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A STUDY ON EFFECT OF ADDITION OF SLAG IN GEOPOLYMER CONCRETE

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Abstract : This paper presents the effect of slag addition on strength development and workability of fly ash/slag based geopolymer (FASLG) concrete cured at normal temperature. Class C fly ash with high ferrite (Fe) content was used as the primary material. The proportions of fly ash (FA) to slag (SL) are: 1 FA: 0 SL, 0.9 FA: 0.1 SL, 0.7 FA: 0.3 SL, and 0.5 FA: 0.5 SL. The workability and strength properties were determined by slump, vikat, and compressive strength tests. The result shows that the highest compressive strength was achieved by FASLG-3 concrete with 30% slag addition and exhibited a comparable strength to that normal concrete at 28 days.

***Keywords* - Geopolymer concrete, slag, Fly Ash.**

I. INTRODUCTION

The name Geopolymer was formed by a French Professor Davidovits in 1978 to represent a broad range of materials characterized by networks of inorganic molecules. The Geopolymer depend on thermally activated natural materials like Meta kaolinite or industrial byproducts like fly ash or slag to provide a source of silicon (Si) and aluminum (Al). These Silicon and Aluminum is dissolved in an alkaline activating solution and subsequently polymerizes into molecular chains and become the binder. The 30% slag addition also improve the workability and increase the setting time of FASLG concrete. It can be concluded that the slag inclusion on fly ash will improve the performance of geopolymer concrete at normal temperature. The utilization of fly ash as cement replacement material has been widely used in concrete. This is due to the environmental problems caused by the cement manufacturing process. According to Davidovits , the production of 1 ton cement releases between 0.6-1 ton CO2 with cement production alone contributes about 5-7% of anthropogenic CO2 emissions, which has led to global warming issues . Concrete with 100% fly ash material, known as Geopolymer, is an alternative replacement of normal concrete that conventionally use cement-based material. Geopolymer concrete (GPC) is a ecofriendly building material. Geopolymers are the products of polymerization reactions of aluminosilicate-rich materials and alkali activators.

II. PROPERTIES OF GEOPOLYMER CONCRETE

The superior properties of Geopolymer concrete, based on Prof. B. Vijaya Rangan and Hardijito, are:

- Sets at room temperature
- Non-toxic, bleed free
- Long working life before stiffening
- Impermeable
- Higher resistance to heat and resist all inorganic solvents.
- Higher compressive strength.

III. OBJECTIVE

- The addition of material with high Calcium content is an alternative to overcome the heat cured issues on fly ash based Geopolymer concrete.
- Slag, a by-product of the metal ore smelting process, contains important materials such as silica and alumina which can be used as building materials.
- In addition, a raw slag material also provides a good Calcium composition up to 40%. It can be used as an addition material with fly ash to overcome the problem of high temperature requirement in Geopolymer concrete production.

IV. MATERIAL USED

- The materials used for this research were class C fly ash with high ferrite (Fe) content, High calcium (Ca) content slag materials.
- Class C fly ash had CaO of 12.65% (> 10%), $SiO_2+Al_2O_3+Fe_2O_3$ of 93.39% (> 50%) and SO_3 of 0.86%(<5%).
- A mix of sodium silicate and 10 Molar sodium hydroxide (NaOH) were used as alkaline activators. Ratio of SiO_2 to Na_2O on sodium silicate was 3.30.

V. MIX PROPORTIONS

- The details of fly ash and slag based geopolymer (FASLG) concrete mix proportions are shown in Table 1. The FASLG concrete mix design developed from the previous research with a design strength of 22.5 MPa. A water solid ratio (w/s) of 0.25 was used rather than a water binder ratio (w/b) due to a solid content on sodium silicate and NaOH. The quantity of water in FASLG concrete mix was calculated as the sum of water contained in the added water, NaOH and sodium silicate. The quantity of solid was taken from the mass of fly ash, slag and the solid content of activator solution.

Mixture	Portland Cement	Fly Ash	Slag	Aggregate		Alkaline Activator		Added Water
				Fine	Coarse	Na_2SiO_3	NaOH	
OPC (CONTROL)	1.0	------	-------	1.50	3.00	-----	------	0.45
FASLG-1	------	1.0	0.0	1.50	3.00	0.25	0.15	0.02
FASLG-2	------	0.9	0.1	1.50	3.00	0.25	0.15	0.02
FASLG-3	------	0.7	0.3	1.50	3.00	0.25	0.15	0.02

TABLE 1: MIX PROPORTIONS OF SLAG BASED GEOPOLYMER CONCRETE

VI. RESULT

The compressive strength of 100 x 200 mm2 cylinder FASLG specimens. The concrete specimens were tested at 3, 7, 14, and 28 days after casting. The test was considered complete until the collapse of concrete specimens. The workability performance of FASLG concrete specimens were performed by slump test value, while the setting time test are measured by depth penetration test (Vikat tests). The slump test was tested using Abrams Cone (300 mm height, 100 mm diameter on top and 200 mm diameter on the bottom) for each fresh FASLG concrete.

A. STRENGTH DEVELOPMENT

The compressive strength results reported for the FASLG concrete specimens for all mixes. The FASLG specimens shows a low strength at early age with all mixes producing compressive strength under 10 MPa during the first three days after casting, with the exception of FASLG-3 mix with a strength of 13.18 MPa. FASLG-1 with no slag addition (0% slag) shows the worst performance.

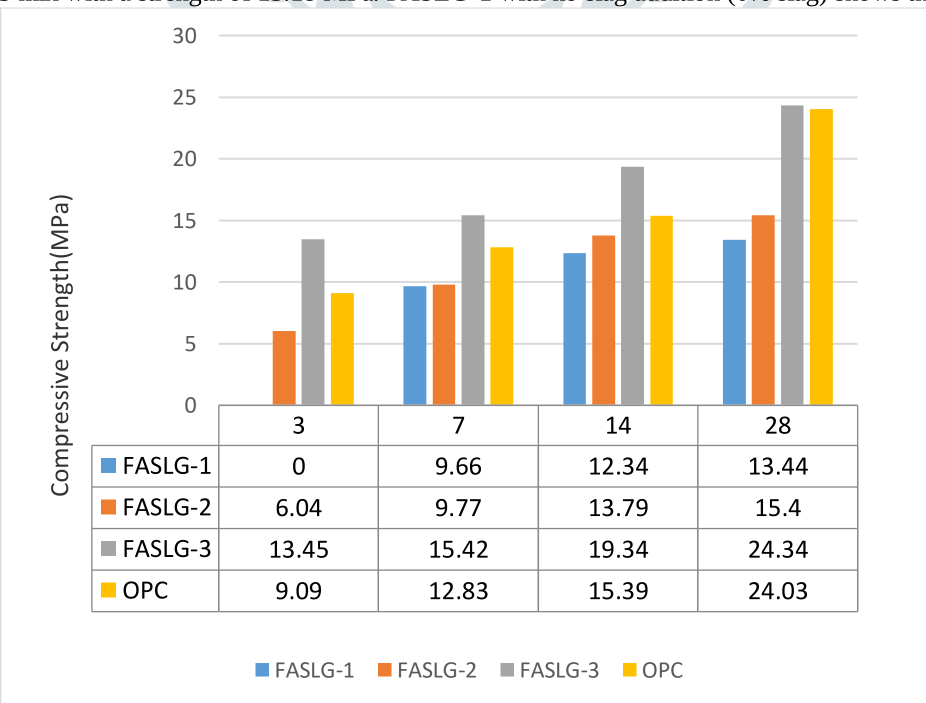

TABLE 2: BAR CHART OF STRENGTH DEVELOPMENT

Table 2 shows that the strength development of FASLG3 mix (30 % of slag addition) shows the highest initial strength with 13.18 MPa at 3 days of age (56.32% of final strength) and significantly increased from 7 to 14 days age to 14.83 MPa and 19.10 MPa, respectively. This might be attributed to Ca content in slag addition material. FASLG-3 also shows a comparable compressive strength to that OPC concrete at 28 days age with strength of 23.40 MPa. On the contrary, other mixes (FASGL-1, FASGL-2 and FASGL-4) does not show any significant increase of strength with time, but shows a slight increase (10% to 16%) in strength from 14 days to 28 days.

B. WORKABILITY

The result of the slump test demonstrates that standard slump test was not a suitable measure as the liquid characteristic of the FASLG concrete results in collapse as soon as slump cone is lifted, as shown in FASLG-1 (0% slag) with slump value of 19.45 cm. The collapse was attributed to the spherical shape of fly ash particles, coupled with a lubricant effect of the sodium silicate and the added water, resulting in a high flow ability and high slump value for the FASLG specimens. However, the slump test of FASLG concrete specimens were significantly affected by the inclusion of slag material.

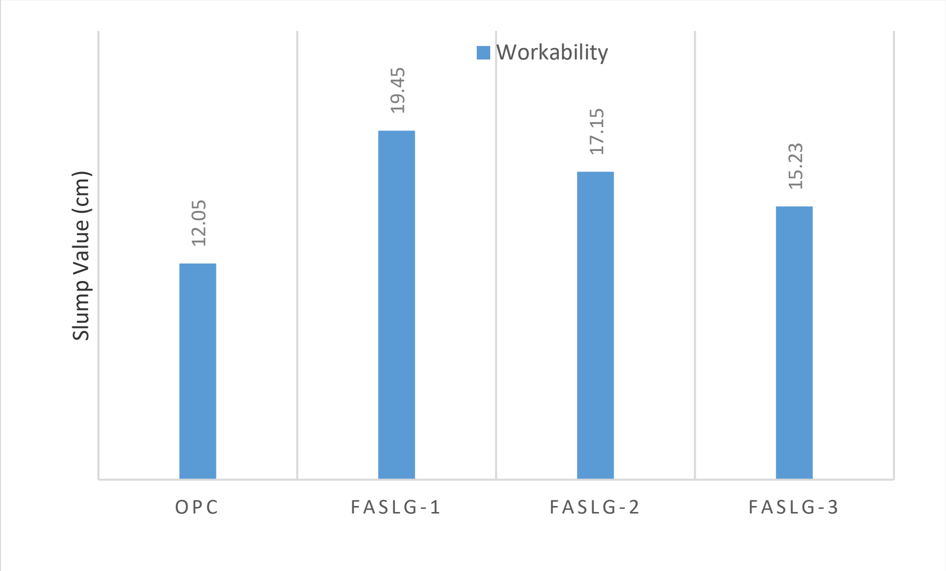

TABLE 3: BAR CHART OF WORKABILITY TEST

VII. LIMITATION

The followings are the limitations

1. Bringing the base material fly ash to the required location.
2. High cost for the alkaline solution.
3. Safety risk associated with the high alkalinity of the activating solution.
4. Practical difficulties in applying Steam curing / high temperature curing process Considerable research is ongoing to develop geopolymer systems that address these technical hurdles.

VIII. FUTURE SCOPE

- In the short term, it has a large potential for Geopolymer concrete applications for bridges, such as precast structural elements and decks as well as structural retrofits using Geopolymer-fiber composites.
- Geopolymer technology is most advanced in precast applications due to the relative ease in handling sensitive materials and the need for a controlled temperature of curing environment required for many current Geopolymer concrete.

IX. CONCLUSION

The reaction mechanism of geopolymer, the workability, mechanical properties and durability of fresh and hardened FA/GGBFS based GPC were reviewed. Based on the review results, the following conclusions can be derived as:

- Finally, the results show a comparable compressive strength of FASLG-3 (30% slag) to that OPC concrete at 28 days age. This would suggest that the slag inclusion is the primarily contribute to the strength gain with the time.
- While 100% fly ash Geopolymer specimens generally required heat curing to achieve high strength, the use of slag on fly ash Geopolymer can provide a solution to the requirement for heat curing of Geopolymer concrete production providing structural integrity at ambient temperatures.
- 30% slag addition shows a comparable compressive strength to that of normal concrete at 28 days.
- Improved workability.
- Provide a solution on heat curing treatment requirement of Geopolymer concrete production.
- Highest compressive strength was achieved by addition of 30% slag.
- An alternative replacement of normal concrete that conventionally use cement-based material.
- Because of the main raw materials used in GPC are industrial wastes, such as FA and GGBS, the application of GPC can reduce CO2 emission.
- Utilizes the waste by recycling process and promote the sustainable development of society. Therefore, the FA/GGBFS-based GPC could be utilized potentially as a replacement for OPC. However, this will only occur when there is an effective raw material supply chain.

- The reaction mechanism of the FA/GGBFS geopolymer material involves the breaking and re-joining of the Si2O and Al2O bonds under the action of an alkaline activator, which results in the production of a hardened geopolymer with excellent mechanical properties and durability.
- The rheology of Geopolymer Concrete differs from that of OPCC. High viscosity of the Na2SiO3 solution, the slump of GPC decreases with an increase in the Na2SiO3 content. The NaOH concentration, and FA/GGBS ratio affect the workability, initial setting time, and final setting time of GPC.
- The workability of GPC with different mix proportions fluctuates greatly. Therefore, the preparation technique of GPC with stable workability is the key problem in the promotion of GPC applications.
- The effects of different phases on the mechanical properties of FA/GGBFS-based GPC has better mechanical properties than OPCC.
- It can be indicated that FA/GGBS-based GPC had a smaller strength loss and mass loss than OPCC after acid attack, suggesting that GPC has excellent acid resistance. The structure of GPC is similar to that of zeolite because GPC is an alkali-activated material. Therefore, FA/GGBFS-based GPC has excellent freezeethaw resistance and high-temperature resistance.
- The properties of GGBS-based GPC depend on the chemical composition of the binders, curing conditions, casting processes, and environmental conditions. The review provides a foundation for understanding the effects of known parameters on the mechanical properties and durability of fresh and hardened FA/GGBS based geopolymer concrete.
- Geopolymer concrete can be used under conditions similar to those suitable for ordinary Portland cement concrete. These constituents of Geopolymer Concrete shall be capable of being mixed with a relatively low-alkali activating solution and must be curable in a reasonable time under ambient conditions.
- Due to the high early strength Geopolymer Concrete shall be effectively used in the precast industries, so that huge production is possible in short duration and the breakage during transportation shall also be minimized.
- Geopolymer Concrete shall also be used in the Infrastructure works. In addition to that the Flyash shall be effectively used and hence no landfills are required to dump the flyash.
- The government can make necessary steps to extract sodium hydroxide and sodium silicate solution from the waste materials of chemical industries, so that the cost of alkaline solutions required for the geopolymer concrete shall be reduced.

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