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EFFECT OF FINE AGGREGATE BLENDING ON SHORT-TERM MECHANICAL PROPERTIES OF GEOPOLYMER CONCRETE

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ABSTRACT

The present investigation is mainly focused on finding the mechanical properties of geopolymer concrete (GPC) mixes with different fine aggregate blending. Sand and granite slurry (GS) are blended in different proportions (100:0, 80:20, 60:40 and 40:60). Coarse aggregates of size 20 mm and 10 mm are blended in 60:40 proportions by percentage of weight of total coarse aggregate. Fly ash (class F) and ground granulated blast furnace slag (GGBS) were used at 50:50 ratio as geopolymer binders. Combination of sodium hydroxide (8M) and sodium silicate solution was used as an alkaline activator. Compressive strength, splitting tensile strength (STS) and flexural strength (FS) were studied after 7, 28 and 90 days of curing at ambient room temperature. From the results, it is revealed that the mechanical properties were increased till fine aggregate blending of 60:40 and decreasing trend has been observed at 40:60 fine aggregate blending. It is concluded that optimum fine aggregate blending was 60:40. The measured STS and FS of all mixes were compared with ACI 363R, CEB-FIP and ACI 318R predicted equations.

Keywords: Geopolymer concrete; granite slurry; fly ash, GGBS; compressive strength; splitting tensile strength; flexure strength.

1. INTRODUCTION

Now a days usage of concrete occupies second place around the world other than the water

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[1]. Ordinary portland concrete primarily consists of cement, aggregates (coarse & fine) and water. In this, cement is used as a primary binder to produce the ordinary portland concrete. Due to increasing of developments in infrastructure, the usage of conventional concrete will be more and as well as the demand of cement would be increases in the future. Approximately it is estimated that the consumption of cement is more than 2.2 billion tons per year (Malhotra, 1999) [2].

On the other hand, the usage of Portland cement may create the some environmental issues such as global warming, green house effect etc. Because these problems may generate due to increasing of carbon dioxide (Co_2) present in the environment, from the past results nearly one tone of portland cement releases equal quantity of carbon dioxide (Co_2) [3]. In order to avoid these environmental issues associated with Portland cement, there is need to use some alternatives [4] such as fly ash (FA), ground granulated blast furnace slag (GGBS), rise husk ash (RHA) etc are as the binders to make the eco friendly concrete [3].

In this respect, Davidovits [1988] [5] proposed an alternative binder for the concrete technology and it shows a good results. These binders are produced by an alkaline liquid reacts with the silica (Si) and aluminium (Al) present in the source materials [6]. The technology proposed by the Davidovits is commonly called as Geo-polymers or Geo-polymer technology. The major advantages of Geopolymer technology are an environmental protection, good volume stability, excellent durability, high fire resistance and low thermal conductivity [7].

1.1 Geo-polymers

There are two major constituents present in the geopolymers, namely the alkaline liquids and source materials [1&3]. The alkaline liquid used in geopolymerisation process is a mixture of sodium hydroxide (NaOH) and sodium silicate (Na_2So_3) or potassium hydroxide (KOH) and potassium silicate (K_2So_3) [8&9]. The source materials used for geopolymers are based on percentage of silica (Si) and aluminium (Al) present in the material [8&9]. Fly ash (FA), silica fume (SF), ground granulated blast furnace slag (GGBS), rise husk ash (RHA) etc are could be used as source materials [9]. The selection of source materials is mainly based on requirement, cost, users demand etc.

The schematic structure of geopolymer material can be shown in Equations (1) and (2) (Davidovits, 1994; van Jaarsveld et al., 1997) [8]:

$$\underset{\text{(Si-Al materials)}}{n(Si_2O_5,Al_2O_2)}+2nSiO_2+4nH_2O+NaOH \text{ or } KOH \rightarrow Na^+, K^+ + \underset{\text{(Geopolymer precursor)}}{n(OH)_3\text{-}Si\text{-}O\text{-}\underset{\substack{|\\(OH)_2}}{Al^-}\text{-}O\text{-}Si\,(OH)_3} \tag{1}$$

$$n(OH)_3\text{-}\underset{\substack{|\\(OH)_2}}{Si}\text{-}O\text{-}Al^-\text{-}O\text{-}Si\text{-}(OH)_3 + NaOH \text{ or } KOH \rightarrow \underset{\text{(Geopolymer backbone)}}{(Na^+, K^+)\text{-}(\text{-}\underset{\substack{|\\O}}{Si}\text{-}O\text{-}\underset{\substack{|\\O}}{Al^-}\text{-}O\text{-}\underset{\substack{|\\O}}{Si}\text{-}O\text{-})} + 4nH_2O \tag{2}$$

The above chemical reaction may consist of the following steps (Davidovits 1999 [10]; Xu and van Deventer 2000 [11]):

- ❖ Dissolution of Si and Al atoms from the source material through the action of hydroxide ions.
- ❖ Transportation or condensation or orientation of precursor ions into monomers.
- ❖ Polymerisation of monomers into polymeric structures.

However, the above three steps can overlap with each other and occur almost simultaneously, thus making it difficult to isolate and examine each of them separately (Palomo et al. [12]).

A geopolymer can take one of the three basic forms (Davidovits 1999 [10]):

- ❖ Poly (sialate), which has [-Si-O-Al-O-] as the repeating unit.
- ❖ Poly (sialate-siloxo), which has [-Si-O-Al-O-Si-O-] as the repeating unit.
- ❖ Poly (sialate-disiloxo), which has [-Si-O-Al-O-Si-O-Si-O-] as the repeating unit.

Sialate is an abbreviation of silicon-oxo-aluminate.

From equation (2), it reveals that the last term i.e., water (H_2O) is released during the chemical reaction that occurs in the formation of geopolymers. This water, removed from the geopolymer matrix during the curing and further drying periods, leaves behind discontinuous nano-pores in the matrix, which provide benefits to the performance of geopolymers.

2. EXPERIMENTAL STUDY

2.1 Experimental program

Our objective was to determine the effect of fine aggregate blended (100:0, 80:20, 60:40 and 40:60) on short-term mechanical properties of GPC. In this respect, Fly ash (Class F) and GGBS were used at 50:50 ratio as geopolymer binders. Combination of sodium hydroxide (8M) and sodium silicate solution is used as an alkaline activator. crushed granite stones of size 20 mm and 10 mm, river sand, granite slurry and SP were used in preparing GPC mixes having alkaline solution/binders of 0.35 (by weight). 20 mm and 10 mm size aggregates are blended in 60:40 proportions by percentage of weight of total coarse aggregate. The fine aggregate (FA) and granite slurry (GS) are blended in 100:0, 80:20, 60:40 and 40:60 proportions by percentage of weight of total fine aggregate. The fresh properties that were determined are filling ability, passing ability and consistence retention. The hardened properties that were determined are compressive strength, splitting tensile strength and flexural strength after 7, 28 and 90 days of curing at ambient room temperature and also Split tensile strength and Flexural strength values were derived from Compressive strength values using the formulae provided in code books.

2.2 Material properties

This section will present the chemical and physical properties of the ingredients. Bureau of Indian Standards (IS) and American Society for Testing and Materials (ASTM) procedures were followed for determining the properties of the ingredients in this investigation.

2.2.1 Fly ash

In this investigation, Class F (low calcium) fly ash produced from Rayalaseema Thermal

Power Plant (RTPP), Muddanur, A.P is used as an additive according to ASTM C 618 [13]. As per IS-456:2000 [14], cement is replaced by 35% of fly ash by weight of cementitious material [15&16]. The specific gravity and Fineness of fly ash are 2.26 and 360 (m^2/Kg).The chemical properties are presented in the Table 1.

Table 1: Chemical properties of fly ash and GGBS from X-ray fluorescence analysis

Particulars	SiO_2 (%)	Al_2O_3 (%)	Fe_2O_3 (%)	CaO (%)	MgO (%)	TiO_2 (%)	SO_3 (%)	LOI[a] (%)
Fly ash	65.6	28.0	3.0	1.0	1.0	0.5	0.2	0.29
GGBS	30.61	16.24	0.584	34.48	6.79	-	1.85	2.1

[a]LOI: loss of ignition

2.2.2 Ground granulated blast furnace slag

GGBS collected from Astrra chemicals, chennai was used in the manufacturing of GPC. The specific gravity and Fineness of GGBS are 2.84 and 400 (m^2/Kg). The chemical properties are presented in the Table 1.

2.2.3 Coarse aggregate

Crushed granite stones of size 20mm and 10mm are used as coarse aggregate. As per IS: 2386 (Part III)-1963 [17], the bulk specific gravity in oven dry condition and water absorption of the coarse aggregate are 2.58 and 0.3% respectively. The fineness modulus of 20mm and 10mm coarse aggregates are 3.35 and 1.89.

The gradation of the coarse aggregate was determined by sieve analysis as per IS 383:1970 [18] and presented in Tables 2 and 3. The grading curves of the coarse aggregates as per IS 383:1970 [18] are shown in Figs. 1 and 2.

Table 2: Sieve analysis of 20 mm Coarse aggregate

Sieve size (mm)	Cumulative percent passing	
	20 mm	**IS 383 (1970) limits**
20	92.84	85-100
16	44.28	N/A
12.5	19.3	N/A
10	7.66	0-20
4.75	0.14	0-5

Table 3: Sieve analysis of 10 mm Coarse aggregate

Sieve size (mm)	Cumulative percent passing	
	10 mm	**IS 383 (1970) limits**
10	99.68	85-100
4.75	8.76	0-20
2.36	2.4	0-5

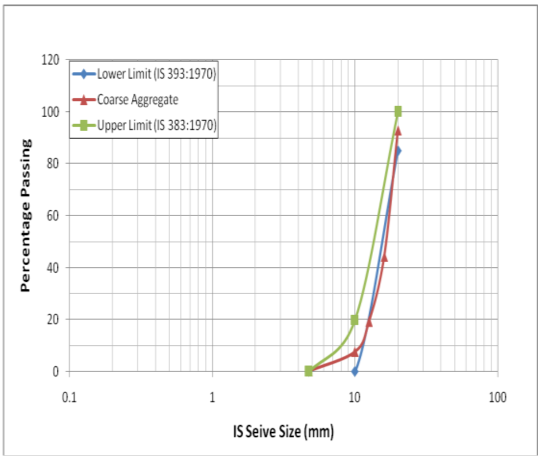

Figure 1. Grading curve of 20 mm Coarse aggregate

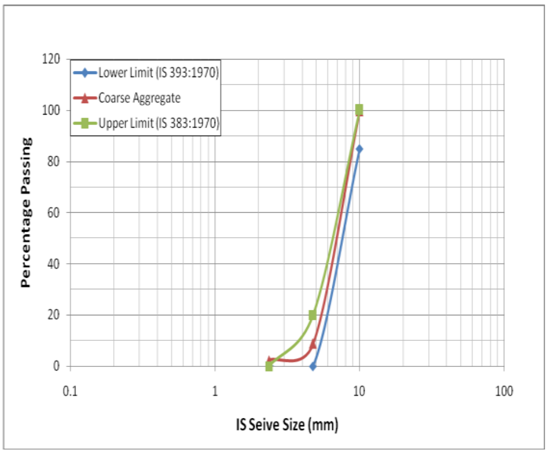

Figure 2. Grading curve of 10mm Coarse aggregate

2.2.4 Fine aggregate

2.2.4.1 Sand

Natural river sand is used as fine aggregate. As per IS: 2386 (Part III)-1963 [17], the bulk specific gravity in oven dry condition and water absorption of the sand are 2.62 and 1% respectively. The fineness modulus of sand is 2.59.

2.2.4.2 Granite slurry

Granite slurry is used as secondary material of fine aggregate and which is collected from granite cutting industry. As per IS: 2386 (Part III)-1963 [17], the bulk specific gravity in oven dry condition and water absorption of the fine aggregate are 2.86 and 1.2% respectively.

The gradation of the fine aggregates was determined by sieve analysis as per IS code [18] and presented in the Tables 4 and 5. The grading curve of the fine aggregate as per IS code [18] is shown in Figs. 3 and 4.

Table 4: Sieve analysis of Fine aggregate (Sand)

Sieve No/ size	**Cumulative percent passing**	
	Fine aggregate	**IS 383 (1970) – Zone II requirement**
3/8” (10mm)	100	100
No.4 (4.75mm)	98.8	90-100
No.8 (2.36mm)	95.3	75-100
No.16 (1.18mm)	81.8	55-90
No.30 (600µm)	45.2	35-59
No.50 (300µm)	16.2	8-30
No.100 (150µm)	3.0	0-10

2.2.5 Chemical admixtures

Sika Viscocrete 10R is used as High Range Water Reducer (HRWR) SP and percentage of dry material in SP is 2%.

Table 5: Sieve analysis of granite slurry

Sieve No/ size	Cumulative percent passing	
	Fine aggregate	IS 383 (1970) – Zone II requirement
3/8" (10mm)	100	100
No.4 (4.75mm)	100	90-100
No.8 (2.36mm)	100	75-100
No.16 (1.18mm)	84.7	55-90
No.30 (600µm)	58	35-59
No.50 (300µm)	29.1	8-30
No.100 (150µm)	8.3	0-10

2.2.6 Water

Ordinary tap water is used in the preparation of GPC.

2.2.7 Alkaline liquid

The alkaline liquid used was a combination of sodium silicate solution and sodium hydroxide solution [4, 6 &19]. The sodium silicate solution (Na2O= 13.7%, SiO2=29.4%, and water=55.9% by mass) and sodium hydroxide (NaOH) in flakes or pellets from with 97%-98% purity [4, 6&15] and it was purchased from a Astrra chemicals, Chennai.

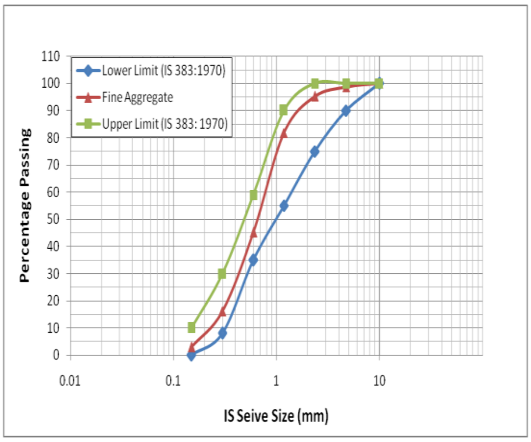

Figure 3. Grading curve of fine aggregate(Sand)

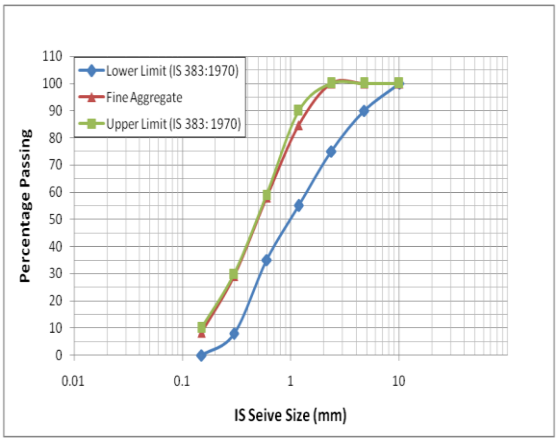

Figure 4. Grading curve of granite slurry

2.3 Mixture proportions

Based on the limited past research on GPC (Hardjito & Rangan, 2005), the following proportions were selected for the constituents of the mixtures[20].In the design of geopolymer concrete mix, coarse and fine aggregates together were taken as 77% of entire mixture by mass [21]. Fine aggregate was taken as 30% of the total aggregates. The density of geopolymer concrete is taken similar to that of OPC as 2400 kg/m^3 [20]. The Class F fly ash and GGBS were taken as 50-50% and the Molarity of sodium hydroxide solution was kept at 8M. The details of mix design and its proportions for different mixes of GPC are given in Table 6.

Table 6: Mix proportions of constituent materials.(kg/m^3)

Mix type	Coarse aggregate		Fine aggregate		Fly ash	GGBS	Na_2SiO_4	NaOH	Extra water	SP
	20 mm	10 mm	Sand	GS						
100:0[a]	774	516	549	0	204.5	204.5	102	41 (8M)	92.5	2.86
80:20	774	516	439.2	109.8	204.5	204.5	102	41 (8M)	92.5	2.86
60:40	774	516	329.4	219.6	204.5	204.5	102	41 (8M)	92.5	2.86
40:60	774	516	219.6	329.4	204.5	204.5	102	41 (8M)	92.5	2.86

[a]100:0:Where 100 is the percentage of fine aggregate (sand) and 0 is the percentage of GS by weight.

2.4 Manufacture of test specimens

2.4.1 Preparation of alkaline liquid

In this study, NaOH solids of 8x40=320 grams have been dissolved in 680 ml of water to prepare one litre of NaOH solution with a concentration of 8 M. Where, 40 is the molecular weight of NaOH pellets. The sodium silicate solution and the sodium hydroxide solution were mixed together one day before prior to use.

2.4.2 Manufacture of fresh concrete

The aggregates were prepared in saturated-surface-dry (SSD) condition. Fly ash, GGBS and aggregates were mixed for about 3 minutes. 70% of extra water was added to the mix and mixed for one minute. Then, the alkaline liquid was added with remaining 30% of extra water and the mix was thoroughly mixed for about 2 minutes. The fresh concrete was cast and compacted by the usual methods used in the case of Portland cement concrete (Hardjito and Rangan, 2005) [20]. Fresh fly ash and GGBS-based geopolymer concrete was usually cohesive. The workability of the fresh fly ash and GGBS-based geopolymer concrete was measured by means of the conventional slump test.

2.4.3 Curing of test specimens

After casting and demoulding, the test specimens were kept for curing at ambient room temperature till the execution of the testing on the specimens.

3. METHODOLOGY

The short-term mechanical properties of the geopolymer concrete are evaluated by using Compressive strength test, Split tensile test and Flexural strength test. The Compressive strength test [22&23] and Split tensile test [24&25] and flexural strength test [22&26] of all specimens were evaluated by using respective codes. These samples were tested at 7, 28 and 90 days of curing at ambient room temperature. The Split tensile strength and Flexural strength results were compared to predicted values which are derived from respective codes (ACI 318/ AASHTO LRFD, ACI 393R, AS, CEB-FIP). [27-31].

4. RESULTS AND DISCUSSIONS

4.1 Compressive strength

Table 7 shows the compressive strength of GPC mixes (100% FA, 20% GS-80%FA, 40% GS-60% FA, 60% GS-40% FA) at different curing periods.

Table 7: Compressive strength of GPC

Mechanical property	**Age (days)**	**Mix type**			
		100:0	**80: 20**	**60: 40**	**40:60**
Compressive strength, f'_c (MPa)	7	29.08	31.97	33.97	22.39
	28	45.87	48.07	51.14	33.63
	90	53.53	57.02	59.93	38.55

Compressive strength was tested for the mixes with the various GS replacement levels of 0%, 20%, 40% and 60%. The samples were tested after curing periods of 7, 28 and 90 days. It was observed that there was a significant increase in compressive strength with the increase in percentage of GS from 0% to 40% in all curing periods. After 7 days of curing, 40% GS sample exhibited a compressive strength of 33.97 MPa, whereas after 28 days of curing it was 51.14 MPa and after 90 days of curing it was 59.93 MPa. It is to be noted that the significant improvement in compressive strength is mainly due to the filling of voids with GS. From the results it is concluded that GS acts as filling material which fills the voids of the concrete and hence makes the concrete dense. However, when the percentage GS was increased to 60% a drastic fall in compressive strength was evidenced irrespective of the time of curing. The compressive strength values of the mixes with 60% replacement of GS were found to be 22.39 MPa, 33.63 MPa and 38.55 MPa respectively after 7, 28 and 90 days of curing. The fall in the compressive strength at 60% GS can be explained presumably due to the excessive content of fine material in concrete.

The experimental values obtained are depicted in Fig.5. This trend of increase in values of compressive strength with increasing GS replacement (0% to 40%) and a further sharp fall in compressive strength was observed at 60% of GS.

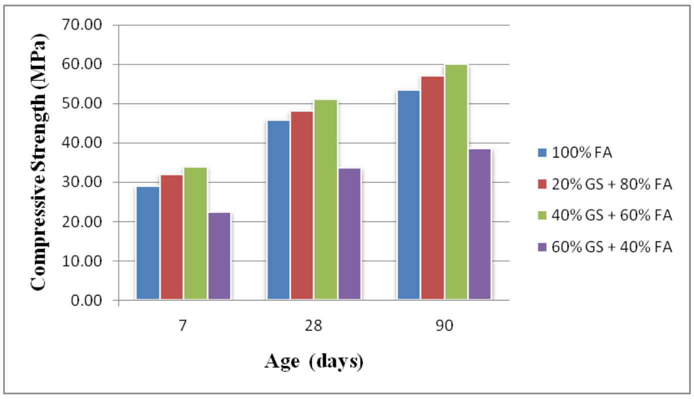

Figure 5. Compressive strength versus age

4.2 Split tensile strength

Table 8 shows the split tensile strength of GPC mixes (100% FA, 20% GS-80%FA, 40% GS-60% FA, 60% GS-40% FA) at different curing periods.

Table 8: Split tensile strength of GPC

Mechanical property	**Age (days)**	**Mix type**			
		100:0	**80: 20**	**60: 40**	**40:60**
Split tensile strength, f_{ct} (MPa)	7	1.89	1.91	2.06	1.27
	28	2.89	3.03	3.31	1.65
	90	3.01	3.16	3.44	1.89

Split tensile strength (STS) was also performed by replacing fine aggregate with from 0% to 60%. The split tensile strength was found to increase with increasing percentage of GS up to 40%, independent of the age of curing. A drastic fall of STS was observed when the GS percentage was increased further to up to 60%. The STS at 40% GS was found to be 2.06 MPa after a curing period of 7 days, whereas at 28 days with 40% GS the split tensile strength was 3.31 MPa. A considerable improvement in STS up to 3.44 MPa was observed after 90 days of curing. It is to be said that GS acts as filling material which improves the interfacial transition zone (ITZ) and leads to the improvement of STS. At 60% replacement of GS, the STS was very low, yielding a value of 1.27 MPa after 7 days of curing. Similarly, at 60% GS replacement and after 28 days and 90 days of curing the STS values were observed to be very low yielding values of 1.65 MPa and 1.89 MPa.

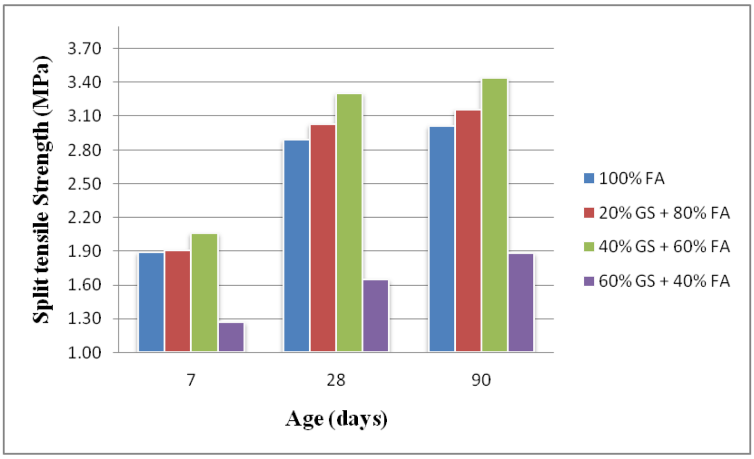

Figure 6. Split tensile strength versus age

The ACI 363R (ACI, 1992) [28] and CEB-FIP (1990) [31] predicted equations for STS of concrete are presented in the Table 9.

The measured STS of all mixes after 7, 28 and 90 days of curing have been compared with the ACI 363R (ACI, 1992) [28] and CEB-FIP (1990) [31] predicted equations and presented in the Table 10.

Table 9: Expressions for STS

Code of practice	Expression for f_{ct} (MPa)	Range of concrete strength
ACI 363R (ACI 1992)	$0.59\,(f'_c)^{0.5}$	21 MPa < f'_c < 83 MPa
CEB-FIP (1990)	$1.56\left[\frac{f'_c-8}{10}\right]^{2/3}$	f'_c < 80 MPa

Table 10: Comparison of measured and predicted STS of all mixes

Mix Type	Age (days)	Split tensile strength, f_{ct}		
		Experiment	ACI 363R	CEB-FIP
100:0[a]	7	1.89	3.18	2.56
80:20		1.91	3.34	2.79
60:40		2.06	3.44	2.95
40:60		1.27	2.79	1.99
100:0	28	2.89	4.00	3.79
80:20		3.03	4.09	3.94
60:40		3.31	4.22	4.13
40:60		1.65	3.42	2.92
100:0	90	3.01	4.32	4.29
80:20		3.16	4.46	4.50
60:40		3.44	4.57	4.68
40:60		1.89	3.66	3.28

[a]100:0: Where 100 is the percentage of FA and 0 is the percentage of GS by weight.

It is seen from the Table 10 and Fig.7, experimental values of STS of all mixes are less than the predicted values. ACI 363R [28] and CEB-FIP [31] overestimates the value of STS as compared to those of experimental values for all mixes.

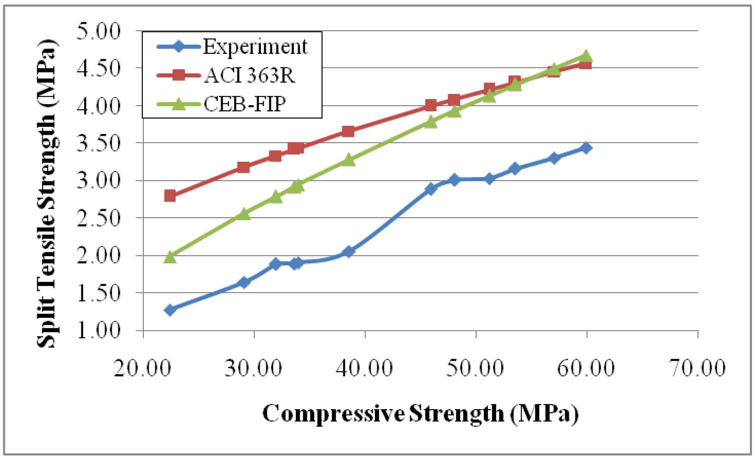

Figure 7. STS versus compressive strength of GPC mixes

4.3 Flexural strength

Table 11 shows the flexural strength of GPC mixes (100% FA, 20% GS-80%, 40% GS-60%FA, 60%GS-40% FA) at different curing periods.

Table 11: Flexural strength of GPC

Mechanical property	Age (days)	Mix type			
		100:0	80: 20	60: 40	40:60
Flexural strength, f_{cr} (MPa)	7	2.52	2.64	3.01	1.82
	28	3.96	4.21	4.56	2.95
	90	4.84	5.16	5.38	3.19

Flexural strength was also performed by replacing fine aggregate with from 0% to 60%. The flexural strength was found to increase with increasing percentage of GS up to 40%, independent of the age of curing. A drastic fall of flexural strength was observed when the GS percentage was increased further to up to 60%. The flexural strength at 40% GS was found to be 3.01 MPa after a curing period of 7 days, whereas at 28 days with 40% GS the flexural strength was 4.56 MPa. A significant improvement in flexural strength up to 5.38 MPa was observed after 90 days of curing. It is to be pointed out that GS acts as filling material which improves the interfacial transition zone (ITZ) and leads to the improvement of flexural strength. At 60% replacement of GS, the flexural strength was very low, yielding a value of 1.82 MPa after 7 days of curing. Similarly, at 60% GS replacement and after 28 days and 90 days of curing the flexural strength values were observed to be very low yielding values of 2.95 MPa and 3.19 MPa.

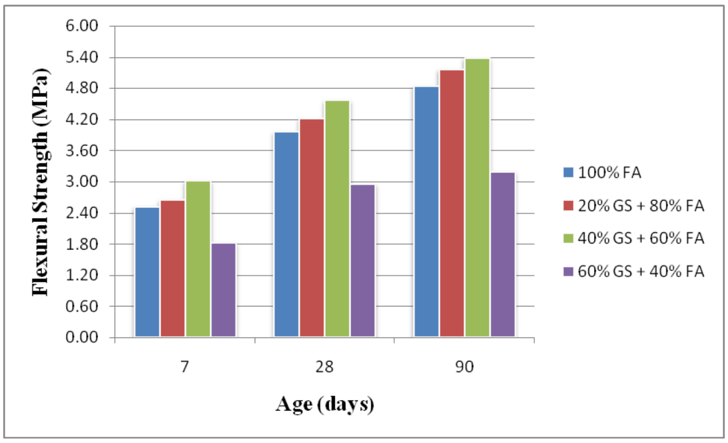

Figure 8. Flexural strength versus age

Table 12: Expressions for FS

Code of practice	Expression for f_{cr} (MPa)	Range of concrete strength
ACI 363R (ACI 1992)	$0.94\ (f'_c)^{0.5}$	Not specified
ACI 318R (ACI 1995)	$0.62\ (f'_c)^{0.5}$	Not specified

The ACI 363R (ACI, 1992) [28] and ACI 318R (ACI 1995) [27] predicted equations for FS of concrete are presented in the Table 12.

Table 13: Comparison of measured and predicted FS of all mixes

Mix Type	Age (days)	Flexural strength, f_{cr}		
		Experiment	ACI 363R	ACI 318R
100:0[a]	7	2.52	5.07	3.34
80:20		2.64	5.31	3.51
60:40		3.01	5.48	3.61
40:60		1.82	4.45	2.93
100:0	28	3.96	6.37	4.20
80:20		4.21	6.52	4.30
60:40		4.56	6.72	4.43
40:60		2.95	5.45	3.60
100:0	90	4.84	6.88	4.54
80:20		5.16	7.10	4.68
60:40		5.38	7.28	4.80
40:60		3.19	5.84	3.85

[a]100:0: Where 100 is the percentage of FA and 0 is the percentage of GS by weight.

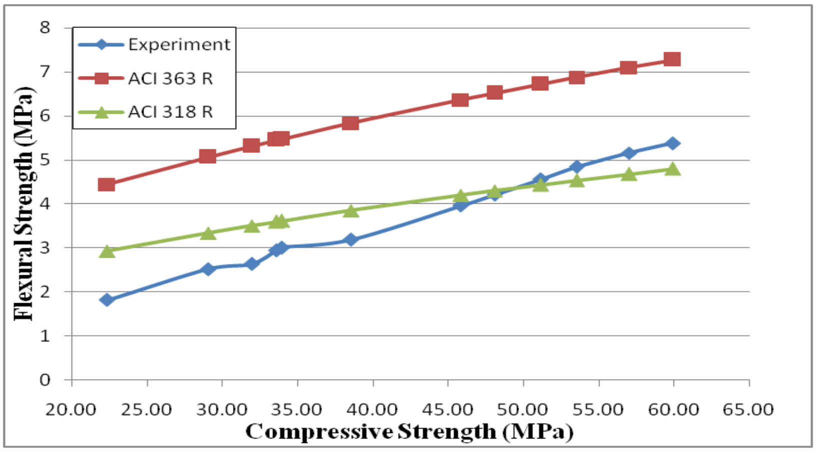

Figure 9. FS versus compressive strength of GPC mixes

The measured FS of all mixes after 7, 28 and 90 days of curing have been compared with the ACI 363R (ACI, 1992) [28] and ACI 318R (ACI 1995) [27] predicted equations and presented in the Table 12. It is seen from the Table 13 and Fig.9, experimental values of FS of all mixes are less than the predicted values and ACI 318 R values are slightly less than the experimental values after compressive strength of 50 MPa. ACI 363R [28] and ACI 318R [27] overestimates the value of FS as compared to those of experimental values for all mixes. It is already revealed that GGBS and fly ash blended GPC mixes have attained enhanced mechanical properties at all ages for natural river sand [32]. From the present study, it is observed that mechanical properties were increased till fine aggregate blending of 60:40.

5. CONCLUSIONS

Based on the investigation, the following conclusions have been drawn.

1. There was a significant increase in compressive strength with the increase in percentage of GS from 0% to 40% in all curing periods.
2. When the percentage GS was increased to 60% a drastic fall in compressive strength was evidenced.
3. When the percentage of GS increased from 0% to 40%, splitting tensile strength and flexural strength have been enhanced.
4. When the percentage GS was increased to 60% a drastic fall in splitting tensile strength and flexural strength have been evidenced.
5. The significant improvement in mechanical properties up to 40% GS replacement is mainly due to the fine material of GS which fills the voids and increases the compressive strength of the concrete which in turn increases the other mechanical properties.

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