Research Journal of Applied Sciences, Engineering and Technology 4(5): 407-414, 2012
ISSN: 2040-7467

Submitted: September 08, 2011 Accepted: September 30, 2011 Published: March 01, 2012

# Effect of Superplasticizer and Extra Water on Workability and Compressive Strength of Self-Compacting Geopolymer Concrete

[1,2]Fareed Ahmed Memon, [1]Muhd Fadhil Nuruddin, [1]Samuel Demie and [1]Nasir Shafiq
[1]Civil Engineering Department, Universiti Teknologi PETRONAS, Malaysia
[2]Civil Engineering Department, Mehran University of Engineering and Technology, Jamshoro, Pakistan

**Abstract:** This study documents the results of an experimental work carried out to investigate the effect of superplasticizer and amount of extra water on strength and workability properties of Fly ash-based Self-compacting geopolymer concrete. The experiments were conducted by varying the amount of extra water and dosage of superplasticizer. A total of nine mixtures with superplasticizer content varying from 3 to 7% and extra water ranging from 10 to 20% of the mass of fly ash were prepared and tested. The essential workability properties of the freshly prepared concrete such as filling ability, passing ability and segregation resistance were evaluated by using Slump flow, $T_{50}$ slump flow, V-funnel, L-box and J-ring test methods. The compressive strength tests were carried out at 1, 3, 7 and 28 days. Test results indicated that extra water and superplasticizer are key parameters and play an important role in the development of self-compacting geopolymer concrete. Workability of self-compacting geopolymer concrete was dependent on the amount of extra water and dosage of superplasticizer. With the increase in amount of extra water and superplasticizer, the workability was improved. However, the addition of water beyond 15% resulted in bleeding as well as segregation and decreased the compressive strength of the concrete. The compressive strength of self-compacting geopolymer concrete was significantly decreased as the amount of extra water exceeded 12% by mass of Fly ash.

**Key words:** Compressive strength, extra water, self-compacting geopolymer concrete, superplasticizer, workability

## INTRODUCTION

Concrete is one of most widely used building material, due to its availability of the raw materials, its ease for preparing and fabricating in all sorts of conceivable shapes. Massive production of concrete and the associated substantial manufacture of Portland cement have, however, been observed to have a very negative impact. One of the biggest issues of growing concern at the moment faced by the concrete industries is the impact of cement production on the environment. Portland cement, an essential constituent of concrete is not an environmentally friendly material. The environmental issues associated with the production of Portland cement are well known. The production of Portland cement not only depletes significant amount of natural resources but also liberates a considerable amount of carbon dioxide ($CO_2$) and other greenhouse gases in to the atmosphere as a result of decarbonation of limestone and the combustion of fossil fuels. In addition, Portland cement is among the most energy intensive construction materials, after aluminium and steel (Hardjito and Rangan, 2005; Rangan, 2008).

To preserve the global environment from the impact of cement production, it is imperative to search and explore new possibilities to develop a concrete material that is more environmentally friendly as well as an efficient construction material to replace conventional Portland cement concrete (Malhotra, 2004; Daniel, 2008). Enormous efforts have been made throughout the world to reduce the use of Portland cement in order to address the global warming issues. These include the utilization of waste by-products, and the development of alternative binders to Portland cement (Rangan, 2008). In this regard, the geopolymer concrete is one of the revolutionary developments related to novel materials resulting in low-cost and environmentally friendly material as an alternative to the Portland cement (Davidovits, 1991; Duxson *et al.*, 2007; Temuujin *et al.*, 2010).

Geopolymers have been considered the cements of the future due to their low ecological impact and relatively high yield from raw materials. Geopolymers can be produced by synthesizing alumino-silicate based source materials with highly alkaline solutions (Davidovits, 1991; Villa *et al.*, 2010). The up to date research on geopolymers has demonstrated that this new binder is likely to have enormous potential as an alternative to ordinary Portland cement. Despite the fact that the exact mechanism of setting and hardening of the geopolymer material is not yet fully understood, in recent

**Corresponding Author:** Fareed Ahmed Memon, Civil Engineering Department, Universiti Teknologi PETRONAS, Malaysia, Tell: 6015230982

Table 1: Chemical composition of fly ash as determined by XRF

| | | Requirements as per | |
|---|---|---|---|
| Oxide (%) | By mass | BS EN450-1:2005 | ASTM C618-01 Class F 2004 |
| Silicon Dioxide ($SiO_2$) | 51.3 | min. 25% | - |
| Aluminum Oxide ($Al_2O_3$) | 30.1 | - | - |
| Ferric Oxide ($Fe_2O_3$) | 4.57 | - | - |
| Total $SiO_2 + Al_2O_3 + Fe_2O_3$ | 85.97 | min. 70% | min. 70% |
| Calcium Oxide (CaO) | 8.73 | - | - |
| Phosphorus Pentoxide ($P_2O_5$) | 1.6 | - | - |
| Sulphur Trioxide ($SO_3$) | 1.4 | max. 3% | max. 5% |
| Potassium Oxide ($K_2O$) | 1.56 | - | - |
| Titanium Dioxide ($TiO_2$) | 0.698 | - | - |

years, geopolymers have become the focus of increasing interest and have received considerable attention because geopolymers may result environmental benefits such as the reduction in consumption of natural resources and the decrease in the net production of $CO_2$. The geopolymer concrete is an innovative binder material and is produced by totally replacing the Portland cement. Unlike to ordinary Portland cement, the production of raw materials for geopolymers does not require a high level of energy consumption because high temperature calcining is not required. It is demonstrated that the geopolymeric cement generates 5–6 times less $CO_2$ than Portland cement (Davidovits, 1993; Davidovits, 2008). Therefore, the use of geopolymer technology not only significantly reduces the $CO_2$ emissions by the cement industries, but also utilises the industrial wastes and/or by-products of alumino-silicate composition to produce added-value construction materials (Hardjito *et al*., 2004).

Self-compacting Geopolymer Concrete (SCGC) is relatively a new concept and can be regarded as the most revolutionary development in the field of concrete technology. SCGC is an innovative type of concrete that does not entail vibration for placing it and can be produced by complete elimination of ordinary Portland cement (Memon *et al*., 2011).

This research study was intended to explore the feasibility of SCGC made with locally available constituent materials by examining its basic physical and mechanical properties. In this part of the experimental work the effects of extra water and superplasticizer on the workability and compressive strength of self-compacting geopolymer concrete were investigated. Test results indicate that extra water and superplasticizer play an important role in the development of SCGC and significantly affect the properties of concrete both in fresh and hardened state.

## EXPERIMENTAL DETAILS

### Materials used for concrete mixture:

**Fly ash:** Geopolymer concrete is produced by activating alumino-silicate based source material with an alkaline solution. Fly ash contains high percentage of silica and alumina, hence is thought to be good candidate as a source material for making geopolymer concrete. For the present study, low-calcium (ASTM C618 Class F 2004) Fly ash obtained from Manjung Power station, Lumut, Perak was used as a source material. The chemical composition of fly ash as determined by XRF analysis is shown in Table 1.

**Aggregates:** Locally available crushed coarse aggregate of maximum size 14 mm with specific gravity of 2.66 and river sand having specific gravity of 2.61 and fineness modulus of 2.76 were used in the preparation of all test specimens. Fine aggregate was sieved for the size less than 5 mm and used in dry condition while coarse aggregate was used in Saturated Surface Dry (SSD) condition.

**Alkaline solution:** In geopolymer synthesis, a combination of sodium silicate or potassium silicate and sodium hydroxide or potassium hydroxide has been widely used as an alkaline activator. In this study, a combination of sodium silicate and sodium hydroxide was used as an alkaline solution.

Sodium Silicate (Grade A53 with $SiO_2$ = 29.43%, $Na_2O$ = 14.26% and water = 56.31%) obtained from Malay-Sino Chemical Industries Sdn Bhd, Malaysia was used in solution form while Sodium hydroxide supplied by Quick-Lab Sdn Bhd, Malaysia was in pellets form with 99% purity. To prepare sodium hydroxide solution, sodium hydroxide pellets were dissolved in ordinary drinking water. Both the liquid solutions were mixed together and alkaline solution was prepared.

**Superplasticizer:** In order to attain superior workability and required flowability of the fresh concrete, a commercially available superplasticizer named as Sika Viscocrete-3430 supplied by Sika Kimia Sdn Bhd, Malaysia, and a specified amount of extra water (other than the water used for the preparation of sodium hydroxide solution) was also used in the mix. The ordinary drinking water available in the concrete laboratory was used for this purpose.

**Mix proportion:** In this experimental study, a total of nine mixtures with the same content of fly ash (400

Table 2: Details of mix proportions

| Mix ID | Fly Ash Kg/m$^3$ | F.Agg Kg/m$^3$ | C.Agg Kg/m$^3$ | Sodium Hydroxide Kg/m$^3$ | Sodium Hydroxide Mol | Sodium Silicate Kg/m$^3$ | Super Plasticizer Kg/m$^3$ | Super Plasticizer % | Extra water Kg/m$^3$ | Extra water % | Curing Time (h) | Curing Temp. (C) |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| $M_1$ | 400 | 850 | 950 | 57 | 12 | 143 | 28 | 7 | 40 | 10 | 24 | 70 |
| $M_2$ | 400 | 850 | 950 | 57 | 12 | 143 | 28 | 7 | 48 | 12 | 24 | 70 |
| $M_3$ | 400 | 850 | 950 | 57 | 12 | 143 | 28 | 7 | 60 | 15 | 24 | 70 |
| $M_4$ | 400 | 850 | 950 | 57 | 12 | 143 | 28 | 7 | 80 | 20 | 24 | 70 |
| $M_5$ | 400 | 850 | 950 | 57 | 12 | 143 | 12 | 3 | 48 | 12 | 48 | 70 |
| $M_6$ | 400 | 850 | 950 | 57 | 12 | 143 | 16 | 4 | 48 | 12 | 48 | 70 |
| $M_7$ | 400 | 850 | 950 | 57 | 12 | 143 | 20 | 5 | 48 | 12 | 48 | 70 |
| $M_8$ | 400 | 850 | 950 | 57 | 12 | 143 | 24 | 6 | 48 | 12 | 48 | 70 |
| $M_9$ | 400 | 850 | 950 | 57 | 12 | 143 | 28 | 7 | 48 | 12 | 48 | 70 |

kg/m$^3$) were prepared to study the effect of extra water and superplasticizer on workability and compressive strength of self-compacting geopolymer concrete by varying the extra water content from 48 to 80 kg/m$^3$ and increasing the superplasticizer dosage from 12 to 28 kg/m$^3$. The details of the mix proportions are given in Table 2. Concrete specimens were cured in the oven at a temperature of 70ºC for 24 and 48 h. For each mix, the alkaline solution-to-Fly ash ratio was kept 0.5 whereas the ratio of sodium silicate to sodium hydroxide and concentration of sodium hydroxide were kept 2.5 and 12 M,, respectively.

**Mixing, casting and curing:** Mixing process was carried out in two stages. Initially, the solid materials i.e., Fly ash, fine sand (dry condition) and coarse aggregate (SSD condition) were mixed together in 100 L capacity pan mixer for about 2.5 min. At the end of this dry mixing, a liquid mixture comprising alkaline solution, superplasticizer and extra water was added in the mixer and the wet mixing continued for another 3 min. Fresh concrete mix was then hand mixed for further 2 to 3 min to ensure the mixture homogeneity. The freshly prepared concrete mixture was then assessed for the essential workability tests required for characterizing SCC. After performing the workability tests, fresh concrete was placed in 100 mm × 100 mm × 100 mm steel moulds and allowed to fill all the spaces of the moulds by its own weight. Three cubes were cast for each test variable. After casting, the moulds were kept in the oven at a specified temperature for a specified period of time in accordance with the test variables selected. At the end of the oven curing period, moulds were taken out from the oven and left undisturbed for about 15 min in order to avoid a drastic change of the environmental conditions. The test cubes were then removed from the moulds and left to air dry at room temperature until the specified age of testing.

**Testing of specimen:**

**Workability tests:** According to EFNARC (2002), a concrete mix can only be classified as self-compacting concrete, if the requirements for all the three workability properties are fulfilled. The three essential fresh properties required by SCC are filling ability, passing ability and resistance to segregation. A wide rang of test methods have been developed to measure and assess these properties; however, no single test method so far has achieved universal approval and is capable of assessing all the workability properties at once. The European guidelines EFNARC (2002), has proposed five test methods to fully characterize an SCC mix. Table 3 list the test methods along with their recommended values given by EFNARC. In the present study, to assess the workability characteristics, for each mix composition, slump flow, $T_{50cm}$ Slump flow, V-funnel, L-box and J-ring test methods were carried out.

Table 3: Test methods and recommended limits as per EFNARC guide lines (EFNARC, 2002)

| S.No. | Test | Permissible limits as Per EFNARC guide lines: Min. | Max. |
|---|---|---|---|
| 1. | Slump flow by abrams cone | 650 mm | 800 mm |
| 2. | $T_{50\,cm}$ slump flow | 2 sec. | 5 sec. |
| 3. | V-Funnel | 6 sec. | 12 sec. |
| 4. | L-Box ($H_2$ /$H_1$) | 0.8 | 1.0 |
| 5. | J-Ring | 0 mm | 10 mm |

**Compressive strength:** Compressive strength test was performed in accordance with (BS EN 12390-3:2002) using 2000 KN Digital Compressive and Flexural Testing Machine. At the end of specified oven curing period, a set of three cubes for each test variable was tested at the ages of 1, 3, 7 and 28 days.

## RESULTS AND DISCUSSION

**Workability properties of SCGC:** As stated earlier, to accomplish the workability properties, for each mix tests such as slump flow, $T_{50\,cm}$ Slump flow, V-funnel, L-box and J-ring were performed. All the tests were performed by following The European Guidelines for SCC. The results of the workability tests are shown in Table 4.

**Compressive strength:** Compressive strength is one of the most noteworthy properties of concrete and is the most common measure used to evaluate the quality of hardened concrete.The compressive strength test results for all mix compositions are presented in Table 5. The

Table 4: Workability test results

| | Workability test results | | | | |
|---|---|---|---|---|---|
| Mix ID | Slump flow (mm) | $T_{50\ cm}$ slump flow (sec.) | V- funnel flow time (sec.) | L-Box($H_2/H_1$) Ratio | J-Ring (mm) |
| $M_1$ | 630 | 6.5 | 12.5 | 0.82 | 12 |
| $M_2$ | 710 | 4.0 | 7 | 0.96 | 5 |
| $M_3$ | 770 | 3.0 | 6 | 1.0 | 3 |
| $M_4$ | 820 | 2.5 | 5.5 | 1.0 | 0 |
| $M_5$ | 625 | 6.5 | 15.5 | 0.84 | 13 |
| $M_6$ | 640 | 6.0 | 14 | 0.88 | 10 |
| $M_7$ | 665 | 5.0 | 12.5 | 0.90 | 8 |
| $M_8$ | 690 | 4.5 | 10 | 0.94 | 7 |
| $M_9$ | 710 | 4.0 | 7 | 0.96 | 5 |
| **Acceptance Criteria for SCC as per EFNARC [2002]** | | | | | |
| Min. | 650 mm | 2 sec. | 6 sec. | 0.8 | 0 mm |
| Max. | 800 mm | 5 sec. | 12 sec. | 1.0 | 10 mm |

Table 5: Compressive strength test results

| | Compressive strength test results (MPa) | | | |
|---|---|---|---|---|
| Mix ID | 1-Day | 3-Day | 7-Day | 28-Day |
| $M_1$ | 53.46 | 54.33 | 55.08 | 56.29 |
| $M_2$ | 45.01 | 45.85 | 46.94 | 48.53 |
| $M_3$ | 37.31 | 37.90 | 38.56 | 39.78 |
| $M_4$ | 22.58 | 22.98 | 23.44 | 24.18 |
| $M_5$ | 40.85 | 41.77 | 42.84 | 44.69 |
| $M_6$ | 42.02 | 42.68 | 44.17 | 46.86 |
| $M_7$ | 44.74 | 45.28 | 46.19 | 48.90 |
| $M_8$ | 47.83 | 48.52 | 49.44 | 51.52 |
| $M_9$ | 51.03 | 51.98 | 52.26 | 53.80 |

reported compressive strength is the average strength of three specimens.

**Effect of extra water:** Water content in the mix plays an important role on the properties of geopolymer binders (Barbosa *et al*., 2000). Tests were performed to establish the effect of the extra water on the workability characteristics and compressive strength of self-compacting geopolymer concrete. For this purpose four mixtures $M_1$, $M_2$, $M_3$ and $M_4$ with identical mix composition, but different amount of extra water ranging from 10 to 20% of the mass of fly ash were prepared. The percentage of the superplasticizer to the mass of fly ash was kept 7% and the concentration of sodium hydroxide solution was held 12 M. The test specimens were cured in the oven at a temperature of 70ºC for a period of 24 h.

Figure 1 illustrates the effect of extra water on the workability characteristics of self-compacting geopolymer concrete. As it was expected, the addition of extra water improvedtheworkabilitycharacteristics of freshly prepared concrete mixtures; however, the addition of extra water beyond 15% resulted in bleeding as well as segregation of fresh concrete mix. The results of the quantitative measuremen and visual observations showed that except for Mixture $M_1$ which failed to exhibit the required workability properties for SCC due to very low percentage of extrawater (10%), all the other three concrete mixtures had good flowability and produced desired results and were within the EFNARC range of SCC.

Figure 2 illustrates the effect of extra water on the compressive strength of concrete. The test results shown in 2 demonstrate that the compressive strength of self-compacting geopolymer concrete decreases as the amount of extra water increases. From Fig. 2, it can be seen that mixture $M_1$ with lower percentage of extra water shows highest compressive strength at all ages compared to mixtures $M_2$, $M_3$ and $M_4$. The compressive strength of SCGC significantly decreases as the amount of extra water increases.

The effect of extra water is also illustrated in Fig. 3 by plotting the compressive strength versus water-to-geopolymer solids ratio by mass. In order to quantify the water content in the geopolymer concrete mix, the ratio of water-to-geopolymer solids was calculated. For a given geopolymer concrete, the total mass of water in the concrete mix can be calculated by adding the mass of water in the sodium hydroxide solution, the mass of water in the sodium silicate solution, and the mass of the extra water. The mass of the geopolymer solids is taken as the sum of the mass of fly ash, the mass of sodium hydroxide pellets, and the mass of sodium silicate solids (i.e., the mass of $SiO_2$ and $Na_2O$ in sodium silicate solution) (Hardjito *et al*., 2004).

The test data shown in Fig. 3 demonstrate that the compressive strength of the self-compacting geopolymer concrete decreases as the ratio of water-to-geopolymer solids by mass increases giving rise to more free water in the geopolymer concrete leading to a more porous microstructure. From Fig. 3, it can be seen that Mix $M_1$ with lower water-to-geopolymer solids ratio of 0.31 shows higher compressive strengths at all the ages as compared to Mixes $M_2$, $M_3$ and $M_4$ with higher water-to-geopolymer solids ratios of 0.33, 0.35 and 0.39 respectively. The trend of the results is similar to those observed by Hardjito *et al.* (2004) and Bondar *et al.* (2010) for their tests on geopolymer concretes. The trend is also somewhat analogous to the well-known effect of the water-to-cement ratio on the compressive strength of ordinary Portland cement concrete, although the chemical

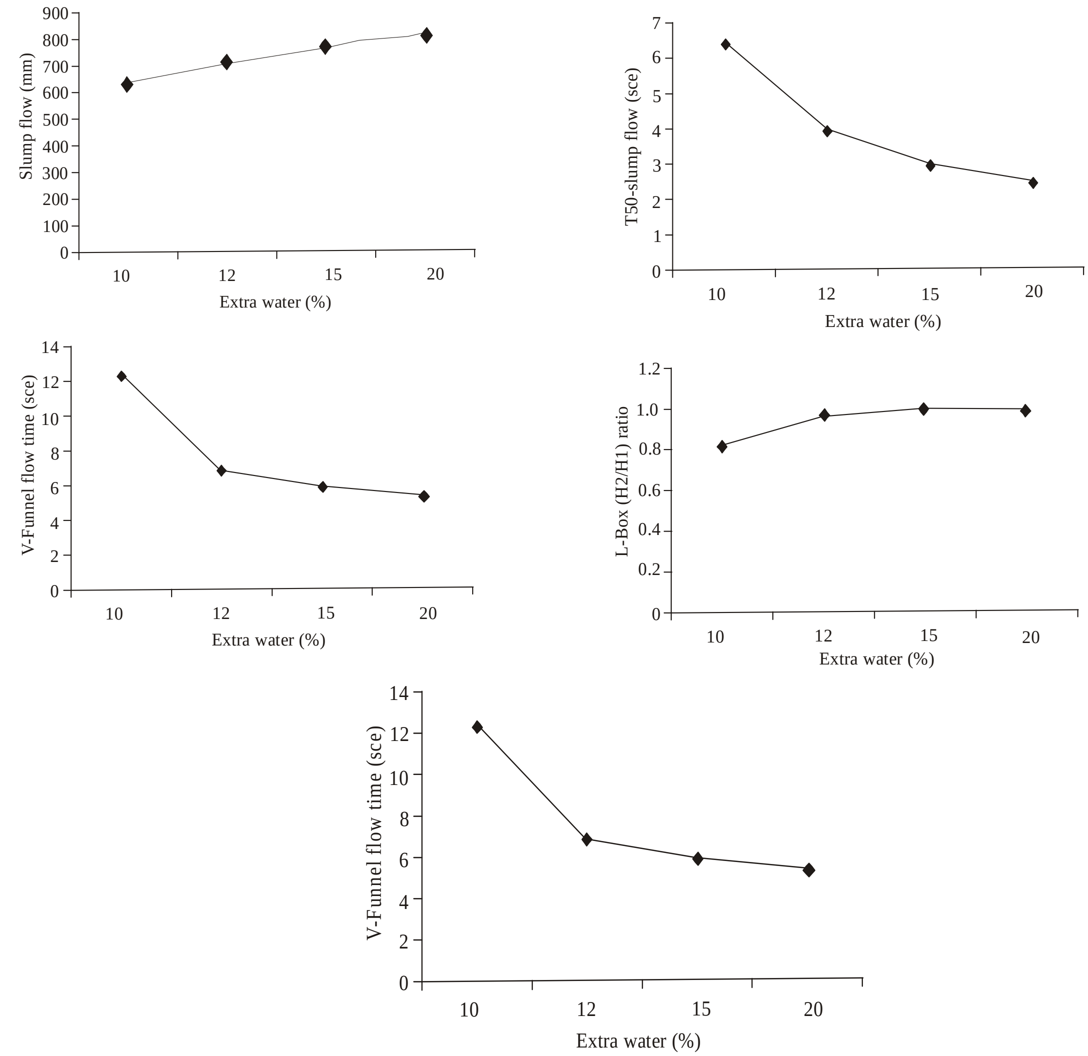


Fig. 1: Effect of extra water on the workability properties of SCGC

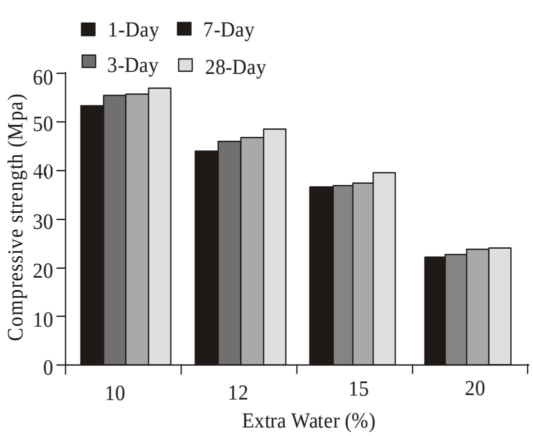


Fig. 2: Effect of extra water on compressive strength

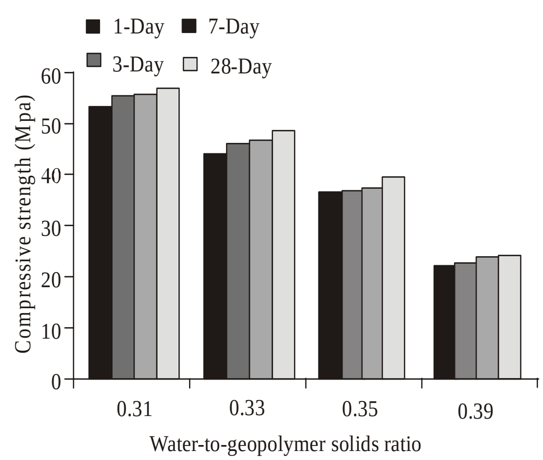


Fig. 3: Effect of water-to-geopolymer solids ratio by mass on compressive strength

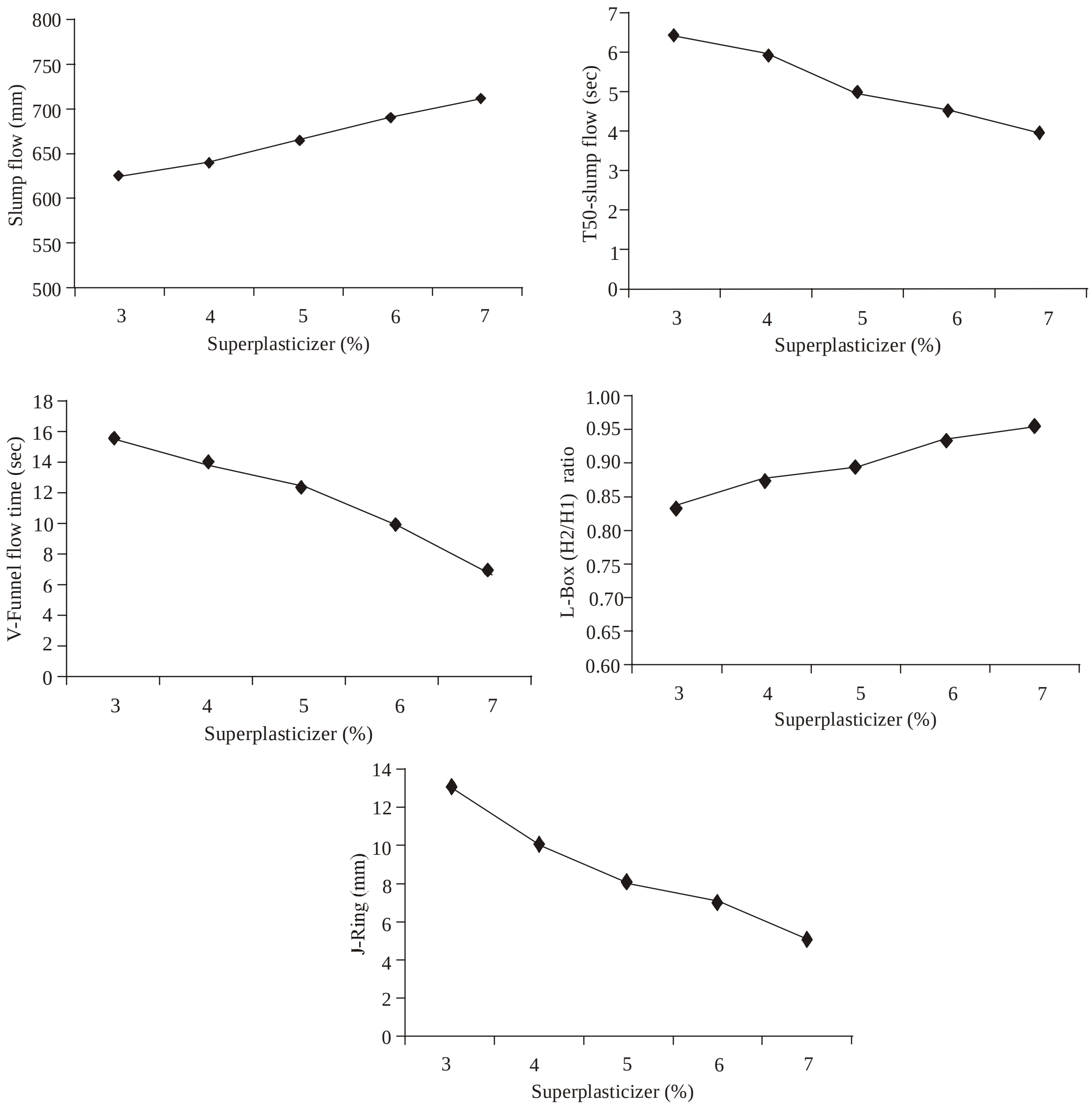


Fig. 4: Effect of superplasticizer on the workability properties of SCGC

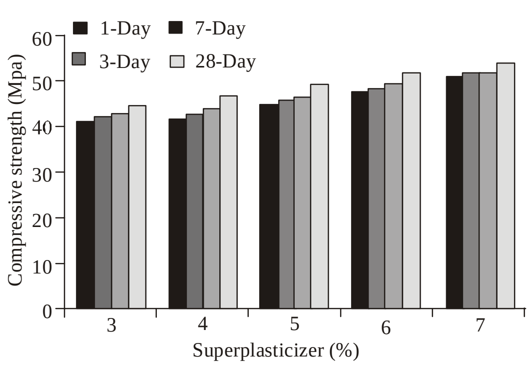


Fig. 5: Effect of superplasticizer on compressive strength

reaction involved in the formation of the binders of both types of concretes is entirely different.

**Effect of superplasticizer:** The common practice to improve the flowing characteristics of concrete and to obtain self-compactability in concrete is to use superplasticizer. To study the effect of superplasticizer on the fresh properties as well as on the compressive strength of self-compacting geopolymer concrete, mixtures $M_5$, $M_6$, $M_7$, $M_8$ and $M_9$, were prepared. All the other test parameters were kept constant while the dosage of superplasticizer varied from 3 to 7% by mass of fly ash. The amount of extra water to the mass of fly ash and the concentration of sodium hydroxide solution were kept 12% and 12 M, respectively. The test specimens were cured in the oven at a temperature of 70ºC for a period of 48 h.

The results of these tests are given in Table 4 and 5. The addition of superplasticizer has shown good indication in effectively improving the fresh properties as well as compressive strength of the self-compacting geopolymer concrete. Increase in dosage of superplasticizer not only improved the workability properties of the fresh concrete but also significantly increased the compressive strength of the hardened concrete.

Figure 4 illustrates the effect of superplasticizer on the workability properties of self-compacting geopolymer concrete. All mixtures showed almost good flowability and displayed good resistance to segregation. As indicated by the L-box test results, all mixtures exhibited good passing ability and no blockage was exhibited in any of the mixes. Test results indicate that superplasticizer dosage of up to 5% was found insufficient to produce desired flowability. The test data shown in Fig. 4 demonstrate that mixes containing superplasticizer dosage of 3, 4 and 5%, respectively were failed to exhibit the required workability properties for SCC. However, mixtures $M_8$, and $M_9$ with superplasticizer dosage of 6% and 7% produced desired results and were within the EFNARC range of SCC. Figure 5 illustrates the effect of sperplasticizer on the compressive strength of concrete. The test results shown in Fig. 5 demonstrate that the compressive strength of self-compacting geopolymer concrete increases as the amount of superplasticizer increases. Concrete specimens containing 7% of superplasticizer exhibited the highest compressive strength at all ages.

## CONCLUSION

In this experimental study, the effects of extra water and superplasticizer on strength and workability of self-compacting geopolymer concrete were studied by comparing the results of different trial mixtures. From the experimental results reported in this paper, the following conclusions are drawn.

The addition of extra water improved the workability characteristics of freshly prepared concrete; however, the inclusion of water beyond 15% resulted in bleeding as well as segregation of fresh concrete and decreased the compressive strength of the concrete. The compressive strength of self-compacting geopolymer concrete was significantly decreased as the amount of extra water exceeded 12% by mass of Fly ash.

- The inclusion of superplasticizer not only improved the workability characteristics of fresh concrete but also increased the compressive strength of hardened concrete. Superplasticizer dosage of up to 5% was found insufficient to produce desired flowability. However, mixes with superplasticizer dosage of 6% and 7% produced desired results and were within the EFNARC range of SCC. Concrete specimens containing 7% of superplasticizer exhibited the highest compressive strength at all ages.

## ACKNOWLEDGMENT

The authors gratefully acknowledges Universiti Teknologi PETRONAS, Malaysia for providing the financial support and research facilities.

## REFERENCES

Astm, C., 2004. Standard specification for coal fly ash and raw or calcined natural pozzolan for use as a mineral admixture in concrete. Annual Book of ASTM standards. Am. Socity Test. Mater., 4(2): 293-295.

Barbosa, V.F.F., K.J.D. MacKenzie and C. Thaumaturgo, 2000. Synthesis and characterisation of materials based on inorganic polymers of alumina and silica: Sodium polysialate polymers. Int. J. Inorg. Mater., 2(4): 309-317.

Bondar D.,C.J. Lynsdale, N.B. Milestone,N. Hassani and A.A.Ramezanianpour,2010. Engineering Propertiesof Alkali Activated Natural Pozzolan Concrete. Proceedings of Second International Conference on Sustainable Construction Materials and Technologies, Universita Politecnica delle Marche, Ancona, Italy.

BS EN, 12390-3:2002, Testing hardened concrete- part 3: Compressive strength of test specimens, British-Adopted European Standard.

BS EN 450-1:2005, Fly ash for concrete-Part 1: Definition, specifications and conformity criteria, British-Adopted European Standard.

Daniel, L.Y.K. and J.G. Sanjayan, 2008. Damage behaviour of geopolymer composites exposed to elevated temperatures. Cem. Concr. Comp., 30: 986-991.

Davidovits, J., 1991. Geopolymers: Inorganic polymeric new materials. J. Ther. Analy., 37(8): 1633-1656.

Davidovits, J., 1993. Geopolymer cement to minimize carbon-dioxde greenhouse-warming. Ceram. Trans., 37: 165-182.

Davidovits, J., 2008. Geopolymer Chemistry and Applications. 2nd Edn., Institut Geopolymer, Saint-Quentin, France.

Duxson, P., J.L. Provis, G.C. Lukey, J.S.J. van Deventer, 2007. The role of inorganic polymer technology in the development of Green concrete. Cem. Concr. Res., 37(12): 1590-1597.

EFNARC, 2002. Specification and Guidelines for Self-Compacting Concrete.

Hardjito, D., S.E. Wallah, D.M.J. Sumajouw and B.V. Rangan, 2004. Factors influencing the compressive strength of fly ash-based geopolymer concrete. Civ. Eng. Dimen., 6(2): 88-93.

Hardjito, D. and B.V. Rangan, 2005. Development and Properties of Low-Calcium Fly ash based Geopolymer Concrete. Research report GC-1, Faculty of Engineering, Curtin University of Technology, Perth, Australia.

Malhotra, V.M., 2004. Role of Supplementary Cementing Materials and Superplasticizers in Reducing Greenhouse Gas Emissions. Proceedings of ICFRC International Conference on Fiber Composites, High-Performance Concrete and Smart Materials, Chennai, India, pp: 489-499.

Memon, F.A., M.F. Nuruddin and N. Shafiq, 2011. Compressive strength and workability characteristics of low-calcium fly ash-based self-compacting geopolymer concrete. Int. J. Civ. Env. Eng., 3(2): 72-78.

Rangan, B.V., 2008. Fly Ash-Based Geopolymer Concrete. Research Report GC-4, Faculty of Engineering, Curtin University of Technology, Perth, Australia.

Temuujin, J., A. van Riessen, K.J.D. MacKenzie, 2010. Preparation and characterisation of fly ash based geopolymer mortars. Const. Build. Mater., 24: 1906-1910.

Villa, C., E.T. Pecina, R. Torres and L. Gomez, 2010. Geopolymer synthesis using alkaline activation of natural zeolite. Const. Build. Mater., 24: 2084-2090.