

Lecture Notes in Civil Engineering

Ahmad Beng Hong Kueh ·  
Lukas Beladi Sihombing ·  
Yee Yong Lee · Harianto Hardjasaputra ·  
Simone Stürwald *Editors*

# Proceedings of the 9th International Conference of EURO ASIA Civil Engineering Forum – Volume 1

EACEF 2025, September 9–11, Kuching,  
Malaysia

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Editors

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# Preface

Civil engineering has long been at the leading edge of human civilization, offering the essential infrastructure that continually strives for advances in both theoretical aspects and practical applications. To date, it experiences ever-expanding challenges that require sustainable, resilient, and future-ready solutions. In this spirit, the 9th International Conference of Euro Asia Civil Engineering Forum (EACEF 2025) was organized with the theme “Beyond Boundaries: Empowering Innovations in Civil and Environmental Engineering.” The conference illuminates the importance of interdisciplinary collaboration and cutting-edge research to meet future needs.

The event was hosted by Universiti Malaysia Sarawak (UNIMAS) in cooperation with Universitas Pembangunan Jaya (UPJ), Indonesia, at Dewan Tunku Abdul Rahman Putra (DeTAR Putra), UNIMAS, Sarawak, Malaysia, on 9–11 September 2025.

EACEF 2025 brought together researchers, academics, and practitioners from across the globe to share insights for a wide range of topics, including structural and materials engineering, geotechnical engineering, construction management, building information modeling, green and sustainable construction, geotechnical construction material innovations, water resources engineering, transportation engineering, and other developing fields within civil and environmental engineering.

This proceedings book reflects the rigorous academic readiness that was carried out for the conference. Eighty manuscripts were received. Each paper underwent a single-blind review process by at least two reviewers. Based on their recommendations and the publication committee’s evaluation, 37 papers were accepted for this book. This procedure ensures that the papers fulfill the required standards for quality and field-relevance.

We extend our heartiest gratitude to the authors for their valuable contributions, the reviewers for their critical and constructive comments, and the organizing team for their dedication in bringing this conference to fruition. We also acknowledge the institutional support from UNIMAS and UPJ, whose collaboration has enriched the success of this event.

To promote the healthy advancement of civil and environmental engineering, we hope that the research outcomes, discussions, and innovations in this proceeding will motivate future cross-disciplinary and cross-border cooperations.

November 2025

Ahmad Beng Hong Kueh  
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# Evaluating the Compressive Strength of Artificial Aggregate Blended with Fly Ash and Rice Husk Ash

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**Abstract.** In response to the severe environmental consequences of traditional aggregate mining, such as land subsidence, land damage, and contributions to climate change, this research explores a sustainable solution. The study focused on developing and testing artificial aggregates made from industrial by-products, aiming to reduce the construction industry's reliance on destructive mining. The primary material was fly ash, with varying amounts of rice husk ash used as a substitute to evaluate the effects on both specific gravity and strength. The manufacturing process centered on a geopolymer reaction, using an alkali activator solution of sodium silicate ( $\text{Na}_2\text{SiO}_3$ ) and sodium hydroxide ( $\text{NaOH}$ ) to bind the silica and alumina present in the ashes. A specific silica-to-alumina ( $\text{SiO}_2/\text{Al}_2\text{O}_3$ ) ratio of 2.6–3.6 was maintained. After forming the mixture into pellets, the aggregates were subjected to two distinct curing regimens for hardening: a rapid, high-temperature treatment at 600 °C for four hours, and a long-term cure over 28 days at ambient temperature. The results of strength testing conclusively validated the approach. The primary finding was that incorporating rice husk ash significantly enhanced the aggregate's durability. An optimal mixture was identified where a 5% substitution of fly ash with rice husk ash yielded the strongest final product. This successful outcome confirms the viability of using these industrial wastes as high-quality construction materials, presenting a promising pathway toward a more sustainable building industry.

**Keywords:** Artificial Aggregate · Building Material · Coarse Aggregate · Fly Ash · Rice Husk

## 1 Introduction

Open-pit mining can cause a reduction in soil stability due to water runoff. In addition, dust produced during mining and the transportation of mined rock can disrupt community activities and interfere with local traffic. According to Law Number 32 of 2009 in Indonesia on Environmental Protection and Management, environmental destruction is defined as any action that directly or indirectly alters the physical and biological characteristics of the environment, resulting in its reduced ability to support sustainable development. Therefore, researchers are looking for alternatives to using natural coarse aggregates by utilizing artificial aggregates formed from pozzolan reactions like geopolymer concrete but using a pelletized method to create grains that resemble natural coarse aggregates. Although natural coarse aggregates are still abundant in several regions of Java, particularly West Java and Central Java, Indonesia the use of manufactured aggregates is an important effort to reduce the demand for non-renewable resources. Furthermore, this approach promotes the utilization of environmentally friendly materials, whether derived from natural waste or industrial by-products.

In the pursuit of sustainable construction materials, the production of artificial aggregates from industrial and agricultural by-products—particularly fly ash (FA) and rice husk ash (RHA)—offers a route to reduce natural aggregate extraction while valorising waste streams. FA-based cold-bonded and alkali-activated artificial aggregates have shown promising physical and mechanical properties, and several recent studies have characterised their durability and abrasion behaviour, providing an important methodological precedent for evaluating novel blends [1]. In Indonesia, the production of fly ash reached approximately 8.7 million tons in 2021. To enhance the mechanical properties of fly ash, materials with high silica and alumina content, like rice husk ash, are needed. According to data from the Central Statistics Agency (2017), rice production in 2015 reached 70,846.5 million tons, but the waste from its processing has not been utilized optimally [2]. To improve the mechanical performance of fly ash-based aggregates, the addition of high-silica and alumina materials such as rice husk ash is highly beneficial. Based on data from the Central Statistics Agency (2017), rice production in 2015 reached 70,846.5 million tons, generating large quantities of waste that have yet to be fully utilized [2].

Rice husk ash, with its high reactive silica content, has been demonstrated to contribute positively to pozzolanic reactions and to enhance mechanical performance and certain durability indicators when incorporated into concretes and engineered aggregates; however, most recent RHA literature focuses on its use as a supplementary cementitious material or filler rather than as a co-constituent in artificial coarse aggregates for abrasion testing. This gap suggests the need to explicitly test abrasion resistance when RHA is combined with FA in artificial aggregate production [3].

Abrasion resistance (commonly measured by Los Angeles, Micro-Deval, Cantabro, or raveling/abrasion protocols in concrete studies) is a decisive indicator of aggregate suitability for wearing surfaces and traffic-exposed structural elements. Recent pervious-concrete and cold-mix asphalt studies that incorporate FA (and in some cases RHA or other SCMs) show that optimized SCM combinations can improve abrasion/wear properties—but these studies stop short of systematically evaluating abrasion of artificial aggregates containing blended FA + RHA [4].

## 2 Data Analysis

This research focuses on coarse aggregates made from eco-friendly materials that are byproducts from factories and production processes. These coarse aggregate materials will include fly ash and rice husk ash. The materials are then reacted with sodium hydroxide (NaOH) and sodium silicate ( $\text{Na}_2\text{Si}_2\text{O}_7$ ) to form bonds between silicon and aluminum, resulting in a strong unit. This reaction is commonly used in geopolymer concrete.

The production of artificial aggregates with the substitution of rice husk ash (RHA) using 3 variations: 0%, 5%, and 10% in fly ash due to the review of rice husk ash which has a high  $\text{SiO}_2$  content (Table 1).

**Table 1.** Variable Samples Artificial Aggregate

Variable (%)	Total Weight Agg (28 Days)	Molarity	Total Weight Agg
ASP (0%)	30 kg	12 M	30 kg
ASP (5%)	30 kg	12 M	30 kg
ASP (10%)	30 kg	12 M	30 kg
Total All Aggregate			90 kg

The data collection conducted in this research involves XRF testing (X-Ray fluorescence), which aims to determine the elemental composition of materials for creating artificial aggregates using Class F fly ash and rice husk ash. The XRF test is intended to provide information on the silica and alumina content in fly ash and rice husk ash (RHA).

Based on the results of the X-Ray Fluorescence (XRF) testing conducted at BRIN (National Research and Innovation Agency) located in Puspitek Serpong, it is stated that rice husk ash contains 38.489% of the total  $\text{SiO}_2$ ,  $\text{Al}_2\text{O}_3$ , and  $\text{Fe}_2\text{O}_3$  (Table 2).

**Table 2.** Content of Fly Ash

Name	Value	Name	Value
Si	19.30%	SiO <sub>2</sub>	41.40%
Fe	12.40%	Al <sub>2</sub> O <sub>3</sub>	22.70%
Al	12.00%	Fe <sub>2</sub> O <sub>3</sub>	17.70%
Ca	6.20%	CaO	8.70%
Mg	2.70%	MgO	4.50%
Na	0.80%	Na <sub>2</sub> O	1.10%
K	0.60%	SO <sub>3</sub>	1.00%
Ti	0.60%	TiO <sub>2</sub>	1.00%

(continued)

**Table 2.** (continued)

Name	Value	Name	Value
S	0.40%	K <sub>2</sub> O	0.70%
Mn	0.20%	P <sub>2</sub> O <sub>3</sub>	0.40%
P	0.20%	MnO	0.30%
Cl	0.10%	Cl	0.10%
Sr	0.10%	SrO	0.10%

### 3 Research Methodology

The production of artificial aggregates involves analyzing raw materials, such as fly ash and rice husk ash, using X-ray fluorescence (XRF) to determine their chemical composition. The SiO<sub>2</sub> and Al<sub>2</sub>O<sub>3</sub> contents are then calculated to ensure that substituting rice husk ash for fly ash maintains a SiO<sub>2</sub>/Al<sub>2</sub>O<sub>3</sub> ratio within the optimal 2.6–3.6 range for effective geopolymerization [5].

Next, the design of the alkaline activator is conducted, considering the proportions of fly ash, rice husk ash, and sand. The alkaline activator consists of 10% NaOH and 15% Na<sub>2</sub>SiO<sub>3</sub> for fly ash, with the overall mixture ratio of fly ash to bottom ash in previous research being 40%:60% of the total aggregate weight. In this study, fine aggregate in the form of sand is used to replace bottom ash due to its similar rough texture. A sieve analysis using a No. 16 mesh is performed to obtain finer sand particles suitable for the aggregate production.

The artificial aggregates are then produced using a concrete mixer tilted at 40° for 15–20 min while gradually adding the alkaline activator to facilitate pelletization. This method ensures proper agglomeration of the materials. Following production, the aggregates are oven-cured at 60 °C for 4 h, a process shown to increase the compressive strength of geopolymer concrete by up to 17.8% [6]. After oven-curing, the aggregates are stored at room temperature for 28 days before further testing.

Subsequently, the specific gravity of the artificial coarse aggregate is determined according to the Indonesian National Standard. This test measures the bulk specific gravity (oven-dry and saturated surface dry) and apparent specific gravity. Initially, the aggregates are oven-dried at 110 ± 5 °C for 24 h and then cooled to room temperature. The samples are then submerged in water for 24 h to achieve a saturated surface dry (SSD) condition. Mass measurements are taken in three states—oven-dry, SSD, and submerged in water—and these values are used to calculate the specific gravity parameters based on the standard SNI formula. The results provide crucial information regarding the density, porosity, and absorption characteristics of the artificial aggregates, which are essential for concrete performance and mix design.

Finally, the durability of the artificial coarse aggregates will be assessed through abrasion testing using the Los Angeles abrasion machine in accordance with the Indonesian National Standard (SNI) [7]. This test evaluates the resistance of the synthetic aggregates to mechanical wear and degradation. The abrasion value is determined by measuring the

percentage of weight loss after a specified number of rotations with standardized steel balls. These results will help determine the suitability of the aggregates for construction applications, particularly in structures requiring high mechanical performance and long-term durability.

## 4 Result Analysis

The abrasion test using the Los Angeles machine on manufactured aggregates is performed with grading A and 12 steel balls, according to SNI 2417:2008 [7] on the method for abrasion testing using the Los Angeles machine. Grading A requires 500 revolutions with coarse aggregates sized up to 37.5 mm (1½ inches) down to a particle size of 9.5 mm (3/8 inches).

In Tables 3, 4, 5 and 6, the abrasion test using the Los Angeles machine was conducted on artificial aggregates with variations in the test variables.

**Table 3.** Artificial Aggregate Abrasion Test Results 0% Rice Husk Ash Fly Ash Class F

Sieve Size (mm)				Gradation and Weight of Test Objects (gram)			
Pass Through		Retained By		A	Sample I	Sample II	Sample III
mm	inci	mm	inci				
75	3.0	63	2 ½	–	–	–	–
63	2 ½	50	2.0	–	–	–	–
50	2.0	37.5	1 ½	–	–	–	–
37.5	1 1/2	25	1	1250 ± 25	1250 ± 23	1250 ± 4,5	1250 ± 0
25	1	19	3/4	1250 ± 25	1250 ± 24	1250 ± 6,5	1250 ± 5
19	¾	12.5	½	1250 ± 10	1250 ± 5	1250 ± 2,5	1250 ± 3
12.5	½	9.5	3/8	1250 ± 10	1250 ± 3	1250 ± 5,5	1250 ± 6
9.5	3/8	6.3	¼	–	–	–	–
6.3	¼	4.75	No. 4	–	–	–	–
4.75	No. 4	2.36	No. 8	–	–	–	–
<b>Total</b>				5000 ± 70	5000 ± 10	5000 ± 8	5000 ± 14
<b>Amount of Ball</b>				12	12	12	12
<b>Weight of Ball (gram)</b>				5000 ± 25	5000 ± 25	5000 ± 25	5000 ± 25
<b>Amount Retained by The Filler Sieve no.12</b>				3988	4094	3775	
<b>Abrasion(%) = <math>\frac{a-b}{a} \times 100\%</math></b>					20.24	18.2507	24.71
<b>Average of Abrasion (%)</b>					21.066		

**Table 4.** Artificial Aggregate Abrasion Test Results 5% Rice Husk Ash Fly Ash Class F

Sieve Size (mm)				Gradation and Weight of Test Objects (gram)			
Pass Through		Retained By		A	Sample I	Sample II	Sample III
mm	inci	mm	inci				
75	3.0	63	2 ½	–	–	–	–
63	2 ½	50	2.0	–	–	–	–
50	2.0	37.5	1 ½	–	–	–	–
37.5	1 1/2	25	1	1250 ± 25	1249 ± 0	1250 ± 4	1250 ± 1
25	1	19	¾	1250 ± 25	1250 ± 6	1250 ± 8	1250 ± 5
19	¾	12.5	½	1250 ± 10	1250 ± 4	1250 ± 1	1250 ± 4
12.5	½	9.5	¾	1250 ± 10	1250 ± 0	1250 ± 3	1250 ± 2
9.5	¾	6.3	¼	–	–	–	–
6.3	¼	4.75	No. 4	–	–	–	–
4.75	No. 4	2.36	No. 8	–	–	–	–
<b>Total</b>				5000 ± 70	5000 ± 9	5000 ± 16	5000 ± 12
<b>Amount of Ball</b>				12	12	12	12
<b>Weight of Ball (gram)</b>				5000 ± 25	5000 ± 25	5000 ± 25	5000 ± 25
<b>Amount Retained by The Filler Sieve no.12</b>					4316	4050	4052
<b>Abrasion (%) = <math>\frac{a-b}{a} \times 100\%</math></b>					13.83	19.25	19.15
<b>Average of Abrasion (%)</b>					17.41		

**Table 5.** Artificial Aggregate Abrasion Test Results 10% Rice Husk Ash Fly Ash Class F

Sieve Size (mm)				Gradation and Weight of Test Objects (gram)			
Pass Through		Retained By		A	Sample I	Sample II	Sample III
mm	inci	mm	inci				
75	3.0	63	2 ½	–	–	–	–
63	2 ½	50	2.0	–	–	–	–
50	2.0	37.5	1 ½	–	–	–	–
37.5	1 1/2	25	1	1250 ± 25	1250 ± 5	1250 ± 13	1250 ± 0.5
25	1	19	¾	1250 ± 25	1250 ± 7	1250 ± 13	1250 ± 6
19	¾	12.5	½	1250 ± 10	1250 ± 6	1250 ± 3	1250 ± 3.5
12.5	½	9.5	¾	1250 ± 10	1250 ± 4	1250 ± 0	1250 ± 6
9.5	¾	6.3	¼	–	–	–	–
6.3	¼	4.75	No. 4	–	–	–	–

(continued)

**Table 5.** (continued)

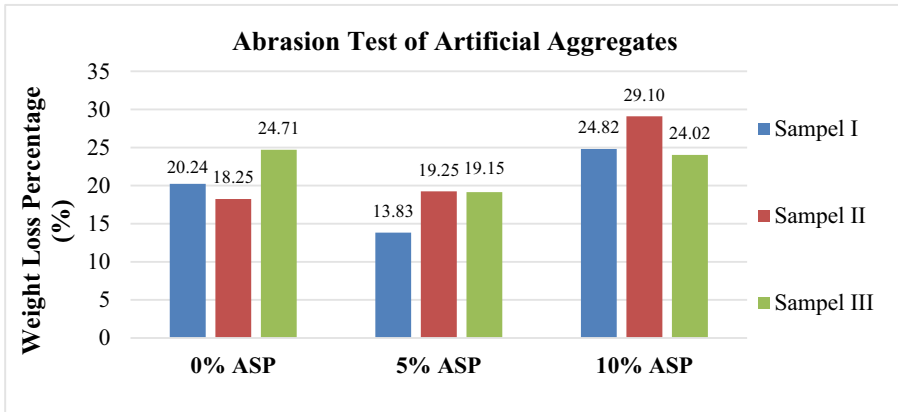
Sieve Size (mm)				Gradation and Weight of Test Objects (gram)			
Pass Through		Retained By		A	Sample I	Sample II	Sample III
mm	inci	mm	inci				
4.75	No. 4	2.36	No. 8	–	–	–	–
<b>Total</b>				5000 ± 70	5000 ± 29	5000 ± 29	5000 ± 16
<b>Amount of Ball</b>				12	12	12	12
<b>Weight of Ball (gram)</b>				5000 ± 25	5000 ± 25	5000 ± 25	5000 ± 25
<b>Amount Retained by The Filler Sieve no.12</b>				3781	3781	3565.5	3811
<b>Abrasion (%) = <math>\frac{a-b}{a} \times 100\%</math></b>				24.816	24.816	29.101	24.023
<b>Average of Abrasion (%)</b>				25.98			

**Table 6.** Natural Aggregate Abrasion Test

Sieve Size (mm)		Sample I	Sample II	Sample III
Pass Through The Filter	Retained By The Filter	Weight I(gr)	Weight II(gr)	Weight III(gr)
76,2	63.5	0	0	0
63,5	50.8	0	0	0
50,8	36.1	0	0	0
36,1	25.4	0	0	0
25,4	19.1	0	0	0
19,1	12.7	2500	2500	2500
12,7	9.52	2500	2500	2500
9,52	6.35	0	0	0
6,35	4.75	0	0	0
4,75	2.36	0	0	0
<b>Total Cycling</b>		500	500	500
<b>Amount of Ball</b>		11	11	11
<b>Weight of Ball (gram) (a)</b>		5000	5000	5000
<b>Amount Retained by The Filler Sieve no.12</b>		3985	4123	4012
<b>Abrasion (%) = <math>\frac{a-b}{b} \times 100\%</math></b>		20.3	17.54	19.76
<b>Deviation of sampel I, II, dan III</b>		2.22		
<b>Average of Abrasion (%)</b>		18.92		

Figure 1 explained that graph illustrates the results of the abrasion test for artificial aggregates with varying percentages of ASP (0%, 5%, 10%). The weight loss percentage represents the material's resistance to abrasion, where a lower value indicates better

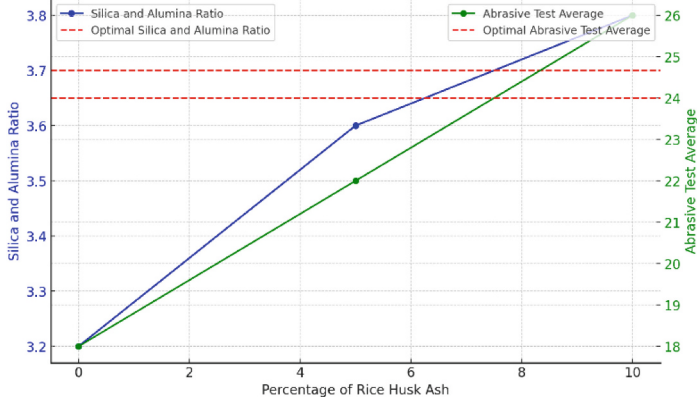
durability. At 0% ASP, Sample III shows the highest weight loss (24.71%), indicating lower resistance compared to Sample I and Sample II. When 5% ASP is added, all samples exhibit reduced weight loss, with Sample I shows the best performance (13.83%), suggesting improved strength and abrasion resistance. However, at 10% ASP, the weight loss increases again, especially for Sample II (29.10%), indicating that excessive ASP content may reduce the aggregates' mechanical strength.



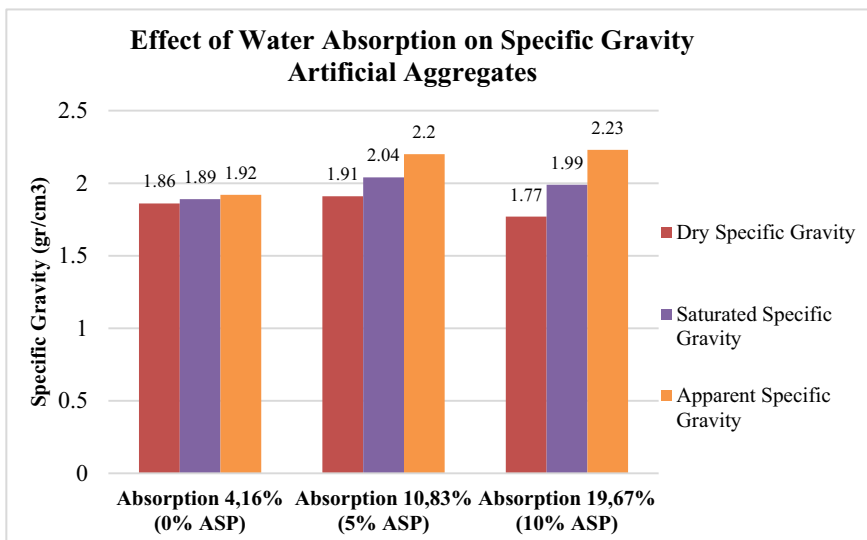
**Fig. 1.** Graphic Abrasive Test of Artificial Aggregates

Figure 2 also shows the importance of the limits on the  $S_iO_2/Al_2O_3$  ratio established in earlier research, which set the limit at a  $S_iO_2/Al_2O_3$  ratio of 2.6 – 3.6 [5]. It has been proven to affect the strength of artificial aggregates in abrasion tests, where a sample with a 10% rice husk ash content achieved the highest  $S_iO_2/Al_2O_3$  ratio of 4.216. The graph illustrates the impact of the  $S_iO_2/Al_2O_3$  ratio on the abrasion test results for the rice husk ash percentage samples (RHA).

Effect of Silica and Alumina Ratio on Abrasive Test Results with Addition of Rice Husk Ash Percentage



**Fig. 2.** Graphic Relationship between Effect of Silica dan Alumina Ratio on Abrasive Test Result with Addition of Rice Husk Ash Percentage (Fig. 3)



**Fig. 3.** Graphic Effect of Water Absorption on Specific Gravity Artificial Aggregates

Testing the specific gravity of artificial aggregates with substitution percentages of rice husk ash at 0%, 5%, and 10% to determine the differences in specific gravity between artificial aggregates and natural coarse aggregates according to SNI 03-1969:2008[8].

Testing the specific gravity of artificial aggregate shows that at a rice husk ash percentage of 0%, the average specific gravity is 1.89 g/cm<sup>3</sup>. At a rice husk ash percentage of 5%, the average specific gravity is 2.05 g/cm<sup>3</sup>, and at a rice husk ash percentage of 10%, the average specific gravity is 1.99 g/cm<sup>3</sup>. Results from previous studies on lightweight

aggregate indicate that the bulk density of lightweight aggregate is less than or equal to  $2.0 \text{ g/cm}^3$  [9].

Testing the specific gravity of artificial aggregates with substitution percentages of rice husk ash at 0%, 5%, and 10% aimed at determining the difference in specific gravity between artificial aggregates and natural coarse aggregates.

Testing the bulk density of artificial aggregates shows no correlation from the differences in the pelletization method. At a rice husk ash percentage of 0%, the bulk density is  $0.974 \text{ gr/cm}^3$  or  $974 \text{ kg/m}^3$ ; at a rice husk ash percentage of 5%, it's  $1.054 \text{ gr/cm}^3$  or  $1,054.0 \text{ kg/m}^3$ ; and at a rice husk ash percentage of 10%, it's  $0.997 \text{ gr/cm}^3$  or  $997 \text{ kg/m}^3$ . In the graph, the equation obtained is  $y = 0.0115x + 0.9853$  with an  $R^2$  value of 0.078, indicating that the bulk density of the aggregates shows no effect at rice husk ash percentages of 0%, 5%, and 10%. The bulk density results from previous lightweight aggregate research indicate that the bulk density of lightweight aggregates is less than or equal to  $1.2 \text{ g/cm}^3$  (Fig. 4).

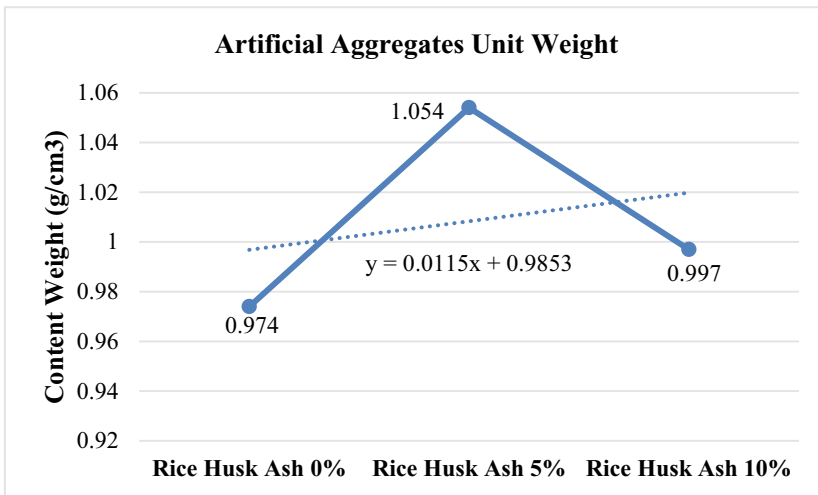


Fig. 4. Graphic Artificial Aggregates Unit Weight

## 5 Conclusion

The optimal substitution of rice husk ash for fly ash in this study was a percentage of 5% rice husk ash with an average crushed weight abrasion test value of 17.41%, an average specific gravity of  $1.97 \text{ g/cm}^3$ , and an average unit weight of  $1.008 \text{ g/cm}^3$  so that it can be classified as a lightweight aggregate[9]. The lowest water absorption of artificial aggregates was 4.16% at a percentage of 0% rice husk ash. These values classify the product as a lightweight aggregate suitable for construction applications. The results also showed that increasing the RHA content beyond 5% did not further improve the mechanical performance.

Furthermore, the study highlights the importance of maintaining a balanced  $\text{SiO}_2/\text{Al}_2\text{O}_3$  ratio, as it significantly influences the geopolymerization process and overall

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