The Strength Behavior of Self-Compacting Concrete incorporating Bottom Ash as Partial Replacement to Fine Aggregate

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Abstract Self-compacting concrete which commonly abbrevited as SCC is a special concrete that have the ability to consilodate fully under its own self-weight without any internal or external vibration. This paper presents the experimental investigation carried out to study the strength of self-compacting concrete incorporating bottom ash at different replacement level of natural sand. The composite cement was used and the replacement level of bottom ash to natural sand is set up to 30% by volume. The strength properties such as compressive strength, split tensile strength and flexural strength of the concrete at the age of 7 and 28 days of curing day were conducted. Results shows that the strength of the concrete with bottom ash increased up to replacement level 15% higher than control specimens. This show that bottom ash can be used as supplimentary cementitious materials, having the pozzolanic reactivty.

Introduction

Self-compacting concrete (SCC) is a latest innovation in concrete technology and can be categorize as a new kind of high performance concrete with excellent deformability and segregation resistance [1]. SCC was first developed in Japan in 1980's with the first SCC's prototype had been completed in 1988. SCC utilized the same material as in the production of normal concrete except for the addition of superplasticizer or viscosity modifying agent or application of both. The employment of superplasticizer helps in achieving flow-able concrete while the viscosity modifying admixture provide segregation resistance, reducing bleeding and maintaining homogeneity between constituent material. The additive materials from waste by-product such as fly ash, bottom ash, quarry dust, and silica fume also can be added to concrete as part of the total constituent system [2,3,4,5,6]. The benefits of these additive materials come from its particle size distribution characteristic and pozzolanic activity. According to Mohamed [5], the utilization of silica fume and fly ash in the concrete as partially cement replacement had shown an increment in compressive strength of the concrete. While Kurama, Topçu, & Karakurt [6] reported that the replacement of bottom ash with quartz sand in the production of autoclaved aerated concrete had demonstrated increased in strength with lower unit weight.

In Malaysia, the source of electricity was mainly generated from coal-fired power plant, and Malaysia consumes about 42 million tonnes of coal annually. The amount is devastated as it will produce tonnes of coal combustion by-products include fly ash and bottom ash. With future planning on the newest construction of coal-fired power plant to uphold the current demand of electricity, the amount of coal combustion by-products are expected to increase. Fly ash and bottom ash are the main by-product waste of coal-fired power plant. These wastes are either deposited on the landfill or dump in the pond. Either way, a larger deposited area and pond are required. However, dumping these waste in the landfill and properly manage the wastes are not the best sustainable solution. Alternatively, a better approach in solving and handling of coal combustion by-product should be explored. This paper intends to investigate the potential used of bottom ash in the production of SCC. The study focused on the strength development of the concrete with bottom ash including compressive strength, splitting tensile strength and flexural strength. The study on the influence of the bottom ash particles on the workability of the concrete was also conducted.

Experimental details

Materials

Portland fly ash cement conforming to MS EN 197-1:2007 [7] was used. Bottom ash was obtained from one of coal-fired power plant in Malaysia. The physical and chemical properties of cement and bottom ash is given in Table 1. The total composition of Silica (SiO2) Alumina (Al2O3) and Iron Oxide (Fe2O3) in bottom ash exceeded 70%, indicating that it can be classified as class F ash as specified in ASTM C 618 [8]. Locally available natural sand with 5 mm maximum size was used as fine aggregate. The particle size distribution of natural sand and bottom ash is presented in Fig. 1. Bottom ash with size bigger than 5mm is discarded. The partially substitution of natural sand with bottom ash resulted in variable particle dimension in the concrete constituent. Almost 50% of bottom ash particle have dimension less than 250 µm, which makes a greater amount of fine element available in the concrete. The maximum and minimum size of coarse aggregate used in this study is 16mm and 10mm respectively. Both sand and coarse aggregate have a specific gravity of 2.61 and 2.67 respectively.

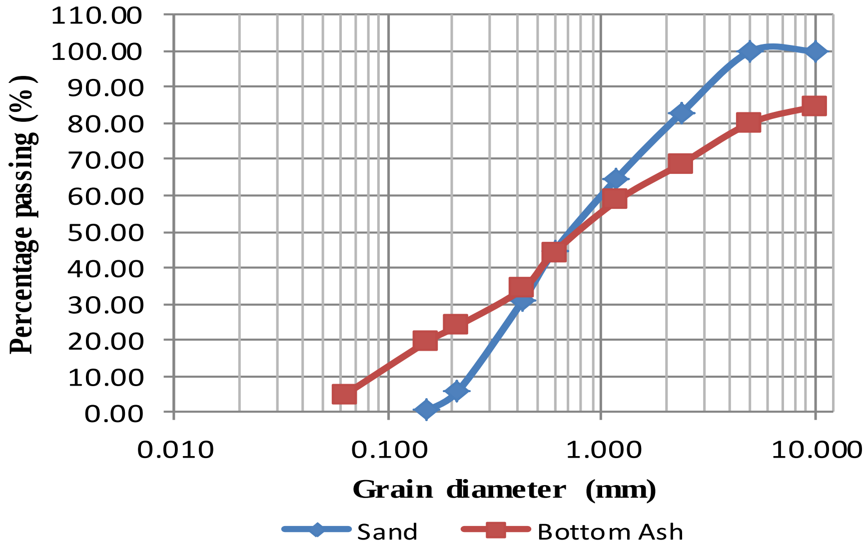

Figure 1: The particle size distribution of natural sand and bottom ash

Mix proportions

In this research, six mixture proportion of fine aggregate replaced with bottom ash ranged from 10% to 30% were made. Due to significant difference between specific gravity of natural sand and bottom ash, volumetric replacement was preferred. The fine aggregate contain was maintained at 45% by volume of mortar and coarse aggregate was maintained at 28% by volume of concrete. The water to cement ratio was maintained at 0.4, while air-content being assumed to be 2%. The amount of superplastisizer was adjusted until the concrete achieve self-compatibility. The mix proportion of this research is given in Table 2.

Preparation of Specimens

The slump flow, slump flow time (T_{500}), L-box blocking ratio and segregation resistance ratio test were performed in order to determine the fresh properties of the self-compacting concrete. The procedure conducting the tests were based on the British Standard [9,10,11]. For each mixture, the compressive strength, splitting tensile strength and flexural strength were determined at 7 and 28 days of water curing. The cube size of 100mm is cast for the determination of compressive strength, cylinder size of 150x300mm for the determination of splitting tensile strength and prism size of 100x100x500mm for the determination of flexural strength.

Table 1: Chemical and physical characteristic of bottom ash and blended cement

	Chemical analysis content (%)										Los on ignition	Specific gravity	Moisture Content
Content (%)	SiO2	Al2O3	Fe2O3	CaO	K2O	TiO2	MgO	Na2O	CO2	MnO			
Bottom Ash	68.9	18.7	6.5	1.61	1.52	1.33	0.53	0.24	0.1	-	2.68	1.72	40%
Cement	22	8.35	3.92	58.9	1.01	0.72	0.52	0.26	0.1	0.15	1.72	3	-

Table 2: The mix design of the self-compacting concrete

Mix	BA0	BA10	BA15	BA20	BA25	BA30
Cement (kg/m3)	561	561	561	561	561	561
Coarse Aggregate (kg/m3)	593	593	593	593	593	593
Sand (kg/m3)	914	822	777	731	685	640
Bottom ash (kg/m3)	0	67	100	133	166	200
w/p	0.4	0.4	0.4	0.4	0.4	0.4
Superplastisizer (%)	0.2	0.2	0.21	0.31	0.34	0.35

Results and Discussion

Properties of fresh Concrete

The fresh properties of the concrete are as presented in Table 3. It show that, the slump flow values for all mixes having a flow in the range of 550-715mm. The European Guideline for Self-compacting Concrete [12] has suggested that the slump flow range value should ranging from 550 to 850 mm. The sample without bottom ash (BA0) shows the highest value of slump flow with 715mm diameter followed by BA10 and BA15. The value decreased gradually with the increase of bottom ash up to 20% to 30%. The reduction in the flow demonstrates that the presence of bottom ash influence the workability of the fresh properties of the concrete. The decreased in workability is due to two factors firstly, the micro pore in bottom ash absorbp both water and cement paste during the mixng, and secondly, the irregular shaped particles of bottom ash increased the inter-particle friction between aggregates hence decreasing its workability [13,14]. In addition to slump flow time (T_{500}), the table shows that BA30 have the longest T_{500} followed by BA25 and BA20. It shows that the T_{500} value increased with the increase of bottom ash in the mixture. The longest T_{500} was considered to be due to inter-particle friction among aggregates, highly from the irregular shape and rough texture of the bottom ash [15,16]. The value of passing ability of SCC was measured by using L-box test. The passing ability ratio was observed to be decreased as the percentage replacement of bottom ash increased. Mixture without bottom ash (BA0) shows the highest passing ability ratio followed by BA10 and BA15. The decreased in passing ability is considered due to the aggregate bridging at the area between clear space and steel bar, resulting from inter-particle reaction between aggregates. The segregation test was used to evaluate the homogeneity of the specimen. The test assessed the resistance of fresh concrete to segregation by evaluating the proportion of sample and the material passing through the sieve having 5 mm square aperture [11]. As observed, the value of the segregation ratio decreased with the increased of bottom ash replacement level. It indicated an excessive resistance of the segregation due to the water absorbed during the mixing.

Table 3: The fresh properties of self-compacting concrete

Sample	BA0	BA10	BA15	BA20	BA25	BA30
Slump flow dia. *(mm)*	715	705	700	615	560	550
T_{500} *(s)*	2.59	2.84	3.72	4.00	4.52	4.57
L-box	0.92	0.89	0.84	0.79	0.75	0.65
SR (%)	9.49	8.17	6.71	5.30	4.88	5.00

Compressive Strength

Fig. 2 presents the effect of bottom ash on the compressive strength of SCC. It shows that the compressive strength of the specimens increased with the increased of bottom ash in the concrete up to 15% of level replacement. At the age of 7 days, BA10 and BA15 gained its strength about 5% and 20% higher than control specimens. This may due to the pore refinery effect by pozzolanic reaction of bottom ash. Despite of the increase in porosity due to the replacement of bottom ash, the silica content in bottom ash particles enhance the formation of C-S-H, a gel responsible for strength development [17]. The compressive strength of the bottom ash concrete starts to decrease when the replacement level increased to 20%. Specimens with BA20 reduced about 7.5% of its strength of the control specimens followed with BA25 and BA30 with 28.7% and 43.2% respectively. The pore refinery effect by pozzolanic reaction is not dominant at this level replacement level [16]. The excessive amount of bottom ash has produced porous concrete and reduces its compressive strength. The strength of concrete at 28 days of curing day exhibits the same strength behavior as 7 days of curing. The strengths recorded were 44.30Mpa, 50.33Mpa, 54.05Mpa, 37.90Mpa, 36.65Mpa, and 36.40Mpa for BA0, BA10, BA15, BA20, BA25 and BA30 respectively.

Splitting Tensile Strength

The results of splitting tensile strength of hardened bottom ash concrete measured at 7 and 28 days are as presents in Fig. 3. It is observed that the splitting tensile strength of concrete have the same pattern of compressive strength results. The splitting tensile strength of the specimens increased as the amount of bottom ash replacement level increased up to 15%. The results suggested that the bonding between aggregate and cement paste are the most important factor in affecting the strength of concrete especially the tensile strength. It has been found that crushable aggregate with rough surface which usually have softer, porous, and mineralogical heterogeneous particle have stronger aggregate-cement paste bond than normal aggregate [18]. The fact that the cement paste able to penetrate into pores on the surface of bottom ash better than the normal aggregate had increased the aggregate-cement bond strength. This has results in increasing of tensile strength of the concrete compared to sample without bottom ash. It also observed that the splitting tensile test increase with the age of curing. The splitting tensile strength of the concrete start to decreased at 20%, 25% and 30% of replacement with bottom ash. The increased in the replacement level of bottom ash had produced more porous concrete with more pores distributed around the bottom ash aggregate surface, hence reducing its strength [19].

Flexural Strength

The flexural strength of all specimens was observed to exhibit the same behavior as compressive strength and splitting tensile strength. The results of flexural strength of the specimens are shown in Fig. 4. From the figure, it is evident that flexural strength of bottom ash concrete with 10% and 15% replacement of bottom ash are higher compared to concrete without bottom ash. At 7 days, an increase of 2.82% and 7.85% were observed for mixes BA10 and BA15, respectively comparison to the control mixture BA0. The same development was observed at the age of 28 days with BA10 and BA15 showing increased of 3.74% and 11.09% respectively. However, the flexural strength of the specimen decreased when 20%, 25% and 30% replacement of bottom ash to sand were used in the concrete. From Fig. 4, it is evident that when the bottom ash mixing ratio increased, the degree of flexural strength reduction decreased. It was found the flexural strength of BA20, BA25, and BA30 decreased to 4.71%, 22.29% and 24.33% respectively at 7 days of curing ages. At age 28 days, the reduction of 1%, 3.89% and 9.22% were observed for specimens BA20, BA25 and BA30 respectively, in comparison to control specimens BA0. The decreased in flexural strength of the specimen as the replacement level of bottom ash increased is believed due to the poor interlocking between the aggregate, as bottom ash particles are spherical in nature [20].

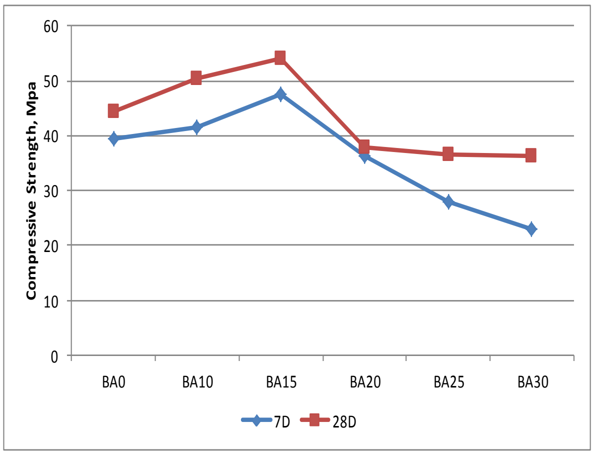

Figure 2: Compressive strength of SCC with bottom ash

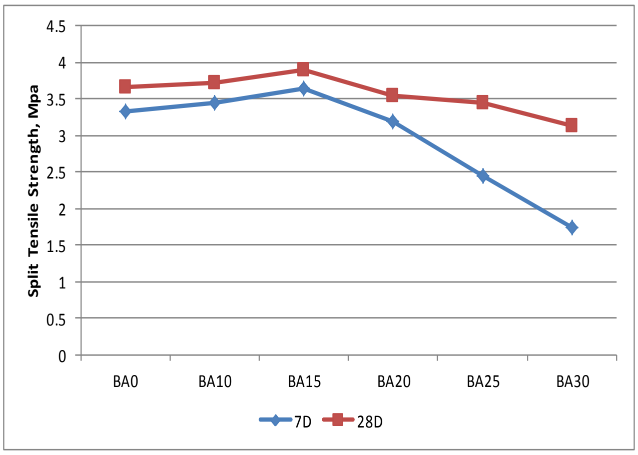

Figure 3: Splitting tensile strength of SCC with bottom ash

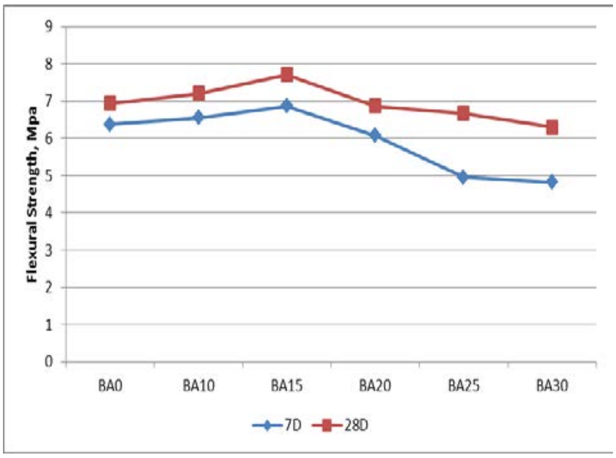

Figure 4: Flexural strength of SCC with bottom ash

Conclusion

The following conclusions were derived at from the study:

1. From the testing results on the fresh properties of concrete mixture with bottom ash, considering the overall aspect which influencing the rheology of the fresh properties, it can be conclude that the presence of bottom ash in the concrete mixture decreased the workability of the fresh concrete
2. The present investigation has shown that it is possible to design SCC with bottom ash on various percentages. Though serious consideration should be made in deciding the water-to-powder ratio, since bottom ash tends to absorb water during the mixing. Otherwise, the addition of superplasticizer is required to improve fresh concrete workability.
3. It is possible to produce concrete strength up to 40 Mpa by replacing sand with bottom ash up to 15%. BA10 and BA15 exhibit higher strength compared to control specimens for compressive strength, slitting tensile strength and flexural strength. This might be due to the pore refinery effect by pozzolanic activity of bottom ash particles.

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