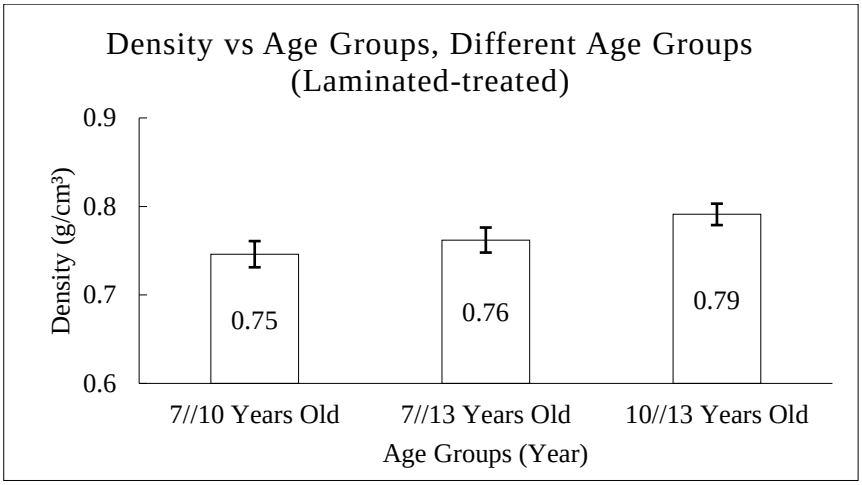


Figure 4.93: Density After Treatment of the Different Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk

Figure 4.93 is indicated the density after treatment of different age groups. The mean and CV density of laminated-treated products age groups of 7 // 10 years old samples is 0.75 g/cm^3 (9.61), whereas the density of laminated-treated products age groups of 7 // 13 years old samples is 0.76 g/cm^3 (8.99). Meanwhile, 0.79 g/cm^3 (7.41) is the density obtained by laminated-treated products age groups of 10 // 13 years old. The $p<0.05$ confidence intervals showed there is a statistically significant difference of density from laminated age groups products of 10 // 13 years old compared to mean density from laminated age groups products of 7 // 10 years old and laminated age groups products of 7 // 13 years old samples. The CVs also are in the acceptable range.

Table 4.78 and Table 4.79 presented the one-way ANOVA analysis and Duncan Multiple Range Test analysis, respectively. Based on Table 4.78, the density of all age groups is significantly different to each other since the significant value obtained is 0.000.

Besides that, the DMRT result showed the density of laminated-treated products age groups of 10 // 13 years old samples has specific difference among three age groups, and it is placed in single groups. Compared to the other two age groups, there are no specific difference among them, and their densities are just slightly different to each other.

Table 4.78: One-way ANOVA of Density After Treatment by the Different Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk

	Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	0.09	2	0.05	10.56	0.00
Within Groups	1.19	267	0.00		
Total	1.28	269			

Table 4.79: DMRT of Density After Treatment by the Different Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk

Age Groups	**N**	**Subset for alpha = 0.05**	
		1	**2**
7 // 10 Years Old	90	0.75	
7 // 13 Years Old	90	0.76	
10 // 13 Years Old	90		0.79
Sig.		0.10	1.00

*//:lamination

4.5.3 Static Bending by the Same Age Groups

The static bending test is derived from two outcomes: modulus of rupture (MOR) and modulus of elasticity (MOE). The analysis involved linear regression analysis between static bending and age groups and the relationship between static bending and density.

i. MOR and MOE Respect to Age Groups

A total of 30 samples of static bending laminated-treated products from each age group are tested, and the analysis done to the MOR and MOE results are presented in Figure 4.94 and Figure 4.95, respectively. Based on Figure 4.94, the MOR recorded from the laminated-treated products age group of 7 // 7 years old samples is 112.77 N/mm^2 (15.72). Meanwhile, the MOR from the laminated-treated products age group of 10 // 10 years old samples is 122. N/mm^2 (16.29). An amount of 115.51 N/mm^2 (21.51) is attained by the laminated-treated products age group of 13 // 13 years old. All the MOR means do not have any statistically significant difference at 95% confidence intervals. In parenthesis, the CVs collected are in the acceptable range since their values are not more than 30.

By referring to Figure 4.95, the highest MOE is obtained by the laminated-treated products age group of 10 // 10 years old, which is 15011 N/mm^2 (11.30), and followed by the laminated-treated products age groups of 13 // 13 years old, which is collected the MOE of 12795 N/mm^2 (15.38). Meanwhile, the lowest MOE is attained by the laminated-treated products age group of 7 // 7 years old, which only recorded a MOE of 12276 N/mm^2 (10.26). The mean of MOE from the age group of 10 // 10 years old samples is a statistically significant difference compared to the other two means at $p<0.05$ confidence intervals. The MOE results from the three age groups are not dispersed too much from the mean since their CVs are not more than 20 and are in the good range.

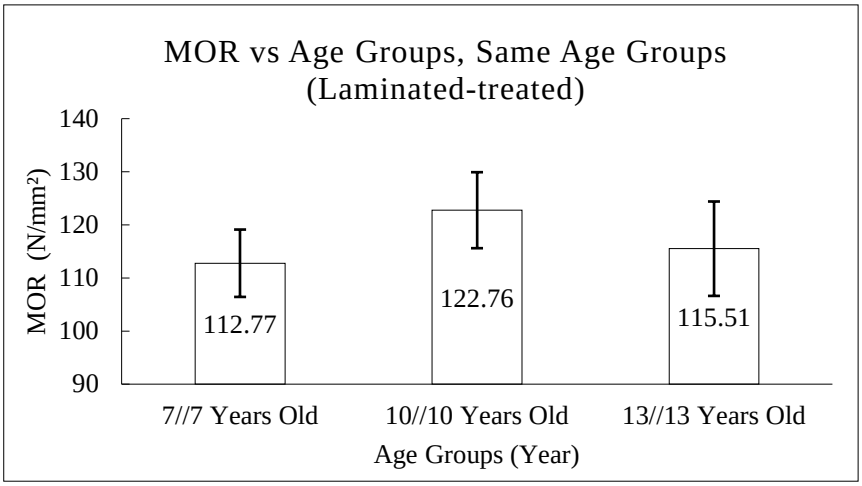


Figure 4.94: MOR Against Age Groups, Same Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk

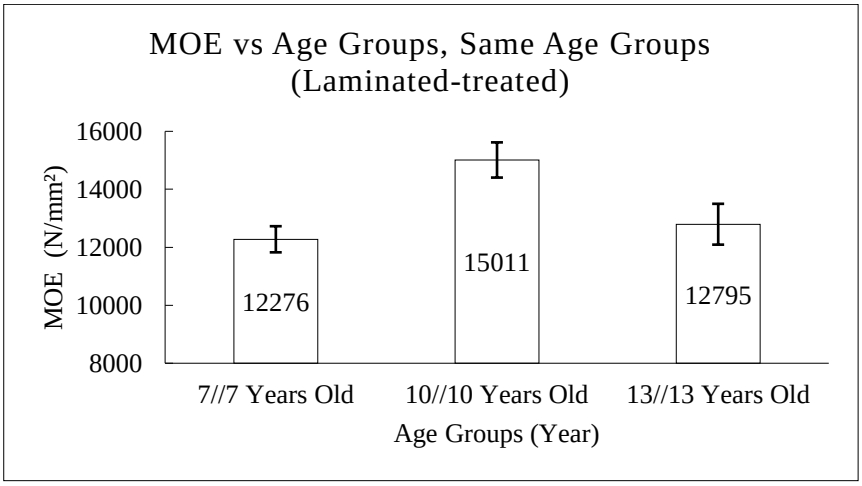


Figure 4.95: MOE Against Age Groups, Same Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk

Further analysis of the results of treatment in both modulus of rupture and modulus of elasticity is introduced with a one-way ANOVA analysis of variance. This analysis aims to determine the significant differences among the results of the static bending test. The one-way ANOVA test results number of samples (n = 90) with the probability of 0.05 is presented in Table 4.80. By referring to Table 4.80, one-way ANOVA analysis shows there is no statistically significant difference in MOR results since the significant value obtained is 0.17,

which is greater than 0.05. Meanwhile, one-way ANOVA analysis for MOE results presents a statistically significant difference among MOE results when the significant value obtained is less than 0.05.

The post-hoc test of DMRT is presented in Table 4.81 and Table 4.82. Based on Table 4.81, the DMRT analysis result shows there is no statistically significant difference since all MOR results from all age groups are set as one class. Meanwhile, DMRT analysis for MOE results from all age groups displayed MOE results of the laminated age group of 10 // 10 years old samples has specific difference compared to the other two age groups, as stated in Table 4.82.

Table 4.80: One-way ANOVA of MOR and MOE by the Same Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk

		Sum of Squares	df	Mean Square	F	Sig.
MOR	Between Groups	1601.98	2	800.99	1.80	0.17
	Within Groups	38622.66	87	433.94		
	Total	40224.64	89			
MOE	Between Groups	126558664.27	2	63279332.13	22.77	0.00
	Within Groups	241818517.83	87	2779523.19		
	Total	368377182.10	89			

Table 4.81: DMRT of MOR by the Same Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk

Age Groups	N	Subset for alpha = 0.05
		1
7 // 7 Years Old	30	112.77
13 // 13 Years Old	30	115.51
10 // 10 Years Old	30	122.76
Sig.		0.09

*//:lamination

Table 4.82: DMRT of MOE by the Same Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk

Age Groups	N	Subset for alpha = 0.05	
		1	2
7 // 7 Years Old	30	12276	
13 // 13 Years Old	30	12795	
10 // 10 Years Old	30		15011
Sig.		0.23	1.00

*//:lamination

In addition, the analysis also recorded the mean of maximum load obtained from each year of lamination. Table 4.83 shows the maximum load of static bending attained from all age groups in the treatment condition. Based on the table, the maximum load gained from a laminated-treated products age group of 7 // 7, 10 // 10, and 13 // 13 'Superbulk' timber species are 2.16 kN, 2.37 kN and 2.23 kN, respectively. In fact, this maximum load is the basis that led to producing the modulus of rupture and modulus of elasticity.

Table 4.83: Maximum Load of Static Bending by the Same Age Groups (Laminated-treated Products) of *Acacia mangium* Superbulk

Age Group (Year)	Maximum Load (kN)
7 // 7	2.16
10 // 10	2.37
13 // 13	2.23

*//:lamination

ii. **MOR and MOE Respect to Density**

Furthermore, the MOR and MOE of laminated-treated products products by the same age groups results are run for the linear regression analysis with respect to density after being treated. The following figures are presented the MOR and MOE versus density for the

laminated-treated products age group of 7 // 7 years old, 10 // 10 years old and 13 // 13 years old. From those analysis, the R-values obtained are in the range of 0.82 to 0.92. These R-values are concluded as strongly considerable correlation (Senthinathan, 2019).

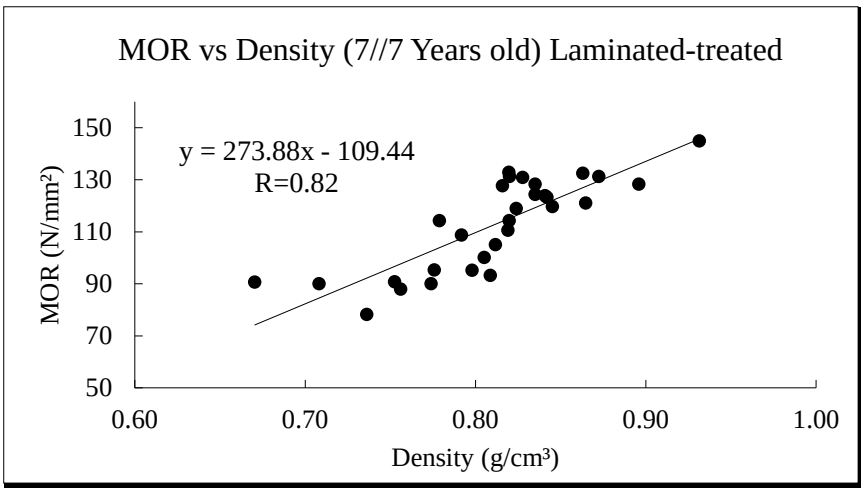


Figure 4.96: MOR Against Density for 7 // 7 Years Old (Laminated-treated Products) of *Acacia mangium* superbulk

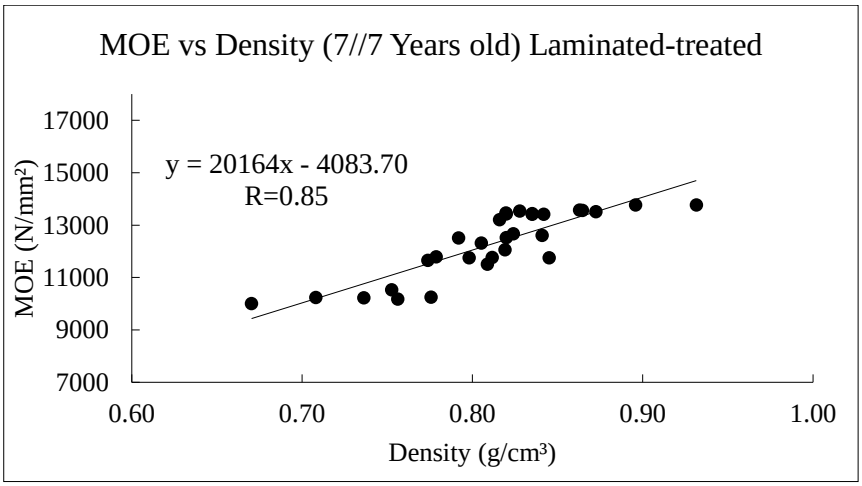


Figure 4.97: MOE Against Density for 7 // 7 Years Old (Laminated-treated Products) of *Acacia mangium* superbulk

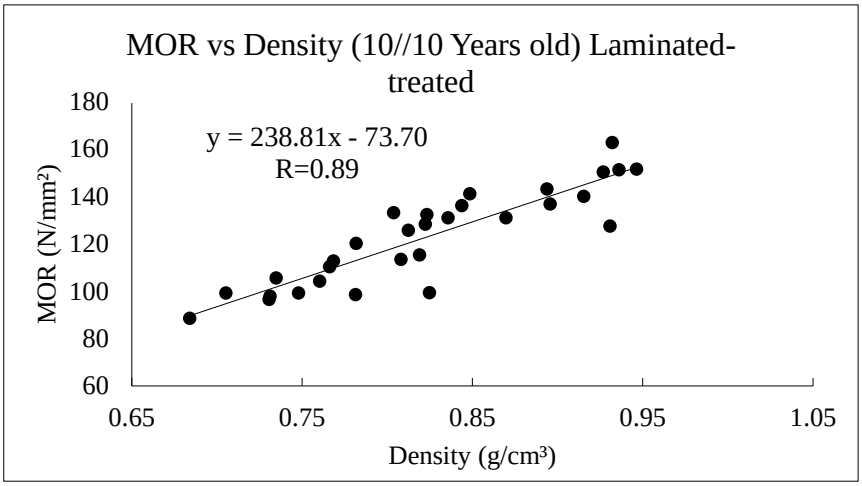


Figure 4.98: MOR Against Density for 10 // 10 Years Old (Laminated-treated Products) of *Acacia mangium* superbulk

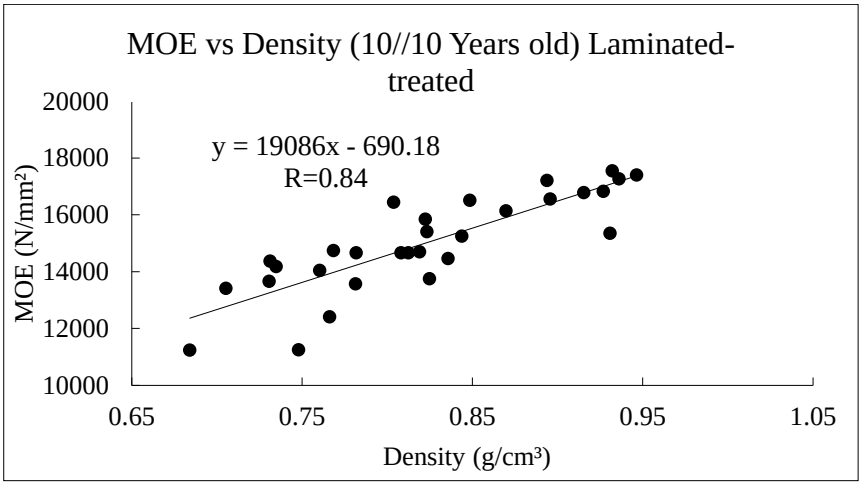


Figure 4.99: MOE Against Density for 10 // 10 Years Old (Laminated-treated Products) of *Acacia mangium* superbulk

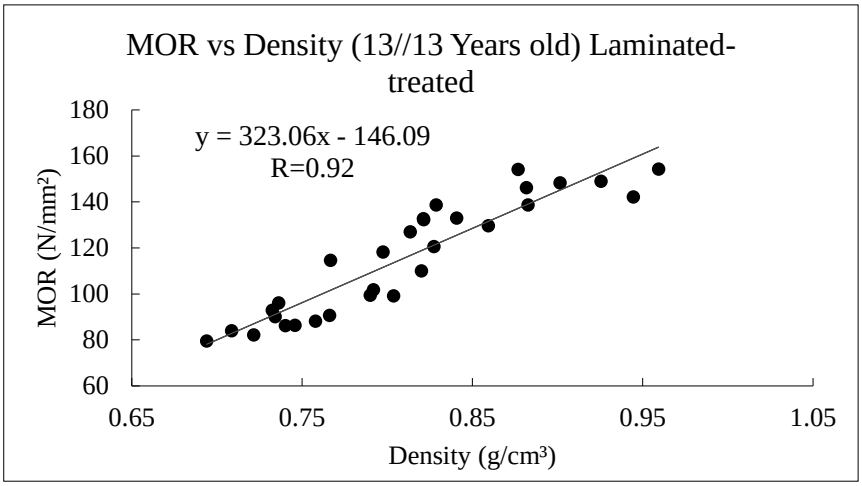


Figure 4.100: MOR Against Density for 13 // 13 Years Old (Laminated-treated Products) of *Acacia mangium* superbulk

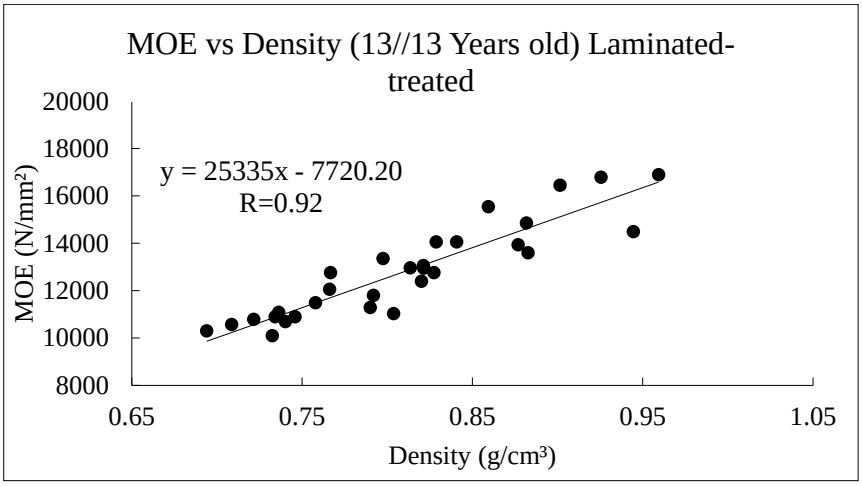


Figure 4.101: MOE Against Density for 10 // 10 Years Old (Laminated-treated Products) of *Acacia mangium* superbulk

In addition to that, it is necessary to evaluate the variance of MOR and MOE results in the untreated and treated specimens from the laminated form. The assessment of untreated and treated results is present in Figure 4.102 and Figure 4.103 for MOR and MOE of all age groups, respectively. Based on Figure 4.102, the highest age groups of laminated product of MOR for untreated and treated are the same, which is the highest from the age group of 10 // 10 years old and followed by 13 // 13 years old and lastly, 7 // 7 years old samples where

the increment in the treated samples compared to untreated samples. From laminated sample products age group of 7 // 7 years old, the increment of MOR denoted from untreated to treated is 13.36 N/mm^2, whereas the age group of 10 // 10 years old samples have 4.83 N/mm^2 differences between untreated and treated MOR's results. Lastly, 10.15 N/mm^2 is increased in the treated result age group of 13 // 13 years old of *Acacia mangium* superbulk. At 95% confidence intervals, only the mean MOR laminated product of 10 // 10 years old for untreated samples has a statistically significant difference compared to 7 // 7 years old and 13 // 13 years old. However, treated laminated products for all age groups had no statistically significant differences. Comparison between untreated and treated mean MOR from each age group shows that only laminated product age groups 7 // 7 years old had statistically significant difference.

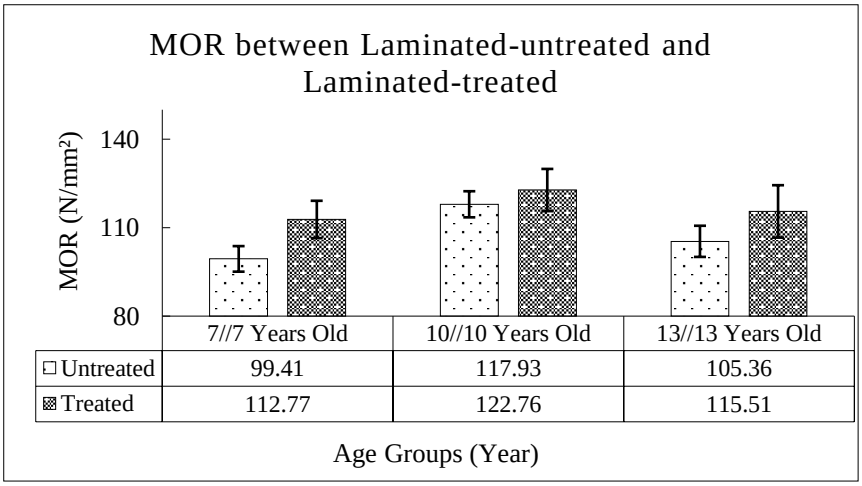


Figure 4.102: Comparison of MOR between Laminated-untreated Products and Laminated-treated Products by Same Age Groups of *Acacia mangium* superbulk

Besides that, the comparison of MOE results for untreated and treated are detailed in Figure 4.103. It is introduced that all age groups have addition in treated MOE values compared to MOE values from the untreated condition. The higher mean recorded is 192

N/mm^2 from the age group of 13//13 years old, followed by 21 N/mm^2 from the age group of 10 // 10 years old and the lowest 254 N/mm^2 from the age group of 7 // 7 years old of 'Superbulk' species. At 95% confidence intervals, only the mean MOE and MOR laminated product of 10 // 10 years old for untreated and treated samples had a statistically significant difference compared to 7 // 7 years old and 13 // 13 years old. Comparison between untreated and treated mean MOE from each age group shows no statistically significant difference.

Thus, it is proved that the treatment process applied to timber samples positively impacts the strength properties of timber. Further discussion on that impact will report in a subsequent chapter.

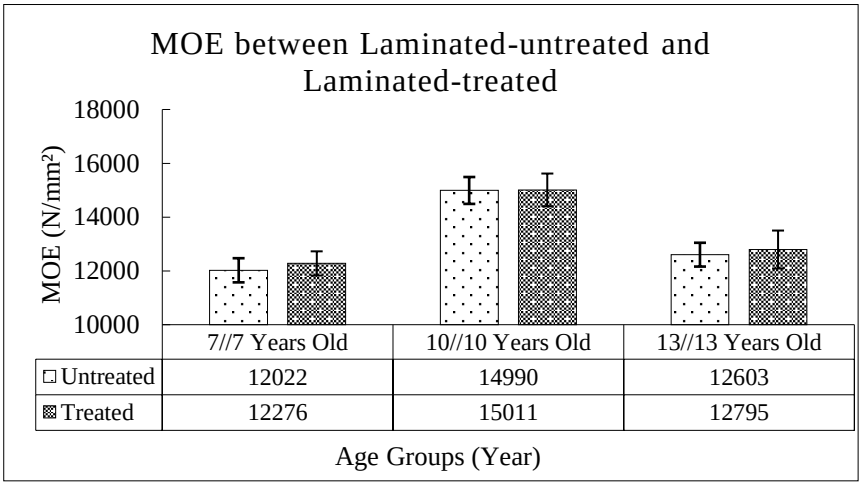


Figure 4.103: Comparison of MOE between Laminated-untreated Products and Laminated-treated Products by Same Age Groups of *Acacia mangium* superbulk

On the other hand, MOR and MOE in solid-treated and laminated-treated products are illustrated in Figures 4.104 and 4.105. These comparisons interpreted either addition or reduction in both MOR and MOE when related to laminated specimens and solid specimens in the same condition. Based on Figure 4.104, the treatability results of MOR remarked an increment for all age groups from solid to laminated specimens. The age group of 10 // 10

years old of *Acacia mangium* superbulk denoted the differences of 4.00 N/mm^2, followed by 13 // 13 years old that recorded an increment of 16.53 N/mm^2, lastly, 7 // 7 years old's 'Superbulk' species resulted in the addition of 15.63 N/mm^2 from solid to laminated testing.

Besides that, the same analysis on comparison in treatment results of solid and laminated was also done to the MOE with respect to all age groups. At 95% confidence intervals, only the mean MOR treated solid product of 10 // 10 years old samples had a statistically significant difference compared to 7 // 7 years old and 13 // 13 years old. However there is no statistically significant difference for laminted product for all age groups. Comparison between solid and laminated products of mean MOR from each age group shows only the age groups of 7 // 7 years old and 13 // 13 years old had statistically significant difference.

Figure 4.105 indicates the comparison of MOE results between solid-treated and laminated-treated products. By referring to the respective figure, it is specified that there is a reduction of MOE in laminated testing results compared to solid testing results. The MOE for age groups 7, 10, and 13 years old samples are dropped to 442 N/mm^2, 9 N/mm^2, and 129 N/mm^2, respectively. At 95% confidence intervals, only mean MOE treated solid and laminated product of 10 // 10 years old samples had a statistically significant difference compared to 7 // 7 years old and 13 // 13 years old. Comparison between solid and laminated products from each age group shows no statistically significant difference.

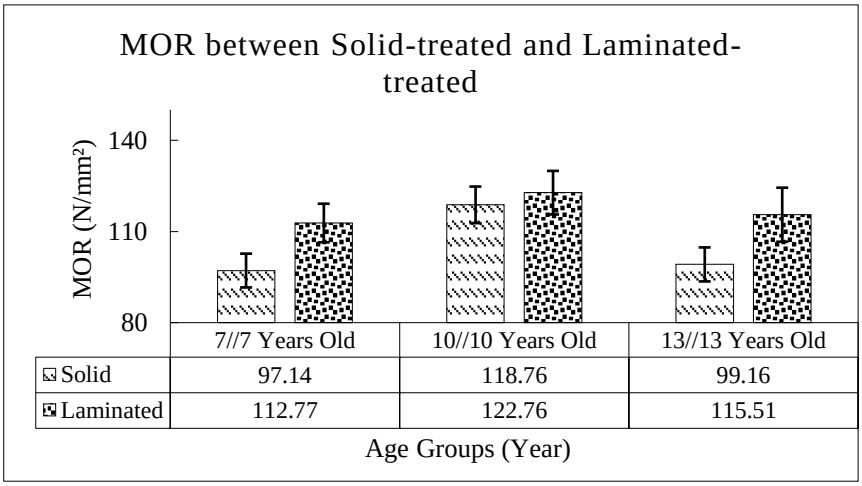


Figure 4.104: Comparison of MOR between Solid-treated and Laminated-treated Products of *Acacia mangium* superbulk

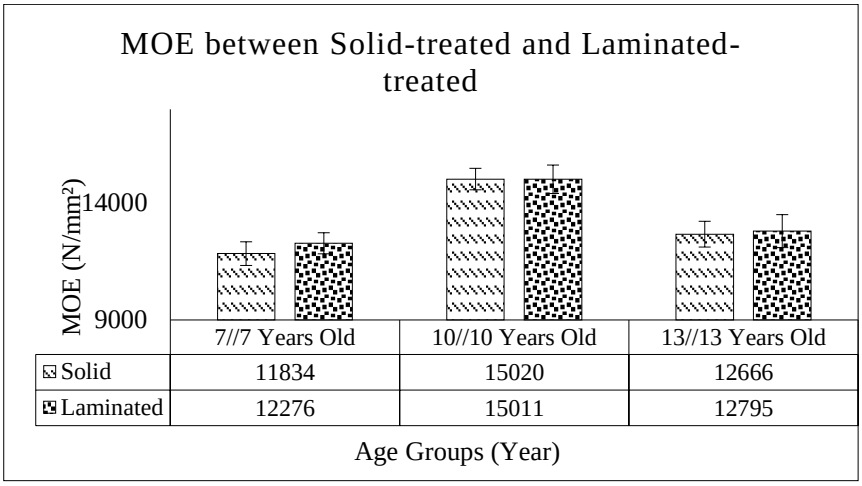


Figure 4.105: Comparison of MOE between Solid-treated and Laminated-treated Products of *Acacia mangium* superbulk

4.5.4 Static Bending by the Different Age Groups

An analysis of static bending of a different year-treated specimen is referred to as MOR and MOE with respect to group and density.

i. MOR and MOE Respect to Age Groups

A laminated static bending test was prepared in treatment conditions by different age groups. The same process and procedures are carried out for this testing. The mean of MOR

and MOE results at 95 % significant level accomplished from the testing is analysed with respect to age groups, which are laminated age groups products of 7 with 10 years old, 7 with 13 years old, and 10 with13 years old of *Acacia mangium* superbulk. The following Figure 4.106 and Figure 4.107 represent MOR and MOE against age groups based on the laminated-treated products samples at different age groups.

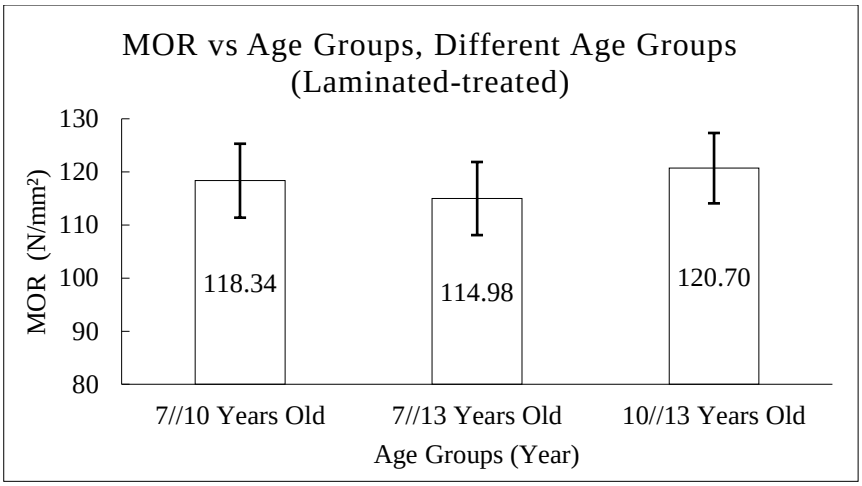


Figure 4.106: MOR Against Age Groups, Different Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk

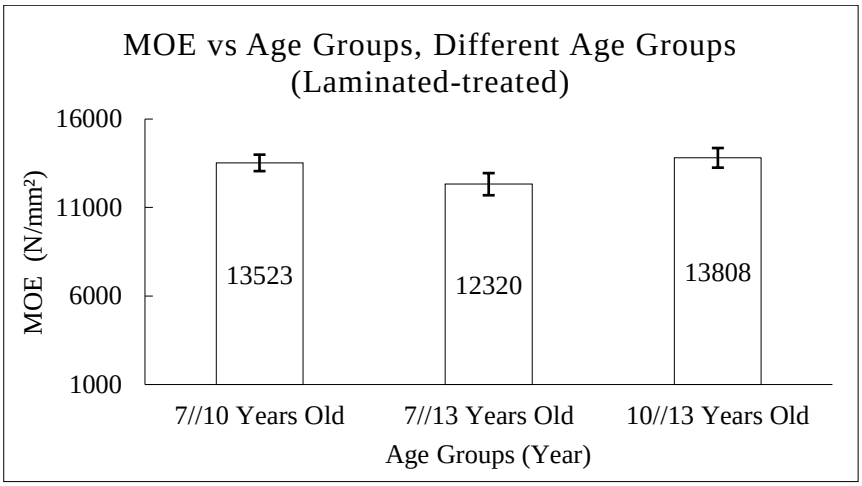


Figure 4.107: MOE Against Age Groups, Different Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk

Based on Figure 4.106, the highest mean with CV of MOR for laminated-treated products products by different age groups obtained is 120.70 N/mm^2 (15.34), which is from laminated age groups products of 10 // 13 years old, followed by 118.34 N/mm^2 (16.44) which is from age groups of 7 // 10 years old, and the lowest is 114.98 N/mm^2 (16.73) resulted from laminated age groups products of 7 // 13 years old. The error bars show there is no statistically significant difference between all of the means by all three age groups ($p<0.05$) of MOR. Meanwhile, Figure 4.107 shows the mean of MOE against age groups. The highest MOE recorded is 13808 N/mm^2 (11.24) which is gained by the age groups of 10 // 13 years old compared to laminated age groups products of 7 // 13 years old samples, which marked the lowest mean of MOE, 12320 N/mm^2 (14.19), while, laminated products of 7 // 10 years old samples listed out the mean MOE about 13523 N/mm^2 (9.61). At $p<0.05$, there is a statistically significant difference in mean MOE from laminated age groups products of 7 // 13 years old compared to mean MOE from laminated age groups products of 7 // 10 years old and laminated age groups products of 10 // 13 years old samples. Both MOR and MOE results for all laminated pairing are good since their CV are just dispersed around the mean.

Table 4.84: One-way ANOVA of MOR and MOE by the Different Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk

		Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
MOR	Between Groups	495.68	2	247.84	0.68	0.51
	Within Groups	31662.48	87	363.94		
	Total	32158.15	89			
MOE	Between Groups	37416455.40	2	18708227.70	7.85	0.00
	Within Groups	207425422.45	87	2486200.26		
	Total	244841877.85	89			

The MOR's and MOE's results from laminated products-treated products by different age groups are added to the one-way ANOVA analysis of variance as stated in Table 4.84. Based on Table 4.84, the F distributions derived from two mean squares for MOR and MOE are 0.68 and 7.85, respectively. Thus, the significant value gained by MOR is 0.51, and MOE is 0.00. From this analysis, there is a statistically significant difference among the MOE's results since the significant value is below 0.05, whereas the MOR's results did not have any statistically significant difference when the significant value resulted from the ANOVA analysis is 0.51, which is higher than the probability level.

Table 4.85: DMRT of MOR by the Different Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk

Age Groups	**N**	**Subset for alpha = 0.05**
		1
7 // 13 Years Old	30	114.98
7 // 10 Years Old	30	118.34
10 // 13 Years Old	30	120.70
Sig.		0.28

*//:lamination

Table 4.86: DMRT of MOE by the Different Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk

Age Groups	**N**	**Subset for alpha = 0.05**	
		1	**2**
7 // 13 Years Old	30	12320	
7 // 10 Years Old	30		13523
10 // 13 Years Old	30		13808
Sig.		1.00	0.48

*//:lamination

In order to determine whether there is any statistically significant difference or not

among the mean of MOR, the Duncan Multiple Range Post-hoc Test is performed. The DMRT test results for the mean of MOR are presented in Table 4.85. From Table 4.85, it is mentioned that there is no specific difference among the three means since there are classified as the same group. In other words, the means of MOR for all laminated products age groups are close to each other. The same procedure of DMRT analysis is run for the MOE's mean results, which is indicated in Table 4.86. Differing from MORs, the DMRT results for MOE is categorised into two classes. Obviously, the MOE's mean of laminated age groups products of 7 // 13 years old samples has specific different among all three means. Means of MOE for laminated age groups products of 7 // 10 years old and 10 // 13 years old samples are placed into the same class as their results are not too distinct.

The maximum load of laminated-treated products products by different age groups are listed in Table 4.87. In Table 4.87, the greatest maximum load is obtained by laminated age groups products of 10 with 13 years old samples, which is 2.32 kN. Meanwhile, the lowest is attained by age groups of 7 with 13 years old samples, which gained a maximum load of 2.22 kN. A maximum load of 2.29 kN is recorded from laminated age groups products of 7 with 10 years old samples.

Table 4.87: Maximum Load of Static Bending by the Different Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk

Age Group (Year)	Maximum Load (kN)
7 // 10	2.29
7 // 13	2.22
10 // 13	2.32

*//:lamination

ii. MOR and MOE Respect to Density

The data of MOR and MOE from laminated products-treated products by different age groups are further analysed using the linear regression analysis. The following figures are represented the linear regression analysis of MOR and MOE against density for laminated-treated products 7 // 10 years old, 7 // 13 years old and 10 // 13 years old. The R-values from all analysis are in the range of 0.76 to 0.89. Thus, the R-values revealed that there are strong correlation between MOR or MOE and density since the values are more than 0.70 which is nearly to 1.00.

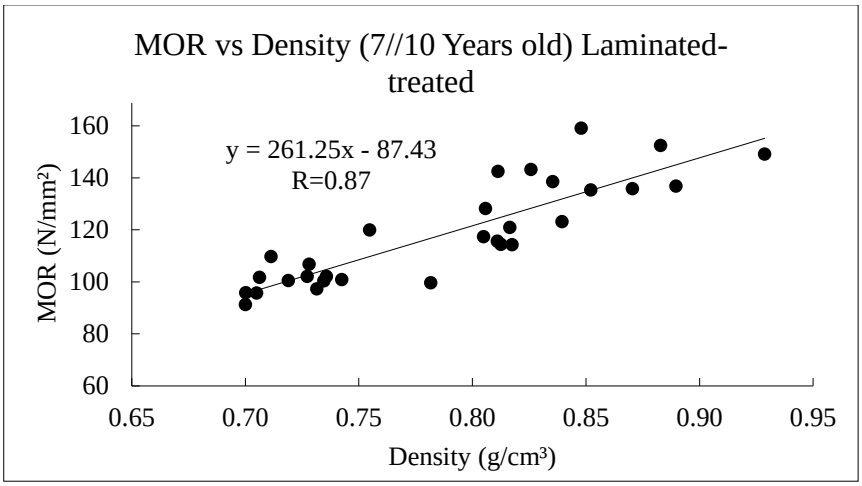


Figure 4.108: MOR Against Density for 7 // 10 Years Old (Laminated-treated Products) of *Acacia mangium* superbulk

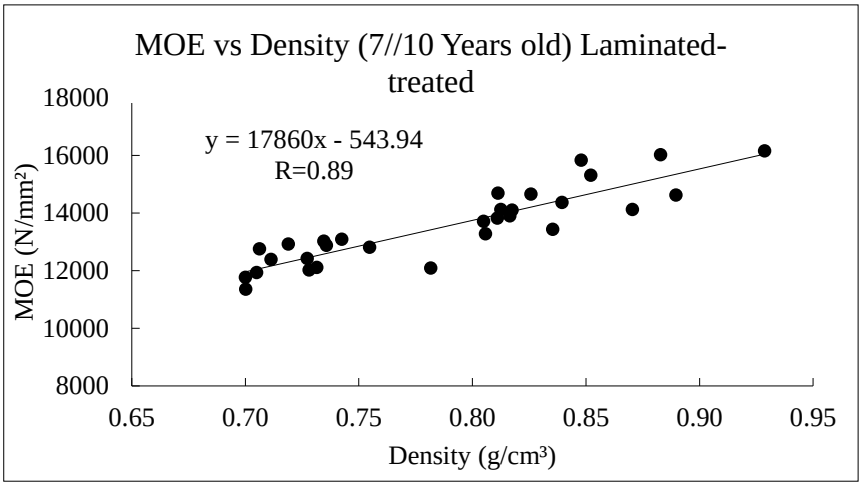


Figure 4.109: MOE Against Density for 7 // 10 Years Old (Laminated-treated Products) of *Acacia mangium* superbulk

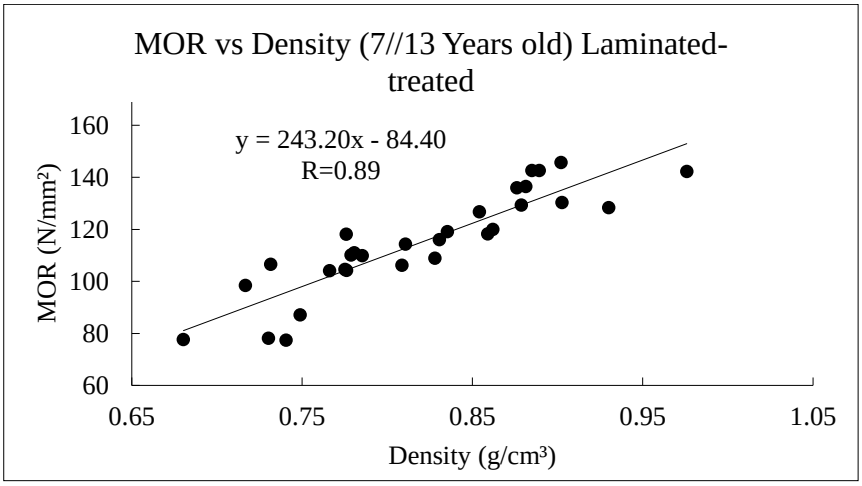


Figure 4.110: MOR Against Density for 7 // 13 Years Old (Laminated-treated Products) of *Acacia mangium* superbulk

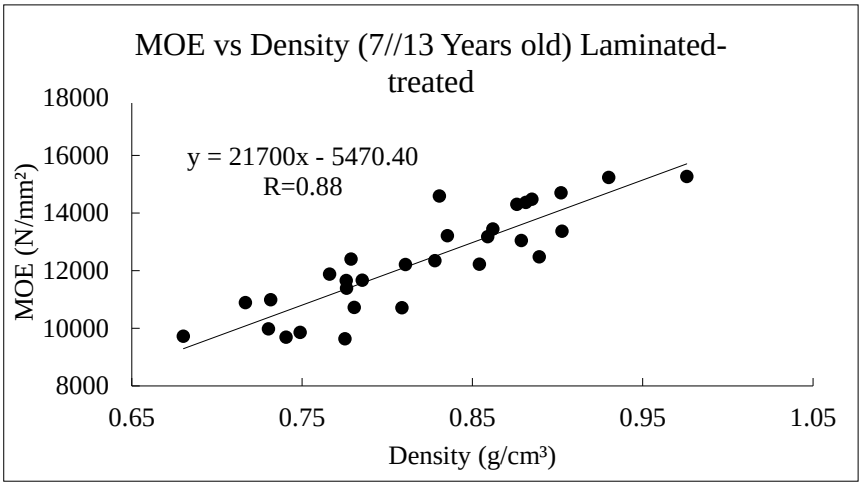


Figure 4.111: MOE Against Density for 7 // 13 Years Old (Laminated-treated Products) of *Acacia mangium* superbulk

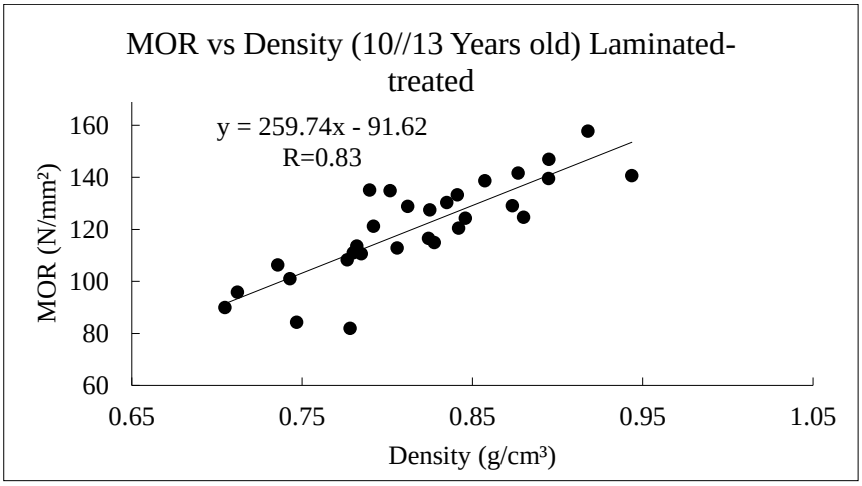


Figure 4.112: MOR Against Density for 10 // 13 Years Old (Laminated-treated Products) of *Acacia mangium* superbulk

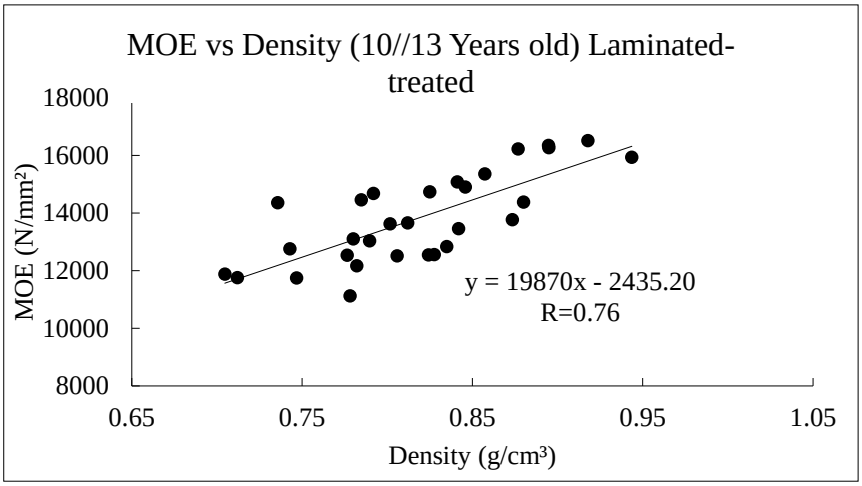


Figure 4.113: MOE Against Density for 10 // 13 Years Old (Laminated-treated Products) of *Acacia mangium* superbulk

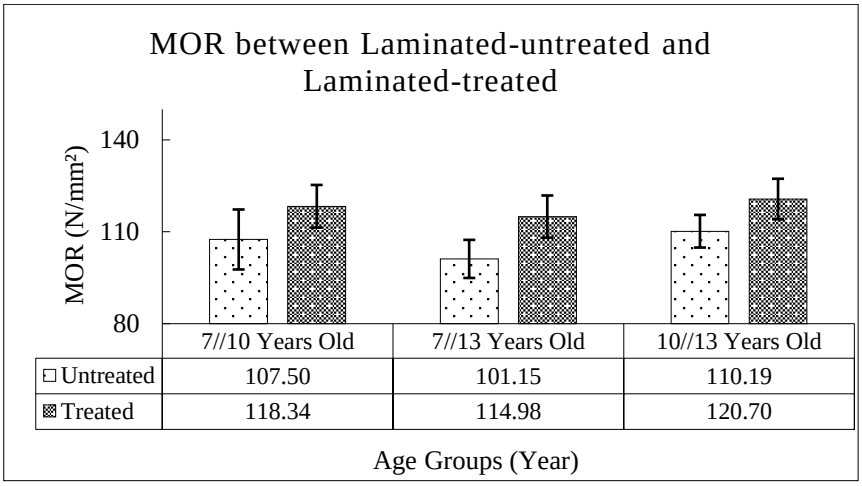


Figure 4.114: Comparison of MOR between Laminated-untreated Products and Laminated-treated Products by Different Age Groups of *Acacia mangium* superbulk

It is essential to identify the differences between MOR and MOE when comparing laminated-untreated products and laminated-treated products. Figure 4.114 is represented the comparison of MOR between laminated-untreated products and laminated-treated products results. As stated in the chart, the laminated age groups products of 7 with 10 years old samples recorded the rise in MOR of about 10.84 N/mm^2, meanwhile, MOR for the laminated age groups products of 7 and 13 years old samples marked the differences of 13.83

N/mm^2 from laminated products-untreated to laminated-treated products. The laminated age groups products of 10 with 13 years old samples grow about 10.51 N/mm^2 from untreated and treated results.

In MOE, results from laminated products-untreated and laminated-treated products are shown in Figure 4.115. Based on Figure 4.115, the MOE of laminated 7 with 10 years old samples increases by about 18 N/mm^2, whereas 32 N/mm^2 rises in MOE's laminated 7 with13 years old samples from untreated to treated results. Besides that, MOE results from laminated age groups products of 10 with 13 years old samples recorded differences of about 39 N/mm^2 from laminated products-untreated to laminated-treated products results.

At 95% confidence intervals, Figure 4.114 shows no statistically significant difference in mean MOR for untreated and treated for all laminated products. Comparison between untreated and treated from each age group of laminated products shows no statistically significant difference. Figure 4.115 meanwhile shows that only laminated products of 7 // 13 years old with 10 // 13 years old had statistically significant differences for mean MOE untreated samples. Whereas the mean MOE-treated samples show only laminated products of 7 // 13 years old had a statistically significant difference. There are no statistically significant differences in comparison between untreated and treated from each age group of laminated products.

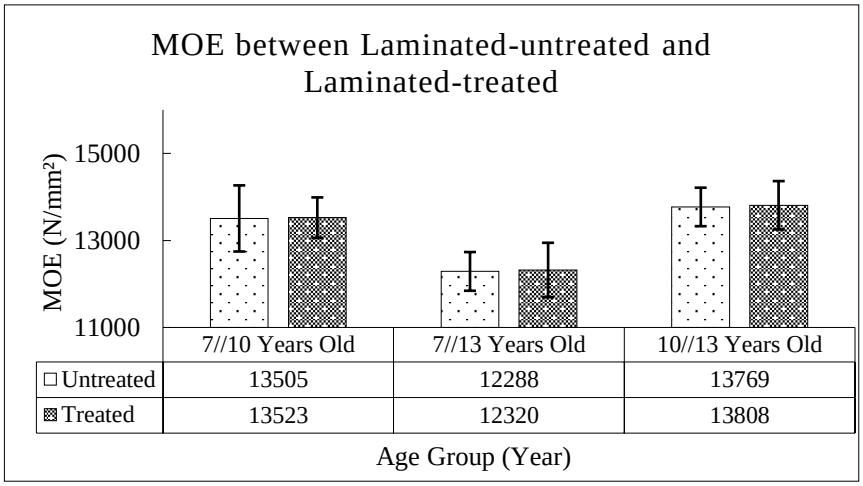


Figure 4.115: Comparison of MOE between Laminated-untreated Products and Laminated-treated Products by Different Age Groups of *Acacia mangium* superbulk

4.5.5 Compression Parallel to Grain by the Same Age Groups

An analysis of compression parallel to grain of laminated-treated products products by the same age groups specimen is run for compression parallel to grain with respect to age groups and also with respect to density.

i. Compression Parallel to Grain Respect to Age Groups

A total of 90 laminated specimens with a finishing size of 20 mm x 20 mm x 60 mm went through the treatment process using a 10 % *Copper Chrome Arsenic* (CCA) timber preservative solution. After all the treatment processes are done, the laminated compression parallel to grain test takes place according to a small clear test procedure by ITTO's Testing Methods for Plantation Grown Tropical Timbers (Tan et al., 2010). Note that the test procedure is similar to the small clear test (solid specimen), although the test specimen is prepared as a laminated specimen.

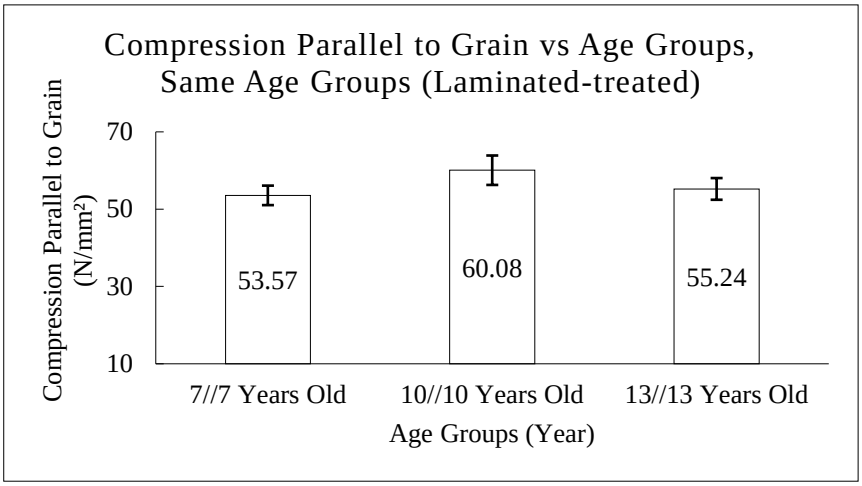


Figure 4.116: Compression Parallel to Grain Against Age Groups, Same Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk

Firstly, the analysis specified a mean and coefficient of variance (CV) of the compressive strength obtained by all laminated products age groups , and this is presented in Figure 4.116. From Figure 4.116, the highest mean of compressive strength is gained by the laminated age group of 10 // 10 years old samples, whose value was 60.08 N/mm^2 (17.71). Meanwhile, the lowest mean of compressive strength is recorded by the laminated age group of 7 // 7 years old samples, whose amount gained was 53.57 N/mm^2 (13.06). In the middle of those age groups is 55.24 N/mm^2 (14.21), which was attained by laminated age group of 13 // 13 years old samples of 'Superbulk'. There is no statistically significant difference in mean compression parallel to grain for all age groups at 95% confidence intervals.

In order to determine whether there is any statistically significant difference or not in all results of compression strength, a one-way ANOVA analysis of variance is performed. With a probability level of 0.05, the result of 90 samples is presented in Table 4.88. From Table 4.88, it is shown that the compression strength results for all samples of all age groups

are significant to each other since the significant value obtained was 0.013, which is below than significant level.

Table 4.88: One-way ANOVA of Compression Parallel to Grain by the Same Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk

	Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	685.18	2	342.59	4.58	0.01
Within Groups	6507.67	87	74.80		
Total	7192.86	89			

Furthermore, a Duncan Multiple Range Test is selected to determine which age groups vary in the mean of compressive strength. These results are presented in Table 4.89. Based on Table 4.89, the post-hoc DMRT recorded that the mean from the age group of laminated 10 //10 years has specific differences compared to the other two age groups. Thus, mean compression strength from the 10 // 10 age group of 'Superbulk' is placed in the single class. Meanwhile, the laminated age group of 7 // 7 and laminated age group of 13 // 13 years old samples shared the same class since their mean of compression strength does not have specific differences to each other.

Table 4.89: DMRT of Compression Parallel to Grain by the Same Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk

Age Groups	**N**	**Subset for alpha = 0.05**	
		1	**2**
7 // 7 years old	30	53.58	
13 // 13 years old	30	55.24	
10 // 10 years old	30		60.08
Sig.		0.46	1.00

*//:lamination

Meanwhile, Table 4.90 indicates a maximum load obtained by compression test in treatment conditions for all age groups. As mentioned in the formula, this maximum load is used to attain compression strength. The maximum load in kN recorded by age group of 7 // 7, 10 // 10 and 13 // 13 years old samples in laminated treated conditions are 2.19 kN, 2.42 kN and 2.25 kN, respectively. In conclusion, the compression strength results from laminated products treatment are better than those from laminated products untreated and higher than solid-treated results. However, the age group of 10 // 10 years old samples is still the best in the strength properties, followed by 13 // 13 years old samples, and the lowest in the age group of 7 // 7 years old.

Table 4.90: Maximum Load of Compression Parallel to Grain by the Same Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk

Age Group (Year)	Maximum Load (kN)
7 // 7	2.19
10 // 10	2.42
13 // 13	2.25

*//:lamination

ii. Compression Parallel to Grain Respect to Density

A further analysis of compression parallel to grain laminates treated by the same age groups is prepared for linear regression analysis with respect to density. This analysis is conducted in order to identify the relationship between compression strength and density and whether there is any correlation between them or not. The strong correlation is always shown in the best regression value (R-value), which approaches 1.00.

From the analysis shown in the Figure 4.117, 4.118 and 4.119, the R-values obtained are 0.87, 0.89 and 0.81 for shear parallel to grain against the density of 7 // 7 years old, 10 //

10 years old and 13 // 13 years old, respectively. It is concluded that there is a strong correlation between shear parallel to grain against density of all age groups.

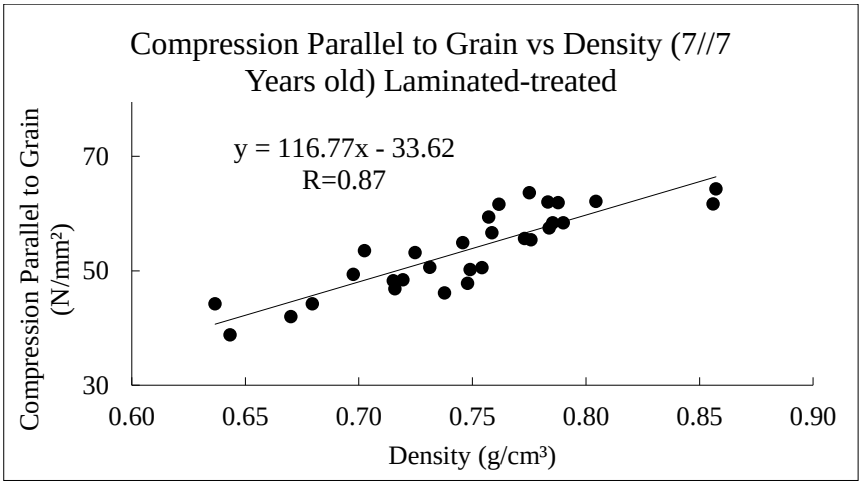


Figure 4.117: Compression Parallel to Grain Against Density for 7 // 7 Years Old (Laminated-treated Products) of *Acacia mangium* superbulk

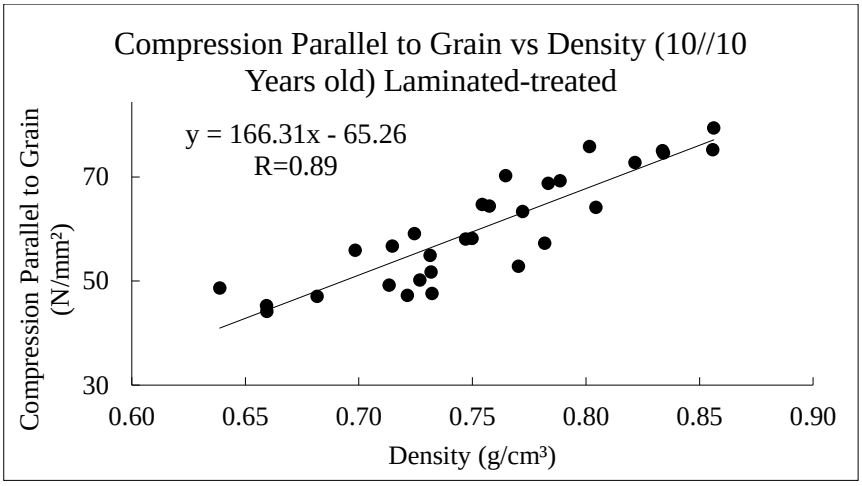


Figure 4.118: Compression Parallel to Grain Against Density for 10 // 10 Years Old (Laminated-treated Products) of *Acacia mangium* superbulk

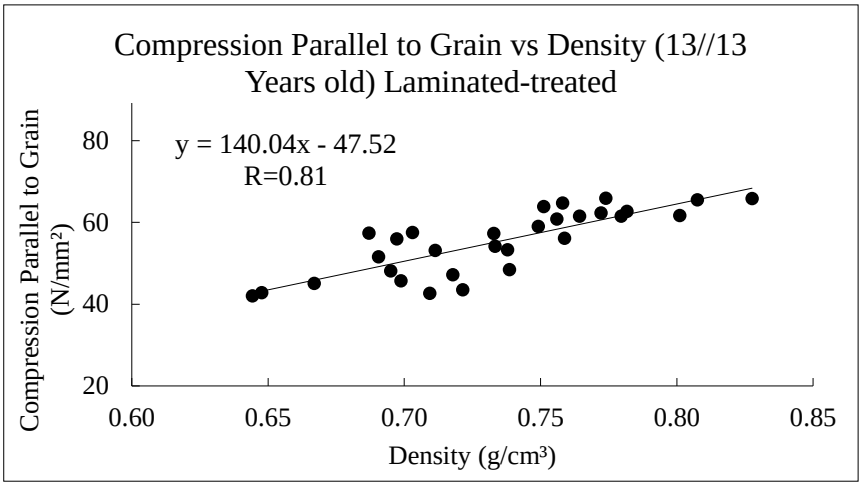


Figure 4.119: Compression Parallel to Grain Against Density for 13 // 13 Years Old (Laminated-treated Products) of *Acacia mangium* superbulk

It is necessary to analyse the comparison of mean compression strength results between laminated untreated and laminated treated in order to introduce which one is better in compressive characteristics. This comparison is exhibited in Figure 4.120. Figure 4.120 clearly shows that there is an increment in the mean of treated compression strength compared to that of untreated compression strength, although these two are from laminated products form. The arrangement of the mean compression strength from highest to lowest with respect to age groups is still the same, but the values in their strength are increased. The increments recorded from the laminated age group of 7 // 7, 10 // 10, and 13 // 13 years old samples from untreated to treated are 1.01 N/mm^2, 0.45 N/mm^2 and 0.63 N/mm^{2,} respectively. At 95% confidence intervals, Figure 4.120 shows that only the age groups of 7 // 7 years old with 10 // 10 years old untreated laminated products had no statistically significant differences in mean compression parallel to grain. Meanwhile, for treated laminated products, there are no statistically significant differences. Comparison between untreated and treated from each age group of laminated products alsoshows no statistically significant difference.

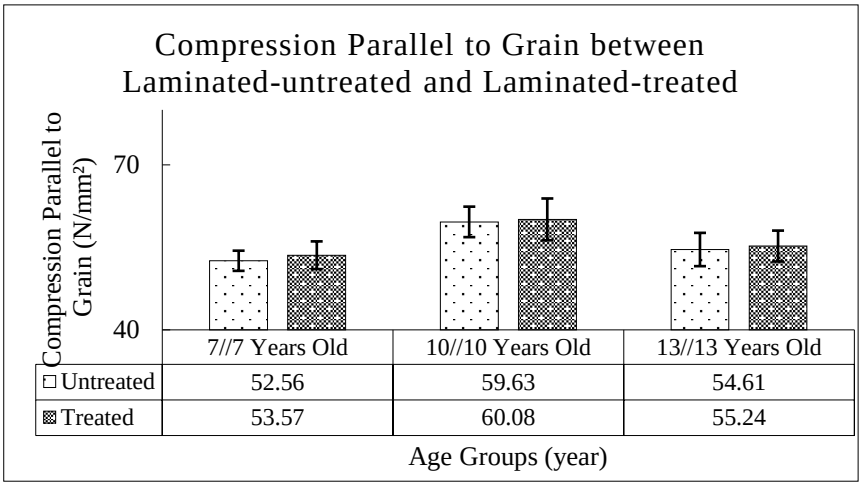


Figure 4.120: Comparison of Compression Parallel to Grain between Laminated-untreated Products and Laminated-treated Products by Same Age Groups of *Acacia mangium* superbulk

The analysis of comparison in mean compression strength between solid-treated and laminated-treated products *Acacia mangium* superbulk is also performed. From Figure 4.121, the mean compression strength results from laminated products-treated are slightly higher than that of solid-treated. The arrangement of age groups from low to high in strength properties is still the same. However, laminated-treated products gained an increment in compression strength compared to solid-treated results. The differences marked from the age group of 7 // 7, 10 // 10 and 13 // 13 are 3.16 N/mm^2, 2.26 N/mm^2 and 2.84 N/mm^2 respectively. At 95% confidence intervals, Figure 4.121 shows that only the treated solid age group 10 years old had statistically significant differences in mean compression parallel to grain. However, for treated laminated products, the age groups between 7 // 7 years old and 10 // 10 years old had statistically significant differences. Comparison between the physical appearance of solid and laminated products shows that treated from each age group had no statistically significant difference.

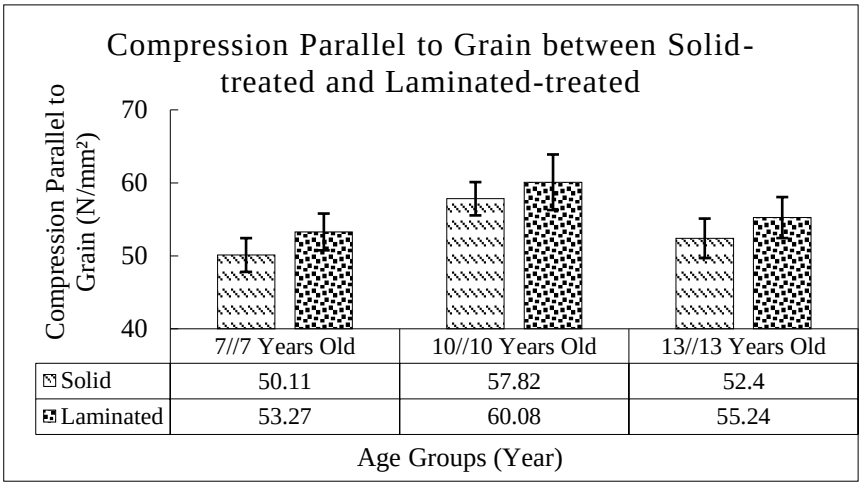


Figure 4.121: Comparison of Compression Parallel to Grain between Solid-treated and Laminated-treated Products by Same Age Groups of *Acacia mangium* superbulk

4.5.6 Compression Parallel to Grain by the Different Age Groups

An analysis of compression parallel to grain from the laminated-treated products sample by the different age groups is performed for compression parallel to grain with respect to age groups and also with respect to density.

i. Compression Parallel to Grain Respect to Age Groups

The compression test specimens are also prepared in treated conditions. A total of 90 specimens were from all age groups. The recorded treated results are being analysed using mean analysis, one-way ANOVA and the Duncan Multiple Range Test. Figure 4.122 indicates the mean compression parallel to grain against age groups for all three laminated products by different age groups.

From Figure 4.122, it is highlighted that the highest mean with CV of compression strength for laminated-treated products is 59.18 N/mm^2 (14.22) which is recorded from laminated age groups products of 10 with 13 years old. The second highest compression strength of laminated-treated products is 57.21 N/mm^2 (15.63) marked by laminated age

groups products of 7 with 10 years old. Meanwhile, the lowest is 55.57 N/mm^2 (12.98) is obtained by laminated age groups products of 7 with 13 years old. At $p<0.05$ confidence intervals, there is no statistically significant difference among the mean from all age groups, as presented in Figure 4.122.

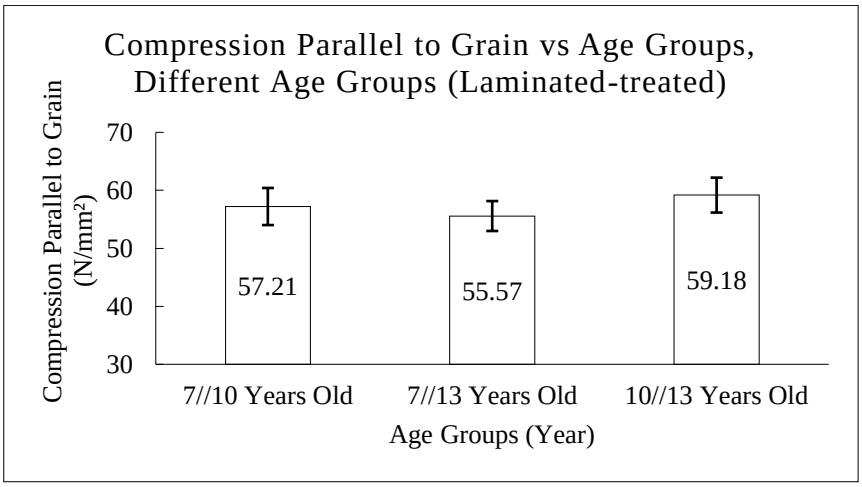


Figure 4.122: Compression Parallel to Grain Against Age Groups, Different Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk

An analysis of variance one-way ANOVA for compression strength results is tabulated in Table 4.91. Table 4.91 shows that from two mean squares, the F distribution obtained is 1.45, whereas the significant value attained is 0.240. Therefore, there is no statistically significant difference since the significant value obtained from the ANOVA analysis is higher than 0.05.

Table 4.91: One-way ANOVA of Compression Parallel to Grain by the Different Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk

	Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	196.34	2	98.17	1.45	0.24
Within Groups	5881.66	87	67.61		
Total	6078.00	89			

Furthermore, DMRT post-hoc analysis is performed in order to determine whether there is any specific difference or not among the three means by all age groups, and the result of the DMRT analysis is presented in Table 4.92. Table 4.92 clearly shows that all three means of compression strength are do not have specific differences each other since all means are placed in one class. In other words, all the means from all age groups do not differ much.

Table 4.92: DMRT of Compression Parallel to Grain by the Different Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk

Age Groups	**N**	**Subset for alpha = 0.05**
		1
7 // 13 Years Old	30	55.57
7 // 10 Years Old	30	57.21
10 // 13 Years Old	30	59.18
Sig.		0.11

*//:lamination

The maximum load obtained by compression test for laminated-treated products dissimilar age groups is tabulated in Table 4.93. Based on Table 4.93, laminated age groups products of 10 with 13 years old samples recorded the highest maximum load of 2.32 kN, followed by 2.29 kN which was obtained by age groups of 7 with 10 years old, and then the lowest is 2.22 kN attained by age groups of 7 with13 years old of *Acacia mangium* superbulk species.

Table 4.93: Maximum Load of Compression Parallel to Grain by the Different Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk

Age Group (Year)	Maximum Load (kN)
7 // 10	2.29
7 // 13	2.22
10 // 13	2.32

*//:lamination

ii. Compression Parallel to Grain Respect to Density

The continuing analysis is the linear regression analysis of compression parallel to grain with respect to density by different age groups of laminated-treated products. Figure 4.123, Figure 4.124 and Figure 4.125 indicate the linear regression analysis of compression parallel to grain versus density for laminated-treated products age groups of 7 // 10 years old, 7 // 13 years old and 10 // 13 years old, respectively.

From the analysis, the R-values obtained are 0.78, 0.71 and 0.86 for all three age groups respectively. Thus, the correlation between those two variables is considered as strongly correlation since the R-values are approaching to 1.00.

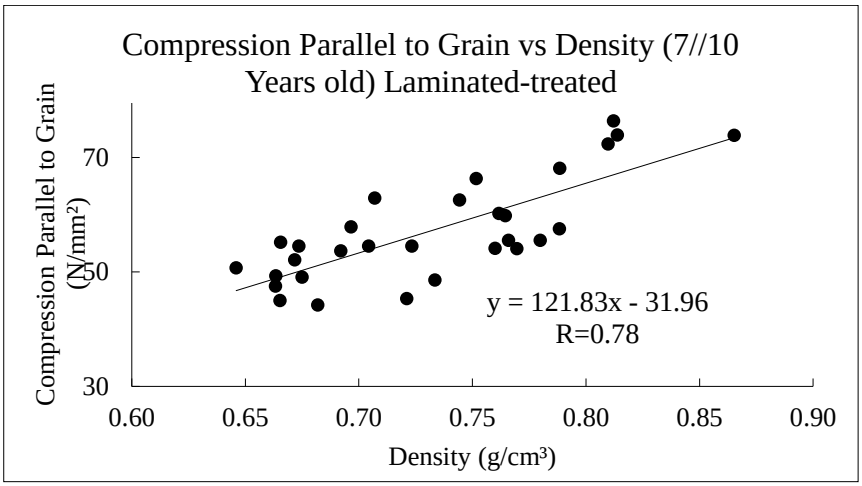


Figure 4.123: Compression Parallel to Grain Against Density for 7 // 10 Years Old (Laminated-treated Products) of *Acacia mangium* superbulk

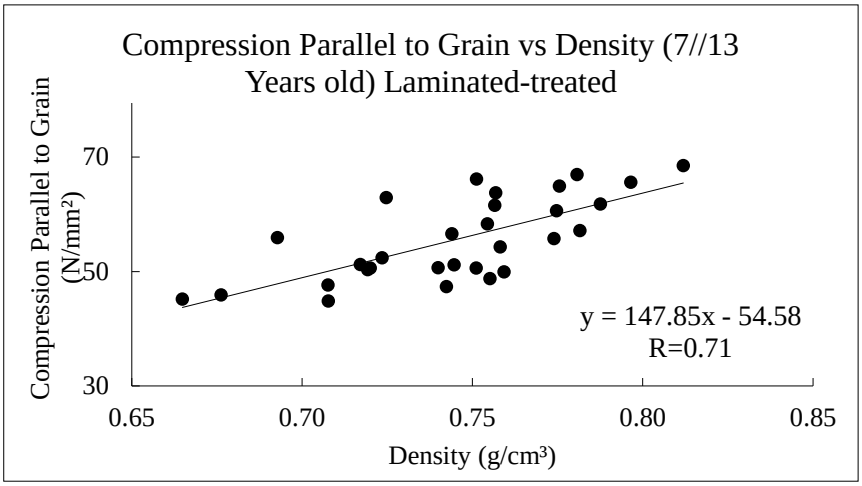


Figure 4.124: Compression Parallel to Grain Against Density for 7 // 13 Years Old (Laminated-treated Products) of *Acacia mangium* superbulk

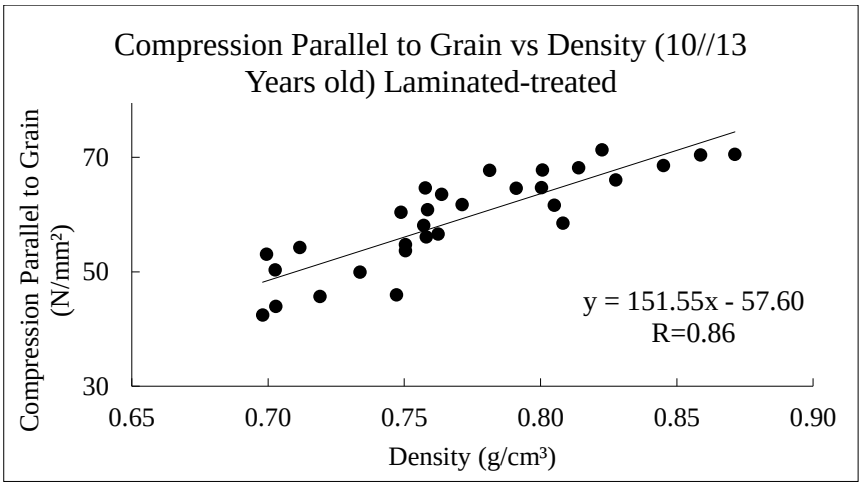


Figure 4.125: Compression Parallel to Grain Against Density for 10 // 13 Years Old (Laminated-treated Products) of *Acacia mangium* superbulk

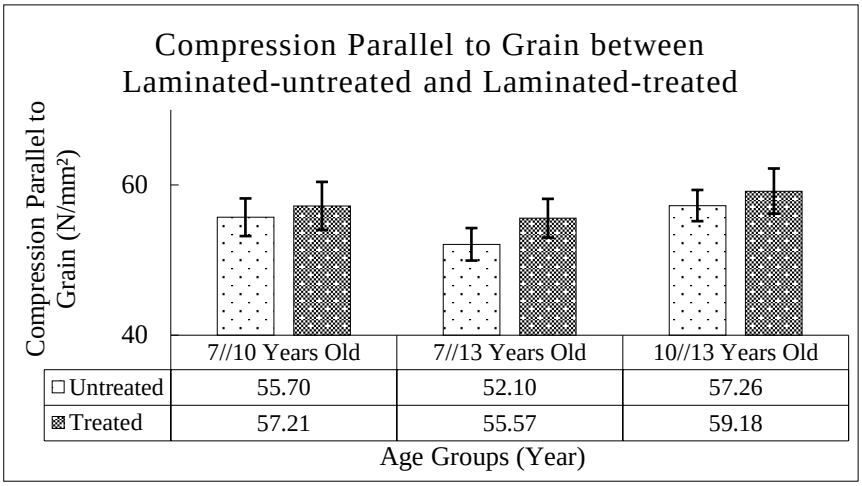


Figure 4.126: Comparison of Compression Parallel to Grain between Solid-treated and Laminated-treated Products by Different Age Groups of *Acacia mangium* superbulk

Figure 4.126 presents the comparison of compression strength between laminated-untreated products and laminated-treated products results for all age groups. From Figure 4.126, all age groups have incremented from untreated results to laminated results. Laminated age groups products of 7 with 10-year-old samples marked differences of about 1.51 N/mm^2. Meanwhile, laminated age groups products of 7 with 13 years old samples have differences of 3.47 N/mm^2 from controlled to treated compression strength results. Moreover, a total of 1.92 N/mm^2 increments are denoted from laminated age groups products of 10 to 13 years old. Analysis using an error bar at 95% confidence intervals, as shown in Figure 4.126 revealed only the age groups of 7 // 13 years old with 10 // 13 years old untreated laminated products had statistically significant differences, meanwhile for treated laminated products had no statistically significant differences in mean compression parallel to grain. Comparison between untreated and treated laminated products for each age group shows no statistically significant difference.

4.5.7 Shear Parallel to Grain in Tangential Direction by the Same Age Groups

An analysis of the shear parallel to grain of laminated-treated products specimens by the same age groups is run for shear strength with respect to age group and density.

i. Shear Parallel to Grain in Tangential Direction Respect to Age Groups

A 20 mm x 20 mm x 20 mm of laminated shear sample with a total of 90 had gone through the shear test right after the CCA treatment process. The shear test is carried out in accordance with ITTO's Testing Methods for Plantation Grown Tropical Timbers (Tan et al., 2010), which is similar to the solid shear test, although the condition of the sample is different. The data is first analysed by getting a mean for each age group. The average shear strength in N/mm^2 is exhibited in Figure 4.127.

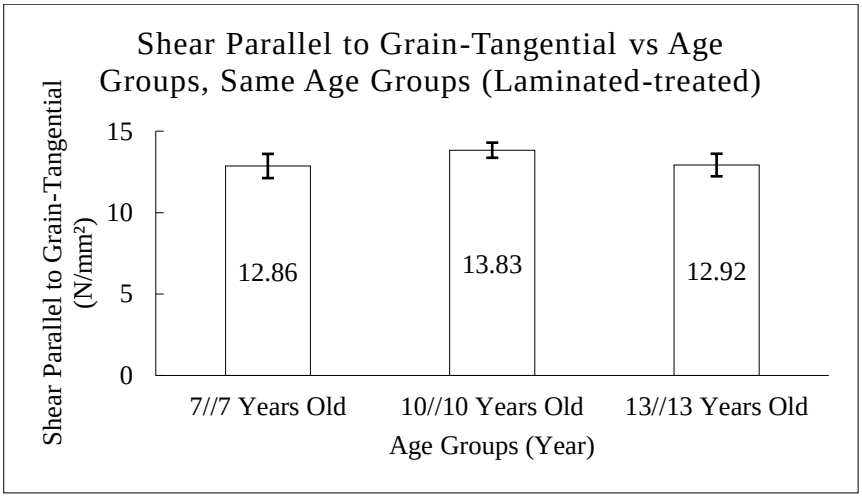


Figure 4.127: Shear Parallel to Grain in Tangential Direction Against Age Groups, Same Age Groups (Laminated-treated Products) of *Acacia mangium* Superbulk

Based on Figure 4.127, the highest mean of shear strength is recorded by the age group of 10 // 10 with a value of 13.83 N/mm^2 (9.40), whereas the lowest mean of shear strength is obtained by the age group of 7 // 7 with the amount of 12.86 N/mm^2 (16.15). At

the middle position age group of 10 // 10, the mean shear strength of 12.92 N/mm^2 (14.98) of 'Superbulk' species was remarked. The error bars at 95% confidence intervals show no statistically significant difference in the mean from the all laminated age groups as presented in Figure 4.127.

An additional one-way ANOVA analysis was performed to determine whether there is any statistically significant difference in the shear strength result of all age groups. The extracted result of the one-way ANOVA analysis of variance is organised in Table 4.94. Table 4.94 indicated no statistically significant difference among all shear strength results since the significant value obtained was 0.069, which is higher than the probability level of 0.05. Meanwhile, the F distribution recorded is 2.76 which getting from the ratio of two mean squares of all shear strength results.

Table 4.94: One-way ANOVA of Shear Parallel to Grain in Tangential Direction by the Same Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk

	Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	17.93	2	8.96	2.76	0.07
Within Groups	282.73	87	3.25		
Total	300.66	89			

In order to determine which age group is varied in the mean of shear strength, a post-hoc test of the Duncan Multiple Range Test (DMRT) is selected. The result of the DMRT analysis is exhibited in Table 4.95. By referring to that table, it is shown that the mean shear strength from the laminated-treated products age group of 13 // 13 does not have any specific difference from the other means since it is placed in both classes, whereas the mean age group of 7 // 7 and 10 // 10 has specific difference to each other.

Table 4.95: DMRT of Shear Parallel to Grain in Tangential Direction by the Same Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk

Age Groups	N	Subset for alpha = 0.05	
		1	2
7 // 7 years old	30	12.86	
13 // 13 years old	30	12.92	12.92
10 // 10 years old	30		13.83
Sig.		0.90	0.52

*//:lamination

The following Table 4.96 lists the maximum loading that can resist in the laminated shear test. The maximum load in Newton unit (N) is applied to the cross-sectional area (mm2) of the shear samples and will introduce a shear strength of the sample. The shear strength is influenced by maximum load, whereby the higher the maximum load, the greater shear strength will be encountered. Based on the table, the highest load is recorded by the age group of 10 // 10, which acquired 5.68 kN, compared to the age group of 7 // 7 years old samples that only obtained a maximum load of 5.25 kN, while the age group of 13 // 13 gained maximum load at the amount of 5.24 kN.

Table 4.96: Maximum Load of Shear Parallel to Grain by the Same Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk

Age Group (Year)	Maximum Load (kN)
7 // 7	5.25
10 // 10	5.68
13 // 13	5.24

*//:lamination

ii. Shear Parallel to Grain in Tangential Direction Respect to Density

The shear parallel to grain results from laminated products-treated products by the same age groups were prepared for linear regression analysis. This analysis involves the shear strength of all three laminated pairs versus their density, as shown in Figure 4.128, Figure 4.129, and Figure 4.130. The R-values obtained are 0.86, 0.86 and 0.82 from shear parallel to grain against the density of 7 // 7 years old, 10 // 10 years old and 13 // 13 years old, respectively. Hence, there is a strong correlation between shear strength and its density since all the R-values recorded are approaching 1.00.

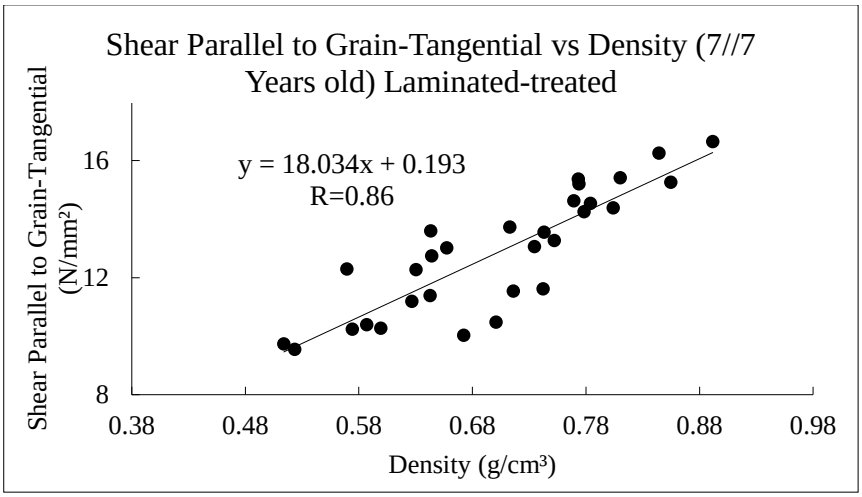


Figure 4.128: Shear Parallel to Grain in Tangential Direction Against Density for 7 // 7 Years Old (Laminated-treated Products) of *Acacia mangium* superbulk

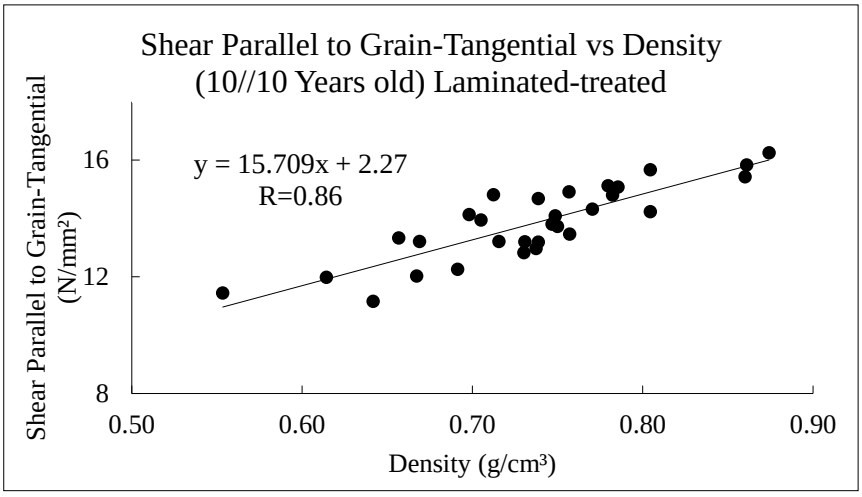


Figure 4.129: Shear Parallel to Grain in Tangential Direction Against Density for 10 // 10 Years Old (Laminated-treated Products) of *Acacia mangium* superbulk

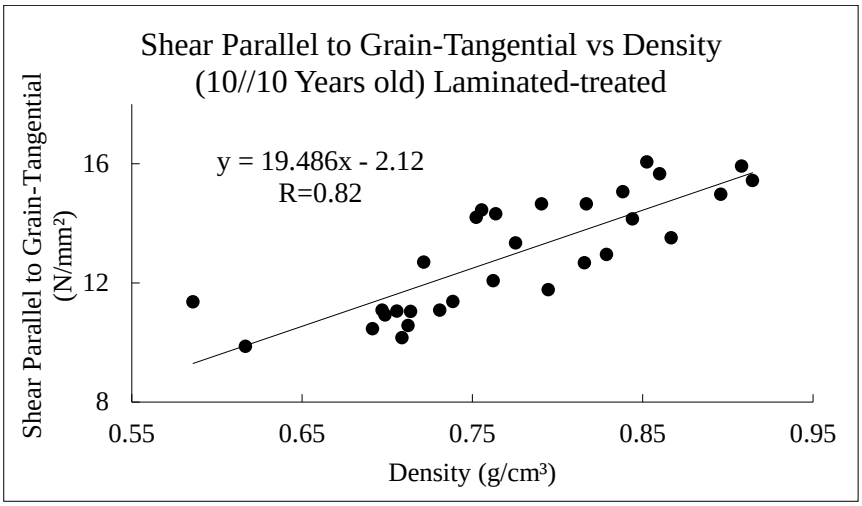


Figure 4.130: Shear Parallel to Grain in Tangential Direction Against Density for 13 // 13 Years Old (Laminated-treated Products) of *Acacia mangium* superbulk

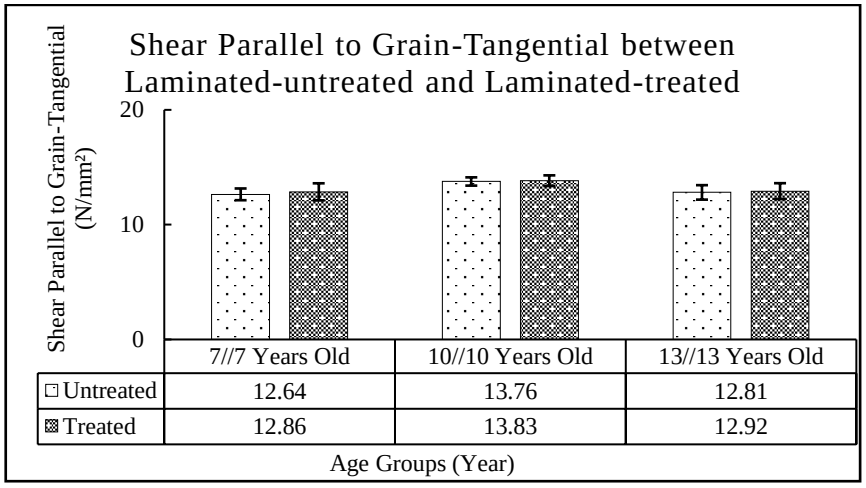


Figure 4.131: Comparison of Shear Parallel to Grain in Tangential Direction between Laminated-untreated Products and Laminated-treated Products by Same Age Groups of *Acacia mangium* superbulk

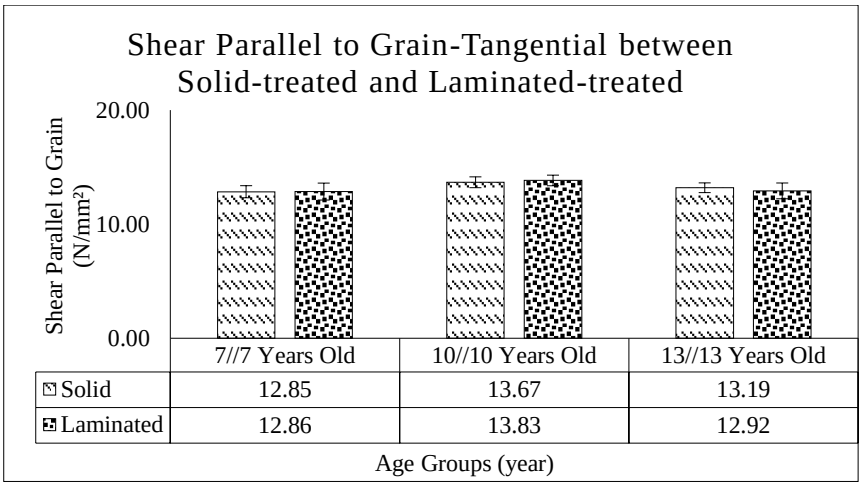


Figure 4.132: Comparison of Shear Parallel to Grain in Tangential Direction between Solid-treated and Laminated-treated Products by Same Age Groups of *Acacia mangium* superbulk

It is necessary to compare the shear parallel to grain between laminated-untreated products and laminated-treated products results. This evaluation is well presented in the bar chart as in Figure 4.131. It was observed that shear strength results from the treated condition are higher than that of shear strength results in an untreated condition. The specific increment in each age group is constituted as follows. The addition in mean shear strength from

untreated to treated age group of 7 // 7, 10 // 10 and 13 // 13 years old samples are 0.22 N/mm^2, 0.07 N/mm^2 and 0.11 $N/mm^{2,}$ respectively. Analysis using an error bar at 95% confidence intervals, as shown in Figure 4.131 revealed only the age groups of 7 // 7 years old with 10 // 10 years old untreated laminated products had statistically significant differences, meanwhile there were no statistically significant differences for treated laminated products for all three age groups. Comparison between untreated and treated laminated products for each age group also shows no statistically significant difference.

Besides that, the comparison means results shear parallel to grain between solid-treated and laminated-treated products, as presented in Figure 4.132. The differences recorded are 0.01 N/mm^2, 0.16 N/mm^2 and 0.27 N/mm^2 that were obtained from age groups 7 // 7, 10 // 10 and 13 // 13 years old, respectively. Analysis using an error bar at 95% confidence intervals, as shown in Figure 4.132 revealed there were no statistically significant differences for treated solid and laminated for all three age groups. Comparison between treated solid and laminated products for each age group also shows no statistically significant difference.

4.5.8 Shear Parallel to Grain in Tangential Direction by the Different Age Groups

An analysis of the shear parallel to grain of laminated-treated products specimens by the different age groups is performed with respect to age group and density.

i. Shear Parallel to Grain in Tangential Direction Respect to Age Groups

The test specimens for the shear test are also being treated using CCA preservatives and, therefore, undergo the testing based on the procedures accordingly. All the recorded results are sorted out using some types of analysis: mean analysis, one-way ANOVA

analysis, and DMRT analysis. The following figure indicates the mean shear strength against the different age groups for the laminated-treated condition.

Based on Figure 4.133, the highest mean with the coefficient of variance (CV) OF shear strength for laminated-treated products products by different age groups is 13.63 N/mm^2 (10.92), which is recorded from age groups of 10 and 13 years old, whereas the lowest is 12.35 N/mm^2 (10.89) that obtained by laminated age groups products of 7 and 13 years old samples. Meanwhile, laminated age groups products of 7 // 10 years old samples attained the mean of shear strength equalled 12.58 N/mm^2 (14.08). There is a statistically significant difference in the mean of shear parallel to grain only between laminated age groups products of 7 // 13 years old and 10 // 13 years old samples at $p<0.05$ confidence intervals. The data from all age groups are dispersed around the mean since the values of the coefficient of variance are below 20.00.

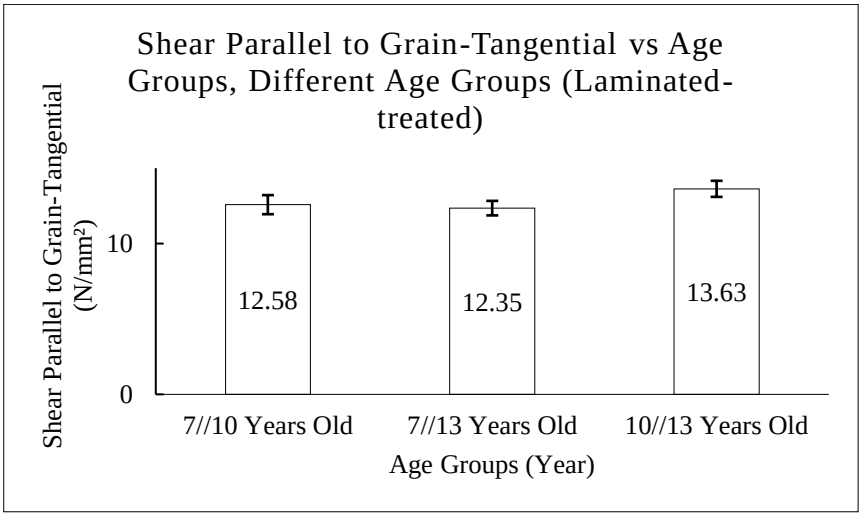


Figure 4.133: Shear Parallel to Grain in Tangential Direction Against Age Groups, Different Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk

Table 4.97: One-way ANOVA of Shear Parallel to Grain in Tangential Direction by the Different Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	27.93	2	13.97	5.85	0.00
Within Groups	207.73	87	2.39		
Total	235.66	89			

Table 4.98: DMRT of Shear Parallel to Grain in Tangential Direction by the Different Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk

Age Groups	N	Subset for alpha = 0.05	
		1	2
7 // 13 years old	30	12.35	
7 // 10 years old	30	12.58	
10 // 13 years old	30		13.63
Sig.		0.58	1.00

*//:lamination

All the shear strength results are listed to perform the one-way ANOVA in order to determine whether there is any statistically significant difference among all the shear strength results. This analysis is presented in Table 4.97. At the significant level of 95 %, the ANOVA analysis results confirmed a statistically significant difference among all the shear strength results since the significant value obtained is 0.00, which is below 0.05.

A DMRT Post-hoc test is performed to determine whether there is any statistically significant difference among all three means by all age groups, tabulated in Table 4.98. Based on Table 4.98, the mean from laminated age groups products of 10 with 13 years old samples has a specific difference compared to the other two age groups. This is because the mean from laminated age groups products of 10 with 13-year-old samples is placed in a single class compared to the two age groups that share the same class.

Table 4.99: Maximum Load of Shear Parallel to Grain in Tangential Direction by the Different Age Groups (Laminated-treated Products) of *Acacia mangium* superbulk

Age Group (Year)	Maximum Load (kN)
7 // 10	5.14
7 // 13	5.05
10 // 13	5.57

*//:lamination

The maximum load of treated shear strength by laminated products of different age groups is tabulated in Table 4.99. Based on the table, the highest maximum load recorded is 5.57 kN, gained by laminated age groups products of 10 with 13 years old samples. Meanwhile, the lowest maximum load obtained is 5.05 kN which is from laminated age groups products of 7 with 13 years old samples. A maximum load of 5.14 kN is the maximum load that can be carried by the shear specimen of laminated products age groups 7 with 10-year-old samples of 'Superbulk' species.

ii. Shear Parallel to Grain in Tangential Direction Respect to Density

The shear strength results by laminated-treated products on different age groups are also performed on the linear regression analysis similar to the previous analysis on the laminated-treated products products by the same age groups. The linear regression analysis between shear parallel to grain against the density of 7 // 10 years old, 7 // 13 years old and 10 // 13 years old are shown in the Figure 4.134, Figure 4.135, and Figure 4.136, respectively. From the analysis, the R-values obtained are 0.90, 0.81, and 0.81 for age groups of 7 // 10, 7 // 13 and 10 //13, respectively. Thus, the analysis can conclude that there is a very strong correlation between those two variables since the R-values are approaching to 1.00.

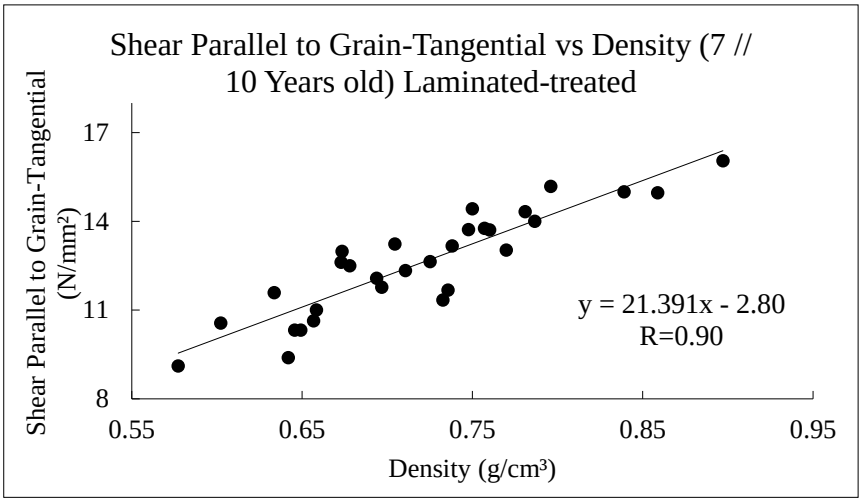


Figure 4.134: Shear Parallel to Grain-Tangential Against Density for 7 // 10 Years Old (Laminated-treated Products) of *Acacia mangium* superbulk

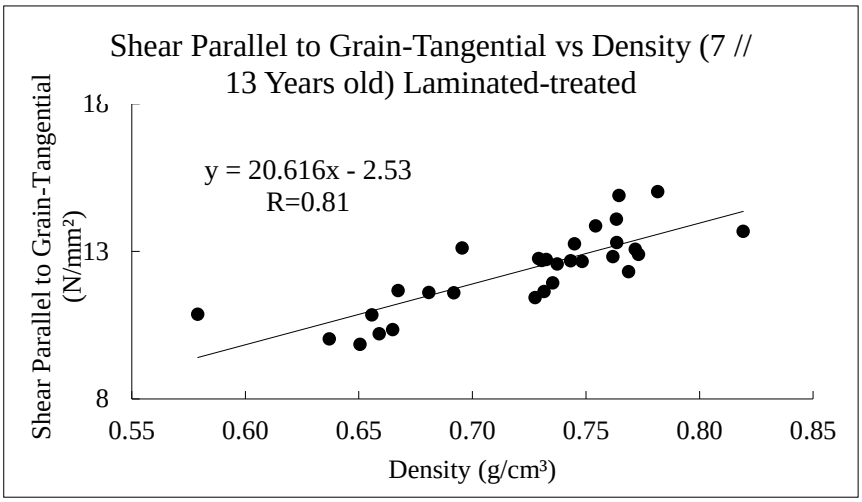


Figure 4.135: Shear Parallel to Grain-Tangential Against Density for 7 // 13 Years Old (Laminated-treated Products) of *Acacia mangium* superbulk

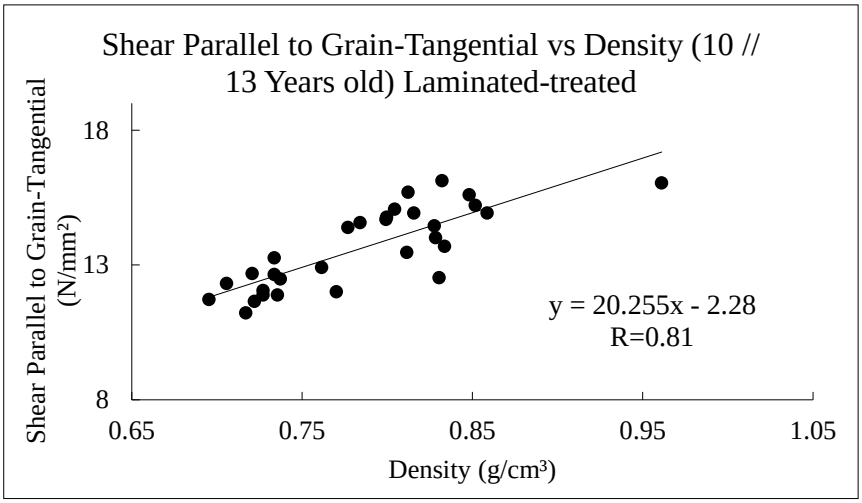


Figure 4.136: Shear Parallel to Grain-Tangential Against Density for 10 // 13 Years Old (Laminated-treated Products) of *Acacia mangium* superbulk

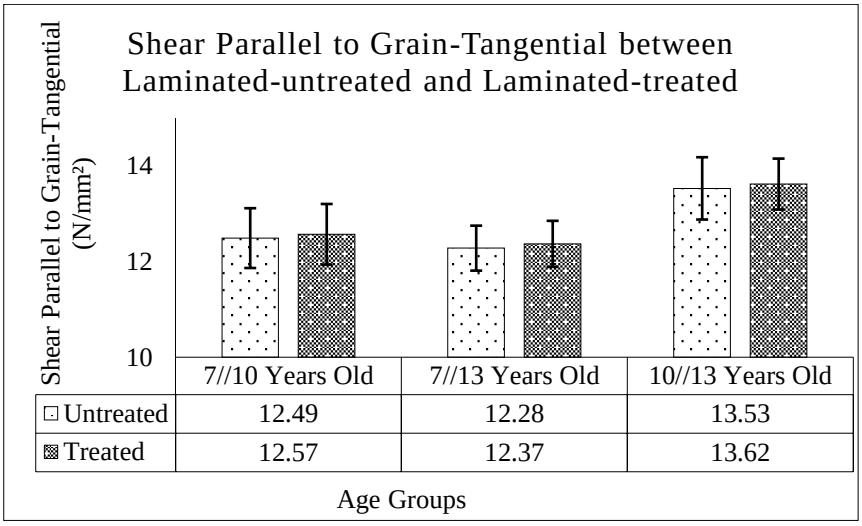


Figure 4.137: Comparison of Shear Parallel to Grain-Tangential between Laminated-untreated Products and Laminated-treated Products by Different Age Groups of *Acacia mangium* superbulk

Figure 4.137 indicated the comparison of shear strength between laminated-untreated products and laminated-treated products results. From Figure 4.137, there is an increment in mean shear strength from untreated results to treated results. The increases of 0.08 N/mm^2, 0.09 N/mm^2 and 0.09 N/mm^2 are recorded from laminated age groups products of 7 // 10 years old, 7 // 13 years old and 10 // 13 years old samples, respectively. Analysis using an

error bar at 95% confidence intervals, as shown in Figure 4.126 revealed only the age groups of 7 // 13 years old with 10 // 13 years old untreated and treated laminated products had statistically significant differences, meanwhile comparison between untreated and treated laminated products for each laminatedage group shows no statistically significant difference.

4.6 Treatability Retention of *Acacia mangium* superbulk

The treatment test is being analysed to meet the treatability classification based on Malaysian Standard (2003) and Malaysian Standard (2006). The results refer to the hazard class from Malaysian Standard (2003) and Malaysian Standard (2006). Both classification tables shall be referred to as Table 2.10 and Table 2.11 in Chapter 2, respectively.

Noted that retention was evaluated by calculating the gross uptake in litre/m^3 and penetration achieved after the treatment. The gross uptake in litre/m^3 is obtained by the difference between the final weight of the specimen after treatment and the initial weight of the specimen before treatment divided by its volume (Lai & Sammy, 2014).

4.6.1 Solid

The overall results of treatability retention level are therefore analysed to identify a mean by age groups. The means of treatability retention are tabulated in Table 4.100. Based on the table, the mean of treatability retention of CCA preservatives by each of the age groups are 147.56 litre/m^3, 146.74 litre/m^3 and 142.25 litre/m^3 recorded from age groups of 7, 10 and 13 years old samples, respectively.

Table 4.100: Treatability Retention Level on Solid *Acacia mangium* superbulk

Age Group (Year)	Treatability Retention Level (litre/m^3)
7	147.56
10	146.74
13	142.25

Thus, by referring to the treatability classification based on Malaysian Standard (2003) and MS 1921 (2006), all three age groups are classified as moderately difficult to treat, hence regarded as refractory heartwood of the species. Ibach (1999) and Lai and Sammy (2014) state that treatability varies among wood species, particularly their heartwood, which generally resists preservative treatment more than sapwood. Factors affecting heartwood treatability include the higher extractive content in heartwood, the increased rate of irreversible aspirated pits in the heartwood of softwoods, and the tyloses formation in the heartwood of hardwoods (Wang & Degroot, 1994; Lai & Sammy, 2014).

The treatability in litres/m3 that is established in Table 4.100 is analysed to get the dry-salt retention in kg/m^3, which is required to be multiplied by 10 % of the CCA solution used. This dry-salt retention expresses the hazard class with exposure, specific service conditions, biological hazard and typical uses of the timber as stated in the hazard class selection guide extracted from Malaysian Standard (2003) and Malaysian Standard (2006). Hence, the complete dry-salt retention by all age groups is presented in Table 4.101.

Table 4.101: Dry-salt Retention on Solid *Acacia mangium* superbulk

Age Group (Year)	Dry-salt Retention (kg/m^3)
7	14.76
10	14.67
13	14.23

Derived from treatability retention results, the dry-salt retention for three age groups is listed in Table 4.101. Based on Table 4.101, age groups of 7, 10 and 13 years old samples collected the dry-salt retention of 14.76 kg/m^3, 14.67 kg/m^3 and 14.23 kg/m^3, respectively. From dry-salt retention results, the analysis shall be referred to the hazard class selection guide extracted from Malaysian Standard (2003) and Malaysian Standard (2006). The values met hazard class H4 requirements (minimum net dry-salt retention 12 kg/m^3, not exceeding 16 kg/m^3) for timber used outside in ground contact and subjected to severe (not extreme) wetting and leaching.

The analysis continues to one-way ANOVA analysis of variance at a significant level of 0.05 in order to determine whether there is any statistically significant difference or not between all the treatability retention results by all age groups. This one-way ANOVA result is tabulated in Table 4.102. Based on Table 4.102, the value of F obtained is 3.00, which is a slightly insignificant p-value of 0.051, which is more than the 0.05 alpha level.

Table 4.102: One-way ANOVA of Treatability Retention on Solid *Acacia mangium* superbulk

	Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	3143.22	2	1571.61	3.00	0.05
Within Groups	300678.73	573	524.75		
Total	303821.95	575			

To determine which age group varied in the mean of treatability retention by all age groups, Duncan Multiple Range Test is selected. With the number of samples 192 from each age group, Table 4.103 indicates the DMRT post-hoc test results of the mean of treatability retention. Based on Table 4.103, it is shown that mean of treatability retention clearly stated

that there is no statistically significant difference in the mean of 10 years old with a mean of 13 years old and seven years old samples since both classes are shared. Meanwhile, mean of treatability retention from 13 years old samples is significantly different to the mean of treatability retention from 7 years old.

Table 4.103: DMRT of Treatability Retention on Solid *Acacia mangium* superbulk

Age Groups	N	Subset for alpha = 0.05	
		1	2
13 years old	192	142.25	
10 years old	192	146.74	146.74
7 years old	192		147.56
Sig.		0.06	0.73

A comparison of treatability retention between the previous study of *Acacia mangium* and the current study of 'Superbulk' species is presented in Table 4.104. Table 4.104, it is clearly shown that mostly the results are significant to each other except for 13 years old samples that recorded a difference in mean treatability retention of 13.15 litres/m^3, which is the greatest difference compared to the other two age groups. Nevertheless, all the results are still under the same treatability classification, which met the permeability class of moderately difficult to treat and also falls to MS544 hazard class of H4 requirements same as the current study of *Acacia mangium* superbulk.

Table 4.104: Comparison of Treatability Retention between Solid *Acacia mangium* and *Acacia mangium* superbulk

Age groups	*Acacia mangium*	*A.mangium* superbulk
7 years old	143.80 litre/m^3	147.56 litre/m^3
10 years old	147.10 litre/m^3	146.74 litre/m^3
13 years old	129.10 litre/m^3	142.25 litre/m^3

4.6.2 Laminated

The treatability retention analysis is performed on laminated products by the same age groups and also by the different age groups.

i. Treatability Retention by the Same Age Groups

Summing up all treatability results from all testing and classifying them by three age groups, the treatability retention collected are presented in Table 4.105. Based on Table 4.105, the average of the analysis of treatability retention by the same year laminated are 141.31 litre/m^3, 142.40 litre/m^3 and 146.45 litre/m^3 attained by 7, 10 and 13 years old samples respectively.

Evaluated from the results in Table 4.105, the analysis came out dry-salt retention in kg/m^3, which required multiplying by 10 % of the CCA solution used. By referring to Table 4.106, the dry-salt retention collected is 14.13 kg/m^3, 14.24 kg/m^3 and 14.65 kg/m^3 obtained by same-year lamination products of 7, 10, and 13 years old samples, respectively.

Table 4.105: Treatability Retention Level on Laminated Products by the Same Age Groups of *Acacia mangium* superbulk

Age Group (Year)	Treatability Retention Level (litre/m^3)
7 // 7	141.31
10 // 10	142.40
13 // 13	146.45

*//:lamination

Table 4.106: Dry-salt Retention on Laminated Products by the Same Age Groups *Acacia mangium* superbulk

Age Group (Year)	Dry-salt Retention (kg/m^3)
7 // 7	14.13
10 // 10	14.24
13 // 13	14.65

*//:lamination

From dry-salt retention results, the analysis shall refer to the hazard class selection guide extracted from Malaysian Standard (2003) and Malaysian Standard (2006). The values met hazard class H4 requirements (minimum net dry-salt retention 12 kg/m^3, not exceeding 16 kg/m^3) for timber used outside in ground contact and subjected to severe (not extreme) wetting and leaching.

The analysis, therefore, proceeds to the analysis of variance one-way ANOVA with a significant level of (alpha = 0.05). A result from the analysis is tabulated in Table 4.107. Based on Table 4.107, the F distribution obtained is 1.58, derived from two mean squares of the total of all results (number of samples, n = 270). Hence, the analysis results with a significant value of 0.21, which means there is no statistically significant difference among all results since the significant value attained are greater than the significant level of 0.05.

The Duncan Multiple Range Test is performed to determine which age groups varied in the mean of treatability retention of same-year lamination. Based on DMRT results in Table 4.108, it is clearly showing that there is no statistically significant difference among three means from three age groups of laminations since all three means are placed in one class. All the mean values are close to each other, and there are just differ with a slight amount of treatability retention in litre/m^3.

Table 4.107: One-way ANOVA of Treatability Retention on Laminated Products by the Same Age Groups of *Acacia mangium* superbulk

	Sum of Squares	df	Mean Square	F	Sig.
Between Groups	1320.65	2	660.32	1.58	0.21
Within Groups	111662.24	267	418.21		
Total	112982.89	269			

Table 4.108: DMRT of Treatability Retention on Laminated Products by the Same Age Groups of *Acacia mangium* superbulk

Age Groups	N	Subset for alpha = 0.05
		1
7 // 7 Years Old	90	141.31
10 // 10 Years Old	90	142.40
13 // 13 Years Old	90	146.45
Sig.		0.11

*//:lamination

ii. Treatability Retention by the Different Age Groups

Combining all the treatability retention results, the analysis provided the mean treatability retention level by three age groups of different year lamination. The mean from all age groups is indicated in Table 4.109. Based on the table, the mean treatability retention level gained is 144.06 litre/m^3, 144.47 litre/m^3 and 144.53 litre/m^3 collected from age groups of 7 // 10 years old, 7 // 13 years old and 10 // 13 years old samples respectively.

Table 4.109: Treatability Retention Level on Laminated Products by the Different Age Groups of *Acacia mangium* superbulk

Age Group (Year)	Treatability Retention Level (litre/m^3)
7 // 10	144.06
7 // 13	144.47
10 // 13	144.53

*//:lamination

Moreover, Table 4.110 is established where treatability retention results are multiplied by 10 % of the CCA solution used and then come out with dry-salt retention in kg/m^3. Based on the respective table, the dry-salt retention obtained is 14.41 kg/m^3, 14.45 kg/m^3 and 14.45 kg/m^3 attained by different year lamination age groups of 7/10 years old, 7/13 years old and 10/13 years old samples respectively.

Table 4.110: Dry-salt Retention on Laminated Products by the Different Age Groups *Acacia mangium* superbulk

Age Group (Year)	Dry-salt Retention (kg/m^3)
7 // 10	14.41
7 // 13	14.45
10 // 13	14.45

*//:lamination

Therefore, as the previous analysis, the dry-salt values met hazard class H4 requirements (minimum net dry-salt retention 12 kg/m^3, not exceed 16 kg/m^3) for timber used outside in ground contact and subjected to severe (not extreme) wetting and leaching. Note that the dry-salt values are referred to in the hazard class selection guide extracted from Malaysian Standard (2003) and Malaysian Standard (2006).

In order to determine whether there is any statistically significant difference among all the treatability retention results of different year of laminated sample products, one-way

ANOVA analysis of variance takes place. The one-way ANOVA result is presented in Table 4.111. Based on Table 4.111, the F distribution collected from the analysis is 0.014, then derived the significant value of 0.986. This brought the meaning of there is no statistically significant difference among all the treatability retention of the different years of laminated sample products since the significant value obtained is greater than the significant level of 0.05 (alpha value).

Table 4.111: One-way ANOVA of Treatability Retention on Laminated Products by the Different Age Groups of *Acacia mangium* superbulk

	Sum of Squares	**df**	**Mean Square**	**F**	**Sig.**
Between Groups	11.71	2	5.86	0.01	0.99
Within Groups	109851.17	267	410.68		
Total	109862.89	269			

Besides that, Table 4.112 is represented the Duncan Multiple Range Post-hoc Test, where this analysis is the consequences of the one-way ANOVA, which is to clarify which age groups are varied in the mean of treatability retention of the different years of laminated sample products, whether there is any statistically significant difference or not among them. By referring to Table 4.112, the DMRT result for all three age groups corresponded to each other since there is no statistically significant difference among all means of treatability retention by different year lamination.

Table 4.112: DMRT of Treatability Retention on Laminated Products by the Different Age Groups of *Acacia mangium* superbulk

Age Groups	N	Subset for alpha = 0.05
		1
7 // 10 Years Old	90	144.06
7 // 13 Years Old	90	144.47
10 // 13 Years Old	90	144.53
Sig.		0.89

*//:lamination

4.7 Summary of Results

This subchapter presents a summary table from all results analysed in this chapter. The details of the overall results for physical and mechanical testing for untreated samples and treated samples are presented in Table 4.113 and Table 4.114, respectively. Meanwhile, Table 4.115 indicates the treatability retention level results of the CCA preservative of *Acacia mangium* superbulk.

Table 4.113: Summary Results for Physical and Mechanical Properties of Untreated Samples of *Acacia mangium* superbulk

			Age Groups								
			7	**10**	**13**	**7//7**	**10//10**	**13//13**	**7//10**	**7//13**	**10//13**
PP	**MC**		18.73	18.64	18.84	12.15	11.97	12.07	12.83	12.47	12.35
	D		0.62	0.66	0.63	0.58	0.59	0.58	0.61	0.59	0.62
	BD		0.53	0.56	0.53	0.52	0.53	0.52	0.54	0.52	0.55
MP	**MOR**	$\bar{x}$	95.80	115.11	98.06	99.41	117.93	105.36	107.50	101.15	110.19
		σ	13.77	13.55	13.88	12.12	12.36	14.76	27.35	17.38	14.90
		CV	14.37	11.77	14.16	12.19	10.48	14.01	25.44	17.18	13.52
	MOE	$\bar{x}$	11770	14945	12512	12022	14991	12603	13505	12288	13769
		σ	1376	1570	1379	1254	1397	1236	2123	1243	1236
		CV	11.72	10.51	11.02	10.43	9.23	9.81	15.72	10.12	8.98
	Compression	$\bar{x}$	49.18	57.57	52.93	52.56	59.63	54.61	55.70	52.10	57.26
		σ	4.90	5.90	6.22	5.12	7.74	8.46	7.01	6.04	5.81
		CV	9.97	10.25	11.75	9.75	12.99	15.49	12.58	11.60	10.14
	Shear	$\bar{x}$	12.50 R 12.65 T	13.72 R 14.24 T	12.94 R 13.35 T	12.64	13.76	12.81	12.49	12.28	13.53
		σ	1.07 R 1.07 T	1.34 R 1.42 T	1.02 R 1.06 T	1.43	1.01	1.76	1.75	1.31	1.82
		CV	8.53 R 8.49 T	9.75 R 10.00 T	7.91 R 7.94 T	11.29	7.32	13.74	13.99	10.70	13.45

*PP: Physical Properties, MP: Mechanical Properties, MC: Moisture Content (%) at Air-dry, D: Density (g/cm^3) at Air-dry, BD: Basic Density (g/cm^3), MOR: Modulus of Rupture, MOE: Modulus of Elasticity, $\bar{x}$: Mean (N/mm^2), σ: Standard Deviation, CV: Coefficient of Variance (%), //: Lamination, R: Radial, T: Tangential

Table 4.114: Summary Results for Physical and Mechanical Properties of Treated Samples of *Acacia mangium* superbulk

			Age Groups								
			7	**10**	**13**	**7//7**	**10//10**	**13//13**	**7//10**	**7//13**	**10//13**
PP	**MC**		18.73	18.64	18.84	12.15	11.97	12.07	12.83	12.47	12.35
	D		0.61	0.63	0.61	0.61	0.62	0.62	0.60	0.61	0.64
	BD		0.76	0.79	0.76	0.75	0.77	0.77	0.75	0.76	0.79
MP	**MOR**	$\bar{x}$	97.14	118.76	99.16	112.77	122.76	115.51	118.34	114.98	120.70
		σ	19.64	21.21	19.78	17.73	20.00	24.85	19.46	19.24	18.52
		CV	20.22	17.89	19.94	15.72	16.29	21.51	16.44	16.73	15.34
	MOE	$\bar{x}$	11834	15020	12666	12276	15011	12795	13523	12320	13809
		σ	1785	1621	1945	1259	1697	1968	1300	1748	1551
		CV	15.09	10.79	15.36	10.26	11.30	15.38	9.61	14.19	11.24
	Compression	$\bar{x}$	50.11	57.82	52.40	53.57	60.08	55.24	57.21	55.57	59.18
		σ	8.09	8.07	9.56	7.00	10.64	7.85	8.94	7.21	8.41
		CV	16.32	13.95	18.25	13.06	17.71	14.21	15.63	12.98	14.22
	Shear	$\bar{x}$	12.76 R 12.85 T	13.55 R 13.67 T	13.12 R 13.19 T	12.86	13.83	12.92	12.57	12.37	13.62
		σ	1.45 R 1.87 T	1.53 R 1.68 T	1.46 R 1.51 T	2.08	1.30	1.94	1.70	1.47	1.36
		CV	11.33 R 14.57 T	11.29 R 12.28 T	11.11 R 11.45 T	16.15	9.40	14.98	13.53	11.89	10.00

*PP: Physical Properties, MP: Mechanical Properties, MC: Moisture Content (%) at Air-dry, D: Density (g/cm^3) at Air-dry, BD: Basic Density (g/cm^3), MOR: Modulus of Rupture, MOE: Modulus of Elasticity, $\bar{x}$: Mean (N/mm^2), σ: Standard Deviation, CV: Coefficient of Variance (%), //: Lamination, R: Radial, T: Tangential

Table 4.115: Summary Results for Treatability Evaluation of *Acacia mangium* superbulk

Age Groups	Treatability Retention (litre/m^3)	Standard Deviation, σ	Coefficient of Variance, CV (%)	Dry-salt Retention (kg/m^3)
7	147.56	21.12	14.31	14.76
10	146.74	23.80	16.22	14.67
13	142.25	23.70	16.66	14.23
7 // 7	141.31	20.34	14.39	14.13
10 // 10	142.40	19.14	13.44	14.24
13 // 13	146.45	21.79	14.88	14.65

*//:lamination

4.8 Factors Affecting Mechanical Strength Properties

Initially, in developing various utilisations of fast-growing timber, it is necessary to evaluate their physical and mechanical properties to comply with the timber industry's requirements. Although the timber species are in the same family, timber is a heterogeneous material, which means one timber may have a different element and compound than another. Therefore, physical and mechanical properties are also contrasted. From this point of view, the findings on the mechanical strength properties of the *Acacia mangium* superbulk may influence various factors. Technically, the strength of timber may tend to vary due to its physical properties and is also affected by some other factors such as maturity, defect, disease, and plantation site condition.

4.8.1 Effect of Physical Properties

The physical property of the timber is the first execution that affects the timber's mechanical strength behaviour. In this study, the physical property, moisture content (MC) of all specimens, is prepared to be constant at 18 % MC as in the range of air-dry MC. The

MC recorded by the solid *Acacia mangium* superbulk is 18.73 % (7 years old), 18.64 % (10 years old) and 18.84 % (13 years old). According to Alik and Kuroda (1996), in Sarawak timber's case, the air-dry moisture content is introduced in the range of 18 % to 20 %. Thus, the MC of the specimens that are to be tested meets the requirement.

Moreover, it was reported that the percentage of MC present in the timber could affect its weight, strength, workability, susceptibility to biological attack and dimensional stability in a particular end use. The average density at air-dry condition of *Acacia mangium* superbulk obtained from this study is 0.61 g/cm^3, which falls into the light hardwood classification (range of 0.40-0.72 g/cm^3). Refer to Table 2.1 in Chapter 2 of this thesis. Meanwhile, the mean basic density from this study is 0.53 g/cm^3. It was reported that the mean value of the basic density of *Acacia mangium* is 0.54 g/cm^3, and it is classified under light hardwood (Ismaili et al., 2011b). Therefore, *Acacia mangium* superbulk is also classified under light hardwood since the findings from the current study and the study done by Ismaili et al. (2011b) are just slightly different.

On the other hand, the increase or decrease in strength is directly related to the amount of moisture removed. The strength and stability of timber are greatly influenced by its moisture content (Ismaili, 2015; Yahya & Ismaili, 2015; Alik et al., 2016). Generally, in other studies comparing strength among green condition and air-dry condition, the maximum strength achieved was in an air-dry condition where moisture content is low compared to in green condition. However, the moisture content of *Acacia mangium* from Malaysia was around 100-110 % in heartwood and 80-90 % in sapwood (Yamamoto et al., 2003). Thus, this species takes a lot of time to dry and tends to distort; for the species containing heart rot, collapse may occur (Lim et al., 2003). Plus, it is difficult to reach the desired moisture

content for all samples because the timber samples are reacted to the surrounding relative humidity. Loffer (2018) reported that wood is hygroscopic, which means it gains or loses moisture as the relative humidity of the air surrounding it changes. Yamamoto et al. (2003) also specified that wood with a higher moisture content dries more slowly than that with lower moisture content, and it is generally more susceptible to drying defects.

In glued-laminated timber or glulam, it is important to ensure the timber samples have achieved adequate moisture content, as according to Japanese Agricultural Standards (2003), the minimum MC for bonded wood is ≤ 14 %. Plus, based on American Society for Testing and Materials (1995), MC for bonding specimens was in the range of 12 % to 14 %. Insufficiently dried veneers or lumbers may affect the bond performance of the products (Sahari & Inoue, 1996). The effect of the imperfect glueing process is that the glulam is not monolithic and might cause a decrease in its mechanical properties (Sulistyawati et al., 2008).

In this laminated study, as stated before, the MC of *Acacia mangium* superbulk for laminated products same-year are 12.15 % (7 years old), 11.97 % (10 years old) and 12.07 % (13 years old). Meanwhile, the MC recorded from laminated products different-year are 12.83 % (7 // 10 years old), 12.47 % (7 // 13 years old) and 12.35 % (10 // 13 years old). Thus, the mechanical strength testing on laminated sample products meets the MC's requirement as all the MCs are in the range according to the standards.

An increment in mechanical strength between solid and laminated are spotted. The characteristics that varied between those two conditions are their moisture content (MC) and, obviously, the adhesive added to the specimens. In the aspect of physical property, the MC in the specimen tends to influence the diverse strength behaviour from solid to laminated

products. The MC of the solid form is in the range of 18 %, whereas the MC of the laminated sample is in the range of 12 %. Thus, Table 4.116 is tabulated to compare the mechanical strength of the solid and laminated sample products. By referring to Table 4.116, roughly, there is additional strength from solid to laminated products. This is due to the less MC amount in the laminated specimen, which led to a higher strength than the solid sample. This discovery is supported by a previous study from Ismaili (2015) that stated the timber would increase in strength as its dried, though this effect does not begin until the water within the cell has dried out.

Table 4.116: Comparison of Mechanical Strength Between Solid and Laminated Products Based on Moisture Content

Mechanical Strength Testing	**Age Groups (Year)**	**Solid (N/mm^2) (MC: ± 18 %)**		**Laminated (N/mm^2) (MC: ± 12 %)**	
Static Bending	7	MOR MOE	95.80 11770	MOR MOE	99.41 12022
	10	MOR MOE	115.11 14945	MOR MOE	117.93 14991
	13	MOR MOE	98.06 12512	MOR MOE	105.36 12603
Compression parallel to grain	7	49.18		52.56	
	10	57.57		59.63	
	13	52.93		54.61	
Shear parallel to grain	7	12.65		12.64	
	10	14.24		13.76	
	13	13.35		12.81	

*MOR: modulus of rupture, MOE: modulus of elasticity, MC: moisture content

4.8.2 Effect of Maturity

The *Acacia mangium*, or the first-generation *Acacia mangium*, is well-known as the species that has better adaptability to a wide range of soil types and environments. This species can achieve a height of 16.8 m and a diameter height breast (DBH) of 17.7 cm at the age of 4 years old (PERKASA, 2004; Jusoh & Adam, 2014). Meanwhile, the improved *Acacia mangium*, which is *Acacia mangium* superbulk (second-generation), can reach a height of 22.9 m and DBH of 21.7 cm at 4 years old. However, the survival rate of *Acacia mangium* superbulk decreases with age, and after 9.83 years of planting, its survival rate is only 57 % (Adam et al., 2012) (refer to Table 2.2 in Chapter 2 of this thesis).

From the findings, among the three age groups that have been tested, most of the maximum mechanical strength is achieved by the age group of 10 years old, even though 13 years old is the greatest age group in this study. These findings are aligned with the pioneering research by Adam et al. (2012), which found that the maximum growth rate of superbulk species is approximately 10 years old. Therefore, it is can concluded that the strength of the timber is affected by the survival rate of the superbulk species as the growth characteristic of *Acacia mangium* superbulk starts to tear down after 10 years old. Thus, it can be described that the strength performance of 13 years old is decreased due to the survival rate that declines as age increases. The study by Adam et al. (2012) recorded an increase in maximum DBH (38.5 cm) has resulted in a reduction in survival rate, and only 57% of trees are left in a plot containing 100 trees. Hence, the current study remarked the best mechanical strength performance belongs to the age group of 10 years old as that is the maximum and most reliable level of growth. Therefore, it is important to understand the new breed of *Acacia mangium* better, as it seems promising to have desirable growth

characteristics.

4.8.3 Effect of Miscellaneous

The mechanical strength properties of timber are influenced by various effects. One of them is the locality of the collection area. Initially, the base of the plantation plot area of samples collected has an impact on the recorded results. By observation and e-numerated tree process, the surrounding plantation plot area might be on a steep slope or flat land, whether they have any termite activity or could be some windblown or fallen trees. These situations drive the performance of the timber species. In this research, by comparing the strength results among all the age groups, the best mechanical strength behaviour is the age group of 10 years old samples, not 13 years old, even though it is much more mature. This could also be due to several factors, such as differences in the proportion of major wood constituents, i.e. cellulose, hemicelluloses and lignin present in the woods or differences in extractive contents, in other words, the microstructure of light hardwood varied between species (Siau, 2012). The summarized report from the e-numeration at the plot area for both age groups established the differences in aspects of the locality (refer to Table 3.1 in Chapter 3 of this thesis). In the plot area of 13 years old's superbulk, some of the trees are infected by Ceratocystis, which affects the overall strength behaviour of timber. Meanwhile, the plot area of 10 years old samples does not infect by any disease. Habitually, *Acacia mangium* is known as a species that has the best adaptability and tolerance to the several ranges of soil types and PH values. It is adapted to a wide range of soils in moist tropical lowlands (Joker, 2000; Ismaili, 2015). Thus, the variations of land types are not discriminate the most strength performance unless, throughout the e-numerated process, the trees are exposed to any disease, attacked by termites, decay at bole and main branches, stunted growth, dead trees

or deformed bole.

On the other side is a defect. This brings out the importance of visual testing in the first process of choosing the best sample to be tested. The visual testing needs to be precise and eliminate the timber's defects such as knots, heart rot, and some might be wood grain. The presence of knots, in general, caused a reduction in mechanical strength. Knots bring negative effects (Yahya and Ismaili, 2015). This natural processing defect is basically left-over portions of fallen trees. If the branches are alive, the tissues are continuous alive with that main stem and the knots so formed are said to be live or tight knots (Lim et al., 2003). Besides that, *Acacia mangium* mainly had heart rot disease, a stem defect with fungal infection of branch stubs, wounds from pruning and singling, and forking injuries (Lee, 2005). Even though superbulk is also known as the second generation of *Acacia mangium*, which is primarily an improved and selected tree, this species is from the same provenance, so it seems not free from heart rot disease. Lee (2005) reported that timber with heart rot is not suitable for general purposes such as construction because of loss of structural strength and poor recovery of high-value products during processing. In addition, wood grain deviation reduces the strength distinctly (Abdul Wahab et al., 2013). Naturally, in small log timber processing, there is a high possibility of having a sawn board with uneven grain. Timber with such deviations in the grain direction is weaker in strength than timber cut with straight grain (Lim et al., 2003).

4.9 Treatability Evaluation and Hazard Classification

The Government of Sarawak has allocated 2 million hectares of land for the forest plantation programme to accomplish 1 million hectares of planted forest by 2020 in order to fulfil the demand for wood by the timber industry (Lai & Sammy, 2014). The factors that

affect the growth of the forest plantations are the long maturation period and the poor quality of the timber produced. The option to plant fast-growing timber has many benefits to ensure the continuation of the commercial timber industry. However, the fast-growing timber faced a low timber quality, such as low strength and low natural durability. All timbers have varying degrees of biodegradability. When dealing with more hazardous situations, the timbers are subjected to different degrees of biodegradation by the different groups of wood-destroying organisms. Thus, to enhance their strength and usage in various situations, it is necessary to apply a proper treatment instead of adding the adhesive material to timber samples.

The treatability assessment of the *Acacia mangium* superbulk used *Copper Chrome Arsenic* (CCA) as a preservative and applied the Full Cell (Bethell) process. The treatment was conducted in three age groups of superbulk such as 7, 10 and 13 years old. The efficiency of preservative performance in treated timber is highly dependent on its retention level. This retention level is used to comply with the hazard classification. Apart from that, mechanical strength testing such as static bending, compression parallel to grain and shear parallel to grain are also conducted on the treated samples to evaluate whether there is any increment of strength in N/mm^2 when compared to the untreated samples. This assessment was also done on laminated sample products.

Based on Table 4.115 before, obviously, all the age groups of *Acacia mangium* superbulk are classified as moderately difficult to treat (refer to Table 2.10 in Chapter 2 of this thesis) as their treatability retention level is in the range 80 litre/m^3 to 160 litre/m^3. The previous findings by Lai and Sammy (2014) also found that *Acacia mangium* is moderately difficult to treat under CCA preservatives. Meanwhile, the dry-salt retention determines the

hazard class of the timber, as in Table 2.11 Chapter 2 of this thesis. From the analysis, the *Acacia mangium* superbulk is classified as hazard class H4 under outside and in-ground exposure, under severe wetting and leaching condition, tends to severe decay, borers and termites, and is also typically used for fence posts, greenhouses, pergolas (in the ground) and landscaping timbers. The one-way ANOVA analysis of treatability retention shown in Chapter 4 clarified that there is no statistically significant difference among all three age groups. This is because the gap between the three age groups is small; hence, the differences in retention levels are not too apparent. When compared to a study that has been done by Salmiah et al. (2011), the 16 and 20 years old of *Acacia mangium* are reported to be classified as H5, and its permeability was not significantly different between these age groups as same as a current study that has a small gap in age. However, this scenario explained that the older tree achieved a higher class than the younger tree since the current study on 13 years old and below only achieved H4 class compared to 16 years old and above that attained H5 in hazard class. Noted that H5 is described as under outside, in-ground contact with or in freshwater exposure, under extreme wetting and leaching condition, tends to very severe decay, borers and termites also shall be used as retaining walls, piling, house stumps, building poles, cooling tower fill. As stated by the Australian Pesticides and Veterinary Medicines Authority (2005), adhering to proper treatment standards is paramount to regulating the utilization of CCA for timber treatment. These standards are specified in section 3.6, Chapter 3 of this thesis. The toxicological assessment conducted by the Australian Pesticides and Veterinary Medicines Authority (2005) found that copper and chromium in the treated timber do not pose a notable risk to public health, as exposure levels are below safety thresholds. The assessment also concluded that utilizing CCA or arsenic trioxide products as directed in their instructions is unlikely to result in any inadvertent harm to human beings, animals, plants,

or the environment (Australian Pesticides and Veterinary Medicines Authority, 2005).

Table 4.117: Comparison of Mechanical Strength Between Untreated and Treated

Mechanical Strength Testing	Age Groups (Year)	Untreated (N/mm^2)		Treated (N/mm^2)	
`Static Bending	7	MOR MOE	95.80 11770	MOR MOE	97.14 11834
	10	MOR MOE	115.11 14945	MOR MOE	118.76 15020
	13	MOR MOE	98.06 12512	MOR MOE	99.16 12666
	7 // 7	MOR MOE	99.41 12022	MOR MOE	112.77 12275
	10 // 10	MOR MOE	117.93 14991	MOR MOE	122.76 15010
	13 // 13	MOR MOE	105.36 12603	MOR MOE	115.51 12794
	7 // 10	MOR MOE	107.50 13505	MOR MOE	118.34 13523
	7 // 13	MOR MOE	101.15 12288	MOR MOE	114.98 12320
	10 // 13	MOR MOE	110.19 13769	MOR MOE	120.70 13808
Compression parallel to grain	7	49.18		50.11	
	10	57.57		57.82	
	13	52.93		52.40	
	7 // 7	52.56		53.57	
	10 // 10	59.63		60.08	
	13 // 13	54.61		55.24	
	7 // 10	55.70		57.21	
	7 // 13	52.10		55.57	
	10 // 13	57.26		59.18	
Shear parallel to grain	7	12.65		12.85	
	10	14.24		13.67	
	13	13.35		13.19	
	7 // 7	12.64		12.84	
	10 // 10	13.76		13.83	
	13 // 13	12.81		12.92	
	7 // 10	12.49		12.57	
	7 // 13	12.28		12.37	
	10 // 13	13.53		13.62	

*//:lamination

Initially, the treatment of the timber is one of the techniques used to protect the timber

itself. It is important to discover new findings in the field of timber research, especially an outcome from the treatment study. Hence, this current study helps introduce variety in the strength of the timber. Firstly, the timber samples prepared for the treatment process are the same as untreated samples. Their moisture content (MC) is the same as the control, which is air-dry MC, and the dimensions of the samples are also the same for static bending, compression, and shear. The method of conducting all the tests is similar, and this treatment process also runs to the laminated sample products. Table 4.117, extracted from Chapter 4, indicates the mechanical strength comparison between untreated and treated samples. From the table, clearly, the recorded result of mechanical strength in a treated condition is increased from the strength in an untreated condition. According to Ismaili et al. (2011a) and Desch (1981) the increase in strength is due to the reduction in moisture content in the timber, which shortens and strengthens the hydrogen bonds that connect the microfibrils in the timber. The study conducted by Faria et al. (2015) had revealed that the influence of CCA preservation on the physical and mechanical properties of *Eucalyptus camaldulensis*. However not all timber species are suitable treated with CCA treatment. Based on the study conducted by Sabila et al. (2015) had found out that Acacia species is the most suitable to be treated using CCA treatment because of its relatively high fixation rate and low leaching characteristics. Thus, from this study, it is concluded that the treatability of the timber enhanced its strength from untreated instead of acting as protection to the timber.

CHAPTER 5

UTILISATION OF ACACIA MANGIUM SUPERBULK

5.1 Background

This chapter discusses the percentage of difference in the findings, strength grouping, hazard classification, and end-user utilisations.

5.2 Percentage Difference of Mechanical Strength Properties to the Reference Point

The percentage of difference in mechanical strength results is based on the reference point, which is the best result from each of the strength properties. The best result from solid untreated and solid treated that had been determined from this study will be chosen as a reference point. This percentage of difference will be used to compare the strength properties between solid (reference point) and laminated sample products, where when a smaller percentage is obtained, meaning the strength properties result of laminated sample products is close to solid (reference point) samples. The ranking is allocated by using the Garrett Score Ranking (Appendix).

The best or maximum result is assigned as a reference point from solid untreated and treated is 10 years old of superbulk species. Thus, Table 5.1 and Table 5.2 represent the percentage difference in mechanical strength properties of 10 years old *Acacia mangium* superbulk as a reference point for solid untreated and solid treated when compared with untreated laminated and treated laminated sample products at air-dry condition, respectively.

Table 5.1: Percentage Difference (%Δ) of Mechanical Properties Between 10 Years Old Solid Untreated and Laminated Untreated *Acacia mangium* superbulk Products at Air-dry Condition

		Solid Untreated (Year) Reference point	Laminated Untreated (Age Groups) Product					
		10	**7 // 7**	**10 // 10**	**13 // 13**	**7 // 10**	**7 // 13**	**10 // 13**
Mechanical Strength Properties	**MOR**	**115.11**	99.41	117.93	105.36	107.50	101.15	101.19
		%Δ	13.64	2.45	8.47	6.61	12.13	4.27
		Rank	6	1	4	3	5	2
		%Position	91.67	8.33	58.33	41.67	75.00	25.00
		Garrett Score	23	77	46	54	37	63
	MOE	**14945**	12022	14991	12603	13505	12288	13769
		%Δ	19.56	0.31	15.67	9.64	17.78	7.87
		Rank	6	1	4	3	5	2
		%Position	91.67	8.33	58.33	41.97	75.00	25.00
		Garrett Score	23	77	46	54	37	63
	C	**57.57**	52.56	59.63	54.61	55.70	52.10	57.26
		%Δ	8.70	3.58	5.14	3.25	9.50	0.54
		Rank	5	3	4	2	6	1
		%Position	75.00	41.67	58.33	25.00	91.67	8.33
		Garrett Score	37	54	46	63	23	77
	S	**14.24**	12.64	13.76	12.81	12.49	12.28	13.53
		%Δ	11.24	3.37	10.04	12.29	13.76	4.99
		Rank	4	1	3	5	6	2
		%Position	58.33	8.33	41.67	75.00	91.67	25.00
		Garrett Score	46	77	54	37	23	63
Average Garrett Score Ranking			32.25	71.25	48.00	52.00	30.00	66.50

*MOR: Modulus of Rupture, MOE: Modulus of Elasticity, C: Compression Parallel to Grain, S: Shear Parallel to Grain, //: Lamination,

Based on Table 5.1, the Garrett Score shows the highest score is obtained by the untreated laminated product age group of 10 // 10 when compared to the reference point. It can be concluded that there is no significant difference in strength performance between untreated *Acacia mangium* superbulk solid 10 years old and untreated laminated 10 // 10 years old samples at air-dry condition. Meanwhile, the Garrett Score for the treated sample products recorded the highest score obtained by laminated age groups product of 10 // 13 years old samples when compared to the reference point. This indicates that there is no significant difference in strength performance between treated solid 10 years old and treated laminated 10 // 13 years old samples, as presented in Table 5.2.

In Table 5.1 also, by referring to the highest Garrett Score, which is laminated 10 // 10 years old, the percentage difference of strength in MOR, MOE, compression parallel to grain and shear parallel to grain between solid and laminated products are 2.45%, 0.31%, 3.58% and 3.37%, respectively. Meanwhile, the highest Garrett Score recorded by treated conditions is laminated age groups of 10 // 13 years old samples, as presented in Table 5.2. Based on that table, the percentage differences obtained between solid and laminated sample products are 1.63%, 8.06%, 2.35% and 0.37%, which were recorded by MOR, MOE, compression parallel to grain and shear parallel to grain, respectively.

The highest Garrett Score ranking clarified that there is no significant difference in strength performance between solid samples and laminated sample products. For untreated condition, solid 10 years old and laminated 10 // 10 years old do not have any significant difference in strength properties. Meanwhile, treated solid 10 years old and treated laminated 10 // 13 years old do not have any significant difference in strength properties.

Table 5.2: Percentage Difference (%Δ) of Mechanical Properties Between 10 Years Old Solid Treated and Laminated Treated *Acacia mangium* superbulk Products at Air-dry Condition

		Solid Treated (Year) Reference point	Laminated Treated (Age Groups) Product					
		10	**7 // 7**	**10 // 10**	**13 // 13**	**7 // 10**	**7 // 13**	**10 // 13**
Mechanical Strength Properties	**MOR**	**118.76**	112.77	122.76	115.51	118.34	114.98	120.70
		%Δ	5.04	3.37	2.74	0.35	3.18	1.63
		Rank	6	5	3	1	4	2
		%Position	91.67	75.00	41.67	8.33	58.33	25.00
		Garrett Score	23	37	54	77	46	63
	MOE	**15020**	12276	15011	12795	13523	12320	13809
		%Δ	18.27	0.06	14.81	9.97	17.98	8.06
		Rank	6	1	4	3	5	2
		%Position	91.67	8.33	58.33	41.67	75.00	25.00
		Garrett Score	23	77	46	54	37	63
	C	**57.82**	53.57	60.08	55.24	57.21	55.21	59.18
		%Δ	7.35	3.91	4.46	1.05	3.89	2.35
		Rank	6	4	5	1	3	2
		%Position	91.67	58.33	75.00	8.33	41.67	25.00
		Garrett Score	23	46	37	77	54	63
	S	**13.67**	12.84	13.83	12.92	12.57	12.37	13.62
		%Δ	5.93	1.17	5.49	8.05	9.51	0.37
		Rank	4	2	3	5	6	1
		%Position	58.3	25.00	41.67	75.00	91.67	8.33
		Garrett Score	46	63	54	37	23	77
Average Garrett Score Ranking			28.75	55.75	47.75	61.25	40.00	66.50

*MOR: Modulus of Rupture, MOE: Modulus of Elasticity, C: Compression Parallel to Grain, S: Shear Parallel to Grain, //: Lamination

5.3 Strength Grouping

The strength grouping of tropical hardwood timber can be classified as SG1 to SG7, which is based on dry-grade stress corresponding to the bending, tension parallel to grain, compression parallel to grain and modulus of elasticity presented in Table 2.4 in Chapter 2 of this thesis. However, for this study, the strength grouping is classified as Group A, B, C and D based on compression strength parallel to grain, as stated in Table 2.5 in Chapter 2 of this thesis. The strength group also can be determined as strength groups A, B, C and D based on basic grade at air-dry condition (Table 2.9 in Chapter 2 of this thesis).

5.3.1 Strength Grouping Based on Compression Parallel to Grain (Burgess, 1958)

From the analysis that has been done, the strength grouping based on compression strength parallel to grain as stated in Table 2.5 in Chapter 2 of this thesis has been presented in Table 5.3. The strength grouping shown in Table 5.3 were based on compression strength at green condition that obtained by interpolation method of compression at air-dry from this study with compression at green from study done by Ismaili (2012), as shown in Table 2.3 in Chapter 2 of this thesis. Based on Table 5.3, the strength group for all age group of 7, 10, and 13 years old samples for solid and laminated are classified as Group B. This is referred to Table 2.5 in Chapter 2 of this thesis which is mentioned that compression strength parallel to grain at range 41.4 N/mm^2 to 55.2 N/ mm^2 are classified as Group B.

Table 5.3: Strength Grouping based on Compression Strength at Green Condition

Sample Product	Age	Compression at Air-dry (N/mm^2)	Compression at Green (N/mm^2)	Strength Group
Solid untreated	7	49.18	44.06	B
	10	57.57	51.57	B
	13	52.93	47.42	B
Solid treated	7	50.11	44.89	B
	10	57.82	51.80	B
	13	52.40	46.94	B
Laminated untreated	7 // 7	52.56	47.08	B
	10 // 10	59.63	53.42	B
	13 // 13	54.61	48.92	B
Laminated treated	7 // 7	53.57	47.99	B
	10 // 10	60.08	53.82	B
	13 // 13	55.24	49.49	B
Laminated untreated	7 // 10	55.70	49.90	B
	7 // 13	52.10	46.67	B
	10 // 13	57.26	51.29	B
Laminated treated	7 // 10	57.21	51.25	B
	7 // 13	55.57	49.78	B
	10 // 13	59.18	53.01	B

*//: lamination

5.3.2 Strength Grouping Based on Basic Grade (Air-dry Condition) (Chik, 1988)

Furthermore, the strength grouping analysis was also done according to the basic grade at air-dry condition (Chik, 1980) (Table 2.9 in Chapter 2 of this thesis). Based on strength grouping on basic grade at air-dry condition, all the samples are classified as group A (bending > 20 N/mm^2, compression > 17 N/mm^2, shear > 3 N/mm^2) as presented in Table

5.4.

Table 5.4: Strength Grouping based on Basic Grade at Air-dry Condition

Sample Product	Age	Bending	Compression	Shear	Strength Group at Air-dry
Solid untreated	7	A	A	A	A
	10	A	A	A	A
	13	A	A	A	A
Solid treated	7	A	A	A	A
	10	A	A	A	A
	13	A	A	A	A
Laminated untreated	7 // 7	A	A	A	A
	10 // 10	A	A	A	A
	13 // 13	A	A	A	A
Laminated treated	7 // 7	A	A	A	A
	10 // 10	A	A	A	A
	13 // 13	A	A	A	A
Laminated untreated	7 // 10	A	A	A	A
	7 // 13	A	A	A	A
	10 // 13	A	A	A	A
Laminated treated	7 // 10	A	A	A	A
	7 // 13	A	A	A	A
	10 // 13	A	A	A	A

*//: Lamination

5.4 The Recommendation for End-user Applications

The *Acacia mangium* superbulk species at air-dry condition is categorised as light hardwood, where the density collected is 0.61 g/cm^3 (0.40 – 0.72 g/cm^3). The recommended applications of light hardwood can be used as general utility timbers, excellent for high-class

joinery work, cabinet making, furniture, decorative panelling, etc. (Sulaiman & Lim, 2004), as presented in Table 5.5.

Table 5.5: The Application of *Acacia mangium* superbulk Based on Hardwood Category at Air-dry Condition

Hardwood category	Density (g/cm^3)	Applications	Source
Light hardwood (0.4 – 0.72 g/cm^3)	0.61	General utility timbers, excellent for high class joinery work, cabinet making, furniture, decorative panelling, etc.	Sulaiman and Lim (2004)

Furthermore, the application of *Acacia mangium* superbulk is also recommended based on strength grouping. Table 5.6 indicates the recommendation of application based on strength grouping by each of the samples at air-dry condition endorsed by MS (2011) and Chik (1998a,b).

The end-user utilisation for timber, either in commercial use or engineering field, depends on its maximum carried load and the surrounding where timber is executed. The timber is tested through experimental work on mechanical strength properties, including its elasticity, rupture, compression, and shear. The test is conducted on small-clear sizes, and the recorded strength is derived from structural sizes in the market or any desired measurement needed. The precise strength value is obtained from the small-clear specimen since it is a defect-free specimen, even when directly tested on a structural size specimen that might have a defect.

The only criteria in selecting the timber species that need to be utilised are identifying their strength or recognising their strength grouping. An evaluation of the mechanical strength properties of timber is an essential criterion for determining the strength grouping

of the timber species which is used for different end-use classifications and for establishing working stresses for structural designing (Alik & Liang, 2014). In obtaining the strength group of the timber species, there must be data from the green and air-dry conditions. However, this current study is only focused on completing at air-dry condition, so the discussions are elaborated by comparing the current air-dry strength result to the prior strength group study.

In this study, the mechanical strength properties of the *Acacia mangium* superbulk that has been analysed are not too diverse from the *Acacia mangium* that has been done by Alik and Liang (2014). It was reported that the strength value of *Acacia mangium* species at air-dry condition obtained are classified as strength group (SG) 5. Ismaili et al. (2011) and Ismaili et al. (2022c) also clarified that *Acacia mangium* is categorised under SG 5.

Necessarily, the users need to identify the location where to apply or use the timber. The timber probably exposes to indoor, outdoor, above ground, inside the ground, in freshwater or in marine. Definitely, not all timber species are able to resist most exposures. Some of the timber needs to preserve and treated first before utilisation begins. In this part of this study, the *Acacia mangium* superbulk has experienced the treatment process by CCA type of preservative acted as protection to the timber samples. The *Acacia mangium* superbulk is classified as moderately difficult to treat (80 to 160 litre/m^3). The treatment process of the *Acacia mangium* superbulk species is important as this species has a high tendency to attack fungi, insects, and termites and is probably exposed to borers. Instead of enhancing the durability level of the *Acacia mangium* superbulk, the pro of treatability evaluation is also improving the timber working qualities by knowing their hazard class. Thus, it will develop a high demand for timber either from consumers or customers.

Table 5.6: Strength-Based Grouping Recommendation Application for Air-Dry Condition for Solid and Laminated *Acacia mangium* superbulk Products

Sample Product		Strength Group		Applications
		Burgess (1958)	Chik (1988a,b)	
Chik	Age			
Untreated	7	B	A	Structural components include columns, beams, bearers, studs, joist, ties, struts and form work. Roofing includes rafters, ties, struts, purlins, bracing & battens. Staircase includes stringers, treads, trimmer beam, handrail and balustrades. Flooring includes floor boarding, parquetry and skirtings. Walling includes wall, partition, framing, external and internal wall boarding, slate screens and facia boards. Ceiling frames include cover battens to joint of ceiling strips, ceiling strips and soffit battens. Door and window frames include door, window and vent frames and vent sashes. Furniture includes built-in fittings, general furniture, workshop furniture and science laboratory tops. Beading fillets and general edgings.
	10	A		
	13	B		
Treated	7	B	A	
	10	A		
	13	B		
Untreated	7 // 7	B	A	
	10 // 10	A		
	13 // 13	B		
Treated	7 // 7	B	A	
	10 // 10	A		
	13 // 13	A		
Treated	7 // 10	A	A	
	7 // 13			
	10 // 13			
Untreated	7 // 10	A	A	Structural component, use as form work. Roofing, use as battens. Staircase, use as balustrades. Flooring, use as skirtings. Walling, use as wall, partition, framing, slate screens and external and internal wall boardings. Ceiling frame, use as ceiling strips and soffit
	7 // 13	B		
	10 // 13	A		battens. Use as door leaves, window and vent sashes. Furniture, built-in fittings, general furniture and workshop furniture. Beadings fillets and general edgings.

In addition, the treatability assessment to the timber species helps introduce the application of the timber in more hazardous conditions satisfactorily. The retention level of the preservative in the treated timber is determined by the hazard class of that timber species based on the MS 544 Part 10 (2003) and MS 1921 (2006) accordingly (refer to Table 2.11 in Chapter 2 of this thesis). From this study, the retention level of *Acacia mangium* superbulk found in the range of 14 kg/m^3, which is met the hazard class of H4. The previous treatability study that has been done by Lai and Sammy (2014) and Yahya et al. (2023) also reported that *Acacia mangium* is classified under the hazard class of H4. The hazard class of H4 can expose to the outside and in-ground. The typical uses for timber under H4 include fence posts, a greenhouse, pergolas, and landscaping, as presented in Table 5.7. The results from this hazard assessment will be the forecast of probability for the risk on health, safety, and environmental (Ismaili, 2012a). As highlighted by Rahim (2012) in her study, one of a primary focus area in hazard assessment is health, safety, and environmental considerations.

Table 5.7: The Recommendation of Application Based on Hazard Class

Hazard Class	Dry-salt Retention (kg/m^3)	Applications
H4 (12 – 16 kg/m^3)	± 14 kg/m^3	Fence posts, greenhouses, pergolas (in ground) and landscaping timber

Glue-laminated timber or glulam is one useful technique to improve the working performance of the timber. In other way, it also helps to produce more varieties of sizes of timber products in the market. It is also giving a variety of architectural effects that are impossible or difficult to obtain from other materials. A large quantity of lower grade timber can be used within the less highly stressed laminations of the beam. Bonded-wood products

such as plywood and glulam are superior to wood in many properties such as greater stability, more uniformly distributed strength, availability in standard dimensions and ease of handling and installation (Sahari & Inoue, 1996). Table 5.8 shows the recommendation of superbulk samples' condition in a way to customise user demand with its compatible strength.

Table 5.8: The Recommendation Sample Products Based on Strength and CCA Retention

		Strength		
		Low	**Medium**	**High**
CCA Retention	**None**	10 // 13 years old	10 years old	10 // 10 years old
	Low	7 // 7 years old	13 years old	10 // 10 years old
	Medium	7 // 10 years old	7 // 13 years old	10 // 13 years old
	High	7 years old	13 // 13 years old	10 years old

*//: lamination

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1 Conclusions

This study established the engineering properties of solid and laminated glulam products of *Acacia mangium* superbulk planted in Sarawak that involved three age groups, which are 7, 10, and 13 years old, at air-dry condition. This study examined the engineering properties of solid untreated and solid treated, laminated with same age groups untreated, laminated with same age groups treated, laminated with same age groups untreated, and laminated with different age groups treated. The samples have been treated with *Copper Chrome Arsenic* (CCA) and glued with *Phenol-resorcinol Formaldehyde* (PRF). A total of 8 trees from each of the age groups with a mean diameter breast height (DBH) of 27.10 cm were collected from Daiken Bintulu Plantation Sdn. Bhd. All the timber logs are processed at Samling Plywood Bintulu Sdn. Bhd. before transferring to Sarawak Forestry Corporation at Kuching for further process of air-drying and cutting into test samples. The sizes for the test samples were 20 x 20 x 300 cm (static bending), 20 x 20 x 60 cm (compression) and 20 x 20 x 20 cm (shear). The test results were recorded and analysed using mean analysis, linear regression analysis, one-way ANOVA, and Duncan's Multiple Range Test (DMRT). The findings have fulfilled the objectives of the study as follows.

i. The maximum mechanical strength properties result of *Acacia mangium* superbulk for solid untreated was obtained by the age group of 10 years old, which is recorded MOR 115.11 N/mm^2, MOE 14945 N/mm^2, compression parallel to grain 57.57 N/mm^2 and shear parallel to grain 14.24 N/mm^2 (tangential). For solid treated, the maximum MOR, MOE, compression parallel to grain and shear parallel to grain was

also obtained by the age group of 10 years old, which is recorded MOR 118.76 N/mm^2, MOE 15020 N/mm^2, compression parallel to grain 57.82 N/mm^2 and shear parallel to grain 13.67 N/mm^2 (tangential). The result of mechanical strength properties in treated were higher than in untreated, except for the shear result in untreated, which was slightly higher than in treated. For the laminated untreated product with the same age groups, the highest mechanical strength properties result was obtained by the age group of 10 // 10 years old, which is recorded MOR 117.93 N/mm^2, MOE 14991 N/mm^2, compression parallel to grain 59.63 N/mm^2 and shear parallel to grain 13.76 N/mm^2. For laminated treated products with the same age groups, the highest mechanical strength properties result was also obtained by 10 // 10 years old, which is recorded MOR 122.76 N/mm^2, MOE 15011 N/mm^2, compression parallel to grain 60.08 N/mm^2 and shear parallel to grain 13.83 N/mm^2 (tangential). The mechanical strength properties resulting from laminated untreated products in the same age group were higher than results from solid untreated products in the same age group, which is 10 years old. The laminated treated products with the same age groups also recorded higher mechanical strength properties results when compared to solid treated and laminated untreated products with the same age groups. The laminated untreated with different age groups 10 // 13 years old were recorded as having the highest mechanical strength properties result compared to 7 // 10 years old and 7 // 13 years old. The MOR, MOE, compression parallel to grain and shear parallel to grain recorded were 110.19 N/mm^2, 13769 N/mm^2, 57.26 N/mm^2 and 13.53 N/mm^2 (tangential), respectively. The laminated treated products with different age groups 10 // 13 years old, also recorded the highest mechanical strength properties compared to the other two age groups. The results obtained were

MOR 120.70 N/mm^2, MOE 13809 N/mm^2, 59.18 N/mm^2 and 13.62 N/mm^2 (tangential). The laminated treated products with different age groups recorded higher mechanical strength properties compared to untreated products. All the samples were at air-dry condition with an average MC of 18.74 % (solid) and 12.31 % (laminated), density at air-dry condition was 0.61 g/cm^3 and basic density 0.53 g/cm^3.

ii. The 10 years old solid, untreated and treated were assigned as reference points to compare with laminated products, as the 10 years old had the maximum mechanical strength at untreated and treated. The differences in strength from both samples were clarified by using the Garrett Score Ranking. The highest mean score from all mechanical strength results represented the strength performance of laminated sample products as a resemblance to the reference point (solid sample). For untreated, the highest mean Garrett score (71.52) was recorded by laminated 10 // 10 years old when compared to the reference point. For the treated group, the mean highest score (66.50) was obtained by laminated 10 // 13 years old when compared to the reference point. It was indicated that there was no significant difference in strength performance between untreated solid 10 years old and laminated 10 // 10 years old, and treated solid 10 years old and laminated 10 // 13 years old. Based on the highest mean of Garrett score, the mechanical strength results of laminated were slightly different from those of solid. For untreated, the percentage difference in mechanical strength of MOR, MOE, compression parallel to grain and shear parallel to grain was 2.45 %, 0.31 %, 3.58 % and 3.37 %, respectively. Meanwhile, for treated, the percentage difference in mechanical strength of MOR, MOE, compression parallel to grain and shear parallel to grain were 1.63 %, 8.06 %, 2.35 % and 0.37 %,

respectively.

iii. The mean of treatability retention levels by CCA preservative of *Acacia mangium* superbulk recorded were 145.52 litre/m^3 (solid), 143.39 litre/m^3 (laminated product by same age groups), and 144.35 litre/m^3 (laminated products by different age groups). Meanwhile, the mean dry-salt retention obtained was 14.55 kg/m^3 (solid), 14.34 kg/m^3 (laminated products by same age groups) and 14.44 kg/m^3 (laminated products by different age groups). Based on dry-salt retention, the hazard class obtained was H4, according to MS 544 (2003) and MS 1921 (2006).

iv. The strength group of *Acacia mangium* superbulk based on compression strength at air-dry condition was group B (41.4 N/mm^2 – 55.2 N/mm^2) for solid untreated, solid treated, laminated untreated products by same age groups, laminated treated products by same age group and laminated untreated products by different age groups, and Group A (> 55.2 N/mm^2) for laminated treated products by different age groups. Based on basic grade at air-dry condition, the *Acacia mangium* superbulk was obtained strength group of A (bending > 20 N/mm^2, compression > 17 N/mm^2, shear > 3 N/mm^2) for all samples. The end-user applications of *Acacia mangium* superbulk based on the hardwood category could be used for general utility timbers, excellent for high class joinery work, cabinet making, furniture, and decorative panelling as the density of *Acacia mangium* superbulk at air-dry condition was 0.61 g/cm^3 which categorized as light hardwood. Based on strength grouping, the end-user applications for solid untreated, solid treated, laminated untreated products by same age groups, laminated treated products by same age groups and laminated treated products by different age groups could be used for structural components (columns, beams, bearers, studs, joist, ties, struts and formwork), roofing (rafters, ties, struts, purlins,

bracing and battens), staircase (stringers, treads, trimmer beam, handrail and balustrades), flooring (floor boarding, parquetry and skirting), walling (wall, partition, framing, external and internal wall boarding, slate screens and facia boards), ceiling frames (cover battens to joint of ceiling strips, ceiling strips and soffit battens), door and window frames (door, window and vent frames and vent sashes), furniture (built-in fittings, general furniture, workshop furniture and science laboratory tops) and beading fillets and general edgings. Meanwhile, based on strength grouping, the end-user applications for laminated untreated products by different age groups could be used for structural components (formwork), roofing (battens), staircase (balustrades), flooring (skirtings), walling (wall, partition, framing, slate screens, external and internal wall boardings), ceiling frames (ceiling strips, soffit battens), door leaves, window, vent sashes, furniture (built-in fittings, general furniture and workshop furniture) and beading fillets and general edging.

6.2 Recommendations

The recommendations for further study are that the study shall determine the mechanical strength properties of *Acacia mangium* superbulk at the green condition and include other testing such as tension, impact bending, cleavage, and hardness. Classification based on MS 544 (SG1 to SG7) should be carried out. More discovery of strength properties of the other fast-growing timber species shall be needed to emphasize. Meanwhile, further studies shall also involve a sample that is made up of various age groups. For the glulam, the next study shall use other types of adhesives or glue that are available on the market, such as PVAc, EPI, etc. The layer for the glulam shall also be added layer by layer and be prepared to cross-laminate the glulam products with the same age group sample and different

age group samples. Besides that, the treatment process of the timber sample shall use other types of preservative chemicals that are approved by the government, such as water-borne borate, oil-borne creosote, or light organic solvent-borne (LOSP).

REFERENCES

Abdul Wahab, M. J., Jumaat, M. Z., & Khaidzir, M. O. M. (2013). Strength Assessment of Malaysian Timbers in Structural Size. In Rohana Hassan, Marina Yusoff, Zulhabri Ismail, Norliyati Mohd Amin, Mohd Arshad Fadzil (Eds.), *InCIEC 2013: Proceedings of the International Civil and Infrastructure Engineering Conference 2013* (pp. 15-26). Springer.

Adam, N. S., Jusoh, I., & Ishak, N. D. (2012, November 5-7). *Growth characteristics of Acacia mangium plantation in Sarawak* [Paper presentation]. 3rd International Plantation Industry Conference and Exhibition, Kota Kinabalu, Sabah.

Alik, D., & Kuroda, N. (1996, March 11-13). *The Relationship Between Basic Density and Mechanical Strength Properties of Some Sarawak Timbers* [Paper presentation]. TRTTC/STA Forest Products Seminar 96, Kuching, Sarawak.

Alik, D., & Liang, N. (2014, December 11). *Mechanical Properties of Acacia mangium* [Paper presentation]. Proceedings of the SFC/STA Research Seminar on Basic and Working Properties of *Acacia mangium* Planted in Sarawak, Kuching, Sarawak.

Alik, D., & Nakai, T. (2000, August 7-12). *Mechanical properties of Acacia mangium planted in Sarawak, Malaysia* [Paper presentation]. Forests and Society: The Role of Research: XXI IUFRO World Congress, Kuala Lumpur, Malaysia.

Alik, D., Lai, J. K., & Sammy, J. (2015). Properties and utilization of *Acacia mangium* planted in Sarawak. *Proceedings of the 17th Malaysian Forestry Conference, A Century of Forest Management: Lessons Learnt & the Way Forward* (pp. 472-476). Sabah Forestry Department. http://myagric.upm.edu.my/id/eprint/16707/1/2014%20-%2017th%20Malaysian%20Forestry%20Conference%20Proceedings.pdf

Alik, L.I., Bakar, E. S., Ashaari, Z., Ismail, P. N. K., Nuh, R. L., & Ismaili, G. (2016). Bend curve characteristics of phenol formaldehyde resin treated oil palm wood (*Elaeisguineensis* Jacq.). *Journal of Scinetific Research and Development, 2*(3), 21-27.

Ambrose, E., Jusoh, I., Duju, A., & Welman, N. (2022). Effects of Incision, Forced-air Drying, and Pressure Pretreatments on Wet Pockets, Drying Rate, and Drying Defects of *Acacia mangium* Wood. *BioResources, 17*(1), 1643-1658.

American Society for Testing and Materials. (1995). *Standard specification for adhesives used in laminate joints for nonstructural glued lumber products* (ASTM D3110). American Society for Testing and Materials.

American Society for Testing and Materials. (1999). *Standard specification for Adhesives Used for Laminate Joints in Nonstructural Lumber Products* (ASTM D5751). American Society for Testing and Materials.

American Society for Testing Materials. (1983). *Standard methods of testing small clear specimens of timber* (ASTM D-143-52). American Society for Testing and Materials.

Ashaari, Z. (2017). *Low density wood from poor to excellent.* Penerbit Universiti Putra Malaysia.

Australian Pesticides and Veterinary Medicines Authority. (2005). *Report of review findings and regulatory outcomes from the reconsideration of registrations of arsenic timber treatment products (CCA and arsenic trioxide) and their associated labels*. Australian Pesticides and Veterinary Medicines Authority. https://www.apvma.gov.au/sites/default/files/publication/14316-arsenic-summary.pdf

Balasso, M., Kutnar, A., Niemelä, E. P., Mikuljan, M., Nolan, G., Kotlarewski, N., &

O'Reilly-Wapstra, J. (2020). Wood properties characterisation of thermo-hydro mechanical treated plantation and native Tasmanian timber species. *Forests, 11*(11), 1189.

Bodig, J., & Jayne, B. A. (1993). *Mechanics of Wood Composites*. Van Nostrand Reinhold.

Bondmass, M. D. (2013). Sampling methods. In M. A. Mateo & M. D. Foreman (Eds.), *Research for advanced practice nurses: From evidence to practice* (p. 187). Springer.

Bootle, K. R. (1983). *Wood in Australia: Types, properties and uses.* McGraw-Hill.

British Standards Institution. (1957). *Method of testing small clear specimens of timber* (BS 373). British Standards Institution.

Burgess, H. J. (1958). *Strength Grouping of Malaysian Timbers* (Malayan Forest Service Trade Leaflet No. 25). Malaysian Timber Industry Board and Forest Research Institute Malaysia.

Calvert, B. (2009). *Module 8: Wood Utilization and Technology.* Nova Scotia Canada. https://novascotia.ca/natr/education/woodlot/modules/module8/

Canadian Wood Council. (1991). *Wood Reference Handbook: A Guide to the Architectural Use of Wood in Building Construction*. Canadian Wood Council.

Cheng, B., & Le Clue, S. (2010). *Issues for responsible investors: Forestry in Asia* (Finance for Nature Report Sep 2010). Responsible Research.

Chik, E. A. R. (1988a). *Basic and Grade Stresses for some Malaysian Timbers* (Malaysia Forest Service Trade Leaflet No 37). Malaysia Timber Industry Board and Forest Research Institute Malaysia.

Chik, E. A. R. (1988b). *Basic and Grade Stresses for Strength Group of Malaysian Timbers* (Malaysia Forest Service Trade Leaflet No 38). Malaysia Timber Industry Board and Forest Research Institute Malaysia.

Connelly, L. M. (2021). Introduction to analysis of variance (ANOVA). *Medsurg Nursing, 30*(3), 218-158.

Derikvand, M., Jiao, H., Kotlarewski, N., Lee, M., Chan, A., & Nolan, G. (2019). Bending performance of nail-laminated timber constructed of fast-grown plantation eucalypt. *European Journal of Wood and Wood Products, 77*, 421-437.

Derkowski, A., Kuliński, M., Trociński, A., Krzosek, S., & Mirski, R. (2022). Selected Mechanical Properties of Glue-Laminated Timber Produced from Locally Repaired Timber. *Materials, 15*(22), 8112.

Desch, H. E. (1981). *Timber Its Structure Properties and Utilisation* (6th ed.). Timber Press: Forest Glove.

Dhanavandan, S. (2016). Application of garret ranking technique: practical approach. *International Journal of Library and Information Studies, 6*(3), 135-140.

Fajar, A., Himmi, S. K., Latif, A., Tarmadi, D., Kartika, T., Guswenrivo, I., Yusuf, S., & Yoshimura, T. (2021). Termite assemblage and damage on tree trunks in fast-growing teak plantations of different age: A case study in West Java, Indonesia. *Insects, 12*(4), 295.

Faria, W.S., Resende, D.R., Guimarães, I.L, Protássio, T.D.P., & Guimarães Junior, J.B. (2015). Evaluation of physical-mechanical properties of Eucalyptus camaldulensis wood treated and not treated with preservative. *Enciclopédia Biosfera Journal, 11*, 287–293.

Firmanti, A., Komatsu, K., & Kawai, S. (2007). Effective utilization of fast-growing *Acacia mangium w*ild timber as a structural material. *Jurnal Ilmu dan Teknologi Kayu Tropis, 5*(1), 29-37.

Gurdal, Z., Haftka, R. T., & Hajela, P. (1999). *Design and optimization of laminated*

composite materials. John Wiley & Sons.

Hadi, Y. S., Rahayu, I. S., & Danu, S. (2013). Physical and mechanical properties of methyl methacrylate impregnated jabon wood. *Journal of the Indian Academy of Wood Science, 10*, 77-80.

Hall N., Turnbull J. W., Doran J. C., & Martenez, P. N. (1980). *Acacia mangium Willd* (Australian Acacia Series Leaflet 9 CSIRO). Division of Forest Research.

Hamid, H. A., & Abiri, R. (2022). The way forward of Forest Plantation in Malaysia. *IOP Conference Series: Earth and Environmental Science, 959*, 1-10. DOI 10.1088/1755-1315/959/1/012001

Ho, K. S., Hamdan, H., Tan, Y. E., & Mohd, S. M. (1999, April 20). *Acacia mangium for timber and a case study of utilisation* [Paper presentation]. 5th conference on forestry and forest product, 1999 Series, Utilisation of Plantation Timber: Sentang: Potential Timber for the Future, Forest Research Institute Malaysia, Kepong, Malaysia.

Hong, L.T., & Yamamoto, K. (1999, October 12-14). *Accelerated Technique for Estimating Natural Durability of Timbers* [Paper presentation]. TRTCC/STA Forests Products Seminar, Kuching, Sarawak.

https://www.admcf.org/research-reports/issues-responsible-investors-forestry-asia/

Ibach, R. E. (1999). Wood Preservation. In Forest Products Laboratory (Ed.), *Wood handbook: Wood as an engineering material* (pp. 1-27). U.S. Department of Agriculture, Forest Service, Forest Products Laboratory.

Ismaili, G. (2005). *Engineering Study on The Behaviour of Shrinkage and Compaction Between Peat and Modified Peat Soil* [Bachelor's thesis, Universiti Malaysia Sarawak]. UNIMAS Institutional Repository. chrome-extension://efaidnbmnnnibpcajpcglclefindmkaj/https://ir.unimas.my/id/eprint/2855/1/

Experimental%20study%20on%20the%20behaviour%20of%20shrinkage%20and%20compaction%20between%20peat%20and%20modified%20peat%20soil.pdf

Ismaili, G. (2007). *Establishment of an Empirical Relationship for Magnitude Conversion and the Construction of an Earthquake Catalogue with Magnitude Equal or Greater Than 5.0 Specific for Malaysia* [Unpublished master's thesis]. Universiti Sains Malaysia.

Ismaili, G. (2012). *Engineering Properties of Selected Sarawak Fast-Growing Indigenous Timber Species* [Unpublished doctoral dissertation]. Universiti Sains Malaysia.

Ismaili, G. (2012a). *Risk Study for the Impact of Deep Sea Oil Spill At Kikeh Field in Sabah, Malaysia: A Case Study of the Gulf of Mexico* [Unpublished master's thesis]. Universiti Teknologi Malaysia.

Ismaili, G. (2015). Engineering Properties of Fast-Growing Indigenous Timber in Sarawak Compare to *Acacia mangium*: Aras. *International Journal of Innovative Science and Modern Engineering, 3*(2), 8-12.

Ismaili, G., & Majid, T. A. (2007, May 29-31). *Establishment an empirical relationship equation of magnitude conversion specific for Malaysia* [Paper presentation]. Prosiding Kebangsaan Awam '07, Langkawi, Kedah.

Ismaili, G., Abdul Rahim, K. K., & Ismaili, Z. (2016). Strength group of Engkabang jantong as fast-growing indigenous species timber in Sarawak. *Journal of Scinetific Research and Development, 3*(2), 28.-32.

Ismaili, G., Abdul Rahim, K. K., Duju, A., Openg, I., & Ismaili, Z. (2015). Strength Classification of Aras as fast-growing indigenous species timber in Sarawak. *Applied Mechanics and Materials, 695,* 617-621.

Ismaili, G., Bakar, B. H. A., & Rahim, K. K. A. (2011). The Behavior of Strength Properties

from Three Different Tree Boles of Aras in Sarawak. *Journal of Civil Engineering, Science and Technology*, *2*(2), 48-52.

Ismaili, G., Bakar, B. H. A., & Rahim, K. K. A. (2011a). Basic and grade stress for some timber in Sarawak. *Journal of Civil Engineering, Science and Technology*, *2*(2), 35-38.

Ismaili, G., Bakar, B. H. A., & Rahim, K. K. A. (2011b). Evaluation of *Acacia mangium* in structural size at green condition. *Journal of Civil Engineering, Science and Technology*, *2*(2), 17-22.

Ismaili, G., Bakar, B. H. A., & Rahim, K. K. A. (2022a). Basic and grade stress for some timber in Sarawak. In Wan Ibrahim, W. H., Taib, S. N. L., & Sutan, N. M Eds.), *Civil Engineering, Scince and Technology Challenges: Structural Engineering and Construction Materials* (pp. 84-87). UNIMAS.

Ismaili, G., Bakar, B. H. A., & Rahim, K. K. A. (2022b). Evaluation of Acacia mangium in structural size at green condition. In Wan Ibrahim, W. H., Taib, S. N. L., & Sutan, N. M Eds.), *Civil Engineering, Scince and Technology Challenges: Structural Engineering and Construction Materials* (pp. 76-83). UNIMAS.

Ismaili, G., Bakar, B. H. A., & Rahim, K. K. A. (2022c). The Behavior of Strength Properties from Three Different Tree Boles of Aras in Sarawak. In Wan Ibrahim, W. H., Taib, S. N. L., & Sutan, N. M Eds.), *Civil Engineering, Scince and Technology Challenges: Structural Engineering and Construction Materials* (pp. 88-92). UNIMAS.

Ismaili, G., Enduat, E., Yahya, N. S., Malek, F. M., Jaimudin, N. A., Abdul Rahim, K. K., Wasli, M.E., Kalu, M., Openg, I., Rizalman, A.N., Liam, J., & Razali, B. (2022). Physical and Mechanical Properties Performance between Untreated and Treated with CCA Treatment at Different Age Groups of Fast-Growing Acacia Hybrid of

Sarawak. *Forests*, *13*(12), 1969. https://doi.org/10.3390/f13121969

Ismaili, G., Hisham Abu Bakar, B., Duju, A., Abdul Rahim, K. K., & Openg, A. (2013). Domination of grain bearing on the strength properties of Engkabang Jantong as fast-growing timber in Sarawak. *Iranian (Iranica) Journal of Energy & Environment*, *4*(3), 311-315.

Ivory, M. H. (1988). *Forest pathology consultancy final report.* Silviconsult Ltd/Compensatory Plantation Unit and Federal Forestry Department of Peninsular Malaysia.

Japanese Agricultural Standards. (2003). *Glued laminated timber* (JAS 234). Ministry of Agriculture, Forestry and Fisheries.

Jenang, K., & Inoue, M. (1996, March 11-13). *Effect of Incising Technique on Preservative Penetration of Refractory Timber Species* [Paper presentation]. Proceedings of TRTTC/STA Forest Products Seminar 96, Kuching, Sarawak.

Jenang, K., Kiguchi, M., & Kawamura, J. (1999, October 12-14). *Finishing Properties of Acacia mangium Grown in Sarawak Compared to Nyatoh Rian and Ramin* [Paper presentation]. Proceedings of TRTCC/STA Forests Products Seminar 99, Kuching, Sarawak.

Jøker, D. (2000). *Acacia mangium Willd* (Seed Leaflet No. 3). Danida Forest Seed Centre, Denmark.

Josza, L. A., & Middleton, G. R. (1994). *A Discussion of Wood Quality Attributes and their Practical Implication*. Natural Resources Canada and British Columbia Ministry of Forests.

Jusoh, I., & Adam, N. S. (2014). *Acacia mangium Plantation in Sarawak and its Wood Quality*. Faculty of Resources Science and Technology, Universiti Malaysia Sarawak.

Jusoh, I., Abu Zaharin, F., & Adam, N. S. (2014). Wood Quality of Acacia Hybrid and Second-Generation *Acacia mangium*. *BioResources*, *9*(1), 150-160.

Kho, P. C. S., Foo, E. P. L., & Hoi, K. G. (1999, October 12-14). *Dimensional Stability of Some Sarawak Timber Species* [Paper presentation]. Proceedings of TRTCC/STA Forests Products Seminar 99, Kuching, Sarawak.

Krishnapillay, B., & Abdul, R. (2000). *Feasibility of planting high quality timber species in Peninsular Malaysia* (JIRCAS Working Report 16). Japan International Research Center for Agricultural Science.

Krisnawati, H., Kallio, M., & Kanninen, M. (2011). *Acacia mangium Willd.: ecology, silviculture, and productivity*. Center for International Forestry Research.

Kumari, K., & Yadav, S. (2018). Linear Regression Analysis Study. *Journal of the practice of Cardiovascular Sciences*, *4*(1), 33-36.

Lai, J. K., & Sammy, J. (2014, December 11). *Treatability Assessment* [Paper presentation]. Proceedings of the SFC/STA Research Seminar on Basic and Working Properties of Acacia mangium Planted in Sarawak, Kuching, Sarawak.

Larcher, W. (2003). *Physiological plant ecology: Ecophysiology and stress physiology of functional groups*. Springer.

Lee, S. (2005). Diseases and potential threats to *Acacia mangium* plantations in Malaysia. *Mortality*, *30*(10).

Lee, S. S., Teng, S. Y., Lim, M. T., & Kader, R. A. (1988). Discolouration and heart rot of *Acacia mangium* Willd. -some preliminary results. *Journal of Tropical Forest Science*, 170-177.

Lee, S. S., Teng, S. Y., Lim, M. T., & Kader, R. A. (2014). Fixation and Leaching Characteristics of CCA-Treated Malaysian Hardwood. *Journal of Tropical Forest*

Science, 27(4), 488-497.

Lemmens, R. H. M. J., Soerianegara, I., & Wong, W. C. (1995). *PROSEA Timber trees: Minor commercial timbers* (Vol. 5/2). PUDOC.

Lim, S. C. (1986). *Uses of some Malaysian timbers* (Timber Trade Leaflet, (31, revised), 48). Malaysian Timber Industry Board and Forest Research Institute Malaysia.

Lim, S. C., Gan, K. S., & Choo, K. T. (2003). The characteristics, properties, and uses of plantation timbers-rubberwood and *Acacia mangium* (Timber Technology Bulletin, 26). Forest Research Institute Malaysia.

Ling, W.C., & Wong, A. H. H. (2005). *Tropical In-Ground Durability of Structural Sarawak Hardwoods Impregnated to High Retention with CCA-salts, CCA-oxide and FCAP after 20 Years Exposure* (IRG/WP 05-30384). International Research Group on Wood Protection, Wood Protecting Chemicals.

Loffer, L. (2018, April 10). *Acceptable Moisture Levels in Wood – Knowing the Moisture Content*. Wagner Meters. https://www.wagnermeters.com/moisture-meters/wood-info/acceptable-moisture-levels-wood/

Lu, H., Condés, S., del Río, M., Goudiaby, V., den Ouden, J., Mohren, G. M., Schelhaas, M. J., de Waal, R., & Sterck, F. J. (2018). Species and soil effects on overyielding of tree species mixtures in the Netherlands. *Forest Ecology and Management*, *409*, 105-118.

Malaysia Timber Industry Board. (2019a). *Development of Forest Plantation Programme*. Malaysia Timber Industry Board.

Malaysia Timber Industry Board. (2019b). *Strength Groups of Timber and Their Applications.* Malaysia Timber Industry Board.

Malaysia Timber Industry Board. (2019c). *Timber Species.* Malaysia Timber Industry Board.

Malaysian Standard. (2001). *Glued laminated timber – Performance Requirements and Minimum Production Requirements* (MS758). Malaysian Standard, Department of Standards Malaysia.

Malaysian Standard. (2003). *Code of Practice for Structural Use of Timber: Preservative Treatment of Structural Timber* (MS544 Part 10). Malaysian Standard, Department of Standards Malaysia.

Malaysian Standard. (2006). *Treatment of Roof, Ceiling and Timber Roof Components with Copper-Chrome-Arsenic Preservatives for Indoor Above-Ground Use Specifications* (MS 1921). Malaysian Standard, Department of Standards Malaysia.

Marini, H. H., & Kee, P. Y. (2002, November 21-22). *Characteristics and Strength Properties of Structural Hardwood Plywood Product in Sarawak* [Paper presentation]. Proceeding of TRTTC/STA Forest Products Seminar, Kuching, Sarawak.

McKenzie, W.M.C. (2000). *Design of Structural Timber*. McGraw-Hill.

Mishra, P., Singh, U., Pandey, C. M., Mishra, P., & Pandey, G. (2019). Application of student's t-test, analysis of variance, and covariance. *Annals of cardiac anaesthesia*, *22*(4), 407.

Mobolaji, O. C., Adeyemo, S. M., Majekobaje, A. R., Olusola, A. O., Omole, A. O., Oyelere, A. T., Alagbada, O. R., & Oluborode, J. O. (2022). Evaluation of Selected Mechanical Properties of Blighia sapida K. Koenig Wood. *Asian Journal of Applied Sciences*, *10*(3), 258-266. https://doi.org/10.24203/ajas.v10i3.6977

Mohd Yusof, N., Md Tahir, P., Lee, S. H., Khan, M. A., & Mohammad Suffian James, R. (2019). Mechanical and physical properties of Cross-Laminated Timber made from *Acacia mangium* wood as function of adhesive types. *Journal of Wood Science*, *65*, 1-11.

Mohd Zin J., Dawen J., and Sahri, M. H. (1991). Physical and Mechanical Properties of *Acacia mangium* Wild. of Selected Ages Grown in Malaysia. *Proceedings of Symposium on Recent Developments in Tree Plantations of Humid/Sub-humid Tropics of Asia*, 774-781.

Montgomery, D. C., Peck, E. A., & Vining, G. G. (2021). *Introduction to linear regression analysis.* John Wiley & Sons.

Moody, R. C., & Hernandez, R. (1997). *Glued-laminated timber*. Forest Product Laboratory. USDA Forest Service.

Nair, K. S. S. (2000). *Insect pests and diseases in Indonesian forests. An assessment of the major threats, research efforts and literature.* Center for International Forestry Research.

National Association of Forest Industries. (2004). *NAFI Timber Manual Data file P1 - Timber Species and Properties.* National Association of Forest Industries.

National Research Council. (1930). *Mangium and other fast-growing acacias for the humid tropics*. National Research Council.

Nguyen, L., Alwi, A., Japarudin, Y., Moltchanova, E., & Bloomberg, M. (2022). Using miniature plots to assess the effects of soils on the productivity of tropical plantation forests: a case study from Sabah, Malaysia. *New Forests*, 1-17.

Old, K. M., See, L. S., Sharma, J. K., & Yuan, Z. Q. (2000). *A manual of diseases of tropical acacias in Australia, South-East Asia, and India*. Centre for International Forestry Research.

Peh, T. B., & Khoo, K. C. (1984). Timber properties of *Acacia mangium, Gmelina arborea,* and *Paraserianthes Albizia falcataria* and their utilization aspects. *Malaysian Forester, 47*(3-4), 285-303.

PERKASA. (2004). *Borneo Tree Seeds and Seedlings Supplies Sdn. Bhd. embarks on large scale production for commercial purposes.* Sarawak Timber Industry Development Corporation Newsletter

Pun, C., Seng, H., Midon, M. S., & Abdul, R. (1997). *Timber design handbook.* Forest Research Institute Malaysia.

Rabbi, M. F., Islam, M. M., & Rahman, A. M. (2015). Wood preservation: Improvement of mechanical properties by vacuum pressure process. *International Journal of Engineering and Applied Sciences*, *2*(4), 75-79.

Rahim, K. K. A. (2012). *Safety Management for Deepwater Oil Exploration in Malaysia: A Case Study of the Gulf of Mexico* [Unpublished master's thesis]. Universiti Teknologi Malaysia.

Rajakaruna, M. (2015). *Properties of Timber*. The University of Western Australia.

Ratnasingam, J., Ioras, F., Farrokhpayam, S. R., Mariapan, M., Latib, H. A., & Liew, K. C. (2021). Perceptions by smallholder farmers of forest plantations in Malaysia. *Forests*, *12*(10), 1378.

Ross, A., & Willson, V. L. (2017). One-way Anova. *Basic and Advanced Statistical Tests*, 21-24.

Sabila, S., Syaidatul, S., Zaidon, A., Mohd Hamami, S., Choi Y. S., & Kim, G. H. (2015). Fixation and Leaching Characteristics of CCA-Treated Malaysian Hardwood. *Journal of Tropical Forest Science 2*, *27*(4), 488-497.

Sahari, S. H. and Inoue, A. (1996, March 11-13). *Bonding Properties of Bonded-wood Products Made in Sarawak* [Paper presentation]. Proceedings of TRTT/STA Forests Products Seminar, Kuching, Sarawak.

Sahri, M. H. (1990). The Durability of *Phenol-Resorcinol Formaldehyde* Glue Joints on

Three Malaysian Hardwood Species. *Pertanika*, *13*(2), 159-163.

Sahri, M. H., Ashaari, S., & Md Tahir, P. (2002, November 21-22). *Stressed Wood in Plantation Timbers: Behaviour and Performance* [Paper presentation]. Proceedings of the TRTT/STA Forests Products Seminar, Kuching, Sarawak.

Sahri, M. H., ASHAARI, Z., Kader, R. A., & Mohmod, A. L. (1998). Physical And Mechanical Properties of *Acacia mangium* and *Acacia* Auriculiformis from Different Provenances. *TROPICAL*, *21*(2), 73.

Salmiah, U., Baharudin, K., & Sabri, A. (2011b). *Assessment of Durability using Accelerated Test. Properties of Acacia mangium Planted in Peninsular Malaysia*; *ITTO Project in Improving Utilisation and Value Adding of Plantation Timbers from Sustainable Sources in Malaysia* (Project No. PD 306/04(1)). Forest Research Institute Malaysia.

Salmiah, U., Lai, J. K., Sammy, J., & Jenang, K. (2011a). *Treatability Assessment of Durability using Accelerated Test: Properties of Acacia mangium Planted in Peninsular Malaysia; ITTO Project in Improving Utilisation and Value Adding of Plantation Timbers from Sustainable Sources in Malaysia* (Project No. PD 306/04(1)). Forest Research Institute Malaysia.

Sammy, J., & Lai, J. K. (2014, December 11). *Accelerated Decay Resistance Assessment* [Paper presentation]. Proceedings of the SFC/STA Research Seminar on Basic and Working Properties of *Acacia mangium* Planted in Sarawak, Kuching, Sarawak.

Selbo, M. L. (1975). *Adhesive Bonding of Wood*. United States Department of Agriculture.

Senthilnathan, S. (2019). Usefulness of correlation analysis. *SSRN Electronic Journal*, 2-9.

Serrano, E. (2002). Mechanical Performance and Modelling of Glulam. *Timber Engineering. Lund University Publications*, 67-80.

Siau, J. F. (2012). *Transport processes in wood*. Springer Science & Business Media.

Sikora, K. S., McPolin, D. O., & Harte, A. M. (2016). Shear Strength and Durability Testing of Adhesive Bonds in Cross-Laminated Timber. *The Journal of Adhesion*, *92*(7-9), 758-777.

Sudin, M., Lee, S. S., & Harun, A. H. (1993). A Survey of Heart Rot in Some Plantations of *Acacia mangium* in Sabah. *Journal of Tropical Forest Science*, 37-47.

Sulaiman, A., & Lim, S. C. (2004). *Structure and Identification of Malayan Woods* (Malayan Forest Records No. 25). Forest Research Institute Malaysia.

Sulistyawati, I., Hadi, Y. S., Surjokusumo, S., & Nugroho, N. (2008, June 2-5). *The Performance of Lamina's Thickness for Horizontally Glued Laminated Beam* [Paper presentation]. Proceedings of the 10th World Conference on Timber Engineering 2008, Miyazaki, Japan.

Suryono, J. (2015). Development Connections Lamina Wood Adhesive on the Quality Strength in Construction. *International Journal of Trend in Research and Development*, *2*(15).

Tan, Y. E., Lim, N. P. T., Gan, K. S., Wong, T. C., Lim, S. C., & Thilagawathy, M. (2010). *Testing methods for plantation grown tropical timbers; ITTO Project on Improving Utilisation and Value Adding of Plantation Timbers from Sustainable Sources in Malaysia* (Project No. PD 306/04 (1)). Forest Research Institute Malaysia.

Thelandersson, S., & Larsen, H. J. (2003). *Timber Engineering*. John Wiley & Sons.

Ting, K. B., & Teng, X. Y. (2014, December 11). *Finger-jointing and Lamination Properties* [Paper presentation]. Proceedings of the SFC/STA Research Seminar on Basic and Working Properties of *Acacia mangium* Planted in Sarawak, Kuching, Sarawak.

United States Department of Agriculture. (1988). *Dry Kiln Operator Manual*. USDA Forest Service, Forest Products Lab., Hardwood Research Council, Memphis, TN, USA.

Wan Mohamad, W. H., Ahmad, Z., & Abd. Jalil, A. (2014). Bending Strength of Glulam from Selected Malaysian Hardwood Timber. *Advanced Materials Research, 879*, 237-244.

Wiedenhoeft, A. C., & Miller, R. B. (2005). Structure and Function of Wood. *Handbook of Wood Chemistry and Wood Composites*, 9-33.

Winandy, J. E. (1994). *Wood Properties*. Encyclopaedia of Agricultural Science.

Wong, A. H. H. (2006). *Laboratory Evaluation of Soft Rot Resistance of Nondurable Lesser-Known Malaysian Hardwoods* (Document No. IRG/WP, 06-10582). International Research Group on Wood Protection.

Wong, A. H. H., Jem, J. M. E., & Lai, J. K. (2012). *Classifying White Rot Decay Resistance of Some Hardwoods from Sarawak and Peninsular Malaysia and their Correlations with their Tropical In-Ground Durability* (Protection Document No: IRG/WP 12-10788). International Research Group on Wood Protection.

Wong, A. H. H., Singh, A. P., & Ling, W. C. (1996, March 11-13). *Major decay types recognised in an extremely durable timber species Belian (Eusideroxylon zwageri) from East Malaysia* [Paper presentation]. Proceedings of the TRTTC/STA Forest Products Seminar 96, Kuching, Sarawak.

Yahya, N. S., & Ismaili, G. (2015). Mechanical Properties of *Endospermum diadenum* sp. Grown in Sarawak. *International Advanced Research Journal in Science, Engineering and Technology (IARJSET). 2*(11). http://dx.doi.org/10.17148/IARJSET.2015.21127

Yahya, N. S., Ismaili, G., Kalu, M., Wasli, M. E., Openg, I., Jaimudin, N. A., Hashim, M. Z., Rizalman, A. N., Mohammad, H., Abdul Rahim, K. K. (2023). The Mechanical Strength Properties, Treatability Retention and Hazard Classification of Treated Small-Clear Fast-Growing *Acacia mangium* Superbulk at Different Age Groups.

Forests, 14(8), 1529. https://doi.org/10.3390/f14081529

Yamamoto, K., Sulaiman, O., Kitingan, C., Choon, L. W., & Nhan, N. T. (2003). Moisture Distribution in Stems of *Acacia Mangium*, *A. Auriculiformis* and Hybrid Acacia Trees. *Japan Agricultural Research Quarterly: JARQ*, *37*(3), 207-212.

Yang, M. C., & Voon, S. L. (2014, December 11). *Wood Anatomy and Quality* [Paper presentation]. Proceedings of the SFC/STA Research Seminar on Basic and Working Properties of *Acacia mangium* Planted in Sarawak, Kuching, Sarawak.

Zakaria, I., Wan Razali, W.M., Hashim, M.N. and Lee, S.S. (1994). *The Incidence of Heart Rot in Acacia mangium Plantations in Peninsular Malaysia* [Pamphlet]. Forest Research Institute Malaysia.

APPENDICES

A. Garrett Ranking Conversion Table

Percent	Score	Percent	Score	Percent	Score
0.09	99.00	22.32	65.00	83.31	31.00
0.20	98.00	23.88	64.00	84.56	30.00
0.32	97.00	25.48	63.00	85.75	29.00
0.45	96.00	27.15	62.00	86.89	28.00
0.61	95.00	28.86	61.00	87.96	27.00
0.78	94.00	30.61	60.00	88.97	26.00
0.97	93.00	32.42	59.00	89.94	25.00
1.18	92.00	34.25	58.00	90.83	24.00
1.42	91.00	36.15	57.00	91.67	23.00
1.68	90.00	38.06	56.00	92.45	22.00
1.96	89.00	40.01	55.00	93.19	21.00
2.28	88.00	41.97	54.00	93.86	20.00
2.69	87.00	43.97	53.00	94.49	19.00
3.01	86.00	45.97	52.00	95.08	18.00
3.43	85.00	47.98	51.00	95.62	17.00
3.89	84.00	50.00	50.00	96.11	16.00
4.38	83.00	52.02	49.00	96.57	15.00
4.92	82.00	54.03	48.00	96.99	14.00
5.51	81.00	56.03	47.00	97.37	13.00
6.14	80.00	58.03	46.00	97.72	12.00
6.81	79.00	59.99	45.00	98.04	11.00
7.55	78.00	61.94	44.00	98.32	10.00
8.33	77.00	63.85	43.00	98.58	9.00
9.17	76.00	65.75	42.00	98.82	8.00
10.06	75.00	67.48	41.00	99.03	7.00
11.03	74.00	69.39	40.00	99.22	6.00
12.04	73.00	71.14	39.00	99.39	5.00
13.11	72.00	72.85	38.00	99.55	4.00
14.25	71.00	74.52	37.00	99.68	3.00
15.44	70.00	76.12	36.00	99.80	2.00
16.69	69.00	77.68	35.00	99.91	1.00
18.01	68.00	79.17	34.00	100.00	0.00
19.39	67.00	80.61	33.00		
20.93	66.00	81.99	32.00		

B. Journal Publications

Ismaili, G., Enduat, E., Yahya, N. S., Malek, F. M., Jaimudin, N. A., Abdul Rahim, K. K., Wasli, M.E., Kalu, M., Openg, I., Rizalman, A.N., Liam, J., & Razali, B. (2022). Physical and Mechanical Properties Performance between Untreated and Treated with CCA Treatment at Different Age Groups of Fast-Growing Acacia Hybrid of Sarawak. *Forests*, *13*(12), 1969. https://doi.org/10.3390/f13121969

Yahya, N. S., & Ismaili, G. (2015). Mechanical Properties of *Endospermum diadenum* sp. Grown in Sarawak. *International Advanced Research Journal in Science, Engineering and Technology (IARJSET). 2*(11). http://dx.doi.org/10.17148/IARJSET.2015.21127

Yahya, N. S., Ismaili, G., Kalu, M., Wasli, M. E., Openg, I., Jaimudin, N. A., Hashim, M. Z., Rizalman, A. N., Mohammad, H., Abdul Rahim, K. K. (2023). The Mechanical Strength Properties, Treatability Retention and Hazard Classification of Treated Small-Clear Fast-Growing *Acacia mangium* Superbulk at Different Age Groups. *Forests, 14*(8), 1529. https://doi.org/10.3390/f14081529