Strength and fracture energy of foamed concrete incorporating rice husk ash and polypropylene mega-mesh 55

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Abstract. This paper presents the utilization of rice husk ash (RHA) as sand replacement and polypropylene mega-mesh 55 (PMM) as fiber reinforcement in foamed concrete. High pozzolanic reaction and the ability to become filler make RHA as a strategic material to enhance the strength and durability of foamed concrete. Furthermore, the presence of PMM optimizes the toughness of foamed concrete in resisting shrinkage and cracking. In this experimental study, cube and cylinder specimens were prepared for the compression and splitting-tensile tests. Meanwhile, notched beam specimens were cast for the three-point bending test. It was found that 40% RHA and 9kg/m³ PMM contribute to the highest strength and fracture energy. The compressive, tensile and flexural strengths are 32MPa, 2.88MPa and 6.68MPa respectively, while the fracture energy achieves 42.19N/m. The results indicate high potential of RHA and PMM in enhancing the mechanical properties of foamed concrete.

1. Introduction

Nowadays, foamed concrete has received high demand in construction industry due to primary characteristics of versatility and lightness. As a lightweight material, foamed concrete has density in around 400kg/m³ to 1800kg/m³. However, foamed concrete possesses low compressive strength in the range of 10MPa to 15MPa [1, 2]. Meanwhile, the fracture energy can only reach up to 35N/m [3]. These drawbacks have limited the application of foamed concrete as bearing structural components. The minimum compressive strength that permitted by Eurocode 2 [4] for reinforced concrete structures is 22MPa. If foamed concrete is employed as composite structures, Rackham et al. [5] insisted that the compressive strength should achieve at least 28MPa. Therefore, there are huge attempts to improve the compressive strength of foamed concrete.

Various types of fibre such as polypropylene, steel, glass and polyvinyl [6-8] were used to improve the mechanical properties of foamed concrete. However, the modification of cementitious using fly ash (FA), palm oil fuel ash (POFA) and rice husk ash (RHA) showed the most favourable outcomes [9, 10]. Therefore, this study intends to utilize RHA and polypropylene mega-mesh 55 (PMM) to produce high-performance foamed concrete that can comply with the code of practise. More focus is given to investigate the effect of RHA and PMM on the strength and fracture energy of foamed concrete. The fascination toward green and sustainable construction material has prompted the use of RHA and PMM. The inspiration is to reduce environmental pollution, improve the quality of foamed concrete and reduce the cost of production, as well as become a novel solution of problems in agriculture-waste.
2. Experimental study

2.1. Material preparation
Material preparation involved the provision of mix design and required quantity of cement, sand, RHA, PMM, foam agent, water and admixture. Figure 1 shows the RHA and PMM as main materials in foamed concrete. The ratios of cement-sand and water-cement are 0.50 and 0.55 respectively. In Stage 1, RHA was used as partially replacement of sand at the range of 0% to 50%. In Stage 2, the optimum contain of RHA and PMM with dosage up to 12kg/m$^3$ were utilized in foamed concrete. RHA was obtained from the combustion process at 700°C for 6 hours. The chemical composition of RHA consists of 89.90% SiO$_2$ which is highly amorphous silica. The pre-forming method was used in the production of foamed concrete. Foam agent of synthetic-based Sika AER 50/50 was diluted with water using concentration ratio of 0.05.

![RHA](image1.jpg)
![PMM](image2.jpg)

**Figure 1.** Main materials in foamed concrete: a) rice husk ash (RHA), and b) polypropylene mega-mesh 55 (PMM).

2.2. Specimen preparation
In Stage 1, a total 45 cube specimens were moulded using size of 100mm length, 100mm width and 100mm depth. Meanwhile, Stage 2 requires 45 cube specimens, 45 cylinder specimens and 10 notched beam specimens. The cylinder specimens were prepared based on size of 350mm depth and 150mm diameter. The notched beam specimens were fabricated with size of 500mm length, 100mm width, 100mm depth and 30mm V-notch depth. The cube and cylinder specimens were underwent air curing for 7, 14 and 28 days. On the other hand, the notched beam specimens were placed at the ambient condition for 28 days.

2.3. Test programme
The compression test on cube specimens was conducted according to BS EN12390-3:2009. On the other hand, BS EN12390-6:2001 was referred for the splitting-tensile test to obtain the tensile strength of foamed concrete. Both compression and splitting-tensile tests were performed using Ele Compact Machine 1500 as can be seen in figure 2. Before the tests, the cube and cylinder specimens were visually inspected, labelled, sized and weighted. The three-point bending test was conducted on the notched beam specimens to determine the flexural strength and fracture energy. The three-point bending test, as shown in figure 3, was equipped with load cell, LVDT and CMOD gauge to capture the load, deflection and crack width respectively.

3. Results and discussion

3.1. Compressive strength
Figure 4 shows the compressive strength of foamed concrete containing RHA. Plain foamed concrete accomplishes the compressive strength of 15.1MPa. The value complies with that determined by Jaini et al. [1] and Abd Rahman et al. [3], where plain foamed concrete with similar mix design has compressive strength around 12MPa to 18MPa. The utilization of RHA as sand replacement indicates...
a statistically significant improvement. At the optimum contain of 40% RHA, the compressive strength increased by up 48% compared to plain foamed concrete. However, the presence of large portion RHA was found to delay the pozzolanic reaction, thereby contributes to the adverse effect.

On the other hand, figure 5 shows the compressive strength of foamed concrete containing 40% RHA and PMM. There is an apparent effect on the compressive strength, where incorporating 9kg/m$^3$ PMM lead to the increment of 30%. This improvement occurs due to the confinement provided by PMM which increases the bonding of foamed concrete. However, higher dosage of PMM decreases the compressive strength due to interfering in cohesiveness of foamed concrete. It was observed that the good binder composition gave high influence to the compressive strength. In addition, PMM also acts as filler that reduce the volume fraction of air-void and subsequently provides an intact condition.

### 3.2. Tensile strength

The tensile strength obtained from splitting-tensile test is shown in figure 6. It can be confirmed that the tensile strength increases due to the dosage of PMM. The optimum dosage is 9kg/m$^3$ that led to the tensile strength of 2.87MPa. It is a very significant increment around 44% compared to foamed concrete containing RHA only. On the other hand, the relationship between compressive strength ($f_c$) with tensile strength ($f_t$) is shown in figure 7, which can also be expressed as:

$$f_t = 0.034 f_c^{1.27}$$  \hspace{1cm} (1)
3.3. Flexural strength
The flexural strength was determined using an empirical formulation as depicted in equation (2):

\[ f_f = \frac{3P_{\text{max}}S}{2B(W - a_o)^2} \]  

(2)

where \( P_{\text{max}} \) is the maximum load while \( S, B \) and \( W \) are the span, width and depth of specimen respectively and \( a_o \) is the notch depth. Table 1 shows the flexural strength of foamed concrete containing RHA and PMM. The presence of PMM resembles significant resistance against the propagation of cracks. In addition, PMM reduces stress concentration accumulated around the cracks. The flexural strength is effectively increased by incorporating 9kg/m\(^3\) PMM, where it conceded 6.68MPa that correspond to the increment of 40%. However, the flexural strength decreases at dosage of 12kg/m\(^3\), a similar condition that was observed on the compressive and tensile strengths.

| Dosage of PMM (kg/m\(^3\)) | \( P_{\text{max}} \) (kN) | \( f_f \) (MPa) |
|-----------------------------|----------------|----------|
| 0                           | 5.08           | 4.76     |
| 3                           | 6.24           | 5.85     |
| 6                           | 6.52           | 6.12     |
| 9                           | 7.12           | 6.68     |
| 12                          | 6.80           | 6.38     |

3.4. Fracture energy
The Hillerborg model as formulated in equation (3) was used to calculate the fracture energy of foamed concrete containing RHA and PMM.

\[ G_f = \frac{U_o + m_s d_o}{B(W - a_o)} \]  

(3)

where \( U_o \) is the area of softening phase from load-deflection curve, \( m_s \) is mass of specimen, \( d_o \) is the fracture deflection, \( a_o \) is the notch depth, \( B \) is span of specimen and \( W \) is thickness of specimen. Table 1 shows the fracture energy of foamed concrete incorporating RHA and PMM. A comparison with Bazant model shows favourable agreement. The presence of RHA and PMM have tendency to increase fracture energy up to 42.19N/m, where the dosage of 9kg/m\(^3\) at 40% RHA contributes to the highest value. It is improved approximately 35% above foamed concrete with 40% RHA, but higher 65% than plain foamed concrete.
Table 2. Fracture energy of foamed concrete incorporating RHA and PMM.

| Dosage of PMM (kg/m$^3$) | $U_o$ (Nm) | $d_o$ (m) | $G_f$ (N/m) |
|---------------------------|-------------|-----------|-------------|
|                           |             |           | Hillerborg  | Bazant      |
| 0                         | 4.117       | 2.171     | 31.33       | 35.32       |
| 3                         | 16.505      | 1.686     | 39.96       | 37.01       |
| 6                         | 26.831      | 0.738     | 41.01       | 38.44       |
| 9                         | 18.033      | 1.548     | 42.19       | 39.18       |
| 12                        | 4.167       | 2.220     | 35.90       | 35.99       |

4. Conclusions
The investigation on the compressive, tensile and flexural strengths as well as the fracture energy of foamed concrete containing RHA and PPM were conducted by using the compression, splitting-tensile and three-point bending tests. The results indicate that RHA and PPM greatly improve the mechanical properties of foamed concrete. The addition of 40% RHA in foamed concrete contributes to the enhancement of compressive strength around 48%. Moreover, the utilization of 40% RHA and 9kg/m$^3$ PPM increase the compressive, tensile and flexural strength around 30% to 40% while the fracture energy improve around 35%. However, the presence of large volume fraction of RHA and dosage of PPM dramatically reduce the strength and fracture energy of foamed concrete.

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