A Comparative Study on Strength Characteristics of Fiber Reinforced Geoactivator Activated Geopolymer Concrete

S. Jagandas, G. Mallikarjuna Rao, and M. Venu

Abstract This paper presents the behavioural comparison of plain and fibers added geopolymer concrete (GPC) prepared by fly ash-ground granulated blast furnace slag (GGBFS) based and activated with geo activator with silica modulus (Ms) of 2.92, test specimens cured under normal temperature curing conditions. The production of carbon dioxide is approximately 8%, experimental work is done in this research to develop a field construction binder that replaces the OPC and reduces the emission of carbon dioxide (CO_2), producing green and sustainable concrete. Any earth crust materials which are rich in silica (Si) and alumina, to activate the source materials combination of sodium or potassium-based activators are used by many researchers but it requires high concentration and oven heat curing at 60 °C for 24 h, to get better strength making it an uneconomical and still it is inconclusive for field construction. In this research, a single reagent alkaline-based solution, geo activator (neutral grade sodium silicate) was used to develop the fiber-reinforced GPC (FRGPC). This research work is done to understand various mechanical properties with geo activator and checked the workability before going to cast the specimens. The results of this paper are useful for construction industries and also future researchers.

Keywords Geopolymer concrete · Geoactivator · SFRGPC · GFRGPC · Fly ash · GGBS

1 Introduction

According to knight frank India-2021 only in 3 months, 76,006 building constructions are started, compared to last year the increment is 38% more. Concrete is the most popular modern composite construction material, today, second only to water,

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concrete is the most consumed composite material with three tons per annum used for each person within the world. Twice the maximum amount of concrete is employed in the construction world as all other building materials combined. The materials required to make concrete are cement, aggregate, and water but cement is the artificial material made by burning the natural limestone at high temperature, release high carbon dioxide, and consuming 4GJ of energy per one ton. Nowadays, fast increases in the construction activity to meet the rapid increase in the development of infrastructure in countries like India and China. Day by day the consumption of cement is increasing, expected to reach 500 million tons by 2030. The OPC binder used in traditional concrete releases approximately 8% of CO_2 which affects the ozone layer and human health and creates climate problems. To overcome this need to plant 2.62 billion acres of forest land which is equal to island and cement is highly energy-intensive. The available limestone to make the OPC is sufficient for the next 50 $_{\text{years}}$ only. To overcome this need to develop alternative geopolymer cement that replaces the OPC and produces green and sustainable concrete material. Finding the necessary substitute to OPC and thus reducing the CO_2 emission. In the modern era, with rapid industrialization and urbanization, world global demand for construction materials increases every year from county to country. The increased demand for construction needs more natural by-products of cementitious materials which bind aggregate 70% of the total volume of concrete. At present, ground granulated blast furnace slag (GGBS), red mud, fly ash, silica fume, metakaolin, graphene powder have been using the partial substitute or additional materials to OPC for better physical and durable properties than OPC concrete. Complete replacement of these materials is not fit based on their mechanical properties and economy. There is a necessity to search for an alternative to OPC paste which is of lower CO_2 emission, make use of the waste by-products. In this context, geopolymer concrete has reached considerable attention from both academics and the concrete industry. Besides environmental friendliness, excellent plastic properties and other properties such as superior resistance against thermal stability chemical attack, or even smartness were extensively reported.

Davidovits [1] produced a geopolymer binder by polymeric reaction combining alkaline reagent with the silica and alumina in the source material of earth crust or by-product material as given in the above paragraph [2] stated that geo activator is used to develop a cast in situ construction concrete which is also called neutral grade sodium silicate, is a single alkaline activator solution not required in the combination of activators instead of water geo activator is used. This project work is done to understand the behavior for fly ash-ggbs mixer-based field geopolymer concrete activated with a single hardener-based activator by conducting a fresh test and harden test, on GPC specimens.

2 Literature Review

Davidovits et al. [3] stated that geopolymer concrete is a by-product inorganic polymer composite produced from the alkaline chemical reaction of aluminosilicate compounds to yield an amorphous to semi-crystalline 3-D structures consisting of repeating Si–O-Al. Further, these monomers are poly-condensed to form a rigid three-dimensional (3-D) structure of silicates and aluminates. Mallikarjuna Rao et al. [4] studies suggested that a combination of fly ash 70% and, GGBS 30% used geopolymer concrete and hardener consisting of mixer sodium hydroxide and metasilicate of few different molarities (16, 12, 8 M). The ratio of metasilicate sodium to sodium hydroxide considered or concluded in this work is 2.5 to 2.6. Mallikarjuna Rao et al. [4] studies suggested geo activator used fly ash-ggbs based combination GPC gives better strength at normal temperature compared to OPC. Vikas Gugulothu et al. [5] different GGBS percentages, activated with geoactivator, concluded that, good workability and good mechanical properties than OPC.

3 Experimental Study

This research paper presents the comparative study of mechanical properties of GPC and FRGPC, prepared by fly ash-GGBS based and activated with a single solution-based activator. Prepared and cured in normal temperature about 28° C ± 2.

3.1 Materials

Fly ash: Indian low calcium class-F fresh dry fly ash used, taken from the silos of rank ready mix concrete plant near Hyderabad outer ring road (ORR) Shamshabad, was used as one of the main base material up to 70%.

GGBS: Waste product from the fresh blast-furnaces manufacturer to make iron. Blast-furnaces became powder at high temperatures of more than 1,600 °C. It is a pozzolanic material with higher percentages of calcium oxide. GGBS took from Toshali cement powder Pvt. Ltd India. The biochemistry of materials fly ash-GGBS is mentioned in Table 1.

Fine aggregate: Locally available best quality Indian fresh sand was used with a specific gravity of 2.62. As per the test sieve analysis, the fine sand material was declared to be in zone II, and conforming to IS 383:1970 it's cleaned from dust, dried from moisture content, and stored in a fresh place before going to use.

Coarse aggregates: Locally available CA are taken and cleaned, dried before going to use. Different sizes of coarse aggregates such as 4.75, 12, 16, and 20 mm are used, from each size, 25% of aggregates are taken for experimental work.

Table 1 Chemical composition of materials pulverised fuel ash & GGBS

Oxide	Percentage (by weight)	
	Fly ash	GGBS
Sio2	61.93	36.3
Al2o3	28.11	16.6
Fe2o3	4.13	1.6
CaO	0.88	34.8
Na_2O	o.37	0.2
K_2O	0.8	0.5
Other oxides	3.3	9.6
Loss of ignition	0.47	0.4
Amorphous content	82(35% of SiO_2 and 46% of mullite)	

Geo activator or Geo hardener: In this study, a single alkaline hardener was used with specific gravity 2.1 and silica modulus SiO_2:Na_2O (Ms) $_=$ 2.92:1 with 28.98% SiO_2, 9.92% Na_2O by mass, which was produced and transported from Chennai, KIRAN GLOBAL Ltd, India.

Steel fiber: End hooked steel fibers (Sf) were used in this work with 0.16 mm dia and 50 mm height and aspect ratio of 60. The fiber dosage was taken at 0.5, 1 and 1.5% on volume fraction (V_F).

Glass fiber: Synthetic macro glass fiber (Gf) is used with 0.1 mm dia and 6 mm height.

Superplasticizer: Naphthalene Conplast-430 based superplasticizer is used to improve the workability of fibers added to GPC.

3.2 Mix Design

The binder to solution ratio is fixed at 0.55. Binder content is fixed at 450 kg/m^3 for every trail of mixing the fly ash content and GGBS content is fixed, i.e., 70% and 30% for set 1 and 50% and 50% for the second set of total binder content. Workability consideration is not required because the workability is excellent by geo activator alone for plain GPC in case of HFRGPC superplasticizer used (Table 2).

4 Results and Conclusions

4.1 Workability

Geo activator used fly ash-ggbs based GPC workability is better than OPC concrete. The viscosity of the geo activator is more than the water and the geo activator is like an oily gel, it increases the cohesion between particles to particles. Even though adding

Table 2 Mix proportion of field geopolymer concrete

S.NO	Binder content (kg/m^3)	FA:GGBS ratio	alkaline/binder ratio	Fine agg. (kg/m^3)	Coarse agg. (kg/m^3)	Alkaline liquid(kg/m^3)	Steel fiber (%)	Glass fiber (%)	SP (kg/m^3)
Mix A	450	70:30	0.55	760	972	247.5	NIL	NIL	NIL
Mix B	450	50:50	0.55	760	972	247.5	NIL	NIL	NIL
Mix C	450	70:30	0.55	760	972	247.5	0.5	0.25	2.25
Mix D	450	70–30	0.55	760	972	247.5	1	0.50	4.5
Mix E	450	70–30	0.55	760	972	247.5	1.5	0.75	6.7
Mix F	450	50–50	0.55	760	972	247.5	0.5	0.25	2.25
Mix G	450	50–50	0.55	760	972	247.5	1	0.50	4.5
Mix H	450	50–50	0.55	760	972	247.5	1.5	0.75	6.7

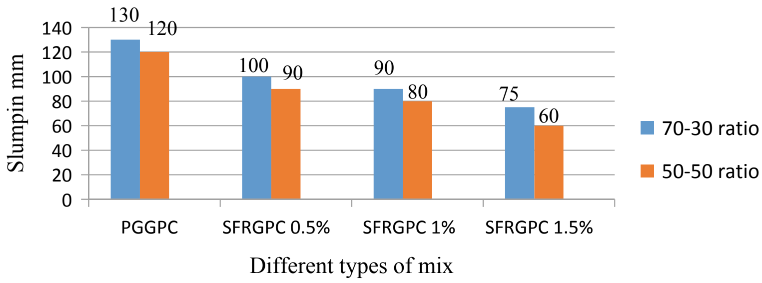

Fig. 1 Workability for SFRGPC

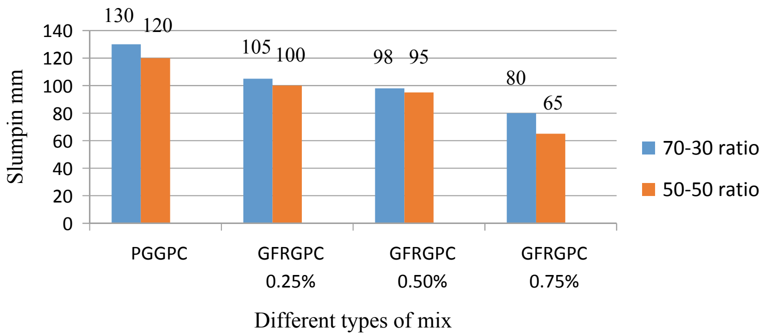

Fig. 2 Workability for GFRGPC

fiber up to 1% the slump is better than OPC slump because fibers are not absorbing activator-like conventional concrete because the solution has oily gel behavior, so obviously workability is better than OPC. The workability is better in the pan mixer compared to the hand mixer. The slump is 130 mm for the fly ash-GGBS combination ratio 70–30 and 125 mm for the 50–50 ratio given in Figs. 1 and 2. Workability is slightly decreased by increasing the GGBS percentage because the shapes of the GGBS particle are angular but still, it is workable. By adding steel fibers 1.5% to GPC workability is reduced to 60 mm, to achieve better workability naphthalene-based superplasticizer is used on the mass of binder content. Sometime extra geo activator were added to improve the workability because in the case of 50–50 ratio concrete settled within a minute. Workability is not too different between SFRGPC compared to GFRGPC however workability is better in GFRGPC because the cluster formed by glass fiber is smaller than steel fibers. As shown in Figs. 3 and 4 in each mix workability has decreased approximately 1% from 70–30 to 50–50 ratio because 20% GGBS has increased. Increment of GGBS percentage leads to decrement in workability.

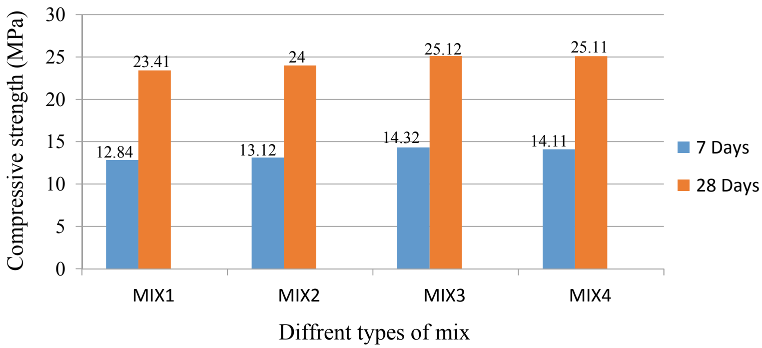

Fig. 3 Comparison compressive strength of SFRGPC between 7 and 28 days

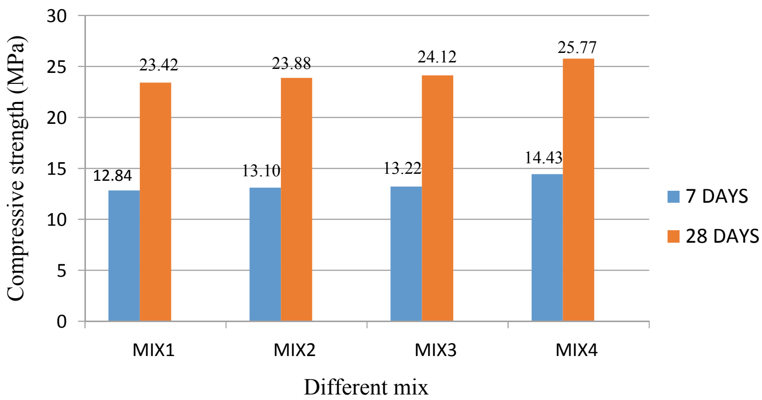

Fig. 4 Comparison compressive strength (MPa) of GFRGPC at 7 days and 28 days

4.2 Compressive Strength

Figure 3 shows that the comparison of compressive strength of fly ash-GGBS is 70–30 ratio based SFRGPC for 7 days and 28 days. Mix1 is plain GPC without steel fiber, strength at 7 and 28 days 12.84 and 23.41. There is an increment in strength by increasing steel fiber dosage 0.5 and 1% but at 1.5% small decrease in the strength. The increment between 7 to 28 days is approximately 50%. It is the same in the case of steel fiber added GPC also. The strength variation is more different between 7 and 28 days. The main observation done in the experiment is that fast increment of strength when specimens are directly exposed to the sun rays but specimens kept in the lab the polymerization process slows down as well as by increasing activator content also increases in the strength. In the case of geo activator-based GPC at 7 days, 64% strength is achieved and at 28 days 117% strength is achieved. Compared to OPC 17% more strength is achieved but in the case of 0.5 and 1% steel dosage mix1, mix2 strength is increased but at 1.5% strength is decreased. In the first 3 mixes, 7 days to 7 days strength is increased approximately 1% and 28 days to 28 days is also approximately 1% increased but in mix4 0.5% strength is decreased.

Figure 4 is analyzed by comparing the compressive strength of fly ash-GGBS to a 70–30 ratio-based GFRGPC for 7 days and 28 days. Mix1 is plain GPC without steel fiber, strength at 7 and 28 days 12.84 and 23.42. There is an increment in strength by increasing glass fiber dosage 0.25, 0.50 and 1%. The increment between 7 and 28 days is approximately 50%. It is the same in the case of steel fiber added GPC also for all mixes. The strength variation is more different between 7 and 28 days. The main observation done in the experiment is that fast increment of strength when specimens are directly exposed to the sun rays, but specimens kept in the lab the polymerization process slows down as well as by increasing activator content also increase in the strength in glass fibers added GPC also. In mix1 the increment of strength is more than the OPC concrete, in the case of geo activator-based GPC at 7 days 64% strength is achieved, and at 28 days 117% strength is achieved. Compared to OPC 17% more strength is achieved but in the case of 0.25, 0.50 and 0.75% micro glass fiber dosage in all mixes compressive strength is increased. In all the 4 mixes compressive strength increased 7 days to 7 days and 28 days to 28 days is approximately 1%.

Figure 5 shows that the comparison of compressive strength of fly ash-GGBS is 50–50 ratio based on SFRGPC for 7 days and 28 days. Mix1 is a plain GPC without steel fiber, strength at 7 and 28 days, 15.64 and 26.13. There is an increment in strength by increasing steel fiber dosage 0.5 and 1% but at 1.5% small decrease in the strength. The increment between 7 to 28 days is approximately 59%. It is the same in the case of steel fiber added GPC also. The strength variation is more different between 7 and 28 days. The main observation done in the experiment is that fast increment of strength when specimens are directly exposed to the sun rays but specimens kept in the lab the polymerization process slows down as well as by increasing activator content also increase in the strength. In mix1 the increment of strength is more than the OPC concrete, in the case of geo activator-based GPC at 7 days 78% strength is

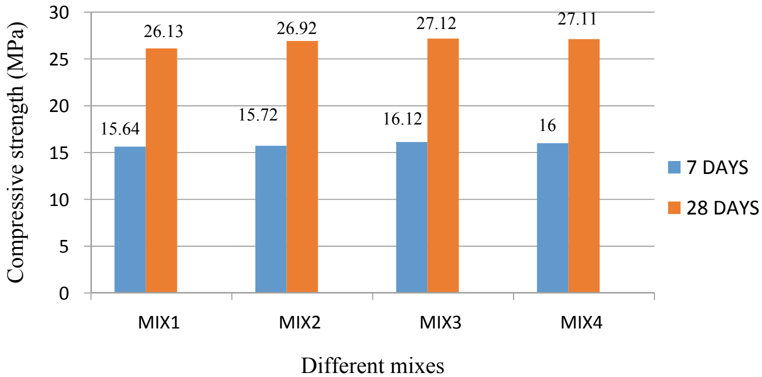

Fig. 5 Comparisons of SFRGPC of 7 days and 28 days

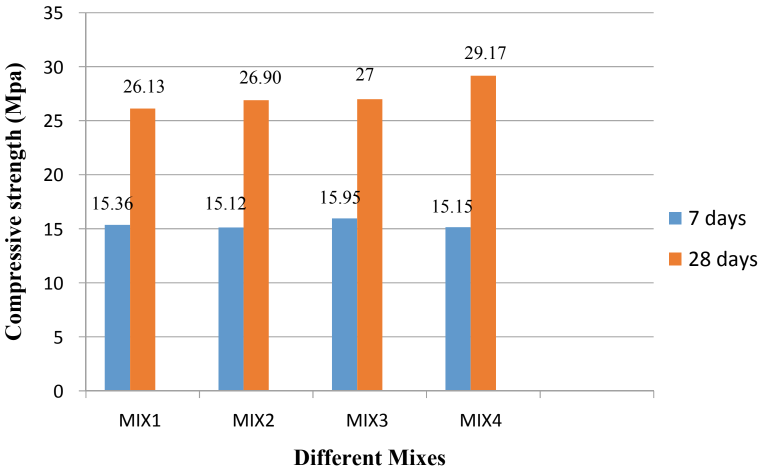

Fig. 6 Comparisons of GFRGPC between 7 and 28 days

achieved, and at 28 days 130% strength is achieved. Compared to OPC 30% more strength is achieved, but in the case of 0.5 and 1% steel dosage mix1, mix2 strength is increased but at 1.5% strength is decreased. In the first 3 mixes, 7 days to 7 days strength is increased approximately 1% and 28 days to 28 days is also approximately 1% increased but in mix4 0.5% strength is decreased.

Figure 6 concludes that the comparison of compressive strength of fly ash-GGBS is 50–50 ratio based on GFRGPC for 7 days and 28 days. Mix1 is plain GPC without steel fiber, strength at 7 and 28 days is 15.36 and 26.13. There is an increment in strength by increasing glass fiber dosage 0.25, 0.50 and 1%. The increment between 7 to 28 days is approximately 58% it is slightly in the case of steel fiber added GPC also for all mixes. The strength variation is more different between 7 and 28 days. By increasing activator content also increases the strength in glass fibers added to GPC also. In mix1 the increment of strength is more than the OPC concrete, in the case of geo activator-based GPC at 7 days 76% strength is achieved, and at 28 days 130% strength is achieved. Compared to OPC 30% more strength is achieved, but in the case of 0.25, 0.50 and 0.75% micro glass fiber dosage in all mixes compressive strength is increased. In all the 4 mixes compressive strength increased 7 days to 7 days and 28 days to 28 days is approximately 1%.

4.3 Split Tensile Strength

Figure 7 shows that the split tensile strength of the geo activator used by is giving better tensile strength for both cases. Split tensile strength is slightly more in the 50–50 ratio compared to the 70–30 ratio. In both cases by increasing the fiber content

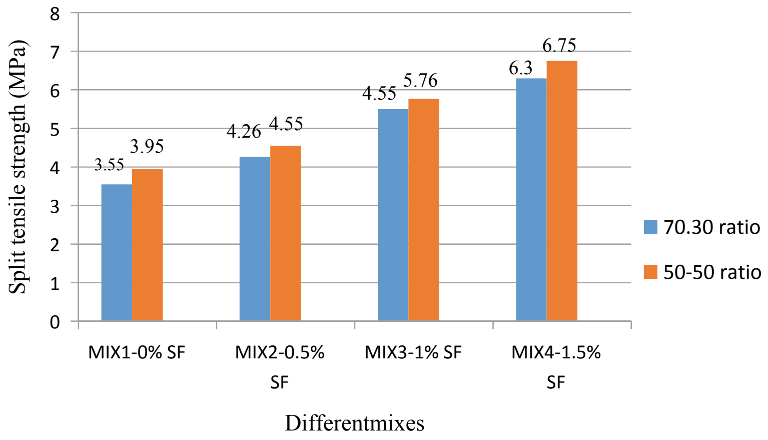

Fig. 7 Comparison of split tensile strength SFRGPC of 70–30 and 50–50 ratio

tensile strength is increasing irrespective of a percentage added but at 1.5% of steel fiber, there is an increment in tensile strength but decrement in compressive strength. We stopped at 1.5% and fixed 1.5% as the optimum dosage.

Figure 8 concluded that the split tensile strength of the geo activator used by GPC is giving better tensile strength for both cases. Split tensile strength is slightly more in the 50–50 ratio compared to the 70–30 ratio. For all the mixes in both cases, by increasing the glass fiber content tensile strength was increased. The ultimate strength for the 70–30 ratio is 5.37 and for the 50–50 ratio is 6.43 at 0.75% of glass fiber dosage.

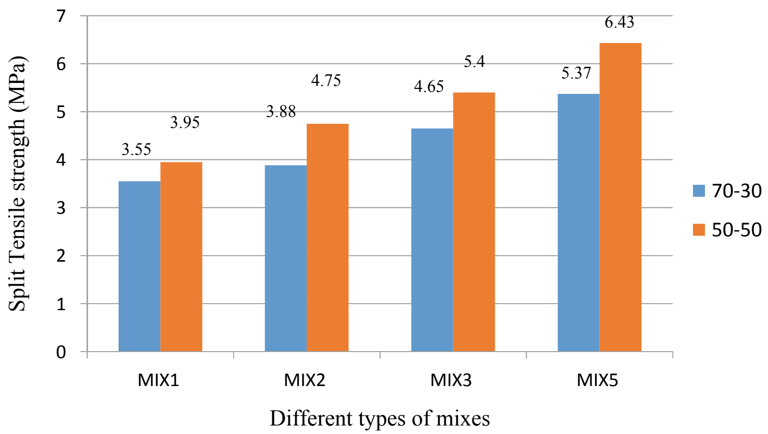

Fig. 8 Comparison of split tensile strength GFRGPC of 70–30 and 50–50 ratio

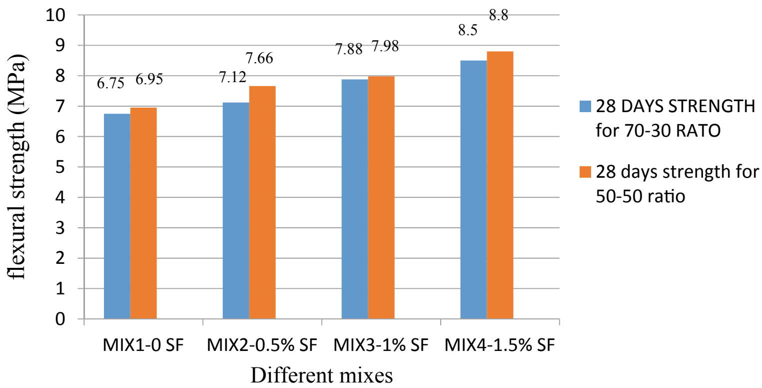

Fig. 9 Comparison of 28 days flexural strength between 70–30 and 50–50 ratio SFRGPC

4.4 Flexural Strength

Figure 9 states that comparative study between 28 days strength of fly ash-GGBS 70–30 and 50–50 ratio. The flexural strength of the 50–50 ratio is slightly more than the 70–30 ratio. The flexural strength of SFRGPC increased the same as tensile strength. By increasing, fiber dosage strength is increased. The strength is increased approximately 1% in each fiber dosage compared to its previous value.

Figure 10 concluded that the flexural strength of the 50–50 ratio is slightly more than the 70–30 ratio. The flexural strength of GFRGPC increased the same as tensile strength. By increasing, fiber dosage strength is increased. The strength is increased approximately 1% in each fiber dosage compared to its previous value.

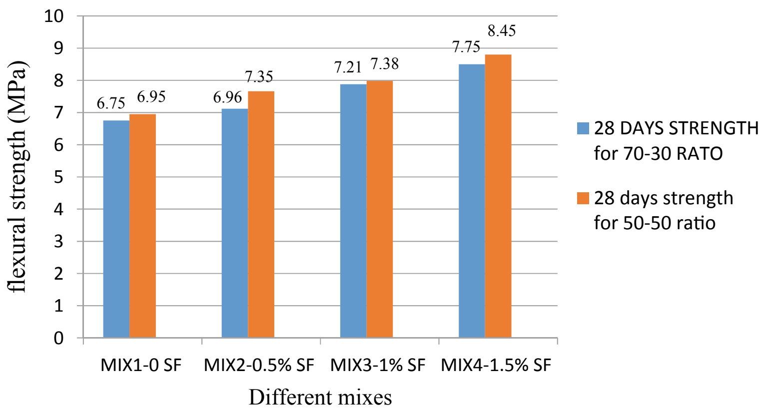

Fig. 10 Comparison of 28 days flexural strength between 70–30 and 50–50 ratio GFRGPC

5 Conclusions

- The slump value of the fresh fly-ash-GGBS base materials used in geopolymer concrete is better than the OPC concrete and it increases with the increased additional extra geo activator to the mixture.
- Mechanical properties are satisfied at ambient curing by using a single hardener activator solution.
- The combination of fly ash 30% and GGBS 70% is a better combination with a single solution geo activator to produce a geopolymer concrete for outdoor usage conditions.
- The compressive strength is approximately 50% increased 7 days to 28 days in both cases.
- The compressive strength is increased by adding steel fiber up to 1% and slightly decreased at 1.5% and by adding glass fibers the strength is increased up to 0.75% in all the mixes.
- Compressive strength is decreased by increasing fiber more than 1.5% but flexural and split tensile strength was increased.
- The geo activator-based GPC concrete got better workability even though adding 1% steel fiber.

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