VOL. 8, NO. 10, OCTOBER 2013 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

COMPARATIVE STUDY ON MECHANICAL PROPERTIES OF GEOPOLYMERS AND THEIR COMPOSITES

Venkateswararao J.[1], Srinivasa Rao K.[2], Rambabu K.[2] and Brahma Reddy T.[1]
[1]Department of Civil Engineering,, GMR Institute of Technology, Rajam, A.P., India
[2]Department of Civil Engineering, Andhra University, Visakhapatnam, India
E mail: jampanivenkat8@gmail.com

ABSTRACT

This paper presents the relative results of an experimental investigation on the fresh and hardened properties of Geopolymer concrete (GPC), Geopolymer Concrete Composites (GPCC) containing 80% Fly ash (FA), 20% Ground Granulated Blast Furnace Slag (GGBS). Sodium based alkaline liquid is used as an activator. The study also analyses the impact of steel fibers on the workability and mechanical properties of GPCC. Steel fibers were added to the mix in the volume fractions of 0.25%, 0.5% and 0.75% volume of the concrete. From the results it is observed that as the age of concrete increases the mechanical properties of GPCC are found to be improving significantly. Inclusion of steel fibers resulted in improved compressive and flexural strengths at the early ages. However tensile strength is found to be improved significantly at later stages.

Keywords: geopolymer, compressive strength, tensile strength, flexural strength, steel fibers.

1. INTRODUCTION

Ever growing applications of concrete in the areas of infrastructure, transportation, and habitation have greatly prompted the development of civilization, economic progress, stability and the quality of life [1]. It is well known fact that concrete consumes huge quantities of virgin materials, production of its principal binder, cement leading to emission of green house gases. The structures suffer from lack of durability. These problems rendered the concrete construction industry to search for sustainable resources. [2]. During the last couple of decades alkali-activated binders are increasingly receiving the worldwide interest in light of the ongoing emphasis on sustainability. Zongjin Li *et al*., [3] termed the geopolymers as sustainable cementitious materials due to their being energy efficient and environment friendly. The source materials used for producing geopolymer composites could be natural minerals such as kaolinite, clays, etc. or industrial by-products such as fly ash, silica fume, slag, etc. Hardjito. D and Rangan B.V have explored extensive investigation on the development and properties of fly ash geopolymer concrete [4]. Not only the mechanical properties of geopolymer concrete are superior to the conventional concrete but it undergoes low creep and very little drying shrinkage [5]. Geopolymer concrete is found to be excellent in resisting acid attack [6-8]. Previous researchers also proved that heat cured geopolymers exhibits better resistance to sulphate attack [9-11]. Studies by Li and Xu proved that geopolymer exhibits better durability and excellent mechanical properties [12].

Despite of having many advantages, mostly the use of the geopolymer concrete is limited to precast industry due to fact that the polymerization reaction is very sensitive to temperature. Usually geopolymer concrete requires to be cured at elevated temperature under a strictly controlled temperature regime [13-14]. Geopolymer concrete produced without heat for curing will widen its application to the areas beyond precast members. Very limited literature is available in respect of production of geopolymers under ambient condition. The investigation by S. Manjunath *et al*. revealed that the geopolymer mortar develops the strength even at ambient conditions without any conventional curing [15]. Research of K. Vijai *et al*., proving that in ambient curing, the compressive strength increases as the age of concrete increases from 7 days to 28 days [16].

From the past experimental investigations it is clear that the usage of fibers in concrete leads to improvement in the mechanical properties. Test results of Yeol Choi *et al*., indicating that the addition of glass and polypropylene fibers to concrete increased the splitting tensile strength of concrete by approximately 20-50% [17]. Mazaheripour *et al*., found that applying 0.3% volume fractions of polypropylene fiber to the light weight self compacting concrete resulted in 40% reduction in the slump flow. They proved that by applying these fibers at their maximum percentage volume determined through this study, increased the tensile strength by 14.4% in the splitting tensile strength test, and 10.7% in the flexural strength [18]. Songa *et al*., investigations showed that at a fiber content of 0.6 kg/m^3 nylon fiber-reinforced concrete exhibited higher compressive and splitting tensile strengths and modulus of rupture than the of the nylon fiber concrete at a rate of 6.3%, 6.7%, and 4.3%, respectively over polypropylene-fiber-reinforced concrete [19]. The laboratory tests of Okan Karahan *et al*., observed that freeze-thaw resistance of polypropylene fiber concrete was slightly more when compared to concrete without fibers [20].

Present experimental investigation is aimed at studying the properties of geopolymer concrete developed under ambient curing condition. Ground granulated blast furnace slag was mixed with low calcium fly ash to study the workability and the mechanical properties of geopolymer concrete. Also to enhance the early strength

VOL. 8, NO. 10, OCTOBER 2013 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

steel fibers are included in the mixes and the effect is also studied.

2. MATERIALS, SPECIMEN PREPARATION, TEST VARIABLES AND TESTING METHODS

In the present study, the materials used were Class F Fly ash and GGBS collected from locally available source NTPC Visakhapatnam, India and Toshali Cements Pvt. Ltd, Visakhapatnam, A.P, India, respectively.

2.1. Materials characterization

The physical properties and chemical composition of the fly ash and GGBS are given in Table 1. and Table 2. respectively. For preparing activator solution, Sodium hydroxide (pellets 97-98% purity) and Sodium silicate solution with specific gravity of 1.39 is used. The chemical composition of sodium silicate solution is: Na_2O = 10.2%, SiO_2 = 27.3% and water 62.5% by mass. Locally available sand and aggregates are used. Specific gravity of fine and coarse and fine aggregates is in the range of 2.66 and 2.67 respectively. Tap water was used in preparing alkaline solution. Steel fibers used in this investigation are of flat crimped cross section with 1.2mm thick and 60mm long.

Table-1: Physical properties of fly ash and GGBS.

Physical Property	Fly ash	GGBS
Specific gravity	1.91	2.9
Fineness (m^2/kg)	365	416

Table-2: Chemical composition of fly ash and GGBS.

Chemical composition (%)	fly ash	GGBS
Al_2o_3	32.4	16.3
Fe_2o_3	4.04	0.68
Sio_2	58.1	34.4
Mgo	0.71	8.83
So_3	0.12	1.44
Na_2o	0.17	0.22
Chlorides	0.02	0.01
L.O.I[a]	0.85	0.19
Cao	1.4	34.6

2.2. Specimen preparation

Sodium hydroxide pellets were dissolved in tap water to obtain a solution of required concentration. Activator solution is prepared by adding measured quantity of Sodium silicate solution and Sodium hydroxide solution. In a mixer fly ash/ground blast furnace slag are mixed thoroughly in required proportions until uniform color is achieved. Next, sand and coarse aggregates are added and mixed thoroughly again for 2 to 3 minutes. At this stage the activator solution which already prepared is added to this mixture and mixed about 5 minutes to get a uniform and homogeneous mix. The mix is then transferred in to cubes (150mm x 150mm x 150mm), cylinders (150mm x 300mm) and prisms (100mm x 100mm x 500mm). During the transferring the mix is compacted in three layers. Mix is then compacted on vibrator to expel the air. For mixes with steel fibers respective quantity of fibers are added along with aggregates and then mixed thoroughly.

2.3. Mix proportions and test variables

For preparing geopolymer concrete (GPC) the ingredients used are fly ash, coarse and fine aggregate, activator solution consists of sodium silicate and sodium hydroxide solution of concentration 16M and some excess water.

2.3.1. Mix design of GPC

For all geopolymer concrete mixes M_{30} grade mix proportions are considered according to the mix design procedure adopted by R. Anuradha *et al*., [21]. The mix proportions used for M_{30} grade are given in Table 3.

Table-3: Mix proportions of GPC.

Ingredients	Quantity per m^3
Sodium silicate solution	239.64 kg/m^3
Sodium hydroxide	95.86 kg/m^3
Extra water	11 kg/m^3
Fly ash	550 kg/m^3
Fine aggregate	600 kg/m^3
Coarse aggregate	838.3 kg/m^3

For preparing geopolymer concrete composites (GPCC) the ingredients used are fly ash, ground granulated blast furnace slag (GGBFS), coarse and fine aggregate, activator solution consists of sodium silicate and sodium hydroxide solution of concentration 16M and some excess water. 20% of fly ash used for making GPC is replaced by slag. Mix prepared with 80% fly ash and 20% GGBFS is designated as GPCC. The steel fibers are added in the volume fractions of 0.25%, 0.5% and 0.75% volume of the concrete. The corresponding mixes are designated as GPCC1, GPCC2 and GPCC3, respectively.

2.3.2. Mix design of GPCC

For all geopolymer concrete composite mixes M_{30} grade mix proportions are considered. The mix proportions used for M_{30} grade of GPCC mix are detailed in Table 4.

VOL. 8, NO. 10, OCTOBER 2013 ISSN 1819-6608
ARPN Journal of Engineering and Applied Sciences

www.arpnjournals.com

Table-4: Mix proportions of GPCC.

Ingredients	Quantity per m^3
Sodium silicate solution	239.64 kg/m^3
Sodium hydroxide	95.86 kg/m^3
Extra water	11 kg/m^3
Fly ash	440 kg/m^3
GGBS	110 kg/m^3
Fine aggregate	600 kg/m^3
Coarse aggregate	838.3 kg/m^3

In addition to the ingredients used in GPCC mix, steel fibers are added in the above mentioned volume fractions for GPCC1, GPCC2 and GPCC3 mixes respectively.

2.4. Curing regime

Geopolymer concrete mixes prepared with fly ash alone are exposed to a temperature of 60^0C after giving a rest period of 30 minutes. On other hand, mixes prepared with the combinations of fly ash and slags are cured at ambient temperature.

2.5. Test set up

The workability of fresh geopolymer concrete mixes (GPC and GPCC) was determined using slump test as per IS: 1199 -1959. The compressive strength tests were performed in accordance to ASTM C109. The specimens were tested for 3, 7 and 28 day compressive strength. The specimens were subjected to a compressive force at the rate of 5 KN/sec until it failed. The mean value of the compressive strengths of three test cubes in a series is reported as compressive strength of a particular mix. For finding the split tensile strength of cylinder IS: 5816-1970 recommendations are followed and to find the flexural strength of prisms IS: 516-1959 guide lines are followed.

3. RESULTS AND DISCUSSIONS

The workability of fresh geopolymer concrete, geopolymer concrete composites without and with steel fibers, and the mechanical properties of hardened concrete are determined and the results are discussed below.

3.1. Workability

Figure 1. shows the slump values of the geopolymer concrete (GPC) and geopolymer concrete composites (GPCC) without and with steel fibers.

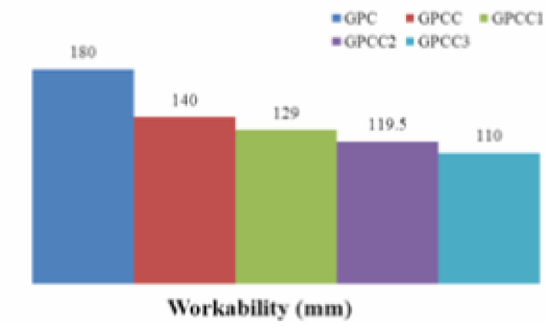

Figure-1. Workability of different mixes.

From Figure 1. it is clear that the workability values are decreasing gradually from GPC to GPCC with steel fibers. Addition of steel fibers causes decrease in workability. This may due to resistance offered by the fibers to the free flow. As the volume fraction of steel fibers increasing the workability values are decreasing.

3.2. Compressive strength

From Figure 2. it can be observed that at the age of 3days the development of strength in GPCC under ambient curing is very less compared to GPC under heat curing. The rates of increase in the compressive strengths of GPC and GPCC from 3 days to 7 days are found to be 21%, 187%, respectively. 28 days compressive strength of GPCC is greater than compressive strength GPC under heat curing. The increment in the compressive strength of GPC and GPCC from 7 days to 28 days is found to be 12% and 91%, respectively. So here an attempt is made to include fibers to increase the strength of GPCC even at early ages.

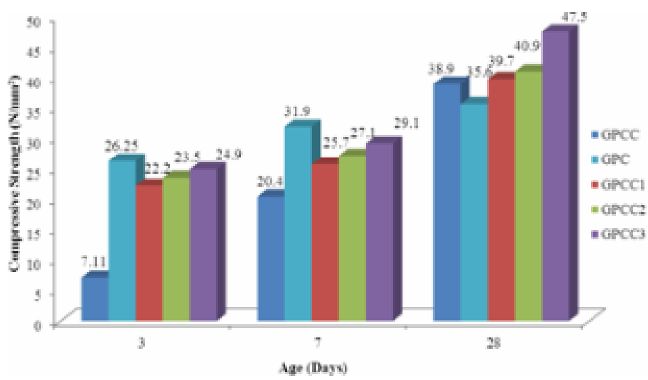

Figure-2. Effect of inclusion of steel fibers on compressive strength.

From Figure 2. it is clear that inclusion of steel fibers in GPCC appreciably improved its compressive strength. Even at the age of 3 days, average compressive strengths of GPCC with steel fibers are comparable with the compressive strength of GPC under heat curing. As the volume fraction increases from 0.25% to 0.75% the rates of increase in the average compressive strength of GPCC with steel fibers from 3 to 7 days are about 16%, 15%, 17%, respectively. While on the other hand for the same mixes, the rates of increase in the average compressive strengths from 7 to 28 days are about 54%, 51% and 63%, respectively. At the age of 28 days, the compressive strengths of GPCC mixes with steel fibers are greater than about 11%, 15% and 33% for GPCC1, GPCC2 and GPCC3, respectively with reference to GPC.

3.3. Split tensile strength

As shown in Figure-3 with the increase in the age of concrete the tensile strength of both GPC and GPCC are improving. In case of GPC the rate of increase in tensile strength from 3-7 days and 7-28 days are found to be 48% and 2.7%, respectively. In the case of GPCC the rate of increase in strength from 3-7 and 7-28 days are found to be 50% and 33%, respectively. At 28 days the average tensile strength of GPCC under ambient curing is more than GPC exposed to heat curing. The split tensile strength of GPC, GPCC without and with steel fibers at 3,7and 28 days is represented in Figure 3.

Addition of steel fibers improved the average tensile strength of GPCC under ambient curing. Although the -

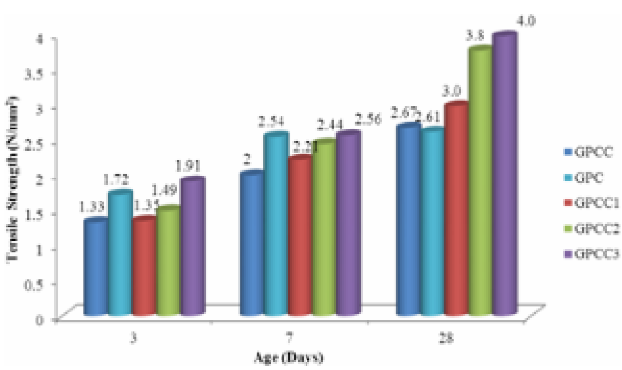

Figure-3. Effect of inclusion of steel fibers on tensile strength.

-improvement is not so significant at early ages, there is significant improvement at the age of 28 days. At the age of 3days, as the volume fraction increases from 0.25% to 0.75%, the increase in average split tensile strength of GPCC is about 1.5%, 12% and 44%, respectively for GPCC1, GPCC2 and GPCC3 respectively compared to GPCC without steel fibers. For the same mixes the increase in tensile strength at 7 days is about 10%, 22% and 28%, respectively compared to GPCC without steel fibers. At the age of 28 days, the increase in average tensile strength of GPCC with steel fibers is about 15%, 46% and 53% for GPCC1, GPCC2, and GPCC3, respectively compared to GPC under heat curing.

3.4. Flexural strength

From Figure 4. it can be seen that at early ages the flexural strength of GPCC under ambient condition is less than the flexural strength of GPC under heat curing, but at the age of 28 days the converse is true. As the age of concrete is increasing from 3 days to 7 days the rate of increase in the flexural strength of GPC and GPCC are found to be 22% and 71%, respectively. The rate of increase in the tensile strength of GPCC and GPC with the increase in the age of concrete from 7- 28 days is 73% and 23%, respectively.

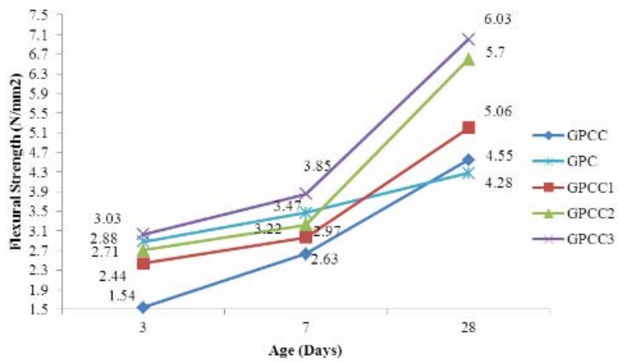

Figure-4. Effect of inclusion of steel fibers on flexural strength.

At the age of 3 days, as the volume fraction increases from 0.25% to 0.75%, the increase in average split tensile strength of GPCC is about 58%, 76% and 97% respectively for GPCC1, GPCC2 and GPCC3, respectively compared to GPCC without steel fibers. For the same mixes the increase in flexural strength at 7 days is about 13%, 22% and 46%, respectively compared to GPCC without steel fibers. At the age of 7 days the average flexural strength of GPCC mixes with steel fibers under ambient curing is comparable to that of GPC under heat curing. At the age of 28 days, the increase in average flexural strength of GPCC with steel fibers is about 18%, 33% and 41% for GPCC1, GPCC2, and GPCC3, respectively compared to GPC under heat curing.

4. CONCLUSIONS

a) From the experimental investigation it can be concluded that Geopolymer concrete can perform well even under ambient conditions and hence the limitations of GPC specifically delay in setting time and heat curing regime can be overcome by replacing 20% fly ash with GGBS.
b) Replacing 20% fly ash by GGBS improved the mechanical properties such as compressive, tensile and flexural strengths. Compared to GPC the compressive, tensile and flexural strength are

enhanced at the rate of 10%, 2.3%, and 6.3%, respectively.

c) To attain better strengths even at the early age of concrete inclusion of steel fibers is recommended.
d) Addition of steel fibers in volume fraction of 0.25% enhanced the compressive, tensile and flexural strengths at the rate of 15%, 14% and 18%, respectively with reference to GPC under heat curing.
e) Addition of steel fibers in volume fraction of 0.5% enhanced the compressive, tensile and flexural strengths at the rate of 11%, 44% and 33%, respectively with reference to GPC under heat curing.
f) Addition of steel fibers in volume fraction of 0.75% enhanced the compressive, tensile and flexural strengths at the rate of 33%, 52% and 41%, respectively with reference to GPC under heat curing.

ACKNOWLEDGEMENTS

Authors are grateful to his friends Praveen.B, Sagar Philip.V, Phanideep .G.V, and Sandeep.K for their assistance through out the work.

REFERENCES

[1] Mehta P. K. 1999. Advanced cements in concrete technology. Concrete International, June. pp. 69-76.

[2] Mehta P. K. 2004. High-performance, high-volume fly ash concrete for sustainable development. Proceedings of International Workshop on Sustainable Development and Concrete Technology, Beijing China. pp. 3-14.

[3] Zongjin Li, Zhu Ding and Yunsheng Zhang. 2004. Development of sustainable cementitious materials. Proceedings of the international workshop on Sustainable Development and Concrete Technology, Beijing China. pp. 55-76.

[4] Hardjito D. and Rangan B.V. 2005. Development and Properties of low calcium fly ash based geopolymer concrete. Research Report GC1, Curtin University of Technology, Australia.

[5] Wallah S. E. and Rangan B. V. 2006. Low-calcium fly ash-based geopolymer concrete: long-term properties, Research Report GC 2, Faculty of Engineering Curtin University of Technology, Australia.

[6] Bakharev T. 2005. Resistance of geopolymer materials to acid attack. Cement and Concrete Research. 35: 658-670.

[7] Song XJ, Marosszeky M, Brungs M and Munn R. 2005. Durability of fly ash based geopolymer Concrete against sulphuric acid attack. Presented at 10 DBMC International Conference on Durability of Building Materials and Components, Lyon, France.

[8] Allahverdi A and Skavara F. 2001. Sulphuric acid attack on hardened paste of Geopolymer Cements, Part 1: Mechanism of Corrosion at relatively high Concentrations, Ceramics- Silikaty. 45: 81-88.

[9] T. Bakharev. 2005. Durability of geopolymer materials in sodium and magnesium sulphate solutions. Cement and Concrete Research. 35: 1233-1246.

[10] Thokchom. S, P. Ghosh. P and Ghosh. S. 2010. Performance of Fly ash Based Geopolymer Mortars in Sulphate Solution. Journal of Engineering Science and Technology Review. 3(1): 36-40.

[11] Hui. LI and Delong. XU. 2009. The future resources for eco-building materials: II. Fly ash and coal waste. Journal of Wuhan University of Technology. 24(4): 667-672.

[12] Lloyd N. and V. Rangan. 2009. Geopolymer Concrete-Sustainable Cementless Concrete. ACI Special Publication SP-261. 10th ACI International Conference on Recent Advances in Concrete Technology and Sustainability Issues. American Concrete Institute, Farmington Hills, MI.

[13] Tempest B., O. Sanusi, J. Gergely, V. Ogunro and D. Weggel. 2009. Compressive Strength and Embodied Energy Optimization of Fly Ash Based Geopolymer Concrete. Proceedings, 2009 World of Coal Ash Conference, Lexington, KY.

[14] Hardjito D., S. Wallah, D. M. J. Sumajouw and B. V. Rangan. 2004. On the Development of Fly Ash-Based Geopolymer Concrete. ACI Materials Journal. 101(6): 467-472.

[15] Manjunath. S, Radhakrishna G.S, C. Giridhar and Mahesh Jadhav. 2011. Compressive Strength Development in Ambient Cured Geo-polymer Mortar. International Journal of Earth Sciences and Engineering. 4(6): 830-834.

[16] K. Vijai, R. Kumutha and B. G. Vishnuram. 2010. Effect of types of curing on strength of geopolymer concrete. International Journal of the Physical Sciences. 5(9): 1419-1423, 18.

[17] Choi Y and Yuan RL. 2005. Experimental relationship between splitting tensile strength and compressive strength of GFRC and PFRC. Cement and Concrete Research. 35: 1587-91.

[18] Mazaheripour H, Ghanbarpour S, Mirmoradi SH and Hosseinpour I. 2011. The effect of polypropylene fibers on the properties of fresh and hardened lightweight self compacting concrete. Construction and Building Materials. 25: 351-358.

ARPN Journal of Engineering and Applied Sciences

[19] Songa S, Hwang S and Sheu BC. 2005. Strength properties of nylon- and polypropylene-fiber reinforced concretes. Cement and Concrete Research. 35: 1546-1550.

[20] Okan Karahan and Cengiz Duran Atis. 2011. The durability properties of polypropylene fiber reinforced fly ash concrete. Materials and Design. 32: 1044-49.

[21] R. Anuradha, V. Sreevidya, R. Venkatasubramani and B.V. Rangan. 2011. Modified guidelines for geopolymer concrete mix design using Indian standard. Asian Journal of Civil Engineering (Building and Housing). 13(3): 353-364.