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Foamed concrete containing rice husk ash as sand replacement: an experimental study on compressive strength

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Abstract. This study presents the utilization of rice husk ash (RHA) as sand replacement in foamed concrete. The study focuses on the effect of RHA on the compressive strength of foamed concrete. RHA contains high pozzolanic material that reacts with cementitious to enhance the strength and durability of foamed concrete. RHA also acts as filler causing the foamed concrete to become denser while retaining its unique low density. A total 243 cube specimens was prepared for the compression test. Two sets of mix design were employed at water-cement (W/C) ratio of 0.55, 0.60 and cement-sand ratio of 0.50, 0.33. The results revealed that the presence of RHA as sand replacement resulted in an increase in the compressive strength of foamed concrete. Moreover, 30% to 40% RHA was the optimum content level, contributing to the compressive strength of 18.1MPa to 22.4MPa. The W/C ratio and superplasticiser dosage play small roles in improving workability. In contrast, density governs the compressive strength of foamed concrete.

1. Introduction

Foamed concrete is a lightweight and versatile material. The basic components of foamed concrete are cement, fine aggregate, stable foam, water and other type of admixtures. The non-presence of coarse aggregate causes foamed concrete to have low density (400kg/m^3 to 1600kg/m^3). Cement consumption is also high due to the need for decent quality and adequate strength in foamed concrete. However, the compressive strength of foamed concrete is deficient when in the range of 10MPa to 15MPa [1-4]. The corresponding fracture energy can be reached at around 20N/m to 35 N/m [5, 6]. These characteristics limit the application of foamed concrete and the prohibition of its use as a structural component. According to Eurocode 2 [7], the minimum compressive strength employed in reinforced concrete structures should be 22MPa.

Previous studies have attempted to improve the compressive strength of foamed concrete. The modifications of cementitious using fly ash [8] and palm oil fuel ash [9] have yielded the most favourable results in terms of producing good foamed concrete. Another approach in enhancing the material properties of foamed concrete is by exploiting lightweight aggregates, such as pelletized fibre [3] and oil palm shell [10], where promising results (as high as 50MPa) can be achieved. This study, however, intends to utilize rice husk ash (RHA) as sand replacement in foamed concrete to fulfil the requirement of characteristics strength for structural purposes. More focus is given to the effect of volume fraction, the role of water-cement (W/C) ratio, superplasticiser (SP) dosage and the density of foamed concrete toward the optimum contain of RHA.

2. Rice Husk Ash

Rice husk ash (RHA) is an agricultural by-product obtained from the process of burning rice husk under controlled temperatures below 800 °C. The by-product is black, grey, or pinkish-white, depending on the burning process [11]. The burning process produces about 25% of ash containing 85% to 90% amorphous silica as well as about 5% alumina, which makes it highly pozzolanic [12]. Studies have thoroughly investigated the mechanical properties and behaviour of concrete incorporating RHA. Kishore et al. [13], Xu *et al*. [14], Jamil et al. [15], Sathawane *et al.* [16] and Abalaka [17] applied RHA as partial replacement for cement. To some extent, RHA can be used to partially substitute for cement, but the addition of RHA exhibits better performance in flexure strength.

RHA with volume fraction of more than 5% to 10% has exhibited a decrease in compressive strength Compressive strength has been found to decrease linearly with the increase in the increments of RHA. However, RHA can enhance the durability of concrete particularly in terms of environmental exposure and chemical attacks. The addition of around 20% to 30% RHA to cement has been found to be advantageous and does not adversely affect the durability of concrete [18]. Che Wan [19] determined that the incorporation of RHA as cement replacement significantly improved its resistance toward sodium sulfate. Ganesan *et al.* [20] and Raman *et al.* [21] revealed that the blending of RHA with cement resulted in approximately 35% decrease in water permeability, 28% reduction in chloride diffusion and 75% reduction in chloride permeation of concrete.

In foamed concrete, Kawabata [22] and Bayuaji [23] performed a series of experimental studies on the influence of RHA as cementitious base and cement replacement and confirmed that RHA was capable of enhancing the strength and workability of foamed concrete. RHA caused an increase in setting times, which improved the early strength of foamed concrete. However, replacing large volumes of cement with RHA would decrease its strength and workability. RHA tends to contribute up to 80% and above to the compressive strength of foamed concrete if the percentage replacement does not exceed 20% and is line with the proper mix proportion, water-cement (W/C) ratio and fineness of RHA.

Until recently, literature reviews on foamed concrete incorporating RHA as sand replacement have been very limited. Hadipramana *et al.* [24] investigated the utilization of RHA in foamed concrete as partial replacement for fine aggregate. Several mixes of RHA with different ratios and densities have been used and the results showed that 25% RHA yielded a higher value of compressive strength. This study suggested that the presence of RHA acts simultaneously as a pozzolanic reaction and a filler, thereby contributing to the good compressive and tensile strengths of foamed concrete. In contrast, Kunchariiyakun *et al.* [25] and Qu & Zhao [26] demonstrated that RHA from the burning process at 180 °C for 8 to 18 hours reduced compressive strength. However, in terms of the microstructure, the highly reactive silica in RHA had a significant effect on the tobermorite transformation.

3. Experimental study

3.1. Material preparation

Material preparation involved the provision of mix design and required quantity of cement, sand, RHA, water, pre-foamed+ foam agent and SP to produce high quality of foamed concrete. Two sets of mix design were considered. In Set 1, cement-sand (C/S) and W/C ratios were 0.50 and 0.55, respectively. The mix design for Set 2 used C/S ratio of 0.33 and W/C ratio of 0.60. The details of the required quantity of materials are specified in tables 1 and 2. In this experimental study, RHA was used as partial sand replacement at the range of 0% to 50%. RHA was obtained from controlled burning at 700 °C for 6 hours. The effects of W/C ratio, SP dosage and density were examined at the optimum RHA content for Set 1 only.

In this experimental study, foamed concrete was produced using pre-foaming method. Foam agent was diluted with water in an LCM foam generator and compressed to create the pre-formed foam. The pre-formed foam is a stable substance added to the foamed concrete mixture to produce air-void. The pre-formed foam functions as an expansion factor and as control for the desired density of foamed concrete. In general, pre-foaming method is better in producing foamed concrete because the pre-formed foam is in a liquid state and reacts effectively with the mixture. Foam agent Sika AER 50/50, which is a synthetic surfactant and polymer-based with brown colour and specific gravity of 1.01, was used with foam-cement (F/C) ratio of 0.07, while foam-water (F/W) ratio of 0.05 for Sets 1 and 2. The concentrated of foam agent with water was kept constant for all cube specimens. The stabilising component of the foam agent promotes uniformity of the air-void with even sizes and shapes.

Table 1. Quantity of foamed concrete for $1m^3$.

Material	Set 1 (kg)	Set 2 (kg)	Remarks
Cement	500	375	BS EN 197-1, Ordinary Portland Cement Type 1
Water	250	225	BS EN 1008:2002, water, free from any impurities
Foam agent	35	27	Sika AER 50/50, the ratio of foam to water is 0.05
SP	4	3	ESTOP Admix AP, consistence content along the mixing

Table 2. Quantity of sand and RHA in proportion to the volume fraction for $1m^3$.

Volume fraction of Sand (%)	Volume fraction of RHA (%)	Set 1		Set 2	
		Mass of Sand (kg)	Mass of RHA (kg)	Mass of Sand (kg)	Mass of RHA (kg)
100	0	920	-	1035	-
90	10	828	14	932	15.8
80	20	736	28	828	32
70	30	644	42	725	48
60	40	552	56	621	64
50	50	460	70	518	79

3.2. Specimen preparation

A total of 243 cube specimens were prepared using mould size of 100mm x 100mm x 100mm. Thus, 108 cube specimens were prepared for volume fraction of RHA (Set 1), while 135 cube specimens were prepared for the parametric investigations on W/C, SP dosage and density at the optimum RHA content (Set 2). The casting process was conducted in batches because the preparation involves a huge number of cube specimens. The cube specimens underwent air curing at 7, 14 and 28 days. In total, this experimental study consumed $0.243m^3$ foamed concrete.

3.3. Test programme

The test programme of the cube specimens involved a compression test, which was conducted according to BS EN12390-3:2009 [27]. Before the compression test, the cube specimens were visually inspected, labelled and sized. The cube specimens were also weighed to determine the density of foamed concrete. The compression test was performed using a calibrated Ele-Campact Machine 1500. Load increased continuously at a normal rate (0.14MPa/min to 0.34MPa/min) was applied to the cube specimens until failure.

4. Results and discussion

4.1. Compressive strength

The results of the compression test on cube specimens indicated the resulting compressive strengths of foamed concrete, which are shown in figures 1 and 2. Compressive strength was observed to increase slightly according to the volume fraction of RHA. Plain foamed concrete developed compressive strength at 12.5MPa and 15.1MPa for Set 1 and Set 2, respectively. The values are in accordance with that determined by the British Cement Association [28]. Jaini *et al.* [3] and Abd Rahman *et al.* [5]

showed that plain foamed concrete with W/C ratio of 0.55 and C/S ratio of 0.55 had compressive strength around 12MPa to 18MPa. Therefore, this experimental study successfully reproduced plain foamed concrete with appropriate compressive strength. Although the mix design has a significant role in producing good foamed concrete, the quality of pre-formed foam also contributed to the uniformity of air voids, which had a direct effect on compressive strength.

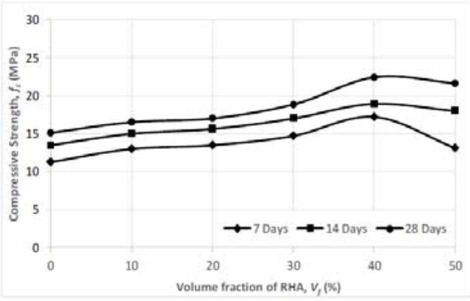

Figure 1. Compressive strength of foamed concrete for mix design Set 1.

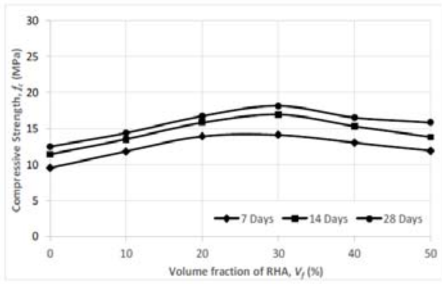

Figure 2. Compressive strength of foamed concrete for mix design Set 2.

Utilization of RHA as sand replacement in foamed concrete yielded significant improvement in compressive strength. Boost phenomenon on the compressive strength could be clearly observed for both sets. Foamed concrete in Set 1 had optimum RHA content at 40%, whereas Set 2 had 30% RHA. Compressive strength increased by up to 22.4MPa and 18.1MPa for Set 1 and Set 2, respectively. However, although the compressive strength increased the decay, the value obtained was still higher than plain foamed concrete. The addition of RHA resulted in higher compressive strength compared to plain foamed concrete by up to 48.34%, which also contributed to the satisfactory characteristic strength of the foamed concrete for the mixed design. If the density of foamed concrete is set at1800kg/m^3, the compressive strength will probably be higher than that obtained in this experiment.

The increase in compressive strength can be attributed to the pozzolanic reaction and the presence of reactive silica in RHA as reported by Rashid *et al.* [29]. The pozzolanic material also improved the impermeability of the foamed concrete, leading to higher durability against environmental exposures and chemical attacks. However, the presence of large RHA and coarse particles were found to delay the pozzolanic reaction, thereby resulting in lower compressive strength [30, 31]. Unlike its utilization as cement replacement that advantageously improved the workability of foamed concrete similar to the findings of Bayuaji [23], the workability of foamed concrete containing RHA as sand replacement indicated negative behaviour. Workability decreased as the volume fraction of RHA increased. Although the workability is not measured directly, it was also observed during the mixing process and specimen preparation.

4.2. Effect of water-cement ratio

The W/C ratio plays an important role in the mix design of foamed concrete and is the main factor affecting the performance of foamed concrete. W/C ratio is dependent purely on the cement content and other admixtures. Nambiar & Ramamurthy [32] reported that low water content caused the mixture to become too stiff and to have broken air-voids during the mixing process, which resulted in increased density. Similarly, at high water content, the mixture was too thin to hold the air-voids, causing segregation of the pre-formed foam and sand from the mixture, causing an increase in the density. The range of W/C ratio is within 0.40 to 1.25 [33]. However, the British Cement Association [28] suggested that the optimum W/C ratio should be limited to between 0.5 to 0.6 only. Moreover, high W/C ratio affected the porosity of foamed concrete, which also contributed to low compressive strength.

At 40% RHA, the amount of water needs to be high enough to maintain workability of the foamed concrete; however, increased water content has an adverse effect on compressive strength. In addition, cement and RHA would absorb water and cause rapid degeneration of pre-formed foam. Figure 3 shows the compressive strength of foamed concrete corresponding to W/C ratio. The increase in W/C ratio caused the compressive strength to decrease. However, the decrease was still too small at around 2.5% to 12% when evaluated based on W/C ratio of 0.50. At 28 days, only W/C ratios of 0.50, 0.55 and 0.60 achieved compressive strength equal or higher than 22MPa. The compressive strength of foamed concrete using W/C ratios of 0.50, 0.55, 0.60, 0.65 and 0.70 is 24.7MPa, 24.1MPa, 22.2MPa, 21.6MPa and 20.9MPa respectively. Blending during casting and drying shrinkage were observed in foamed concrete with W/C ratios of 0.65 and 0.70.

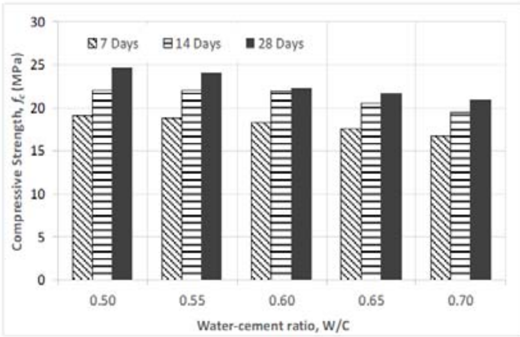

Figure 3. Compressive strength of foamed concrete due to water-cement ratio.

4.3. Effect of superplasticizer

The effect of SP was analyzed using the ratios of W/C and C/S at 0.55 and 0.50, respectively. At constant water content and 40% RHA, the dosage of SP was 0.4% to 0.8% of the cement content. The results of compressive strength could be attributed to the dosage of SP as shown in figure 4. The SP dosage had no effect on the compressive strength of foamed concrete instead it caused an increase in its workability. Basically, foamed concrete containing RHA requires higher water content than plain foamed concrete because of the higher specific surface area and higher carbon composition in RHA. In fact, RHA absorbs water during the mixing process. Increasing the volume fraction of RHA in foamed concrete requires more water, which in turn caused an increase in the SP dosage as the volume fraction of RHA increases. Hence, treating SP as a water reducing agent is important to ensure that the bond and stability in foamed concrete can be enhanced.

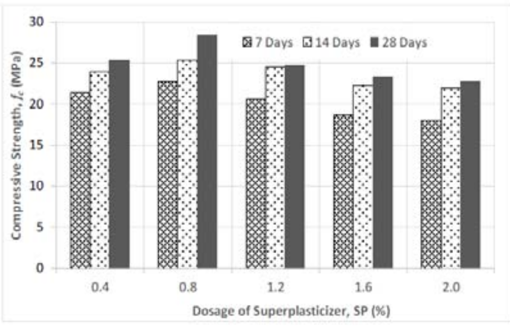

Figure 4. Compressive strength of foamed concrete due to dosage of SP.

However, it can be observed that 0.8% SP resulted in an improvement in compressive strength by approximately 24% as compared with foamed concrete with no SP. Increasing the dosage of SP at a constant volume fraction of RHA led to the decrease in compressive strength, which is a similar trend to that observed by Memon *et al.* [34]. The compressive strengths of foamed concrete containing 40% RHA + 0% SP is 17.2MPa, 18.9MPa and 22.4MPa at 7, 14 and 28 days. The addition of SP accelerated the early strength of foamed concrete. As a comparison, at 7 days, foamed concrete with 40% RHA + 0.8% SP surpassed the compressive strength of foamed concrete with 40% RHA + 0% SP. Foamed concrete with 40% RHA + 0.8% attained compressive strength of 22.8MPa, which is 32.5% above foamed concrete with 40% RHA + 0% SP. In the fresh mixture, no significant effect on segregation was observed at any dosage of SP.

4.4. Effect of density
Two density behaviours were observed in foamed concrete containing RHA as shown in figure 5. The first behaviour pertains to the effect of density due to the volume fraction of RHA. The density of foamed concrete was reduced with the increase in volume fraction of RHA. In Set 1, the density of foamed concrete with 0%, 10%, 20%, 30%, 40% and 50% RHA was $1800kg/m^3$, $1740kg/m^3$, $1717kg/m^3$, $1663kg/m^3$, $1633kg/m^3$ and $1600kg/m^3$, respectively. Sparse reduction was observed around 1.5% to 3.5%. Although the density decreased with the addition of RHA, the compressive strength significantly increased by 40% RHA. RHA is low in density, which can also be attributed to RHA having a filler effect with air-void in foamed concrete. As a comparison, the density of sand is $1380kg/m^3$ while RHA has density of $210kg/m^3$. If sand is replaced partially by 40% to 50% RHA, the decrease in density would be approximately 10% to 15%.

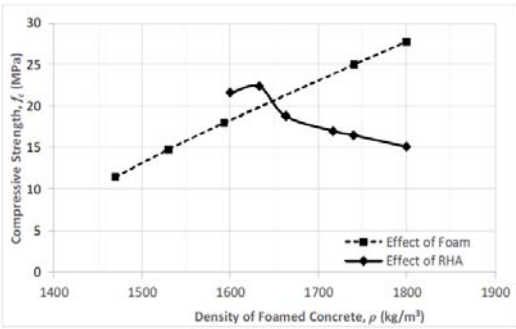

Figure 5. Density of foamed concrete due to the volume fraction of RHA and amount of preformed foam.

The second behaviour was observed from the effect of pre-formed foam in foamed concrete at 40% RHA. Adding a larger amount of pre-formed foam in foamed concrete contributed to higher porosity and larger air-void size. Therefore, ultimately, the density of the foamed concrete will be reduced, subsequently lessening its compressive strength. A pronounced relationship can observed between compressive strength, porosity and density. In this experimental study, the decrease in density caused the compressive strength to decrease linearly. At the same W/C ratio and volume fraction of RHA, the higher amount of pre-formed foam used, the higher the porosity and the lower the density. Narayanan & Ramamurthy [35] found that the main factor affecting the density of the foamed concrete is the pre-formed foam, which can be controlled to obtain the desired compressive strength.

5. Conclusion
An investigation on the effect of RHA as sand replacement in foamed concrete was conducted using two sets of W/C and C/S ratios. The results indicated that RHA had a significant effect on the compressive strength of foamed concrete. Increasing the volume fraction of RHA contributed the significant increments in compressive strength. However, the optimum RHA content depended on the W/C and C/S ratios. The highest value of compressive strength at 22.4MPa was obtained at 40% RHA, which is 48.34% higher than plain foamed concrete. The improvement on compressive strength of foamed concrete can be credited to the presence of pozzolanic material and reactive silica in RHA. In addition, RHA also acts as filler, which caused the foamed concrete to become denser. However, the presence of large volume fraction of RHA dramatically reduced compressive strength.

The effects of W/C ratio, SP dosage and density on the compressive strength of foamed concrete were also examined at 40% RHA. The W/C ratio was the main factor that influenced the compressive strength of foamed concrete. When W/C ratio was increased from 0.50 to 0.70, the compressive strength decreased at a limited rate from 2.5% to 12%. The results indicated that the W/C ratios of 0.50, 0.55 and 0.60 were the only ones suitable for use in foamed concrete incorporating RHA. The suitable SP dosage is 0.8% of the cement content, which increased the compressive strength to approximately 24% and improved the workability. An increase in SP dosage could result in unsatisfactory performance of the foamed concrete. The investigation on the effect of density indicated that presence of RHA contributed to the low density but high compressive strength. However, the portion of pre-formed foam significantly reduced density and compressive strength.

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