The Effect of FRCA and WPSA on the Strength Properties of Foamed Concrete

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ABSTRACT

In view of the escalating environmental problems faced in this millennium with consideration to the rapid depletion of natural resources, the use of by-products or waste materials from different industries are highly desirable. One such alternative is waste paper sludge ash (WPSA), a local by-product produced abundantly by the paper newsprint industry. It has been observed through previous studies that WPSA possesses pozzolanic characteristics in enhancing concrete properties. On the other hand, progressive development in the construction sector recently has contributed as the main producer of construction wastes, particularly concrete wastes. Therefore, the present paper investigates the strength development of lightweight foamed concrete produced with various replacements level of WPSA and ultrafine recycled concrete aggregate (FRCA) to the cement and sand content respectively. The cube specimens were casted in size 100 mm x 100 mm x 100 mm and water cured. The compressive strengths were evaluated at 3, 7, 28 and 60 days. The results of this study showed that the inclusion of WPSA and FRCA have significant influence on the development of strength properties of foamed concrete.

Keyword: waste materials, waste paper sludge ash, ultrafine recycled concrete aggregate, foamed concrete, compressive strengths

INTRODUCTION

Concrete is one of the oldest manufactured construction material that most widely used in construction sectors all over the world until today. Recently, tremendous research in area of concrete technology has contributed in production of various types of concrete to fulfill the current construction demand for better concrete performance which are high strength, lightweight, high toughness, durable and others. Consequently, one of the concrete that having unique characteristics and becoming famous in the modern era is foamed concrete due to it's lightness and versatility. This innovative lightweight concrete is produced in numerous established methods for the use of construction application in many countries.

Foamed concrete is basically envisaged as an insulation material because of its low weight (Jones & McCarthy, 2005a). However, there has been renewed interest in view of its savings in material and possibility for utilization of wastes (Lee & Hung, 2005). Various types of wastes or industrial by-product with recycled materials are potential use in foamed concrete becomes an increasingly attractive option in order to leave an enormous environmental footprint on Planet Earth which associated with carbon dioxide emission and wastes disposal problem. Furthermore, the world's yearly consumption of Portland cement rose from 2 million to 1.3 billion tons, where for every one ton of cement produced, 1 to 1.25 ton of CO_2 is released into the atmosphere with 4GJ energy per tone is required (Habeeb & Mahmud, 2009; Malhotra, 1998, 2002). In addition, in manufacturing one ton of cement, 1.6 tons of natural resources are consumed such as limestone, clay, and coal, results in extensive deforestation and top-soil loss.

Currently, the use of replacement materials in Portland cement has attracted much attention. Numerous papers have been proven the applications of wastes and supplementary cementing materials such as fly ash, ground granulated blast furnace slag (GGBS), silica fume (SF), and palm oil fuel ash (POFA) as partial cement replacement are appropriated for foamed concrete construction because of its pozzolanic nature. In blended cements, the replacement material may take part in the hydration reactions and contributed in hydration product (CH) (Nuruddin & Bayuaji, 2009). In recent years, a few research efforts have been conducted on using waste paper sludge ash (WPSA) as a cementing material. From Malaysia situation, the disposal of WPSA in landfill is about 80 tons per day. Concern for this environmental issue, successful use of WPSA to partially replace cement has been extensively demonstrated as an alternative way for disposing of waste material and provides a valuable resource for concrete production.

On the other hand, foamed concrete is considered as a cost effective mix by maximising the fine aggregate content in its production. The strength development of foamed concrete is mainly dependent on the amount of fine aggregate instead of other parameters such as water-cement ratios and curing regimes (Hamidah, Azmi, Ruslan, & Kartini, 2005). Thus, with the tremendous utilization of fine aggregate in concrete industry, hence the need for alternative aggregate namely ultrafine recycled concrete aggregate in foamed concrete. In Malaysia, along with the growth in population and urbanization, huge amount of wastes concrete are being generated widely. Previous study reported that the waste concrete has amounted to 239 million tones in 2010 and 638 million tones in 2020. Therefore, recycling these wastes has good potential to replace virgin aggregate and environmental benefits related to the scarcity of land disposal. Moreover, at present, natural aggregate deposits have already been depleted in many areas leads exhausted of aggregate in future. In this paper, an investigation is carried out to understand the impact of ultrafine recycled concrete aggregate and waste paper sludge ash on the strength characteristics of foamed concrete.

EXPERIMENTAL PROGRAMME

Preparation of Materials

The constituent materials used in the laboratory to produce foamed concrete comprised of cement (Ordinary Portland Cement) in accordance with BS EN 197-2000, fine aggregate, ultrafine recycled concrete aggregate (FRCA), waste paper sludge ash (WPSA), free water, and foaming agent. FRCA was obtained from crushing waste concrete in the form of concrete cubes by using jaw crusher. The crushed concrete was than sieve into single size fraction of FRCA. The grading of fine aggregate and FRCA are illustrated in Fig. 1 with the fineness modulus of 2.20% and 2.50% respectively. WPSA was collected from Malaysian Newsprint Industries, Pahang. The foaming agent used was synthetic-based for the production of the preformed foam concrete. The chemical properties of OPC and WPSA used are shown in Table 1. The fineness of WPSA obtained based on percentage retained on 90µm sieve was about 5.4%.

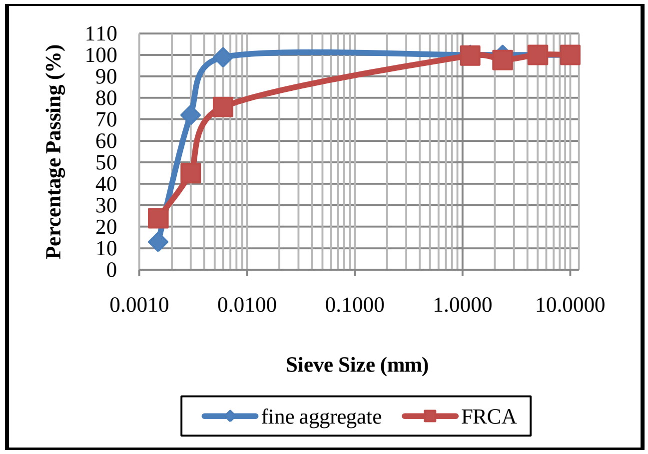

Figure 1. Particle size distribution of fine aggregate and FRCA

Table 1. Chemical Properties of OPC and WPSA

Chemical Properties	Contents (%)	
	OPC	WPSA
Silicon dioxide (SiO_2)	15.05	15.16
Aluminium oxide (Al_2O_3)	2.56	6.06
Ferric oxide (Fe_2O_3)	4.00	1.11
Titanium oxide (TiO_2)	0.12	0.45
Magnesium oxide (MgO)	1.27	2.00
Calcium oxide (CaO)	72.17	55.87
Sodium oxide (Na_2O)	0.08	0.19
Pottasium oxide (K_2O)	0.41	0.34
Phosphorous oxide (P_2O_5)	0.06	0.48
Manganese oxide (MnO)	0.06	0.05
Sulphur trioxide (SO_3)	2.90	0.78
Loss of Ignition (LOI)	1.33	17.51
Specific gravity	3.1	1.9

Mix Proportion

In this present research, the density of foamed concrete which is 1400 kg/m^3 was prepared. For this density, waste paper sludge ash (WPSA) at different replacement levels of 0%, 10%, 20% and 30% of cement replacement by mass was adopted. Additionally, 0%, 5%, 10%, and 15%

replacement of the ultrafine recycled concrete aggregates (FRCA) to fine aggregate was incorporated. A series of mixes were designated as shown in Table 2. The sand-cement (S/C) and water-cement/binder ratios were kept constant for all mixes at 0.7 and 0.6 respectively. The concrete specimens size of 100 mm x 100 mm x 100 mm was prepared and tested for 3, 7, 28 and 60 days of water curing. Table 2 summarized the detail of mix proportions of samples employed.

Table 2. Mix Proportions of Foamed Concrete

Mix Designation	Cement (kg/m^3)	WPSA (kg/m^3)	Fine Aggregates (kg/m^3)	FRCA (kg/m^3)	Water (kg/m^3)	Foaming Agent (Litre/m^3)
Control	454	-	681	-	273	330
5FRCA	454	-	657	23	273	330
10FRCA	454	-	634	46	273	330
15FRCA	454	-	606	74	273	330
Control (10WPSA)	408	45	681	-	273	320
10WPSA/5FRCA	408	45	657	23	273	320
10WPSA/10FRCA	408	45	634	46	273	320
10WPSA/15FRCA	408	45	606	74	273	320
Control (20WPSA)	363	91	681	-	273	310
20WPSA/5FRCA	363	91	657	23	273	310
20WPSA/10FRCA	363	91	634	46	273	310
20WPSA/15FRCA	363	91	606	74	273	310
Control (30WPSA)	318	136	681	-	273	300
30WPSA/5FRCA	318	136	657	23	273	300
30WPSA/10FRCA	318	136	634	46	273	300
30WPSA/15FRCA	318	136	606	74	273	300

Casting and Preparation of Foamed Concrete Specimens

The preparation of foamed concrete can be divided into four (4) steps include preparation of mortar mix, preparation of foam, production of foamed concrete and finally, determination of foamed concrete density. The density of the mortar was determined prior the inclusion of the foam. Obviously, a tolerance on plastic density was set about ±50kg/m^3 of the target density, which is typical of the tolerance used by industry for foamed concrete production (Jones & McCarthy, 2005b, 2006; Kearsley & Mostert, 2005). If the density was higher, additional foam was prepared until the acceptable density was achieved. The foamed concrete was sampled as described in BS EN 12350-1: 2009. The foam added in the present study was generated by foaming machine, namely Portafoam.

Testing

The compressive strength was determined from 100 mm cube samples accordance to BS EN 12390-3: 2009 by using Compression Auto Test machine. The cubes were cast in steel moulds, demoulded after 24hr and cured in water up to the day of testing. The compressive strength was recorded from the average of three cubes. The strength properties of the cube specimens were evaluated at 3, 7, 28 and 60 days of age.

RESULT AND DISCUSSION

Effect of WPSA on the Compressive Strength Performance

The compressive strength of paste mixtures containing different percentages of waste paper sludge ash (WPSA) is plotted as a function of time in Fig. 2. In line with normal concrete, the replacement of Portland cement with WPSA has a significant influence on the compressive strength of foamed concrete. As can be seen from Fig. 2, the compressive strength of all mixes increases with age. Generally, Fig. 2 reveals that increase in the level of WPSA replacements contribute to the reduction of compressive strength in foamed concrete. However, it can be observed that 30% replacement of WPSA achieved strengths greater than that of the control mix at 28 days by the value of 6.83 N/mm^2. This pattern is increased up to 60 days with 6.91 N/mm^2 which is relatively close to the compressive strength obtained by the mix without WPSA. On the other hand, it can be seems that the addition levels of WPSA by 10%, 20% and 30% replacement of cement, showing the effectiveness WPSA in enhancing compressive strength in foamed concrete. Furthermore, this present study is broadly followed the research carried out by Kearsley and Wainwright that the maximum percentage of cement content which can be replaced using ash was limited to 30%.

Regardless of obtaining the increment of compressive strength by the increasing of percentages of WPSA, but most of the trends still lower compared to the reference mix. The reduction of compressive strength by 10% incorporation of WPSA in comparison with reference mix are 2.75 N/mm^2, 3.5 N/mm^2, 4.83 N/mm^2 and 5.5 N/mm^2 for 3, 7, 28 and 60 days respectively. Besides that, for the 20% replacement of WPSA indicated the values of 3.52 N/mm^2, 4.26 N/mm^2, 5.96 N/mm^2 and 6.35 N/mm^2. Moreover, for the 30% combination of WPSA obtained the data of 3.01 N/mm^2, 4.57 N/mm^2, 6.83 N/mm^2 and 6.91 N/mm^2 throughout the period. This results are reasonable according to Massazza, stated that too much pozzolana content decreases compressive strength at all ages. Besides that, WPSA composed of high carbon content which is indicated by loss of ignition (LOI) with 17.51% compared to cement by the value of 1.33%. On that matter, the carbon content is absorbed water lead to reduction of water demand in the process of hydration. Moreover, the presence of carbon in WPSA has high porosity and a very large specific surface (Wesche, 1991). Hence, the inclusion of WPSA by cement replacement in percentages is clearly found to result a reduction on the compressive strength.

Base on the compressive strength achieved from the Fig. 2, this situation can be attributed to the fact that the compressive strength gain at early ages was in part due to the slightly hydration in cement, since the introduction of WPSA is decreased the cement content . In addition, retardation of compressive strength is observed to the presence of dilution of cement with WPSA lead the establishment of slower reactions in foamed concrete production. At this situation, the dilution of cement contributed in reducing Ca^{2+} concentration in the solution, hence delaying the CH and CSH crystallization (Jones & McCarthy, 2006). Meanwhile, the later development of compressive strength is mainly resulted of pozzolanic reaction, causing replacing large amount of calcium hydroxide that did not have cementitious properties with calcium silicate hydrate as a binder (Kearsley and Wainwright).

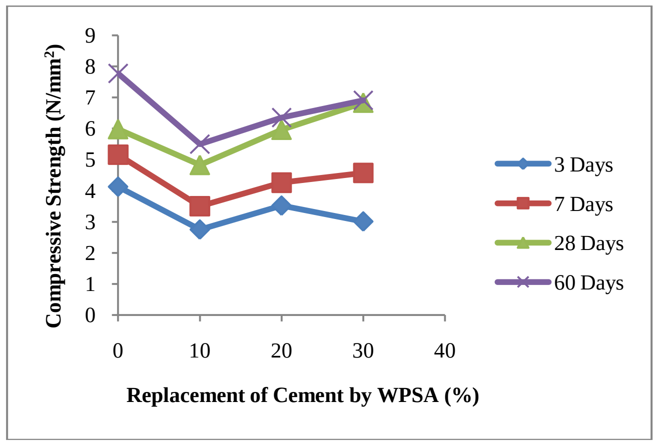

Figure 2. Effect of WPSA Content on Compressive Strength of Foamed Concrete at 3, 7, 28 and 60 days

Effect of FRCA on the Compressive Strength Performance

The effect of different percentages of ultrafine recycled concrete aggregate (FRCA) to the fine aggregate content on the compressive strength of foamed concrete is recorded in Fig. 3. From the figure, it can be highlighted that the higher replacement levels of FRCA, the compressive strength reduced accordingly. However, 5% of the samples employed gave higher compressive strength compared than control samples by 5.05 N/mm^2, 5.52 N/mm^2, 8.12 N/mm^2 and 10.56 N/mm^2. In contrast, 15% incorporation of FRCA is observed to result the lowest value which were 2.86 N/mm^2, 3.12 N/mm^2, 5.32 N/mm^2 and 5.78 N/mm^2 through out the period. This trend is also followed by the 10% replacement of FRCA which indicated no significant difference between both of these mixes. From the obtained results, the retardation of compressive strength with FRCA is true according to the research conducted by other authors, found that compressive strength gradually decreases as the amount of FRCA increases (Obla, Kim, &

Lobo, 2007). As can be seen in figure, there was slightly different between the compressive strength induced by FRCA with 10% and control mix at 60 days is 7.06 N/mm^2 and 7.77 N/mm^2 respectively.

In addition, a graphical representation of reduction in compressive strength with 10% and 15% of FRCA employed was might be due to the presence of a large volume fraction of porosity governed by FRCA that affected water demand in producing the product of cement hydration. Hence, higher addition of FRCA into foamed concrete lead to higher water absorption. Furthermore, higher absorption rate indicates the higher quantity of old cement mortar adhering to the virgin aggregate particles in the original concrete. Besides that, the maximum compressive strength that illustrated by the figure was 10.56 N/mm^2 when incorporation 5% of FRCA into foamed concrete. This situation has confirmed by the another researcher that the replacement levels of FRCA was suggested remain at or below 30% of fine aggregates content (Obla, et al., 2007). Meanwhile, other study reported that the use of FRCA does not influence the mechanical properties of concrete for substitution ratios up to 30% (Evangelista & Brito, 2007).

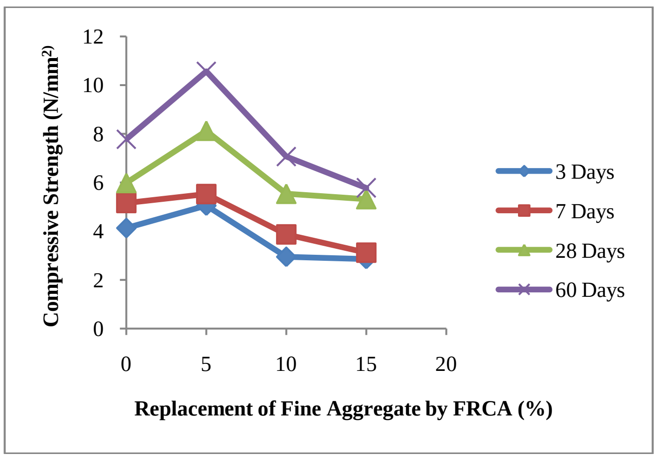

Figure 3. Effect of FRCA Content on Compressive Strength of Foamed Concrete at 3, 7, 28 and 60 days

Effect of Combinations of WPSA and FRCA on the Compressive Strength Performance

The compressive strength of foamed concrete containing different percentages of waste paper sludge ash (WPSA) with 0%, 10%, 20% and 30% incorporation of ultrafine concrete aggregate (FRCA) by 0%, 5%, 10% and 15% to cement and fine aggregate content respectively is described in Fig. 4. It can be illustrated from Fig. 4, the effect of the combination of WPSA and FRCA on the compressive strength is presented a quite similar trend in which 20% of WPSA incorporation 15% of FRCA replacement give the maximum compressive strength at 28 and 60 days compared to the control mix (without FRCA). The results obtained exhibit higher the incorporation of WPSA and FRCA into foamed concrete can be improved the compressive strength development. In addition, this condition is might be influenced by the presence of the old cement mortar attached to FRCA. It is reasonable to realize that FRCA have high level of cement that can increase the total amount of cement in the foamed concrete mix (Evangelista & Brito, 2007).

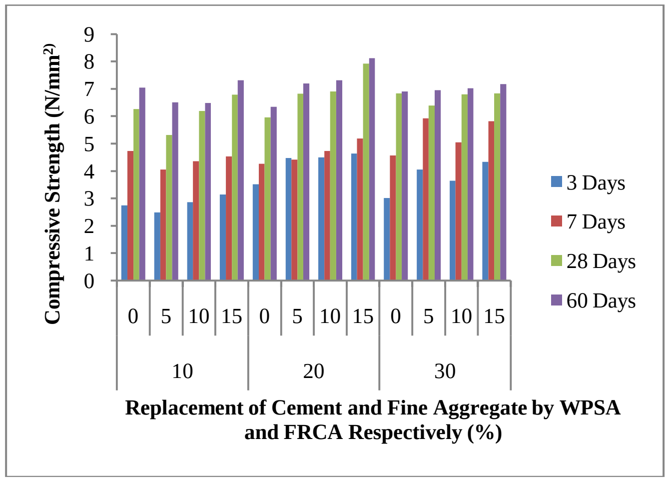

Figure 4. Effect of WPSA and FRCA Content on Compressive Strength of Foamed Concrete at 3, 7, 28 and 60 days

CONCLUSIONS

Base on all findings, it can be conclude that the inclusion of WPSA and FRCA at certain percentage as cement and fine aggregate replacement have been influenced the compressive strength of foamed concrete. According to the result of this investigation, it can be summarized that replacing high proportion of cement with WPSA possible to contribute higher compressive strength at long term period. However, high amount of addition of FRCA result in foamed concrete of lower compressive strength. Interestingly, incorporation of WPSA and FRCA show higher compressive strength compared to reference mix at 20% and 15% respectively. Therefore, this research begin to highlight that there is possibility that WPSA and FRCA would no more be considered as problematic wastes.

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