Mechanical Strength Characteristics of Ternary Blend Geopolymer Concrete with Steel Fibres under Ambient Curing

Leela D., Manjula S.

***Abstract:** As the concrete industry continues to expand, the changes and design of infrastructure is given due insight owing to the current trend. The demand for special concrete is thereby increased. In this present experimental work, production of concrete aims at achieving a strength of 50 N / mm^2. Here, cement is replaced by fly ash, GGBS and metakaolin at the nominal proportions integrated with steel fibers in percentages of 0.5, 1 and 1.5 by volume of concrete. Steel fibers used are crimped in shape of aspect ratio 66. Concrete being soft in tension and strong in compression is designed to combat the pressure generated. This will render concrete where tension is resisted by steel fibers.*

Mix proportion for ternary blend geo polymer used in this study consists of 25% fly ash, 60% GGBS and 15% metakaolin. GGBS and low calcium-based fly ash supplied by the local thermal plant are utilised. At 1.5% of the integration of steel fibers, the highest increase in strength was reported. The introduction of steel fibers showed a good improvement in flexural, compressive and split tensile strength. Out of the three mixes, the one with 1.5% steel fibres, which was the maximum percentage added, showed the best result. Split tensile strength was found to improve by 9% and flexural strength by 73%, which is a commendable result. On the contrary, the Modulus of elasticity showed a decline in its value. A reduction of 13.2% was observed for steel fibre content of 1.5%. It can therefore be concluded that geo polymer concrete with steel fibres has improved ductile properties, besides which, it help in reducing the carbon footprint due to emission of carbon dioxide and carbon monoxide produced by the cement industry.

***Key Words:** Geo polymer, Steel Fibers, metakaolin, Fly-ash, GGBS.*

I. INTRODUCTION

Development of infrastructure throughout the world has led to utilization of concrete in large proportions. Though steel structures are also being erected, the most popular building material in India is still concrete. This trend has led to depletion of natural resources as well as environmental pollution. The binder used constantly in manufacturing concrete is cement which is again a main source of pollution due to CO_2 emission in its manufacturing process.

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Production of one ton of cement releases an equivalent amount of CO_2 in the air leading to global warming. Besides extraction of lime stone at the present rate for manufacturing of cement will result in the depletion of natural resources such as lime stone in the near future. Hence in the present scenario it becomes a matter of extreme importance to develop an eco friendly alternate binder material replacing cement.

Considering this, the present study is focused on the experimentally investigating the feasibility of using ternary blend geopolymer concrete ingressed with steel fibres.

Research studies on geopolymer concrete are being widely carried out recently. This aids in developing a green environment ternary blend geopolymer concrete utilizes fly ash, GGBS and metakaolin which are mixed in an alkaline solution. Steel fibres are also added to this concrete as they are capable of enhancing tensile strength property of concrete. Moreover, no study has been conducted on steel fibre reinforced ternary blend geo polymer concrete under ambient curing, which increases the potency of research.

Mechanical properties pertain to testing of specimens for their compressive strength, along with split tensile strength and flexural strength. The results are analysed to derive conclusions based on feasibility of using this concrete.

Literature study on geo polymer concrete reveals that it is indeed a good alternative for cementless concrete. Though less literature is available on ternary blend GPC under ambient curing , the experimental programme has been designed based on literature available on GPC, SFRGPC and SFRC.

Davidovits J [1] introduced the technology of geo polymer concrete as an alternate binder material. These are produced by activating alumina and silica rich materials using alkaline medium. Bakharev T [2] has investigated the durability aspect of GPC with respect to acid and sulphate resistance. The studies conducted by Sathia and Ganesh Babu [3] also supports the usage of GPC owing to its durability. Better performance was observed under acid resistance and absorption characteristics. Rajamane et al .[4] have reported low permeability of chloride ion penetration in GPC. Satish Kumar et al. [5] have investigated ternary blend GPC which was prepared using varying molarities of NaOH and curing methods. Curing was done using hot air oven as well as closed steam curing. Ramesh Babu Chokkalingam [6] has studied the microstructural properties of geopolymer concrete. Pawan Anand Khanna [7] has done studies on the optimum temperature of geopolymer concrete. Behzad Nematollahi [8] has studied the effect of super plasticizers and activator combinations on the workability and strength. Gum Sung Ryu [9] has analysed the micro structure of the mortar through SEM, EDS and XRD.

II. EXPERIMENTAL PROGRAMME

2.1 Materials used

Materials used in this study include fly ash, GGBS, metakaoline, fine aggregate, coarse aggregate, steel fibres, alkaline liquid and super plasticisers.

Fly ash utilized was collected from Ennore thermal power plant. This is low calcium type fly ash, conforming to IS 3812:2003 [10] .It serves as the base binder material, major components of which are silica(SiO_2) and alumina(Al_2O_3).

GGBS which is used in this study mainly consists of CaO, MgO and SiO_2. This conforms to BS 6699:1992 where particle size is less than 30 microns.

Metakaolin, a creamy white powder is used where again the major components are SiO_2, Al_2O_3 and Fe_2O_3. Fine aggregate used was M sand. Sieve analysis of M sand done shows that it conforms to IS 383:1970 (reaffirmed 2002) [11]. Fineness modulus is 2.92 and specific gravity 2.39.

Locally available blue metal is the coarse aggregate used of size 2.5mm and specific gravity 2.78.

Alkaline solution was prepared using sodium silicate (Na_2SiO_3) and 12M sodium hydroxide (NaOH). Solution of Na_2SiO_3 consists of 8% Na_2O, 28% of SiO_2 and 64% water by mass. Pellets of NaOH were used to prepare 12M solution. Conplast SP(430) was used as superplasticizer. This ensured better workability.

Steel fibres of crimped type and aspect ratio 66 were used in different percentages for making this concrete.

2.2 Mix Design

Geopolymer concrete preparation is yet to be specified, coded and standardized. Hence, recommendations by Prof. B.V. Rangan [12]. has formed the basis for mix proportioning. The mix was designed to make concrete of grade M50. This was achieved by trial and error method of various combinations until the required strength was reached. Steel fibres were introduced in percentages of 0.5, 1 and 1.5 by volume of concrete.

Mix proportion for ternary blend geoploymer used in this study consists of 25% fly ash, 60% GGBS and 15% metakaolin. Details are tabulated in Table 1.

Table 1 Properties and mix propotitions

Component used	Quantity used (kg/m^3)
Fly ash	119.05
GGBS	285.71
Metakaolin	71.43
Fine aggregate (M sand)	685.71
Coarse aggregate	1380.95
NaOH sol. (12M)	40.95
Na_2SiO_3	101.9
Super plasticizer	7.14
Water	95.24

2.3 Preparation of test specimens

The materials for making GPC were mixed in surface dry condition for few minutes using a pan mixer. Steel fibres were added intermittently to ensure even distribution. The alkaline solution was added along with Super plasticizer and water following which thorough mixing was repeated.

Cubes of size 150mm were cast to test the compressive strength. Cylinders of diameter 150mm and 300mm height were cast for testing split tensile strength and for calculating the modulus of elasticity. Prisms of size 150mm X 150mm X 700mm were cast to test the flexural strength. Each experiment was done on three samples per test, the average result of which was taken and recorded. The cast specimens are depicted in Fig. 1

Curing of the samples was done in ambient temperature conditions for 28 days.

Fig. 1 showing the casted specimen

2.4 Testing of specimens

The cured specimens were then tested for various mechanical properties namely compressive strength, splitting tensile strength and flexural strength. Modulus of elasticity of GPC was also tested and calculated. Results for the test values with different percentages of steel fibres and without the same were compared and the pattern was analysed.

2.5 Results and discussion

The test set up and the results of the various samples for different parameters were presented in the following paragraphs. The test set up is shown in Fig 2(a) for compressive strength, Fig. 2(b) for split tensile strength, Fig. 2(c) for flexural strength and Fig 2(d) for modulus of elasticity. The testing was done as per IS : 516 – 1959. [12].

Fig.2(a), Fig.2(b), Fig.2(c), Fig.2(d) Showing the testing details

2.5.1 Compressive strength

Cubes were tested for compressive strength in a compression testing machine. Load was applied gradually and the reading was noted for each cube. The average value of three cubes was taken for each mix. The Results are tabulated in Table 2.

Table 2 Showing the test results

Sl.No	Specimen	Volume fraction of steel (%)	Compressive strength (N/mm^2)
1	GPC	0	56.3
2	$SGPC_1$	0.5	57.1
3	$SGPC_2$	1.0	59.1
4	$SGPC_3$	1.5	59.2

From the experimental results, it may be noted that the addition of fibres increases the compressive strength marginally.

2.5.2 Splitting tensile strength

The load was noted when cracks started to appear and the average value was taken for three specimens per test. Results obtained are shown in Table 3.

Table 3 showing the test results

Sl.No	Specimen	Volume fraction of steel (%)	Split tensile strength (N/mm^2)
1	GPC	0	3.84
2	$SGPC_1$	0.5	3.92
3	$SGPC_2$	1.0	4.03
4	$SGPC_3$	1.5	4.19

The split tensile strength indicate that addition of steel fibres increases the tensile strength significantly. The addition of 1.5% of volume fraction steel fibres improves the strength by 9%.

2.5.3 Flexural strength

The prisms were subjected to two point loading and results showing the flexural strength are tabulated in Table 4.

Table 4 showing the test results

Sl.No	Specimen	Volume fraction of steel (%)	Flexural strength (N/mm^2)
1	GPC	0	4.89
2	$SGPC_1$	0.5	5.79
3	$SGPC_2$	1.0	6.41
4	$SGPC_3$	1.5	8.46

The test results indicate that the flexural strength could be enhanced by the addition of steel fibres significantly and the maximum improvement obtained was 73% when 1.5% of fibres were added to GPC.

2.5.4 Modulus of elasticity

Modulus of elasticity of GPC is an important parameter in the analysis of strength and behavioural characteristics of the composite. The test is conducted on cylinders of 150 mm diameter and 300 mm height. These are subjected to uniaxial compression in the UTM and strains are measured using strain gauges. The graph obtained for various mixes showing the stress strain relationship is depicted in Fig.3 and the corresponding stress strain values, pertaining to modulus of elasticity are tabulated in table 5.

The values are noted, stresses and strains are calculated in order to draw a stress strain curve for each mix. From the different moduli of elasticity for concrete, the tangent modulus is determined in this study. This is determined from the graph, corresponding to the strain value of 0.002.

Table 5 showing the test results

Sl.No	Specimen	Volume fraction of steel (%)	Modulus of elasticity (kN/mm^2)
1	GPC	0	36
2	$SGPC_1$	0.5	33
3	$SGPC_2$	1.0	32.5
4	$SGPC_3$	1.5	31.25

It may be noted from the table that E_c of GPC obtained was 36 kN/mm^2. As the fibres increased, there is a marginal reduction in the value of E_c and is 31.25 kN/mm^2 at 1.5 % steel fibres. The reduction in value of E_c may be attributed to the following reasons. Without steel fibres, the GPC behaves as a brittle material and exhibit a steeper slope in the stress strain curve. As the fibres are added, the compressibility and softening behaviour of GPC with fibres improve leading to mild reduction in the slope of stress-strain curve.

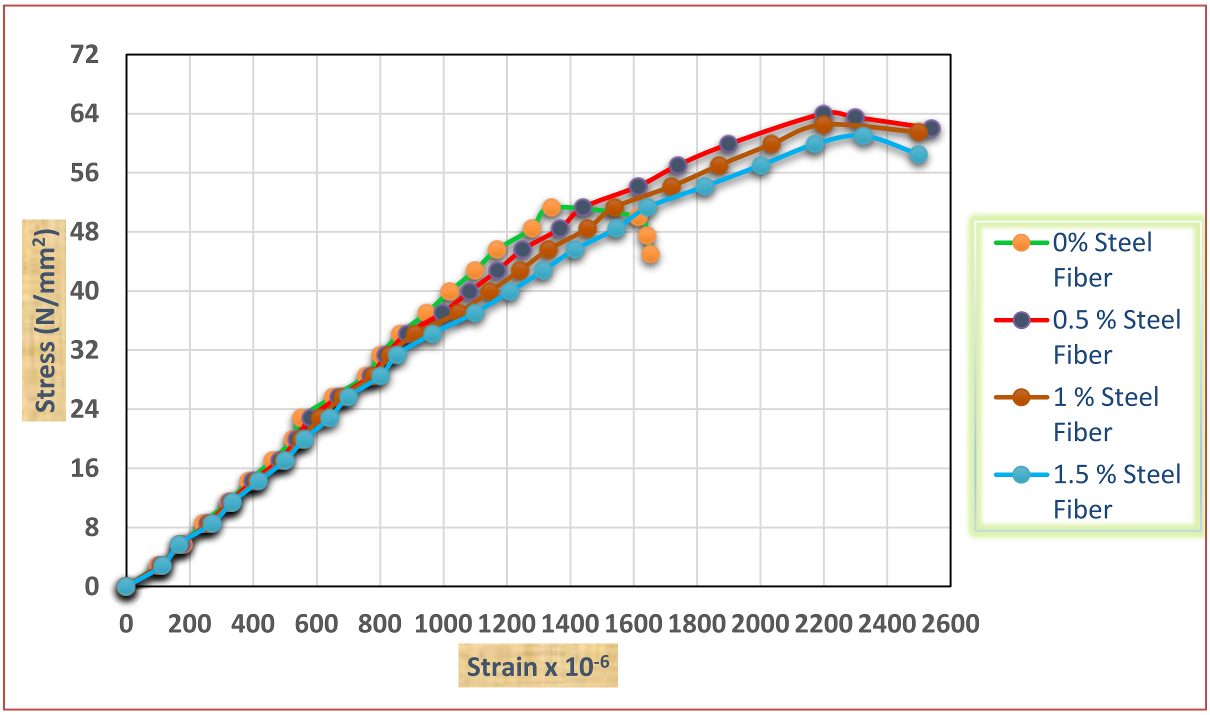

Figure 3 showing the stress strain relationship

III. CONCLUSION

From the above experimental investigations conducted on steel fibre reinforced geopolymer concrete, it is observed that the strength characteristics pertaining to compressive strength has shown a slight increase with increase of percentage of steel fibres added.
On the other hand, the tensile strength gauged by splitting tensile strength test and flexural strength test have shown a significant increase. Out of the three mixes, the one with 1.5% steel fibres, which was the maximum percentage added showed the best result. Split tensile strength improved by 9% and flexural strength by 73%, which is a commendable result.
On the contrary, the Modulus of elasticity showed a decline in its value. A reduction of 13.2% was observed for steel fibre content of 1.5%. It can therefore be concluded that geopolymer concrete with steel fibres has improved ductile properties.

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