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# Nomograph of Self-Compacting Concrete Mix Design Incorporating Coal Bottom Ash as Partial Replacement of Fine Aggregates

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**Abstract:** In this study, a waste mineral by-product produced from coal-fired power plant known as Coal Bottom Ash (CBA) is composed as admixture and used as a substitute materials to the fine aggregates in Self-Compacting Concrete (SCC) with replacement ratio range from 0-30% by volume. A brief account of experimental investigations is presented based on the physical and mechanical properties were determined by consuming water cement ratios (W/C) of 0.35, 0.40 and 0.45. The data obtained shown are significant in relationship of CBA percentage between W/C ratios, compressive strength, tensile strength and flexural strength. The results were combined into a graph form to develop a primary mix design nomograph. It is shown that the developed nomograph is able to assist in designing mix proportion based on the essential parameter required.

**Key words:** Nomograph, self-compacting concrete, strength, rang, assist

## INTRODUCTION

Self-compacting concrete also known as SCC is a high performance concrete without compaction and vibration for placing. This high fluidity concrete is proficient to strengthen only under force of gravitation and will be very suitable to apply in complex formwork, where fully reinforced or mechanical vibration would be difficult, and handled without bleeding and segregation (Dinakar *et al*., 2013; Ramanathan *et al*., 2013; Azeredo and Diniz, 2013; Pathak and Siddique, 2012). SCC has lots of benefits for pre-stressed and precast concrete industries and for cast *in situ* construction due to plants, low noise-level, construction site, and fast construction. Conversely, even SCC had obtainable good concrete performance, however, the lack of relations between engineering properties and mixture design properties makes SCC more complex (Pathak and Siddique, 2012). It involves the influence of different mixture variables such as utilization alternative materials to verify adequate fresh properties and excellent mechanical properties (Uysal and Sumer, 2011. The basic materials utilized in the making of SCC characteristically analogous to conventional concrete. Compared to normal concrete, SCC incorporates high volume of powder content and superplasticizer consumption to develop the essential workability. The improvements to utilize other materials in replacing cement powder and fine aggregates especially for SCC also have been widely exposed. The most common materials are used in construction with SCC such as fly ash; rice husk ash and silica fume as alternative for cement. These materials are well-known because of their prospective for decreasing permeability and improving the overall performance of cured concrete. However, there is a few materials have been investigates for replacing fine aggregates. Recently, Coal Bottom Ash (CBA) has gained great consideration as alternative for fine aggregate replacement (Ibrahim *et al*., 2015). Several findings informed that the influence of CBA in the concrete as fractional replacement material of fine aggregate in the concrete (Ibrahim *et al*., 2015; Andrade *et al*., 2009, 2007; Kasemchaisiri and Tangtermsirikul, 2008; Park *et al*., 2009; Siddique *et al*., 2012). By considering the ecosystem and environmental aspect, various options and alternative are present towards the utilization of construction materials. In the context of environmental impact, these alternate fine aggregates are significant for depleting supplies of the sand and mining river.

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Table 1: Mix proportion of SCC

| W/C | Density ($kg/m^3$) | | | | | Coal bottom ash volume replacement (kg) | | | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | Cement | CA | Sand | Water | SP | 10% | 15% | 20% | 25% | 30% |
| 0.35 | 557 | 715.5 | 874.5 | 194.95 | 1.09 | 13.64 | 20.46 | 27.28 | 34.11 | 40.93 |
| 0.40 | 518 | | | 207.20 | 1.11 | | | | | |
| 0.45 | 485 | | | 218.25 | 1.14 | | | | | |

CBA has physical characteristics that are similar to that of natural sand which make it a suitable material for use in concrete in replacing sand. According to Siddique (2009) and Abubakar and Baharudin (2012), CBA is a porous materials with irregular angle in texture, the reason of unfeasible to be employed in concrete making.

However, Jaturapitakkul and Cheerarot (2003) found that this material was confirmed presenting good pozzolanic element reactivity in contact with finer elements. Kasemchaisiri and Tangtermsirikul (2008) has done the properties of SCC comprising CBA as a supplementary material of fine aggregate and claimed that percentage replacement of CBA as 10% as a great performance in terms of strength and durability compared to the control specimens. Conversely, Siddique *et al.* (2012) suggested the percentage replacement was 20% of CBA in SCC. Because of this, the compressive and tensile strength increased with the decrease of CBA present in concrete. Meanwhile, Ernida *et al.* (2014) claimed that 15% of CBA can be considered as optimum percentage as replacement fine aggregates. It is acknowledged that the compressive, tensile and flexural strength increased with the decrease of coal bottom ash present in concrete at certain percentage.

This study presents the influence of coal bottom ash as a fractional auxiliary of fine aggregates. The researchers showed the results in the shape of strength with different water cement ratios and developed a preliminary nomograph for SCC.

## MATERIALS AND METHODS

Composite cement that conforming with MS EN 197-1:2007 was used in SCC production as a main blinder. The fine aggregates were natural river sand and CBA that collected from one of coal-fired power plant in Malaysia. CBA had physically like to dark grey coarse sand and its size distribution with the range of 0.075 and 20 mm. The fine aggregates including CBA were grading size passing through a sieve 5 mm. The coarse aggregates were sieved passing through a sieve 16 mm and retained on a sieve 10 mm. Polymer-based super plasticizer has a specific gravity of 1.09 with pH 5.3 which is used to increase the workability of fresh concrete.

A mix design method used in this experimental work was referred to Jawahar. The key proportions of the constituent are given in Table 1. The water/binder ratios of 0.35, 0.40 and 0.45 concrete mixtures were designed in six batches: BA10, BA15, BA20, BA25 and BA30. In every batch the reference concrete prepared without CBA whereas in the remaining mixtures fine aggregates was partially replaced with the CBA. Based on the experimental work, CBA was partially replaced at 10, 15, 20, 25 and 30%, volumetrically. The coarse aggregate and fine aggregate was preserved at 28% by volume of concrete and 45% by volume of mortar respectively. The air content is assumed to be 2% in all mixtures. The polymer-based Superplasticizer (Sp) was used to achieve good condition of viscosity and governing the rheological properties. The dosage of Sp in all mixes adapted to attain an outstanding flowability without segregation. The cylindrical, cube and prism specimens were prepared for experimental works with dimension of 150×300, 100×100×100 and 100×100×500 mm, respectively. The preparation, casting and curing process were according to BS EN 12390-1:2012 and BS EN 12350-1:2009.

The fresh properties of mixtures such as slump flow, slump spread time ($T_{500}$), L-box ratio and segregation resistance were performed before sampling. These tests are important in order to classify the mixtures are good as SCC fresh state. All specimens were unmould after 24 h and placed in water tank for curing process. The densities of concrete, compressive strength, tensile strength and flexural strength were tested and recorded at age of 28 days. Normally, concrete have reached 99% of strength on that period. After 28 days, concrete continues to gain strength; however the rate of gain in strength is very less compared to that in 28 days (Neville, 2003). The practice of the tests were conducted by technique describe in agreement to British Standard. In this study, all mixtures were satisfied during fresh properties testing.

## RESULTS AND DISCUSSION

**Density:** The average density of concrete containing coal bottom ash as aggregate at 28 days is 2330 $g/m^3$ signifying the reduction of the self-weight of 3.1% compared to the average density of normal concrete which is 2404 $g/m^3$. This range is slightly lower than conventional concrete densities which are within 2300-2400 $g/m^3$. Figure 1 shows the reduction in the density according to the coal bottom ash aggregate replacement content and water/cement (W/C) ratio, respectively.

The results indicate control mixture achieves the highest density while 30% replacement level of CBA shows the lowest density. It can be seen that the increases of replacement level of CBA is parallel with the

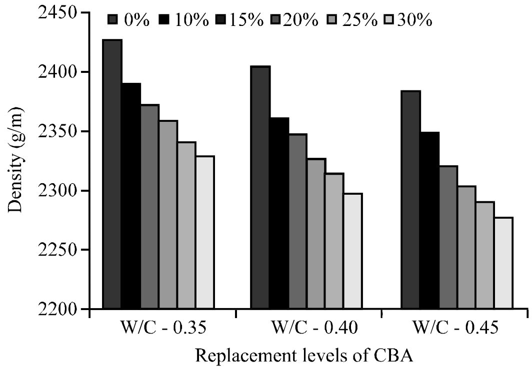


Fig. 1: Density of concrete

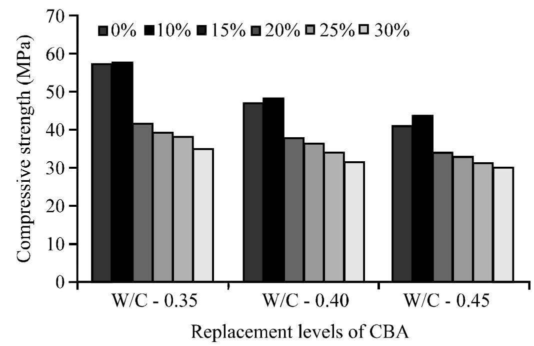


Fig. 2: Compressive strength of concrete with various percetange of CBA and water cement ratio

decrement density of concrete specimen. The decreasing in density of concrete is the result of increases replacement level of CBA which affected the density in all mixtures. Meanwhile, the lower W/C ratio shows higher density of concrete. It is understood that the variation of water cement ratio would affected the concrete density. Lower density indicates the presence of voids within a specimen. Higher coal bottom ash content results in lower density value, which indicates that more voids are present within the specimen.

Concrete with W/C ratio 0.35 shows the average reduction of 2.86% of the density compare to concrete mixtures with w/c ratio 0.40 and 0.45 which are 3.01% and 3.2% respectively. Pore refinery effect by pozzolanic reaction of bottom ash attributed to the major reduction of concrete density. Besides, higher w/c ratio would induce pore spaces of water that does not participate in water-binder reaction hence producing a very small diameter of capillaries channel. Voids are formed within the specimen during the water evaporation and thus contribute to the decrement of concrete density (Siddique *et al*., 2012; Siddique, 2009; Abubakar and Baharudin, 2012; Jaturapitakkul and Cheerarot, 2003; Abidin *et al*., 2014; Arshad and Abidin, 2015).

**Compressive strength:** Figure 2 presents the effect of CBA on compressive strength of SCC when it was used to replace fine aggregates at different percentages. The higher percentage of CBA and higher water cement ratio has reduced the compressive strength. The maximum compressive strength achieved by 10% CBA samples which are 58.0, 48.7 and 44.0 MPa for water cement ratio 0.35, 0.40 and 0.45, respectively.

It was found that almost all of the bottom ash mixtures had lower compressive strength than the control SCC at all concrete ages. It can be explained that the increase of porosity in hardened concrete due to the use of bottom ash results in the reduction of compressive strength (Siddique *et al*., 2012; Siddique, 2009; Abubakar and Baharudin, 2012; Jaturapitakkul and Cheerarot, 2003; Abidm *et al*., 2014). As can be seen, higher percentage of CBA has produced more porosity of concrete which are leading to the decreasing compressive strength. The increase of porosity in hardened concrete is due to the use of bottom ash which has a higher water absorption compared to the sand. In context of physical properties, it is known that bottom ash has a porous texture. At the age of 28 days, the compressive strength of the SCC mixed with 10 % CBA was slightly less to that of the control SCC, while those of the mixtures containing 15 , 20, 25 and 30 % bottom ash were still lower. This could be a reason of pore refinement by pozzolanic reaction of bottom ash which dominates over the effect of increase of porosity at the replacement level of 10%. Based on the results, it is indicates that the long term compressive strength can be improved by replacing 10% of total fine aggregate by the CBA.

**Tensile strength:** The results of tensile strength measured at 28 days are presents in Fig. 3. It is recorded that the results have similar form of compressive strength results. The tensile strength of the samples increased as the amount of bottom ash replacement level increased up to 10% for all water cement ratios. The tensile strength starts decreasing at 15-30% of replacement with bottom ash. The connection between aggregates and cement paste are the most significant influence in affecting the tensile strength of concrete. It has been directed that porous aggregates with irregular bottom ash surface have tougher aggregate-mortar combined than conventional aggregates (Abidm *et al*., 2014; Ibrahim *et al*., 2015). The mortar in concrete that infiltrate into pores had improved the strength of aggregate-cement bond strength through concrete hydration.

**Flexural strength:** The trend of flexural strength was experimental to display the same performance as compressive strength and tensile strength. The results of

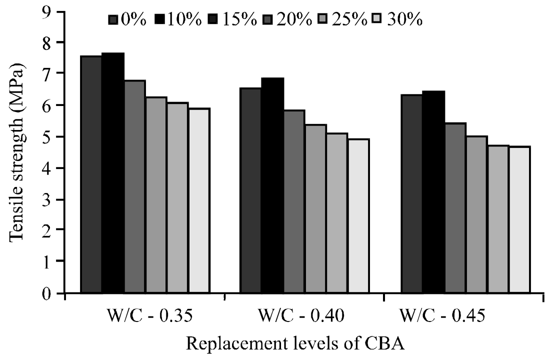


Fig. 3: Tensile strength of concrete with various percentage of CBA and water cement ratio

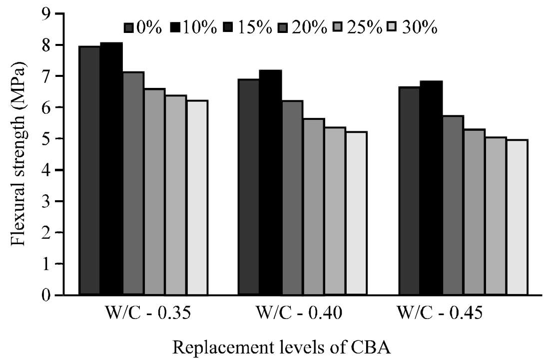


Fig. 4: Fiexural strength of concrete with various percentage of CBA and water cement ratio

flexural strength at 28 days are shown in Fig. 4. It is markedly that flexural strength of bottom ash concrete with 10% replacement of bottom ash is higher compared to concrete without bottom ash for all water cement ratios. At the age of 28 days, an increase of 1.7, 4.4 and 2.0% were observed for water cement ratios of 0.35, 0.40 and 0.45, respectively in comparison 10% mixture to the control mixture. However, the flexural strength decreased when 15, 20, 25 and 30% replacement of bottom ash to sand were used in the concrete. Figure 4 shows the flexural strength development in manipulating coal bottom ash. It clearly indicates that as the bottom ash mixing ratio increased up to 10%, the degree of flexural strength starts decreased.

Development of nomograph: Nomograph is developed by the arrangement of four relationships of the concrete properties in one single graph. Concrete properties such as water cement ratios, compressive strength, tensile strength and flexural strength were used in producing nomograph. The relationship between compressive strength and water cement ratio is firstly plotted by Duff Abram in 1918. The engineering key on relation water cement ratio that controls the

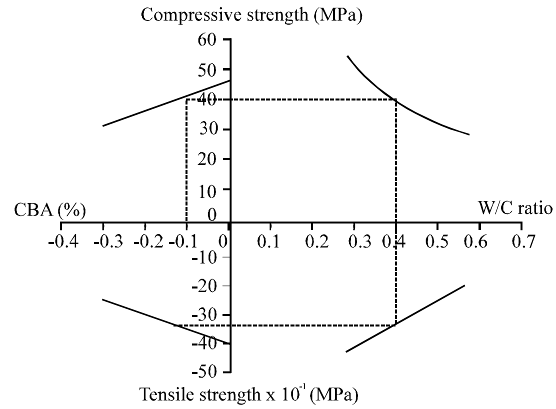


Fig. 5: Compressive-tensile strength nomograph

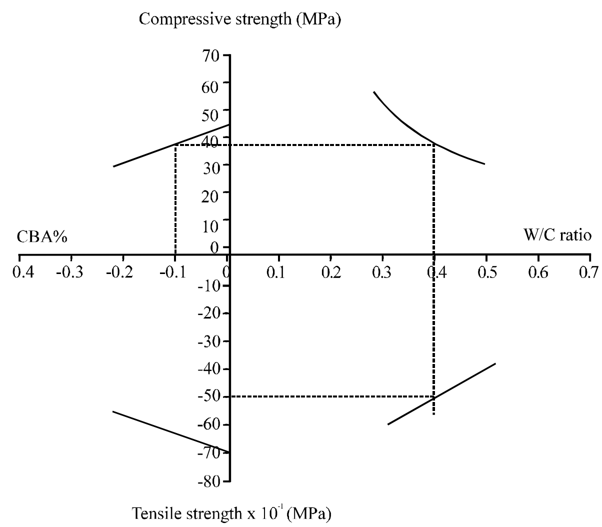


Fig. 6: Compressive-flexural strength nomograph

workability and strength of concrete was called Abrams law (Sear *et al*., 1996). Abrams law associates the compressive strength of concrete with the water cement ratio in power expression. While others is developed by referred to best line fit to all data plotted into the nomograph as shown in Fig. 5 and 6. The preliminary nomograph for self-compacting concrete with coal bottom ash can is used to design the concrete mix proportion for an essential compressive strength. For instance, if the design strength requirement for coal bottom ash concrete is 40 MPa, the proportion obtained from the nomograph is 0.40, 10% and 3.2 MPa for water cement ratio, coal bottom ash replacement percentage and tensile strength , respectively

## CONCLUSION

In general, the results of the present study exposed that the CBA have a potential as a supplementary cementitious material for Self-Compacting Concrete (SCC). The amount of the CBA used should be highlighted because excessive amount will affects the rheology and properties of hardened concrete. In present study, the optimal percentage of utilization in concrete was 10% replacement to fine aggregates. Samples with 10% of CBA have higher strength properties compared to control specimens due to the pore refinery effect by pozzolanic activity of CBA particles. The water-cement ratio give a major influence in designing SCC with CBA, thus serious consideration should be taken as CBA characteristically absorbing water during mixing. The further research to explore the possible ways to enhance the early age strength of CBA concrete is needed. Incorporation of higher CBA replacement to sand up to 100% in SCC could be investigated for future work. The preliminary nomograph that combined by compressive, tensile and flexural strength would help in designing concrete strength with desire percentage of CBA.

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