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Strength and Porosity of Bagasse Ash-based Geopolymer Mortar

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Abstract: In this study, waste bagasse ash was used as a source material for making geopolymer in order to reduce the negative environmental impact of waste disposal. Ground Bagasse Ash (BA), sodium silicate and NaOH were the materials used. A constant liquid to ash ratio and similar flow were applied to the test. The effects of curing temperature, sodium silicate to NaOH ratio and concentrations of NaOH on strength and porosity were investigated. Test results indicated that the strength of geopolymer mortar was strongly dependent on curing temperature, sodium silicate to NaOH ratio and concentration of NaOH. To obtain good strength and low porosity BA geopolymer mortars, NaOH concentration of 10 M, sodium silicate to NaOH ratio of 2.5 and temperature curing at 65°C should be used. The reasonable strengths of 11.6-15.8 MPa and porosity of 20.5-23.5% were obtained.

Key words: Bagasse ash, geopolymer, porosity, strength, waste ash

INTRODUCTION

Waste ashes are the by-product from the energy generating system and need to be managed and disposed. A large number of investigations have been directed towards the utilization of waste ashes. Waste ashes (derived from the industrial and agricultural by-products) such as fly ash, palm oil fuel ash, bagasse ash and rice husk ash are now receiving a high attention for use as pozzolans in blending with Portland cement as they offers several advantages (Chindapasirt and Rukzon, 2008). These ashes generally improve the properties of blended cement. The costs are also inexpensive. Furthermore, the environmental problems can be reduced if these ashes are reused instead of disposal. Owing to the growth of energy demand, the output of waste ashes increases annually. As a result, a large amount of ashes is discarded in the landfills which cause unpleasant environment and other associated problems.

Recently, the other form of cementitious materials using silicon and aluminum activated in high alkali solution was developed (Davidovits, 1999). This material is usually based on fly ash as source material and is termed geopolymer or alkali-activated fly ash cement (Palomo *et al.*, 1999; Hardjito *et al.*, 2004). The geopolymer mortar and concrete possess similar strength and

appearance to those from normal Portland cement (Chindapasirt *et al.*, 2007). It is also well known that geopolymers possess excellent mechanical properties such as fire resistance and acid resistance properties (Davidovits, 1999; Hardjito *et al.*, 2004). These materials are formed by the alkali-silicate dissolution at high pH in the presence of soluble alkali metal silicate. The manufacturing of geopolymer neither needs cement nor create high CO₂ emission (Davidovits, 1999). For agricultural ash, the silica content is usually very high and hence additional alumina is needed (Detphan and Chindapasirt, 2009). For the high silica to alumina ratio source materials, the geopolymer is useful in terms of fire resistance (Davidovits, 1999). The use of industrial and agricultural by-products as source materials in making geopolymer is, therefore, very attractive.

Attempts have been made to utilize the bagasse ash (Aigbodion *et al.*, 2010; Worathanakul *et al.*, 2009). However, the utilization of bagasse ash is still very low and a large amount is disposed of by Landfill and is still the problem for the power plants in Thailand. Therefore, the objective of this research is to utilize the bagasse ash as a source material for producing geopolymer mortar in order to reduce negative environmental effects. The benefits of applying this material to concrete are cost saving, reduction of green house gas emission and improvement of mechanical properties of cement matrix.

MATERIALS AND METHODS

Materials: Bagasse ash (from Singhaburi Province sugar mill in central Thailand) was used as a source material. Ground Bagasse Ash (BA) were obtained using ball mill grinding until the 3% weight were retained on a sieve No. 325 (45 μm). The physical properties and chemical constituents are given in Table 1 and 2, respectively. The river sand from Nonthaburi Province in Thailand with specific gravity of 2630 kg m⁻³ and a fineness modulus of 2.82 in saturated surface dry condition was used for making mortar. Sodium hydroxide (NaOH) with 10 and 15 M concentrations and sodium silicate (with 15.3% Na₂O, 32.8% SiO₂ and 15% water) were used as liquid solutions. Sodium hydroxide was obtained from O.V. Chemical and supply and sodium silicate was obtained from Eastern Silicate Limited.

Mix design and mixing of mortar: Geopolymer mortars were made with BA to sand ratio of 2.75, liquid to ash ratio of 1.3 and sodium silicate (Si) to NaOH ratio by mass (or Si/OH) of 0.50, 1.50 and 2.50 were used. The mix proportions of geopolymer mortars are given in Table 3. The mortar flow of 110±5% was used as the mortar was workable and easily placed into mould. In order to produce the workable geopolymer mortar, a minimum base water content of 5% by mass of geopolymer paste (BA, sodium silicate, NaOH and water) was included in the mix. The mixing was done in a 25°C controlled room.

For the mixing procedure, NaOH solution, base water and BA were first mixed for 5 min in a pan mixer. Sand was then added and mixed for 5 min. Finally, sodium silicate solution and water were included and were mixed for another 5 min. This mixing procedure was tested and found to produce high strength geopolymer (Chindaprasirt *et al.*, 2007). The flow test was done in accordance with (ASTMC 230, 1997). The flow table was 110±5%.

Strength and porosity test: The 50×50×50 mm specimen cube was prepared for the compressive strength test of geopolymer mortar. The test was done in accordance with (ASTM 39, 2001) using an Instron Universal Testing Machine. For porosity test, cylindrical specimens of 100 mm diameter and 200 mm height were prepared in accordance with (ASTM C109, 2001). An additional vibration of 10 sec using a vibrating table was given to ensure the uniform compaction. The mortars and moulds were wrapped with vinyl sheet in order to prevent moistures loss. The mortars were then put in the oven for heat curing at 45, 65 and 90°C for 24 h. After curing at an elevated temperature, the mortars were put in laboratory to cool down and demoulded the next day and kept in

Table 1: Physical property of pozzolanic materials

Physical properties	Ground bagasse ash (BA)
Median particle size (μm), d ₅₀ -μm	19.5
Retained on a sieve No. 325 (%)	3
Specific gravity (kg m ⁻³)	2240
Blaine fineness (cm ² g ⁻¹)	12,000

Table 2: Chemical composition of pozzolanic materials (Oxides, % by volume)

Oxides (%)	Ground bagasse ash BA
CaO	9
SiO ₂	65
Al ₂ O ₃	5
Fe ₂ O ₃	3
MgO	0
K ₂ O	2
SO ₃	0
LOI	17
SiO ₂ + Al ₂ O ₃ + Fe ₂ O ₃	73

Table 3: Mix proportions of geopolymer mortar with BA

Mix symbol	Sodium silicate to NaOH ratio	Concentrations of NaOH (M)	Water (% by mass) (minimum)	Flow (%)
0.5Si/OH-BA-10 M	0.5	10	5	110±5
1.5Si/OH-BA-10 M	1.5	10	5	110±5
2.5Si/OH-BA-10 M	2.5	10	5	110±5
0.5Si/OH-BA-15 M	0.5	15	5	110±5
1.5Si/OH-BA-15 M	1.5	15	5	110±5
2.5Si/OH-BA-15 M	2.5	15	5	110±5

Sand-to-binder ratio 2.75, Liquid-to-ash ratio 1.3, Flow 110±5%

25°C room until testing age. The specimens were tested at the age of 7 days. The reported results were the averages of three samples.

For porosity test, mortars were cut into 50 mm thick slices and the 50 mm ends were discarded. They were dried at 100±5°C until the weight was constant. They were then placed in desiccators under vacuum for 3 h. The set-up was finally filled with de-aired and distilled water in order to measure the effective porosity of mortar at the age of 7 days. The porosity was calculated by using Eq. 1 (Rukzon and Chindaprasirt, 2008, 2009):

$$P (\%) = \frac{(W_a - W_d)}{(W_a - W_w)} \times 100 \tag{1}$$

Where:

P(%) = Vacuum saturated porosity

W_a = The weight of specimen in the air at saturated condition (g)

W_d = the dry weight of the specimen after 24 h in oven at 100±5°C (g) and

W_w = the weigh of the specimen in water (g)

RESULTS AND DISCUSSION

Characteristics of BA: The chemical constituents of BA as given in Table 2 showed that the main chemical composition of BA was 65% of SiO₂, 9% of CaO and 5.0%

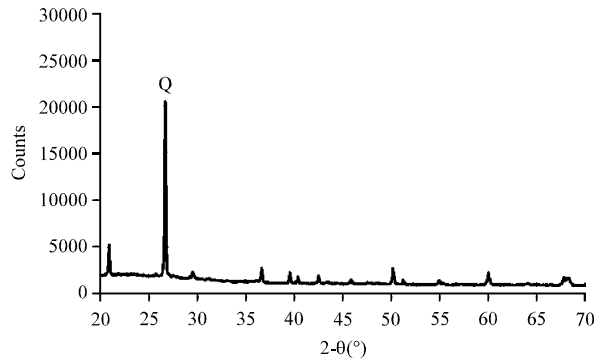


Fig. 1: X-ray diffraction analysis of BA (Q = Quartz)

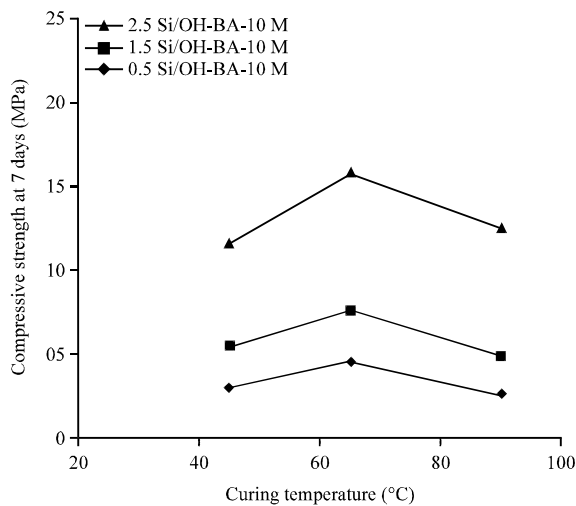


Fig. 2: Effect of curing temperature on strength of mortar with 10 M NaOH

of Al_2O_3 with Loss on Ignition (LOI) of 17%. The sum of SiO_2 , Al_2O_3 and Fe_2O_3 was 73% which was slightly higher than 70% as required for natural pozzolan according to (ASTM C 618, 2001). According to the X-ray Analysis (XRD) pattern of BA (Fig. 1), the BA was mainly amorphous silica as indicated by the hump around $25^\circ 2\theta$ with a small amount of quartz.

Effects of curing temperature: The results of the effect of curing temperature on the strength of geopolymer mortar at NaOH 10 and 15 M (Molar) are given in Fig. 2 and 3. Test results indicated that the strength of mortar was affected by curing temperature. As shown in Fig. 2, at $45^\circ C$ curing, the strength of 2.5 Si/OH-BA-10 M mortar was 11.6 MPa. At $65^\circ C$ curing, the strength increased to 15.8 MPa. However, when the temperature was $90^\circ C$, the strength dropped to 12.5 MPa. When curing temperature was high, the heat curing adversely affected the strength of the samples. The small 50 mm cube specimen

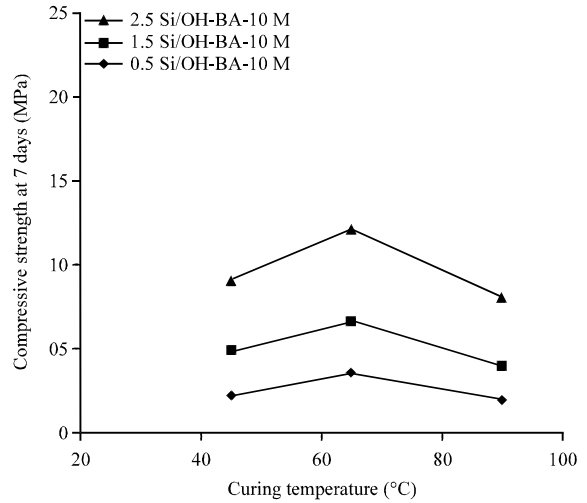


Fig. 3: Effect of curing temperature on strength of mortar with 15 M NaOH

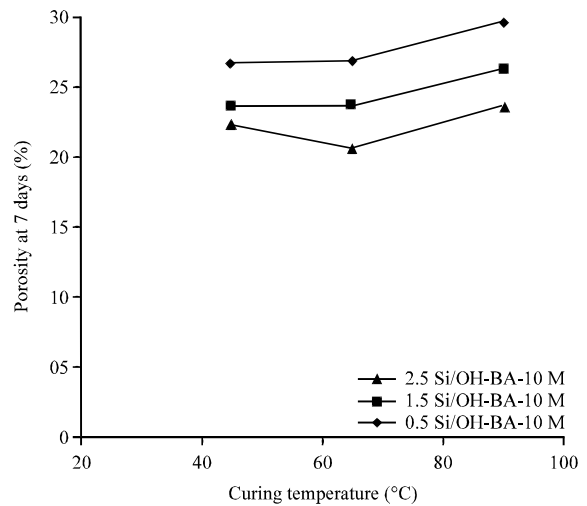


Fig. 4: Effect of curing temperature on porosity of mortar with 10 M NaOH

with high surface to volume ratio was more susceptible to the high curing temperature and loss of moisture than the large specimen. The optimum temperature (with 10 M NaOH mix) was $65^\circ C$ and the maximum strength was 15.8 MPa. The initial curing at appropriate temperature improved the geopolymerization and the compressive strength of BA geopolymer mortar.

Figure 4 and 5 shows the effect of curing temperature on the porosity of geopolymer mortar at 10 and 15 M NaOH. As shown in Fig. 4, the porosity of geopolymer mortar was also dependent on the curing temperature. For example, at the temperatures of 45, 65 and $90^\circ C$, the porosities of 2.5Si/OH-BA-10M mortar were 22.2, 20.5 and 23.5%, respectively. The optimum curing temperature of

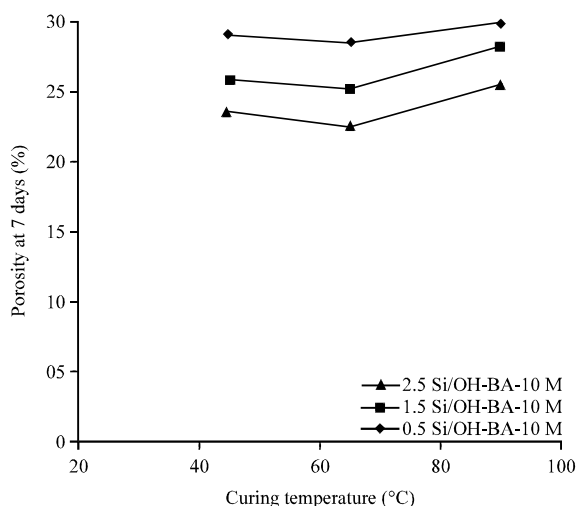


Fig. 5: Effect of curing temperature on porosity of mortar with 15 M NaOH

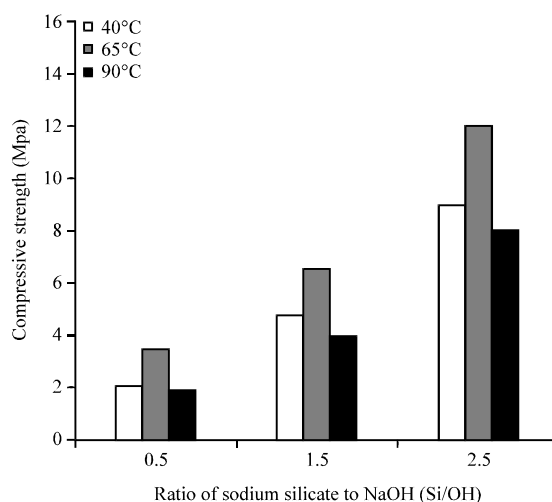


Fig. 7: Effect of Si/OH on strength of mortar with 15 M NaOH

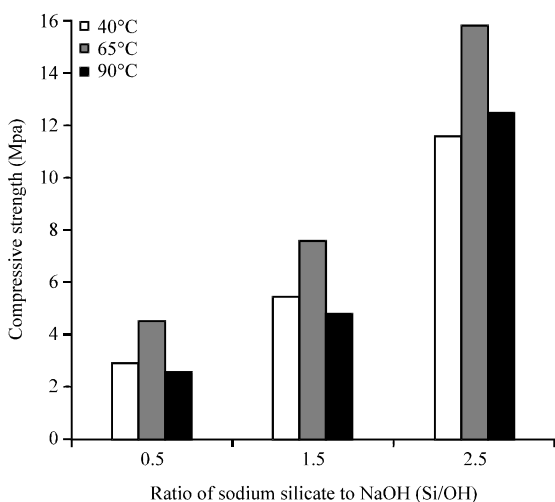


Fig. 6: Effect of Si/OH on strength of mortar with 10 M NaOH

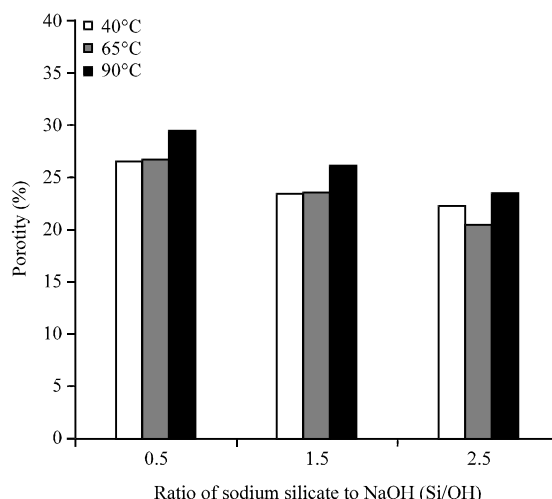


Fig. 8: Effect of Si/OH on porosity of mortar with 10 M NaOH

65°C produced a high strength and low porosity geopolymer mortar. The effect of curing temperature on the strength and porosity of mortars is therefore very significant.

Effects of sodium silicate (Si) to NaOH ratio: The results of strength of geopolymer mortar as affected by sodium silicates (Si) to NaOH ratio (Si/OH ratio) at the curing temperature of 45, 65 and 90°C is shown in Fig. 6 and 7. The strength of mortar with Si/OH ratio of 2.5 was higher than that with Si/OH ratio of 1.5 and of 0.5. For instance, at the curing temperature of 65°C, the strength of 0.5Si/OH-BA-15 M mortar with Si/OH ratio of 2.5 was

12 MPa, whereas, the strength of that mortar with Si/OH ratio of 1.5 and 0.5 were 6.5 MPa and 3.5 MPa, respectively as shown in Fig. 7.

The results of porosity of geopolymer mortars with different Si/OH ratios are shown in Fig. 8 and 9. The porosity of mortar with Si/OH ratio of 2.5 was lower than that with Si/OH ratios of 1.5 and 0.5. The mortar with low Si/OH ratio resulted in high porosity. On the other hand, the mortar with high Si/OH ratio resulted in low porosity. For example, at curing temperature of 45, 65 and 90°C, the porosities of the 2.5Si/OH-BA-10 M mortar with high Si/OH ratio of 2.5 were 22.2, 20.5 and 23.5%, respectively. The porosities of 2.5Si/OH-BA-15 M mortar at the same

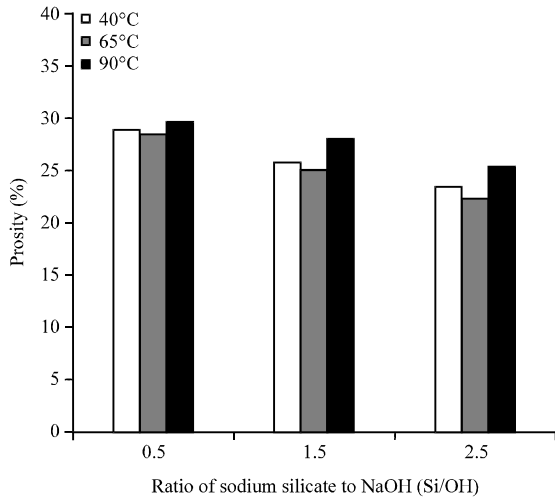


Fig. 9: Effect of Si/OH on porosity of mortar with 15 M NaOH

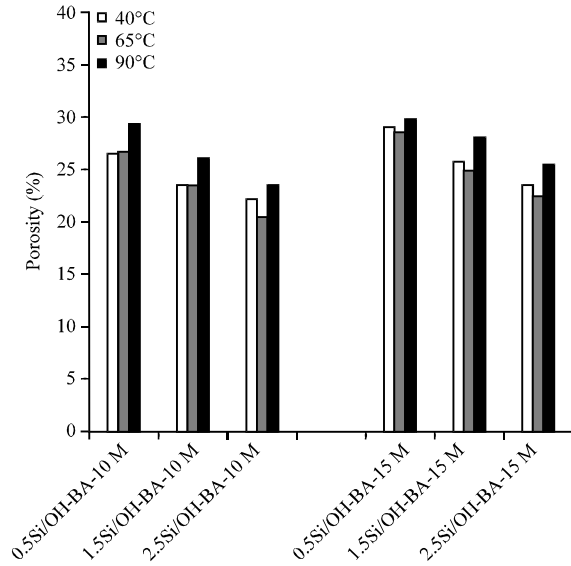


Fig. 11: Effect of NaOH concentration on porosity of mortar at 45, 65 and 90°C

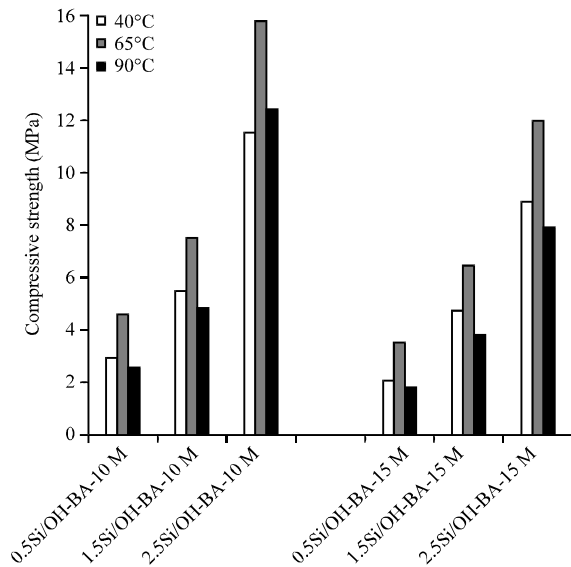


Fig. 10: Effect of NaOH concentration on strength of mortar at 45, 65 and 90°C

temperature with Si/OH ratio of 2.5 were 23.5, 22.4 and 27.6%, respectively. It was obvious that the geopolymer mortar was stronger with lower porosity. In addition, the increase in Si/OH ratio to 2.5 increased the strength and lowered the porosity of mortar. This was due to the increase in Si/OH ratio and the associated increase in Na ions content of the mixture (Sathonsaowaphak *et al.*, 2009). The sodium silicate (Si) to NaOH ratio it was therefore important as it affected the strength and porosity of mortars.

Effect of concentration of NaOH: The strength results of BA geopolymer with different concentrations of NaOH solutions cured at 45, 65 and 90°C, are shown in Fig. 10. It described the strength development of BA geopolymer mortar at 10 M NaOH, The strength of 2.5Si/OH-BA-15M mortar was 11.8 MPa while the strength of mortar 2.5Si/OH-BA-10 M was good at 15.8 MPa. The increase in NaOH concentration decreased Na ions in the system which was important to the geopolymerization since Na ions were used for balancing the charges and forming the alumino-silicate networks (Sathonsaowaphak *et al.*, 2009). So, the concentration of NaOH had an influence on the strength of geopolymer mortar.

The results of porosity of geopolymer mortars with NaOH solution at 10 and 15 M concentrations are shown in Fig. 11. The porosities of mortar with 10 M NaOH concentration was lower than that with 15 M NaOH (for all mixes). Moreover, the relationship between the compressive strength and porosity of mortar followed the conventional pattern as shown in Fig. 12. When all ages were considered, the porosity of mortar ranged from 20.5 to 29.8%. It should be noted that this range of porosity values corresponded to the compressive strength over the range 15.8 to 1.9 MPa (Fig. 12). The use of BA as a source material in making geopolymer mortar is desirable because of the fine particle size, high surface area, silica content and degree of reactivity.

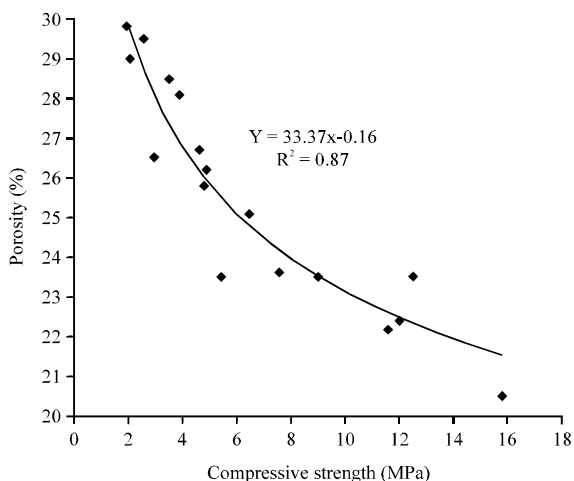


Fig. 12: Relationship between strength and porosity of mortar at 45, 65 and 90°C

CONCLUSION

It was possible to use the finely ground bagasse ash to produce medium-strength and low porosity geopolymer with high silica to alumina ratio. Curing temperatures, sodium silicate to NaOH ratio and concentration of NaOH are the essential factors that influence the strength and porosity of geopolymer mortar. The good bagasse ash geopolymer mortar could be produced using high sodium silicate (Si) to NaOH ratio of 2.5, 10M NaOH concentration and cured at 65°C. The reasonable strengths of 11.6-15.8 MPa and porosity of 20.5-23.5% were obtained.

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REFERENCES

ASTM 39, 2001. Standard Test Method for Compressive Strength of Cylindrical Concrete Specimens. Vol. 04.02 ASTM Standard Press, USA., pp: 18-22.

ASTM C 618, 2001. Standard Specification for Coal Fly ash and Raw or Calcined Natural Pozzolan for use as a Mineral Admixture in Concrete. Vol. 04.02, ASTM Standard Press, USA.

ASTM C109, 2001. Standard Test Method for Compressive Strength of Hydraulic Cement Mortars (Using 2in or [50 mm] Cube Specimens). Vol. 04.01, ASTM Standard Press, USA., pp: 83-88.

ASTMC 230, 1997. Standard Specification for Sample and Testing Fly Ash or Natural Pozzolans for use as a Mineral Admixture in Portland Cement. Vol. 04.01, ASTM Standard Press, USA., pp: 172-176.

Aigbodion, V.S., S.B. Hassan, T. Ause and G.B. Nyior, 2010. Potential utilization of solid waste (Bagasse ash). *J. Miner. Mater. Char. Eng.*, 9: 67-77.

Chindaprasirt, P., T. Chareerat and V. Sirivivatnanon, 2007. Workability and strength of coarse high calcium fly ash geopolymer. *Cem. Concr. Composites*, 29: 224-229.

Chindaprasirt, P. and S. Rukzon, 2008. Strength, porosity and corrosion resistance of ternary blend Portland cement, rice husk ash and fly ash mortar. *Constr. Build. Mater.*, 22: 1601-1606.

Davidovits, J., 1999. Chemistry of geopolymeric systems, terminology. Proceedings of the 99th International Conference on Geopolymer. June 30-July 2, 1999, Saint, Quentin, France.

Detphan, S. and P. Chindaprasirt, 2009. Preparation of fly ash and rice husk ash geopolymer. *Int. J. Miner. Metal. Mater.*, 16: 720-726.

Hardjito, D., S.E. Wallah., D.M.J. Sumajouw and B.V. Rangan, 2004. On the development of fly ash-based geopolymer concrete. *ACI Mater. J.*, 101: 467-472.

Palomo, A., M.W. Grutzeck and M.T. Blanco, 1999. Alkali-activated fly ashes: A cement for the future. *Cem. Concr. Res.*, 29: 1323-1329.

Rukzon, S. and P. Chindaprasirt, 2008. Development of classified fly ash as a pozzolanic material. *J. Applied Sci.*, 8: 1097-1102.

Rukzon, S. and P. Chindaprasirt, 2009. Use of disposed waste ash from landfills to replace Portland cement. *Waste Manage. Res.*, 27: 588-594.

Sathonsaowaphak, A., P. Chindaprasirt and K. Pimraksa, 2009. Workability and strength of lignite bottom ash geopolymer. *J. Hazad. Mater.*, 168: 44-50.

Worathanakul, P., W. Payubnop and A. Muangpet, 2009. Characterization for Post-treatment effect of bagasse ash for silica extraction. *World Acad. Sci. Eng. Technol.*, 56: 360-362.