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Influence of Fly Ash on the Compressive Strength of Foamed Concrete at Elevated Temperature

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Abstract. Foamed concrete is a lightweight concrete that is widely used in the construction industry recently. This study was carried out to investigate the influence of fly ash as a cement replacement material to the residual compressive strength of foamed concrete subjected to elevated temperature. For this study, the foamed concrete density was fixed at 1300 kg/m^3 and the sand-cement ratio and water-cement was set at 1:2 and 0.45, respectively. The samples were prepared and tested at the age of 28 days. Based on the results, it has been found that with 25% inclusion of fly ash, the percentage of compressive strength loss was decreased by 3 – 50%.

1 Introduction

Foam concrete is classified as lightweight concrete containing no coarse aggregates. It contains fine aggregates (sand), cement, water and foam. The main advantage of foamed concrete is that it is lightweight and low in density as compared to the normal concrete. It is a low density concrete with a large number of air bubbles created by the foam. The air bubbles existence results in producing high workability and lighter concrete. Currently, the application of foamed concrete has become common, therefore the risk of exposing it to elevated temperature also increases. Influence of the elevate temperature on mechanical properties of foamed concrete is important especially for its fire resistance properties.

The properties and characteristics of foamed concrete are different as compared to the normal concrete. Foamed concrete has the capability to resist fire and does not absorb much water [1]. It also can be sawn, nailed or drilled using the conventional tools. Strength is the main behavior of concrete that is important. Nowadays many buildings constructed in Malaysia face problems during construction such as structural crack and damages due to a few factors. Due to the temperature, compressive strength decrease if foamed concrete exposed to the high temperature.

The properties of foamed concrete are subjected to degradation when exposed to elevated temperatures. This includes chemical and mechanical deterioration. The chemical degradation occurs when the chemically bound water inside the foamed concrete mix is released from the cement paste. The dehydration process diminishes the calcium silicate hydrate (CSH) links which provide the load bearing formation in the hydrated cement [2]. During the hydration of the cement paste, the internal water pressure is built up therefore increases the internal stresses and further induced micro cracks in the material. This phenomenon will further cause decrement in the compressive strength of the foamed concrete. Therefore, research has to be done to find alternative materials that can be used in concrete mixture to increase its performance after exposure to high temperature and at the same time reduce the construction cost. Fly ash is one of the recycle materials that are suitable as a partial replacement for the Ordinary Portland Cement (OPC). Studies have shown that with partial replacement of fly ash in the cement content, the compressive strength increases as the fly ash amount increases to the optimum value [3,4]. Improvement of the compressive strength in the concrete containing fly ash is probably due to the pozzolanic reaction. The increment of the strength was due to the reaction with calcium hydroxide, forming compound with cementing properties [4].

2 Experimental Method

A total of 24 samples were prepared for this study; 12 cube samples and 12 cylinder samples. For this research, the foamed concrete samples were prepared, which consist of 100 x 100 x 100 mm cubes and 100 mm diameter x 200 mm length cylinders. The densities of all samples were fixed to 1300 kg/m3. A synthetic foam agent used for the mixing process was Noraite SA-1B (Portafoam) which is developed and provided by USM (Universiti Sains Malaysia). An additive was added in the preparation of samples was Noraite PS-1.

2.1 Specimen preparation

The mortar mix containing cement sand and water was prepared based on the mix proportion of 1:2, cement to sand ratio with the water cement ratio of 0.45. Fly ash is incorporated in the mix as a cement replacement material. The proportions of fly ash used in this study are 25%, 30% and 35% replacing the cement content in every mix. Four batches of mortar mix were prepared for this study. One mix is as a control mix while the other three are the mixes with fly ash replacing a certain percentage of cement. The mortar were mixed and tested for slump and density before incorporating the mix with foam. The foam was prepared by mixing the foam agent, Noraite SA-1B with water at the ratio of 1:33 in a tank before transferring the mixture into the foam generator. The foam generator (Figure 1) was used to produce stable foam to be combined with the mortar mixture prepared earlier. The amount of foam required for the mix was calculated using the design mix form aiming for a 1300 kg/m^3 wet density. The foam was gradually added to the mortar mix until it was well combined. The additive of Noraite PS-1 (0.1% of the cement content) was added to the mix at this point. A portion of the foamed concrete was then weighed to measure the density. The mix that has reached the desired density immediately poured into the molds to avoid the disintegration of the air bubbles. The samples were demoulded after 24 hours and wrapped in polythene wrapping and kept at room temperature up to the day of testing

2.2 Heating of the specimens

During the process of curing, the foamed concrete samples developed their strength. At 28 days, the cubes and cylinders were exposed to high temperature in and electrical furnace as shown in Figure 2 setting the temperature to be at 200°C, 400°C and 800°C.

Figure 1: Foam generator

Figure 2: Electric furnace

2.3 Testing of the specimens

After exposing the samples to the specified temperature, they were then cooled off at room temperature before testing. The compression test was done using the ADR-Auto 3000. The loading were applied without shock and continuously at the nominal rate. The range of the rate is in between 0.2 N/mm^2s and 0.4 N/mm^2s. The maximum loading that can be sustained by the samples were then recorded together with the stress that being resisted by the samples.

3 Results and Discussions

3.1 Influence of fly ash in the compressive strength of foamed concrete

Figure 3 shows effect of fly ash to the compressive strength of controlled samples. An increase of about 25% - 55% in compressive strength was observed at 28 days with the inclusion of the fly ash at the percentage of 25%, 30% and 35% of the cement content. Then highest compressive strength of the cube and cylinder samples was achieved by replacing the cement by 35%. The result that is presented in the figure shows that with the increase of fly ash percentage to replace cement content, there is a significant increase in the compressive strength of the samples.

This is due to the pozzolanic reaction that forms the hydrates of calcium silicate. Therefore, in foamed concrete containing fly ash, the pozzolanic reaction of fly ash improves the structure and therefore ensures the strength growth. The reaction process reduced the calcium hydroxide content, which is the weakness in the concrete strength and increases the C-S-H gel to form the structure of hardened cement.

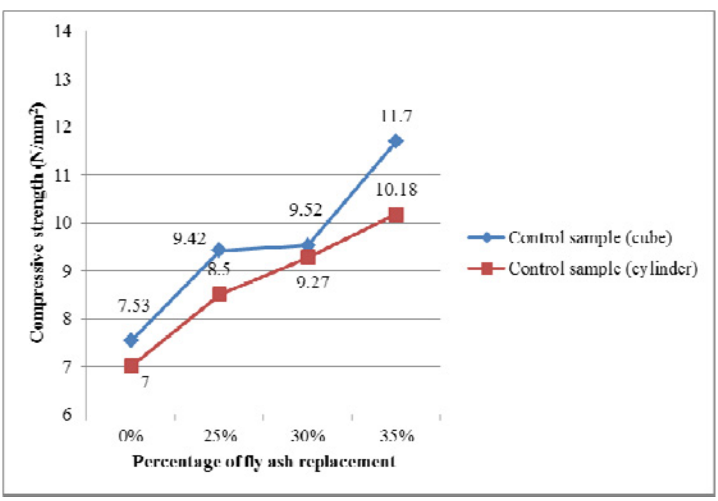

Figure 3: Effect of fly ash to the compressive strength of controlled samples

3.2 Influence of elevated temperature to the compressive strength of foamed concrete

Figure 4 shows the compressive strength of the controlled samples without fly ash at normal temperature and after heating to 200°C, 400°C and 800°C is shown in The strength in all samples tends to decrease as the heating temperature increases from 200°C to 800°C. After heating to 200°C and subsequent cooling, the compressive strength of the cube samples decreases from 7.53 N/mm^2 to 6.53 N/mm^2 while for cylinders, the strength decreases from 7 N/mm^2 to 6.47 N/mm^2. A decrease of approximately 13.28% and 7.6% for the cube and cylinder samples was observed. With further increase of the temperature, from 200°C to 400°C and 800°C, the compressive strength decreased more to a percentage of approximately 23% and 69%, for the cube samples and 15% and 72% for the cylinder samples.

The increasing of the temperature causes the foam concrete to lose bonding between the particles of the sample. The cube samples showed a higher value of compressive strength as compared to the cylinder.

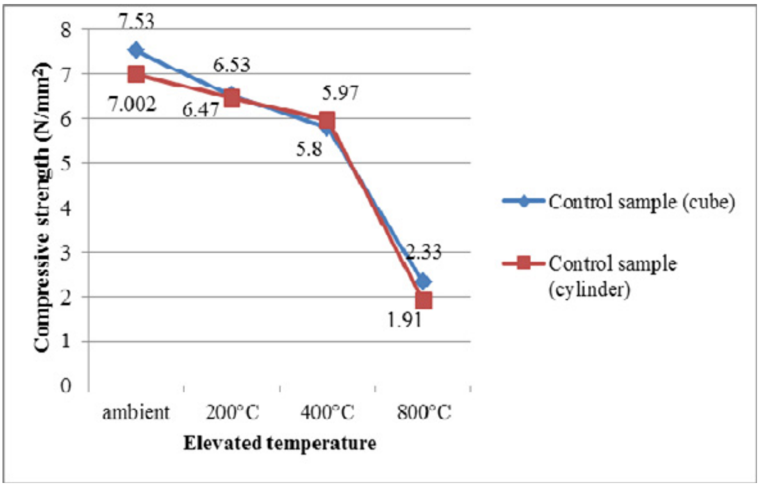

Figure 4: Effect of elevated temperature to the compressive strength of controlled samples

3.3 Influence of fly ash inclusion to the residual compressive strength of foamed concrete

Figures 5 and 6 shows the effect of fly ash inclusion to the residual compressive strength of foamed concrete after been exposed to elevated temperature (cube and cylinder). The trend of the foamed concrete with fly ash is almost similar to the trend of the controlled samples where the compressive strength decreases as the temperature increases. The residual compressive strength is at the lowest value when the samples were subjected to the temperature of 800°C.

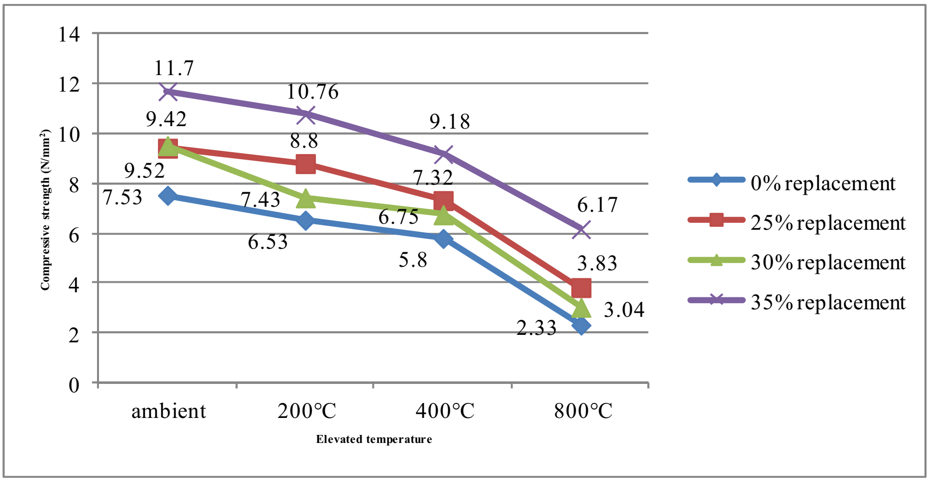

Figure 5: Effect of elevated temperature to the residual compressive strength of cube samples

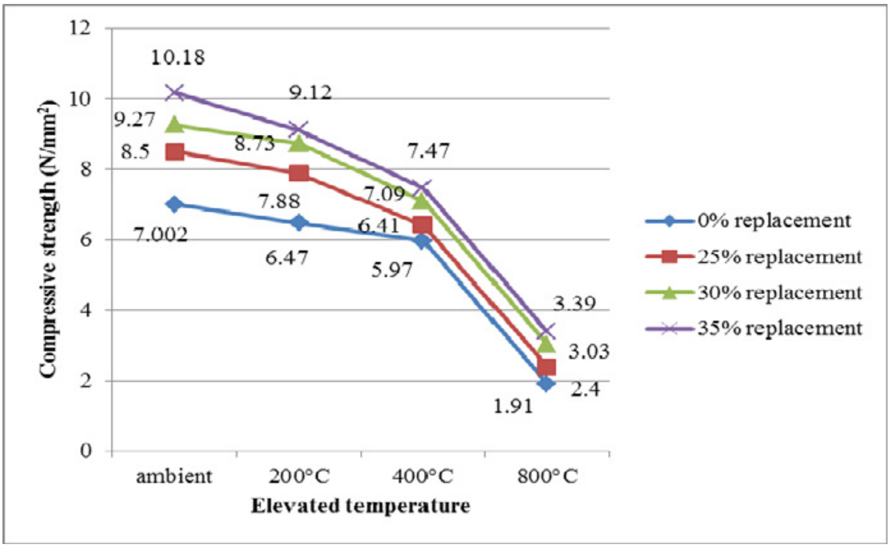

Figure 6: Effect of elevated temperature to the residual compressive strength of cylinder samples

When exposed to 200°C temperature, the compressive strength of the foamed concrete cube sample without any inclusion of fly ash by approximately 13% for cubes and 7.6% for cylinders. Exposed to the same temperature, but with 25% replacement of fly ash, the strength is decreased by 6.6% and 7.3% for cube and cylinders. This result shows a decrement in the strength loss up to 50%. As the temperature increases further to 400°C, the compressive strength of the controlled samples decreased by 23% and 14.7%, for both cubes and cylinders.

The compressive strength loss of the samples is observed to be at the highest when they are exposed to the highest temperature of 800°C. For the controlled samples without fly ash, the percentage of strength loss was 69.1% for cubes and 72.7% for cylinders. The same trend was found with 25% replacement of fly ash where the strength loss decreases by 1.3 – 14%. These results of the percentage of strength loss can be seen in

With the replacement of 25% of fly ash, most samples showed a decrement in the strength loss percentage as compared to the controlled samples without the fly ash replacement when heated to all temperatures (refer Figures 7 and 8).

This result might be due to the inclusion of fly ash that has the ability to increase the resistance of the concrete against high temperature. The pozzolanic properties of the fly ash will remove the negative effects of calcium hydroxide since the pozzolanic reactions decreases the amount of $Ca(OH)_2$. This could therefore reduce cracking in foamed concrete when subjected to high temperature [5].

However, an increment of the strength loss percentage was observed in a few samples with 30% and 35% replacement fly ash. For the cube samples with 30% fly ash replacement, the strength loss percentages are about 27 – 60% higher than the controlled samples when exposed to temperatures 200°C and 400°C. The result shows that higher replacement of fly ash does not contribute to significant effect in the residual compressive strength of the foamed concrete after being exposed to elevated temperature.

Generally, the overall effect of subjecting the foamed concrete samples to different temperatures results in reduction in strength. Upon heating to high temperatures, the samples losses its moisture content and this will later affect the hydrated cement products resulting in strength loss [6].

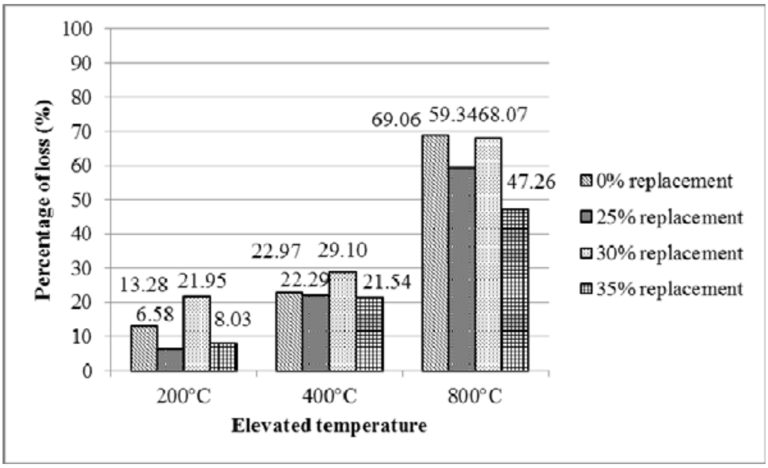

Figure 7: Percentage of compressive strength loss due to elevated temperature (cubes)

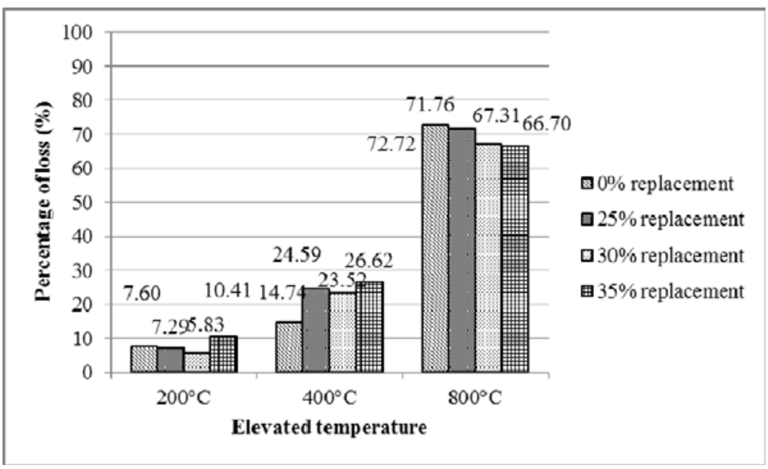

Figure 8: Percentage of compressive strength loss due to elevated temperature (cylinders)

4 Conclusion

This paper presented the results of a study on the influence of fly ash on the compressive strength of foamed concrete subjected to elevated temperatures. Compressive strength test was carried out on cubes and cylinder samples produced with the same density of 1300 kg/m^3. The variation in parameters that is introduced in this research is the fly ash content to replace cement and the samples were exposed to a range of temperature up to 800°C. From the experimental results, the following conclusion can be drawn:

1. By replacing the Ordinary Portland Cement (OPC) with fly ash, the compressive strength of the foamed concrete samples was found to be increased at 28 days.
2. The increment of the heating temperature from 200°C to 800°C, decreases the residual compressive strength of the samples. The highest decrease of the strength was found on samples subjected to 800°C.
3. For samples that are produced by replacing the cement content with 25% fly ash, the effect of elevated temperature to the residual compressive strength of the samples was reduced by up to 50%.

The effect of the shape of the samples on the residual compressive strength of the foamed concrete samples will be discussed later in other publication.

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