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PERFORMANCE EVALUATION OF AMBIENT CURED QUARRY ROCK DUST (QRD) INCORPORATED GEOPOLYMER CONCRETE (GPC) BEAMS

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Abstract- Geopolymer concrete (GPC) an alternative of Ordinary Portland Cement concrete (OPC) is prepared by mixing three waste/by-products that are Fly-ash (FA), ground granulated blast furnace slag (GBS) and quarry rock dust (QRD) at the rate of 50%, 35% and 15% of binder respectively. Since GPC has gained interest of many researchers due to the harm that OPC is causing to the environment. However, GPC exhibit somewhat brittle behavior. To improve this property of GPC the steel fibers (SF) and natural fibers called sisal fibers (SsF) are incorporated into the GPC both separately and in hybrid form. The purpose of this research work is to prepare natural fiber (i.e SsF) reinforced GPC which can be a potential sustainable construction material having good mechanical properties and lesser environmental impact. The SsF is used individually and also in hybrid form with SF for purpose of replacing the SF with natural counterpart. The control sample with no fibers and fibers reinforced matrices with increasing content of SsF (varying from 0.8 to 2.4 %) and novel hybrid SsF and SF (by keeping SF fixed at 0.5% and increasing the amount of SsF from 0.5 to 1.5%) were casted and mechanical tests were performed for optimum values. Then the four types of shear deficient GPC beams were casted that are unreinforced control GPC and GPC reinforced with optimum values already calculated which are SF at 0.75%, SsF at 2.4% and hybrid fiber reinforcement at 0.5% and 1% of SF and SsF respectively. To ensure shear is dominant mode of failure moderate shear reinforcement along with required flexural reinforcement were provided. The load carrying capacity through four point loading was then checked for GPC and fiber reinforced GPC beams. The load carrying capacity of simple GPC versus 2.4% SsF reinforced GPC, hybrid fibers reinforced GPC (having 0.5% SF and 1% SsF) and 0.75% SF reinforced GPC beams was found to have increased by 22.22%, 38.89% and 75% respectively.

Keywords- geopolymer, steel fibers, sisal fibers, ambient curing

1 Introduction

In the present world cement concrete is most widely used man made material. Large amount of natural resources are consumed during the production process of this binding material i.e ordinary Portland cement (OPC). Also during the production of OPC the CO_2 produced is key contributor in causing environmental pollution [1]. The CO_2 is produced during the chemistry of OPC production (calcination of limestone) but not during the use of OPC. Consequently, the need of some environmental friendly material that can replace the cement has gained attention of many researchers. Fly-ash (FA) and ground-granulated blast furnace slag (GBS) are the industrial waste/by products which are supplementary binding materials widely used for partial replacement of OPC. Their use has gained attention because of their low cost and good binding or pozzolanic properties. The widely available low calcium FA is considered to be a suitable material because of its pertinent silica, alumina composition and very low water requirement. Also the geopolymer concrete (GPC) incorporated with heat cured low calcium FA when tested in fresh and hard state has shown excellent mechanical properties and durability [2]. The quarry rock dust (QRD) is a residue and calcium rich material which can also be used as partial replacement of binder or filler material in GPC [3]. This can help in reducing the environmental and land pollution by avoiding its deposition at landfills [4].

Researcher have found that these waste or by-products (FA, GBS and QRD) have great potential to be used as innovative replacement of OPC [5]. Therefore the GPC can be a sustainable and green solution for construction industry because of its excellent properties. However GPC has shown comparatively brittle behavior than OPC concrete [6]. But with the addition of fibers, GPC has improved behavior not only in splitting tensile strength, flexural strength and flexural toughness but also in the post-peak behavior i.e the stress-strain response in comparison from brittle to ductile [7]. Therefore these fibers had gain attention of researchers for making GPC less brittle material. There are many options of fibers for researchers such as steel fibers (SF), synthetic fibers and natural fibers [29]. Tung T. Tran [18] found in its research that ultimate load carrying capacity of fiber reinforced GPC beams increased with increase of SF content with showing optimum value at 0.75%, he also concluded that fibers length of 60 mm has approximately 10% lesser load carrying capacity than fibers having length of 35 mm. The SF are widely used fibers since they show excellent properties both in OPC and GPC under fracture toughness, splitting tensile and flexural strengths [19]. However, according to Food and Agriculture Organization of the United Nations (FAO), natural fibers are considered to be the future fibers because no harm is done to the environment while using these fibers [13,30]. It has been found that 11 tons of oxygen is produced and 15 tons of CO_2 is consumed during one hector cultivation of jute fibers plant. Also the SsF plant absorb more CO_2 than the oxygen they produce, and the organic wastes which are produced during preparation of SsF can be used in the feeding the animals, bioenergy generations and fertilizer production. [8].

It is therefore a wise solution to add natural fibers as a reinforcing material to the composites based on GPC matrix. The growing environmental awareness and the need to ensure sustainability of construction materials have led many researchers to look for some alternative fibers to reinforce GPC [20]. In this respect natural fibers (like SsF) are attractive because they are reproducible, have low density, high specific strength and are cheap to obtain. They do not pose any problems in terms of closing important life cycles (especially CO_2) of the products based on natural fibers [8]. The replacement of SF with SsF is not only important because of its low cost but also due to environmental concern, because the production of SF is energy consuming process while the production of SsF is natural process which involve emission of oxygen along with the consumption of CO_2. Therefore, in this study, composites with GPC matrices reinforced with SF and natural fibers i.e. SsF are studied and compared. The use of SsF with GPC is very limited especially its hybridization with SF is a novel work, the intention of this combination is to replace the SF with natural fibers to promote the use of more environment friendly construction materials. The hybridization method used in the initial trials to find out optimum values consist of fixing the SF at 0.5% and increasing the SsF content like 0.8%, 1.2% and 2.4% [27, 28]. The performance of these new composites is investigated by a series of laboratory experiments which are explained in the following sections.

2 Experimental Program

The experimental program comprises two stages (this manuscript is a part of parallel research work). In the first stage, a mix design study was carried out for finding the optimum ratio of SsF and hybrid with SF for mixing in the GPC composites. The optimum value of SF was taken as 0.75% by weight of concrete from the previous study [9]. For strength tests cubes, cylinders and prisms were casted for finding out mechanical properties (three specimens for each test and mix type, mix types are shown in table 1).

In the second stage, based upon the results from the first stage, the optimum values of fibers were identified and beams of size 150mm (W), 150mm (H) and 1000mm (L) were cast for evaluating the flexural performance of beams. The types and optimum mix proportions for casting of beams are shown in table 2. To ensure that the shear is the dominant mode of failure in the beams, moderate shear reinforcement was provided along-with the required flexural reinforcement in the tension and compression zone [22]. In order to make shear deficient beams, 2 nos 12mm bars are used as main bars and 2 nos 9mm bars are used as anchor bars with shear reinforcement of 6mm diameter bars @ 150 mm c/c. For each mix type (table 2) three beams along with three cubes and cylinders were cast.

Table 1: The Mix types for initial trials

SsF-R-GPC		Hybrid SF and SsF R-GPC	
Mix ID	**Mix Composition**	**Mix ID**	**Mix Composition**
GPC	GPC without Fibers	0.5SF+0.5SsF-R-GPC	GPC with 0.5% SF and 0.5% SsF
0.8SsF-R-GPC	GPC with 0.8% SsF only	0.5SF+1SsF-R-GPC	GPC with 0.5% SF and 1% SsF
1.2SsF-R-GPC	GPC with 1.2% SsF only	0.5SF+1.5SsF-R-GPC	GPC with 0.5% SF and 1.5% SsF
2.4SsF-R-GPC	GPC with 2.4% SsF only		

Note: SsF=sisal fibers, R-GPC= reinforced with fibers geopolymer concrete, SF=steel fibers

Table 2: The types and mix proportions for casting the fiber-reinforced GPC beams

Mix ID	AL/B Ratio	W/B Ratio	SS/SH Ratio	B	Binder			CA 20mm	CA 10 mm	S	Alkaline Solution		SP	SF	SsF	W
					FA	GBS	QRD				SH	SS				
GPC (control mix)	0.5	0.45	1.5	400	31.3	21.9	9.4	53.3	117.6	106.5	12.5	18.8	3.8	-	-	9.1
0.75SF-R-GPC	0.5	0.45	1.5	400	31.3	21.9	9.4	53.3	117.6	106.5	12.5	18.8	4.6	9.2	-	9.1
0.5SF+1SsF-R-GPC	0.5	0.45	1.5	400	31.3	21.9	9.4	53.3	117.6	106.5	12.5	18.8	5.7	6.1	2.3	9.1
2.4SsF-R-GPC	0.5	0.45	1.5	400	31.3	21.9	9.4	53.3	117.6	106.5	12.5	18.8	7.8	-	5.5	9.1

Note: AL=Alkaline solution, B =binder, W/B= water/binder ratio, SH= Sodium hydroxide, SS=Sodium silicate, FA= Fly-ash, GBS=Ground granulated blast furnace slag, QRD=Quarry rock dust , CA=Coarse aggregates, S= Sand, SP= Super plasticizer, SF= Steel fibers, SsF= Sisal fibers, W=Water

2.1 Materials and mixing of ingredients

The Low Calcium FA is used for manufacturing of GPC since high calcium FA has poor performance in polymerization process. The QRD was collected from Margalla, Taxila, and was grinded to cement size at Pakistan Council of Scientific and Industrial Research (PCSI) Peshawar, by ball Mill Machine. The Molarity of sodium hydroxide (SH) used for GPC is 12M in pallets forms and was mixed in water 24 hours prior to be used for concrete preparation. The sodium silicate (SS) was purchased from commercial manufacturer from Islamabad in the liquid form and was mixed with SH 30 minutes prior to mix them with the other ingredients. The sand (S) and coarse aggregates (CA) were taken from Margallah quarries and Lawrencepur respectively. The fineness modulus of fine aggregate was conforming to ASTM-C-136-06 [10], whereas specific gravity and water absorption was conforming to ASTM-C128-15 [11]. The specific gravity of coarse aggregate was conforming to ASTM-C127-07 [12]. The sisal (Agave Sisalana) fibers (SsF) were purchased from Ayub Research Centre (ARC) Faisalabad which have water absorption capacity of 120% [8]. The SsF is mainly composed of cellulose, hemicellulose and lignin and have a density around 1.45g/cm^3 [8]. The SsF were cut into size of 10 mm length with an average diameter of 137µm resulting in an aspect ratio of 73. The 10 mm length of SsF were used because it is considered to have shown better results than 20 mm or 30 mm due to workability problems [8]. The SF used were both end hooked with length 35 mm, diameter 0.55 mm (aspect ratio 65 mm) and having tensile strength of 1350 MPa.

The SH pallets are mixed in water for 24 hours prior to be mixed with the concrete. The SS is added into solution of SH 30 minutes prior to add them into the other ingredients [21]. The CA, S, binder consisting of FA, GBS and QRD are mixed in dry condition for 2 minutes. The FA, GBS and QRD were mixed in the ratio of 50%, 35% and 15% of the binder. This ratio of binder was taken from an already published study of the second author [9]. The SF or/and SsF are then added and mixed for another 2 minutes in concrete mixer drum for homogenous dispersion of fibers. Then solution of SH, SS along with water is added into the mixer. The remaining water (amount of water already present in SH and SS is 47.08 kg/m^3 and 75 kg/m^3 respectively) is added to maintain 0.45 W/Binder ratio and slump was checked.

2.2 Testing of specimens

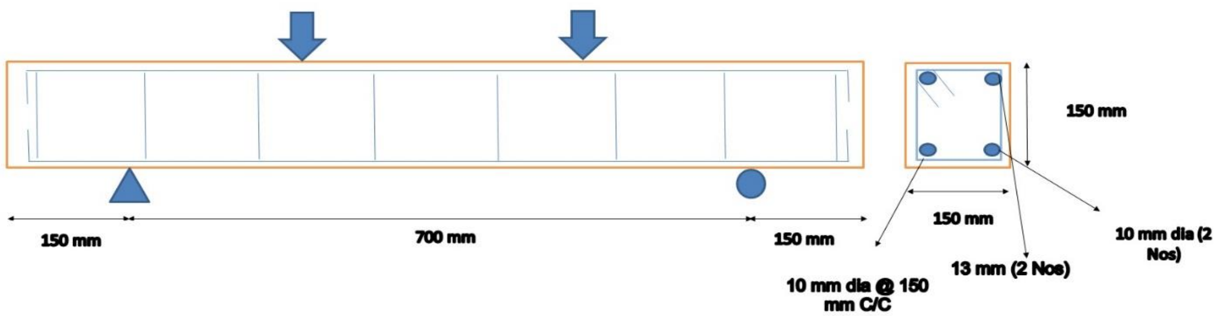

Figure 1: Reinforcement detail and four point loading of beam

Figure 2: Shear failure of the beams

The mixing procedure was carried out according to ASTM C-143M-15a [14]. A universal testing machine (UTM) was used for performing compressive, split cylinder and flexural strengths according to ASTM C39/39M-03 [15], C496/C496M-11 [16] and 1609/C1609M-19a [17] respectively. In the second stage of experimental program, the load bearing capacity of GPC beams was checked by four point loading test. The four point loading of beams with reinforcement detail are shown in figure 1 and beams after loading/failure are shown in figure 2. The loading arrangement consist of a load cell with hydraulic jack. The maximum load applying capacity of reaction frame was 2000 KN. The load was applied with the help of hydraulic jack whose capacity was 200 KN. The hydraulic jack was placed over steel plate and it was connected to load cell over the top of it.

3 Results and Discussion

3.1 Workability.

The workability of mixes was checked using slump cone test. An effort was made to maintain the slump value in between 70 and 90 mm by varying the quantity of superplasticizer (SP) for a workable mixture. The slump value was dependent on both the percentages and type of fibers. It was noted that along with increase of percentage of SsF there was decrease in the slump value in both type of fiber reinforcement with showing minimum slump value at 2.4% SsF. This decrease is due to large water absorption capacity of SsF. The slump values for GPC, 0.8SsF-R-GPC, 1.2SsF-R-GPC, 2.4SsF-R-GPC, 0.5SF+0.5SsF-R-GPC, 0.5SF+1SsF-R-GPC and 0.5SF+1.5SsF-R-GPC were calculated to be 84, 81, 78, 70, 78, 75 and 73 mm respectively.

3.2 Mechanical Properties

The mechanical properties of the mixes were evaluated using cube (150 mm), cylinder (dia 150mm, H 300 mm) and prisms (150x150x750mm) specimens for each mix type given in table 1. The uniaxial compression strength test was performed to determine cube strength after 28 days of casting and results are shown in figure 3. From the figure it is clear that the compressive strength of GPC (20.5 MPa) versus 2.4SsF-R-GPC (28.56 MPa) and 0.5SF+1SsF-R-GPC (29.5 MPa) has shown maximum increase of 39.31% in case of SsF incorporation and 43.90% in case of hybrid fibers respectively, similar trend was also observed by Guido silva [8]. The addition of 0.8% SsF has shown greater increase in compression strength than the addition of a mixture of 0.5% SsF and 0.5% SF, this may be due improper dispersion of fibers among the mix since less quantity of fibers are used in earlier case than in the later one.

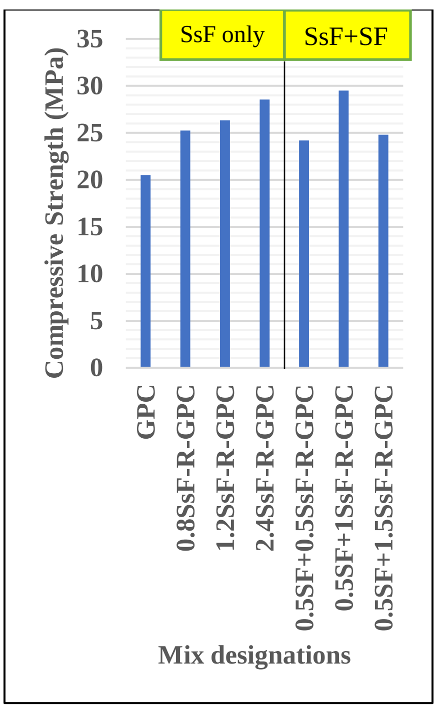

Figure 3: Compressive strength

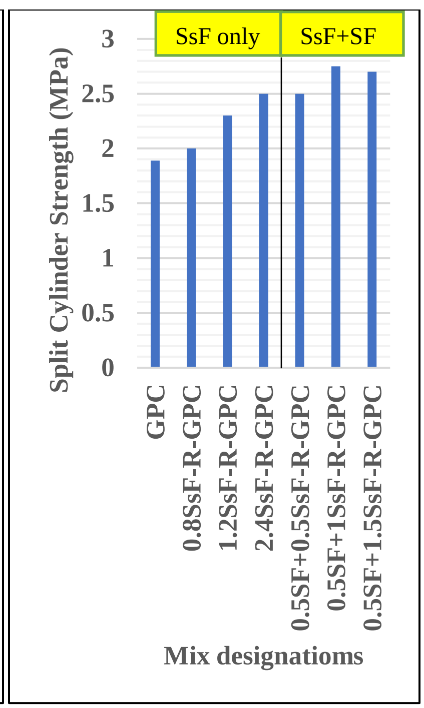

Figure 4: Split cylinder strength

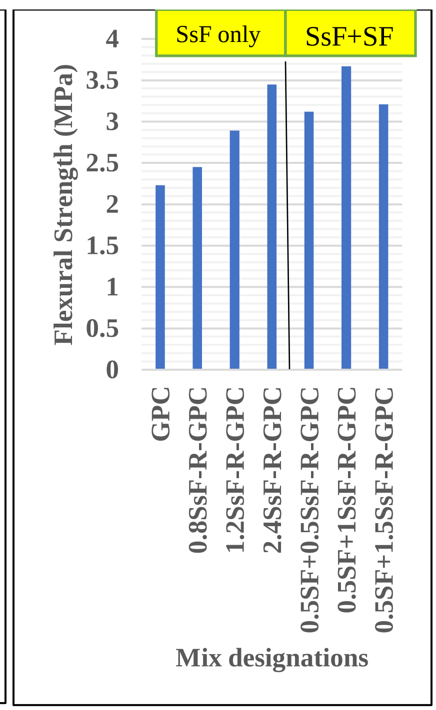

Figure 5: Flexural strength

Also with the increase of fibers content in 0.5SF+1.5SsF-R-GPC there is decrease in the compressive strength. This decrease in the strength is also due to low workability in case of higher fiber content which resulted in uneven distribution of fibers among the mix.

The results of split cylinder are reported in the figure 4. From the figure it is clear that tensile strength also follow similar trend that was observed for compressive strength with showing maximum value of 2.5 MPa for 2.4SsF-R-GPC which is 32.27% more than unreinforced GPC. Similarly maximum value of hybridized fiber reinforcement was observed for 0.5SF+1SsF-R-GPC of 2.75 MPa which is 45.5% more than control mix. Also the fiber reinforced GPC showed more ductile failure as compared to the control mix. The failure of fiber reinforced GPC was accompanied by the multi cracking due to fact that fibers allow load transference from the cracked area to the other parts of the specimen. These results are in same pattern with what observed by the other researchers [23].

The results of three point bending test are shown in the figure 5. Like above the flexural strengths also show similar trend with the increase of values along with increase of fiber content. The maximum value of 3.45 MPa was observed for 2.4SsF-R-GPC which is 54.70% more than the control mix. For hybridized fiber reinforced GPC the maximum value was noted for 0.5SF+1SsF-R-GPC of 3.67 MPa (64.57% more than GPC). It may be noted that for tensile and compression strength tests nearly same amount of increase in strengths is noted with addition of fibers however this increase is more dominant in case of flexural tests, this my be due to fact that the fibers pulling and stretching is not tested as in the flexural strength test also observed by Sun et al. [23] and Chen et al. [24]. The standard deviation of compressive, split cylinder and flexural strength results are calculated to be 2.970 MPa, 0.341 MPa and 0.525 MPa respectively.

3.3 Load carrying capacity of beams

The shear deficient beams for each mix types having optimum values in initial trials and 0.75% SF-R-GPC selected from earlier research [9] along with control GPC (all mix types are shown in Table 2) were casted and tested for maximum load under four point loading arrangement as shown in figure 1. The sample of beams after the tests are shown in figure 2. From the figure 2 it is clear that all the beams failed by the formation of diagonal cracks near the supports, no tensile splitting was noticed along the main reinforcement. Such failure was also observed by Shoaib et al. [25].

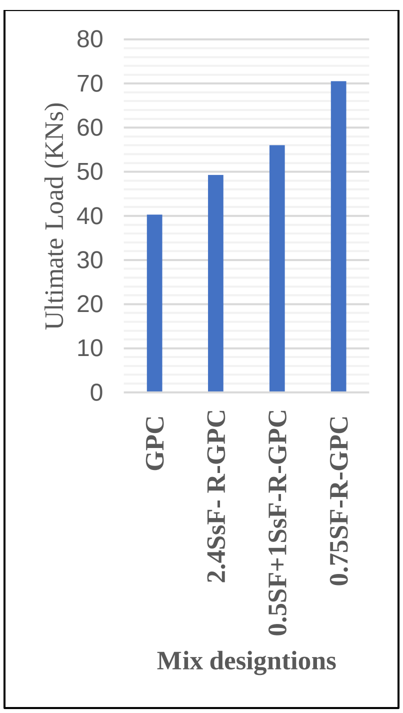

Figure 6: Ultimate load capacity of beams

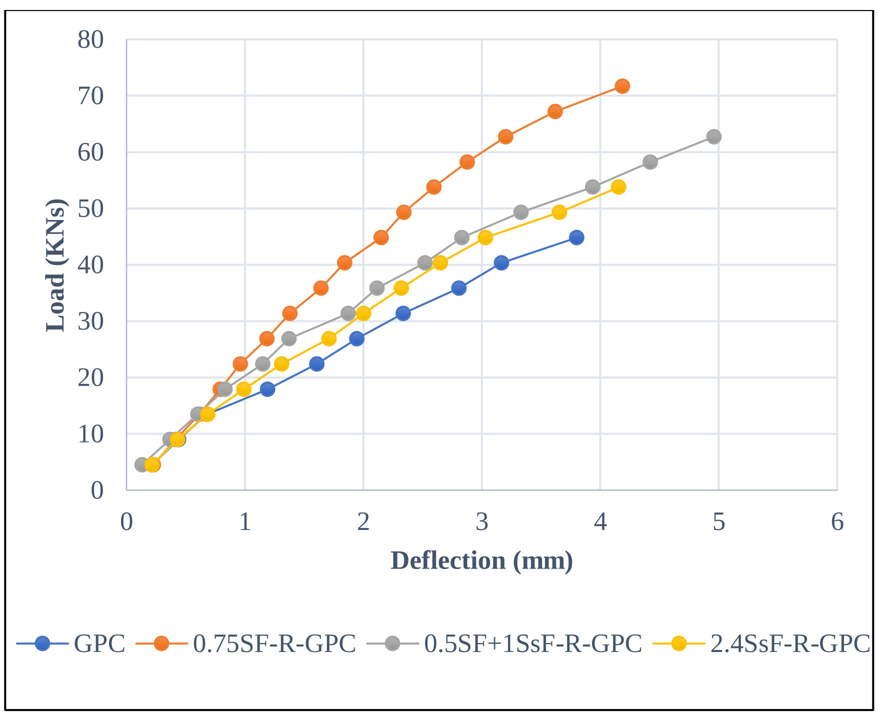

Figure 7: Load Deflection Curve

It was found that fibers addition enhanced the ultimate load carrying capacity of the beams with 2.4SsF-R-GPC showing 49.28 KNs (22.22% more than unreinforced GPC), 0.5SF+1SsF-R-GPC having 56 KNs (38.89% increase) and 0.75SF-R-GPC showing maximum value of 70.56 KNs (75% more than its counterpart GPC) value of ultimate load. Unlike the specimens without fibers (GPC) which failed at once, fibers reinforced GPC (both SsF and SF) having fibers stitching the cracks showed more ductile failure by resisting opening of crack with pulling out of fibers from concrete through the crack. The load carrying capacity of beams are shown in figure 6 (the values has standard deviation of 12.75 KNs).

3.4 Load deflection curve of beams

Figure 7 shows the load deflection curve of the beams having size of 150x150x1000 mm. According to ASTM C1018 the flexural toughness is the area under load deflection curve. From figure 7 it is quite obvious that fibers addition has enhanced the flexural toughness. The greater the flexural toughness more will the capacity of the beams to absorb the energy. During the pulling out of fibers in crack propagation has led to more energy/load absorption than normal GPC, which resulted in more ductile failure of fiber reinforced concrete as also observed by other author [26]. The SF-R-GPC has shown maximum toughness however the SsF both individually and in hybridized form has shown improved results than their counterpart unreinforced GPC. The stiffness is the ratio of load applied and deflection in the beam. The stiffness of beams is also observed to increase with incorporation of fibers especially with hybrid fibers having SF has shown maximum stiffness. However from the figure it can also be observed that that SsF reinforced GPC also has more stiffness than its counterpart GPC.

4 Practical Implementation

The SsF with GPC in both form that is individually and in hybridized form at optimum rate can prove to be a environment friendly, economical and efficient construction material for important structure. Since incorporation of SsF into calcium rich FA, GBS and QRD based GPC at ambient curing has yielded excellent results. However its behavior in concrete for longer period of time is still needed to be found.

5 Conclusion

Following conclusions can be drawn from the conducted study:

- Natural fiber (SsF) reinforced GPC which can be a potential sustainable construction material is developed having good mechanical properties and lesser environmental impact. The SsF addition into QRD incorporated GPC at various fraction has yielded improved performance in mechanical properties and flexural strength with having maximum values at 2.4SsF-R-GPC.
- The novel hybrid natural fibers (SsF) and SF has also shown increased results (maximum values are observed for 0.5SF+1SsF-R-GPC). In case of hybrid fibers for higher fiber content the decrease in the strength is due to less workability that resulted in uneven dispersion of fibers among the mix.
- The fiber incorporation into GPC has resulted in increased ultimate load carrying capacities of beams with 0.75SF-R-GPC showing maximum values however the SsF both individually and in hybridized form has shown improved results than their counterpart unreinforced GPC.
- The fibers addition into GPC in both of the cases has promoted more prolonged failure than their counterpart GPC with the fact that fibers stitching and resisting the opening of cracks during the application of loads.

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