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Interlocking Bricks: Density and Compressive Strength Reduction Due to Addition of Kaolin Clay and RHA

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Abstract: This study investigates the density and compressive strength of interlocking bricks made of mortar added with kaolin clay as cement replacement and RHA for sand replacement. This research also investigated the chemical composition of kaolin clay and RHA used for the interlocking bricks. The mortar used was designed based on the concrete mix proportion of 1:2:3 but removed the coarse aggregate. The water-to-cement ratio utilized was 0.6. Each design mix comprises a combination of kaolin clay and RHA at 5%, 10% and 15% by the total weight of cement and sand, respectively. This paper demonstrates the chemical elements of the kaolin clay and RHA and reports the density and compressive strength of the interlocking bricks compared to control samples. The results indicate that the density and compressive strength of the interlocking bricks decreases as the percentage of kaolin clay and RHA increases. The design mix containing 5% kaolin clay and RHA showed the highest density and compressive strength at 28 days, but the values were smaller than the control mix. In comparison to the control mix, the finding is as follows. At 28 days, the range of density reduction from day 3 for all mixes is between 16 to 25%. Meanwhile, the compressive strength of all mixes decreased by more than 65%, measured in the same duration. The result also showed that silicon dioxide (SiO2) contributes the most significant chemical element in kaolin clay and RHA. Kaolin clay contains almost 65% of SiO2, while RHA holds more than 90% of SiO2.

Keywords: Kaolin clay, Rice Husk Ash (RHA), interlocking bricks, chemical composition, silicone dioxide

1. Introduction

Currently, cement is the most important construction material used worldwide, which causes cement production to increase [1]. Efforts to minimize cement usage through supplemental materials have arisen due to environmental concerns arising from the high energy cost and CO_2 emissions of cement manufacturing. Cement production, like all other elements of concrete or mortar, is hazardous to the environment because enormous amounts of CO_2 are released throughout the manufacturing process.

Moreover, cement in the market is in very high demand and costly. According to Omar Hashim [2], the recent increase in cement costs is attributable to price increases in raw materials in the international market. Hence, both government organizations and private sectors in Malaysia shall keep on supporting the preference for more sustainable and eco-friendly blended types of cement, as opposed to utilizing the ordinary OPC, which generates a much higher amount of CO_2 and is less sustainable [3].

Sand is reported to be one of the essential resources in our contemporary society, and the study suggests that governments and the private sector should increase investment in research and development to identify sustainable alternatives for common sand as a building material [4]. The same paper also demonstrated that Malaysia is one of the significant sand producers, contributing ten thousand metric tons of sand in 2019.

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Bricks, sometimes called blocks, are known as natural building materials. Over the last 20 years, interlocking mortar bricks or blocks of different shapes have been widely used and commonly applied for pavement in many countries for specific reasons. These natural building materials are an environment-friendly and labor-intensive paving technology to solve special-purpose problems [5]. Pavement made of mortar bricks has been utilized for many areas, such as highways, airports, parking lots, industrial facilities, and various types of infrastructure. Furthermore, if appropriately designed and built from durable materials according to the specifications, mortar bricks can provide a long service duration with little or almost no maintenance [6].

As the need for construction materials grows, so does the use of cement and sand. As a result, a large amount of cement and sand has been used, resulting in the depletion of natural resources, which impacts the local and global environment, and urgent measures are needed to limit these effects [5]. As a result, stringent environmental regulations have been imposed. Therefore, partially replacing cement with a more friendly material is an initiative to reduce the use of cement in construction. Several materials, including kaolin clay and RHA, have been researched as partial replacements for cement or sand in concrete or mortar mix. The uniqueness of the current study is using kaolin clay and RHA in a design mix of interlocking bricks. This study is conducted to achieve objectives as follows:

- To determine the chemical composition of kaolin clay and RHA
- To determine the density of interlocking bricks
- To determine the compressive strength of the interlocking bricks

2. Previous Works

In 2012, Shen et al. [7] did a study to assess the viability of replacing some fine particles in Portland cement concrete (PCC). The strength of concrete using Portland cement can be improved using kaolin clay. High air void content results from kaolin substitution above 3%. The ideal strength range was established as 1-3% kaolin replacement. The maximum working limit was established at 2% kaolin replacement. It was found that kaolin significantly impacted the concrete slurry, resulting in a soft cohesive and viscous mixture.

A study was conducted three years later by Shafiq et al. [8] to investigate a highly reactive metakaolin from Malaysian kaolin. Compressive strength, splitting tensile, and flexural strength of concrete at ages 7, 28, 56, and 90 days were examined in this work employing the locally manufactured metakaolin as a cement replacement material to confirm the reactivity of the metakaolin. As a result, the mechanical properties of concrete were improved by locally manufactured metakaolin, and the concrete's compressive strength was determined to be around 5% greater than that of silica fume concrete.

Abdullah et al. [6] carried out an investigation to examine the performance of concrete pavements incorporating kaolin clay and their engineering qualities. For the duration of the investigation, grade 30 MPa concrete was employed, with a constant water-to-cement ratio of 0.49. In this study, tests for compressive strength, flexural strength, and water absorption were performed. The percentages of cement used in the cement mix using kaolin clay as a cement substitute were 0, 5%, 10%, and 15%. The findings show that when kaolin clay increases, pavement concrete strength falls. Additionally, it demonstrates that water absorption rises as cement replacement percentages do. Nevertheless, the best amount to replace is 5% kaolin clay.

A partial replacement of cement with kaolin powder was studied by Hailu et al. [9]. At seven days of curing, concrete with 5% and 10% kaolin powder as cement strengthened by 6.3% and 1.09%, respectively, while concrete with 15% and 20% replacement levels lost strength by 10.18% and 18.91%, respectively. The compressive strength of concrete is still increased by 10% of kaolin powder replacement compared to control concrete, but 5% of kaolin powder replacement was chosen for the best results. Finally, the findings support using kaolin powder as a pozzolanic material to substitute cement partially in traditional concrete production and to offset the technical, economic, and environmental problems associated with cement manufacturing.

Kamaruddin et al. [10] found that the compressive strength of RHA concrete was lower than that of OPC concrete. An increase of RHA replacement in the mix decreased the compressive strength. However, 10% of RHA replacement of cement achieved the desired compressive strength. It was also observed that RHA concrete is more impermeable and has superior resistance to chloride ions as the percentage of RHA replacement level was increased until it reached 50%. The high composition of SiO_2 in the RHA might cause this. By substituting RHA for cement, concrete gains better durability due to the low percentage of water absorption produced. The average water absorption rate for all mixes is between 2.5% and 3.0%.

Park et al. [11] discovered that the diluting effect has an enhanced influence on the hydration degree of the cement in the cement-RHA blends compared to the plain Portland cement paste. As the RHA replacement ratio rises, the calcium hydroxide concentration in cement-RHA mixes falls. Two years later, Nuhu & Makwal [12] studied replacing OPC with RHA on sandcrete blocks. They found that replacing OPC with RHA reduces the hardening rate at which sulphate ions attack the sandcrete block. This condition occurs due to silica in RHA replacing most of the calcium oxide in OPC, which is less reactive to sulphate compounds. The compressive strength of all block specimens rises with age during curing and falls as RHA concentration rises. It was clear that as the RHA content increases, the setting time of OPC/RHA paste increases, which can enhance block hardening.

It takes a lot of energy and carbon to produce cement. They thereby make a significant contribution to the world's anthropogenic CO_2 emissions. With 900 kg of CO_2 released with every tonne of cement produced, the cement industry has long been one of the biggest producers of CO_2 emissions. Massive amounts of biogenic wastes, including rice husk, sawdust, and wood ash, are produced in Malaysia. Malaysia produces about 0.3 million tonnes of palm oil fuel ash annually, although there are no notable uses for these ashes [3]. Despite the technical and financial advantages for Malaysia, these ashes are still only used as landfill material. Over-reliance on this energy will increase CO_2 emissions, which are ultimately to blame for global warming. Hence, researchers must investigate and make discoveries on swapping cement with biogenic wastes. Since sand mining is expensive, rice husk is a very affordable alternative.

3. Design Mix and Materials

This study aims to investigate the compressive strength of interlocking bricks made of mortar mixed with kaolin clay to replace cement, and RHA replaces sand. In addition, this study also examined the chemical composition of kaolin clay and RHA. Hence, the materials used for this research include cement, fine aggregate (sand), kaolin clay, RHA and water. The following sections demonstrate the design mix, materials and methodology of the study.

3.1 Design Mix

Table 1 illustrates the percentage of kaolin clay and RHA utilized in the design mix. There were four design mixes: CO, D1, D2 and D3, which stands for Control Mix, Design Mix 1, Design Mix 2 and Design Mix 3, respectively. Each design mix contains an equal percentage of kaolin clay and RHA. For example, D1 contains 5% kaolin clay and 5% RHA. Nine samples of interlocking bricks were moulded for each design. The weight of materials (kg) was based on a previous study [9] and the total weight of materials used in this investigation is shown in Table 2.

Table 1 - Percentage of kaolin clay and RHA in each design mix of interlocking bricks

Design Mix	Kaolin clay (%)	RHA (%)	Number of samples			Sample identity
			3 days	7 days	28 days	
CO	0	0	3	3	3	COS1- COS9
D1	5	5	3	3	3	D1S1-D1S9
D2	10	10	3	3	3	D2S1-D2S9
D3	15	15	3	3	3	D3S1-D3S9

Table 2 - Weight of materials for each design mix

Design Mix	Weight of cement (kg)	Weight of kaolin (kg)	Weight of sand (kg)	Weight of RHA (kg)	Weight of water (kg)
CO	2.31	0	6.73	0	1.39
D1	2.19	0.12	6.39	0.34	1.39
D2	2.08	0.23	6.05	0.67	1.39
D3	1.96	0.35	5.72	1.01	1.39
Total	8.54	0.7	24.89	2.02	5.56

3.2 Materials

Kaolin used in this study was collected from a small village in Sayong, Perak. Meanwhile, RHA was collected from Parit Buntar, also in Perak. The collected RHA was in powder form after being burnt at a temperature between 550°C to 800°C. The type of cement used was OPC, obtained from the Civil Laboratory of UiTM Shah Alam. The fine aggregate was also obtained from the same laboratory. The water used was from the tap water available in the laboratory.

4. Methodology

The methodology is divided into an X-ray fluorescence spectroscopy (XRF) test, sample preparation, density measurement and compressive strength test.

4.1 XRF Test

Both kaolin clay and RHA were tested for chemical composition using XRF tests following ASTM E1621-21 [13]. XRF is a quantitative X-ray microanalytical technique that provides information on the chemical composition of a sample [11]. XRF is a popular, non-destructive, and quick technique to determine the elemental composition of a material and its quantity requiring very little sample preparation. XRF can detect chemical elements down to 100 parts per billion (part per billion). This test was conducted at IIESM, Seismology lab, to comprehend the quality and composition of chemical substances and materials used in manufacturing and industrial processes. The type of testing that was conducted is limestone - limestone. For safety precautions, only authorized users were allowed to use the instrument because the instrument produces ionizing radiation. Materials prepared for the test were cups, S1 Titan Handheld XRF Analyzer, RHA powder and kaolin powder. Fig. 1 shows the materials prepared for the XRF tests while Fig. 2 exhibits the ready samples and the XRF Analyzer.

(a) (b)

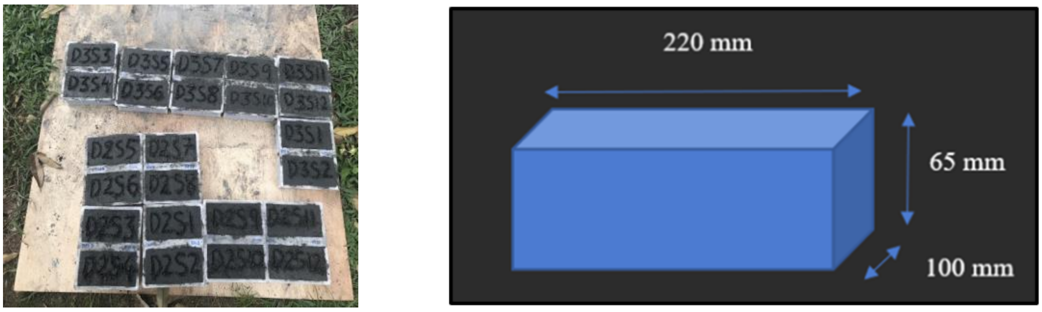
(c) (d)

Fig. 1 - Materials used; (a) cement; (b) sand; (c) kaolin; (d) RHA

(a) (b)

Fig. 2 - XRF test; (a) samples; (b) XRF analyzer

Interlocking brick samples were prepared following ASTM C62-17 [14]. First, cement, sand, RHA and kaolin were weighed according to the mix proportion in Table 2. Next, cement and sand were mixed, followed by adding RHA and kaolin, the mix was then transferred to the mixer machine, and water was added afterwards. Once the mortar paste looked homogenous, it was transferred into the brick moulds and labelled. The mould size is 200 × 980 × 550 mm. The bricks were kept in the moulds for 24 hours. After 24 hours, all the bricks were removed from the moulds and submerged in water for curing. Fig. 3 illustrates the interlocking bricks after moulding and a schematic diagram of the mould size.



(a) (b)

Fig. 3 - Samples preparation; (a) after moulding; (b) mould size

4.2 Density and Compressive Strength Test

The density and compressive strength tests were carried out for each 3, 7 and 28 days using dry brick samples according to Table 1 following ASTM C67-14 [15]. The same three samples were used for both tests. Fig. 4 shows a sample being tested in the compression test machine.

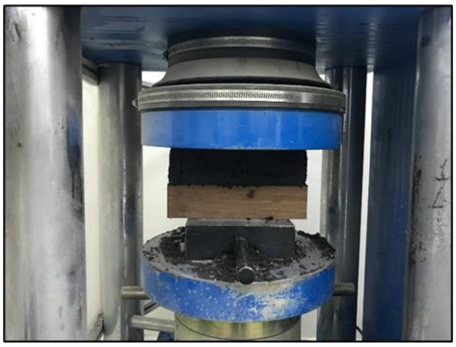


Fig. 4 - An interlocking brick sample being tested in the compression test machine

5. Results and Discussion

5.1 Chemical Composition of Kaolin Clay and RHA

Table 3 and Table 4 present the chemical composition of kaolin clay and RHA, respectively. There are ten elements detected by the XRF test in both kaolin clay and RHA. The biggest contributor to the chemical composition of kaolin clay is Silicon Dioxide, SiO_2, followed by Aluminium Oxide, Al_2O_3. SiO_2 contributes 64.91%, while Al_2O_3 makes up 64.91% of the whole chemical composition. Meanwhile, SiO_2 also contributes the biggest among all the chemical compositions of RHA. However, the existence of Al_2O_3 is negligible. Each other element makes up less than 5% of the whole element.

5.2 Density

Three samples were used for each test day, and results were calculated from the average of the three samples. Fig. 5 presents the density of all the design mixes at 3, 7 and 28 days of age. The density of control specimens increased by 0.03 kg/m^3 from day 3 to day seven but decreased by 0.02 kg/m^3 from day seven day to day 28. For D1, the density value is the same for all ages, which is 1.88 kg/m^3. Meanwhile, the density of D2 decreases as age increases. At day 3, the density was 1.85 kg/m^3 but decreased to 1.82 kg/m^3 at the age of 7 days. This value was then decreased to 1.8 kg/m^3 on day 28. At the same time, there is a small decrement in density for D3 from day 3 to day 7, which is from 1.7 to 1.68 kg/m^3. However, the density of D3 came back to 1.7 kg/m^3 at the age of 28 days. For the age of 28 days, the highest density is demonstrated by D1 with a value of 1.88 kg/m^3, while the lowest comes from D3, and the value is 1.68 kg/m^3. The difference between the lowest and highest is 0.2 kg/m^3. In all cases, there is no big difference from age 3 to age 28, which shows that the density stabilized as early as three days of age.

Table 5 shows the percentage of density reduction compared to the control mix specimens for all design mixes at all ages. For D1, D3 and D3, the percentage of density reduction is between 16 to 18%, 17 to 21% and 24 to 27%, respectively. These results show that a higher quantity of combination of kaolin clay and RHA in the mortar mix produces a bigger reduction of the interlocking brick density. Since this study did not measure the unit weight of any raw material, raw data from internet sources are used. In general, the unit weight of Portland cement, kaolin clay, sand

and RHA is around 1440, 2650, 1631 and 781 kg/m^3, respectively. The unit weight of kaolin clay is 1.84 to the unit weight of cement. Meanwhile, the unit weight of RHA is only 0.48 to the unit weight of sand. With reference to Table 2, the weight of RHA was bigger than the weight of kaolin clay used in a mix. Therefore, the density of the interlocking bricks with kaolin clay and RHA is smaller than the density of the control mix.

Table 3 - Chemical composition of kaolin clay

Chemical composition / element	Quantity (%)
Magnesium Carbonate, $MgCO_3$	1.00
Aluminium Oxide, Al_2O_3	22.87
Silicon Dioxide, SiO_2	64.91
Phosphorus Pentoxide, P_2O_5	<LOD
Sulfur Trioxide, SO_3	0.09
Potassium, K_2O	4.70
Calcium Carbonate, $CaCO_3$	1.18
Titanium Dioxide, TiO_2	0.65
Manganese II Oxide, MnO	0.08
Iron, Fe_2O_3	4.54

Table 4 - Chemical composition of RHA

Chemical composition	Quantity (%)
Magnesium Carbonate, $MgCO_3$	4.5
Aluminium Oxide, Al_2O_3	<LOD
Silicon Dioxide, SiO_2	90.34
Phosphorus Pentoxide, P_2O_5	1.21
Sulfur Trioxide, SO_3	0.15
Potassium, K_2O	2.29
Calcium Carbonate, $CaCO_3$	1.15
Titanium Dioxide, TiO_2	0.01
Manganese II Oxide, MnO	0.19
Iron, Fe_2O_3	0.17

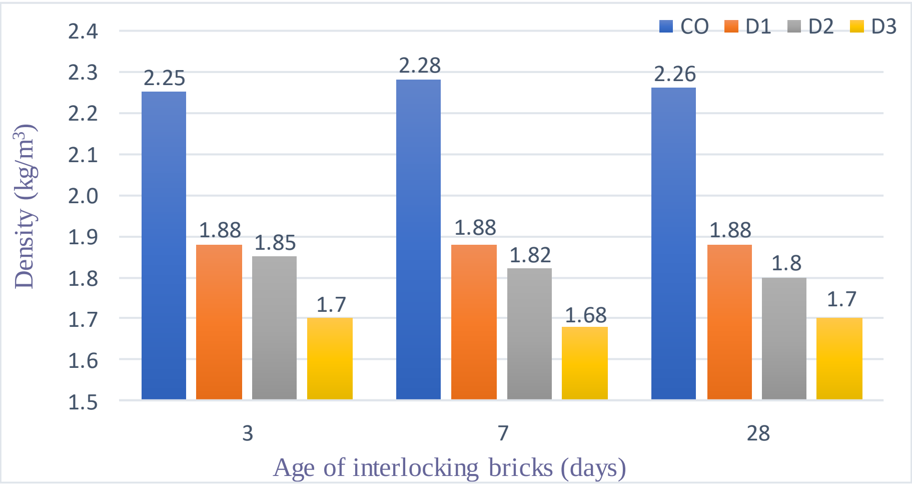


Fig. 5 - Density (kg/m^3) of the interlocking bricks for all design mix according to age (days)

Table 5 - Density reduction for all design mix

Design mix	Reduction (%)		
	3	7	28
CO	0	0	0
D1	-16.44	-17.54	-16.81
D2	-17.78	-20.18	-20.35
D3	-24.44	-26.32	-24.78

5.3 Compressive Strength

Three samples were used for each test day, and results were calculated from the average of the three samples. Fig. 6 presents the compressive strength of all the design mixes at 3, 7 and 28 days of age. The compressive strength of the control specimens increased from 11.68 at the age of 3 days to 15.56 N/mm^2 at the age of 7 days and further increased to reach 17.19 N/mm^2 at the age of 28 days. However, the compressive strength of all the mixes containing kaolin clay and RHA hardly reached one-third of the compressive strength of the control specimens on all days. Finally, at 28 days, D1 obtained the highest compressive strength with a value of 5.42 N/mm^2, while the lowest is demonstrated by D3 with a value of 2.99 N/mm^2.

Table 6 depicts the percentage of compressive strength reduction compared to control specimens. The compressive strength of D1, D2 and D3 was reduced by 68 to 72%, 78 to 82% and 80 to 85%, respectively, from the control specimens for all three testing days. The biggest strength reduction is from D3, which occurred at the age of days. Fig. 7 demonstrates the development of compressive strength versus brick age. As expected, compressive strength of the control specimens rose rapidly from day 3 to day seven and the rate reduced from 7 to 28 days. All other design mixes also demonstrate the same trend but at a slower rate. Although D1 showed only an 18.36% compressive strength increment from day 3 to day 7, it increased rapidly to reach 45.84% on day 28. The increment of compressive strength from day 3 to day 28 is less than 25 and 35% for D2 and D3, respectively.

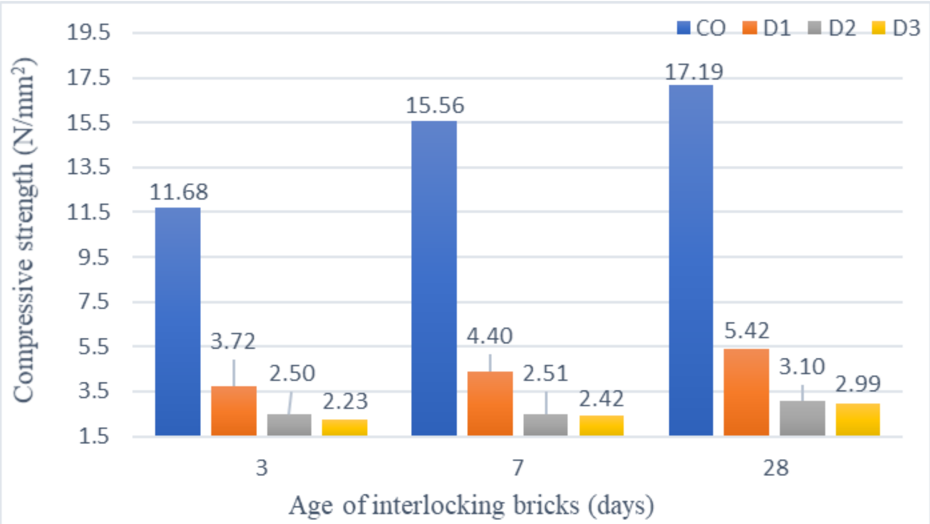


Fig. 6 - Compressive strength (N/mm^2) of the interlocking bricks for all design mix according to age (days)

Table 6 - Compressive strength reduction (%) for all design mix compared to control specimens

Design mix	Reduction (%)		
	3	7	28
CO	0	0	0
D1	-68.20	-71.75	-68.49
D2	-78.61	-83.87	-81.99
D3	-80.88	-84.46	-82.63

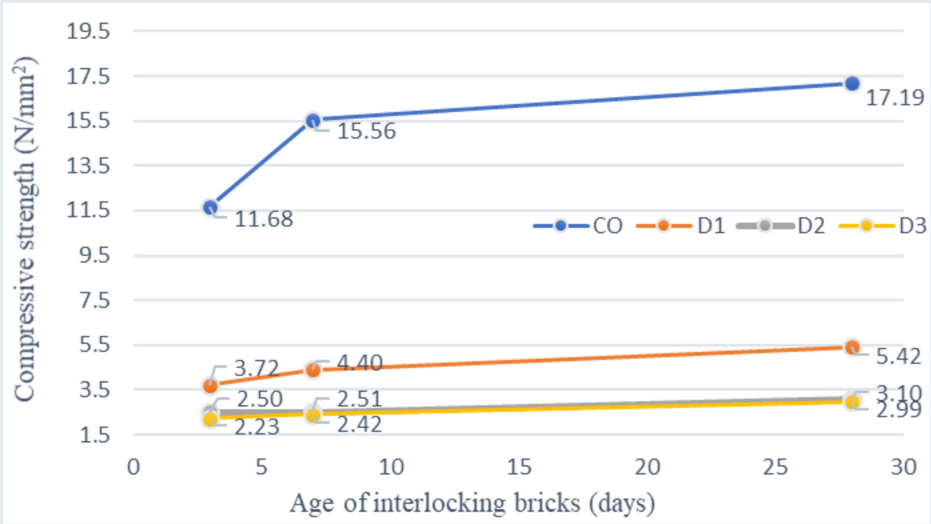


Fig. 7 - Development of compressive strength (N/mm^2) of the interlocking bricks for all design mix versus age (days)

Table 7 - Compressive strength increment (%) for all design mix compared to day 3

Design mix	Increment (%)		
	3	7	28
CO	0	33.24	47.20
D1	0	18.36	45.84
D2	0	0.48	23.93
D3	0	8.28	33.72

6. Conclusion

The experimental investigation found that kaolin's chemical composition is mainly contributed by silicon dioxide (64.91%), followed by aluminium oxide (22.87%). In parallel with that result, RHA is also mainly contributed by silicon dioxide, with a percentage of 90.34%. The highest compressive strength comes from 5% of replacement with a value of 5.4 MPa. A more significant percentage of replacement of kaolin clay and RHA results in smaller compressive strength. Although the brick with a combination of kaolin and RHA demonstrates smaller compressive strength than the control mix, the value is still high for non-load-bearing structures such as partitions, fences and pavement. These structures can be produced at a lower cost.

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