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Laboratory Investigation on Compressive Strength and Micro-structural Features of Foamed Concrete with Addition of Wood Ash and Silica Fume as a Cement Replacement

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Abstract. Wood Ash (WA) and Silica Fume (SF) exhibit good cementation properties and have great potential as supplementary binder materials for the concrete production industry. This study will focus on enhancing the micro-structural formation and compressive strength of foamed concrete with the addition of WA and SF. A total of 3 mixes were prepared with the addition of WA and SF at various cement replacement levels by total binder weight. For this particular study, the combination of WA (5%, 10%, and 15% by binder weight) and SF (5%, 10%, and 15% by binder weight) were utilized as supplementary binder materials to produce foamed concrete mixes. As was made evident from micrographs obtained in the study, the improvement observed in the compressive strength of the foamed concrete was due to a significant densification in the microstructure of the cement paste matrix in the presence of WA and SF hybrid supplementary binders. Experimental results indicated that the combination of 15% SF and 5% WA by binder weight had a more substantial influence on the compressive strength of foamed concrete compared to the control mix. Furthermore, the addition of WA and SF significantly prolonged the setting times of the blended cement paste of the foamed concrete.

1 Introduction

Foamed concrete is a versatile material which consists primarily of a cement based mortar mixed with at least 20% of volume air [1,2]. It possesses high flow ability, low self-weight, minimal consumption of aggregate, controlled low strength and excellent thermal insulation properties [3]. It can have a range of dry densities, typically from 400 kg/m^3 to 1600 kg/m^3 and a range of compressive strengths from 1 MPa to 15 MPa [4]. It should be pointed out that the physical characteristics of foamed concrete are determined by the use of one of a number of mix designs.

Foamed concrete can be placed easily, by pumping if necessary, and does not require compaction, vibrating or levelling [5,6]. It has excellent resistance to water and frost, and provides a high level of both sound and thermal insulation [7]. The material is now being used in an ever increasing number of applications, ranging from one step house casting to low density void fills [8,9]. Figure 1 and Figure 2 show some examples of the application of foamed concrete in real projects. This particular research is carried out in reaction to the need for improvement of the economic and

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ecologically friendly green concrete while maintaining the existing goal of creating sustainable building materials without any harms to the built environment

Figure 1. Cast in-situ wall in Surabaya, Indonesia

Figure 2. Slab thickening for airport project in Malaysia

2 Materials

Portland Cement with a specific surface area of 1043.2 m^2/kg, specific gravity of 3.02 and median particle size of 3.9 μm was used for specimen preparation. Uncrushed fine aggregates were used in mortar mixes as a constituent material with a specific gravity of 2.83 and a maximum aggregate size of 5mm. In addition, low-density fill material admixtures are also surfactants but were added directly into a sand-rich, low-cement-content concrete to give 15 to 25% air. In terms of silica fume, ultrafine silica fume with spherical particles of less than 1 μm in diameter were utilized. Finally, wood which contains calcium carbonate (25-45%) , potash (10%) and phosphate (less than 1%) with trace elements of iron, manganese, zinc, copper and some heavy metals were used. Water-cement ratio was fixed at 0.45 for all mixes.

3 Mix Proportion

For this study, the mix proportion of foamed concrete was calculated based on Standard Mix Design [10,11] according to the British Department of Environment (DoE) method [12,13]. Table 1 shows the mix proportion of 1350kg/m^3 density foamed concrete fabricated for this study.

Table 1. Mix proportion of mortar specimens

Mix	Cement (kg)	Wood Ash (%)	Silica Fume (%)	Fine aggregates (kg)	w/c ratio
Control	54.2	-	-	81.3	0.45
5% WA, 15% SF	43.4	5	15	81.3	0.45
10% WA, 10% SF	43.4	10	10	81.3	0.45
15% WA, 5% SF	43.4	15	5	81.3	0.45

4 Results and Discussion

4.1 Compressive Strength

The compressive strengths of foamed concrete mortar containing different proportions of silica fume and wood ash were compared as presented in Fig. 3. At the age of 7 days, the compressive strength of 5% WA - 15% SF mortar was found to be higher than that of the control mortar. Meanwhile, the compressive strengths of the 10% WA - 10% SF and 15% WA - 5% SF mortars were lower than that of the control mortar. At 28 days, it was noted that the compressive strength of the 5% WA - 15% SF mortar was higher compared to the other mortars. This was followed by the 10% WA - 10% SF mortar which has a slightly higher strength than the control mix. Meanwhile, the 15% WA - 5% SF foamed concrete mix exhibited a lower compressive strength compared to that of the control foamed concrete mix. At 60 days, the foamed concrete containing 5% WA - 15% SF cement replacement outperformed all other mixes in terms of compressive strength, which was mainly made possible thanks to the mix's constituent binders [14]. Furthermore, at the age of 60 days, the compressive strengths of 10% WA - 10% SF and 15% WA - 5% SF were also found to be higher than the control mix.

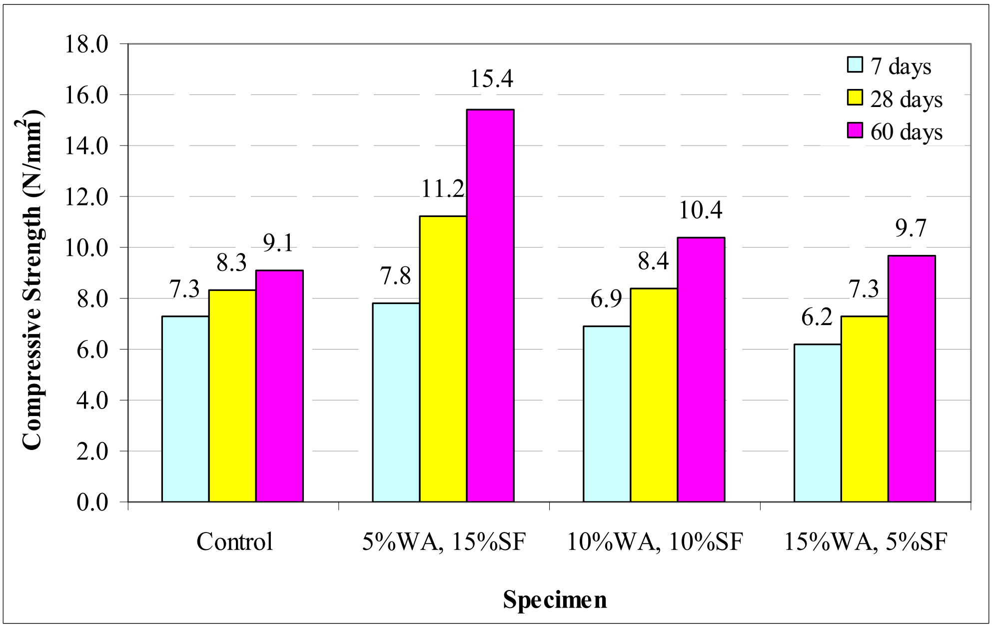


Figure 3. Compressive strength by mortar mixes

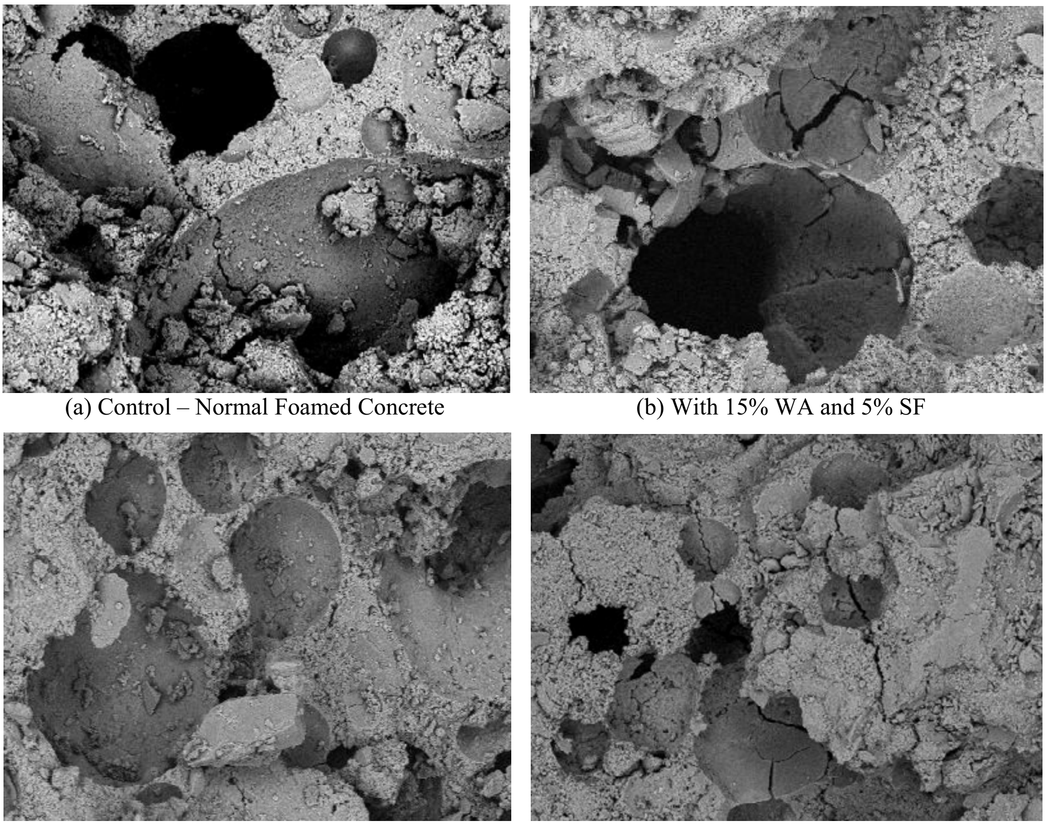
Upon a prolonged curing duration of 60 days, a significant enhancement in compressive strength was exhibited by foamed concrete with 5% WA - 15% SF, where the observed compressive strength was about 35% higher compared to the control mortar. The inclusion of a higher percentage of silica fume than wood ash for cement replacement produced stronger foamed concrete with a compressive strength of as high as 15.4 N/mm² at the age of 60 days.

4.2 SEM Analysis

A scanning electron microscope (SEM) is a type of electron microscope that produces images of a sample by scanning it with a focused beam of electrons. The electrons interact with atoms in the sample, producing various signals that can be detected and which contain information about the sample's surface topography and composition. The electron beam is generally scanned in a raster scan pattern, and the beam's position is combined with the detected signal to produce an image. A SEM can achieve resolution better than 1 nanometre and specimens can be observed in both high vacuum and low vacuum.

Fig. 4 demonstrates the comparison of the formation of pores in normal foamed concrete (control) and foamed concrete with different percentages of Wood Ash (WA) and Silica Fume (SF) at a density of 1350 kg/m^3. It was found that the formation of pores in foamed concrete mortars was significantly affected by the percentage of wood ash and silica fume introduced into the base mix. Evidence of this comes from the formation of larger sized pores in the control foamed concrete mix

[15]. Meanwhile, the foamed concrete mixes using different percentages of wood ash and silica fume by replacing 20% of the cement quantity reduced the size of pores and also the number of pores in each different mortar mix. The most effective foamed concrete was that with a composition of 5% wood ash and 15% silica fume. This occurred due to the nature of silica fume, which has extreme fineness and high silica content, while wood ash contains calcium carbonate as its major component.



(a) Control – Normal Foamed Concrete (b) With 15% WA and 5% SF

(c) With 10% WA and 10% SF (d) With 5% WA and 15% SF

Figure 4. Comparison of the formation of pores in normal foamed concrete (control) and foamed concrete with different percentages of Wood Ash (WA) and Silica Fume (SF) at a density of 1350 kg/m^3

5 Conclusion

This study took an in depth look at all of the processes from the primary stages of mortar mix design up to the analysis of data obtained. Experimental laboratory work was carried out to obtain data on compressive strength and scanning electron microscope analysis. In conclusion, 5% Wood Ash (WA) and 15% Silica Fume (SF) foamed concrete mix displayed remarkable results in comparison to other foamed concrete mixes. It was determined that the ideal percentages for wood ash and silica fume are 5% and 15% of binder weight respectively.

The improvement in the compressive of foamed concrete with the use of wood ash in combination with silica fume is due to the higher pozzolanic reaction rate between the amorphous silica mineral in silica fume and Portlandite mineral which encourage the formation of smaller pores in comparison to control foamed concrete. The refined pore structure of the cement matrix ultimately contributes to the enhancement of the mechanical strength and compressive stiffness of the wood ash and silica fume foamed concrete mixes.

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