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High Performance Fibre Reinforced Alkali Activated Slag Concrete

A. Sivakumar, K. Srinivasan

***Abstract*—**The main objective of the study is focused in producing slag based geopolymer concrete obtained with the addition of alkali activator. Test results indicated that the reaction of silicates in slag is based on the reaction potential of sodium hydroxide and the formation of alumino-silicates. The study also comprises on the evaluation of the efficiency of polymer reaction in terms of the strength gain properties for different geopolymer mixtures. Geopolymer mixture proportions were designed for different binder to total aggregate ratio (0.3 & 0.45) and fine to coarse aggregate ratio (0.4 & 0.8). Geopolymer concrete specimens casted with normal curing conditions reported a maximum 28 days compressive strength of 54.75 MPa. The addition of glued steel fibres at 1.0% V_f in geopolymer concrete showed reasonable improvements on the compressive strength, split tensile strength and flexural properties of different geopolymer mixtures. Further, comparative assessment was made for different geopolymer mixtures and the reinforcing effects of steel fibres were investigated in different concrete matrix**.**

***Keywords*—**Accelerators, Alkali activators, Geopolymer, Hot air oven curing, Polypropylene fibres, Slag, Steam curing, Steel fibres.

I. Introduction

IN recent times alternate cement based geopolymer concrete finds potential application on par that of conventional cement based concrete. Geopolymer concrete are typically energy efficient due to less release of carbon dioxide emissions during burning of kiln as produced in the case of cement. Geopolymer based concrete had drawn good attention due to its viable alternate for Portland cement which is commonly used as a binder. Since, the production of cement consumes lot of raw material as well as increases the carbon dioxide emissions. Since, then much research work concluded that geopolymer concrete system can be produced with the industrial waste product such as ground granulated blast furnace slag, bentonite, metakaolin, fly ash etc. Geopolymer concrete systems are typically produced in silica rich source material.

The first geopolymer was produced by Professor Joseph Davidovits [1] in its research laboratory with the activation of sodium hydroxide produced alumina-silicate components, which was found to be a binding medium. From then many systematic investigations were carried out on geopolymer concrete system and its properties were studied extensively.

The findings from many studies on geopolymer concrete have shown promising results on the improvement on the matrix properties. In this direction many fruitful investigations had produced this wonderful material with different types of industrial waste materials such as silica fume, fly ash, blast furnace slag, rice husk ash and bentonite. Experimental studies had proved the advantageous properties of geopolymer concrete [1]. The incorporation of fine discrete fibres improves the fracture properties of fly ash based geopolymer when the addition ranges from 0.3 to 1.0% by the weight of binder. It is also observed that the mechanical properties of geopolymer mixtures were greatly improved with optimum fibre content 0.5% cotton fibres and also the density of the geopolymer composites were found to decrease with the increase in the fibre content [2]. It is understood that the properties of geopolymer concrete depends on the activator to binder ratio as well as varying alumina to silica ratio. Most importantly the mechanical and durability characteristics of alkaline cement mortars reinforced with polypropylene fibres were known to improve the hardened properties. Most notably, the mechanical properties of alkali activated slag consisting of sodium silicate and sodium hydroxide with 4% sodium oxide by mass of slag cured at room temperature were indicative of effective geopolymerisation. The reaction of geopolymer mixtures depends on the molarity ratio or the concentration of alkali activator such as sodium hydroxide, sodium silicate, potassium hydroxide, potassium silicate etc.

Geopolymer mixtures prepared at 8M sodium hydroxide was tested at room temperature and the incorporation of fibre percentages of 0.5% and 1% by mortar volume shows lesser shrinkage as well as shown higher strength gain properties [3], [4]. The proper selection of silica to alumina ratio and concentration of sodium hydroxide/sodium silicate ratio play a major role on the formation of geopolymer. It is indicative that the reaction of geopolymer depends on the matrix potential and typically the hardening properties vary over a period of curing regime. The accelerated hardening was achieved in hot environment providing rapid geopolymerisation. This was profoundly agreed in many research investigations on geopolymer which were typically produced in the presence of hot curing environment greater than 50°C. The formation of alumina-silicate compound occurs rapidly at high temperature curing and was found to produce stable chain formation occurring at high concentration of alkali activator. The test results also justify that the matrix will be the most important factor for the strength development in the case of slag based alkali activated concrete [5]. The presence of fibres provides adequate toughness to the composite [6]. Several investigations in studied the potential geopolymerized product the mechanical properties and long term durability properties.

A. Sivakumar is with the Vellore Institute of Technology, Vellore, TN 632006, India (corresponding author; Phone: +91416-2242026; fax: +91416-2243092; e-mail: sivakumara@vit.ac.in).

K. Srinivasani is with the Vellore Institute of Technology, Vellore, TN 632006, India (e-mail: srinivasan.k@vit.ac.in).

It was observed that the influence of 0 to 40% of red mud on the reaction as well as structural formations of geopolymer based concrete was studied using different advanced characterization methods [7]. The improvement in the intensity of reaction was observed with the addition of red mud of all replacements level but improvement in setting time and compressive properties was noticed when the samples contain 5 to 10% of red mud. Structural properties reveal that the reaction was dependent on the concentration of alkali and the developments of the mechanical properties were related to the micro structural densification [8]. The high strength geopolymer was found to obtain with proper selection of molarity of alkali activator and typically presence in the alumina-silicate sources aided with alkali- silicate resume [9]. The fly ash to slag ratio and the activator concentration was found to be a significant factor affecting the geopolymerisation rate. The influence of curing temperature and the development of compressive properties was found to be dependent with the nature of the reaction product and the dissolving ability [10]. The reaction process at ambient temperature is slightly affected due to delayed polymerization. The main reaction product in the past consists of calcium silicate based hydrate compound and consisting of tetra coordinate alumino silicate structure as well as sodium ions in interlayer spaces [11]. The detailed review of various literatures shows the advantages of using geopolymer concrete and the detailed production strategies. The present study is motivated with the production of geopolymer concrete for varying binder to aggregate ration and activator to slag ratio. Further experimental studies were conducted to evaluate the mechanical properties of geopolymer concrete with the inclusion of steel fibers [12].

II. Materials and Test Methods

A. Materials Used

Ground granulated blast furnace slag was used as raw material for the production of geopolymer. The composition of slag comprise of 31.73%, alumina of 11.48%, magnesium oxide of 7.32% and calcium of 42.47%. Glued steel fibres of length 35 mm x 0.5 mm diameter having an aspect ratio of 70 was added in geopolymer concrete mixes consisting of proportions 1:1.56:2.63 and 1:1.81:2.92 at various dosages of 0.5%, 1.0% and 1.5% by volume fraction (V_f). A sodium hydroxide based alkali activator at concentration level of 12 M was used for triggering the geo-polymer reaction. The loss in the consistency of fresh geopolymer mixes were achieved with the addition of high range superplasticizer upto 1.5%. The specimens were cured initially in hot air oven and later subjected to steam curing. In the case of hot air oven curing, the specimens were cured at two different temperatures 100°C for 6 hours from immediate casting of concrete.

A specially fabricated steam chamber was used for curing the specimens at 75°C for 6 hours and the fresh geopolymer specimens in the mould were transferred to the steam chamber immediately after casting.

B. Testing Methodology

Mechanical properties such as compressive strength, split tensile strength and flexural strength were determined. Compressive and split tensile strength of hardened geopolymer specimens were tested in a digital compression testing machine of 2000 KN capacity operated at a rate of loading 2.5 KN/sec was used. Cube specimens of size 100 x 100 x 100 mm, cylindrical specimens of size 100 x 200 mm and 150 mm x 300 mm were used to assess the compressive, split tensile and elastic modulus of various geopolymer concretes respectively. Flexural performance of geopolymer concrete specimens of size 100 x 100 x 500 mm were tested in a load controlled machine (100 KN) at the rate of 2 KN/sec.

III. Mechanical Properties Investigated

A. Compressive Properties

The mechanical properties of various geopolymer based concrete mixtures tested in compressive and flexural properties are provided in the Table II and shown in Fig. 1. It can be noted from the test results that the synthesis of geopolymer mixture can produce a maximum compressive strength of around 54.75 MPa in the case of mixture constituents consisting of binder to aggregate ratio of 0.3. It is also observed that the increase in the activator to binder ratio of around 0.3 also exhibited that geopolymer based mixtures compressive properties was likely affected after third day and the significant of geopolymer based material possess the maximum polymerization reaction within the shorter curing period. The results confirm that at 28th day, the maximum strength achieved was almost similar to 3rd day strength of around 90% of the maximum compressive strength reached in the case of all geopolymer concrete based mixtures this essentially reveal that in the case of geopolymerisation reaction the polycondensation type of reaction occurring within the silico-aluminate minerals and there by the strength of the compound was found to be enhanced with respect to type of alkali activator and dosage of the alkali activator. It is also apparent that the concentration of alkali depends strongly on the side chains formed during the polymerization reactions. The cross network structure formed during the geopolymerisation resulting in the multi stage polycondensation reaction leading to polysialate compound.

B. Flexural Strength

Flexural strength properties of all steel fibre reinforced geopolymer concrete mixes showed a reasonable improvement as seen in Fig. 2. In the case of flexural performance, the highest performance was noted for the geopolymer mixture consisting of higher steel fibre content and the maximum flexural strength was noted in the case of GPS4 mixture with the maximum flexural strength of 13.11 MPa and in the case of the lower fine to coarse aggregate ratio, the flexural strength was found to be affected and showed the reduction in the strength value. On the other hand, the increase in the activator to binder ratio and fine to coarse aggregate ratio was found to be apparently higher compared to lower fine to coarse aggregate ratio. This shows that the selection of proper ingredient proportions can result in better geopolymer based mixtures. Analyzing all the mechanical properties tested, it is noted that the geopolymer concrete mixtures were found to be a useful material in replacing the plain cement concrete in construction practice. Flexural properties of geopolymer showed significant improvements with the steel fibre addition. The hooked ends of steel fibres provided better anchorage in the matrix and increased the post crack performance of the composite.

C. Split Tensile Strength

Similar test results were also observed in the case of split tensile property wherein, the maximum split tensile value of mix GPS4 was around 6.98 MPa. From Fig. 3 it can be noted that the increase in strength was found to be appreciable with 1.5% steel fibre addition. The improvement on the strength property was noted with the addition of steel fibres and found to affect the split tensile strength. Since the failure is anticipated in tensile direction along diametral direction during indirect split tension testing of geopolymer concrete specimens. In the case of split tensile strength, the effect of steel fibres was found to be contributing towards the increase in tensile strain. A result with the increase in fibre dosage in which the split tensile property found to be increased.

TABLE I
GEOPOLYMER MIXTURES USED IN THIS STUDY

Mix ID	Relative composition of volume of concrete (%)			Slag	Aggregate		Water
	Slag	*Aggregate*			*Fine*	*Coarse*	
		Fine	*Coarse*	(Kg/m^3)			
GPS1							
GPS2	27.9	17.5	45.6	6969.6	420.0	1094.4	216
GPS3							
GPS4							
GPS5							
GPS6	19.8	28.4	45.8	475.2	681.6	1099.2	216
GPS7							
GPS8							

Note: Mix ID GPS1 to GPS4 consists of the mix proportions 1:1.56:2.63
Mix Id GPS5 to GPS8 consists of the mix proportions: 1:1.81:2.92

IV. SALIENT CONCLUSIONS

From the experimental studies conducted, it can be concluded that slag based concrete exhibited better performance in terms improved mechanical performance. The slag based geopolymer concrete activated by 12 M sodium hydroxide containing binder to total aggregate ratio of 0.3 showed highest compressive strength. This was better observed for geopolymer concrete consisting of fine to coarse aggregate ratio of 0.8 with 1.5% V_f of steel fibres has achieved the maximum compressive strength of 54.77 MPa. A similar observation was also noted in the case of split tensile strength properties and flexural strength of 6.98 MPa and 14.38 MPa (GPC4) respectively. The steel fibres have helped to gain better strength compared to its control mix concrete. The ratios between the binder to total aggregate ratio and fine to coarse aggregate provided the matrix strengthening to the concrete and the steel fibres have enhanced the post crack performance of the geopolymer composite.

TABLE II
MECHANICAL PROPERTIES OF VARIOUS GEOPOLYMER MIXTURES

Mix ID	B/AG	Steel fibre (%)	Compressive Strength (MPa)		Flexural Strength (MPa)		Split Tensile Strength (MPa)	
			Day					
			3rd	*28th*	*3rd*	*28th*	*3rd*	*28th*
GPS1	0.30	0	42.27	45.86	7.23	8.44	1.5	1.58
GPS2		0.5	49.53	51.22	8.94	8.23	3.23	3.82
GPS3		1.0	53.42	54.15	9.62	11.3	5.57	6.27
GPS4		1.5	53.92	54.77	13.1	14.3	6.27	6.98
GPS5	0.45	0	32.23	42.58	5.97	7.52	2.77	3.4
GPS6		0.5	19.89	23.85	4.49	7.25	2.67	3.72
GPS7		1.0	17.65	23.92	4.73	7.33	2.96	3.75
GPS8		1.5	15.96	22.13	5.26	7.86	2.67	3.78

Note: The AC/B ratio 0.30 and NaOH 103.68 (kg) is constant for all mix proportions.

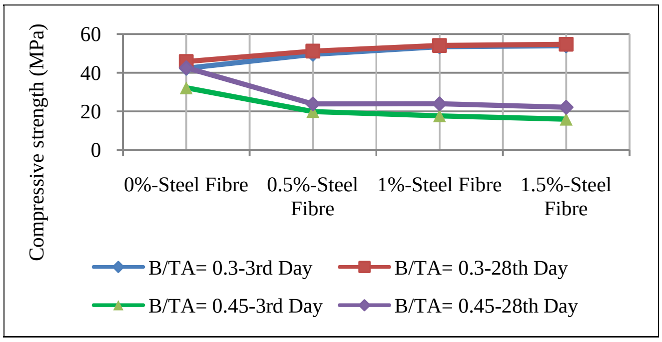

Fig. 1 Compressive strength property of the steel fibre reinforced geopolymer concrete

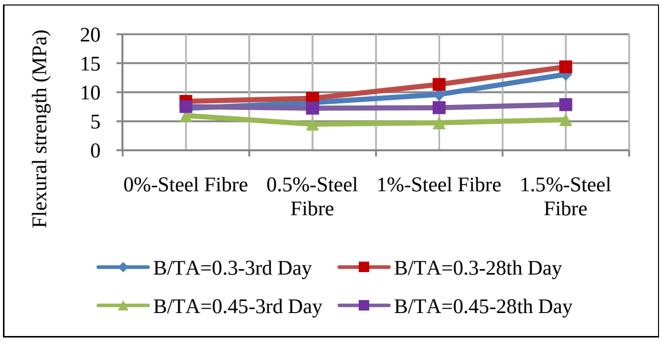

Fig. 2 Flexural strength property of steel fibre reinforced geopolymer concrete

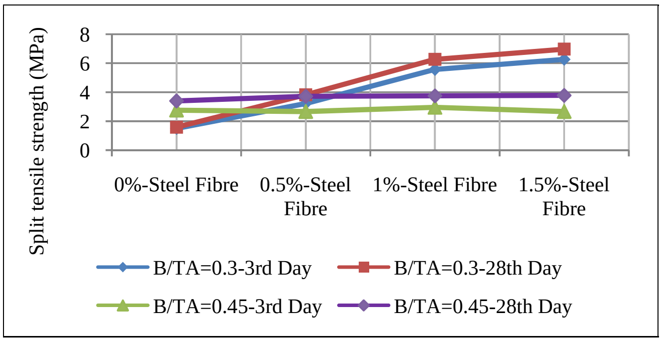

Fig. 3 Split tensile strength property of steel fibre reinforced geopolymer concrete

REFERENCES

[1] J. Davidovits, "Geopolymers and geopolymeric materials," *Journal of Thermal Analysis*, vol. 35, pp. 429–441, 1989.

[2] T. Alomayri, F.U.A. Shaikh, and I.M. Low, "Characterisation of cotton fibre-reinforced geopolymer composites," *Composites: Part B*, vol. 50, pp. 1–6, Feb. 2013.

[3] F. Puertas, S. MartõÂnez-RamõÂrez, S. Alonso, and T. VaÂzquez, "Alkali-activated fly ash/slag cement Strength behaviour and hydration products," *Cement and Concrete Research*, vol. 30, pp. 1625-1632, Apr. 2000.

[4] F. Puertas, T. Amat, A. Ferna´ndez-Jime´nez, and T. Va´zquez, "Mechanical and durable behaviour of alkaline cement mortars reinforced with polypropylene fibres," *Cement and Concrete Research*, vol. 33, pp. 2031–2036, June 2003.

[5] Valeria F.F. Barbosa, Kenneth J.D. MacKenzie, and Clelio Thaumaturgo, "Synthesis and characterisation of materials based on inorganic polymers of alumina and silica: sodium polysialate polymers," *International Journal of Inorganic Materials*, vol. 2, pp. 309–317, May 2000.

[6] D. Hardjito, and B. V. Rangan, "Fly Ash-Based Geopolymer Concrete Develoment and properties of low-calcium fly ash- based geopolymer concret," *Research Report GC 1*, 2005.

[7] Anuj Kumar, and Sanjay Kumar, "Development of paving blocks from synergistic use of red mud and fly ash using geopolymerization," *Construction and Building Materials*, vol.38, pp. 865–871, Oct. 2012.

[8] Hua Xu, and J.S.J. Van Deventer, "The geopolymerisation of alumino-silicate minerals," *International Journal Mineral Process*, vol. 59, pp 247–266, Nov. 1999.

[9] Peter Duxson, John L. Provis, Grant C. Lukey and Jannie S.J. van Deventer, "The role of inorganic polymer technology in the development of 'green concrete'," *Cement and Concrete Research*, vol. 37, pp. 1590–1597, Aug. 2007.

[10] S. Oniseia, Y. Pontikesb, T. Van Gervenc, G.N. Angelopoulosd, T. Veleae, V. Predicae, and P. Moldovana, "Synthesis of inorganic polymers using fly ash and primary lead slag," *Journal of Hazardous Materials*, vol. 205– 206, pp. 101– 110, Dec. 2011.

[11] A. Autef, E. Joussein, G. Gasgnier, and S. Rossignol, "Role of the silica source on the geopolymerization rate," *Journal of Non-Crystalline Solids*, vol. 358, pp. 2886–2893, Aug. 2012.

[12] Isabella Lancellotti, MichelinaCatauro, ChiaraPonzoni, FlaviaBollino, and CristinaLeonelli, "Inorganic polymers from alkali activation of metakaolin: Effect of setting and curing on structure," *Journal of Solid State Chemistry*, vol. 200, pp. 341–348, Feb. 2013.

A. Sivakumar Presently working as professor in a reputed university in India and has 8 years of teaching experience. Expertise areas include advanced concrete making materials, alternative construction materials, fracture properties of concrete.

K. Srinivasan Presently working as Assistant professor in a reputed university in India and has 3 years of teaching experience. Expertise areas include Geopolymer concrete, advanced cement materials, high performance concrete.