SSRG International Journal of Civil Engineering
ISSN: 2348 – 8352 /doi:10.14445/23488352/IJCE-V6I3P103

Volume 6 Issue 3, 22-28, March 2019

Characteristics of Lightweight Foamed Concrete Brick Mixed with FlyAsh

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Abstract

Lightweight concrete has become a sweet solution in the construction industry. The foamed concrete brick can be substitute with the normal clay burnt brick, which consumes more energy and carbon footprint. To reduce cement in the foamed concrete, fly ash as a scheduled wastage by-product of the coal-fueled power plant is added into the mixture. This paper presents the development of fly ash mixed with a foamed concrete brick. The samples were prepared with different percentages of fly ash substituting the cement. The compressive test and the flexural test were conducted to evaluate the mechanical properties of the brick. This study's main objective is to evaluate lightweight foamed concrete brick's mechanical properties with flyash, such as compressive strength, flexural strength, and water absorption behavior. It was found that specimens containing 10% fly ash and 10% foam after 28 days of curing in water achieved the highest flexural and compressive strengths by almost 3 MPa and 9.1 MPa, respectively. The study concludes an optimal mix design with 10% fly ash and 10% stable foam to produce lightweight foamed concrete brick with fly ash. Based on the results, the fly ash caused a decrease in water absorption percentage in lightweight foamed concrete.

Keywords—*Brick, Fly ash, Lightweight, Stable foam, strength.*

I. INTRODUCTION

Rapid industrialization in countries is the reason for the growth in urbanized areas [1]. Today's construction and buildings require new materials such as lightweight blocks and bricks. On the other hand, waste materials such as fly ash, bottom ash, biomass ash, rice husk, and micro-silica have become more common. Nowadays, concrete is made with cement types and containing admixtures such as foam, silica fume, fly ash, slag, polymers, and tire chips. Concrete also can be prepared with many methods such as heated, steam-cured, extruded, and sprayed[2]. Foamed concrete, also known as foam create, CLC, or reduced density concrete, is lightweight. The foamed concrete's mass is lighter than the normal concrete, but the strength of the lightweight foamed concrete is less than the normal concrete [3].To reduce the construction industry's carbon footprint, lightweight foamed concrete can be used as an alternative, moving towards sustainable construction by lessening the frequency of transportation and heavy types of machinery usage [4]. Foamed concrete brick consists of some materials such as fine aggregate, cement, water, and foaming agent. The foamed concrete application can be obtained to structural, partition, insulation, and filling grades [5]. Foamed concrete is suitable for producing lightweight bricks. Lightweight foamed concrete blocks were developed more than 60 years ago and have been used internationally for different construction applications. It has been used in the building industry for applications like apartments, houses, schools, hospitals, and commercial buildings. A foamed concrete block is a mixture of cement, fine sand, water, and foam bubbles. Foamed concrete is more suitable for the manufacturing of blocks. There has been interesting in making use of lightweight concrete blocks for wall construction. Foamed lightweight blocks can be used for wall panels, insulating panels over the wall to make it more thermal insulating [6]. Attempts are being made to develop lightweight solid, hollow, and interlocking blocks. In foamed concrete, macroscopic air foamed bubbles are produced mechanically and added to the base mix mortar during mixing. This type of foamed concrete technique is called preformed foamed concrete. The foaming agent required for producing stable foam can be the either natural or synthetic origin. Foamed concrete is highly flow-able and self-compacting in nature. Since the foamed concrete contains air bubbles, it cannot be rammed and vibrated in a machine to produce the blocks. The stiffness of foamed concrete depends primarily on the added porosity [7]. Hence the foamed concrete needs to be cast in a mould. Normal foamed concrete, when cast in moulds, can be demoulded only after 24 hours. This imposes constraints on the productivity of the block manufacture[8]. The problem encountered in buildings and structures is a larger dead load by ordinary brick concrete. In foamed concrete, uniform distribution of air bubbles through the mass of concrete makes 20% of entrapped air, making it so light than the conventional concrete[9]. According to previous research, less connected air voids caused a lower reduction in compressive strength, and with the increase in air voids, the thermal resistance is increased [10]. Utilization of stable foam in concrete can be minimized the Weight of brick and thus reduce the dead load. Besides, Fly ash can replace with cement, and therefore cement can be saved in concrete products. By substituting fly ash to cement, it caused to reduce CO_2 emissions, especially taking high volume fly ash [11]. Using fly ash as an additive cause increases the strength of foamed concrete in the long term [12], [13]. This study's main objectives are to evaluate compressive Strength, flexural Strength, and water absorption of lightweight foamed concrete brick with fly ash. Foamed concrete, lightweight bricks would be lighter than normal concrete brick. The addition of foam to concrete can sharply decrease the mass of fresh and hardened concrete. Thus, the compressive and flexural strength of lightweight foamed concrete brick must be evaluated.

II. MATERIALS and METHODS

A. Materials

a) Stable Foam

Foams are being used in a number of petroleum industry applications that exploit their high viscosity and low density [14]. The dosage of a foaming agent influences the density of mix and hardened foamed concrete. The density of foamed concrete is strongly correlated with the foam content in the mix [15]. The foaming agent was used to obtain foamed concrete. It is defined as an air-entraining agent. The foaming agent is the essential influence on the foamed concrete. There are two types of foaming agent: protein-based foam and synthetic based foam. Protein-based foaming agents are more easily available, less expensive, and have lower consistency and strength than synthetic foaming agents [16]. The foam used in this experiment was prepared from the DRN Concrete Resources Sdn-Bhd factory, Malaysia. It is a protein-based foam that comes from animal proteins (horn, blood, bones of cows, pigs & other remainders of animal carcasses). Synthetic foam is suitable for densities of 1000kg/$m^3$and above, and Protein foam is suitable for densities from 400 kg/$m^3$to 1600 kg/m^3[17]. Initial observation of the foam was shown that it is liquid with dark brown color and oily form. To produce stable foam from aqueous foam, one liter of protein foam was thoroughly blended with 30 liters of water by a mixing machine, as explained in its instruction. The aqueous foam and water were mixed for about 15 minutes with a mixing machine to produce stable foam (Fig. 1). In the next step, the stable foam is added to the concrete paste and replaced with the paste by volume to produce lightweight foamed concrete.

Fig. 1: Stable Foam

b) Fly ash

According to ASTM C, 618 fly ash can use as an additive in cement concrete. Fly ash is classified into two general types: class F and class C [18], [19]. Fly ash used in this experiment is class F type prepared from Sdn-Bhd, Selangor, Malaysia. It is replaced by cement in mixture by Weight. The results of X-ray Fluorescence analysis illustrates that the SiO_2 and Al_2SiO_3 content in fly ash is very similar to Portland cement, which makes fly ash suitable to be used in construction materials. Fly ash caused a great reduction in concrete's strength, especially for higher replacements, i.e., for 20% fly ash concrete. This is due to high impermeability and moisture gained in a longer curing period resulting in high pore pressure and low initial strength gain[20], [21]. Fly ash caused to slow down the process of hardening in the concrete specimens[15]. Using of class F fly ash in concrete exhibited lower water sorptivity and chloride permeability. Furthermore, a significant drop of sorptivity and chloride permeability was observed for fly ash concrete between the curing periods of 28–180 days [22]. Fly ash helps produce a small size and uniform distribution of pores that caused a better strength as it provides a better connection between pores and voids [23].

B. Methods

The best lightweight concrete will be obtained based on its maximum compressive strength and other mechanical behavior. Therefore, the optimum percentage of foam and fly ash gained the highest compressive strength would be optimized. As a mixing procedure, cement, aggregates, fly ash, and water mixed in a mixer to produce slurry at the first stage. Then the foam bubbles were added to the slurry in the mixing machine to produce the foaming concrete.

a) Optimization of Stable Foam

To obtain an optimum percent of stable foam, various percentages of stable foam substitute with normal concrete paste. For this purpose, from 5% of stable foam starts to substituting with paste and increase this percentage till decreasing in strength occurred. According to Fig. 2, 5%, 10%, 15%, and 20% of stable foam was replaced with normal weight concrete paste, and the specimens were cured 28 days in distilled water. Fig. 2 demonstrates that the compressive strength would be decreased by increasing foam percentage (more than 10%). All brick specimens were produced based on 10% foam as it is obtained as the optimum percentage of foam.

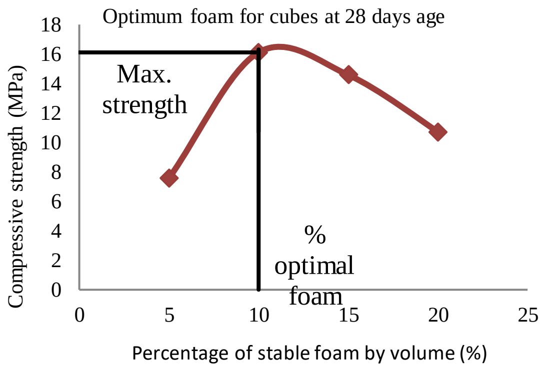

Fig. 2:Optimization of the Foam in Terms of Compressive Strength

b) Optimization of Fly ash

After the optimum percentage of foam was found, Weight found the optimum percentage of fly ash and various fly ash percentage substituted with cement by Weight. According to previous research, to reach this aim, 5%, 10%, and 15% of fly ash replaced with cement in the foamed concrete paste and cured in water for 3, 14, and 28 days.

c) Compressive Strength Test

Previous research shows that the relationship between density and strength in lightweight foamed concrete is the same. The low density described the weak strength [24], [25].To evaluate the compressive strength of the lightweight concrete bricks, a compressive strength test was carried out. Usually, lightweight concrete bricks are produced for partition and walls. Therefore, it can be considered as a non-load bearing brick.

Fig. 3: Brick Specimen and Compressive Strength Test

To find the maximum compressive strength of foamed concrete, concrete with foam was cast in a square metal mould with 100 mm dimensions. The test specimens were cured for 28 days in water and then tested in universal compression equipment. After the optimum foam percentage is found, a compression test of lightweight bricks with fly ash with a surface area of 210×92 $mm^2$and, a height of 60 mm is tested (Fig. 3).

d) Flexural Strength Test

A flexural strength test was performed on concrete bricks based on ASTM C293(Fig. 4)[26]. This test method covers the determination of the flexural strength of concrete and masonry brick specimens using brick with center-point loading. It is not an alternative to the test method, and it is a destructive test.

Fig. 4: Flexural Strength Test on Bricks

e) Water Absorption Test

The water absorption test is determined for brick specimens. They were put in an oven at a temperature of 105°C for 72 hours. After 72 hours, the specimens were taken out from the oven and immersed in distilled water 24 hours (Fig. 5). The specimens were weighted in all steps. According to previous research, the water absorption percentage is decreased in concretes with a high volume of fly ash contents. This may be due to the lack of hardening of fly ash-based concrete during the early ages. Due to the presence of high volume fly ash, hardening and related properties are attained at a later period of curing (56 days, 90 days, etc.) compared to ordinary concrete [27].

Fig. 5: Flexural Strength Test on Bricks

According to ASTM C 140, one of the most important properties of good quality concrete is low permeability, especially one resistant to freezing and thawing [28]. A concrete with low permeability resists the ingress of water and is not as susceptible to freezing and thawing. Water enters pores in the cement paste and even in the aggregate.

III. RESULTS and DISCUSSION

A. Compressive Strength

Table I shows the summary of the results of the compressive strength test on bricks. The strength is decreased by adding the foam to concrete. According to the table, the highest compressive strength was found for ordinary concrete. After that, the highest compressive strength was found for the foamed concrete with 10% fly ash.

TABLE II
Summary of the Results of Compressive Strength Test on Bricks

Composition of specimen	**Average compressive strength of bricks after 28 days curing in water (MPa)**
Ordinary Concrete (OC)	11
OC 85%, FA 5%, FO 10%	8.4
OC 80%, FA 10%, FO 10%	9.1
OC 75%, FA 15%, FO 10%	8.1

**OC: Ordinary Concrete, FA: Fly Ash, FO: Foam*

Based on Fig. 6, the compressive strength of bricks is increased while the curing time increased.

Therefore, the highest compressive strength was yielded for bricks after 28 days of curing in distilled water. Ordinary concrete, compare to foamed concrete with fly ash, gives a slightly faster setting at the beginning. But in the foamed concrete with fly ash, setting time is slowing down. There is a possibility of continuance in hydration progress by increasing curing time and increasing strength in the long term, which offers greater strength to the building [29].

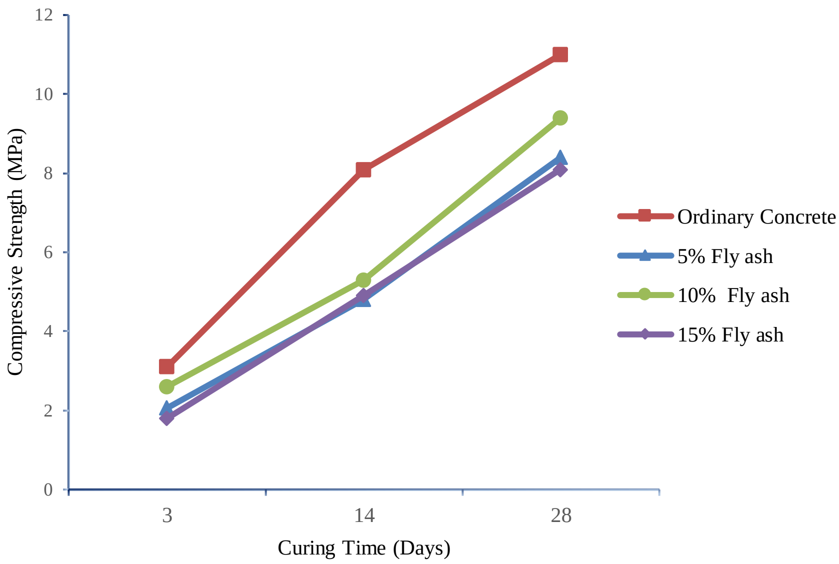

Fig. 6: Effect of Curing and Fly ash on Compressive Strength

According to Fig. 7, which illustrates the effect of fly ash on lightweight foamed concrete brick, the optimum fly ash percentage is found by 10%, which gives strength of about 9.1 MPa. The strength of lightweight foamed concrete with 5% and 15% fly ash were obtained 8.4 and 8.1 MPa, respectively.

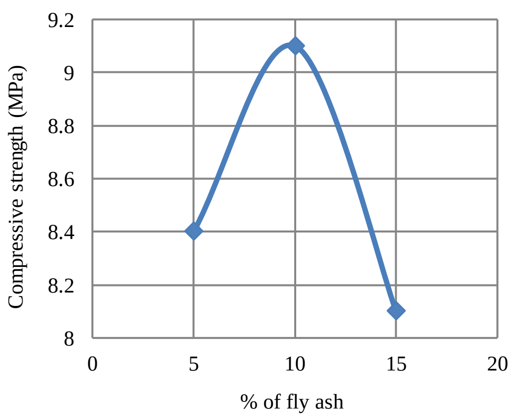

Fig. 7:Effect of Fly ash on Compressive Strength of Lightweight Bricks after 28 Days Curing in Water

B. Flexural Strength

In this section, specimens of bricks with a surface area of 210×92 mm^2after 28 days of curing in water were tested under flexural test. Results obtained from the laboratory flexural test are shown in Tables IIIIV, VVIVII, and IV. There are taken five samples for each mixture.

TABLE VIIIIX
Flexural Strength of Lightweight Bricks after 28Days Curing in Water with 5% Fly ash and 10% Foam

Specimen	Area (mm^2)		Flexural Strength	
	Length (mm)	Width (mm)	KN	MPa
1	210	92	44.44	2.3
2	210	92	34.78	1.8
3	210	92	50.23	2.6
4	210	92	46.37	2.4
5	210	92	40.57	2.1
Average				1.8

TABLE XXIXII
Flexural Strength of Lightweight Bricks after 28 Days Curing in Water with 10% Fly ash and 10% Foam

Specimen	Area (mm^2)		Flexural Strength	
	Length (mm)	Width (mm)	KN	MPa
1	210	92	59.89	3.1
2	210	92	54.10	2.8
3	210	92	50.23	2.6
4	210	92	61.82	3.2
5	210	92	59.89	3.1
Average				3

TABLE IV
Flexural Strength of Lightweight Bricks after 28 Days Curing in Water with 15% Fly ash and 10% Foam

Specimen	Area (mm^2)		Flexural Strength	
	Length (mm)	Width (mm)	KN	MPa
1	210	92	25.31	1.31
2	210	92	15.82	0.82
3	210	92	15.65	0.81
4	210	92	16.03	0.83
5	210	92	31.30	1.62
Average				1.08

Based on the results average value of flexural strength of the specimens with 5%, 10%, 15% fly ash, and 10% foam was determined 1.8 MPa, 3 MPa, and 1.08 MPa. Therefore, lightweight brick with 10% fly ash and 10% foam has reached the maximum flexural strength.

The effect of adding 5%, 10%, and 15% fly ash to concrete on bricks' flexural strength is illustrated in Fig. 8. Fig. 8 shows that by increasing the amount of fly ash, the compressive strength of lightweight bricks was increased until it reached 3 MPa. Fig. 8 shows that the addition of 15% fly ash was decreased the compressive strength. Therefore, the maximum value of flexural strength was 3 MPa for the brick specimen with 10% fly ash and 10% foam.

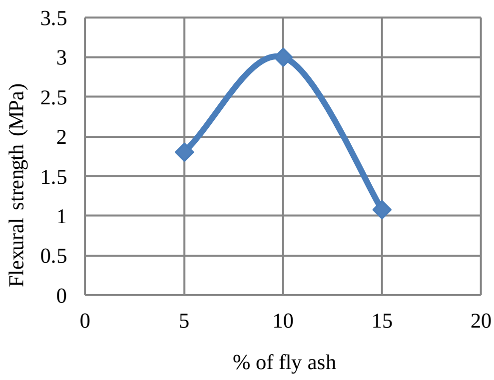

Fig. 8:Effect of Fly ash on Flexural Strength of Lightweight Bricks after 28 Days Curing in Water

C. Water Absorption

The volume of water (in kg/m^3) absorbed by foamed concrete was approximately twice that of an equivalent cement paste but was independent of the volume of air-entrained, ash type, or ash content [30]. For the water absorption test of bricks, three specimens of each composition are tested. The average results of water absorption and Weight of specimens compared with normal-weight concrete are illustrated in Table V. According to the table, by replacing fly ash and foam with cement and concrete paste in all compositions, there are decreasing in their Weight are found. It is about to averagely by 9.2%.

TABLEV
Bricks Water Absorption after 28 Days of Curing

Test Specimen	Average Weight lighter than Ordinary Concrete (%)	Water absorption (%)	Average
OC 85%, FA 5%, FO 10%	8.73	4.4	4.2
		4.4	
		4.0	
OC 80%, FA 10%, FO 10%	9.1	4.1	3.9
		3.8	
		3.8	
OC 75%, FA 15%, FO 10%	9.78	3.5	3.2
		3.1	
		3.0	

The water absorption test was carried out for all specimens. The highest amount was found in materials incorporated with 10% foam and 5% fly ash, and the lowest was found for concrete with 10% foam and 15% fly ash. Table V demonstrates the influence of fly ash in foamed concrete. The water absorption decreased when fly ash increased in foamed concrete with the same foam volume in the paste. It is because of fly ash's small particle size that causes well to fill the pores and air voids in foamed concrete.

IV. CONCLUSIONS

Several laboratory tests such as compression, flexural, water absorption, and determination of lightweight concrete mass were performed to determine compressive strength, flexural strength, and mass of the lightweight concrete cube and bricks with various percentages of fly ash and foam. According to this study's results, foamed concrete, lightweight bricks have acceptable compressive strength compared with normal concrete. Therefore, foamed concrete, lightweight brick can be used in construction and building applications. Concerning results, lightweight bricks can be used in the indoor application of buildings like partition walls. The best lightweight concrete will be obtained based on its maximum compressive strength and other mechanical behavior. Therefore, the optimum percentage of foam and fly ash that gained the highest compressive strength was determined 10% for both materials. From the laboratory investigations, the following conclusions were obtained:

(1) In overall can be concluded that the optimum percentage of foam is determined 10%.

(2) The optimum mixture of lightweight concrete for brick is obtained for the composition containing 10% fly ash and 10% foam.

(3) The average value of flexural strength for lightweight bricks is found 3MPa in 28 days of curing.
(4)The average value of compressive strength for lightweight brick is determined 9.1 MPa in 28 days of curing.
(5) Water absorption by lightweight concrete containing 10% fly ash and 10% foam is obtained 3.9%, and the value decreased by the fly ash percentage increased.
(6)The percentage improvement in the Weight of brick is determined around 10%.
(7) In this research, fly ash is replaced with cement. Besides that, stable foam is replaced with concrete paste.
(8) The characteristics and mechanical behavior of Lightweight foamed concrete with fly ash illustrate that it is ideal to use in constructions, especially in non-structural applications.

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