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EXPERIMENTAL STUDY ON PERFORMANCE OF CELLULAR LIGHTWEIGHT CONCRETE DUE TO EXPOSURE HIGH TEMPERATURE

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ABSTRACT: Generally, making the building load lighter is to use lightweight concrete on wall components. Cellular Lightweight Concrete (CLC) is lighter than red-bricks because CLC contains pores. Changes in temperature due to building fires impact the characteristics and performance of CLC, especially in density, compressive strength, and visual shape of CLC. The research aims to analyze the performance of CLC; compressive strength and appearance of CLC surfaces after exposure to high temperatures. CLC sample is the block with size 60 cm length, 10 cm width, and 20 cm height. Variation of temperature exposure time is 10 minutes, 20 minutes, 30 minutes and 40 minutes. CLC is placed close to traditional brick kilns with an average surface temperature of 370 degrees Celsius along 40 minutes of combustion. The CLC block compressive strength value due to exposure to high temperatures for 40 minutes is 0.3 MPa. The compressive strength of CLC after exposure to high temperatures decreases by 42.3% compared to CLC at room temperature. Whereas, the visual form on the surface of CLC gives rise to a blackish grey colour resulting from exposure to high temperatures. This study indicated that the dry and cracked surface texture on CLC has caused a decrease in the performance includes density and compressive strength of CLC. Therefore, CLC needs to maintain after being exposed to high temperatures by providing an additional layer on the CLC surface.

Keywords: Cellular lightweight concrete, Compressive strength, Density, High temperature

1. INTRODUCTION

Red-brick is one of the most widely used construction materials in Indonesia. The brick has made by using clay as a primary material in its manufacture conventionally. An excellent red brick has the characteristics of a rough surface, not cracked, not easily broken, a deep red uniform colour, both on the inside or outside of the brick which indicates that the brick is ripe [1].

The development of construction technology has led to a shift in the use of red bricks. The impact of technological developments in the construction sector is discovering new construction materials such as Cellular Lightweight Concrete (CLC) and Autoclaved Aerated Concrete (AAC) as a substitute for red brick. AAC is a cellular concrete with air bubbles produced from the chemical reaction of aluminium powder or aluminium paste as a mixture developer [2]. In comparison, CLC is a cellular concrete block that undergoes natural treatment processes. The CLC work process uses organic foam which is very stable, and no chemical reactions occur during the material mixing process [3-6].

Cellular lightweight concrete has advantages over conventional red-brick because CLC has a low-density index as partition walls, acoustic and thermal insulation materials [7,8]. The CLC contains sufficient air cavity due to the addition of foam to the mortar and aims to reduce the value of volume weight [7]. Therefore, the advantages of CLC make it a viable alternative to wall partitioning compared to red clay bricks.

Increased temperature due to heat exposure from a burning building or direct sunlight can affect the mechanical properties of CLC. In the previous study [8], the authors have studied the mechanical properties of CLC such as deformation, tensile strength, compressive strength, and shear strength in various sand and cement ratio in concrete foam admixture. In addition to influencing the mechanical properties of lightweight concrete, the effect of heat transfer also affects the physical properties of CLC [9]. The CLC physical properties are measured without changing their original identity [10], [12-14].

Researchers examined the mechanical properties of CLC using several testing methods. The method includes a non-destructive and destructive test to all parts of CLC. The compressive strength of CLC was generated through destructive testing using a load cell mounted on a steel frame in the study. The fundamental problem is how the effect of heat exposure on the compressive strength and appearance of CLC surface. Therefore, the study aims to identify changes visually and analyze the compressive strength of CLC after exposure to high temperatures. Thus, the wall of buildings have made of CLC exposed to high temperatures can be anticipated with improvements so that the walls are still suitable for use.

2. RESEARCH SIGNIFICANCE

CLC blocks on the building walls have an advantage such as a low-density index, a good material for partition walls, and can make the room more comfortable because the pores in CLC can absorb heat. However, high heat absorption can affect the strength of CLC. Therefore, this study aims to visually identify changes in the CLC surface and analyze the compressive strength of CLC after exposure to high temperatures.

3. THEORETICAL BACKGROUND

Commonly wall construction used red-brick, natural stone, brick, wood, plywood, and asbestos. Today, the development of these materials is replaced by renewable materials such as Cellular Lightweight Concrete (CLC) block, as shown in Fig. 1.

(a) (b)

Fig. 1 (a) The Cellular Lightweight Concrete (CLC) block, (b) and the texture of CLC [8].

CLC is considered more economical compared to conventional red-brick. Also, the relatively larger form of CLC can shorten the wall working time. CLC is made from a mixture of cement, water, sand and foam to produce a mix of mortar ready to be poured on a CLC mould [13]. The most critical aspect in planning CLC is how to create lightweight and economical concrete, without ignoring the strength of this lightweight concrete [13-15]. CLC is also suitable for building walls of soft soil areas because they can reduce the load on the foundation. Therefore, CLC is ideal for use in tall buildings. Another advantage of CLC is in terms of dimensions. CLC has larger sizes than traditional bricks. Fig. 2 shows the difference in dimensions of conventional brick (red-brick) and CLC block. In-wall installation, every one m^2 requires 8.3 CLC blocks, whereas traditional red-bricks need 125 bricks. The size of CLC block is 60 cm length, 10 cm width, and 20 cm height. Meanwhile, the red-brick size is 16 cm length, 5 cm in width, and 7.5 cm height.

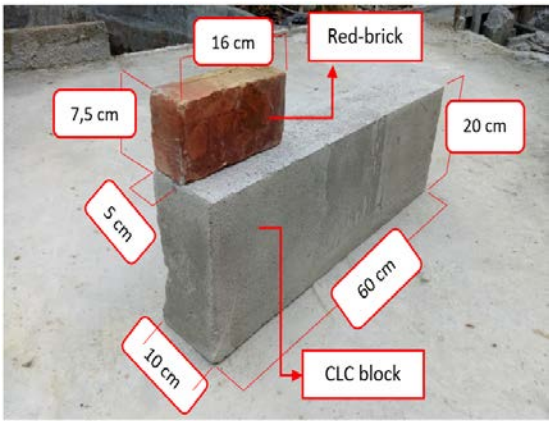

Fig. 2 Dimension of red-brick and Cellular Lightweight Concrete (CLC)

According to [6], foam stability is critical for achieving the optimal density of the CLC mix design and having a closed pore structure. Hydrolyzed protein foaming agents impart the desired properties to the produced foam. The Sunlite Foam SF-30 SPL, a commercially available foaming agent, was used for this analysis. The foaming agent and water were combined in a ratio of 1:40 and fed into the foam generator to achieve a preformed foam density of 70 g/litre. The volume fraction of the mixture of foam is 16 per cent of the overall volume.

The material used in the making CLC is cement, water, fine aggregate and foaming agent [5,16]. The composition of the mixture dramatically influences the quality of CLC. Cement water factor is essential in making lightweight concrete. Based on research conducted by [6,7], [17,18], by varying the cement water factor in making concrete, the compressive strength value of the concrete decreases due to an increase in the cement water factor. The selection of aggregates is essential in making CLC. The use of coarse aggregate tends to be problematic during the lightweight concrete mixing process because the coarse aggregate will settle to the bottom so that the lightweight concrete is not mixed evenly.

The necessary ingredients of foam agents consist of synthetic materials and protein components. Synthetic based foam has a density of around 40 kg/m^3 and can expand about 25 times the initial volume. The type of foaming agent is very stable for CLC with masses above 1000 kg/m^3. The ratio of foam and water used is 1:19. The solution of 20 litres of foam can expand into about 500 litres of foam with a weight of about 40 kg/m^3.

In comparison, protein-based foam obtained from natural materials weighs around 80 kg/m^3 and can expand about 12.5 times the original volume. The foam is relatively more stable and has a higher strength compared to synthetic foam. But the foam can only last up to 12 months in an open state. The ratio of foam and water is 1:33 to 1:39. A solution of 40 litres of foam can expand into about 500 litres of stable foam weighing around 80 kg/m^3 [8].

High temperature is very influential on CLC. Light bricks exposed to high temperatures can experience colour changes, such as in concrete. According to [8,19], the colour change of post-burnt concrete's physical properties depends on the temperature during combustion. Discolouration of the concrete begins to appear at a temperature of 500 ^oC, which is greyish brown. The condition occurred because of iron salt compounds in the aggregate or concrete sand that causes the concrete to change colour. For temperatures reaching 750 ^oC, CLC can create a carbonation process that is formed of Calcium Carbonate ($CaCO3$), which is whitish. So the CLC becomes brighter. Based on research conducted by [9,20], the higher the combustion temperature of the concrete, the higher the damage to the concrete.

According to [21], thermal conductivity is the transfer of heat through solid objects. The heat moves from the hotter particles to the cooler molecules, but this heat transfer does not cause the displacement of the object molecules. The thermal conductivity of the material indicates heat flow velocity in a solid object. The greater the thermal conductivity value of a material, the better the material is at transferring heat, and vice versa. The greater the heat is given, the greater the amount of thermal conductivity. If the thermal conductivity is small, the longer it takes for heat to propagate. Based on [22], building materials with low thermal conductivity is significant to reduce the spread of building heat in tropical countries such as Indonesia. Lightweight brick has recognized its superior performance in thermal insulation and sound insulation characteristics due to its microcellular. The thermal conductivity of light bricks is usually 5% - 30% of standard concrete. Table 1 shows the value of thermal conductivity in lightweight bricks.

Table 1 Thermal Conductivity of CLC

Density (Kg/m^3)	Thermal Conductivity (W/m^{0}K)
600	0.19
1000	0.43
1400	0.59
mortar	0.96

Compressive strength is one of the main performances of light-bricks to withstand the compressive force in each unit surface area. Theoretically, the compressive strength of lightweight bricks influences by the strength of its components, namely cement paste, cavity volume, aggregate, and the interface between cement paste and aggregate. The compressive strength test has conducted by providing a compressive load with a speed of 0.15 MPa/second to 0.34 MPa/second until the test object is broke. Before carrying out the test, the compressed surface of the test object must be even so that the stress is evenly distributed in the cross-section of the specimen.

According to [11], the compressive strength test with a compression machine at the age of 7 days is 0.489 MPa, 14 days is 0.578 MPa, and 28 days is 0.667 MPa with the compressive strength plan of 1 MPa. The compressive strength test carried out on variations in the composition of the lightweight brick mixture. It has found that the compressive strength was 3.92 MPa, with a composition of 50% fly ash and 50% cement. The test was conducted on a cube-shaped sample measuring 15 cm x15cm x15 cm with a light brick weight of 900 kg/m^3. The average compressive strength is 3.00 Mpa for 0.7 liter/m^3 foam agent, 2.53 MPa for 0.9-liter foam agent/m^3, and 2.17 MPa for foam agent 1.1 liter/m^3. The test has done with a cylindrical sample and 0.541 kg of gypsum powder as an ingredient. This study used a ratio of cement and fine aggregate 1: 2 with a cement water factor of 0.4%.

Based on the other research conducted by [4,23], by varying the concrete's quality, the post-burn compressive strength test results were 19.1 MPa for 20 MPa of concrete quality design, 21.8 MPa for 25 MPa of concrete quality design, and 22.2 MPa for 30 MPa of concrete quality design. From the results obtained, it founds that the quality of 30 MPa concrete has decreased significantly. Based on research conducted by [11], the compressive strength of post-burn concrete has decreased. Normal concrete compressive strength ranges from 229.58 kg/cm^2 - 266.19 kg/cm^2, after being burned at a temperature of 200°C the compressive strength decreases in the range of 183.22 kg/cm^2 - 242.53 kg/cm^2.

The compressive strength of concrete at a temperature of 250°C ranges from 131.15 kg/cm^2 - 209.96 kg/cm^2, while at temperatures of 300 °C, 350 °C, 400 °C ranges from 139.42 kg/cm^2 - 160.61 kg/cm^2. A significant decrease occurred again at a temperature of 450 °C, the compressive strength ranged from 120.40 kg/cm^2 - 138.24 kg/cm^2, while at a temperature of 500 °C which ranged from 76.96 kg/cm^2-114.79 kg/ cm^2. The compressive strength of concrete that is burned at a temperature of 550 °C ranges from 78.89 kg/cm^2 - 107.82 kg/cm^2, and concrete that is burned at a temperature of 600 °C, the compressive strength ranges from 62.11 kg/cm^2 - 105.82 kg/cm^2.

The compressive strength value has been obtained from testing the light brick sample subjected to a load and pressed to shreds. The compressive strength value has calculated by the following Eq. (1) :

$$f'c = \frac{P\ (N)}{A\ (mm^2)} \qquad (1)$$

f'c is compressive strength value in MPa unit, A is a cross-sectional area in mm^{2,} and P is load in Newton unit.

4. RESEARCH METHODOLOGY

This work used two different mass-ratio cement and sand compositions. The first composition is called Variation 1, with the cement-sand ratio being 1:2, and the second composition is called Variation 2, with the cement-sand rate being 2:3. Table 2 describes the variable design of the CLC.

Table 2. Design of mortar mixture

Specimen Code	Material			
	Cement (kg)	Sand (kg)	W/C ratio	Sikamen (ml)
Variation (1)	100	200	0.5	200
Variation (2)	100	150	0.5	200

The research has tested 24 specimens to get lightweight concrete strength and density: the foaming agent and water-mass ratio of 1:30 and Sikamen addictive. The CLC paste has made with cement to water ratio (W/C) of 0.5.

CLC material consists of cement, sand, water and foam agent. Foam agent functions to produce foam using foam generator equipment with 200 litres per minute and a pressure compression machine of 100 kN, as shown in Fig 3.

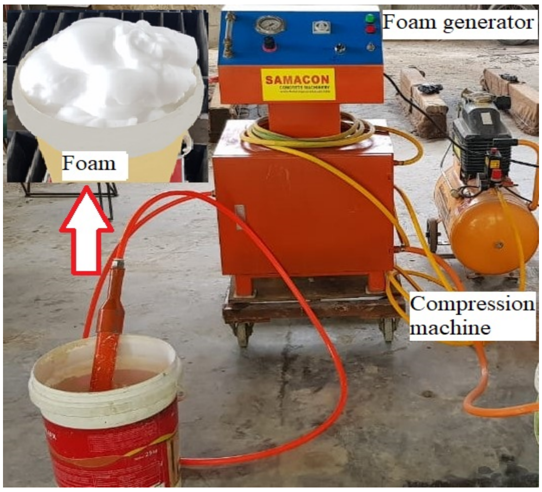

Fig. 3 The process of making foam using a foam generator

CLC specimens have reached 28 days since the making process is heated in a brick kiln for 10, 20, 30 and 40 minutes. The furnace temperature is an average of 465 degrees Celsius measured using an infrared digital thermometer. The CLC heating process, as shown in Fig 4.

Fig. 4 Process of heating CLC block in the furnace

The compressive strength test is carried out in the structural laboratory after the specimen has cooled and reaches room temperature. The compressive strength equipment uses a loading frame with a load cell, hydraulic actuator and jack, as shown in Fig 5.

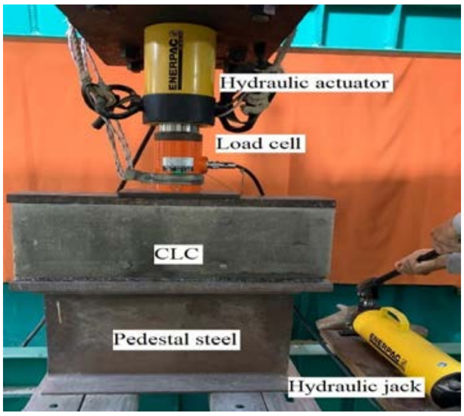

Fig. 5 Instrumentation setting out

5. RESULT AND DISCUSSION

Table 3 shows the fine-aggregate test results suggested the amount of mud on the fine aggregates used in this study met condition according to ASTM C-33 [24], and the fine aggregates provided a medium sand group with a fineness modulus of 2.04. The fine-aggregates mud average is 4.87 per cent. The adequate sum has an apparent absolute gravity of 2.65. The sieve review findings on fine aggregates showed that fine aggregates were based on Indonesian Standard SNI 03-2828-2011 [25] in Specification No. 4, which notes fine aggregates are fine grading. The value of the sufficient modulus is an indication that the amount of the fine aggregate is in the mortar.

Table 3. Fine Aggregate Characteristic

No	Testing item	Result	Standard Range
1	Mud rate (%)	4.87	< 5
2	Specific Gravity		
	a. Apparent Specific Gravity	2.65	2.58-2.83
	b. Bulk Specific Gravity on Dry	2.28	2.58-2.83
	c. Bulk Specific Gravity on SSD	2.40	2.58-2.83
	d. Absorption (%)	5.49	2.0 – 7.0
3	Water content (%)	3.73	3 – 5
4	Volume weight (gr/cm^3)		
	Table 3 continued		
	a. Solid condition	1787.77	1400-1900
	b. Dry condition	1297.74	1400-1900
5	Rate of Organic	No. 2	Max No. 3
6	Fine-Modulus	2.04	1.5-3.8

Figure 6 and Table 4 display the effect of the contents of variation composition on the compressive intensity of CLC. Variation 2 with higher cement content demonstrates higher compressive strength at 3, 7, 14, and 28 days of age than Variation 1. The research resulted in the various compositional effects, including density and compressive strength, of the physical and mechanical properties of CLC. In Variation 1 and Variation 2, sand consumption in 1 m^3 of mixing concrete was 200 kg and 150 kg, respectively, when the cement consumption was 100 kg for both variations. Therefore, sand consumption in a fixed quantity for 1 m^3 of concrete mixture in Variation 1 and Variation 2 resulted in decreased cement use in Variation 2 instead of Variation 1. Variation 2 indicates a higher value for density than Variation 1. The condition stated that increased cement in Variation 2 has caused the mixing foam concrete to increase mixed density.

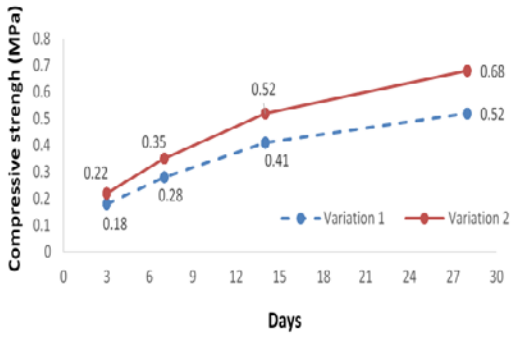

Fig. 6. Compressive strength of CLC

Table 4. The Compressive strength with the variation of composition cement and sand

Variation No.	Cement : Sand	Compressive Strength (MPa)			
		3 days	7 days	14 days	28 days
1	1 : 2	0.18	0.28	0.41	0.52
2	2 : 3	0.22	0.35	0.52	0.68

Laboratory testing showed the failure of the specimen after heating for Variation 1 (Fig 7) and Variation 2 (Fig 8). The increased density allowed the addition of cement to the lightweight mixture of concrete. Hence Variation 2 has compressive strength is higher than Variation 1. Nevertheless, due to cement's small addition (low-strength), the increase in force generated is not massive. While this study's findings are similar to studies published in the literature, such as [4] and [5], reducing sand particles' size will lead to increased foam concrete resistance.

Fig 7. The compressive test on specimen Variation 1

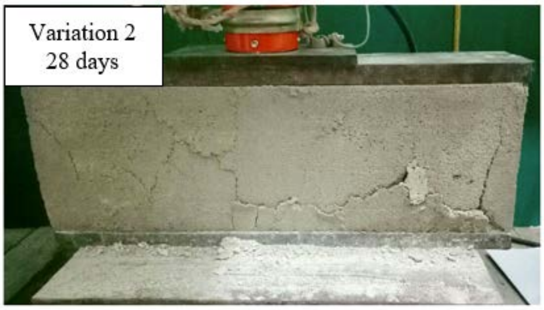

Fig 8. The compressive test on specimen Variation 2

Based on visual observations of CLC due to exposure to high temperatures, several changes such as CLC colour changes and changes in pore size have occurred. Colour-changes in the CLC began to appear since the CLC has exposed for 30 minutes. The exposed surface has turned brownish. Table 5. shows the exposure temperature of CLC in parts directly exposed to high temperatures.

Table 5. The temperature of CLC exposure

Minute	Variation 1 (°C)	Variation II (°C)
10	313	289
20	340	358
30	345	366
40	370	370

Exposure to temperature every 10 minutes with an average of 342 degrees Celsius for Variation 1 and 345.75 degrees Celsius for Variation 2 during a total firing of 40 minutes has resulted in cracked light brick surfaces, dry layer. In addition to changes in colour, exposure to high temperatures also cause changes in the pore size of the lightweight concrete. Pores that have initially been small in size, as shown in Fig 8, due to exposure to high temperatures caused the size of the CLC block pores to become enlarged, as shown in Fig 9.

Fig. 9 CLC block pores before exposure high temperature

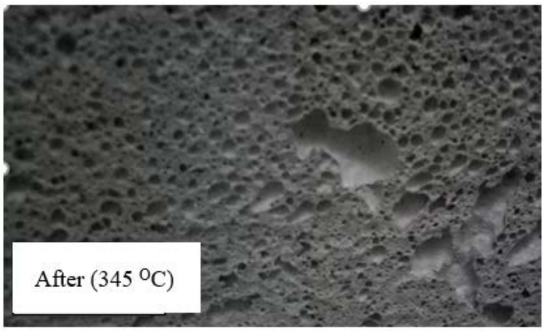

Fig. 10 CLC block pores after exposed high temperature.

Fig 11 shows the relationship between Variation 1 and Variation 2 during the heating time ranging from the initial conditions of 0 minutes to 40 minutes of exposure to temperature and compressive strength during high-temperature exposure.

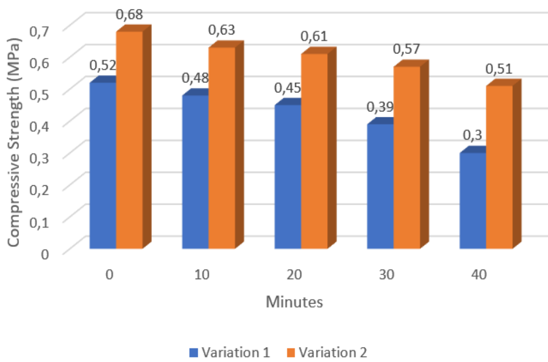

Fig. 11 The performance of CLC on 28 days after exposed high temperature during 0 to 40 minutes

Based on the compressive strength test results on 28 days, CLC before exposure to high temperatures has a density value of 0.850 grams/cm^3. Exposure to high temperatures for 10, 20, and 30 minutes has led to a decrease in the weight of the volume of CLC, respectively to 0.833 grams/cm^3, 0.811 grams/cm^3 and 0.808 gram/cm^3. Finally, at 40 minutes exposed to high temperature, there was a decrease to 0.803 gram/cm^3.

Thus it can be stated in Variation 1 where a light brick mixture with a cement and sand ratio of 1: 2 has a reduction in compressive strength due to exposure to heat for 40 minutes by 42.3%. Meanwhile, Variation 2, with a cement and sand ratio of 2: 3, resulted in a 25% reduction in compressive strength due to heat exposure for 40 minutes.

6. CONCLUSION

Based on the research that has conducted, the following conclusions are:

1. Exposure to high temperatures in CLC can cause discolouration, change in pore size, change in volume weight, and change in compressive strength of the CLC.
2. Cellular lightweight concrete exposed to high temperatures for 40 minutes caused a decrease in the compressive strength value of 42.3% from 0.52 MPa to 0.3 MPa for a CLC mixture with a cement and sand ratio of 1: 2 and a decrease of 25% from 0.68 MPa to 0.51 MPa for CLC mixtures with cement to the sand ratio of 2:3.

7. ACKNOWLEDGMENTS

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