Partially Replacement of Cement By Sawdust And Fly Ash in Lightweight Foam Concrete

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Abstract. The rapid growth of population has led to increased demand for fast, affordable and quality housing development. Today, the construction industry in Malaysia has shifted from conventional methods to Industrial Building Systems (IBS). The most commonly used IBS component is precast concrete with lightweight foam concrete. This study focuses on the main component of foam lightweight concrete, which is a partially replacement of cement by sawdust and fly ash. Among the features of lightweight concrete is density below 1800 kg/m\textsuperscript{3}. Therefore, the objectives of this study is to determine the effects of sawdust and fly ash as part of cement replacement in terms of mechanical properties (compressive strength) and physical properties (water absorption). In addition, this study also determine the optimum percentage of cement replacement by sawdust and fly ash in building material. The percentage of saw dust and fly ash used in this study as a partial replacement cement are 5\%, 10\%, 15\% and 20\%. The results show that increasing the percentage of mix proportion will increase the water absorption rate as well as decrease the compressive strength of strength. Also, the density and compressive strength of lightweight foam concrete will decrease as the percentage of partial replacement cement increases. According to JKR Standard Specification for Building Works that referred in Malaysia, the minimum compression strength of lightweight foam concrete allowed for hollow blocks is 2.8 N / mm\textsuperscript{2}. The results obtained from this study show lightweight concrete blocks using saw dust and fly ash as part of the cement replacement meet the standards and can be commercialized in the industrial building system development.

1. Introduction
Lightweight concrete is a type of concrete made up of Ordinary Portland Cement, sand, water and voids. The voids are usually imported into the system by adding the suitable foaming agent to the water at the required ratio in a foam generator to produce manufactured foam [1]. Lightweight concrete which density between 400 kg/m\textsuperscript{3} and 1850 kg/m\textsuperscript{3} with high flowability, low cement usage, low aggregate usage and good thermal insulation [2]. The foaming agent can be used with all types of OPC and blended into cement only, or sand-cement mortar slurries to produce foamed concrete when used it. There are two types of foaming agents that can be added into the mix design which categorized into the protein-based foaming agents and synthetic foaming agents. Protein-based foaming agents can be obtained from animal proteins out of the horn, blood, bones of cows, pigs and other remainders of
animal carcasses [3]. Besides that, synthetic foaming agents are made up of purely chemical products. Synthetic foaming agent which is used widely in the world due to its easier production and availability in every country [4]. It has permanent properties and working life much longer compared to a protein-based foaming agent [5, 6]. The synthetic foaming agent is very stable at concrete with densities above 1000 kg/m³ and it can give more strength to the concrete [7]. In addition, sawdust is produced during sawing of logs of timber into different sizes like a small irregular shape or small fragments of wood [8]. Sawdust has many advantages such as low bulk density, improved in heat preservation and heat insulation property, and reduce the pollution to the environmental [9]. Therefore, sawdust has been identified as one type of suitable filler material in which the industry can be used to produce hollow concrete blocks [9, 10]. Another material is fly ash as a type of waste produced by burning coal in an electrical generating station. It can help to improve workability, reduce permeability, and increase the ultimate strength. It also reduced bleeding, had a better surface and reduced heat of hydration [11]. The suitable replacement in the construction of new road networks was by applied the usage of brown coal fly ash [12].

2. Experimental Procedure

2.1 Raw Material
Sawdust used in this research was collected from the wood factory around the Kangar and Kaki Bukit, Perlis, Malaysia. The collected sawdust was put into the furnace for 1 hour at 600°C [13]. Next, the burnt sawdust ash was cooled under normal conditions for 24 hours. After that, the sawdust ash was ground into powder form by using mortar. The ground sawdust ash was sieved through 600 μm sieve (sieve no. 30). The foaming agent is formed through the Sodium Lauryl Sulphate (SLS) along with Sodium hydroxide (NaOH) at an SLS concentration of 2.5% (the ratio of SLS to water is 1:40 by volume) and NaOH concentration of 4% (the ratio of NaOH to water is 1:25 by volume) with a pressure of 130 KPa. The foam is generated by using a foam generator [14].

2.2 Mix Design and Process
Three types of materials will be mixed, which are cement together with 5%, 10%, 15% and 20% combination of sawdust and fly ash as a partial cement replacement material, sand as fine aggregate and water. The water to solid ratio used in the trial was fixed at 0.38. Besides that, the amount of foam used was fixed at 10 kg/m³. In addition, for the concrete mixing process the amount of Ordinary Portland Cement (OPC), sand, sawdust and fly ash were weighted according to the trail mix. All the weighted materials are poured into a mixing pot for mixing until evenly mixed. After that, the water was weighed and added into the dry mix slowly. At the same time, the foam was generated by using the foam generator. The foam was then weighted and added into the wet mix. The wet mix was mixed until it was uniformly mixed. Then, the inverted slump test will be carried out to determine the properties of lightweight concrete. Lastly, the fresh concrete mixes and poured into the mold for casting.

2.3 Testing and Analyzing
The fresh density test was carried out based on ASTM C796 (2004) [19] to ensure the densities of lightweight concrete is below 1800 kg/m³. The inverted slump test was carried out to determine its workability per ASTM C1611 (2005) [20]. As complied with BS 1881-116 (1983) [21], the compressive strength test was conducted by using the Compressive Strength Testing Machine. The load is applied continuously at a constant rate within the range 0.2 N/(mm²·s) to 0.4 N/(mm²·s) until the specimen failed. A water absorption test was carried out in this research to calculate the water absorption capacity of hardened lightweight concrete in accordance with BS 1881-122 (1983) [22].
3. Results and Discussion

3.1 Fresh Density Test

Fresh density test is one of the tests which can be used to determine the unit weight of the concrete admixture before it is casting. The density of lightweight concrete is below 1800 kg/m3. Table 1 to Table 4 shows the differences between fresh densities of various concrete samples before and after adding the foam were in the range of ± 50 kg/m3. The decrease of the densities can be due to the foam volume as it will increase the voids inside the concrete [6, 15]. The manufacturing of foamed concrete which had been done in the industry was controlled in the range of ± 50 kg/m3 [16].

| Table 1. The fresh density test for 5% of cement replacement. |
|---------------------------------------------------------------|
| Description                      | Density of sample (kg/m³) |
| Before adding foam              | 1755 1705 1710 1690 1700 1725 |
| After adding foam               | 1725 1730 1750 1720 1650 1690 |
| Differences                     | -30   25   40   30   -50   -35 |

| Table 2. The fresh density test for 10% of cement replacement. |
|---------------------------------------------------------------|
| Description                      | Density of sample (kg/m³) |
| Before adding foam              | 1570 1590 1575 1605 1610 1620 |
| After adding foam               | 1605 1620 1605 1580 1580 1590 |
| Differences                     | 35    30   30   -25  -30   -30 |

| Table 3. The fresh density test for 15% of cement replacement. |
|---------------------------------------------------------------|
| Description                      | Density of sample (kg/m³) |
| Before adding foam              | 1520 1480 1470 1450 1490 1500 |
| After adding foam               | 1480 1530 1510 1490 1475 1465 |
| Differences                     | -40   50   40   40   -15   -45 |

| Table 4. The fresh density test for 20% of cement replacement. |
|---------------------------------------------------------------|
| Description                      | Density of sample (kg/m³) |
| Before adding foam              | 1370 1320 1330 1375 1390 1310 |
| After adding foam               | 1350 1370 1380 1320 1340 1340 |
| Differences                     | -20   50   50   -45  -50   30  |

3.2 Slump Value

The slump test value must be between 500mm to 700mm for self-consolidating concrete [15]. The slump test value obtained for 5%, 10%, 15% and 20% of cement replacement were over 500mm which can be categorized as self-consolidating concrete. Table 5 shows the slump test value for each percentage of cement replacement of the sample.
Table 5. Slump test value for each percentage of cement replacement.

| Percentage of cement replacement (%) | Slump test value (mm) |
|--------------------------------------|-----------------------|
| 5                                    | 520                   |
| 10                                   | 510                   |
| 15                                   | 525                   |

3.3 Density and Compressive Strength

28 days compressive strength of each percentage of cement replacement of the samples were studied in order to determine its suitability to be used as a building material. The density of the lightweight concrete is decreased when the percentage of cement replacement is increased as shown in Figure 1. This is because the density of sawdust and fly ash used to replace cement reduced the overall density of the lightweight concrete [16]. In addition, the decrease in density will also decrease the compressive strength. Based on British Concrete Association (BCA), the dry density of 1600 kg/m³ of foamed concrete will have compressive strength between 7.5 – 10.0 N/mm². Based on Figure 1 and Figure 2, 5% of cement replacement achieved the highest compressive strength as compared with others for 28 days of age and had achieved the standard set by BCA. The compressive strength is decreasing linearly when the cement replacement is increasing. For the sample of 10%, and 15% cement replacement by sawdust and fly ash, the compressive strength set by the BCA should be at the range between 6.0 – 8.0 N/mm². The result obtained was in the range of the standard by BCA. In addition, the compressive strength for the sample of 20% cement replacement by sawdust and fly ash had achieved the BCA as the average density is 1341.7 kg/m³. As BCA standard of compressive strength for density between 1200 kg/m³ to 1400 kg/m³ was 4.5 – 5.5 N/mm².

Figure 1. The density of the each percentage of cement replacement of the samples at 28 days.

Figure 2. Compressive strength of each percentage of cement replacement of the samples at 28 days.
3.4 Water Absorption
Water absorption is a test that can be classifying the durability of the concrete. Normally, concrete with low water absorption was better as it can protect the reinforcement within the concrete. Based on Figure 3 and Figure 4, the water absorption increases when the weight of the concrete becomes lighter. The concrete with lower density can produce large amount of air voids between them. The air voids can be filled up with the water which causes high water absorption. Besides that, the higher percentage of cement replacement had a significant increase in the percentage of water absorption. The percentage of water absorption was high can be caused by the total voids distributed inside the sample that had been increased due to the replacement cement by sawdust and fly ash [17]. In addition, the maximum water absorption for reinforced masonry units under category lightweight concrete is 288 kg/m³ which is stated in the ASTM (C90-01) [23]. Based on the result obtained, the concrete with 20% cement replacement is not suitable to be used as masonry units as the water absorption is more than 288 kg/m³.

![Figure 3. Density of the samples with different percentage of cement replacement.](image1)

![Figure 4. Water absorption of the samples with different percentage of cement replacement.](image2)

3.5 Application as Building Material
The eco-friendly building material had a high demand in the market to reduce environmental issues. Based on the result obtained the sample with 5%, 10% and 15% of cement replacement by sawdust and fly ash can be chosen to be used as a building material. This is because of the compressive strength of 5%, 10%, and 15% had achieved the requirement with an acceptable range of water absorption. The density between 1600 kg/m³ and 1800 kg/m³ was recommended to be used as slabs...
In addition, the concrete sample with 15% cement replacement can be used as housing applications.

4. Conclusions
The density of lightweight concrete will affect the compressive strength. The highest compressive strength of lightweight concrete with partially cement replacement is at 5%. The water absorption for the sample 5%, 10% and 15% of cement replacement was accepted in the range of water absorption which was 288 kg/m³. Furthermore, 5%, 10% and 15% cement replacement by sawdust and fly ash can be used as building material such as slabs and housing applications.

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