Replacement of Coarse Aggregate with Clay in Lightweight Reinforced Concrete Beam

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Abstract. Concrete is a material that has a high compressive strength but has a low tensile strength and has a high density. To solve its weakness, reinforcement steel bars are used to resist the tensile strength and lightweight coarse aggregates are used to reduce the concrete density. The purpose of the research is to determine the impact of substituting normal coarse aggregates with clay roof tile fractions on concrete density, concrete cylinder compressive strength, and reinforced concrete beam flexural strength. The samples are concrete cylinders and reinforced concrete beams, with 3 samples for each substitution variation. The variations are 0%, 20%, 40%, 60%, 80%, and 100%. All samples are tested after 28 days. The tests are obtained maximum pressure force data. The data are processed to obtain the research results. The calculation found that samples with 100% lightweight coarse aggregate proportion have the lowest density of 1868.58 kg/m^3. Also, the result of compressive strength is between 29.071 MPa and 20.054 MPa. And the result of flexural strength is between 14.650 MPa and 11.391 MPa.

Keywords: Lightweight Concrete, Clay Roof Tile Fraction, Density, Compressive Strength, Flexural Strength.

1 Introduction

Concrete is a material that is strong in resisting compressive strength, but weak in resisting tensile strength and has a high density. Concrete is made from a mixture of coarse agregates, fine agregates, cement, and water. The agregates in concrete are the main material that filling 50-80% of concrete's volume [1]. A high density of the agregates will result in a high density of the concrete. A high density of the concrete will result in a high self-weight of the building structure. Meanwhile, self-weight can significantly influence the the building structure design. So, one solution to reduce the high self-weight of building structure is by using structural lightweight concrete [2].

Lightweight concrete is a concrete that contains lightweight agregates and has a density less than 1900 kg/m^3 [3]. Lightweight concrete can be made by entraining air

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into the concrete or by using lightwieght agregates with a density less than 2000 kg/m^3, such as burned clay, and pumice stone [4].

This research is an experimental research that substituting normal coarse agregates with clay roof tile fractions to make lightweight concrete. The purpose is to determine the effect of clay roof tile substitution on concrete density and result a density value under 1900 kg/m^3. The research also aim for determine the effect of clay roof tile substitution on concrete cylinder compressive strength and result a value above 18.26 MPa, also the effect of clay roof tile substitution on reinforced concrete beam flexural strength and result a value above 6.21 MPa [5].

2 Materials and Methods

This research is an experimental research that substituting normal coarse agregates with clay roof tile fractions to make a lightweight concrete. A normal size of clay roof tile will be crushed to make a size under 20 mm and used as substitution in scale of 0%, 20%, 40%, 60%, 80%, and 100%. The samples are concrete cylinders (150 mm diameter and 300 mm height) and reinforced concrete beams (150 mm x 150 mm x 1200 mm), with 3 samples for each variation. All samples will be tested after 28 days to determine the impact of substituting clay roof tiles on concrete density, concrete cylinder compressive strength, and reinforced concrete beam flexural strength.

2.1 Materials

Equipment and Materials Preparation. The equipments that needs to be prepared, are material container, weight scales, oven, cone mold, *pycnometer*, aggregate sieve set, wire basket, measuring glass, color code, *los angeles* machine set, volumetrical container 5 litres and 10 litres, *l*e *chatelier* flask, concrete mold, concrete mixer, concrete vibrator, *slump* test set, compression testing machine, and universal testing machine. The materials that needs to be prepared, are potland composite cement (PCC), water, fine aggregate, normal coarse aggregate (crushed rock), lightweight coarse aggregate (clay roof tile fraction), reinforced steel bar Ø 6 mm, reinforced steel bar Ø 10 mm, and additional admixture *superplasticizer*.

Lightweight Coarse Aggregate Making. Prepare the required amount of clay roof tile. Break it into 5-19 mm fraction. Test the physical properties of the aggregate based on SNI 2461-2014 requirements. Also test the strength of the material with *Los Angeles* Test. Afterward, clean and soak it for 24 hours, then dry the surface to make *Saturated Surface Dry* (SSD) condition. Keep it into an airproof plastic bag to make it still on SSD condition until the day it will be used as a concrete mixture.

Physical Properties of Materials Testing. The purpose of the test is to determine that the materials are fulfill the requirements to be a concrete materials. The requirements are American Standard Testing and Material (ASTM) [6] and SNI 2461-2014 – Spesification of Lightweight Aggregate for Structural Lightweight Concrete [7].

Mix Design. The mix design will be adjusted using two methods, which are ACI 211.1-91 (Standard Practice for Selecting Proportions for Normal, Heavyweight, and Mass Concrete) to adjusting mixture for normal concrete [8] and ACI 211.2-98 (Standard Practice for Selecting Proportions for Structural Lightweight Concrete) to adjusting mixture for lightweight concrete [9].

Samples Making. The research samples are concrete cylinders (150 mm diameter and 300 mm height) and reinforced concrete beams (150 mm x 150 mm x 1200 mm dimensions). For the reinforced concrete beam, reinforced steel bar Ø 10 mm will be used for flexural reinforcement and reinforced steel bar Ø 6 mm will be used for shear reinforcement. Samples will be made in 6 variations of lightweight coarse aggregate substitutions with 3 samples for each variation. The details are shown in **Table 1**.

Table 1. The variations of substitutions.

Mixture Variation	**NCA Percentage**	**LCA Percentage**	**Amount of Cylinder Sample**	**Amount of Beam Sample**
100% NCA + 0% LCA	100%	0%	3	3
80% NCA + 20% LCA	80%	20%	3	3
60% NCA + 40% LCA	60%	40%	3	3
40% NCA + 60% LCA	40%	60%	3	3
20% NCA + 80% LCA	20%	80%	3	3
0% NCA + 100% LCA	0%	100%	3	3
Amount of All Samples			**18 samples**	**18 samples**

NCA is acronym of Normal Coarse Aggregate
LCA is acronym of Lightweight Coarse Aggregate

2.2 Methods

The test will be conducted when the samples are 28 days old. The test are density test, compressive strength test with CTM, and beam flexural strength test with UTM.

Concrete Density Test. The purpose of this test is to determine that the cylinder samples are fulfill the compressive strength target. The compressive strength can be determined with the following equation.

$$\gamma_c = \frac{W}{V} \tag{1}$$

with :
γ_c = Concrete Density (kg/m^3)
W = Concrete Weight Average (kg)
V = Volume of Concrete (m^3)

Cylinder Compressive Strength Test. The purpose of this test is to determine that the cylinder samples are fulfill the compressive strength target. The compressive strength can be determined with the following equation.

$$f'c = \frac{P}{A} \tag{2}$$

with :
$f'c$ = Compressive Strength (MPa)
P = Pressure Force Average (N)
A = Area of Cross Section (mm^2)

Reinforced Beam Flexural Strength Test. The purpose of this test is to determine the maximum force or load that the sample can resist before it starts to collapse. The flexural strength can be determined with the following equation.

$$f'c = \frac{P\,L}{b\,h^2} \tag{3}$$

with :
fs = Flexural Strength (MPa)
b = Base of Cross Section (mm)
P = Pressure Force Average (N)
h = Height of Cross Section (mm)
L = Length of the Beam (mm)

Flexural Capacity of Reinforced Concrete Beam. Flexural capacity of reinforced concrete beam is the ability of a reinforced concrete beam to resist the maximum bending moment without experiencing structural failure [5]. The maximum bending moment can be determined with the following equation.

$$M = \frac{1}{6}PL \tag{4}$$

with :
M = Maximum Bending Moment (Nmm)
L = Length of Span (mm)
P = Pressure Force Average (N)

3 Result and Discussion

3.1 Physical Properties of Materials

The purpose of the test is to determine that the materials are fulfill the requirements to be a material of concrete. The results of the tests are shown in Table 2.

Table 2. Physical properties of materials.

Types of Test	Materials	Test Result	ASTM Standard	SNI 2461-2014 Standard
Water Content	FA[1]	0.531 %	0 – 1 %	
	NCA	2.110 %	0 – 3 %	
	LCA	18.133 %		0 – 20 %
Specific Gravity	FA[1]	2.587	2.5 – 2.7	
	NCA	2.545	2.5 – 2.9	
	LCA	1.636		1.0 – 1.8
Absoption	FA[1]	1.031 %	1 – 3 %	
	NCA	2.489 %	1 – 3 %	
	LCA	18.008 %		0 – 20 %
Fineness Modulus	FA[1]	2.972	2.3 – 3.1	
	NCA	6.876	6.0 – 8.0	
	LCA	6.669	6.0 – 8.0	
Density	FA[1]	1489 kg/m^3	-	
	NCA	1517.5 kg/m^3	-	
	LCA	967.4 kg/m^3		1040 kg/m^3
Los Angeles Test	NCA	19.96%	20 %	
	LCA	57.4 %	20 %	
Organical Content	FA[1]	Number 2	< Number 3	

FA is acronym of Fine Aggregate

Based on the results above, all materials are fulfill almost all of the requirements. Basically, this lightweight coarse aggregate are not capable to be a material of concrete. But, the purpose of this research is to compare the strength of concrete containing normal coarse aggregates with the strength of concrete containing lightweight coarse aggregates. Therefore, this research can still continued to next step.

3.2 Trial Mix and Mixture Redesign

The first mix design is adjusted using a compressive strength f'c 20 MPa. Then, the trial mix are done and the result are shown in Table 3.

Table 3. Trial mix result.

Mixture Variation	*Slump* (mm)	Density (kg/m^3)	Compressive Strength Average (MPa)
(100% NCA + 0% LCA)	45	2227.213	20.002
(0% NCA + 100% LCA)	25	1860.063	12.828

Based on the results above, the compressive strength of the lightweight concrete doesn't fulfill the strength target, f'c 20 MPa. Due to the unfulfilled results above, the variation value of compressive strength is found. Then, the standard deviation value can be calculated. With the standard deviation value, the final mix design can be adjusted using the new compressive strength f'c 28.23 MPa, to gain the compressive strength target for all samples. Meanwhile, the water-cement ratio used for all samples is 0.5613. The results of the mix design are shown in Table 4.

Table 4. Materials composition for 1 m^3 of concrete.

Materials	Material Weight (kg)	
	Normal Concrete	Lightweight Concrete
NCA	914.69	
LCA		660.50
FA	847.28	706.16
Water	187.00	187.00
Cement	333.15	333.15

With the materials composition for 1 m3 of concrete above, the materials composition for 1 mixture can be calculated. There will be 6 concrete mixtures based on 6 substitution variations of lightweight concrete, which are 0%, 20%, 40%, 60%, 80%, and 100%. The volume for 1 mixture will be calculated based on the volume of 3 cylinders (diameter 150 mm and height 300 mm) and the volume of 3 beams (dimensions 150 mm x 150 mm x 1200 mm). The mixture calculation will be based on the materials composition according to each substitution percentage. The calculation results are shown in Table 5.

Table 5. Materials composition for each mixture (the volume for 3 cylinders and 3 beams).

Mixture Variation	Material Weight (kg)				
	NCA	LCA	FA	Cement	Water
100% NCA + 0% LCA	110.80	0.00	102.64	40.36	22.65
80% NCA + 20% LCA	88.64	16.00	99.22	40.36	22.65
60% NCA + 40% LCA	66.48	32.00	95.80	40.36	22.65
40% NCA + 60% LCA	44.32	48.01	92.38	40.36	22.65
20% NCA + 80% LCA	22.16	64.01	88.96	40.36	22.65
0% NCA + 100% LCA	0.00	80.01	85.54	40.36	22.65

3.3 Slump Test Result

The purpose of this test is to determine the consistency of fresh concrete mixture. The test is using slump test sets. The result is obtained by measuring the height of fresh concrete after it was slumped. The slump test results are shown in Fig. 1.

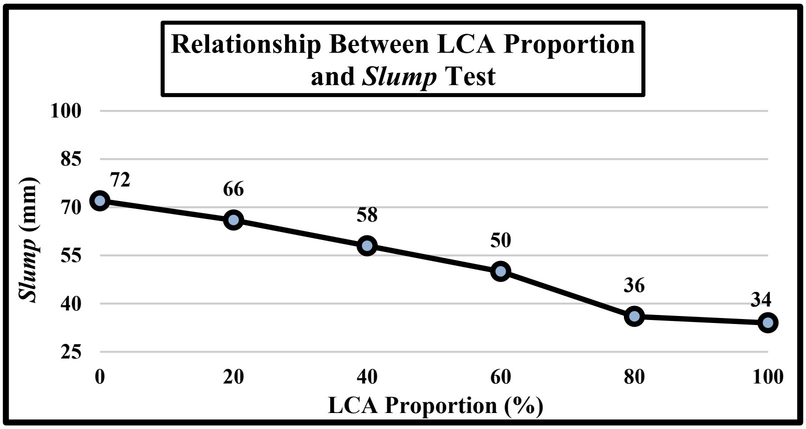

Fig. 1. Relationship between LCA proportion and *slump* test result.

Based on the figure above, the higher proportion of lightweight coarse aggregate, the lower result of slump test. The decrease in slump value comes because of the physical property of lightweight coarse aggregate, which has a high absorption percentage of 18.008%. Also, there is a mistake that makes the aggregate doesn't reach the perfect SSD condition because it isn't soaked for the full 24 hours. However, all the results still fulfill the slump target 25-100 mm, according to ACI 211.1-91 Table 6.3.1. and ACI 211.2-98. Table 3.1. requirements.

3.4 Concrete Density Test Result

The purpose of this test is to determine that the samples are classified as lightweight concrete. The test is carried out by weighing and maesuring the volume of concrete cylinder. The data are calculated using the first equation in subtitle **2.2** (concrete density equation). The concrete density test results are shown in Fig. 2.

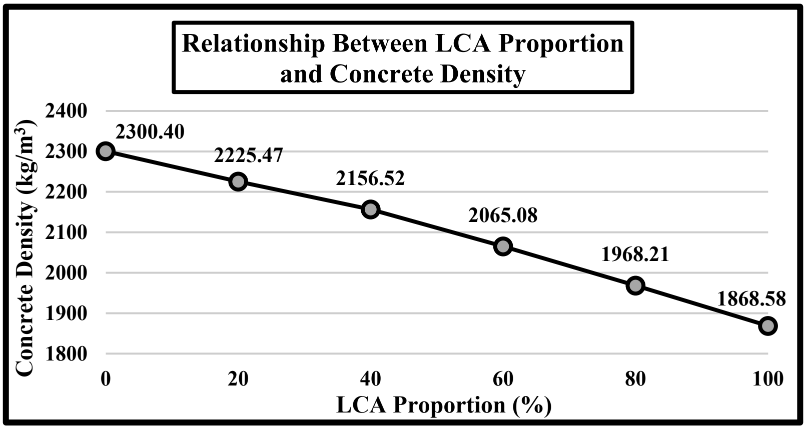

Fig. 2. Relationship between LCA proportion and concrete density.

Based on the figure above, the higher proportion of lightweight coarse aggregate, the lower result of concrete density test. The decrease in concrete density comes because lightweight coarse aggregate has a 967.4 kg/m3 density, lighter than normal coarse aggregate with 1517 kg/m3 density. The use of lightweight coarse aggregate makes the concrete density lighter and results in lightweight concrete. According to SNI 03-2847-2002, concrete with 100% lightweight coarse aggregate proportion fulfilled the density requirement less than 1900 kg/m3 and classified as lightweight concrete. But concrete with other proportion of lightweight coarse aggregate doesn't fulfill the requirement and doesn't classified as lightweight concrete.

3.5 Cylinder Compressive Strength Test Result

The purpose of this test is to determine that the cylinder samples fulfill the compressive strength target. The test is carried out using compressive testing machine to obtain the maximum pressure force that the sample can resist. The data are calculated using the second equation in subtitle **2.2** (compressive strength equation). The cylinder compressive strength test results are shown in Fig. 3.

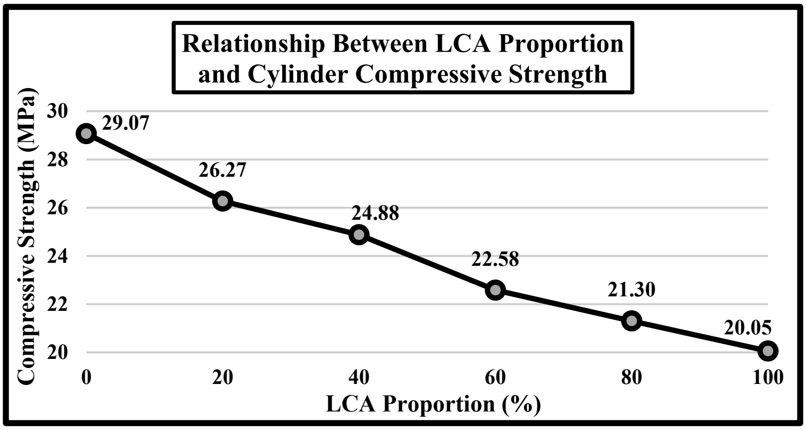

Fig. 3. Relationship between LCA proportion and cylinder compressive strength.

Based on the figure above, the higher proportion of lightweight coarse aggregate, the lower result of cylinder compressive strength test. The decrease in compressive strength comes because lightweight coarse aggregate has 57.4% hardness degradation that means this aggregate is not as strong as normal coarse aggregate. Also, this aggregate has a high absorption percentage of 18.008% that means this aggregate has large pores and low dense. Because aggregates fill 50-80% of the concrete volume, this aggregates substitution greatly affects the strength of the concrete. However, all the results of the test still fulfill the compressive strength target, f'c 20 MPa.

3.6 Reinforced Beam Flexural Strength Test Result

The purpose of this test is to determine the maximum force or load that the reinforced concrete beam sample can resist before it starts to collapse. The test is carried out using universal testing machine to obtain the maximum pressure force that the sample can resist. The data are calculated using the third equation in subtitle **2.2** (flexural strength equation). The reinforced beam flexural strength test results are shown in Fig. 4.

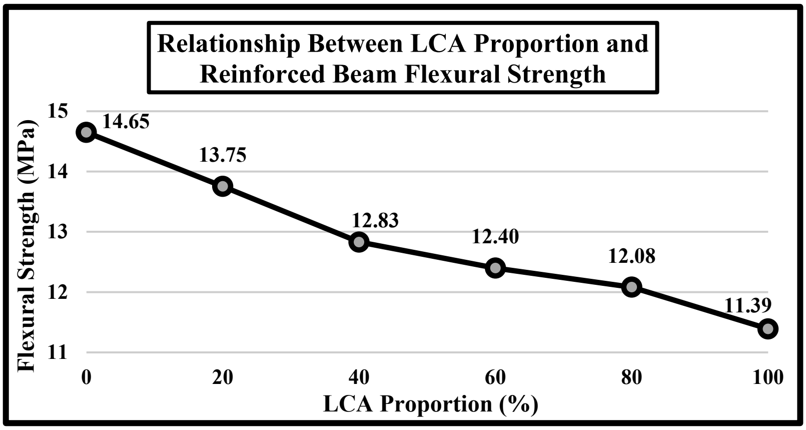

Fig. 4. Relationship between LCA proportion and reinforced beam flexural strength.

Based on the figure above, the higher proportion of lightweight coarse aggregate, the lower result of reinforced beam flexural strength test. The decrease in flexural strength comes because of the same reasons as the decrease in compressive strength. This lightweight coarse aggregate has 57.4% hardness degradation and has a high absorption percentage of 18.008% that means this aggregate has low strength. Basically, this test result cannot representing the real strength of the sample because the sample is using reinforced steel bar. To obtain the real strength of the sample, it needs to calculating the flexural capacity of the sample.

3.7 Flexural Capacity of Reinforced Concrete Beam

The flexural capacity of reinforced concrete beam is the ability of a reinforced concrete beam to resist the maximum bending moment without experiencing structural failure. The calculation is using the forth equation in subtitle **2.2** (flexural capacity of reinforced concrete beam equation). The calculation result is the real strength of reinforced concrete beam because it has calculating the reinforced steel bar inside. Flexural capacity by the maximum bending moment from loading test result are shown in Table 6.

Table 6. Flexural capacity by the maximum bending moment from loading test result.

Mixture Variation	Maximum Pressure Force Average (N)	Flexural Capacity Average (MPa)
100% NCA + 0% LCA	41204.42	6.867
80% NCA + 20% LCA	38681.85	6.447
60% NCA + 40% LCA	36085.40	6.014
40% NCA + 60% LCA	34871.69	5.812
20% NCA + 80% LCA	33981.81	5.664
0% NCA + 100% LCA	32036.20	5.339

Based on the table above, the higher proportion of lightweight coarse aggregate, the lower result of flexural capacity from loading test. The decrease in flexural capacity comes because of the lightweight coarse aggregate having 57.4% hardness degradation and high absorption percentage of 18.008% that means this aggregate has low dense and has low strength.

Meanwhile, flexural capacity can also be determined theoretically by the data of concrete compressive strength, reinforce steel bar tensile strength, and the cross-section design of the reinforced concrete beam. The calculation result of theoretical flexural capacity are shown in Table 7.

Table 7. Flexural capacity by the theoretical calculation result.

Mixture Variation	Concrete Compressive Strength (MPa)	Reinforce Steel Bar Tensile Strength (MPa)	Flexural Capacity Average (kNm)
100% NCA + 0% LCA	29.071	280	5.408
80% NCA + 20% LCA	26.273	280	5.305
60% NCA + 40% LCA	24.878	280	5.242
40% NCA + 60% LCA	22.583	280	5.136
20% NCA + 80% LCA	21.303	280	5.074
0% NCA + 100% LCA	20.054	280	5.015

Based on the table above, the higher proportion of lightweight coarse aggregate, the lower result of flexural capacity by the theoretical calculation. The decrease comes because of the same reasons before, that the lightweight coarse aggregate has low dense and has low strength. Based on the two results above, flexural capacity from loading test and flexural capacity by the theoretical calculation should be compared to each other. The purpose is to determine that the flexural capacity from loading test has fulfilled the flexural capacity by the theoretical calculation.

Table 8. Comparison between flexural capacity from loading test (**Table 6**) and flexural capacity by the theoretical calculation (**Table 7**).

Mixture Variation	Loading Test (kNm)	Theoretical Calculation (kNm)
100% NCA + 0% LCA	8.241	5.408
80% NCA + 20% LCA	7.736	5.305
60% NCA + 40% LCA	7.217	5.242
40% NCA + 60% LCA	6.974	5.136
20% NCA + 80% LCA	6.796	5.074
0% NCA + 100% LCA	6.407	5.015

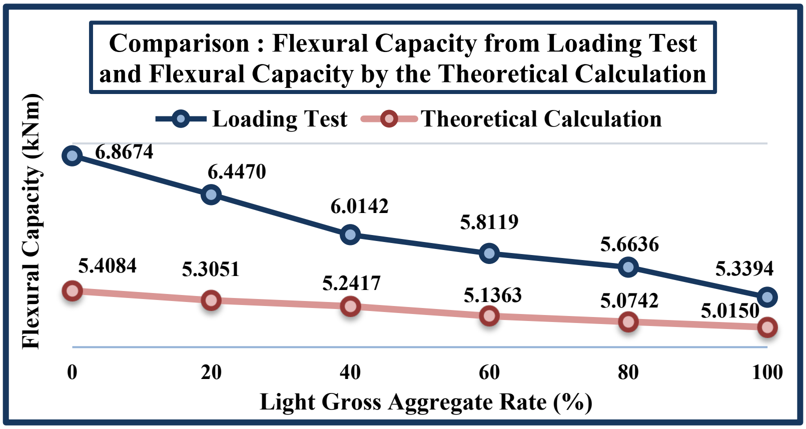

Fig. 5. Comparison between flexural capacity from loading test and flexural capacity by the theoretical calculation.

Based on the figure above, flexural capacity from loading test has a higher value than flexural capacity by the theoretical calculation. It means that all the flexural capacities of the reinforced concrete beams are fulfilled the theoretical calculation. Therefore, a reinforced concrete beam with similar specification as this research, or even on a larger scale, can be used in real building structures.

4 Conclusion

A higher proportion of lightweight coarse aggregate can result in lower concrete density. The decrease comes because lightweight coarse aggregate has a 967,4 kg/m3 density. Concrete with 100% lightweight coarse aggregate proportion classified as lightweight concrete. But concrete with other proportions isn't classified as lightweight concrete.

A higher proportion of lightweight coarse aggregate can result in lower concrete compressive strength. The decrease comes because lightweight coarse aggregate has 57.4% hardness degradation and high absorption percentage of 18.008%, that means this aggregate has low dense and has low strength. However, all the results of the test are still fulfilling the compressive strength target, f'c 20 MPa

A higher proportion of lightweight coarse aggregate can result in lower reinforced beam flexural strength. The decrease comes because lightweight coarse aggregate has a high hardness degradation and high absorption percentage, that means this aggregate has low dense and has low strength. Basically, this test result cannot representing the real strength of the sample because the sample is using reinforced steel bar. To obtain the real strength of the sample, it needs to calculating the flexural capacity of the sample.

Flexural capacity from loading test has a higher value than flexural capacity by the theoretical calculation. It means that all the flexural capacities of the reinforced concrete beams are fulfilled the theoretical calculation. Therefore, a reinforced concrete beam with similar specification as this research, or even on a larger scale, can be used in real building structures.

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