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Study of Characteristic Physical and Mechanic of Foamed Lightweight Concrete with Fly Ash Added for Wall Materials

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Abstract

The self-weight of foamed lightweight concrete is lighter than normal concrete nor brick. Application of foamed lightweight concrete on the wall of high rise buildings will decrease the structural load. With a lower structural load, the structural dimension will significantly decrease and also construction costs. Utilization of fly ash waste as an added material of sand on lightweight concrete will reduce the negative impact on the environment and increase the strength of concrete. This study will examine the physical and mechanical characteristics of lightweight foam concrete for wall materials referring to the Indonesian National Standard (SNI). Comparison used 1 cement: 1 aggregate. Aggregates consist of sand and fly ash added material 0%, 15%, 30%, 45%, 60%, and 75% by weight of sand. Cement water factor 0.35, and foam 30%, 40% and 50% of lightweight concrete volume. The cylinder sample dimension is 75 mm in diameters and 150 mm in height—the number of test samples of compressive strength, water absorption, and a specific gravity of 170 units. The results of the research are the density of the foamed lightweight concrete of 868.4 - 1582.4 kg / m3 fulfilled the criteria as lightweight concrete. The novelty of this research is the optimal compressive strength of various percentages of foam achieved at 45% fly ash. Foam with 30% has a compressive strength of 12.52 MPa fulfill the quality of I, foam with 40% has a compressive strength of 6.75 MPa fulfill the quality of III, and foam with 50% has a compressive strength of 1.66 MPa does not fulfill the quality of SNI. The lowest water absorption is 5.12%, 8.35%, and 15.97% fulfill the quality of I SNI at the 45% fly ash, Self-weight of 1 m^2 wall of foamed lightweight concrete thickness of 120 mm 25.88% lighter than a half-brick brick wall with the same area.

Keywords - *foamed lightweight concrete; foam; fly ash; wall material*

I. INTRODUCTION

Foamed lightweight concrete is a building material currently widely needed for the construction industry (Ahmad et al., 2014). Foamed lightweight concrete is a cement mortar material with a minimum foam volume of 20% (Awang et al., 2012). Foamed lightweight concrete weights lower than normal concrete. The weight of lightweight concrete 300 - 1800 kg/m^3, while the normal concrete weight is about 2400 kg/m^3 (Al Bakri Abdullah et al., 2012). It foamed lightweight concrete effect of the percentage of foam in lightweight concrete (Othuman Mydin 2013). The more the percentage of foam will be, the lower the density and compressive strength (Azmi et al., 2016). The self-weight foamed lightweight concrete will reduce the structural load and will significantly reduce the dimensions of the structural components as well as those that impact on material savings (Hájek, Decký, and Scheffel).

Foam agent is a concentrated solution of surfactant material. Foam agents for lightweight concrete must be added water with a certain ratio. The pre foam generated foam generator is suitable for mortar products containing foam (Malau 2014). Foam agent for light concrete has two kinds, namely animal protein foaming agent produced from horns, blood, bones, and other animal carcasses, and synthetic foam agent is a chemical product (Khalid 2011). Synthetic foam agents have a smoother air bubble than protein foaming agents. Synthetic foam agent suitable for lightweight concrete above 1000 kg/m^3, and produces low compressive strength in lightweight concrete under 1000 kg/m^3 (Mydin).

Fly ash is a B3 waste (Hazardous and Toxic Substances) which can be used as an aggregate of filler or cement replacement in concrete or as a brick material (Bing et al., 2012). The addition of fly ash in lightweight concrete mixtures can be categorized as Green Hight Performance Concrete (GHPC), which can increase concrete mixtures (Pejman Keikhaei De hdezi, Savas Erdem 2015).

Waste fly ash now reaches about 600 million tons and only used 10% (Tariq M 2017). The use of fly ash as a lightweight concrete added material requires more volume than cement instead. The use of fly ash as a lightweight concrete added material is expected to increase the utilization of fly ash and will reduce the negative environmental impact.

The addition of fly ash percentage in lightweight concrete not only improves workability but also increases the strength of lightweight concrete. The addition of fly ash in lightweight concrete has a positive impact on different ages of curing (Bing Chen 2008). Several previous studies have shown that the addition of fly ash to a lightweight concrete mix will improve lightweight, fresh concrete, and hardened concrete (Niyazi Ugur Kockal 2011).

The addition of fly ash to foamed lightweight concrete gives better compressive strength than the compressive strength of lightweight foam concrete with only sand (Ahmad et al. 2014). The added fly ash material in foamed lightweight concrete is 0%, 15%, 30%, 45%, 60%, and 75% from the weight of sand aggregate. Added foam of 30%, 40% and 50% of the volume of 1 m^3 of concrete with a ratio of 1 foam of synthetic agent: 40 water.

Its self-weight foamed lightweight concrete is low, and the high compressive strength is quite suitable for wall materials and significantly reduces a load of building structures. The physical requirement of concrete brick for a wall in Indonesia is, among others, compressive strength and water absorption, which compulsory to Indonesian National Standard (SNI 03-0349-1989 1989).

II. EXPERIMENTAL DETAILS

A. Material

Lightweight concrete materials used for this research are cement, fine sand, fly ash waste, water, and foam agent. The cement used is Portland Cement Composite (PCC) Holcim product. The sand used lightweight concrete is a fine aggregate. The use of coarse aggregates destroys air bubbles in foamed lightweight concrete (Mydin 2012). Fly ash used is derived from Steam Power Plant (PLTU) Cilacap Central Java Indonesia. Table 1 shows the chemical composition of fly ash waste.

Table 1. Chemical composition fly ash with EDX test.

No.	Unsur	Massa %	Komponen	Massa %
1	C	21,07	C	21,07
2	O	34,56	-	-
3	Na	2,01	Na2O	2,71
4	Mg	1,67	MgO	2,76
5	Al	10,15	Al2O3	19,17
6	Si	16,46	SiO2	35,22
7	S	0,48	SO3	1,20
8	K	1,4	K2O	1,69
9	Ca	3,14	CaO	4,39
10	Ti	0,41	TiO	0,69
11	Fe	7,76	FeO	9,99
12	Cu	0,89	CuO	1,11
	TOTAL	100	TOTAL	100

Used foam agents like synthetic product Kip Light Small Industrial Center (PIK) Penggilingan, Cakung, East Jakarta, Indonesia. The specific gravity of pre-foam obtained from foam generator $\pm$ 80 gr/litre. Synthetic foam agent has a smooth bubble, suitable for lightweight concrete above 100 kg/$m^{3,}$ which will produce good strength (Khalid 2011).

B. Mix Proportioning and Specimen Preparation

The factor of cement water 0.35 with a ratio of 1 cement: 1aggregate. The diameter of sand aggregate 4.75 mm, and fly ash added with 0%, 15%, 30%, 45%, 60%, and 75% of the weight of sand aggregate. Foam with 30%, 40%, and 50% of the volume of 1 m^3 of mortar concrete. Foam is obtained from a ratio of 1 foam agent: 40 water. A mixed proportion of 1 m^3 is presented on **Error! Reference source not found.**

Table 2. Mix Proportion Lightweight Concrete 1 m^3

No.	Fly ash (%)	Cement (kg)	Sand (kg)	Fly ash (kg)	Water (kg)	Foam agent (ltr)	Density (kg/m³)
FOAM 30% DARI VOLUME MORTAR							
A1	0%	657.72	657.72	0.00	230.20	1.20	1546.84
A2	15%	619.74	619.74	92.96	216.91	1.20	1550.55
A3	30%	585.91	585.91	175.77	205.07	1.20	1553.86
A4	45%	555.58	555.58	250.01	194.45	1.20	1556.82
A5	60%	528.24	528.24	326.94	184.88	1.20	1569.50
A6	75%	503.46	503.46	377.60	176.21	1.20	1561.93
FOAM 40% DARI VOLUME MORTAR							
B1	0%	563.76	563.76	0.00	197.32	1.60	1326.44
B2	15%	531.21	531.21	79.68	185.92	1.60	1329.62
B3	30%	502.21	502.21	150.66	175.77	1.60	1332.45
B4	45%	476.21	476.21	214.30	166.67	1.60	1334.99
B5	60%	452.78	452.78	271.67	158.47	1.60	1337.30
B6	75%	431.54	431.54	323.65	151.04	1.60	1339.37
FOAM 50% DARI VOLUME MORTAR							
C1	0%	469.80	469.80	0.00	164.43	2.00	1106.03
C2	15%	442.67	442.67	66.40	154.94	2.00	1108.68
C3	30%	418.51	418.51	125.55	146.48	2.00	1111.05
C4	45%	396.84	396.84	178.58	138.90	2.00	1113.16
C5	60%	377.31	377.31	226.39	132.06	2.00	1115.07
C6	75%	359.62	359.62	269.71	125.87	2.00	1116.82

The sample is cylindrical diameter 75 mm high 150 mm for compressive strength test, water absorption, and specific gravity. A compressive strength test of 4 samples with 3 variations of percentage foam and 6 variations of percentage fly ash with a total of 72 samples. For water absorption test and a specific gravity of each 3 samples with 3 variations of percentage foam and 6 variations of percentage fly ash with a total of 108 samples. Samples removed after 1 x 24 hours were printed and sample curing for 28 days.

C. Proses Produksi Foamed lightweight concrete

The process of making a foamed lightweight concrete mixture is shown in Figure 1. The material foamed lightweight concrete mixed design (a) material is mixed to homogeneous (b.1), added water (b), mixed until homogeneous (b.2). Add prefoam (c) into a mortar and stir in the mixer until homogeneous (b.3). The weight of the paste foamed lightweight concrete weighs to match the density of the plan, then molding the foamed lightweight concrete (d).

Concrete mixed water requirement is bigger than mixed design (Table 2) on added fly ash 45%, 60%, and 75%. The addition of water samples done by at A4, B4, C4 by 5%, samples A5, B5, C5 of 7.5%, and sample A6, B6 C6 of 11.6% of mix design. This is because fly ash consists mainly of particles of glass, hollow, and spherical particles (Al Bakri Abdullah et al. 2012), which is a good absorber compared to cement (Rommel 2014).

D. Curing of Foamed Lightweight Concrete).

The foamed lightweight concrete curing is guided by ASTM (ASTM C495-99a 1999). The foamed lightweight concrete sample after 1 x 24 hours is removed from the mold. Day 2 - 25 treatments with room temperature 21 ºC ± 5,5 ºC. Daycare 26 - 28 samples in oven with temperature 60 ºC ± 2.8 ºC for 3 days. Samples were tested at 28 days of curing age. Test the compressive strength of the sample using the Shimadzu Universal Testing Machine.

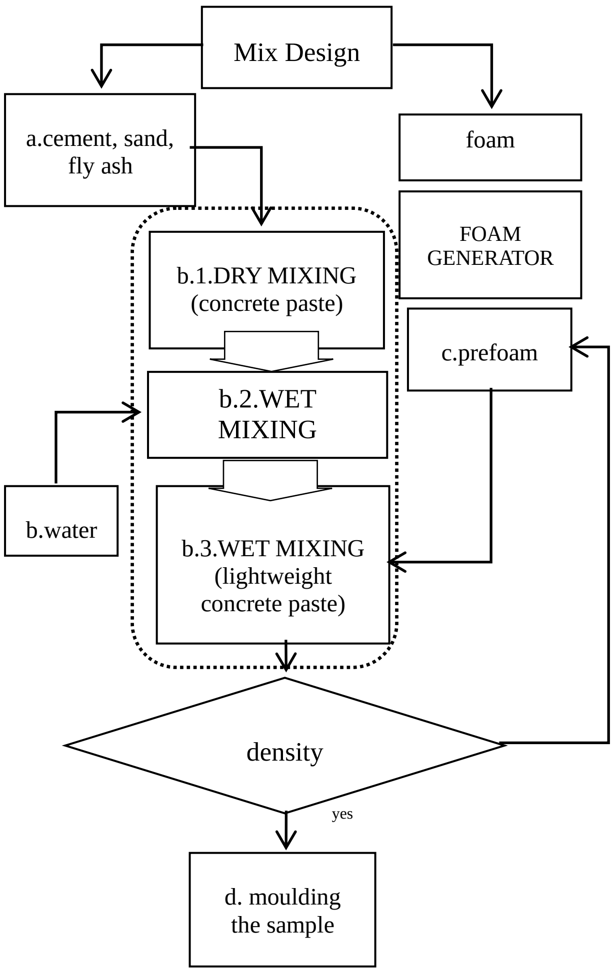


Figure 1. Production process diagram

E. Test technique

1. Compressive strength

After curing for 28 days, the foaming lightweight concrete sample was tested for compressive strength. The sample shape of each composition amounted to 4 samples. Test equipment used Shimadzu Universal Testing Machine with capacity 5000 kgf. The compressive strength test sample is according to ASTM 495-99 a.

2. Absorption

The absorption test was performed after the curing of lightweight concrete samples for 28 days. The sample shape of each composition amounted to 3 samples. The procedure and calculation of absorption are per ASTM C 20-00.

3. Density

The density test was performed after the curing of lightweight concrete samples for 28 days. The sample shape of each composition amounted to 3 samples. Test procedures and density calculations are as per ASTM C 134-95.

III. INDONESIAN NATIONAL STANDARD

Standard of brick foamed lightweight concrete not yet existed, so this article used SNI 03-0349-1989 physical feasibility standard about concrete brick for the wall (SNI 03-0349-1989 1989). The standard has not been up-to-date and is still in use, so in this research, the standard is used as a reference. The feasibility of lightweight concrete brick as wall pairs are viewed from the standard of compressive strength and water absorption. Each quality standard is classified in I, II, III, and IV qualities, as shown in the following table.

Table 3. Terms concrete bricks SNI 03-0349-1989

	Physical requirement	Unit	The quality level of solid concrete brick			
			I	II	III	IV
1.	Compressive strength of average gross minimum	kg/m2	100	70	40	25
2.	The minimum gross compressive strength of each specimen	kg/m2	90	65	35	21
3.	Water absorption maximum average	%	25	35	-	-

IV. TEST RESULT AND DISCUSSION

Light concrete percentage foam 30%, 40% and 50% produce specific gravity 868,4 - 1582,4 kg/m^3 (Table 4, Table 5, Table 6) fulfill criteria as light concrete (Othuman Mydin 2013). The percentage of 30% foam in lightweight concrete with various fly ash percentages produces specific gravity of 1203.7 - 1582.4 kg/m^3, a compressive strength of 7.089 - 12.525 MPa (*Table 4*). Percentage foam 40% in light concrete with 15%, 30%, 45%, 60% and 75% fly ash percentage yield 1044,1 - 1298,8 kg/m^3 with compressive strength 3,012 - 6,756 MPa.

Previous research has suggested that synthetic foam agents are suitable for lightweight concrete with a density above 1000 kg/m^3 and will produce a low compressive strength in lightweight concrete under 1000 kg/m^3 (Khalid 2011). Table 6 reinforces previous research that lightweight concrete less than 1000 kg/m^3 occurs at 50%

foam percent with a low compressive strength of 0.981 - 1.664 Mpa.

Table 4. Lightweight concrete with 30% foam

Foam	FA	ρ (kg/m³)	P (MPa)	W (%)
30%	0%	1203.7	7.1	8.42
	15%	1248.5	8.2	7.87
	30%	1393.9	10.0	6.75
	45%	1582.4	12.5	5.12
	60%	1433.5	11.4	5.62
	75%	1376.5	10.9	6.14

Table 5. Lightweight concrete with 40% foam

Foam	FA	ρ (kg/m³)	P (MPa)	W (%)
40%	0%	974,2	2,1	12,75
	15%	1044,1	3,0	12,1
	30%	1181,4	5,2	9,34
	45%	1298,8	6,8	8,35
	60%	1129,8	6,4	8,94
	75%	1088,5	4,7	9,95

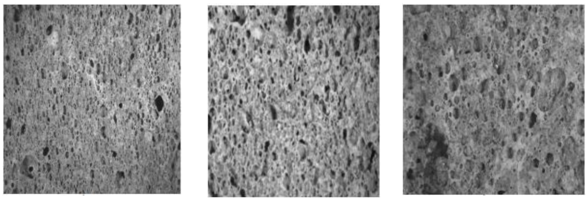
Table 6. Lightweight concrete with 50% foam

Foam	FA	BJ (kg/m3)	P (MPa)	W (%)
30%	0%	1203.7	7.1	8.42
	15%	1248.5	8.2	7.87
	30%	1393.9	10.0	6.75
	45%	1582.4	12.5	5.12
	60%	1433.5	11.4	5.62
	75%	1376.5	10.9	6.14

A. *Density*

The result of density foamed lightweight concrete test 894 - 1636 kg/m^3 (Table 4, Table 5, Table 6) fulfilled the criteria as light concrete, maximum 1900 kg/m^3 (Al Bakri Abdullah et al. 2012; Othuman Mydin 2013). This study support previous research (Bing et al., 2012) that foamed lightweight concrete with the same percentage of fly ash and increasing foam percentage yield lower density (Figure 2). Physically it is shown from the results of research Md. Agree with Mydin (Othuman Mydin 2013) that increasing the percentage of foam, the larger the void size in foamed lightweight concrete (figure 2), resulting in a lower density.

Previous researchers showed the value of lightweight concrete density rose from 25%, 30% increase, and the largest value in 35% fly ash (Andriani 2016).



Foam 30%, Densitas 1400 kg/m^3 (0,429 mm void size)

Foam 40%, Densitas 1200 kg/m^3 (0,47 mm void size)

Foam 50%, Densitas 900 kg/m^3 (0,59 mm void size)

Figure 2.Microscopic image foamed lightweight concrete *(Othuman Mydin 2013)*

Figure 3 shows the density foamed lightweight concrete value increases with the maximum percentage of fly ash 45%. It is the novelty of this research that is the increasing of foamed lightweight concrete weight in the percentage of fly ash 45% and a decrease in the percentage of fly ash 60% and 75%.

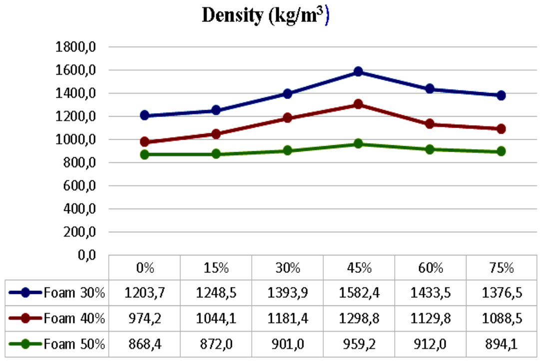


Figure 3. Density diagram

B. *Compressive strength*

The addition of fly ash percentage to foamed lightweight concrete increases the compression strength of lightweight foam as research of Khalid (2011) that the more fly ash content in foamed lightweight concrete is the higher compressive strength. Andriani's research (Andriani 2016) showed that lightweight concrete compressive strength with foam leak and fly ash percentages of 0%, 25%, 30%, and 35% showed greater number, i.e. from 7; 8.5; 9,27; and 10.18 N/mm^2.

This study showed that the addition of fly ash increased the compressive strength of lightweight concrete at a 30% foam percentage; 40%; 50%. The increase of compressive strength is maximal up to 45% fly ash addition and decrease at fly ash 60% and 75%. This is a novelty of this research. This is due to fly ash such as hollow glass particles and spherical particles with diameters from 0.01 to 0.015 mm (Al Bakri Abdullah et al. 2012), which will fill between the larger diameter sand grains (ASTM C33, 1982). The maximum capability of increased compressive strength due to the addition of fly ash is only up to 45%, and the strength drops on the following percentage of fly ash.

The strength of concrete foam increases with the increase of density and the foamed lightweight concrete compressive strength decreases with increasing foam volume (Bing et al., 2012). The decrease in compressive strength and specific gravity is caused by the increasing percentage of foam, which causes more air bubbles in the concrete. Air is the lightest substance that causes the weight of foamed lightweight concrete to fall significantly.

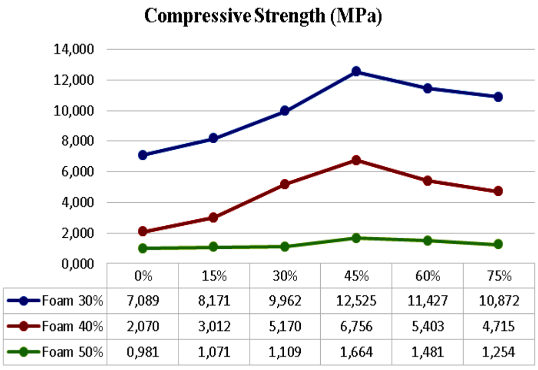


Figure 4. Compressive strength diagram

Lightweight concrete with foam 30%, fly ash 0%, 15%, 30%, 45%, 60% and 75% yielding compressive strength of 7.089; 8,171; 9,962; 12,525; 11,427; and 10,872 MPa fulfill the quality of II SNI (Table 3). Lightweight concrete with foam 40%, fly ash 0% resulting compressive strength of 2.070 MPa does not fulfill SNI. Lightweight concrete with foam 40%, fly ash 15% resulting compressive strength of 3.012 MPa fulfill the quality of IV SNI. Lightweight concrete compressive strength at 30%, 45%, 60% of foam and 75% of fly ash complied with compressive strength of III SNI. Lightweight concrete with foam 50%, fly ash 0%, 15%, 30%, 45%, 60% and 75% yielding compressive strength of 0,981 ;, 1,071; 1,109; 1,664; 1,482; and 1,254 MPa does not fulfill SNI.

C. Water Absorption

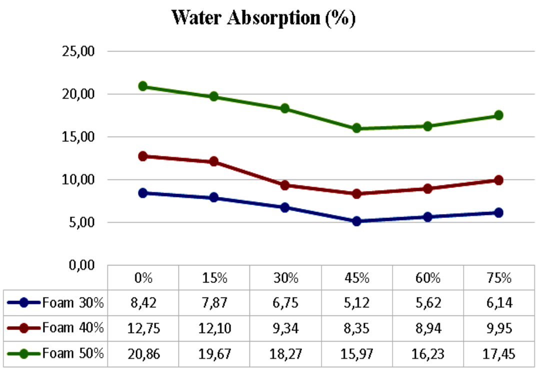


Figure 5. Absorption diagram

Result shows the greater the content of foam in the lightweight concrete, the greater the water absorption. The more foams in the lightweight concrete will produce more bubbles in the concrete, causing the greater the water to absorption. Figure 4 is inversely proportional to Figure 5; the greater the compressive strength, the smaller the water absorption capacity (Al Bakri Abdullah et al., 2012).

Light concrete at 30%, 40%, and 50% foam percentages resulted in maximum absorption of water 20.86% smaller than 25% water absorption rate (Table 3) to meet the quality of I SNI of concrete brick for wall construction. Minimum absorption of lightweight concrete water percentage foam 30%, 40%, and 50% achieved in fly ash percentage 45% that is respectively equal to 5,12%; 8.35%; and 15.97%.

The more foam, the more water absorption, the more pore foamed lightweight concrete absorbs water. More fly ash water absorption foamed lightweight concrete is lowered to a maximum of 45% fly ash, and water absorption will increase in fly ash 60% and 75%.

D. Selfweight of Lightweight Concrete Foam Fly ash)

Hájek, Matej, Martin Decký, and Walter Scherfel. “Objectification of Modulus Elasticity of Foam Conceret Poroflow 17-5 on The Sub-Base Layer.” 12.1 (2016): 55–62. Web.

Mydin, Md Azree Othuman. “Mechanical, Thermal, and Functional Properties of Green Lightweight Foamcrete.” “*Eftime Murgt” Resitas, Anul XIX, NR 1, ISSN 1453-7397* (2012): n. pag. Print.

The self-weight of foamed lightweight concrete is smaller than that of a brick. The self-weight of wall ½ brick 250 kg/m^2, while self-weight wall thickness 12 cm brick of lightweight concrete with foam 30%, fly ash 45% equal to 190 kg/m^2. The surface of the brick wall is uneven, then the thickness of the plaster 15 – 20 mm, and The surface of the foamed lightweight concrete wall is relatively flat, then the thickness of the plaster is 7 - 10 mm—the specific gravity of plaster per centimetre thickness of 21 kg / m2.

Calculation of wall self-weight
Lightweight concrete brick wall thick 12 cm thick
= 190,00 kg/m^2
Plaster 2 surfaces each 10 mm thick = 42,00 kg/m^2
Selfweight of lightweight concrete brick wall of 1 m^2
= 232,00 kg/m^2

Thick 1/2 brick wall = 250,00 kg/m^2
Plaster 2 surfaces each 15 mm thick = 63,00 kg/m^2
Selfweight ½ brick wall of 1 m^2 = 313,00 kg/m^2

The calculation results found that the weight of the wall foamed lightweight concrete 26% lighter than the brick wall.

V. CONCLUSIONS

The above discussion shows that the resulting light concrete fulfils the criteria as lightweight concrete. The addition of fly ash to foamed lightweight concrete increases the compressive strength to a maximum extent of 45% fly ash addition of the aggregate sand weight. Thus the conclusion of the results of the discussion as follows:

- Density of lightweight concrete is lowest 868,4 kg/m^3 at percentage of foam 50%, fly ash 0% and biggest density value 1582,4 kg/m^3 at 30% foam, fly ash 45% fulfill criteria as lightweight concrete.

- The optimum compressive strength of foamed lightweight concrete 30%, 40%, and 50% is achieved on the fly ash percentage of 45%, 12,525 MPa fulfil the quality of II, 6,756 MPa fulfil the quality of III, and 1,664 MPa does not fulfil the quality of SNI.
- The lowest water absorption of 5.12%, 8.95%, and 15.97% in 30%, 40%, 50% foam, and 45% fly ash fulfil the water absorption quality of I SNI.
- Self weight 1 m^2 wall foamed lightweight concrete 25.88% lighter than the brick wall will significantly reduce overall building load.

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