THE USE OF FLY ASH AND BOTTOM ASH IN GEOPOLYMER MORTAR

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ABSTRACT

This experimental research focused on utilizing fly ash as source material and bottom ash as partial sand (fine aggregates) substitution in geopolymer mortar. Both of these products of combustion were obtained from Sejingkat coal fired power plant in Kuching. The effects of inclusion of bottom ash to partially replaced sand in geopolymer mortar on the mixture water demand and mechanical property were investigated with fixed flow. With 10% of sand substitution by bottom ash, the influences of the following quotients by mass on flow and compressive strength were studied: liquid alkaline to fly ash ratio, extra water to fly ash ratio, extra 12M potassium hydroxide (KOH) to fly ash ratio and the superplasticizer (SP) to fly ash ratio. Besides, the effect of mixing procedures on compressive strength of potassium activated geopolymer mortar was also being studied. Inclusion up to 50% of sand replacement by bottom ash in the geopolymer mixtures with 110± 5% fixed flow decreased the extra water demand of the fresh mortars. Further substitution beyond 50% increased the water requisite to maintain the flow within the addressed range. More bottom ash content has resulted in decreasing maximum sustainable compressive load per unit area of the mortars. Additions of liquid alkaline by mass of fly ash quotient linearly increased the flow of the geopolymer mortars; with duly rise in strength relative to the control sample due to boosted geopolymerisation process. The incorporation of extra water was more efficient than modified polycarboxylate superplasticizer in terms of flow improvement, with similar slight reduction in the strength at 7 days on account of the increased in liquid content. However, the mortar incorporated with the superplasticizer possessed superior compressive strength at 28 days over the mortar added with extra water. Additional extra 12M KOH has been effective in improving the flow of the control sample and inclusion of extra KOH/FA ratio by mass up to 0.06 has increased the maximum stress the specimen mortars can withstand under crush loadings. Incorporation beyond the ratio led to deterioration in the compressive strength. Premixing of fly ash with KOH solution has complimentary effect over the normal mixing sequence on the compressive strength of the geopolymer mortars.

Keywords: *fly ash, bottom ash, geopolymer, compressive strength, workability*

INTRODUCTION

Extensive consumption of natural sources, massive amount production of industrial wastes and environmental pollution require new solutions for a more sustainable development. The use of modern day cement contributes to two billion tonnes of Carbon Dioxide (CO_2) annually into the atmosphere, which makes it the third largest man-made source of CO_2. The production of cement is responsible to produce one ton of Carbon Dioxide per one ton of cement produced and the cement manufacturing industry is causative to contribution of 7% of global CO_2 emission, which is one of the greenhouse gasses that causes climate change due to global warming. Besides, production of cement is energy intensive and is only succeeding to steel and aluminium production [1].

Meanwhile, the growth of the coal fired power plant industry produces flue gases from hydrocarbon combustion that generates extensive particulate emissions such as fly ash and bottom ash as waste products. Fly ash is finer in particle size, flies out with flue gas whereas coarser grain of bottom ash falls to the bottom of the boiler. These solid waste ashes from coal fired boilers have previously been dumped into the landfill that contributes to the subsequent environmental contamination. Sejingkat Coal Fired Power Station in Sejingkat, Kuching with 4x50 MW produced 80,000 tons of fly ash annually [2]. About half of the fly ash produced was transported to Bakun Dam construction and the remaining fly ash and bottom ash from the power station were dumped into a 81,000 m^2 area and 2.4 m deep ash pond situated next to the power station [2-4]. Currently there are two ash ponds and the first pond was fully filled [2]. Hence, green demands are raised for alternative ways to utilize the ashes to mitigate further environmental pollution by copious uncontrolled disposal of the coal ashes into the landfills.

Due to fly ash's property which has strong silica alumina glassy chain, it has been used as supplementary cementing material to substitute Ordinary Portland Cement (OPC). It has already been used as a pozzolana for a long time with cement due to its pozzolanic properties[5]. Strong alkali activators are used to break the sturdy silica alumina chain to enhance polymeric process of fly ash to form cementitious binder. This process was termed "Geopolymer" by Davidovits [6]. This geopolymer technology could reduce approximately 80% of CO_2 emission contributed by the cement and aggregate industry [7].

So far, there are still limited studies on the use of bottom ash as fine aggregates to partially replace sand in fly ash-based geopolymers. Bottom ash is widely utilised as an aggregate substitute in OPC concrete and studies had been done by researchers to investigate on the effect of the bottom ash inclusion [8-12]. Chindaprasirt et. al revealed the comparative study on the characteristic of fly ash and bottom ash-based geopolymers in their paper [8]. Hardjito et. al. utilised fly ash as source material in their studies [13-16] and Sathonsaowaphak et. al. used lignite bottom ash as supplementary cementing material in their geopolymer specimen mortars [17]. Fung [18] has done a research on fly ash-based geopolymer mortars with bottom ash as fine aggregates to partially replaced sand. In his research, the effect of the incorporation of bottom ash as partial sand replacement was studied without fixing the flow. The flow of the designed mixture increased and later decreased with the increment of bottom ash content from 0% to 100%. Previous researches had also shown that some superplasticizers were inefficient in improving the flow [16, 17, 19] or have detrimental effect on the later strength of the OPC concrete or geopolymers [20].

In this paper, we will be reporting on the effects of the inclusion of bottom ash and addition of extra alkaline solutions on fly ash-based geopolymer mortars with bottom ash as partial sand replacement. Alternative ways to improve flow of stiff mortars and effect of mixing sequence upon preparing the geopolymer mixtures were also being investigated and will be reported and evaluated in this paper.

In general, this research is dedicated to contribute in the benefaction of promoting environmentally sound products as alkali activated geopolymer offers a possible solution to deal with by-product materials, extensive energy consumption, and carbon dioxide emissions.

PREVIOUS RESEARCHES

Bottom ash (BA) is a waste material generated from coal-fired thermal power plants. Bottom ash being in contrast to fly ash, usually has much lower pozzolanic property which makes it unsuitable to be used as a cement replacement material in concrete. However, as its particle distribution is similar to that of sand which makes it attractive to be used as a sand replacement material [21]. Also according to Andrade et. al. [9], bottom ash plays an efficient filling role to fill up voids in the concrete specimens. It is therefore a suitable material to be used as fine aggregates for the replacement of natural sand.

Suwanvitaya et. al. had done researches to utilise Mae Moh bottom ash as fine aggregate (natural sand replacement) to examine its effect on the compressive strength of mortar mixes. The authors revealed that the compressive strength of the mortars decreased with the increase in bottom ash content [22]. Previous experiments [11, 21] have shown that with fixed water-cement (W/C) value, the increase of sand replacement by bottom ash by mass increased the slump of the fresh concrete; whereas the free water content to decrease with the specimens prepared with fixed slump value. The authors have proved that with different level of substitution of sand by bottom ash and with fixed slump value, compressive strength of the concrete specimens increased with the increment of substitution level from 0% to 100% as an attribute of decreased in W/C value.

Workability has been an important property to fresh mortars or concretes for the ease in handling and compacting to obtain well compacted hardened mass. Inclusion of water helps to significantly increase the flow of the mixes to reach the most desirably workable flow with the least reduction of its later strength [17]. As an alternative to the addition of water to improve the flow, addition of extra NaOH solution to improve workability was effective, with the reduced sodium silicate to NaOH ratio by mass and the increase in liquid content of the mix [17].

Superplasticizer can be used as high range water reducers to produce flowing concrete without affecting the workability for fabrication of higher strength concrete. Previous study has shown that Type F melamine formaldehyde SP caused some undesirable effects on the strength of the geopolymer concrete [20]. The use of naphthalene-based superplasticizer (NSP) in the geopolymer system activated by NaOH and sodium silicate solutions in order to improve workability was found to be not helpful [17] such that addition of water with similar amount is sufficient to increase the flow with comparable effect on the strength.

MATERIALS AND EXPERIMENTAL DETAILS

Materials

The source material which is the fly ash being used in this experiment is low calcium (ASTM Class F) fly ash. It was obtained from Sejingkat Coal-Fired Power Station. The main coal used in the power station is predominantly supplied from the coal mine in Merit Pila, Kapit, Sarawak, Malaysia. Specific surface area and particle density of the fly ash are 1.51 m^2/ml and 2370 kg/m^3 respectively. The chemical composition of the fly ash, as determined by X-Ray Fluorescence (XRF) analysis is shown in Table I. The mass ratio of SiO_2 to Al_2O_3 of the fly ash used is 2.34.

Bottom ash used in this experiment was also obtained from Sejingkat Coal-Fired Power Station. Relative density of the bottom ash is 2.23 with fineness modulus of 0.14. The bottom ash was prepared with 21% moisture content and river sand in saturated surface-dry (SSD) condition were used as fine aggregates in this experiment. Fineness modulus and relative density of the sand is 1.29 and 2.65 respectively.

Sand and bottom ash that was pre-prepared prior to the experimental work were kept in plastic bags and sealed to prevent change in the moisture content.

Table 1 : Chemical Composition of Fly Ash

Elements	% mass
SiO_2	58.0
Al_2O_3	24.8
Fe_2O_3	7.17
K_2O	3.14
CaO	2.40
MgO	1.95
TiO_2	1.05
P_2O_5	0.34
Na_2O	0.30
MnO	0.18
SO_3	0.08
LOI	0.32

To activate the fly ash, a combination of potassium hydroxide solution and potassium silicate solution were chosen as the alkaline activators. This is because according to Palomo et. al. [23], geopolymers or alkali activated mortar which contains only hydroxides revealed in a lower reaction rate than the mortars activated by both hydroxides and soluble silicates. Also potassium-based activator was able to produce a comparatively higher strength than the sodium-based activator [24].

Specimen Composition

The detail of the mixture proportion was shown in Table II.

- **Series A:** To examine the effect of the content of bottom ash on water demands and compressive strength of fly ash based geopolymer mortars with fixed flow of 110 ± 5%. The control sample is the mortar with 0% substitution of sand by bottom ash.

- **Series B:** To determine the effect of the liquid alkaline to fly ash ratio on workability and compressive strength of fly ash based geopolymer mortars with 10% sand replacement by bottom ash. The control sample is the mortar with 0.325 liquid alkaline to fly ash ratio.
- **Series C, D and E:** To study the improvement on workability with additions of extra water, 12 M of KOH or superplasticizer respectively and their effect on the compressive strength of the fly ash based geopolymer mortars with 10% of sand replacement by bottom ash. The control sample is the mortar with 0.429 liquid alkaline to fly ash ratio and with no additional liquid.
- **Series F:** To determine the effect of mixing procedure for preparing geopolymer mortar. This test series has the same mixing proportion as well as curing regime with test series B which were prepared with normal mixing procedures.

Table 2 : Mass ratios of mixture of fly ash based geopolymers

Series	**Mixing Sequence**	**Level of Sand Replacement by BA (%)**	**Liquid Alkaline/FA ratios**	**Extra Water/FA ratios**	**Extra 12M KOH/FA ratios**	**SP/FA ratios**
A	N	0, 25, 50, 75, 100	0.429	0	0	0
B	N	10	0.325, 0.429, 0.518, 0.597, 0.709	0	0	0
C	N	10	0.429	0, 0.01, 0.03, 0.06, 0.09	0	0
D	N	10	0.429	0.03	0, 0.01, 0.03, 0.06, 0.09	0
E	N	10	0.429	0.03	0	0, 0.01, 0.03, 0.06, 0.09
F	S	10	0.325, 0.429, 0.518, 0.597, 0.709	0	0	0

Note: All mixtures are prepared with KOH to potassium silicate ratio of 1.0

Specimen preparation

All the geopolymer specimens in this experiment were made with fine aggregates to sand ratio by mass of 2.75. Mixing was carried out in an air conditioned room with a temperature of 25 ± 2 ˚C to eliminate possible effect of temperature variation. Saturated surface dry (SSD) sand and bottom ash of 21% moisture content were prepared in advance and kept sealed in plastic bag for later use.

The normal mixing (herein after being denoted as “N”) and casting procedures in making of the geopolymer mortar involved dry mixing of fly ash, sand and bottom ash in a Hobart mixer for 2 minutes. For series B, C, D and E, the alkaline activators (KOH and potassium silicate) and other liquids (extra water, 12 M KOH or Superplasticizer) were then mixed together in another mixer for another 2 minutes. This was then followed by the addition of the premixed dry ingredients into the liquids for combined mixing of 10 minutes. For series A with fixed flow, extra water (after each addition of water to mix for another 2 minutes) was added if necessary after the 10 minutes combined mixing to adjust the flow to 110 ± 5%.

For separate mixing procedures (herein after being denoted as “S”) designed for series F, fly ash was pre-mixed with KOH for 10 minutes to allow leaching of ions. Potassium silicate solution, bottom ash and sand were then added to the mixture and mixed for another 10 minutes. Further mixing of potassium silicate solution, bottom ash and sand for 10 minutes were designed to correspond to the time of exposure to sodium silicate solution for normal mixing.

The 3 gang moulds were greased in advance and the mixture was then poured into the 50 x 50 x 50 mm specimen moulds. After all the specimens were cast in moulds, the specimens were sent to the vibrating table for 2 minutes to remove air voids. Final touch-up was done after on using a trowel to cut off overflowing mortar.

All the moulds were then sent to the oven for curing at 60˚C for 24 hours. The specimens were taken out from the oven after 24 hours and were left standing in the room temperature for at least 6 hours before demoulding to prevent drastic change in the temperature difference that leads to thermal cracking. As a rule of thumb, the maximum temperature difference between the interior and exterior of the specimens should not exceed 25˚C [25] by leaving the mortar in the oven after 24 hours of curing to allow gradual cooling. The specimens were then kept in the ambient temperature until the age of testing.

Specimen Testing

Workability test: The workability of the fresh concrete was measured using the flow table in accordance with ASTM C1437 - 07. The flow is expressed as a percentage of the original base diameter of the conical mould.

Compressive strength test: ASTM C 109 which specifies the standard procedures used to determine the compressive strength of the hydraulic cement mortars was used to determine the compressive strength of the specimens in this research. The compressive strength was measured by crushing 50 mm cubes using the Universal Testing Machine. The loading rate used was 90 kN/min. The compressive strength of the geopolymer mortars was determined as the ages of 7 and 28 days and the reported strength was the average of 3 tests.

RESULTS AND DISCUSSIONS

Workability

Bottom Ash Content

Mortars for series A were prepared with a fixed flow of 110± 5% by adding in extra water, when necessary. Figure 1 shows that the addition of bottom ash into the mixture increased the overall water content at a fixed flow of 110± 5%. The figure was plotted with the summation of total moisture content in the bottom ash (21%) and extra water required to reach a flow of 110± 5% against bottom ash content. On the other hand, Figure 2 was plotted with the total extra water required to be incorporated into the mixture to achieve the designated flow against bottom ash content. With 0 to 50% level of sand replacement by bottom ash, the mixtures were maintained within the flow range by reducing the amount of extra water.

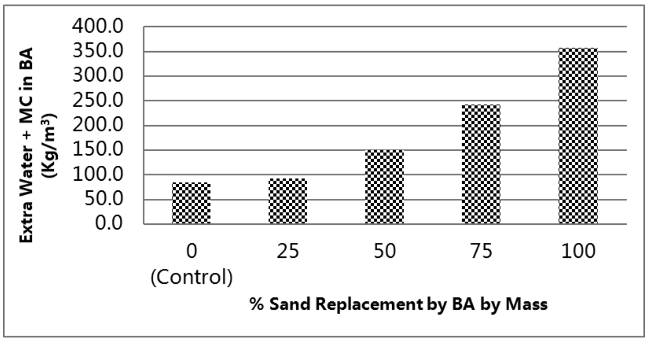

Figure 1 : Extra Water Content with Additions of 21% Moisture Content in BA in Geopolymer Mortar with Varying Level of Sand Substitution by BA at Fixed Workability

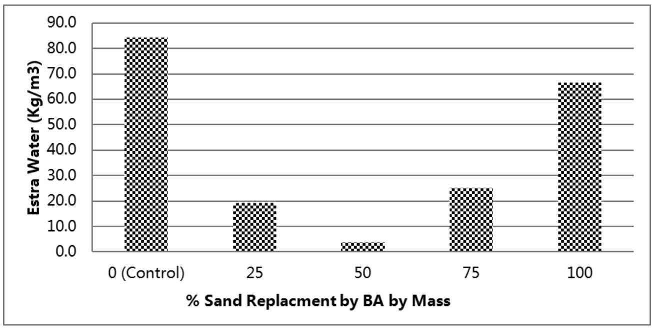

Figure 2 : Effect of Bottom Ash Content on Extra Water Demand at Fixed Workability

This result of flow corresponding with the increase in bottom ash content was akin to the results revealed by Fung [18]. In his research which the flow of the mortar was not fixed, the addition of bottom ash by percentage of sand replacement from 0 to 100% has shown an initial increase in flow up to a certain percentage where further inclusion of the ash decreased the flow. This indicates that the water demand actually reduced with the increase of bottom ash content before it started to decline. This is also in agreement with the results revealed by Bai et. al. and Kou et. al. [11, 21] that with fixed slump or flow, the water demand decreases with the increment of bottom ash content in the designed mixture. This is due to the properties of bottom ash which allow it to behave like a water reservoir that retains water and later released it back into the mixture during mixing, therefore decreased the water requirements to achieve the required workability.

However, the water demand ceased to decline after the sand replacement level of 50% of which Figure 2 indicates a gradual increase of extra water in order to maintain the fresh mortar flow of 110 ± 5%. The consensual reason behind this depolarization is the irregular particle shape and rough surface texture of bottom ash that contribute to high inter-particle friction which reduced the workability of the mixture when too much bottom ash was included [26, 27]. Higher amount of water is then necessary to achieve the required degree of workability.

Liquid Alkaline to Fly Ash Ratio by Mass

Figure 3 shows the effect of the liquid alkaline to fly ash ratio by mass on workability of the fresh geopolymer mortars. It indicates the results from test series B that shows a considerably linear increase in the flow of the fresh mortars with the increase in the quotient values. Mortars with liquid alkaline to fly ash ratio of 0.325 were very stiff with no flow. The workability significantly increased with more content of KOH and potassium silicate with reference to the control sample.

Total mass of water in a designated mixture is inclusive of the water in the liquid alkaline [15]. Sathonsaowaphak et. al. [17] claimed that the increasing amount of liquid alkaline in the mixture, subsequently increased the water content in the reaction medium that provides a larger room between the particles and reduced the friction action between them when they flow.

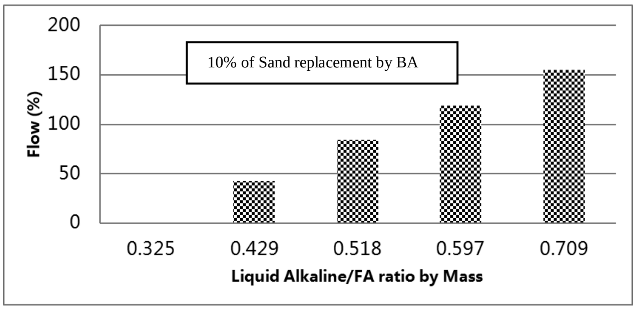

Figure 3: Effect of Liquid Alkaline to Fly Ash ratio by Mass on Workability

Extra Water to Fly Ash Ratio by Mass

Figure 4 shows the effect of addition of extra water on the flow of fresh geopolymer mortars. As shown in the figure, the flow for control specimen which was the mortar with no addition of extra water was very stiff. Thus several tests with different amount of extra water by mass of fly ash incorporated into the mixtures were carried out with intention to enhance the flowability of the sample mortar.

The addition of extra water into the design mixtures has considerably increased the flow of the fresh mortar. Incorporation of extra water with only 1% by the mass of fly ash has drastically increased the flow of the control specimens by 22%. Addition of extra water from 3% to 9% of fly ash mass resulted in a flow ranging from 81.5 to 115.8% which was highly desirable. The incorporation of extra water has thus shown good indication in effectively improving the flow of the fresh mortars.

Extra 12M KOH to Fly Ash Ratio by Mass

As another alternative to addition of extra water to improve the workability of the mortar mixture, extra 12M of KOH was being added into the mixtures to study its efficiency in reducing the stiffness of the flow. Flow of the mortars increased with the addition of extra KOH as indicated in Figure 4. The increment in flow however was not as much as the case with the inclusion of extra water. Incorporation of KOH increased the liquid content in the mixture thus resulting in improved flow.

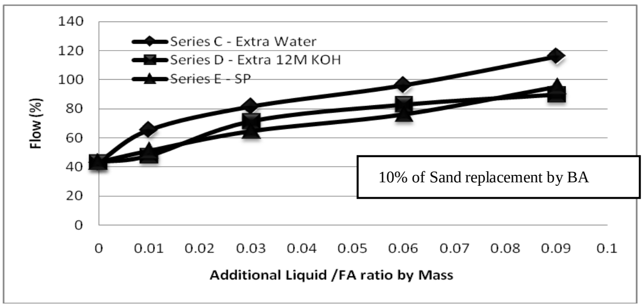

Figure 4: Effect of Additional Liquid to Fly Ash ratios by Mass in improving workability of Geopolymer Mortar

Superplasticizer to Fly Ash Ratio by Mass

A third generation of modified polycarboxylate superplasticizer suitable for both concrete and mortar use was incorporated into the mixtures for series E to investigate the effect of this particular type of superplasticizer on the flow of the fresh geopolymer mortars. Results plotted in Figure 4 revealed that the superplasticizer improved the workability of the mixture in correspondence with the increase in SP/FA ratio.

It was claimed by Sathonsaowaphak et. al. [17] that the improvement in workability upon addition of naphthalene-based superplasticizer was a result of the increase in water content of the mixtures from the superplasticizer solution. Meanwhile, Chindaprasirt et. al. [20] had concluded that type F melamine formaldehyde superplasticizer was not effective in improving the workability of the fresh geopolymer mortars. Conversely in this test series, it is shown that the modified polycarboxylate superplasticizer was efficient in improving the flow of the geopolymer mortar with the increase in incorporation of superplasticizer by mass of fly ash up to the ratio of 0.09.

Compressive Strength

Bottom Ash Content

Figure 5 reveals the decreased in compressive strength of mortar from 0% to 100% of sand replacement by bottom ash for compressive strength on 7 and 28 days. With fixed flow of 110±5%, extra water was added into the mixture to alter the flow to reach the targeted workability range. As discussed earlier, the total water content in the geopolymer mixes increased with the increasing level of replacement by bottom ash. As more water is available to be dried out, more pores will be left behind and weak matrices will be formed, thus deteriorate the mechanical strength of the hardened geopolymer mortar. Also, the decrease in strength was as a result of diluted alkaline solutions that deferred the geopolymerization process.

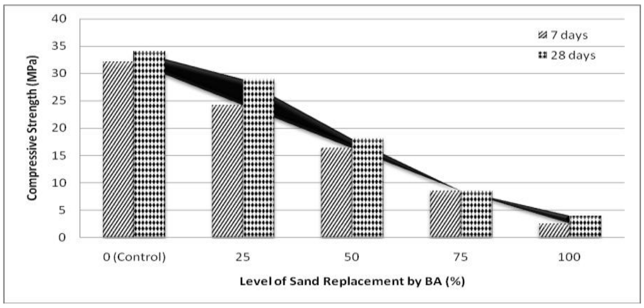

Figure 5 :Effect of Bottom Ash Content on Compressive Strength with Fixed Flow

Liquid Alkaline to Fly Ash Ratio by Mass

With the results revealed in this test series, it can be seen that both the compressive strength on the 7 and 28 days of the mortar specimens increased with the increase of the liquid alkaline content by mass of fly ash. For the compressive strength of the geopolymer mortar at the age of 28 days, the increase was relatively more drastic than the 7 days' for the liquid alkaline to fly ash ratio beyond 0.518 as illustrated in Figure 6. The increment of samples strength is believed to be mainly due to the increased in K ion and water molecules which are the basic ingredients for geopolymerization [28] that enhances the dissolution and reaction of the geopolymer mortars that eventually increases the final compressive strength.

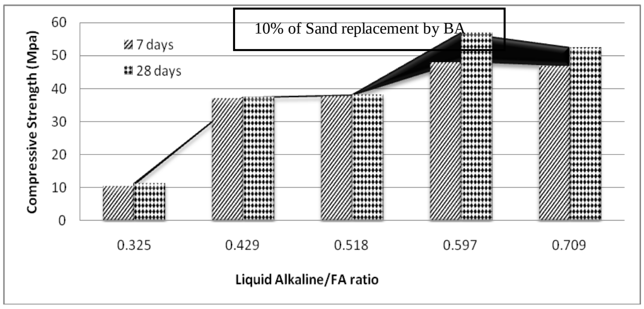

Figure 6: Effect of Liquid Alkaline to Fly Ash ratio by Mass on Compressive Strength

Extra water to Fly Ash Ratio by Mass

It can be seen from Figure 7 and Figure 8 that the addition of extra water by 1% of the total mass of fly ash has effectively improved the compressive strength of the control sample. The control sample has comparatively dry and stiff mixture which had become the limiting factor for the strength development of the geopolymer mortar due to difficulty in compaction. Thus, with addition of extra water the workability of the stiff mortars significantly improved and the geopolymerization process enhanced to result in strength gain.

However, further increment of extra water content beyond 1% reduced the compressive strength. The outcome from this test was in agreement with the results reported by Sathonsaowaphak et. al. [17]. The authors have claimed that the additional water would dilute the alkaline solutions that directly delayed the geopolymerization process. The strength gain after 7 days for mortars with extra water to fly ash ratio of 0.03, 0.06 and 0.09 was minimal. However their compressive strength at both 7 and 28 days remained rather constant with the control samples which indicate inconsequential drop in strength with additions of extra water within the specified range. Therefore, it can be claimed that the inclusion of extra water to improve the flow has very little effect on the compressive strength of the geopolymer mortar for the extra water to FA ratio up to 0.09.

Extra 12M Potassium Hydroxide to Fly Ash Ratio by Mass

As shown in Figure 7 and Figure 8, addition of extra 12M of KOH by 1% of the mass of fly ash has effectively improved the compressive strength of the control sample. The control samples having a comparatively dry and stiff mixture, with addition of extra KOH resulted in improved workability and at the same time promote significant strength gain as an effect of improved geopolymerization process.

The results indicate that the addition of extra KOH up to 6% by mass of fly ash (i.e. extra KOH/FA ratio of 0.06) increased the compressive strength of the hardened geopolymer mortar. Further addition of KOH solution beyond 6% has caused drastic drop in compressive strength of specimen especially for the strength on the 7 days as shown in Figure 7. Higher amounts of hydroxyl ions facilitate the dissociation of different silicate and aluminate species, promoting thus further polymerization [29]. However, if a very high alkaline environment (>30 mol% overall Na_2O content) is used, the connectivity of silicate anions may be reduced resulting thus in poor polymerization [30]. This may explain the drop in strength for both 7 and 28th day strength of mortars with incorporation of extra KOH/FA ratio more than 0.06 by mass.

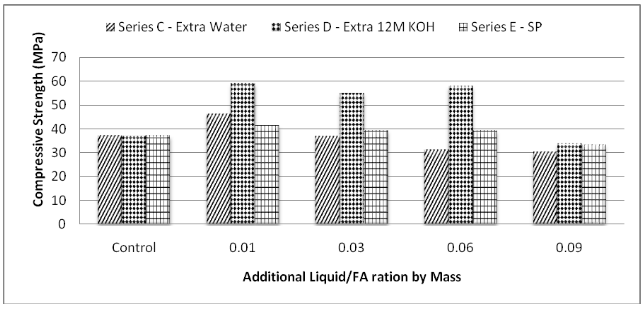

Figure 7 : Effects of Additional Liquid to Fly Ash ratios by Mass on the 7 days Compressive Strength of Geopolymer Mortar

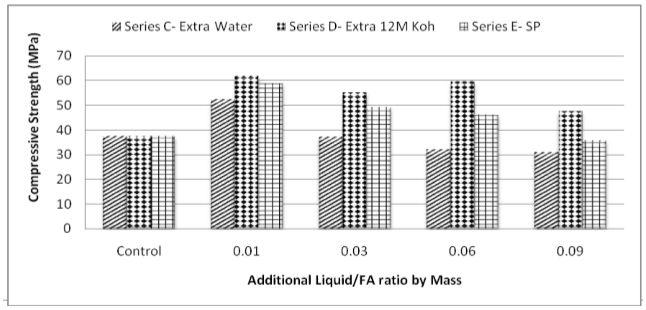

Figure 8: Effects of Additional Liquid to Fly Ash ratios by Mass on the 28 days Compressive Strength of Geopolymer Mortar

Superplasticizer to Fly Ash Ratio by Mass

Figure 7 has shown that the increased in the superplasticizer amount by mass has very little effect on the compressive strength of the specimens in series E at the age of 7 days. However, for the compressive strength at 28 days of age (Figure 8), more obvious effect of the SP can be noticed with the increase in strength with SP/FA ratio of 0.01, followed by gradual decrease in strength beyond this ratio. Sample mortars with addition of superplasticizer by 1% of the total mass of fly ash has drastic strength gain after 7 days whereby this strength development started to decrease with higher percentage of superplasticizer inclusion.

Effect of Mixing Procedures

Comparison of compressive strengths at the 7th day of fly ash geopolymer mortars prepared with separate mixing (series F) and normal mixing (series B) are shown in Figure 9. Both the mortar specimens prepared with separate mixing and normal mixing procedures shares similar influence on the compressive strength with increasing maximum endurable stresses of the test samples under crushing load with the increase of the liquid alkaline to fly ash ratio.

Separate mixing with leaching time of 10 minutes has produced samples with relatively higher compressive strength in comparison with the normal mixing procedure as shown in Figure 9. The compressive strength for all the samples in test series F (S) is superior to that of series B (N). Rattanasak et. al. [31] has claimed that separate mixing procedures allowed time and condition for leaching of silica and alumina from fly ash into the NaOH solution of which in this case was the KOH solution. This proves that the separate mixing sequence has complimentary effect on the compressive strength of the geopolymer mortars prepared with both potassium-based and sodium-based alkali activators.

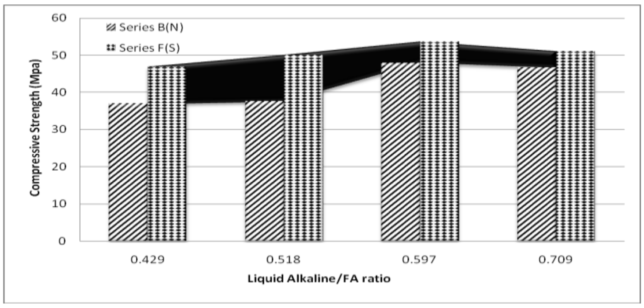

Figure 9 : Effect of Mixing Procedures on Compressive Strength

Utilization of Coal Combustion Ashes

One of the major concerns of all coal combustion power plants is unutilized fly ash and bottom ash that imposes adverse impacts on the environment such as air pollution and groundwater contamination due to leaching of metals from disposed ashes from the landfill [32, 33]. Benefits of fly ash and bottom ash recycle and reuse result in three main advantages; firstly, the use of a zero-cost raw material, secondly, the conservation of natural resources, and thirdly, the elimination of waste. Use of fly ash to replace cement can decrease cement in concrete mixture and results in decreasing both energy and CO_2 from the production of cement. Bottom ash can be used in cementless pressed blocks manufacturing, road construction and as lightweight aggregates [34-37]. The use of these waste materials offers both environmental and economical benefit. Besides, several structures of different varieties (Petronos Towers, Great Belt Bridge, Euro Tunnel, etc.) have already been built utilizing fly ash as mineral admixture in concrete [38]. Previous researches have also proved that geopolymers offer superior mechanical strength, durability and fire resistance to conventional OPC concrete with correct design mix proportion and formulation [39, 40]. Geopolymer, with properties such as abundant raw resource, little CO_2 emission, less energy consumption, low production cost, high early strength, fast setting make geopolymer find great applications in many fields of industry such as civil engineering, automotive and aerospace industries, non-ferrous foundries and metallurgy, plastics industries, waste management, art and decoration, and retrofit of buildings [39]. Further research should continue on conducting fundamental research on geopolymer technology to investigate ways this technology be adapted in new and existing applications.

CONCLUSION

The increase in bottom ash content from 0% to 50% as partial sand replacement with fixed flow of 110 ± 5% has decreased the water demand of the geopolymer mix. Beyond the 50% of sand substitution by bottom ash, the water demand increased. Increased in the bottom ash content generally decreased the compressive strength of the mortar. The increase in the liquid alkaline to fly ash by mass ratio resulted in linear increased with the flow of the fresh geopolymer mortars as well as their compressive strength.

In terms of flow improvement, the increase in the incorporation of extra water by mass of fly ash into the designed geopolymer mixtures has considerably increased the flow of the fresh mortars. The flow of the fresh fly ash based geopolymer blends also increased with the increase in the extra 12M KOH to fly ash ratio and the superplasticizer to fly ash ratio. In terms of mechanical property, extra water inclusion reduced the compressive strength of the geopolymer mortar. Addition of extra KOH by 1-6% of fly ash mass increased the compressive strength of the hardened specimen but further addition of KOH solution beyond 6% of fly ash mass caused drastic drop in its strength especially for the 7th day strength. The incorporation of extra water improved the workability of the geopolymer mortar more efficiently than the modified polycarboxylate superplasticizer with similar slight reduction in the compressive strength at the age of 7 days. However, the mortar incorporated with the superplasticizer possessed superior 28th day compressive strength over the mortars added with extra water.

Separate mixing increased the compressive strength of the geopolymer mortar activated by potassium based alkali activators. It is concluded that the separate mixing sequence has complimentary effect on the compressive strength of the geopolymer mortar over the normal mixing sequence.

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