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Use of Incineration Solid Waste Bottom Ash as Cement Mixture in Cement Production

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Abstract. Incineration solid waste bottom ash was use to examine the suitability as a substitution in cement production. This study enveloped an innovative technology option for designing new equivalent cement that contains incineration solid waste bottom ash. The compressive strength of the samples was determined at 7, 14, 28 and 90 days. The result was compared to control cement with cement mixture containing incineration waste bottom ash where the result proved that bottom ash cement mixture able achieve its equivalent performance compared to control cement which meeting the requirement of the standards according to EN 196-1. The pozzolanic activity index of bottom ash cement mixture reached 0.92 at 28 days and 0.95 at 90 and this values can be concluded as a pozzolanic material with positive pozzolanic activity. Calcium hydroxide in Portland cement decreasing with the increasing replacement of bottom ash where the reaction occur between $\text{Ca}(\text{OH})_2$ and active SiO_2 .

1. Introduction

Today incineration solid waste (ISW) such as blast furnace slag, fly ash, silica fume, limestone, and natural pozzolans are widely used in construction field. The use of ISW helps to utilize by products of industrial manufacturing processes and reduced the amount of cement required while convert waste materials into value added products [1]. Each of the ISW possesses different properties and presents potential use for cement and concrete industry by reacts differently in the presence of water while reduce the dependency on Portland cement and also replace part of the clinker to enhance the performance of the hydrated cement [2,3]. Many ISW have been successfully used as cementing materials where this application would be the future trend in cement industry [4].

The amount of ISW bottom ash (BA) mainly come from major portion of the waste combustion products that generated from combustion furnace and accounting for 20-30 wt.% of the original waste



[5][6][7]. ISWBA is a coarse, fused, glassy texture, and granular material make it an ideal substitute for natural aggregates. It also often used as low cost replacement for sand in concrete blocks and based in road construction [8]. Anyway, the quality and chemical composition may vary due to the coal used and technology applied especially the temperature during the combustion process. Furthermore, disposing the ash efficiently and economically is very challenging else these ashes gone to the landfills causing wastes of land resources and environmental pollution problems.

In cement industry point of view, use of ISWBA in large scale is beneficial to sustainable development and environmental friendly which could partially reduce its carbon footprint and reduce high energy of cement manufacturing. Studies of the utilization of ISWBA to produce ecofriendly Portland cement are gaining attention in relation to recycle and reuse of these materials [9]. This paper shows most significant results on analyzing and evaluating the material with mechanical properties of cement containing ISWBA. Little attention has been given to the possibility of ISWBA to be utilized in Portland cement. Optimization of ISWBA content into cement mixture to produce the desired strength according to standard is needed and the result shown in this study is optimistic and possible to promote the use of ISWBA in large quantities and could technically apply in cement industry. The compressive strength, pozzolanic strength activity index, and phase analysis of ISWBA cement mixture are reported and compared with controlled Portland cement in this paper.

2. Materials and Methods

The bottom ash that used in this study was located in Manjung Coal-Fired Power Station, Lumut, Perak, Malaysia and the plant is composed of three identical incineration rotating speed lines for a total capacity of 2100MW per day. The cement used in all the mixtures was from Cement Industries of Malaysia Berhad (CIMA). In order to mix equally with Portland cement, ISWBA was undergo milling to less than 150um to increase the surface area and enhancing chemical reactivity.

Cement was replace by ISWBA with simple volume replacement where five different mixture including a reference mortar with 10%, 20%, 30% and 40% replacement ratio. The water to cement ratio was fixed at ratio 0.5 in all the samples where the details of mixes proportion are shown in Table 1. By the way, there is a plain cement sample without ISWBA that serves as control sample. Cement mortar samples was casted and mix until homogeneous by molded in 50 x 50 x 50mm³ molds. The samples were demolded after 24 hours to ensure the sufficient strength for demolding and then put in curing tank until the curing age reach at 7, 14, 28, and 90 days.

The best possible performance in term of optimizing the mixture composition can be through different ISWBA composition and choose the best combination by comparing the desired characteristic and properties of cement. The method of choosing the optimization mixture in this study is based on the minimum requirement of standard EN 196-1.

Table 1. Mix proportions of different curing day.

ISWBA content (%)	w/c ratio	Water (kg/m ³)	Cement (kg/m ³)	ISWBA (kg/m ³)
0	0.5	270	540	0
10	0.5	270	486	54
20	0.5	270	432	108
30	0.5	270	378	162
40	0.5	270	324	216

3. Results and discussions

3.1. Compressive strength

Compressive strength is the critical parameter to determine the design process and influence the cost of cement industry. In this study, the compressive strength were conducted accordance to ASTM C109 where the compressive strength increased with curing time for all the series. With the progress of curing ages, compressive strength of ISWBA cement mixture increase at a faster rate after 7 days of curing. Fig. 1 shows all the series of mixtures and the control mixture generally produced highest compressive strength at age of 7, 14, 28, and 90. The compressive strength of 10% substitution of ISWBA into Portland cement mortar (33.62MPa, 35.24MPa) was lower than control Portland cement (36.52MPa, 37.23MPa) but the difference of compressive strength was less distinct on 28 days of curing where the value was comparable for 90 days of curing. The compressive strength development with addition of 40% ISWBA at 7, 14, 28, and 90 days experienced a decline in compressive strength by 59.4%, 63.9%, 30.4%, 25.5% respectively compared to control Portland cement.

It is believe that the addition of ISWBA in Portland cement may altered the nature of hydration phases. The compressive strength of 10% ISWBA reaching 92.1% in the 28 days curing was slightly higher than commercial cement according to EN 196-1 and classified as class 32.5 or 32.5R Portland cement. This finding proved that ISWBA suitable to substitute in Portland cement as cementitious material. Besides that, fine particles of ISWBA absorbed largest portion of cement paste to ensure the texture and compactness of the mixture through providing nucleation sites for the hydration of C_3S and C_2S while accelerating the hydration process and enhances the inter particle friction on the flow of the mortar [10]. Furthermore, it also enter the spaces that exist between the particles of cement to improve the packing and contribute to the formation of C-S-H which it is the main contributor compound of strength development [11].

Partial replacement of ISWBA into Portland cement reduced the proportion of primary hydration reactant ($(CaO)_3.SiO_2$, C_3S) and dicalcium silicate ($(CaO)_2.SiO_2$, C_2S), the reduction of C_3S and C_2S led to insufficient formation of Ca/Si C-S-H which causing retardant of hydration process [12] and the result is expected to display lower mechanical strength since the reduction of C-S-H compounds of ISWBA cement mixture samples. This result indicates that the addition of ISWBA was not able to promote the mechanical strength but only bring dilution effect to the hydrate system and retard the cementitious reaction. Hence, it can be concluded that more cement in the composition leads to higher early strength and the best composition is 10% ISWBA replacement.

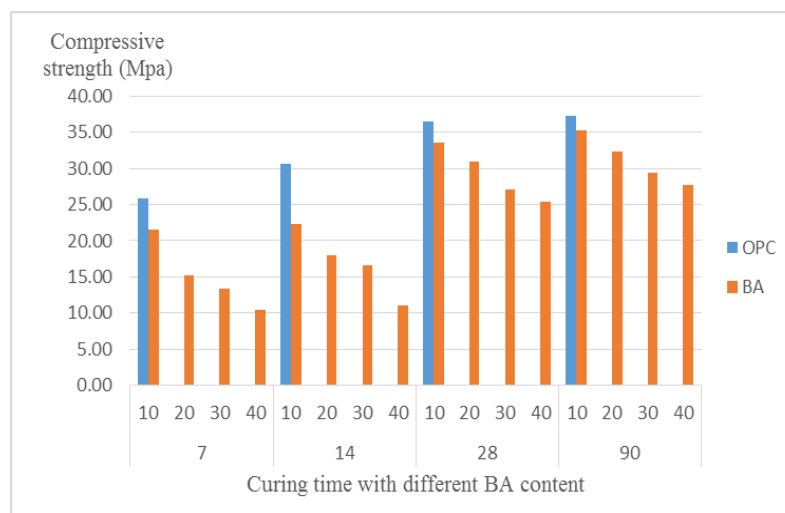
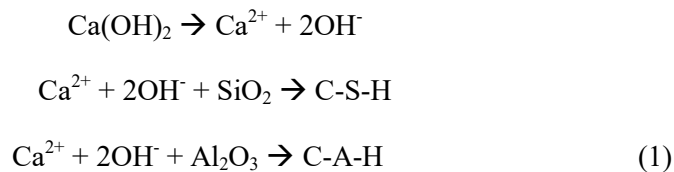


Figure 1. Compressive strength of Portland cement and various bottom ash content with different curing time.

3.2. Pozzolanic Activity Index (PAI)

Pozzolanic activity index defined as percentage of compressive strength compared to the control where the index that greater than 0.75 at 28 days and 0.85 at 90 days consider as a positive pozzolanic activity according to ASTM C618 and ASTM C311. A test of pozzolanic activity is considered a suitable means of evaluation the strength contribution potential of a mineral admixture [13].

The summation of silica (SiO_2), aluminium oxide (Al_2O_3), and iron oxide (Fe_2O_3) is more than 70% can be assumed as pozzolanic materials with pozzolanic activity [4,14] whereas these compounds are the major components in ISWBA [15]. In this study, fine particles of ISWBA react with calcium hydroxide and produce C-S-H gel. After long curing period, the reactive silica in ISWBA reacts with alkali calcium hydroxide that produced by the hydration process of cement and forms calcium silicates and aluminate hydrates, these are the new reaction products that exhibited binding character as shown in Equation 1. This could be explained from the PAI value which the 90 days of curing is higher 2.7% than 28 days indicated that PAI increases slightly with age as can be seen in Fig. 2. Thus, the pozzolanic reaction can contribute to strength development as a function of curing time where the higher the value of PAI indicates that the good reaction between ISWBA and Portland cement.



However, the pozzolanic properties of ISWBA was very weak and causes the mechanical properties always lower than Portland cement for the mixture of ISWBA that investigated in this study. The reduction in mechanical strength was due to cement dilution which the addition of ISWBA might not counterbalanced to the mechanical properties of Portland cement. Anyway, pozzolanic activity in the ISWBA make it possible to be used as replacement material for Portland cement and its addition could have a beneficial role in the development of hydrated cement paste.

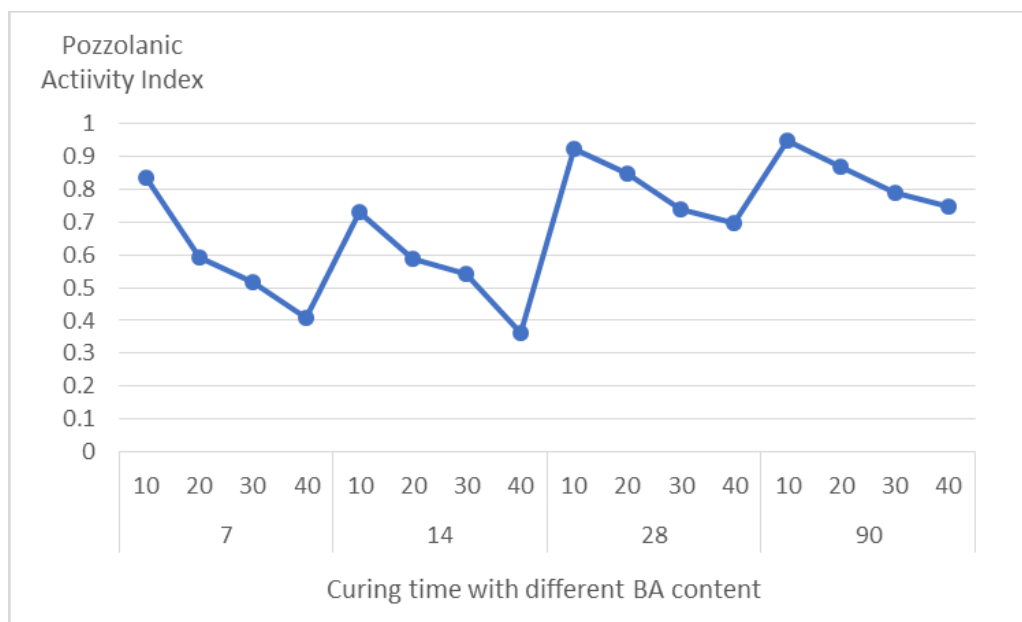


Figure 2. Pozzolanic activity index of ISWBA in Portland cement mortar.

3.3. Phase analysis

The XRD analysis was carried out with 2θ scanning ranging between 10° to 70° by 1s counting time after 90 days of curing and presented in Fig. 3. The Portland cement phase was compared with ISWBA cement mixture. According to the result shown in Fig. 3, portlandite, calcite, dicalcium silicate, and quartz was observed as main hydration products. For 10 and 20% of ISWBA replacement, the amount of portlandite produced was lower because the amount of Portland cement was reduced. Hence the hydration of calcium silicate phases also reduced subsequently. The relative decrease of CaCO_3 peaks and increases of C-S-H peaks intensity even at higher level of cement was due to the reaction occur with $\text{Ca}(\text{OH})_2$. Whereas for 30% and 40% ISWBA replacement mixtures, there was some silica that did not react with Portland cement.

There are phase composition change in the 10-40% in ISWBA cement mixture was observed in the XRD spectrum indicates that the absolute intensities of portlandite peaks of ISWBA cement mixture was lower than control Portland cement. Assuming the peak intensity of portlandite is equal to the amount of the Portland cement, the lower peak intensity of portlandite indicates that the influence of quantities of ISWBA is significant. Portlandite produced is the product of cement hydration and also the result of pozzolanic reactions of ISWBA and it forms phases of C-S-H with the silica from ISWBA.

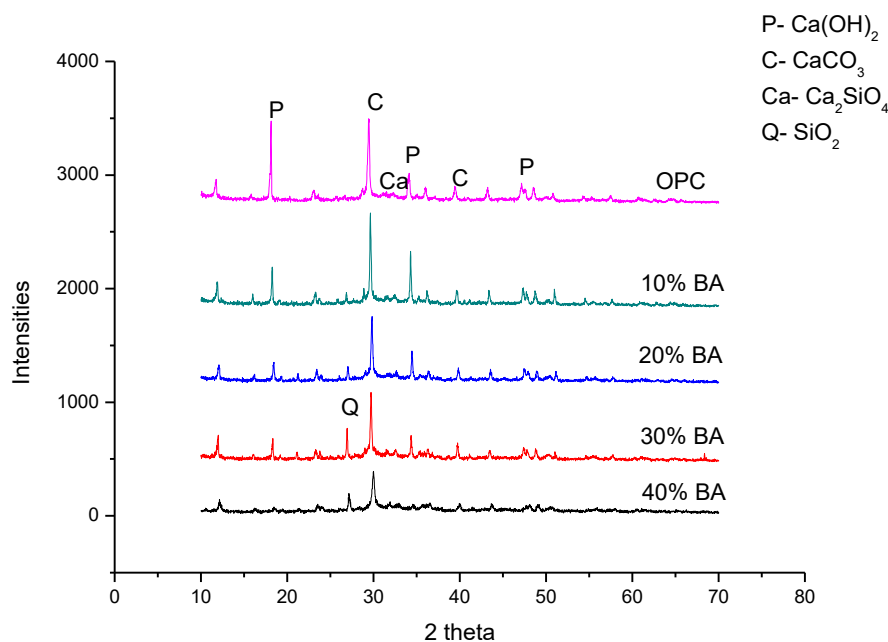


Figure 3. Phase analysis of ISWBA cement mixture.

4. Conclusion

The result of this study leads to good improvement by using large replacement of ISWBA through simple and beneficial way to industrial application.

It can be concluded that up to 40% replacement level can be used in Portland cement and there is no significant negative effect on strength properties at any curing age. The compressive strength of ISWBA cement mixture are gradually decreased with the addition amount of ISWBA. At 7 and 14 days, all mixes showed the compressive strength test lower than control, but as the curing age increased to 28 and 90 days, all mixes showed almost comparable strength result to control. The compressive strength is meeting the requirement for commercial cement of class 32.5 or 32.5R class as per EN 197-1.

The pozzolanic activity of ISWBA is relatively lower and it might delay the hydration process of cement at early curing age. The pozzolanic activity index reached 0.92 at 28 days and 0.95 at 90 days for 10% replacement ISWBA, such values allow and confirm the use of ISWBA in Portland cement and can be concluded as a pozzolanic material with positive pozzolanic activity. For phase analysis, main hydration products such as portlandite, calcite, dicalcium silicate, and quartz was observed.

Calcium hydroxide ($\text{Ca}(\text{OH})_2$) in Portland cement decreasing with the increasing replacement of ISWBA where the reaction occur between $\text{Ca}(\text{OH})_2$ and active SiO_2 in ISWBA. The peak intensity of portlandite is equal to the amount of the Portland cement, the lower peak intensity of portlandite indicates that the influence of quantities of ISWBA is significant.

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