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Impact of Bio-Adhesive Addition on the Properties of Cement Bricks Incorporating Quarry Dust and Kenaf Core

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Abstract

In the context of sustainability issues arising from the disposal of waste materials like quarry dust and agricultural residues such as kenaf core, there is an important need to discover alternative materials and additives for enhancing the properties of cement-based products. The purpose of this study is to assess the effect of integrating bio-adhesive into cement bricks, including those containing quarry dust and kenaf core. The evaluation was to compare cement bricks' water absorption properties and compressive strength with and without bio-adhesive. The study used the volume approach in mix proportions (M1 to M6), considering weight proportions and ratios of kenaf core, quarry dust, and bio-adhesive. A total of 54 samples were produced. Tests included specific gravity tests, sieve analysis, water absorption, hardened density, and compressive strength tests to evaluate the cement bricks. According to the study, substituting kenaf core with quarry dust should not exceed 25% in order to satisfy the specified compressive strength of 5.2 Mpa. Water absorption increases as the proportion of the kenaf core increases. The use of more than 25% kenaf core lowers the brick density. Furthermore, bio-adhesive strengthens the contact between cement and fibres, increasing strength performance and decreasing brittleness. Mix M5, combining quarry dust and kenaf core, emerged as the best option with strong weathering resistance (11.73%), compressive strength (10.22 MPa), and lightweight properties (1555.2 kg/m^3).

1. Introduction

The global construction industry is a major contributor to the world economy and is also a significant source of greenhouse gas emissions and waste. The escalating interest in sustainable building materials addresses the environmental impact of construction, particularly regarding cement bricks, which, while commonly used, pose environmental challenges due to high energy and raw material requirements. In Malaysia, sand cement bricks are widely used, particularly in affordable housing, resulting in a heightened demand for river sand and associated environmental risks. (Sheikh Khalid *et al.*, 2017). To address this, studies have explored alternative materials like waste and renewable resources to reduce the reliance on river sand.

However, the rapid growth in demand for sand exacerbates resource limitations, prompting extensive research to find suitable substitutes. The emphasis on sustainable materials and environmentally friendly activities is influenced by environmental concerns associated with the resource-intensive manufacturing

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process of common building materials like cement (Sukesh et al., 2013). The purpose of this research is to evaluate the influence of adding bio-adhesive to cement bricks with quarry dust and kenaf core, with a focus on physical, mechanical, and durability factors.

Aligned with Sustainable Development Goal (SDG) 9, the study promotes sustainable industrialization by reducing the environmental impact of cement manufacturing through bio-based binders. Additionally, incorporating quarry dust and kenaf core supports responsible resource management, aligning with sustainable development ideals. The research examines the potential of bio-adhesive, derived from plant materials, as an environmentally friendly alternative to synthetic adhesives in cement brick production, aiming to minimize the environmental footprint of the manufacturing process.

The findings of this study have the potential to influence the development of environmentally friendly building materials that reduce waste and environmental impact in the construction sector. This study only evaluated the properties of cement bricks with compressive strength, water absorption and hardened density. Finally, the research will only focus on creating cement bricks in a laboratory setting. hence, the results may not be applicable to large-scale manufacturing.

2. Literature Review

Based on previous research on cement bricks and their properties, The structures of the bricks phases in a stable condition, with binding energy increasing as the curing time extends (Gnyrya *et al.*, 2019). The most common cement is ordinary Portland cement (OPC). and is classified into eight subgroups based on ASTM C150 (Saleh & Rahman, 2018). The compressive and flexural strength of the concrete increased up to a 10% replacement level when quarry dust was used as a partial substitute for sand in cement bricks, while the impact resistance of the concrete improved with a 5% dust content. According to the findings, adding quarry dust to concrete increases its compressive strength. The predictability of quarry dust concrete performance is that properly expect concrete compressive strengths at 7 and 28 days (Kolo & Enwongulu, 2022). Furthermore, the results suggest that by substituting quarry dust for 50% of the fine aggregate, maximum compressive strength concrete may be attained. At all curing ages, the addition of quarry dust in varied amounts (0% to 50%) significantly increases compressive strength and tensile strength (Ajamu S. O., Raheem I. A., 2020).

Moreover, the previous studies on kenaf core as a partial replacement for fine aggregate in cement bricks found that as the kenaf core content increased, both the compressive strength and density decreased (Hamid *et al.*, 2018). Adding kenaf fibres significantly reduces autogenous shrinkage and drying shrinkage cracking in cement pastes (Liu *et al.*, 2022). In addition, in these studies was choose bio-adhesive name Cellulosa Nanofibrils Adhesive (CNF). Bio-adhesive generated from plants has the potential to be a long-lasting binding agent. Nanocellulose is cellulose that can be extracted from natural cellulose fibres in the form of fibres or crystals with a length of a few micrometres and a diameter of 100 nm. (Sharma *et al.*, 2019). It can be observed that to improve mechanical performance and sustainability, the research looks at adding bio-composite materials into cement-based mortars, such as natural fibres or bio-based additives (Yu & Gao, 2018).

3. Materials and Method

3.1 Materials

In this study were used four (4) different materials which used Ordinary Portland Cement (OPC), quarry dust, kenaf core, and Bio-Adhesive.

(i) **Ordinary Portland Cement (OPC)**

This study made use of Ordinary Portland Cement (OPC), according to ASTM C150 classification. OPC was used as a primary binding material in this study to make cement bricks with quarry dust, kenaf core, and bio-adhesive. In order to avoid contamination and moisture, the cement was stored in an airtight container to maintain its quality.

(ii) **Quarry Dust (QD)**

Quarry dust was collected from quarry plants located in Johor. This study looks into using quarry dust as a partial replacement for sand in the production of cement bricks. The quarry dust used in this study is from a quarry plant with a passing sieve of 4.75 mm.

(iii) **Kenaf Core (KC)**

Kenaf core is a fibrous fibre obtained from the kenaf plant's inner core (Hibiscus cannabinus). Kenaf core was collected from Lembaga Kenaf dan Tembakau Negara (LKTN). Kenaf core used in this study was a passing sieve 4.75 mm.

(iv) **Bio-adhesive (BD)**

Cellulose Natural cellulose-rich resources, such as wood pulp or agricultural waste are used to make nanofibers. To obtain nanofibers, cellulose is extracted mechanically and chemically. The bio-adhesive is stored in the bottle and put at room temperature.

3.2 Methodology

Table 1 obtained the laboratory test and standards test method used in this study The tests on cement bricks, including compressive strength, water absorption, and hardened density, were performed at the Advanced Building Material Laboratories E17, at Universiti Tun Hussein Onn Malaysia (UTHM).

Table 1 *Laboratory test and standards test method*

Properties	Laboratory Test	Standards
Material Properties	• Sieve Analysis • Specific Gravity	- ASTM C 136-06 (2015) - ASTM 128-07a, (2009)
Physical Properties of Specimen	• Hardened Density (kg/ m3) • Brick dimension (200 mm x 100 mm x 65 mm)	- BS EN 12390-7 (2019) - BS 4729 (2005), BS EN 771-3, (2011)
Mechanical Properties of Specimen	• Compressive Strength	- ASTM C140-11a (2011)
Durability Properties of Specimen	• Water Absorption	- ASTM C140-11a (2011)

Fig 1 shows the flow chart methodology implemented in this investigation. A flow chart is a diagram of the research process that highlights each process required for this investigation.

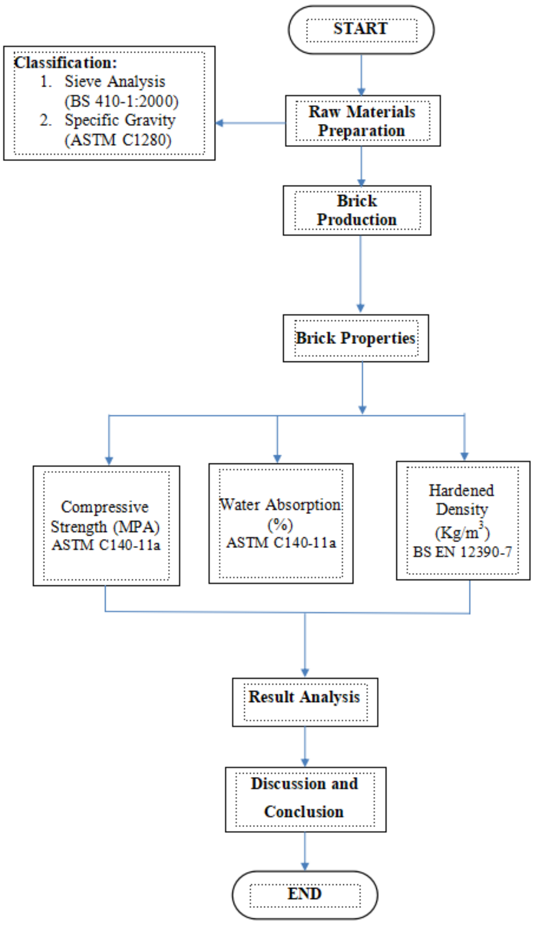


Fig 1 *Flow chart of methodology*

3.3 Mix Proportions

There were six (6) types of samples with different mix proportions for cement brick prepared. The aggregate-to-cement ratio (A-CR) used in this study is 1:6 for all types of mix proportions The water-cement ratio (W-CR) will be constant at 0.6. The appropriate amount for the water-to-cement ratio (W-CR), the quantity of kenaf core to quarry dust (KCQD-RR), and the additional bio-adhesive as stated in Table 2

Table 2 *Mix design proportion KCQD and bio-adhesive*

Mixes	W-CR	A-CR	KCQD-RR	Bio-Adhesive
M1			0%	0%
M2			25%	0%
M3	0.6	1:6	100%	0%
M4			0%	12%
M5			25%	12%
M6			100%	12%

The percentages indicated for bio-adhesive represent its ratio to the weight of cement. M1 to M3 did not include any bio-adhesive (0%). Conversely, M4 to M6 incorporated 12% of bio-adhesive. This research aims to explore how these additives influence the characteristics of cement bricks by adjusting the proportions of quarry dust, kenaf core, and bio-adhesive across different mixes. These mix variations provide a comprehensive analysis of how different elements affect the strength, durability, and other essential attributes of the bricks.

3.4 Specific Gravity Test

Table 3 shows specific gravity parameters and observations of quarry dust and kenaf core. The test was carried out in accordance with ASTM C 128-07a.

Table 3 *Specific gravity parameters and observations*

Test Parameters			
Apparatus	:	Pycnometer Jar 1000 ml	
Temperature for Drying	:	110 ± 5°C	
Water Temperature	:	23 ± 2°C	
Duration of Immersion	:	24 hours	
Observation			
		Quarry Dust	Kenaf Core
Weight of Saturated & Surface Dry Sample (S)		500 g	50 g
Weight of Pycnometer + Sample + Water (C)		1838 g	1517.67 g
Weight of Pycnometer + Water (B)		1514	1514
Weight of Oven Dry Sample (A)		492.67	17.6

Table 4 *Specific gravity result*

Result		
	Quarry Dust	**Kenaf Core**
Relative density (specific gravity) (OD)	2.80	0.38
Relative Density (Specific Gravity) (SSD)	2.84	1.08

Table 4 displays measurements of two key properties related to aggregate density: oven-dried specific gravity and saturated-surface dry specific gravity. The study presents data for both quarry dust (QD) and kenaf core (KC). The oven-dried specific gravity values are 2.8 for QD and 0.38 for KC, showing how their densities compare to water. Additionally, under saturated surface-dry conditions, where aggregates have absorbed some water but aren't fully soaked, the specific gravity values are 2.84 for QD and 1.08 for KC. These findings offer insights into the compactness and pore structure of these aggregates, benefiting various engineering uses.

3.5 Sieve Analysis Test

The particle size distribution of quarry dust and kenaf core will be determined through a sieve analysis test following ASTM C136 standards. Before conducting the test, the samples of quarry dust and kenaf core were dried in an oven at a consistent temperature of 110 ± 5°C (230 ± 9°F). The sieves are set up from smallest to largest mesh size, ranging from 10 mm down to 0.075 mm at the bottom. After placing the sample, it's shaken for 5 minutes to let particles of different sizes pass through the sieves. After sieving, the trays are taken out, weighed to the nearest 0.1g, and any material caught in the sieves is cleaned out and added to the weight retained.

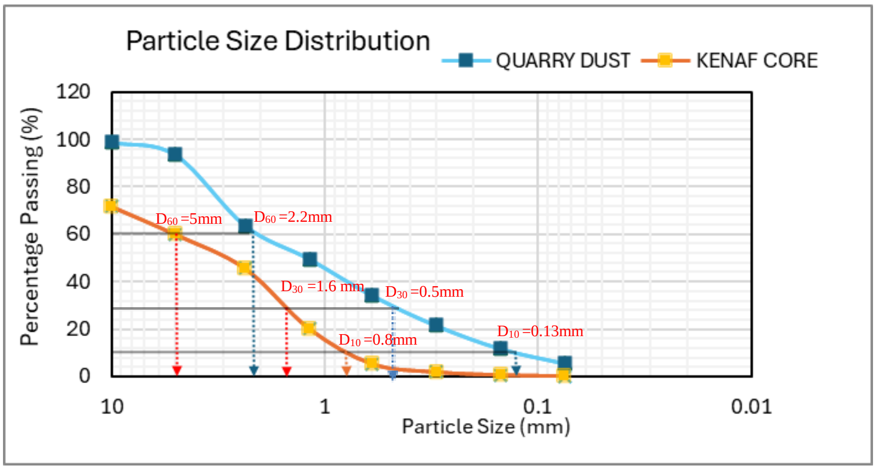


Fig 2 *Particle size distribution of quarry dust and kenaf core*

Fig 2 shows the particle size distribution of quarry dust (QD) and kenaf core (KC) was carried out as per ASTM C136 guidelines. The results showed that the diameter (D_{10}) for QD was 0.13 mm and for KC was 0.8 mm. The larger diameters (D_{60}) were 2.2 mm for QD and 5 mm for KC. Additionally, (D_{30}) values at 0.5 mm for QD and 1.6 mm for KC. The uniformity coefficients (Cu) were found to be 16.92 for QD and 6.25 for KC. Moreover, the gradation coefficients (Cc) were 0.87 for QD and 0.64 for KC. Based on these values, QD is classified as well-graded sand since both materials encompass all particle sizes. In line with the grading curve, both the fine aggregate and kenaf core samples fall within the classification of medium sand to fine gravel.

3.6 Sample Preparation

Four different materials were used in this study, OPC cement, quarry dust, kenaf core, and Bio-Adhesive. A total of 54 bricks were carefully produced using the precise mix ratios stated in Table xx. In addition, quarry dust was used as a substitute for fine aggregate in this investigation. The brick size sample used in these studies is 200 mm x 100 mm x 65mm complying with BS 4729 (BS 4729, 2005); BS EN 771-3 (British Standard, 2011).

3.6.1 Process of Batching and Mixing

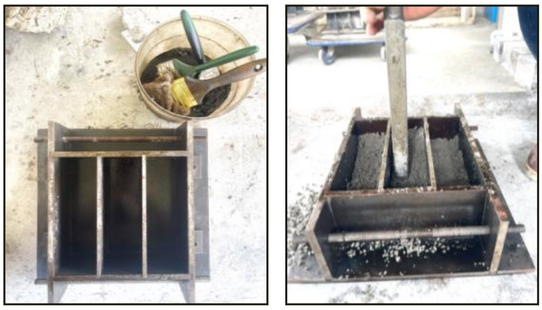
The electronic weight balance was used for precise weight batching. The batching procedure follows the specified mix proportions. After all the components are ready, the mixing process will occur in the mechanical mixer.

(a) (b)

Fig 3 *Process batching and mixing (a) Electronic Weight Balance; (b)Mechanical Mixer*

3.6.2 Process of Placing and Compacting

In order to avoid bonding between the mould and the mixture, Before placing and compacting the brick samples, the moulds were cleaned and coated with oil. After the material was placed, it was spread and levelled with trowel tools to produce a uniform surface. Hand-tamping was used to compress the mixture in accordance with ASTM C-109-11a specifications. In the mould, the mixture was layered four times, and each layer was tamped 32 times in 10 seconds for four rounds.



(a) (b)

Fig 4 *Process placing and compacting (a) Mould set and coated mould with oil; (b) Placed and compacted fresh mixture using a tamping rod*

3.6.3 Process Demoulding and Curing

Following the placement and compacting procedure, the samples were marked and set for 24 hours before being demoulded. All samples were cured in the laboratory before testing by air curing at room temperature for 7 and 28 days. The plastic cover was utilised to maintain the optimum temperature and humidity levels in the curing environment.

(a) (b)

Fig 5 *Process demould and curing (a) Labelled sample; (b) Labelled and demoulded*

4. Result and Discussion

This section the findings from the experiment and data analysis, presented through tables and graphs. In this research, quarry dust was substituted with 0%, 25%, and 100% of the kenaf core. Additionally, the study investigates the impact of incorporating 0% and 12% Bio-adhesive on factors such as compressive strength, water absorption, and hardened density.

Table 5 *Summary results of all testing methods*

	W-CR:	**0.6**						
	C-AR:	**1:6**			**7 Days**	**28 Days**		
	Proportions	**QD**	**KC**	**BD**	**CS7**	**CS28**	**WA28**	**HD28**
M1	0%	100	0	0%	26.68	35.80	8.1	1994.60
M2	25%	75	25	0%	6.96	8.95	15.7	1535.50
M3	100%	0	100	0%	0.13	0.35	81.1	423.00
M4	0%	100	0	12%	32.08	41.99	5.5	1987.37
M5	25%	75	25	12%	8.01	10.22	11.3	1555.20
M6	100%	0	100	12%	0.15	0.40	57.3	461.07

Table 5 above shows the summary results of all laboratory tests that had been carried out for compressive strength, water absorption, and hardened density. The results were obtained by averaging 3 readings for every each mix proportion.

4.1 Compressive Strength

In this investigation, compressive strength tests were performed on samples at 7 and 28 days. Each mix type had three samples used to carry out this testing. This test was conducted in accordance with ASTM C140-11a.

Fig 6 of the result in the graph shows that replacing some of the quarry dust in the brick mixture with the kenaf core significantly affects the strength of the bricks. The results demonstrate that the blue region represents mixes without bio-adhesive, while the pink area includes a 12% bio-adhesive addition to the brick mix.

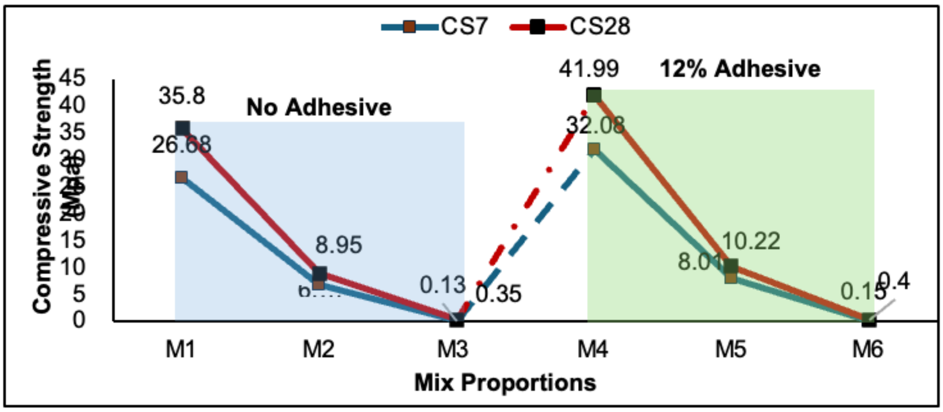


Fig 6 *Compressive strength testing at age 7 and 28 days*

The graph clearly demonstrates that sample M4 achieved the highest compressive strength at 41.99 MPa after 28 days of curing, using 0% kenaf core and 12% bio-adhesive. Conversely, M6 had the lowest compressive strength, suggesting that using 100% kenaf core-quarry dust is not practical. In comparison, the control specimen (M1) with 100% quarry dust and 0% bio-adhesive had a lower strength at 35.8 MPa than M4. These results strongly indicate that adding bio-adhesive improves the compressive strength by serving as a bonding agent, enhancing bonding and cohesion within the brick matrix. According to Arshad *et al.* (2022)and Hassan *et al.* (2021), the compressive strength of M2, which consists of 25% kenaf core and 75% quarry dust, is 8.9 MPa and 8.5 MPa, respectively. When the kenaf core content is above 0%, the compressive strength decreases significantly. M3 has the lowest compressive strength, measuring 0.13 MPa after 7 days and 0.35 MPa after 28 days of cure. This corresponds with Hassan *et al.* (2021) study, which found a similar compressive strength of 0.3 MPa for M3 after 28 days. According to the JKR 20800-0183-14 standard, the minimum required average compressive strength at 28 days is 5.2 MPa. All compressive strength values exceeded the Malaysian Public Works Department's allowable average of 5.2 N/mm^2 for non-load-bearing walls, as noted by Hassan et al. (2021), except for M3 and M6, which used 100% kenaf core.

4.2 Water Absorption

This section that follows discusses the result of the water absorption test of the brick. This test was carried out in accordance with ASTM C140-11a. In this investigation, three brick samples were made for each proportion for the water absorption test, which was performed on day 28. Fig 7 below shows the result of water absorption illustrated in graph.

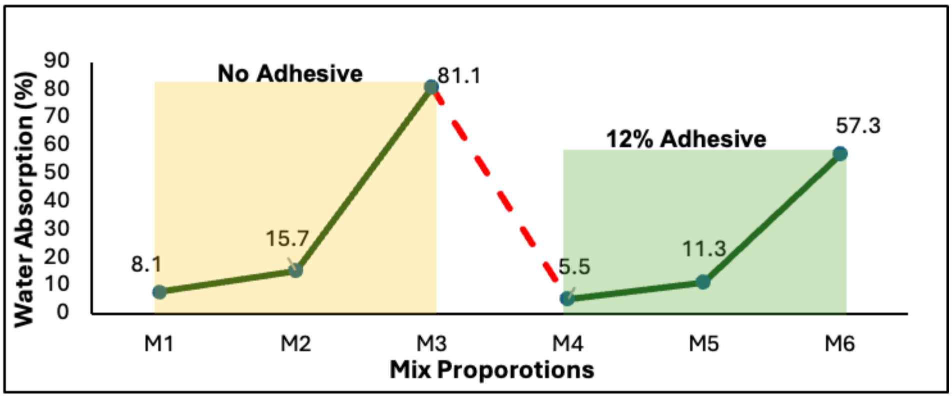


Fig 7 *The addition of a kenaf core enhanced water absorption*

According to ASTM C67-07a (2003), water absorption levels are categorized based on weathering exposure: 17% for strong weathering resistance, 22% for moderate weathering, and no set limit for minimal weathering resistance. M3 and M6, made entirely of kenaf core, showed the highest water absorption with 81.1% and 57.3%, respectively. This indicates that using more kenaf core leads to greater water absorption. The introduction of the kenaf core led to increased water absorption due to its higher porosity. The results show that replacing 25% and 100% of the kenaf core raised water absorption by approximately 15.7% and 81.1%, respectively, compared to M1 with 0% bio-adhesive. Furthermore, it can be observed that the addition of 12% bio-adhesive increases the percentage of water absorption. This clearly shows that water absorption is greater with 0% bio-adhesive compared to 12% bio-adhesive. This might be because of the finer particle size of the kenaf core, which is coarser than quarry dust causing larger voids inside the brick (Nurul Aini *et al.*, 2021).

4.2.1 Relationship Between Water Absorption and Compressive Strength

Fig 8 shows the relationship between compressive strength and water absorption.

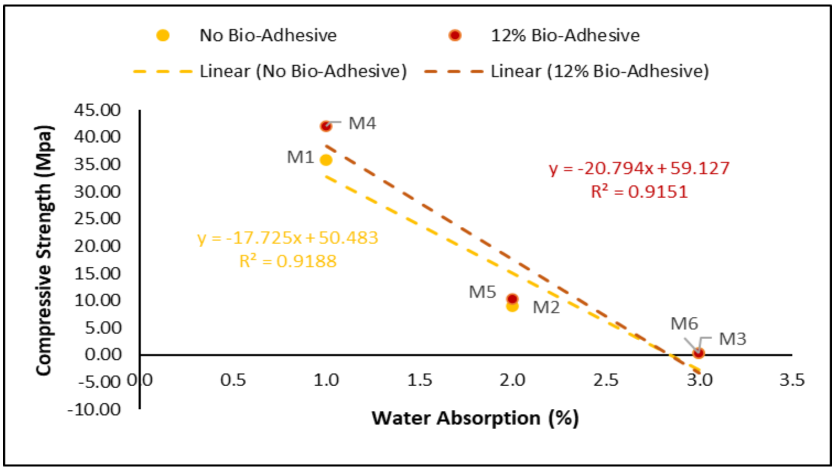


Fig 8 *Percentage of water absorption increase in the decrease of compressive strength*

As seen in Fig 8 the water absorption was negatively influenced and had a connection with compressive strength. The R^2 values for this connection were 0.92 for both no bio-adhesive and 12% bio-adhesive. As water absorption increased, the compressive strength decreased. This is because higher water absorption leads to lower compressive strength. A higher rate of water absorption indicates more porosity and an increased risk of bricks. Meanwhile, lower water absorption indicates stronger moisture resistance (Arshad *et al.*, 2022).

4.3 Hardened Density

The following sections discuss the density of hardened cement bricks. Hardened brick density is a key non-mechanical characteristic of bricks, assessed in this study using the BS EN 12390-7 standard. The graph below represents the hardened density results for various mix proportions.

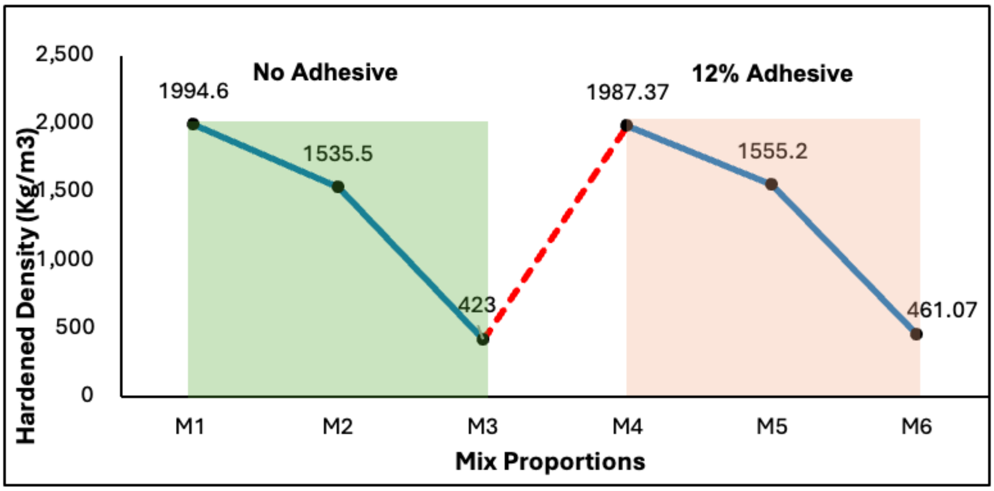


Fig 9 *The change in hardened density based on the different mix proportions*

The hardened density decreased significantly from M1 to M3 with 0% bio-adhesive and from M4 to M6 with 12% bio-adhesive. The results indicate that as the percentage of kenaf core increases, the hardened density decreases. After 28 days of curing, M3 had the lowest density at 423.0 kg/m³, while M6 with 100% kenaf core had a density of 461.07 kg/m³. Moreover, M4 is a bit lower than M1 the highest hardened density with 1987.37 kg/m³. This is because of the addition of 12% bio-adhesive and 100% from quarry dust. This indicates that the addition of 12% of the bio-adhesive effect reduces the hardened density. In the mix proportion of 25% of KCQD-RR (M2 and M5) shows that M5 has increased the value of hardened density compared to M2 because of the addition of 12% of bio-adhesive in the proportion. According to ASTM C55-11 (2011), lightweight concrete blocks have a dry density below 1680 kg/m³. Medium-weight blocks range between 1680 kg/m³ and 2000 kg/m³, and anything over 2000 kg/m³ is considered average-weight. Based on this, the blocks created in this study fall into the medium weight building brick category.

4.3.1 Relationship Between Hardened Density and Compressive Strength

As the hardened density increases, it also affects the material's ability to absorb water. Materials with a high hardened density are often more compacted and less porous. Less porosity in a denser material provides fewer places for water to enter, resulting in reduced water absorption (Baghban & Mahjoub, 2020). The figure below shows the relationship between hardened density and water absorption in the graph.

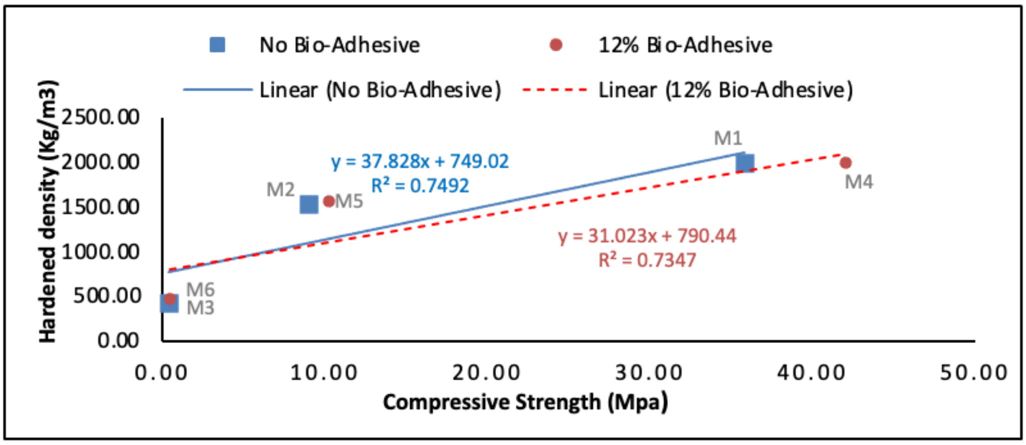


Fig 10 *The relationship is characterized by an increase in hardened density followed by an increase in compressive strength*

From Fig 10 the higher of hardened density, the higher the compressive strength of the bricks. The graph above represents the connection between the hardened density and compressive strength of the kenaf core, quarry dust, and bio-adhesive. For 0% bio-adhesive and 12% bio-adhesive, the R^2 values were 0.75 and 0.73, respectively. The linear graph shows a significant relationship between hardened density and compressive strength of all mix combinations. This study showed that a brick with a compressive strength of 8.95 MPa could be created with a kenaf core percentage of 25%. Although having a density of 1,535 kg/m^3, its strength exceeds the minimum allowed compressive strength of 5.2 N/mm^2 specified in JKR 20800-0183-14.

4.3.2 Relationship Between Hardened Density and Water Absorption

The hardened density of a material and its water absorption often have an opposing connection. In summary, as the hardened density increases, the material's ability to absorb water decreases.

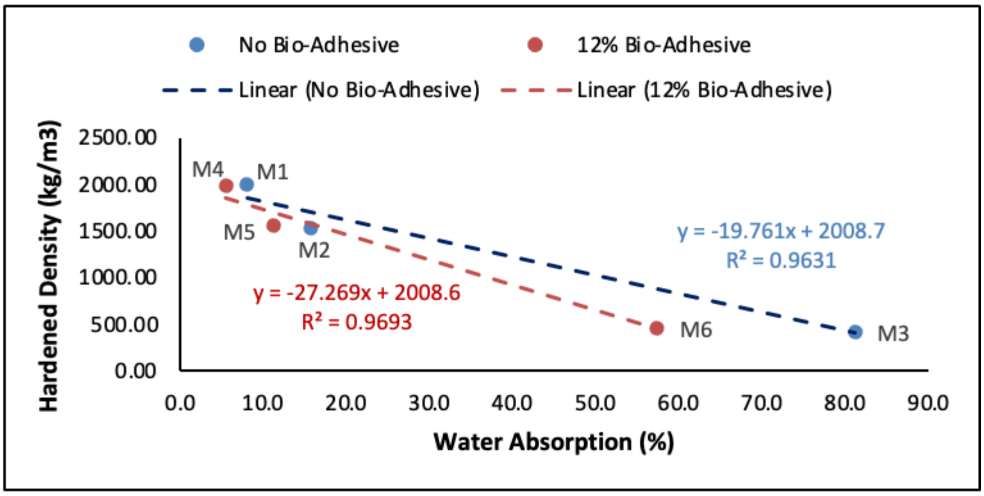


Fig 11 *Hardened density decreases, the water absorption increases*

Fig 11 shows the relationship between hardened density and water absorption. This relationship has an R^2 value of 0.96 for both no bio-adhesive and 12% bio-adhesive. The linear graph indicates a strong negative connection between hardened density and water absorption for all mixed amounts. The lower the water absorption, the higher the hardened density. After analyzing the effect of the kenaf core, it was shown that increasing the amount of the kenaf core correlates to enhanced water absorption and porosity in mixed proportions. Bricks with higher porosity have lower density, whereas bricks with lower porosity have higher water absorption values (Hassan *et al.*, 2021)

5. Conclusion

According to the findings, quarry dust, kenaf core, and bio-adhesive may efficiently replace natural sand in the production of cement bricks. Several conclusions can be made from the data presented in previous chapters. The study shows that as the amount of kenaf core used in bricks increases, their compressive strength decreases. The maximum allowable replacement of the kenaf core is 25% (seen in M1, M2, M4, and M5), meeting the standard strength requirement of 5.2 MPa. Bricks with 100% kenaf core (M3 & M6) have potential as lightweight materials. Furthermore, adding 12% bio-adhesive improves the brick's compressive strength.

Additionally, based on the water absorption results, it can be inferred that an increase in the kenaf core percentage is linked to a higher water absorption percentage. This is primarily impacted by the course kenaf core particles, resulting in a very porous structure in the bricks. As per the results, only M3 and M6 meet the specified standard requirement of 22% water absorption, indicating bricks with moderate weathering resistance. On the other hand, other mix proportions only fulfil the criteria for bricks with insignificant weathering resistance, displaying lower water absorption.

Moreover, using more kenaf core, from 25% up to 100% as a replacement for quarry dust, reduced the density of the bricks. However, adding 12% bio-adhesive helped increase the density, especially in M5 and M6. The density measured was 1555.20 kg/m^3 for M5 and 461.07 kg/m^3 for M6.

The data show that the addition of bio-adhesive can increase compressive strength by roughly 30% when compared to scenarios without bio-adhesive. This demonstrates the great potential of bio-adhesive as a material for brick strengthening. Furthermore, it was discovered that the strength of the bricks is greater at later stages of development than at earlier stages of growth.

In conclusion, based on the result, M5 chose the best mix proportion (quarry dust & kenaf core) with classification Strong Weathering Resistance Bricks (11.73%), compressive strength (10.22 MPa) and Lightweight bricks (1555.2kg/m3). The utilisation of industrial waste such as quarry dust and kenaf core in the M5 brick shows a positive impact on the brick properties and the practical approach to using this product is in the non-load bearing application such as brick walls. For future research, there are some suggestions that can made to improve the cement brick performance. Firstly, there is a need to enhance the compressive strength. Introduce 10% fly ash as a partial replacement of cement in the mix design and perform compressive strength tests to assess the impact of fly ash on enhancing the strength properties of cement bricks. Lastly, the duration of curing should be addressed. Extending the curing duration to 60 days

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