Investigation of Concrete Paving Block Characteristics and Performance across Different Shapes and Thicknesses

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ABSTRACT

Concrete Paving Blocks (CPBs) are generally used in pavement structures. Quite often there are differences in the test result characteristics of cube and block-shaped samples. This research aims to analyze the characteristics of differences in height by considering 60 samples from five different factories. The sample dimensions are 200 mm length and 100 mm width with varying heights of 60 mm, 80 mm, and 100 mm. The tests include water absorption, compressive strength, flexural strength, tensile splitting strength, skid resistance, and abrasion resistance. The results of the mortar content show no significant difference between the five sources. According to the findings, the weight loss value depends on strength, and tensile splitting strength is influenced by density, with higher density producing higher tensile splitting strength. It was also found that the compressive strength test method is more realistic when using cube-shaped samples, while beam-shaped samples are more suitable for identifying bending characteristics. Finally, it was shown that the flexural strength value is influenced by density.

Keywords-Concrete Paving Blocks (CPBs); thickness; density; mechanical properties; durability

I. INTRODUCTION

The road surface layer is an essential part of the road pavement structure, and thus selecting the appropriate pavement type is an important decision. CPBs can be used as a light and medium traffic pavement type [1]. Selecting the type of CPB pavement has several benefits in road construction. The paving block is a road pavement material widely utilized due to its long service life, fast production, and easy replacement for maintenance purposes [2]. The use of CPBs is increasingly requested, especially in pedestrian areas, as well in local roads, where heavy vehicles can enter at low speeds of no more than 40 km/h [3]. With a specific design, CPBs can also withstand heavy static traffic loads and can be easily rearranged if changes to the pavement are required [4]. However, apart from having several advantages, this type of pavement also has several weaknesses. The fact that it is unsuitable for high-speed roads, due to the existing noise and vibration, requires roadside noise barriers and manual work that takes longer time [5]. The paving block structure is similar to the flexible pavement structure. This material layer is placed above the foundation layer by adding joint material and bedding sand [6]. CPBs can support traffic loads with each block built in a uniform pattern and connected in a continuous structure to minimize rotation and movement of the beam for structural stability to be achieved [7]. Material properties, namely thickness, quality, and the form of vertical connection types influence CPB behavior [8]. Various laboratory and field tests on the performance of CPB structures show that this pavement system has adequate structural capacity [9]. Another parameter used to analyze CPB characteristics is durability. CPB is suitable for use in road pavements because it can withstand the effects of abrasion [10]. Its abrasion resistance is critical to service life because abrasion wear occurs on surfaces subjected to abrasive forces between the surface and moving objects on the pavement [11]. Factors influencing abrasion resistance are compressive strength, water-cement ratio, aggregate type, and treatment [12]. Skid resistance is another parameter that needs to be considered in terms of CPB durability and it is highly dependent on weather conditions [13]. The value must be higher than 45 BPN (British Pendulum Number) [14]. CPBs come in various sizes and shapes according to the needs of the field. The most common shape used in pavement structures is the rectangle one. Various tests, including compressive strength tests, can be performed to determine its characteristics. Multiple studies have been carried out on the compressive strength test of this shape of CPBs. The results demonstrate that thin dimensions are stronger than the thicker ones [1, 15].

Several studies have tested the compressive strength of cube CPBs in relation to the height difference. The results suggest almost close values because the compressive strength value is mostly influenced by density [1, 16, 17]. Various studies have conducted flexural strength tests using the three-point beam shape method, in various shapes [18, 19]. In other studies, compressive and flexural strength values are interconnected [20, 21]. This relationship also aligns with CPB's splitting tensile strength characteristics according to which compressive strength is related to splitting tensile strength [22]. Another identification result is the influence of the shape of the paving block on the splitting tensile strength value [19]. Apart from the shape, the longer life of the CPB can also increase the splitting tensile strength value due to the impact of the continued hydration of the cement and the pozzolanic effect of ash [23]. Several structural and strength test results disclose similarities in their characteristics, but generally different thicknesses give different results. These differences can confuse, so further studies on their characteristics need to be carried out.

One important parameter that can influence the characteristics of CPBs is the mixture composition. Research showed increasing compressive strength with increasing fine aggregate content [24]. A similar trend has been also observed when the cement is substituted, reducing the compressive strength value [25]. Poor mechanical properties, including poor bonding between cement paste and aggregate, can cause a decrease in mechanical strength [26]. The physical properties of the mixed material will affect the characteristics of the paving block. Physical properties in the form of specific gravity and water absorption impact mixture performance [23]. The composition of the mix affects durability. Cement concrete waste can also be used in making CPBs. Judging from the abrasion resistance, substituting waste concrete content significantly negatively impacts the former [27]. The composition of the mixture also affects the skid resistance value. The right substitute material can reduce slip resistance. Adding crumb rubber can slightly reduce the slip resistance of CPBs [28]. Furthermore, the quality of CPBs is also influenced by the way these blocks are constructed. Several studies have applied methods for making CPBs, namely manual, hydraulic pressing, and vibropressing [29]. Applying pressure during sample molding will likely increase the final strength of the sample [30]. Apart from that, manufacturing CPBs using hydraulic machines can produce high productivity [31].

Density is an essential factor in obtaining the best characteristics of CPBs. High density can reduce existing voids, so the compressive strength of CPBs is increased [32]. The composition of the mixture can affect density, by adding various types of aggregates [33]. Authors in [34] demonstrated that the rise in plastic composition decreases the density of plastic paving blocks. The same thing happens when substitute materials are added to cement, reducing the density of CPBs [35]. CPB density can decrease as the concrete waste content increases [36]. Authors in [37] identified the influence of water-cement ratio on the density of CPB mixtures. Therefore, controlling density is an essential stage in maintaining CPB quality.

II. MATERIALS

CPB samples were collected from five different factories to ensure sample diversity. Paving Block type 1 (PB1) comes from Tambun, PB2 from Rawa Kalong and Bekasi Regency, PB 3 comes from Cileungsi, while PB4 and PB5 come from Mount Sindur (Bogor Regency). After crushing the samples, mortar content and aggregate gradation were identified for each source.

A. Cement

The binder used in the CPB mixture is Portland Type I cement or other hydraulic adhesives that do not reduce the quality of the concrete [38]. The samples were crushed using a mini stone crusher (Figure 1). The mortar level results from the fine CPB samples are presented in Table I.

TABLE I. MORTAR CONTENT OF CPB

CPB mixture	**6 cm**					
	Source	PB1	PB2	PB3	PB4	PB5
Mortar Content (%)	Medium Aggregate	5.6	3.6	4.7	5.5	3.8
	Coarse Aggregate	3.7	5.1	3.6	4.2	3.3
	8 cm					
	Source	PB1	PB2	PB3	PB4	PB5
	Medium Aggregate	4.1	4.8	4.1	3.5	4.7
	Coarse Aggregate	5.7	4.2	3.4	4.5	3.1
	10 cm					
	Source	PB1	PB2	PB3	PB4	PB5
	Medium Aggregate	3.1	5.3	3.8	3.4	3.6
	Coarse Aggregate	3.6	3.8	3.5	4.6	4.9

Fig. 1. Mini stone crusher.

B. Aggregate

Aggregate identification was carried out by arranging the five CPB samples in different thicknesses of 6, 8, and 10 cm. As a result, the aggregates were separated in three groups: coarse, medium, and fine (Figure 2). These groups were then used for gradation analysis. From the comparison of the gradation analysis graphs of each CPB sample, no significant differences in sample thickness and sample source were observed (Figures 3 - 5).

Fig. 2. Aggregate separation.

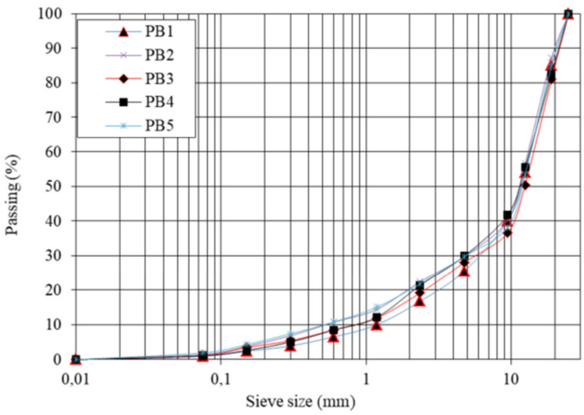


Fig. 3. Sieve analysis of 6 cm CPBs.

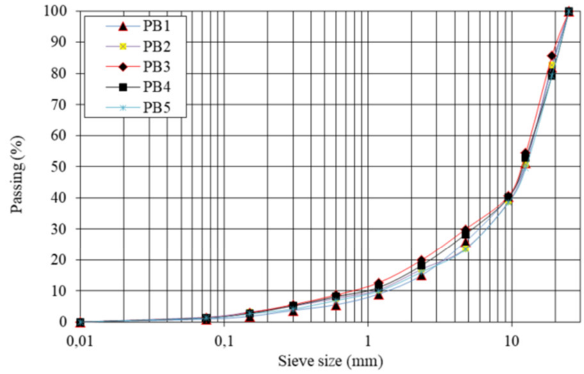


Fig. 4. Sieve analysis of 8 cm CPBs.

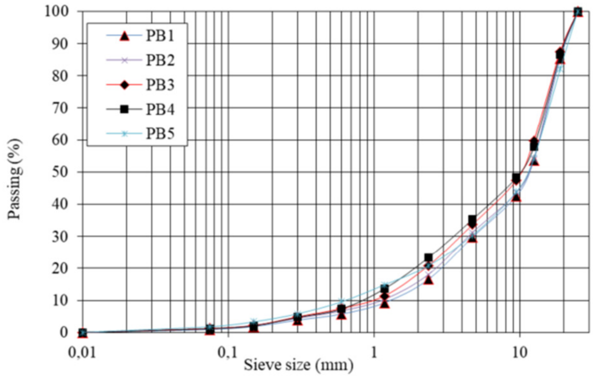


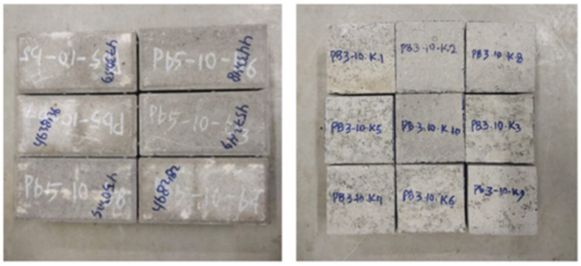
Fig. 5. Sieve analysis of 10 cm CPBs.

C. Water Cement Ratio

The water-cement ratio is essential in determining the strength, durability, and workability of concrete. It is measured by the amount of water used in mixing concrete relative to the amount of cement utilized. The water-cement ratio is important because water is needed to form chemical reactions between cement aggregates and other additives. The amount of water in the mixture determines the void content in cement concrete. Too much water can cause the concrete to become weaker and more porous, decreasing its durability. On the other hand, if the water content is too low, it can produce a mixture that is difficult to bond. Various factors, including the cement type and the type and size of aggregate, influence the optimal water-cement ratio for a concrete mixture. Generally, a lower water-cement ratio produces stronger and more durable concrete. Still, forming CPBs either by pressing through the utilization of a machine or manually is challenging. So, the water-cement ratio needs to be lower than that of the cement concrete mixtures.

III. METHODS

The samples were identified by analyzing the gradation and mortar content. After looking at the initial characteristics, the subsequent analysis stage identified basic properties: water absorption and density tests. Next, functional properties were identified using a skid resistance test in dry and wet conditions. The identification of durability properties was carried out by abrasion resistance testing. Also, mechanical properties were identified using compressive, flexural, and split tensile strength tests. This analysis aims to determine similarities or differences in characteristics based on sample source and thickness variations. Next, the relationship between split tensile strength and density on the variations in CPB height were analyzed. Afterwards the relationship between flexural strength and density with variations in height were investigated. The samples were divided into two shapes: blocks and cubes, as seen in Figure 6. The initial sample dimensions were in the form of a block with a length of 200 mm and a width of 100 mm, with variations in height of 100 mm, 80 mm, and 60 mm. Half of the samples were cut into cubes using a cutting core machine with cube dimensions of 60 mm, 80 mm, and 100 mm. As the Indonesian National Standard proposes, this cube sample was used for compressive strength testing, which compares the strength value with a block-shaped sample.



(a) (b)

Fig. 6. CPB shapes, (a) Block sample, (b) Cube sample.

A. Density

The dimensions of each sample were carefully measured to obtain the correct volume value. Then, the samples were placed in an oven at 105 °C for 24 hours. Afterward, they were left for 5 hours out of the oven, and they were subsequently weighed. Density is calculated by:

$$\text{Density} = \frac{M}{V} \quad (1)$$

where M is the mass of the specimen (g) and V is the volume of the specimen calculated from the measured dimensions (cm^3).

B. Compressive Strength

Compressive strength testing was carried out using a compression machine with a capacity of 250 kN at an 1 mm/minute speed until specimen failure [1]. The compressive strength is calculated by:

$$\text{Compressive strength} = \frac{F}{A} \quad (2)$$

where F is the failure load of the specimen (N), and A is the surface area of the applied load (mm^2).

C. Flexural Strength

Flexural strength testing was carried out deploying the 3-point method using a beam sample. The sample heights for flexural strength testing were 60 mm, 80 mm, and 100 mm. The load was applied to the sample utilizing a compression machine with force control at 0.05 kN/s [39]. Flexural strength is calculated by:

$$\text{Flexural strength} = \frac{3P \cdot L}{2b \cdot d^2} \quad (3)$$

where P is the load at failure (N), L is the span length (mm), b is the width of specimen (mm), and d is the depth of the specimen (mm).

D. Splitting Tensile Strength

Splitting tensile strength testing was carried out over the longest span of the samples. Plates were attached on the top and bottom sides along the sample span and load was applied to the compression machine until the sample was split. The splitting tensile strength is calculated by:

$$T = 0.637 \cdot k \cdot \frac{P}{S} \quad (4)$$

where P is the load at failure, as in (3), k is the correction coefficient for the thickness of the specimen, and S is the fracture surface area (cm^2). S can be calculated by:

$$S = I \cdot t \quad (5)$$

where I is the average fracture length (cm), measured from both sides of the test object's surface, and t is the thickness of the test object (cm).

E. Abrasion Resistance

Abrasion resistance testing was carried out using a rotating cutter drill press. The rotating cutter gets into contact with the surface of the CPB to obtain the CPB abrasion value. A constant load of 98 N through the spindle was applied three times on different sides [40]. The results obtained in this test are total weight loss (gr) and depth.

F. Water Absorption

Water absorption was measured in 28-day aged CPBs. The control value for water absorption, according to [41], is 6%. To obtain the water absorption value, the sample was placed in an oven at 105 °C for 24 hours to dry and then was weighed. Next, the sample was soaked again in water for 24 hours and then weighed in Saturated Surface-Dry (SSD) conditions. Water absorption (%) is calculated by [42]:

$$\text{Water absorption} = \frac{w_1 - w_0}{w_0} \quad (6)$$

where w_0 is the weight (gr) of the oven-dried sample, and w_1 is the weight (gr) of the saturated surface-dry sample.

Table II outlines the water absorption of CPB samples. The results show that all variations still meet the water absorption value limits of 5% and 6%, proposed by [42] and [22], respectively, and that the water absorption from variations in CPB height increases as the sample becomes thinner. The water absorption test sample was then used for strength testing. The analysis demonstrates that the higher the water absorption value is the lower is the strength. This result aligns with those of several similar studies that show the same trend. Regression analysis exhibits a strong correlation between physical properties and mechanical properties. A perfect correlation exists between water absorption and compressive strength. When water absorption decreases, the compressive strength increases [43]. Low water absorption is related to the durability of CPBs [10]. In [35], it was explained that water absorption will be in line with the density and that they have a strong correlation with each other. Authors in [23] demonstrated that density is closely related to porosity and water absorption.

TABLE II. WATER ABSORPTION OF CPBs

Mixture	Water absorption		
	6 cm	8 cm	10 cm
PB1	4.86	4.26	3.84
PB2	4.29	4.20	4.16
PB3	3.82	3.56	3.38
PB4	3.69	2.60	1.60
PB5	3.28	2.24	1.83

G. *Skid Resistance*

Skid resistance was measured using a pendulum friction test. Before being tested, the sample was adjusted until the surface contact with the rubber slider reached 5 inches of friction [44]. The sample was cut with a surface dimension of 160 mm × 90 mm and a height of 50 mm. Next, the samples were treated in both dry and wet conditions. Table III presents the skid resistance results.

TABLE III. SKID RESISTANCE OF CPBs

Mixture	Condition	
	Dry	Wet
PB1	65	57.8
PB2	68.2	60.4
PB3	68.1	60.2
PB4	65.1	59.5
PB5	64.9	58.5

The results reveal that for all sample variations, dry conditions produce higher BPN values than wet conditions, with all meeting the BPN value standards set by BSEN 133, namely a BPN value limit of more than 45 [14]. The fact that all variations tend to produce almost the same values is because in all variations, substitutes or added materials were not used. Authors in [28] employed an additive material that can influence skid resistance, crumb rubber, which increased the BPN value.

H. *Statistical Analysis*

TABLE IV. DATA VALIDATION TEST

		Block	Cube	Total
Block	Pearson Correlation	1	0.221**	0.794**
	Sig. (2-tailed)		0.006	0.000
	N	150	150	150
Cube	Pearson Correlation	0.221**	1	0.769**
	Sig. (2-tailed)	0.006		0.000
	N	150	150	150
Total	Pearson Correlation	0.794**	0.769**	1
	Sig. (2-tailed)	0.000	0.000	
	N	150	150	150
**. Correlation is significant at the 0.01 level (2-tailed).				

The validity test is utilized to measure whether the data are valid or not. A test has high validity if it carries out its measuring function or provides precise and accurate measuring results, according to the test purpose. A test that produces data outside the measurement purpose is a test with low validity. This research used 300 CPB samples for validity testing. The results of the validity test are portrayed in Table IV. The validity test results show that all the data are valid and can be used as research measuring tools.

IV. RESULTS AND DISCUSSION

A. *Analysis considering the CPB Sources*

This analysis aims to determine the characteristics of CPB from five different factory sources. The analysis at this stage involved aggregate gradation tests and mortar content from these sources. These results were utilized as a benchmark to determine whether these samples can be used for subsequent analysis. The gradation analysis discloses that the five different factory sources produce relatively uniform gradation values. The same thing happens to the CPB variations with heights of 6 cm, 8 cm, and 10 cm. The statistical analysis results demonstrate that all CPB variations have almost the same characteristics. This variation can be seen from the significance value of 0.24 for all CPB samples, which indicates that the mortar content of all factories has a homogeneous tendency. The analyses of all five sources have the same characteristics, so the samples can be used for further analysis.

B. *Abrasion Resistance and Compressive Strength Relationship*

The abrasion resistance test using the rotating-cutter drill press produces a weight loss value on the CPB. The testing produced varying values for each CPB. Figure 7 indicates that the greater the weight loss in the CPB is the lower is the strength. Other studies show similar results, such as [20], where adding additional materials increased weight loss and reduced strength values. In [2], it was explained that adding mixed materials to CPB increases the value of weight loss and minimizes strength.

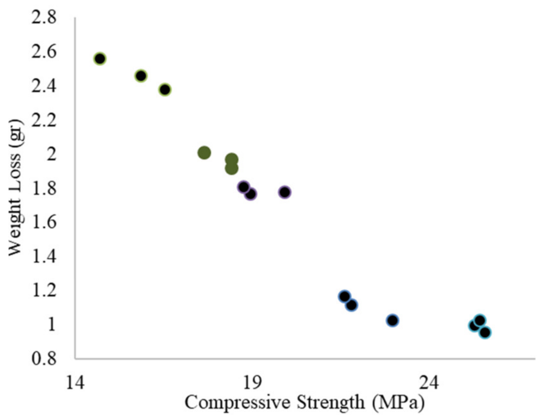


Fig. 7. Abrasion resistance and compressive strength.

C. *Splitting Tensile Strength*

Figure 8 depicts the relationship between the splitting tensile strength of CPB samples and the variations in height and sources. The analysis results exhibit that the splitting tensile strength value increases as the height increases. The CPBs with a height of 10 cm produce the highest splitting tensile strength values, followed by heights of 8 cm and 6 cm.

Figure 8 presents the relationship between the tensile splitting strength of the CPB samples and the variation in height difference to the density value. The higher the density value is the higher is the tensile splitting strength value. This aligned with other studies which displayed that density is influenced by several mixed materials [23]. Increasing density can reduce cavities [25]. This can be done by hydraulic pressing, which produces a better bond between the aggregate and the paste volume, resulting in higher splitting tensile strength. Authors in [32] showed that density influences dramatically the strength value and that the higher density achieved by CPBs produces higher strength. The density of CPBs lies in the range of 2168 kg/cm^3 [45]. Based on the variations in CPB heighT, the splitting tensile strength value is influenced by density. CPB with high density produces high tensile splitting strength.

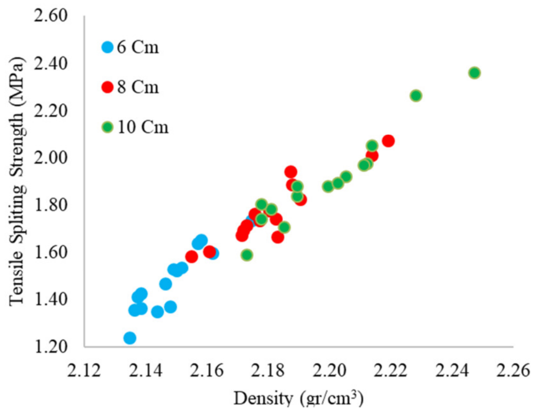


Fig. 8. Tensile splitting strength graph.

D. *Effect of Density in Flexural Strength*

The 3-point bending test method was utilized to test the flexural strength of beam samples. According to [24], compressive strength is related to flexural strength and split tensile strength. A higher CPB sample can have reduced deflection [17]. This indicator suggests that a higher CPB has greater strength. The relationship between density and flexural strength can be seen in Figure 9, which demonstrates that density greatly influences flexural strength.

The CPB samples with a height of 10 cm produced the highest flexural strength value. The 8 cm samples results were in the middle, and the lowest values were acquired from the 6 cm samples. This trend is similar to the results of compressive strength and split tensile strength tests because flexural strength is related to them [20, 24]. In this research, cube samples were selected for testing the compressive strength, as proposed by the Indonesian Standard National, whereas for flexural strength testing, beam samples were used. According to the test results, CPB with a higher thickness produces better strength.

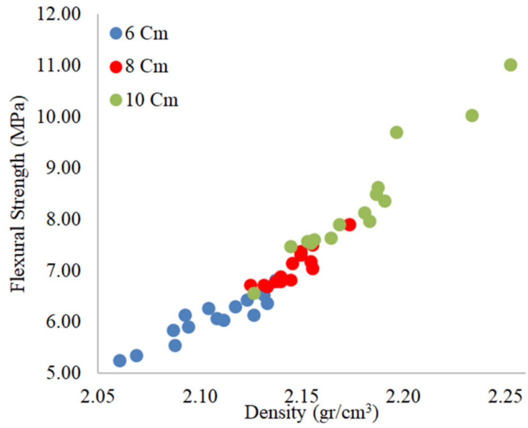


Fig. 9. Density and flexural strength.

E. *Effect of Density in Compressive Strength*

Figure 10 displays the results of the testing samples in blocks and cubes for compressive strength with different thicknesses. The beam-shaped sample is stronger than the cube sample. The same thing also happened to the samples with different heights, where those with a height of 6 cm produced the highest strength, followed by a height of 8 cm, with the lowest strength having been produced from the samples with a height of 10 cm.

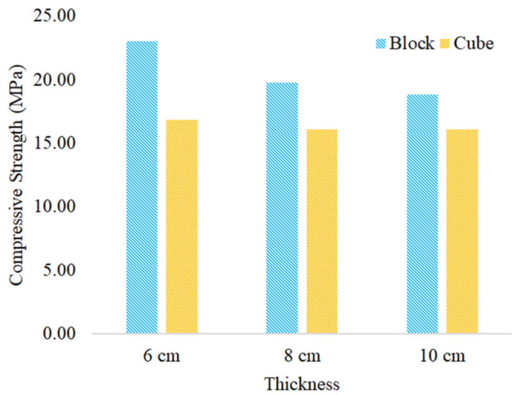


Fig. 10. Compressive strength and thickness of CPB.

The three height variations for the beam-shaped sample gave higher values than the cube-shaped sample. The cube-shaped samples produced similar values in height variations. This phenomenon was also observed in previous studies, which stated that abnormal results occurred during the CPB testing process [1, 16]. The analysis results for cube samples show that different thicknesses tend to produce almost the same strength values. This result is more realistic and follows the recommendation that CPB testing should utilize cube samples [46].

Next, an analysis of the relationship between compressive strength and density was carried out based on the thickness of the CPB with different block and cube shapes. A total of 300 (150 block-shaped and 150 cube-shaped) samples were utilized. Density characteristics are essential because they can influence the mechanical properties of CPB. Several factors, including mixture composition, preparation, and treatment, affect density. Compressive strength increases with density [16, 32]. Figure 11 depicts the relationship between density and compressive strength regarding the cube shape. The analysis results exhibit a close linear relationship between density and compressive strength.

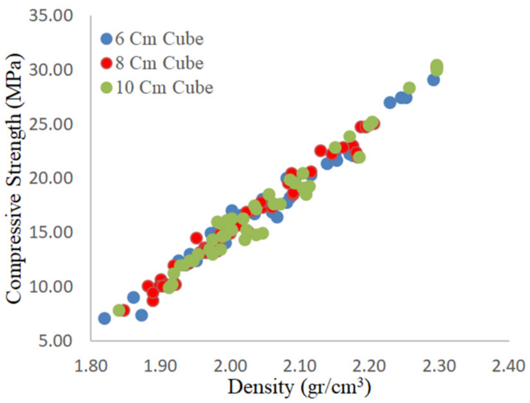


Fig. 11. Density and compressive strength of cube-shaped sample.

Figure 12 depicts the relationship between density and compressive strength in CPBs. The different heights of the beam-shaped CPBs produce values that tend to be inconsistent. Likewise, several previous studies show that the compressive strength of the beam samples tends to produce different results even with the same density [1, 16]. This underlines the importance of appropriate methods in CPB testing because this form factor can also influence CPB strength [47].

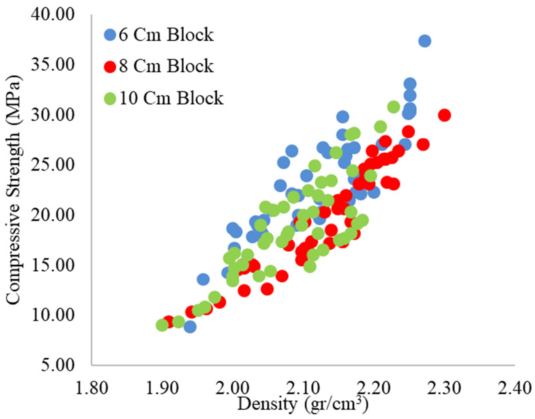


Fig. 12. Density and compressive strength of block sample.

F. Correlation between Compressive Strength and Density

The results of the compressive strength values, demonstrate that the cube-shaped samples obtained consistent values compared to the block-shaped ones. The relationship between compressive strength and density shows a strong correlation. Figure 13 portrays the R^2 value of the relationship between compressive strength and density, which is 0.9729.

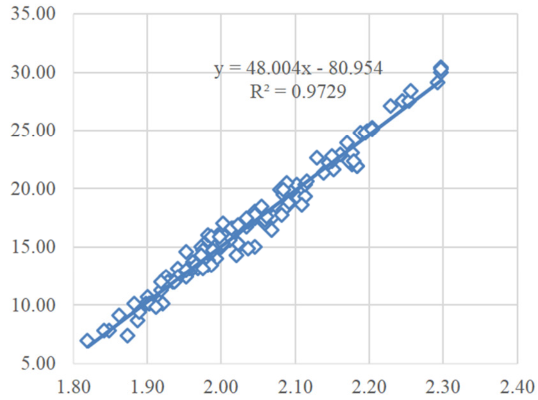


Fig. 13. Density and compressive strength.

G. Model Development

Based on the survey results of the 5 CPB factory samples, it is noted that CPB density is influenced by the pressing machine performance during CPB's formation. The relationship between the compressive strength values with machine characteristics and CPB thickness factors was analyzed using multiple linear regression. The compressive strength of the beam was utilized as the independent variable, while the compressive strength of the cube was the dependent variable expressed by:

$$Y = \beta_0 + \beta_1 X + \beta_2 X \quad (7)$$

where β_0 is a constant, β_1 is the machine characteristic coefficient, β_2 is the thickness factor, and X is the value of the beam compressive strength. Table V lists the values of β_1 and β_2.

TABLE V. MACHINE COEFFICIENT CHARACTERISTIC AND THICKNESS FACTOR

Machine characteristic coefficient (β_1)	Thickness factor (β_2)		
	6 cm	8 cm	10 cm
0.205 - 0.248	0.675	0.785	0.912

From the results of the data analysis performed on the samples, a β_0 value of -4.65 was obtained, so the equation for each CPB thickness is:

- For 6 cm thickness:

$$Y = -4.65 + \beta_1 X + 0.675X \quad (8)$$

- For 8 cm thickness:

$$Y = -4.65 + \beta_1 X + 0.785X \quad (9)$$

- For 10 cm thickness:

$$Y = -4.65 + \beta_1 X + 0.912X \quad (9)$$

The compressive strength value results of the model along with the compressive strength value laboratory test results, with $\beta_1 = 0.21$, $\beta_1 = 0.23$, and $\beta_1 = 0.25$, are presented in Figures 14, 15, and 16, respectively.

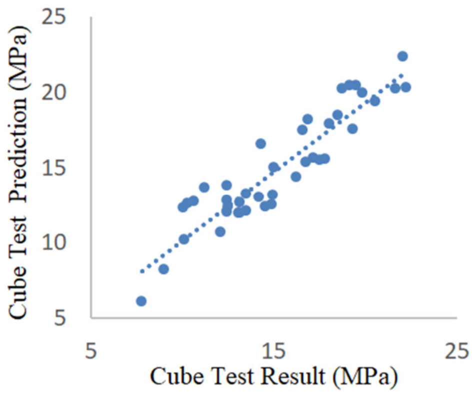


Fig. 14. Cube compressive strength value, model – test results, $\beta_1 = 0.21$.

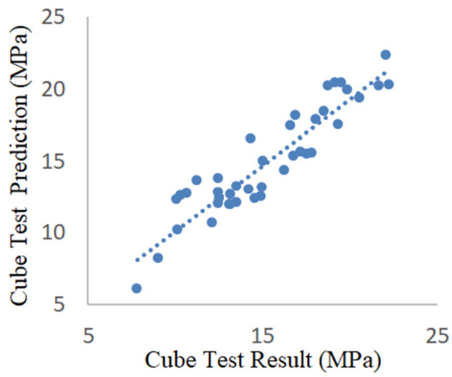


Fig. 15. Cube compressive strength value, model – test results, $\beta_1 = 0.23$.

The comparison of the compressive strength value of the model and the compressive strength of the laboratory results produces an R^2 value of 0.8547 with $Y = 0.9179\ X + 0.9474$, where Y is the prediction and X is the result. These results can help predict the compressive strength value of the cube-shaped sample, obtained from the compressive strength value of the beam.

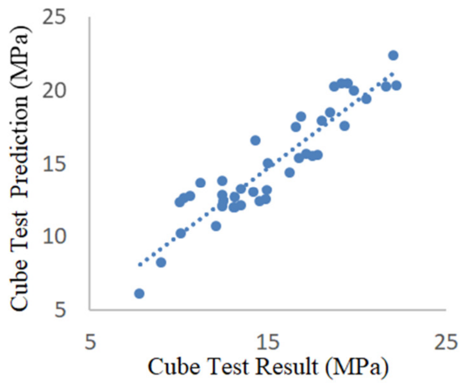


Fig. 16. Cube compressive strength value, model – test results, $\beta_1 = 0.25$.

V. CONCLUSIONS

This research identified the characteristics of Concrete Paving Blocks (CPBs) from five factory sources and then analyzed the characteristics of differences in their height and shape. The conclusions drawn are:

- The compressive strength and abrasion resistance are correlated with the strength value. The greater the weight loss in CPB was the lower was the strength value aligned with the results of other studies.
- Different thickness samples were studied to identify the characteristics of splitting tensile strength. A hydraulic machine produced CPBs to obtain a good density value. Based on in thickness variations, the splitting tensile strength value was influenced by density. That is, CPBs with high density produced high tensile splitting strength. Other works have explained that increasing density can reduce cavities, which produces a better bond between the aggregate and the paste volume, resulting in higher splitting tensile strength.
- There are differences in the characteristics between the block-shaped and cube-shaped CPBs. Based on the relationship between compressive strength and density, cube-shaped CPBs exhibit consistent compressive strength values with some differences in thickness. Other research works show similar results in characteristics between block-shaped and cube-shaped CPBs. Based on these results, the CPB testing method is more suitable for cube-shaped samples.
- The correlation between density, thickness, and compressive strength can be analyzed using the concept of multiple linear regression, resulting in the development of a model to obtain a new formula. The formula can provide a new perspective on mechanical properties, considering CPB utilization.

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