International Journal of GEOMATE, Oct., 2022, Vol.23, Issue 98, pp.189-196
ISSN: 2186-2982 (P), 2186-2990 (O), Japan, DOI: https://doi.org/10.21660/2022.98.3565
Geotechnique, Construction Materials and Environment

COMPRESSIVE STRENGTH OF CONCRETE USING LIGHTWEIGHT BRICK WASTE AS THE SUBSTITUTE FOR FINE AGGREGATE

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*Corresponding Author, Received: 02 Aug. 2022, Revised: 10 Sept. 2022, Accepted: 20 Oct. 2022

ABSTRACT: Concrete is one of Indonesia's most widely used construction materials. Thus, the need for concrete materials, mainly sand keeps increasing. Excessive sand mining will harm the environment, causing erosion and landslides. In addition, recent trends in construction have created negative impacts to the nature, such as the dumping of lightweight bricks remnant. This study was conducted to examine the use of lightweight brick waste as a substitute for fine aggregate on the compressive strength of concrete. The design of concrete in this research uses SNI 03 – 2834 – 2002 as the guidelines. The variations are 0%, 10%, 20%, and 30% of lightweight brick waste to replace fine aggregate. This research uses quantitative primary data to obtain the compressive strength of concrete. The tests were held on the seventh, fourteenth, and twenty-eighth day of concrete age, and simple regression analysis was used to determine the effect of weight on the use of brick wastes as a partial substitution of fine aggregate on the compressive strength of concrete. The results show that the maximum and minimum compressive strengths were obtained in variation 10% and variation 30%, which produce the compressive strengths 24.45 MPa and 18.03 MPa at the twenty-eighth day of concrete. Based on the results of the simple regression analysis with SPSS, the use of lightweight brick waste has a significant effect on the compressive strength of twenty-eight day of concrete by 64.8% and the linear regression formula in this test can be written as Y = 24.3 -0.170x.

Keywords: Concrete, Compressive Strength of Concrete, Fine Aggregate, Lightweight Brick Waste, Sand Substitutes, Construction Material Substitutes

1. INTRODUCTION

During the rapid development in Indonesia, concrete has become the widely used primary construction material because of the behavior of concrete that is easy to shape according to construction needs and relatively easy to maintain. The large number of uses of concrete requires many innovations related to concrete [1], [2]. One area of innovation is related to finding alternative concrete-making materials [3]–[6].

In 2002, 55 billion tonnes of natural materials were extracted, of which 42% were used in construction activities. The high demand of concrete has increased the need for constituent materials. The more the construction projects, the more waste [7]–[11]. There are 10 billion tons of construction waste generated worldwide in every year [12]. As much as 44% of the waste dumped is construction waste [13]. Approximately 2.379 billion tons of construction waste were produced in 2017, with only 11,900 tons being used as resources [14]. 80% of waste generated from materials used during construction processed can be reused [15]. Poor managed construction waste can negatively impact the environment [16]. Thus, recycling can be socially valuable, in addition to its substantial economic benefits [17]–[19].

Reusing construction waste can be one way to reduce construction waste [20]. One of the wastes frequently produced, especially in building construction, is wall building materials such as lightweight bricks [21]. Lightweight bricks are widely used because they are larger in physical form but lighter, making the process easier [22], [23]. Although lightweight brick powder has a lower density than sand commonly used in concrete, it contains silica., which can improve the quality of concrete [24].

Several studies have been carried out on the use of lightweight brick as a substitute for aggregate in concrete. Previous study investigated the use of lightweight brick waste on the compressive strength of light concrete. The brick was crushed and used as a substitute for coarse aggregate as much as 100%, produced compressive strength 7.35 MPa at seven days 7.35 MPa and 12 MPa at 28 days [25]. Beside that, a study that uses lightweight brick as a substitute for coarse aggregate with variations of 20%, 25%, 30%, and 35%. The results of this study indicate that the maximum compressive strength of produced in concrete with a variation of 25% is 35.04 MPa [26].

Excessive sand mining can harm the environment [7]–[9]. Mining has several impacts on the environment, such as increasing the potential for landslides, changing soil structure, decreasing infiltration capacity and groundwater absorption, affecting local biota, causing health hazards, destructing riparian vegetation, depleting organic matter in the soil, and reducing water discharge surface/springs [10]. Therefore, innovations are needed to reduce the use of sand [27].

In this study, the effect of lightweight brick waste as a substitute for sand as fine aggregate in proportions of 0%, 10%, 20%, and 30% on the compressive strength of concrete is investigated. Therefore, the authors take the waste variable lightweight brick as one of the variables used in this study to be utilized.

2. RESEARCH SIGNIFICANCE

Lightweight brick waste is one of the construction wastes which, if accumulated, will negatively impact the environment. This study is expected to reduce the waste of lightweight brick in the environment by using it as a replacement for fine aggregate in concrete.

This study aims to obtain and analyze the values of compressive strength by utilizing lightweight brick waste as a substitute for fine aggregate in concrete which can be useful in the development of science, especially in the materials science.

3. METHODS

This research was conducted experimentally at the Civil Engineering Materials Laboratory of Jakarta State Polytechnic from April 2022 to July 2022. The test object of this study is a concrete cylinders with the diameter of 15 cm and the height of 30 cm. SNI 2834 2002 [28] was used as the guideline for the concrete mix design. The concretes in this study were designed with variations in the substitution of fine aggregate as much as 0%, 10%, 20%, and 30% to complete the previous research.

Table 1. Aggregate Testing

Name of Testing	Standard Method
Bulk Density and Voids	ASTM C29/C29M – 07 [29]
Sludge Levels	ASTM C117 [30]
Sieve Analysis	ASTM C136 [31]
Moisture Content	ASTM C566 [32]
Specific Gravity and Water Absorption	ASTM C127 [33] ASTM C128 [34]

The first stage of this experiment was the preparation and testing of fine and coarse aggregate that shown in (Tabel 1). The next stage was making the concretes and testing the fresh concrete and put them to cylinder molds. After 24 hours of sitting time, the concretes were demolded and placed in curing water tank for 7, 14, and 28 days. The final stage was testing their compressive strength using crushing machine

The lightweight brick waste used in this study came from the construction waste of the Apartment Project in Tanjung Barat and of residential houses in Bekasi. The tests performed on the aggregates are outlined in the following section.

3.1. Specific Gravity

Specific gravity of aggregate is obtained from the ratio between the weight of the aggregate and the weight of water which has the same volume as the aggregate[35].

3.2. Bulk Density and Voids

The bulk density also called the apparent density of an aggregate, can be defined by the mass or weight of the aggregate required to fill a container of a specified unit volume. The volume here is that occupied by both aggregates and the voids between aggregate particles. The void content between particles affects the paste requirements in the mix design which affected by the density of specific gravity, aggregate gradation, aggregate shape, and the maximum diameter of the aggregate [36].

3.3. Sieve Analysis and Fineness Modulus of Aggregate

Table 2. Classification of Fine Aggregate Gradation

Sieve Size (mm)	% Passing			
	Zone I	Zone 2	Zone 3	Zone 4
9.6	100	100	100	100
4.8	90-100	90-100	90-100	95-100
2.4	60-95	75-100	85-100	95-100
1.2	30-70	55-90	75-100	90-100
0.6	15-34	35-59	60-79	80-100
0.3	5-20	8-30	12-40	15-50
0.15	0-10	0-10	0-10	0-15

Source: SNI 03 2834 2000

Aggregate grading is the grouping or distribution of aggregate grain size as the cumulative percentage of grains from each sieve aperture size [37].

3.4. Sludge Levels

Aggregate grains with the size of <0.075 can be called silt or mud [24]. The mud content in the fine aggregate should not be more than 5%, and the coarse aggregate should not be more than 1% of the dry weight of the aggregate. Futhermore, the silt content in the aggregate exceeds the standard, it will affect the compressive strength of the concrete [38], [39].

SNI 2834 2002 [28] was used as the guideline in designing the concrete mixtures of this research. The fresh concrete testing was carried out by testing the slump values, testing the setting time of concrete, and fresh concrete's density. The mixed concrete was put into a tube mold with the diameter of 15 cm and the height of 30 cm. The number of test objects in each variation is three.

3.5. Compressive Strength of Concrete

This experimental research is conducted to determine the compressive strength of concrete that uses lightweight brick as the substitute for fine aggregate. SNI 1974-2011 [40] was used as a guideline in the testing. The compressive strength of the concrete was determined by the following formula:

$$fc' = P/A \quad (1)$$

fc' is compressive strength (MPa)
P is the maximum load (kN)
A is area (mm^2)

Referring to Eq (1), the compressive strength values of concrete can be defined by the ratio between the maximum load to the surface press of the concrete [41]. The data obtained from the compressive strength test was then analyzed using simple regression analysis in SPSS application. The analysis was carried out to determine the relationship between the two research variables [42].

4. RESULTS AND DISCUSSIONS

3.1 Results

The data result of this study consist of the aggregate testing result, the mix design of the concrete, and the result of the compressive strength test of concrete for each variation.

The results of this research are described in the following explanation.

3.1.1. Aggregate testing

From the aggregate test result (Table 3) below, the Fineness Modulus (FM) values of fine aggregate, lightweight brick and coarse aggregate values, respectively, are 3.41, 3.56, and 6.27. The weights of the contents are 1610.4 kg/m^3, 711.3 kg/m^3, 1214.2 kg/m^3 with void values are 36.89%, 22.02%, and 52.10%. The values of fine aggregate, lightweight brick, and coarse aggregate absorptions, respectively, are 1.71%, 34.53%, and 1.24%. Based on the result, lightweight brick has high absorption value, lightweight brick moisture content must be considered at mixing time, so the planned amount of water is not absorbed by lightweight bricks and reduce the workability of concrete. The Saturated Surface Dry (SSD) density of fine aggregate, lightweight brick, and coarse aggregate was used to design the concrete mixture. The values, respectively are 2.601, 1.214, and 2.570. Based on the standard, ranges for normal-weight aggregate used in concrete is between 2.30-2.90 [43]. This indicates that the coarse aggregate and sand used in this study are classified as normal-weight aggregates, while the bricks are included in lightweight aggregate. The standard silt contents are 1% for coarse aggregate, and 5% for fine aggregate [38]. Based on the sludge level test, the silt contents of fine aggregate and coarse aggregate are 2.55%, 0.35% meeting the standard. In contrast, the sludge level in lightweight brick does not meet the standards, so it needs to be washed to reduce their silt content.

Table 3. Data Result of Aggregate Testing

Aggregate Testing	Units	Values		
		Fine Agg.	LB	Coarse Agg.
Bulk Density		2.557	0.902	2.54
SSD		2.601	1.214	2.570
Apparent Density		2.673	1.31	2.623
Absorption	%	1.71	34.53	1.24
Specific Gravity	kg/m^3	1610.4	711.3	1214.2
Voids	%	36.89	22.02	52.10
Sludge Levels	%	2.55	5.224	0.35
FM		3.41	3.56	6.27

3.1.2. Mix design

The quantity of materials in mix design of this study is calculated based on SNI 2834 2002. The results were used as a guideline for making concrete for each variation. Based on the Mix design calculation of concrete, the materials needed were as much as 148.8 kg of cements, 221 kg of fie aggregates, 377.6 kg of coarse aggregates, 57.4 kg of waters, and 33.1 kg of lightweight bricks. The quantity details of material for each variations are obtained in (Table 4) below.

Table 4. Result of Mix Design

Material (Kg)	Var. 0%	Var. 10%	Var. 20%	Var. 30%
Cement	37.2	37.2	37.2	37.2
Fine Agg.	66.6	59.1	51.4	43.9
Coarse Agg.	94.4	94.4	94.2	94.2
Water	13.0	13.9	14.9	15.6
Light Brick	0	5.68	11.12	16.3

3.1.3. Compressive strength of concrete

A lot of factors influence the compressive the compressive strength of concrete, such as the material properties of cement and aggregates, the specimen size, etc [44]. In this study the results of the compressive strength test with lightweight brick waste used as the substitute for fine aggregate of each variations are shown in (Fig. 1) below.

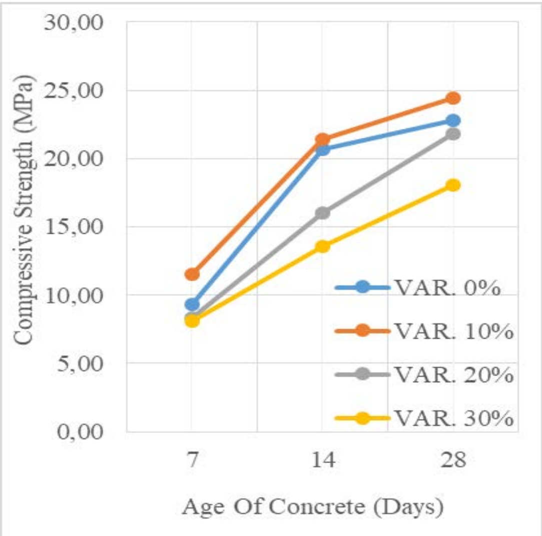

Fig. 1 Compressive Strength of Concrete in Each Variations

The compressive strengths of the 7 days old, with the variations of 0%, 10%, 20%, and 30%, respectively, are 9.34 MPa, 11.54 MPa, 8.38 MPa, and 8.13 MPa. The maximum compressive strength value is on concretes with the variation of 10%, and the minimum value is on concrete with variation of 30%.

The compressive strengths of the 14-day-old concretes with the variations of 0%, 10%, 20%, 30% are 20.67 MPa, 21.37 MPa, 16.01 MPa, and 13.58 MPa respectively, shown in (Fig. 2). The maximum compressive strength is on concretes with the variation of 10%, while the minimum is on those with the variation of 30%

The compressive strengths of the 28-day-old concretes with the variations of 0%, 10%, 20%, and 30% are shown in (Fig. 2). They are 22.81 MPa, 24.45 MPa, 21.81 MPa, and 18.03 MPa respectively. The maximum strength is on concretes with the variation of 10%, while the minimum is on those with 30% variation.

The effect of using lightweight brick as the substitute for fine aggregate on the compressive strength of concrete was obtained by using SPSS. Based on the results of the SPSS analysis test, the significance values of using lightweight brick as the substitute for fine aggregate are shown in Table 5 & Table 6 below.

Table 5. Compressive Strength Coefficients For Each Variation of Concrete

Age	Unstandardized coefficients		Sig.
	B	Std. Error	
7	10.4	1.312	0.016
	-0.07	0.070	0.435
14	21.9	1.507	0.005
	0.27	0.081	0.081
28	24.3	1.615	0.005
	-0.17	0.089	0.195

The simple linear regression analysis results in that the 7-day-old concrete has the significance value of 0.435. It indicates that the addition of lightweight brick replacing fine aggregate has no significant effect on the compressive strength of concrete because the significance value is more than 0.05. As shown in table 5, the constant and b values are 10.4 and -0.07. It shows that the constant value of the compressive strength, if there is no addition of light brick variation is 10.4. Further, each addition of lightweight brick decreases the compressive strength of the concrete by 0.07 MPa. The simple linear regression formula of this test can be written as Y = 10.4 – 0.07x.

The simple linear regression analysis results in that the 14-day-old concrete has the significance value of 0.081. Hence, the utilization of lightweight brick as the replacement of fine aggregate has no significant effect on the compressive strength of concrete because the significance value is more than 0.05. As shown in (table 5), the constant and b values are 21.902 and -0.27. It shows that the constant value of the compressive strength, if there is no addition of lightweight brick variation is, 21.902. Then, each addition of a lightweight brick variation decreases the compressive strength of the concrete by 0.27 MPa. The linear regression formula of this test can be written as Y = 21.902-0.27x.

The simple linear regression analysis results in that the 28-day-old concrete has the significance value of 0.195. The result shows that the addition of lightweight brick as the substitute for fine aggregate has no significant effect on the compressive strength of concrete because the significance value is more than 0.05. As shown in (table 5), the constant and b values are 24.3 and -0.170. It shows that the constant value of the compressive strength, if there is no addition of lightweight brick variation, is 24.3. Then, with each addition of a lightweight brick variation, the compressive strength of the concrete will decrease by 0.170 MPa. The linear regression formula in this test can be written as Y = 24.3 -0.170x.

The percentage of effect of using lightweight brick usage on the compressive strength shown in (Table 6)

Table 6. Model Summary of Compressive Strength for Each Concrete Variations

Days	R	R Square
7	0.565	0.319
14	0.919	0.845
28	0.805	0.648

As shown in (Table 6), the R Squared value of the 7-day-old concrete is 0.319. The result shows that the use of lightweight brick affects the compressive strength of concrete because there is a decrease and increase in the compressive strength. The magnitude of the use of lightweight brick as the substitute for fine aggregate on the compressive strength of concrete in this study is 31.9%.

The R Squared value of the 14-day-old concrete is 0.845. The result shows that the use of lightweight brick affects the compressive strength of concrete because there is a decrease and increase in the compressive strength. The magnitude of the use of lightweight brick as the substitute for fine aggregate on the compressive strength of concrete in this study is 84.5%.

The R Squared value of the 28-day-old concrete is 0.648. The result shows that the use of lightweight brick affects the compressive strength of concrete because there is a decrease and increase in the compressive strength. The magnitude of the use of lightweight brick as the substitute for fine aggregate on the compressive strength of concrete in this study is 64.8%.

3.2. Discussions

As shown in (Table 7) below, there is an increase in the compressive strength of the 10% variation of concrete by 2.4% in the 7-day-old concrete, 3.38% in the 14-day-old concrete, and 7.18% in the 28-day-old concrete; while the strength of the 20% and 30% variation of concrete decreased. Lightweight bricks contains silica [46]. This is the basis for an increase in the compressive strength of concrete with lightweight brick waste as the substitute for fine aggregate as much as 10% since silica can strengthen the bond between cement paste and the aggregate [47].

Table 7. Percentage Change in Compressive Strength

Age of Concrete	Variation of Light Brick	% increases/ Decreases
7 days	10%	+2,37%
	20%	-10.20%
	30%	-12.97%
14 days	10%	+3.38%
	20%	-22,53%
	30%	-34,31%
28 days	10%	+7,18%
	20%	-4%
	30%	-20,93%

Singh & Ravindra (2020) found that the maximum compressive strength is produced in the variation of substitution of lightweight brick with coarse aggregate by 25%. However, this particular research gives different results by finding that there is a decrease in the compressive strength of concrete using lightweight brick at the variations of 20% and 30%

The reason for the decrease was because the researchers used lightweight brick waste that crumbles easily when gripped or rubbed with other solid objects. Therefore, the lightweight bricks were crushed and become silt with the size of <0.075. This is evidenced by the amount of mud at the time of testing the sludge level. Aggregate with the grain size of <0.075 can be categorized as silt [38]. High levels of mud can result in reduced concrete strength because large amounts of silt can cover the aggregate’s surface and weaken its bond with cements [47]. In addition, very small silt grains can stick to the aggregate. The mud attached to the aggregate will absorb water and cause the amount of water to increase so that the concrete mixture is not proportional [48].

The decrease occurred because of the high water absorption in the lightweight brick, as shown in (table 2). Absorption of aggregate can affect the workability of the concrete [49]. Concrete with low workability can cause imperfect compaction of the test object and produce porous concrete. Highly porous concrete will experience a decrease in compressive strength due to the large number of air voids in the concrete [50]. The air voids reduce the adhesion and compressive strength of the aggregate in the concrete and decrease the concrete's compressive strength [51]. This is why the compressive strength of concrete with the variations of 20% and 30% in this study decreases.

5. CONCLUSIONS

Based on the test results, the compressive strength of the 10% variation of concrete increased by 2.4% in the 7-day-old concrete, 3.38% in the 14-day-old concrete, and 7.18% in the 28-day-old concrete, while the strength of that with 20% and 30% variations decreased. Based on the results of the simple regression analysis, it was also found that the use of lightweight brick as the replacement of fine aggregate has a significant effect on the compressive strength of concrete with the equation of $Y = 10.4 + 0.07x$ for 7-day-old concrete, $Y = 21.902 + 0.27x$ for 14-day-old concrete, and $Y=24.3+0.17x$ for 28-day-old concrete. The data shows that the use of lightweight brick waste affects the compressive strength of concrete. The 10% variation increases the concrete's compressive strength, while the 20% and 30% variations decrease the strength. The increases occurred because lightweight brick contains silica that can strengthen the compressive strength of concrete. Meanwhile, the decrease occurred because lightweight concrete has high absorption and make the concrete porous.

This investigation revealed that lightweight brick can increase the compressive strength of concrete at a variation of 10%. On this basis, future research can examine the effect of using lightweight brick waste less than 10%. Besides that, based on the aggregate testing, lightweight brick has lighter weight and lower specific gravity. Futher research can examine the effect of using lightweight brick as substitute for fine aggregate on the compressive strength of lightweight concrete.

6. ACKNOWLEDGMENTS

The researcher would like to express his gratitude to the Research and Community Service Unit (UP2M) of Politeknik Negeri Jakarta for providing funding through the 2022 Student Research program.

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