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Compressive Strength and Water Absorption Capacity on Brick Interlock with Fly Ash Addition

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Abstract. *Interlock brick is an environmentally friendly substitute for house wall materials because the manufacturing process is not burned like red brick. This method of installing interlocking walls, like Lego, can function as a structure for sluice gates, columns and ring beams without the need for plastering or painting, so it is more effective and efficient and can reduce cement consumption. Several actions must be taken to minimize the use of cement by using environmentally friendly materials. One of the environmentally friendly materials that will be researched is Interlock bricks made from a mixture of Fly Ash . This research aims to determine the compressive strength and water absorption capacity of Interlock bricks mixed with Fly Ash. The research method begins by looking for interlock brick parameter data in the form of compressive strength and water absorption capacity. Compressive strength is a parameter of the mechanical suitability of interlock bricks , while water absorption is the ability of a material to absorb water. There are 3 variations of the mixture, namely with the ratio Fly Ash : Sand: Cement, mixture I (3: 3: 1) Fly Ash 43% , mixture II (4 : 3 : 1) Fly Ash 50% , and mixture III (5 : 3 : 1) Fly Ash 56% calculation divided based on the percentage of the amount of Fly Ash , obtained the compressive strength value of Interlock brick from the Fly Ash mixture in mixture I 16.0 kg/m2 and water absorption capacity 20%, mixture II 24.7 kg/m 2 and strength water absorption 17.5%, mixture III 10.3 kg/m 2 and water absorption 21.8%. According to SK-SNI-S-04-1989-F Interlock brick mix II with a Fly Ash composition of 50% is close to class K25 (25 kg/m 2) and has an absorption capacity value of <20.0% according to the absorption capacity limit based on SNI 15- 2094-2000*

Keywords: Interlock Bricks, Fly Ash, Compressive Strength, Water Absorption.

Introduction

The construction industry in Indonesia, a developing country, has shown notable growth, with a 4.88% increase in completed works by the 3rd Quarter of 2023, as reported by the Central Statistics Agency [1]. Traditional brick walls in building construction have been a common practice, but concerns have been raised regarding their safety during earthquakes, especially in supporting heavy objects. This has underscored the necessity for innovative wall materials that can offer improved safety standards. Lightweight concrete bricks have been explored as an alternative,

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although they often require additional finishing processes like trimming, plastering, and painting to achieve a polished building structure [2].

Innovations such as composite bricks, also known as interlock bricks, have been proposed as a solution to create lighter and more easily arranged walls [3]. These composite bricks not only offer a more environmentally friendly option compared to traditional materials but also eliminate the need for burning during manufacturing processes. Studies have shown that using composite bricks can lead to cost savings of up to 23% compared to red bricks, particularly in residential construction [4]. Researchers have focused on optimizing the compressive strength of interlock bricks through material ratios and water-cement modulus to ensure structural integrity [5].

By leveraging interlock bricks, which do not require additional finishing like plastering or painting, the construction process can become more efficient and effective. Furthermore, the use of sustainable and innovative building materials, such as interlock bricks made from a mixture of Fly Ash, has been emphasized to address the challenges faced by earthquake victims trapped under traditional brick walls [6]. These efforts aim to enhance the overall safety and efficiency of construction practices, particularly in regions prone to seismic activities.

The research aimed to address the challenges faced by earthquake victims trapped under traditional brick walls by proposing the use of lightweight concrete bricks and composite systems. By leveraging interlock bricks, which do not require plastering or painting, the construction process becomes more efficient and effective. The study also sought to analyze the water absorption test on interlock bricks made from a mixture of Fly Ash, emphasizing the importance of sustainable and innovative building materials in the construction industry.

Theoretical Background

Interlock Bricks

Interlocking bricks, are wall components designed with hooks on the sides to withstand compressive forces. These bricks feature puzzle-like locks on specific sides that interlock with adjacent bricks, eliminating the need for additional cement during installation. This characteristic offers advantages over traditional bricks by simplifying the installation process. Research by [7] emphasizes that interlocking bricks do not require post-treatments like plastering and painting, as the interlock system between bricks obviates the need for cement as an adhesive.

The robust interwoven style of interlocking bricks, highlighted by [7], makes them suitable for building wall construction due to their structural integrity and ease of installation. The simplicity and speed of installation are key factors driving the adoption of interlocking bricks. Other researcher further elaborates that interlocking bricks are assembled like puzzles, reducing the reliance on adhesive cement. Then [8] emphasizes that composite bricks, including interlocking bricks, can serve as structural components in buildings, offering high compressive strength and an efficient interlocking system.

Interlocking bricks not only provide structural stability but also enhance wall aesthetics and dimensional stability, as noted by various researchers. The interlocking mechanism of these bricks, equivalent to a compressive strength of 7800 kg/block or 2.6 MPa, as demonstrated by [8], ensures their suitability for diverse construction applications. The use of interlocking bricks,

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with their efficient installation process and inherent strength, presents a sustainable and cost-effective alternative to traditional brick construction methods.

Interlocking bricks are wall components designed with hooks on the sides to withstand compressive forces. These bricks feature puzzle-like locks on certain sides that interlock with neighboring bricks, eliminating the need for additional cement during installation. This unique feature provides several advantages over traditional bricks by simplifying the installation process [9]. The interlocking bricks offer the benefit of not requiring post-treatments such as plastering and painting, as the interlock system between bricks eliminates the need for cement as an adhesive [3].

The robust interwoven design of interlocking bricks, makes it ideal for building wall construction due to their structural integrity and ease of installation. The simplicity and speed of installation are crucial factors driving the adoption of interlocking bricks. It is further explained that interlocking bricks are assembled like puzzles, reducing the reliance on adhesive cement [10].

Interlocking bricks not only ensure structural stability but also enhance wall aesthetics and dimensional stability, as noted by various researchers. The interlocking mechanism of these bricks, with a compressive strength of 7800 kg/block or 2.6 MPa, as demonstrated, confirms their suitability for diverse construction applications [11]. The use of interlocking bricks, with their efficient installation process and inherent strength, presents a sustainable and cost-effective alternative to traditional brick construction methods [12].

In conclusion, interlocking bricks represent a significant advancement in construction materials, offering enhanced structural integrity, ease of installation, and cost-effectiveness compared to conventional brick options. The innovative design of interlocking bricks not only simplifies the construction process but also contributes to improved aesthetics and durability of building structures. The adoption of interlocking bricks is poised to revolutionize the construction industry by providing a sustainable and efficient solution for various construction needs.

Figure 1. *Interlock Brick*

Fly Ash

One of the industrial wastes is fly ash, fine-grained gray produced by burning coal, which is recovered from the final combustion of coal. Basically, *fly ash* contains chemical elements such as silicon oxide (SiO_2), aluminum oxide (Al_2O_3), iron oxide (Fe_2O_3), calcium oxide (CaO), magnesium oxide (MgO), titanium oxide. Other additions such as (TiO_2) are also included. alkali (Na_2O and K_2O), Sulfur Trioxide (SO_3), Phosphorus Oxide (P_2O_5) and Carbon. The following are the properties of *fly ash* :

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Figure 2. *Fly Ash*

a. For downgrades, the number of percent that passes filter No. 200 (0.074 mm) range from 60% to 90%.
b. Carbon content influences the color of fly ash from gray to black, with lighter colors indicating lower carbon content.
c. Fly Ash is waterproof (hydrophobic) [13].

Measurement

The maximum variation in standard brick sizes permitted in S NI-10-78 is 3% of maximum length. 4% of maximum width; 5% of maximum thickness. The difference between the largest stone and the smallest stone allowed is 10 in length mm, width 5 mm and thickness l.

Water Absorption Rate

According to [14] Water absorption is the ability of a material to absorb water (water absorption rate). Density is the ratio of dry matter to the mass in saturated water. High water absorption negatively affects the laying of bricks and mortar. This is because the water vapor in the mortar is absorbed by the stone, causing the mixer to malfunction and reducing the mixing intensity. Because stone contains large pores (unlike dense brick), it has high absorbency. The density and suction power of the direct test sample, the shape and size according to the SK SNI S-04-1989-F M6 module (230 x 110 x 55 mm). This process is carried out by weighing the sample when it is dry and immersing the surface of the sample in water to a depth of 1 cm. Soaking time is 4 minutes [15]. Based on the SNI 15-2094-2000 standard, bricks are said to be good if they have a water absorption capacity of ≤ 20% which can be calculated by:

$$\frac{M_b - M_k}{M_k} \text{ x } 100\% \quad (1)$$

Information :
M_b : Dry mass of test object (g)
M_k : Wet mass of the test object, after soaking in water for 4 minutes (g)

Density

According to [16] Density is the mass of a sample contained in a unit volume. Density is often also called density, or sometimes the density of a material. The required density for use is

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between 1.60 g/cm ^{3} and 2.50 g/cm^3. The formula used to calculate the density or density of bricks is

$$\rho = \frac{m}{v} \tag{2}$$

Information :

ρ	=	Density (g/cm^3)
m	=	Dry Sample Mass (grams)
v	=	Sample Volume (cm^3)

Compressive Strength

The compressive strength test is a test that uses a compression test tool (ELE ADR Touch 2000 Standard Compression Machine) to test the compressive strength and apply a load to the test object to determine the compressive strength when the test object breaks. If the sample is damaged, the ratio displayed on the tester is recorded as the maximum load value. The compressive strength value can be calculated using the following formula:

$$P = \frac{\text{fc} * \text{GF}}{A} \tag{3}$$

P	=	compressive strength of the test object (kg/cm^2)
fc	=	maximum load (kg)
A	=	cross-sectional area of the test object (cm^2)
GF	=	Geometric Factor (101.3)

Materials and Methods

Fly ash was obtained from Coal powered steam power plant in Anggrek, Gorontalo Utara regency. While cement and sand are purchased from local material shop in the Gorontalo city. It is estimated that the time required to prepare tools and materials to carry out the fly ash removal process is about 2 weeks for the composite brick manufacturing process, from the molding process to the fly ash mixing process It takes ±1 month for the tile samples to dry and ±2 weeks for testing and results The research was conducted in Boludawa village, Suwawa District, Bone Bolango Regency, UPTD Material Testing Center of the Gorontalo Province Public Works Service and the Physics Laboratory of Gorontalo State University.

Making Interlock Bricks

The study focused on investigating interlock brick material and drying time, with data collected from interviews with interlock brick manufacturers in Boludawa village, Suwawa subdistrict, Bone Bolango Regency. The drying time for these bricks was found to be approximately 28 days. The composition of the material mixture used to create the texture of interlock bricks was also examined.

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The research delved into the characteristics of interlocking bricks, highlighting their unique design with hooks on the sides to resist compressive forces, as discussed by various researchers [12, 17-18]. Interlocking bricks feature puzzle-like locks that eliminate the need for additional cement during installation, offering advantages over traditional bricks [17-18]. Notably, interlocking bricks do not require post-treatments like plastering and painting, as the interlock system between bricks serves as an adhesive [17].

Moreover, the study explored the benefits of interlocking bricks in terms of structural stability and ease of installation, as emphasized by researchers [12, 17-18]. The interwoven style of interlocking bricks provides robustness in building wall construction and simplifies the installation process [12]. The use of interlocking bricks, with their efficient installation process and inherent strength, presents a sustainable and cost-effective alternative to traditional brick construction methods [17].

The investigation into interlock brick material composition and drying time sheds light on the practical aspects of utilizing these innovative building materials, offering insights into their properties and application in construction projects.

The process involves providing tools and materials, sampling Fly Ash, sand, and cement with varying compositions, mixing them into a homogeneous mixture, and then feeding the mixture into a hydraulic press to solidify it. The solidified mixture is then pressed into interlock brick molds placed on a base, labeled accordingly, and left to dry for approximately 28 days. This methodology, as outlined by the researchers [9, 19-20] ensures the creation of interlocking bricks with robust structural integrity and dimensional stability. The study's focus on material composition and drying time, as well as the utilization of hydraulic machinery, highlights the meticulous approach taken in producing these innovative bricks, offering insights into the practical aspects of interlock brick manufacturing.

The process of conducting a compressive strength test on interlock bricks involves preparing the samples, scraping any protruding parts, weighing the samples using digital scales, measuring their size with a caliper, and then inserting them into the ELE ADR Touch 2000 Standard Compression Machine for testing. The compressive strength values are read and recorded from the machine, with the test repeated up to five times for each mixture. This methodology, as outlined by various researchers [9, 17, 21] ensures a systematic approach to evaluating the strength properties of interlock bricks, providing valuable insights into their structural integrity and performance characteristics. The detailed steps involved in the compressive strength testing process underscore the meticulous nature of assessing the quality and durability of interlock bricks for construction applications.

To conduct a water absorption test on interlock bricks, the procedure involves initially weighing and recording the mass of dry brick samples, followed by soaking the bricks in water for 24 hours. After the soaking period, the samples are re-weighed, and the resulting mass is recorded to calculate the absorption capacity. This methodology, as outlined by various [22-23], ensures a systematic approach to evaluating the water absorption properties of interlock bricks, providing valuable insights into their durability and suitability for construction applications. The detailed steps involved in the water absorption testing process underscore the importance of assessing the brick's ability to resist water ingress, a critical factor in determining its performance and longevity in various environmental conditions.

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Results and Discussion

Maximum Load (kN)

Table 1. Manometer Observation Results

No. Sample	Mix I 3 ; 3 ; 1 (43% *Fly Ash*)	Mix II 4 ; 3 ; 1 (50% *Fly Ash*)	Mix III 5 ; 3 ; 1 (56% *Fly Ash*)
1	23.9	33.6	23.9
2	24.2	35.2	23.8
3	25.9	37.6	21.2
4	34	47	12
5	34.9	68.3	11.5
Average	**28.58**	**44.34**	**18.48**

Based on **Table 1**, observations on the *ELE ADR Touch 2000 Standard Compression Machine (Manometer)* at the UPTD Material Testing Center for the Public Works Department of Gorontalo Province carried out three experiments with five samples of each mixture where in the first mixture with a concentration of 43% *Fly Ash* the maximum load (kN) was obtained. is in the interval 23.9 - 34.9 with an average of 28.58 (kN) which can withstand a load of 2858 kg, while in the second mixture with a concentration of 50% *Fly Ash* the maximum load (kN) is obtained in the interval 33.6 – 68.3 with an average of 44.34 kN can withstand a load of 4434 kg, and in the third mixture with a concentration of 56% *Fly Ash,* the maximum load (kN) obtained is in the interval 11.5 - 23.9 with an average of 18.48 (kN) which can withstand load of 1848 kg. This shows that the one that can withstand the greatest load is the second mixture with a *Fly Ash composition* of 50%; Sand 37%; and Water 13% with an average maximum load of 4434 kg or ±4.434 tons.

Mass (grams)

Table 2. Results of mass measurements (grams)

No. Sample	Mix I 3 ; 3 ; 1 (43% *Fly Ash)*	Mix II 4 ; 3 ; 1 (50% *Fly Ash*)	Mix III 5 ; 3 ; 1 (56% *Fly Ash*)
1	2714	2773	2873
2	2694	2888	2685
3	2838	2823	2989
4	2876	2990	2571
5	2916	3043	2568
Average± SD	**2808±99**	**2903±113**	**2737±188**

Based on the data presented in **Table 2**, the mass of mixtures one and two exhibits a similar range, averaging between 2807.6 grams to 2903.4 grams, contrasting with the third mixture which shows a lower average mass of 2737.2 grams and a maximum standard deviation of 1.40 grams. This deviation of 5% from the average value is deemed acceptable for industrial use. Notably, the mass of interlock bricks, falling below 3000 grams, is lighter than conventional bricks that typically weigh around 5000 grams, indicating potential load reduction benefits, especially in earthquake-prone regions like Gorontalo Province. Furthermore, while building strength necessitates bricks with high compressive strength, the interconnectivity of interlock bricks offers an advantage over

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red bricks or concrete blocks, ensuring structural cohesion akin to Lego bricks. This high level of interlocking enhances the building's integrity, as highlighted by [9], providing a promising alternative for construction applications requiring both durability and reduced mass loads.

Table 3. Results of Density Measurements (g/cm^3)

No. Sample	Mix I 3 ; 3 ; 1 (43% *Fly Ash*)	Mix II 4 ; 3 ; 1 (50% *Fly Ash*)	Mix III 3 ; 3 ; 1 (56% *ly Ash*)
1	1.9	2.0	2.0
2	1.9	2.1	1.9
3	2.0	2.1	2.0
4	2.0	2.2	1.7
5	2.1	2.2	1.7
Average	**2.0**	**2.1**	**1.9**

Based on observations in **Table 3**, *interlock* bricks have a density interval of 1.7 g/cm ^{3} - 2.2 g/cm ^{3} with an average of 2.0 g/cm ^{3}, this is higher than earth bricks reported elsewhere [24-25].

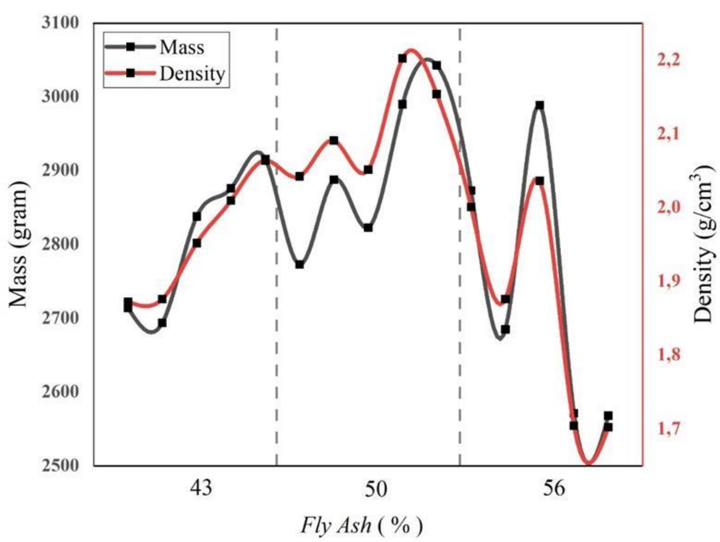

Figure 3. Relationship between Mass (grams), Density (g/cm ^{3}), and *Fly Ash concentration* (%)

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Dimensions (cm)

Table 4. Dimension measurement results (cm)

No.	*Fly Ash* Mix; Cement; Sand	Dimensions			
		Length (cm)	Width (cm)	Thickness (cm)	Diameter (cm)
1	Mixture I 3 : 3 : 1 (43% Fly Ash)	25	12.5	7.9	5.5
2		25	12.4	7.9	5.6
3		24.9	12.4	8	5.6
4		24.8	12.3	7.8	5.5
5		24.9	12.4	7.7	5.5
6	Mixture II 4 : 3 : 1 (50% Fly Ash)	24.8	12.5	7.4	5.5
7		24.8	12.5	7.6	5.6
8		25.2	12.5	7.5	5.5
9		25	12.6	7.4	5.5
10		24.9	12.4	7.7	5.5
11	Mixture III 5 : 3 : 1 (56% Fly Ash)	24.9	12.6	7.9	5.6
12		25	12.5	7.8	5.5
13		25.2	12.6	8	5.5
14		24.9	12.5	8.3	5.6
15		24.9	12.3	8.3	5.6
Rata - rata C1		**24.9**	**12.4**	**7.9**	**5.5**
Rata - rata C2		**24.9**	**12.5**	**7.5**	**5.5**
Rata - rata C3		**25.0**	**12.5**	**8.1**	**5.6**

Likewise, the length, width and height measurements obtained respectively in mixture I are 24.976; 12.431; 7.894 cm , mixture II 24,971; 12,521 ; 7,576, and mixture III of 25,010; 12,513 ; 8,078 cm . The hole diameter is 5.5 5 cm. The consistency of the size of all length quantities is acceptable because it is below 5%. The maximum variation in standard brick sizes permitted in SNI-10-78 is 3% of the maximum length. 4% of maximum width; 5% of maximum thickness. The difference between the largest stone and the smallest stone allowed is 10 in length mm, width 5 mm and thickness 4 mm.

Compressive Strength (kg/cm^2)

Table 5. Calculation Results of Compressive Strength Values (kg/cm^2)

No. Sample	Mixture 1 3 ; 3 ; 1 (43% *Fly Ash*)	Mixture 2 4 ; 3 ; 1 (50% *Fly Ash*)	Mixture 3 3 ; 3 ; 1 (56% *Fly Ash*)
1	13.3	18.7	13.4
2	13.6	19.7	13.2
3	14.5	20.9	11.8
4	18.9	26.1	6.7
5	19.4	37.9	6.4
Average	**15.9**	**24.7**	**10.3**

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Based on calculations using equation (6), interlock bricks in mixture II it is more recommended than other mixtures with an average compressive strength of 24.7 kg/cm ^{2} which is close to class K25 (25 kg/cm^2) standard for compressive strength of brick SK-SNI-S-04-1989-F as shown in table 4.8 . The results obtained show that the mass of *interlock bricks* is in the range of ±28-16 grams per piece (lighter compared to the mass of bricks which reaches ±5000 grams per piece) with an average density value of ±2.0 gc/m ^{3} , with the recommended mixture. for making *interlock bricks* with *Fly Ash ratio* : Sand : Cement in mixture II (composition 4 : 3 : 1) with 50% *Fly Ash aggregate* by producing a compressive strength of ± 24.7 kg /cm ^{2} .

Table 6. Compressive Strength Values SK-SNI-S-04-1989-F

Class	Average compressive strength of bricks	
	kg/cm2	N/m2
25	25	2.5
50	50	5
100	100	10
150	150	15
200	200	20
250	250	25

Water Absorption Capacity (%)

Table 7. Water Absorption Calculation Results (%)

No. Sample	C1 3 ; 3 ; 1 (43% Fly Ash)	C2 4 ; 3 ; 1 (50% Fly Ash)	C3 3 ; 3 ; 1 (56% Fly Ash)
1	16.8	19.5	17.7
2	17.6	18.4	20.8
3	20.0	17.0	21.9
4	22.1	16.8	23.4
5	23.5	16.0	25.5
Rata - Rata	**20.0**	**17.5**	**21.8**

Based on the tests above, it was found that the absorption capacity of mixture I ranged from 17.6% - 23.5% with an average of 20.0%. Furthermore, in mixture II it ranges between 16.0% - 19.5% with an average of 17.5% and in mixture III it ranges between 17.7% - 25.5% with an average of 21.8%. Based on power standards The desired absorbency of the brick according to SNI 15-2094-2000 means that the *interlock brick mixture* has met the desired absorption capacity. Absorption capacity is influenced by the nature of the constituent materials, density during the printing process and cracking during the drying process. The finer and denser *the interlock* brick mixture, the smaller the absorption capacity of the brick, and vice versa, if the mixture is rough and hollow, this can cause a high absorption capacity, which ultimately results in the installation of interlock bricks absorbing the water of the mortar mixture that will be used in one of the brick binding holes. making it unable to stick, This can also cause the compressive strength of the *interlock bricks* to decrease. Therefore, absorption capacity greatly influences the bond between *interlock bricks.*

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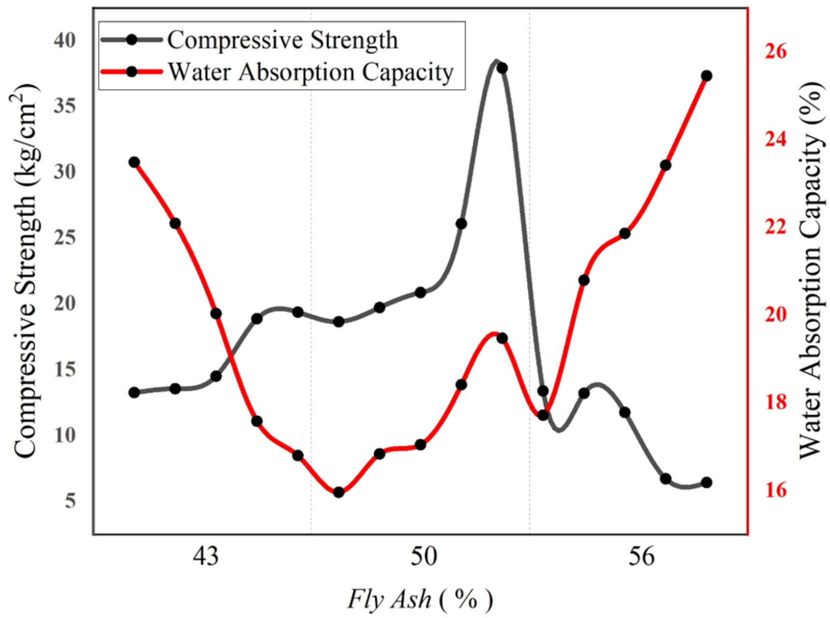

Figure 4. Relationship between Fly Ash (%), Compressive Strength (kg/cm^2) , and Water Absorption Capacity (%)

Based on **Figure 4**, compressive strength is inversely proportional to the water absorption capacity of the aggregate with the addition of fly ash, where in mixture I of *fly ash* with 43% aggregate the compressive strength value is <20 kg/cm^2 with an absorption capacity of >20%, while in mixture II *of fly ash* and aggregate 50% compressive strength value is >20 kg/cm^2 with an absorption capacity of <20%, and in mixture III of *fly ash* with aggregate 56% the compressive strength value is <15 kg/cm^2 with an absorption capacity of >20%. This shows that mixture II with 50% *fly ash aggregate* is better than mixture I with 43% fly ash aggregate and mixture III with 56% *fly ash aggregate* , the compressive strength value is quite high or at least falls within the SK-SNI-S-04-standard. 1989-F class K25 as in table 4.8 can meet the interlock brick standards and the desired water absorption capacity is below <20% according to SNI 15-2094-2000 standards

Calculation of Interlock Brick Limit (n)

Based on **Table 6** Average compressive strength of *Interlock bricks* in mixture II with 50% Fly Ash aggregate ± 24.7 kg/cm^2 with a mass of 2903 grams, density ± 2.1 g/cm^3 in brick dimensions Length x Width x Height x Hole diameter ± 24.9 cm x 12.5 cm x 7.5 cm x 5.55 cm.
then 1 m^2 requires ± 52 *interlock bricks* with arrangement of 4 x 13 so that the *interlock* brick arrangement limit is obtained from the comparison of the compressive strength value with the *interlock brick mass* as in equations (7) and (8)

$$n = \frac{2,47\ kg\ /\ m^2}{2,903\ kg} = \pm\ 8508 \text{ bricks} / m^2, \quad (7)$$

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with area,

$$l = \frac{8508\ t\ /\ m^2}{52\ \text{bata}} = \pm\ 163.6\ \text{m}^2 \qquad (8)$$

Conclusions

Mixture I, with an average mass of 2807.6 kg and a density of 1.9 g/cm², produces a compressive strength value of 16.0 kg/cm² and an absorption capacity value of 20%. Mixture II, with an average mass of 2903.4 kg and a density of 2.1 g/cm², produces a compressive strength value of 24.7 kg/cm² and an absorption capacity value of 17.5%. Mixture III, with an average mass of 2737.2 kg and a density of 1.9 g/cm², produces a compressive strength value of 10.3 kg/cm² and an absorption capacity value of 21.8%. This shows that Mixture II has a brick compressive strength value close to class K25 (25 kg/cm²) based on SK-SNI-S-04-1989-F and an absorption capacity value of 17.5% according to the absorption capacity limit based on SNI 15-2094-2000 with a tolerance of 20%. In Mixture II, this is the threshold for constructing interlock bricks, which allows for approximately 8508 units or an area of ± 163.6 m².

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