

INVESTIGATION OF SETTING BEHAVIOUR AND COMPRESSIVE STRENGTH OF MINING COAL BOTTOM ASH BLENDED CEMENT

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Abstract. *The unused abundant generation of mining coal bottom ash (MCBA) as an industrial by-product from power plant causes the earth and environmental pollution. The aim of this study is to analyze elemental composition, physical properties, morphology of mining coal bottom ash powder (MCBAP) and investigate the compressive strength and setting behaviour of mining coal bottom ash powder blended cement (MCBAPC). The elemental composition and morphology were observed using X-ray fluorescence (XRF) and Scanning electron microscopy (SEM) techniques, respectively. ASTM standard methods were used to observe setting time and water for normal consistency. The compressive strength of MCBAPC was explored with water to cement ratio of 0.40 and cement to sand ratio of 0.50. In this experiment, the ordinary portland cement (OPC) was replaced by MCBAP up to 60% by weight. Result found that the setting time and water demand increase, but compressive strength decreases with replacement level. Moreover, the compressive strength development rate of curing age 7 to 28 days is lower with respect of curing age 28 to 90 days. Rigorous reckoning found that the MCBAP is feasible to use in blended cement.*

Keywords: Mining coal bottom ash powder, Setting time, Blended cement, Compressive strength.

1 INTRODUCTION

Rapid industrialization and urban development lead to increase the consumption of power, and the generation of mining coal bottom ash (MCBA) waste residue has increased drastically all over the world[1]. In present practice, land filling is the only way to dispose MCBA waste that change the composition of soil and also contaminate ground water. Safe treatment and sustainable reuse of mining coal bottom ash powder (MCBAP) waste has become a society, environmental and economic problems that need to be resolved urgently. The suitability for utilization MCBAP in blended cement depends on its' chemical, Physical, mineralogical and morphology properties[2]. The chemical composition of MCBAP is similar with fly ash of the coal burning power plant. Moreover, there has some sort of difference both in chemical and physical composition of MCBAP and fly ash. Usually, MCBAP is denser and coarser than fly ash particles[3].

The physical properties, chemical composition, mineralogy and morphology of bottom ash depends on the sources from where it is produced, burning condition, geological condition of the area where coal is generated[4]. The chemical composition of Malaysian coal bottom ash mainly SiO_2 (58-67%) with Al_2O_3 , Fe_2O_3 and MgO . XRD observation found that quartz and mullite are main mineral present in coal bottom ash and amorphisity halo present in the two theta angle in range 10-30°. The coal bottom ash has pozzolanic activity, but not so strong as like as fly ash. Moreover, slag and fly ash is an industrial by product which widely used for composite cement production in industrial scale[5],[6]. The coal bottom ash reduces compressive strength at an early age, but increase at later age due to formation of more C-S-H gel by pozzolanic reaction. The presence of bottom ash particle in between two active cement particle retards the hydration reaction rate. As result setting time of blended cement comparatively higher than corresponding OPC paste. The target of this work is to analyze the chemical and morphological characterization of MCBAP and suitability in term of compressive strength, setting time and water consistency to use in blended cement. This knowledge could be adventitious for utilization MCBAP in composite cement production at industrial level.

2 MATERILAS & METHODS

The MCBA(Figure 1a) was collected from a local power plant in Kuala Lumpur, Malaysia. The raw MCBA was dried and grinded for 8 hours in a ball mill of 150 rpm to achieve MCBAP (Figure 1b). The chemical composition and morphology of MCBAP were analyzed through XRF (Table 1) and SEM (Figure 2), respectively. The specific gravity, loss of ignition, specific surface area, water consistency and setting time were determined according to ASTM C118-15, ASTM C114-15, ASTM C204-14, ASTM C191-13, respectively. The type of OPC, binder/sand ratio, and water/binder ratio were kept constant as CEM I 42.5 N, 0.50

and 0.40, respectively. The superplasticizer (SP) was used to maintain mortar flow 170 ± 10 mm. The ASTM C778 standard graded sands were used. The MCBAP based blended cements as designated in this article as MCBAP-10, MCBAP-20, MCBAP-30, MCBAP-40, MCBAP-50 and MCBAP-60, were prepared with a replacement of OPC of 10, 20, 30, 40, 50 & 60% blending in a control ball mill. Blended cement and sand were mixed properly following two minutes with water and then another two minutes with SP. The mortar flow was measured according to ASTM C1437-13. Eighteen numbers of $50 \times 50 \times 50$ mm³ cubes were casted for each blended cement mortar. The specimens were demoulded after 24 hours and cured in water at a controlled room temperature and humidity of $27 \pm 3^\circ\text{C}$ and $65 \pm 18\%$, respectively. The compressive strength of mortar was tested at the age of 1, 3, 7, 28, 56 and 90 days according to ASTM C209-15.

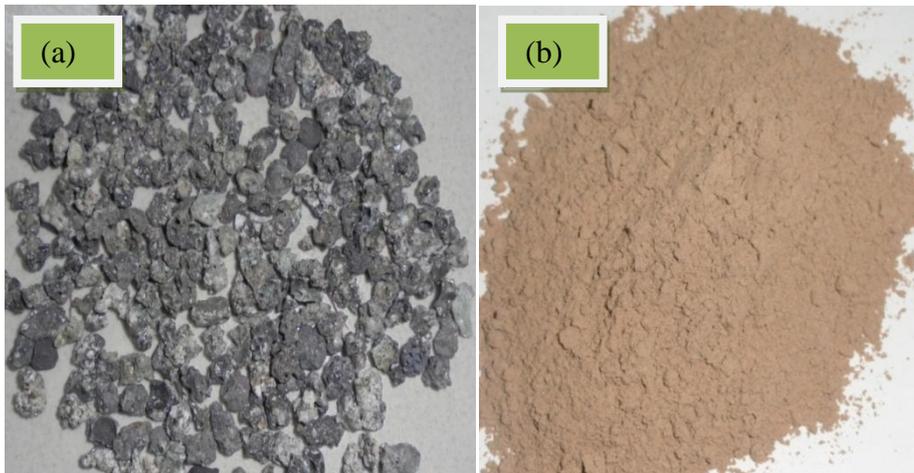


Figure 1: (a) MCBA stone (b) MCBAP collected from a power plant

3 RESULTS & DISCUSSION

3.1 Chemical and Morphological Analysis

The common physical and chemical properties of OPC and MCBAP are illustrated in the Table 1.

Table 1: Physical and Chemical Compositions of OPC and MCBAP

Parameter	OPC	MCBAP
SiO ₂ (%)	20.65	51.32
Al ₂ O ₃ (%)	5.10	28.46

MgO(%)	1.47	0.30
Fe ₂ O ₃ (%)	2.29	6.31
CaO(%)	64.19	1.37
K ₂ O(%)	0.21	2.20
TiO ₂ (%)	0.11	0.69
SO ₃ (%)	3.48	0
Specific gravity	3.15	1.87
Fineness (m ² /kg)	404	429
LOI (%)	0.89	2.86

The SiO₂ is the main ingredient with Al₂O₃, Fe₂O₃, MgO of MCBAP. The total percentage of SiO₂, Al₂O₃ and Fe₂O₃ was 86.09 %. It is good for low calcium pozzolanic materials. The LOI of MCBAP is higher than OPC due to the incomplete burning coal in power plants. The specific gravity of MCBAP (1.87) was lower than OPC (3.15). This low value specific gravity is mainly due to hollow particle such as micro pore significantly present in MCBAP.

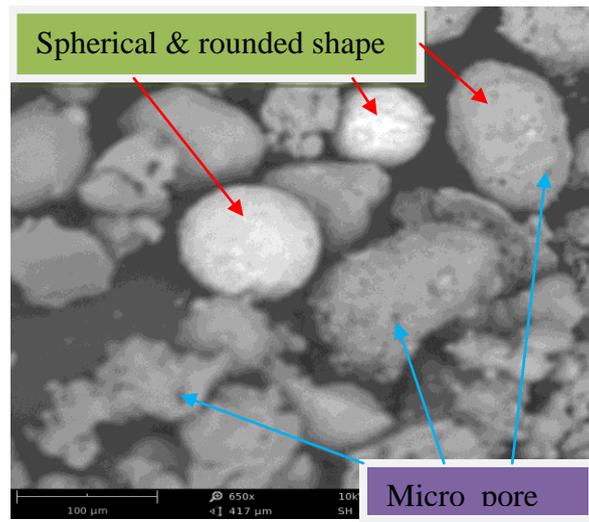


Figure 2: Micrograph of MCBAP

The SEM micrograph of MCBAP in Figure 2 shows that both spherical and rounded particles present [7]. The MCBAP contains micro pore. Small pore was formed in the combustion process of power plant. The black color of MCBAP is due to incomplete burning of mining coal. The chemical composition, burning condition and unburned carbon are responsible for irregular shape and porosity.

3.2 Investigation of Setting Time and Water for Normal Consistency

The rheological properties studies focused on the water demand for normal consistency. The water demand for the normal consistency of OPC and MCBAPC are represented in Figure 3. The water demand in MCBAPC increase with the replacement level of OPC. The free bulk water is to fill interspaces among micro pore of MCBAP more compare with OPC. The initial and final setting time of OPC and MCBAPC are shown in the Figure 4. Both of the IST and FST of MCBAPC significantly increases with replacement of OPC by MCBAP. The percentage of active OPC clinker phase such as C_2S , C_3S and C_3A decrease due to dilution effect and MCBAP particle take place between two active cement particles, both of the factors are responsible to decrease the hydration reaction rate[8].

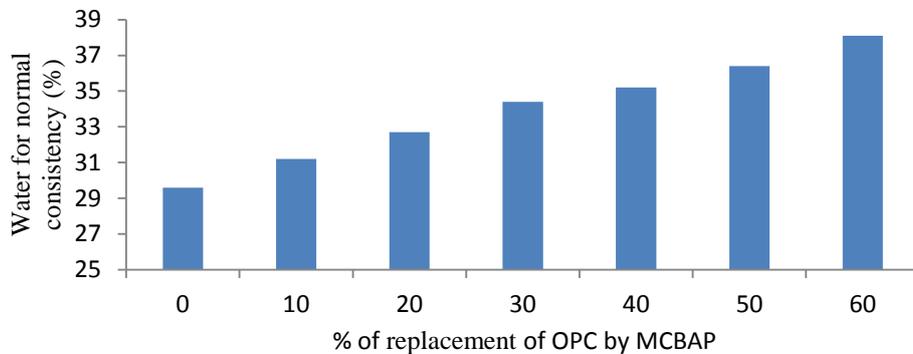


Figure 3: Water demand of MCBAPC and OPC

3.3 Effect of MCBA in Strength Development

The compressive strength of OPC and MCBAPC mortars are shown in Figure 5. From the figure, the compressive strength of the MCBAPC mortars increase with curing time, but decrease with the increment of the replacement level.

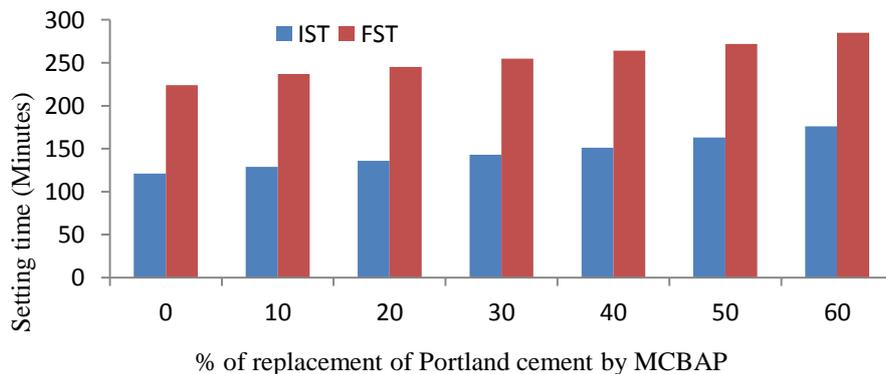


Figure 4: Setting time of OPC and MCBABC (IST-Initial setting time, FST-final setting time)

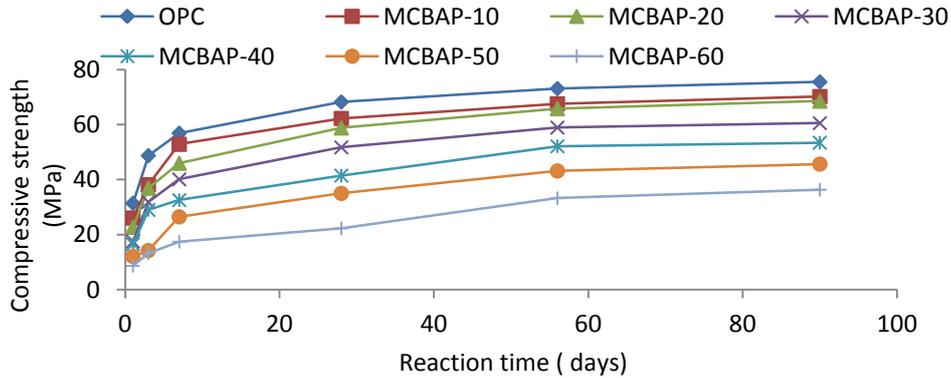


Figure 5: Variation of compressive strength with reaction time

The compressive strength developing rate of the blended cement mortar depends on factors such the hydration reaction rate, nucleation effect, packing effect and pozzolanic reaction. The compressive strengths of MCBAPC lower than OPC because of the low content active phase C_2S , C_3S and C_3A present in the MCBAPC[2]. Active phases cannot produce sufficient calcium silicate hydrate (C-S-H) polymeric layer like OPC in the presence of water for strength development [6]. The compressive strength developing rate could be calculated by using the following equation stated below.

$$CSDR_{7-28} = \frac{(CS_{28D} - CS_{7D})}{CS_{7D}} \times 100 \quad (1)$$

$$CSDR_{28-90} = \frac{(CS_{90D} - CS_{28D})}{CS_{28D}} \times 100 \quad (2)$$

where, $CSDR_{7-28}$, $CSDR_{28-90}$ indicate the rate of strength development from 7 to 28 days and 28 to 90 days, respectively. And CS_{7D} , CS_{28D} and CS_{90D} denoted that the compressive strength mortar of 7, 28, 90 day, respectively. Figure 6 shows that the percentage of MCBAP addition in OPC accelerate the $CSDR_{7-28}$, $CSDR_{28-90}$. The rate of strength development from 28 to 90days are significant. For instance, the $CSDR_{28-90}$ for MCBAP-10, MCBAP-20, MCBAP-30, MCBAP-40, MCBAP-50, MCBAP-60 are 12.81%, 16.55%, 17.02%, 28.79%, 30.33% and 42.88%, respectively. This trend of strength development may imply that SiO_2 of MCBAP reacts with $Ca(OH)_2$ at a later age[9].

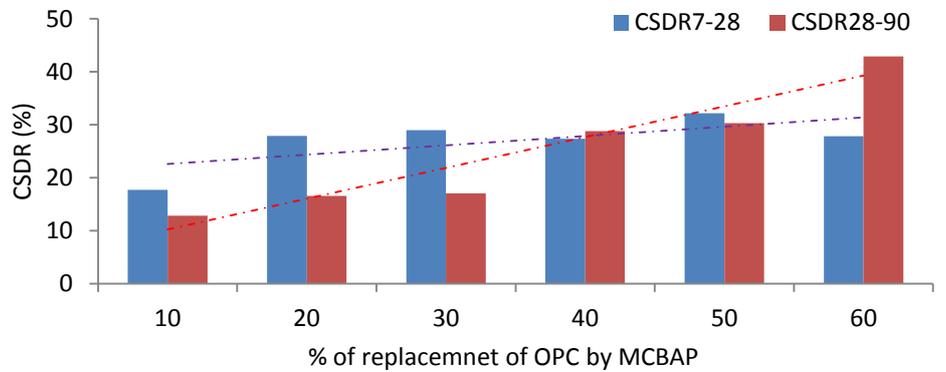


Figure 6: Compressive strength developing rate from 7 to 28 days (CSDR 7-28) and from 28 to 90 days (CSDR 28-90) for mortar.

4 CONCLUSIONS

This research illustrated the influence of MCBAP on blended cement properties and setting behaviour. The conclusions are drawn as follows:

- The SiO_2 is the main ingredient with Al_2O_3 , Fe_2O_3 , MgO in MCBAP. The total percentage of SiO_2 , Al_2O_3 and Fe_2O_3 was 86.09 %. It is good for low calcium pozzolanic materials.
- The SEM observation found that MCBAP is porous, irregular shape, black colored materials.
- The water demand, IST and FST are increased with addition of MCBAP with OPC. Moreover, the addition of MCBAP with OPC weakened the micro structural properties, decrease the matrix density of mortar that lowers the compressive strength.
- Compressive strength developing rate reveal that a lower rate of strength development from 7 to 28 days compared with 28 to 90 days reaction time.

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