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Influence of Type and Size of Fine Aggregate on Glass Fiber Reinforced Self-Compacting Mortars (GFRSCM)

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Abstract

This paper addresses the fresh and hardened state behavior of glass fiber reinforced self-compacting mortars (GFSCMs) with various types and sizes of fine aggregate. Mini-slump flow and mini V-funnel tests were performed to evaluate the workability of GFSCMs. Compressive strength, split tensile strength, and flexural strength tests at the end of 28 days of water curing were determined. Water sorptivity tests were conducted on 28-day cured cube specimens. The variable parameters in this study include type of fine aggregate, particle size of aggregate, and mix proportions. The test results showed a decrease in the compressive strength, split tensile strength, and flexural strength with decrease in size of aggregate whereas sorptivity decreased with increase in size of aggregate and time of immersion. The strength of GFSCMs was more with natural sand compared to crushed stone fine aggregate and foundry sand.

Keywords: glass fibers, mini slump cone, mini V-funnel, self-compacting mortars, sorptivity

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INTRODUCTION

Self-compacting mortar (SCM) is a highly flowable cement paste preferred for repair and rehabilitation of structures where normal mortars fail to serve the functionality for want of requisite high flowability. The repair mortar applied to concrete surfaces is generally hard to consolidate and in majority of the cases vibration is a problem. Under these circumstances, self-compatibility of mortars brings substantial advantages particularly in narrow Mould systems. It was also reported that assessing the properties of SCMs forms an essential part of self-compacting concrete (SCC) design since mortar plays a vital role in the workability properties of SCC. The choice of the amount of cementitious or inert powders in SCMs, to achieve self-consolidation by modification in rheological properties of pastes, depends on the physical and physio-chemical properties, i.e., particle shape, surface texture, surface porosity, finest fraction content, and particle size distribution of these powders as they affect the performance of fresh paste. On the other hand, due to the high powder content and absence of coarse aggregate, SCMs are prone to surface abrasion, particularly in repair of surfaces (slabs and floors) with high abrasion impact. The use of fibers in SCMs may significantly increase the toughness, energy absorption capacity, reduce cracking, improve the impact resistance, and durability of cement-based materials. Thus, the glass fiber reinforcement in SCMs can be an excellent solution for bending and tensile resistance.

LITERATURE REVIEW

Shah *et al.*[1] conducted the compressive, tensile, and flexural tests on mortar specimens reinforced with steel and glass fibers. It was reported that the tensile or flexural strength of reinforced specimens was about two to three times, while the corresponding strains or deflections were as much as ten times that of plain mortar. David *et al.*[2] proposed an analytical relationship in order to predict the complete stress–strain curve of fiber reinforced mortar in compression. It was reported that the fibers delayed the crack propagation and enhanced the peak strain and the post peak ductility. Wang[3]conducted an experimental study on synthetic fiber reinforced mortars, using fibers at volume fractions below 3%, to obtain the tensile properties of the composites under both monotonic and cyclic loading. Kosa *et al.*[4] studied the durability properties of four types of fiber reinforced cement composites, i.e., conventional steel fiber reinforced mortar (SFRM), polypropylene fiber reinforced mortar (PFRM), glass fiber reinforced mortar (GFRM), and slurry infiltrated fiber concrete (SIFCON).

Shinobu *et al.*[5] made an experimental study on the rheological characteristic estimation of self-compacting mortars and reported the existence of strong relations between yield value and flow value as well as plastic viscosity and discharging time of J funnel test. Lappa et al.[6] tested the fresh and hardened state properties of self-compacting fiber reinforced high strength mortar mixtures.

Saharan *et al.*[7] studied the effectiveness of various mineral additives and chemical admixtures in producing SCM's. It was concluded that among the mineral additives used, fly ash and limestone powder significantly increased the workability of SCM's. Felekoglu *et al.*[8] studied the effect of fly ash and limestone fillers on the viscosity and compressive strength of self-compacting repair mortars. It was reported that beyond 28 days, mixes incorporating fly ash gave higher strength values than the control mixtures due to the pozzolanic effect of fly ash. Turkeland Altuntas[9] studied the effect of limestone powder (LP) on the properties of Self compacting repair mortar (SCRM) in comparison to other mineral additives such as silica fume (SF), fly ash (FA) and their combinations.

The results showed that certain FA, SF and LP combinations improve the workability of SCRMs, more than FA, SF and LP alone. Rathish Kumar and Srikanth[10] evaluated the effect of fiber and mesh in Self Compacting Mortar from the viewpoint of fresh state behavior and mechanical performance. Guneyisi and Gesog˘lu[11] studied the properties of SCMs using mineral admixtures (metakaolin-MK and fly ash-FA) in binary (two-component) and ternary (three-component) cementitious blends. It was concluded that use of FA and MK in ternary blends improves the fresh properties and rheology of the mixtures in comparison to those containing binary blends of FA or MK.

Dawood *et al.*[12] determined the mechanical properties and the durability of high-strength flowable mortar (HSFM) by using of different percentages of steel fiber and also with the use of the hybridization of steel fibers, palm fibers, and synthetic fiber (Barchip). The results indicate that hybrid fibers of 1.5% steel fibers +0.25% palm fibers +0.25% Barchip fibers provide large improvement in the different mechanical properties of HSFM. Mayowa and Chinwuba[13] investigated on the compressive strength development of mortar reinforced with Oil Palm Fiber (OPF) and concluded that 0.6 % is the most effective additive level of OPF for obtaining the self-compacting repair mortar that can be used in concrete structures.

RESEARCH SIGNIFICANCE

Researchers in the past focused on the mechanical properties of steel fiber and polypropylene fiber reinforced mortars using natural sand (NS), lime stone with replacement or addition of fly ash, and waste brick powder.

The literature review revealed that the published work on glass fiber reinforced SCMs using various types and size of fine aggregate is scant. As the improvement in the gel structure caused by pozzalanic action of fly ash leads to a very impervious cement paste and partial replacement of cement with fly ash is very energy efficient and economical, 20% fly ash by weight of cement has been used as an additive in order to achieve higher ultimate strength to mortars under study.

This paper presents the mechanical resistance and capillary sorptivity of 18 design mixes of Glass Fiber Reinforced Self Compacting Mortars (GFRSCM), consisting of different types and sizes of aggregate selected from various trial mixes. The mortars were developed with NS, crushed stone fine aggregate (CSFA), and foundry sand (FS) to fill the information gap in the literature. Also, use of CSFA and FS is one step forward to meet the demand for a sustainable concrete.

EXPERIMENTAL PROGRAM

Materials

53-grade Ordinary Portland cement with specificgravity3.15, normal consistency 34%, fineness 6%, initial and final setting times 45 and 175 min confirming to IS: 12269-1987,[14] was used in the study. Locally available river sand (NS) conforming to Zone-2 as per IS: 383-1970,[15] CSFA, and FS was used as fine aggregate. A high range water reducing new generation admixture, STRUCTRO 201, based on modified polycarboxylic ether and STRUCTRO-480, a Viscosity Modifying Admixture (VMA), were used to achieve the desired workability, as per EFNARC specifications,[16] in mortar mixtures reducing the tendency of segregation of highly fluid mix. Fly ash obtained from VTPS, Vijayawada, India was used as a supplementary cementitious material. Glass fibers of Cem-Fil glass with 1700 MPa tensile strength and 72 GPa modulus of elasticity was used in the study. Potable water was used for both mixing and curing in this investigation. Physical properties of NS, CSS, and FS are given in Table 1.

Table 1. *Physical Properties of Fine Aggregates (NS, CSFA, and FS).*

Property	Value		
	NS	CSFA	FS
Specific gravity	2.54	2.74	2.68
Fineness modulus	2.85	2.28	2.45
Porosity (%)	45.5	45.8	47.8
Voids ratio	0.75	0.84	0.88
Moisture content (%)	1.0	1.0	1.0
Water absorption (%)	1.0	1.0	2.0
Bulk density (kg/m^3)	1278	1345	1254
Air voids (%)	48	45	50

Mix Proportions

A total of 18 mortar mixtures were selected from trials conducted on several mortars with various mix proportions. Of these 18 mixes, nine each correspond to 1:1/0.4 w/c and 1:2/0.4 w/c ratio. The other variables include three types of fine aggregate (NS, CSFA, and FS) and three sizes of fine aggregates (4.75, 2.36, and 1.18 mm down). All these mixes satisfied the fresh properties as per EFNARC specifications. The optimum dosage of fly ash was 20% and the glass fiber content of 0.034% by weight of cement was used. Table 2 shows the details of the final mix proportions. The mortar mixtures thus developed are hence forth termed as GFRSCM.

Table 2. *Mix Proportions and Fresh State Properties of GRFSCM.*

Mix	Powder content (kg)		Fine aggregate (kg)	Glass fiber (gm)	W/C ratio	Water content (lts)	SP (lts)	VMA (lts)	Slump flow (mm)	V-funnel time (sec)
	Cement	Fly ash								
GS1	909.4	181.9	909.36	1546	0.4	436.5	9.09	0	260	9
GS2	606.3	121.3	1212.6	1546	0.4	291.0	10.61	0	260	10
GS3	909.4	181.9	909.36	1546	0.4	436.5	13.64	0	255	9
GS4	606.3	121.3	1212.6	1546	0.4	291.0	18.19	0	250	10
GS5	909.4	181.9	909.36	1546	0.4	436.5	9.09	0	250	10
GS6	606.3	121.3	1212.6	1546	0.4	291.0	24.25	0	252	9
GC1	909.4	181.9	909.36	1546	0.4	436.5	9.09	0	260	11
GC2	606.3	121.3	1212.6	1546	0.4	291.0	60.63	30.3	255	12
GC3	909.4	181.9	909.36	1546	0.4	436.5	13.64	0	260	9
GC4	606.3	121.3	1212.6	1546	0.4	291.0	51.53	24.3	260	10
GC5	909.4	181.9	909.36	1546	0.4	436.5	13.64	0	265	9
GC6	606.3	121.3	1212.6	1546	0.4	291.0	66.66	36.4	250	11
GF1	909.4	181.9	909.36	1546	0.4	436.5	13.64	0	255	11
GF2	606.3	121.3	1212.6	1546	0.4	291.0	90.94	36.4	255	10
GF3	909.4	181.9	909.36	1546	0.4	436.5	9.09	0	260	9
GF4	606.3	121.3	1212.6	1546	0.4	291.0	97.00	36.4	250	10
GF5	909.4	181.9	909.36	1546	0.4	436.5	13.64	0	255	10
GF6	606.3	121.3	1212.6	1546	0.4	291.0	121.26	60.6	250	11

Mixing, Casting, and Curing

After achieving the required fresh properties, to inspect the hardened properties 216 test specimens including 162 cubes and 54 prisms with two mortar proportions of 1:1 and 1:2 with 0.4 w/c ratio. The entire casting was carried out in 9 batches, at the rate of three batches for each type of fine aggregate i.e. NS, CSFA, and FS used. Glass fiber reinforced self-compacting mortar specimens were cast using NS, CSFA, and with three different particle sizes of 4.75, 2.36, and 1.18 mm down. After the completion of casting all the GFRSCM specimens were kept at ambient conditions, viz. temperature of 27 ± 2 °C and 90% relative humidity for 24 hours. The specimens were removed from the molds and submerged in clean fresh water for 28 days of wet curing.

Test Methods

Fresh state properties: The fresh state properties were evaluated using mini-slump cone and mini V-funnel tests as per EFNARC specifications.[16]

Hardened State Properties

The hardened concrete cubes and prisms are tested in direct compression, split tension and flexure to determine the related mechanical properties as per IS 516[17] and IS 5816[18] while sorptivity test is conducted to determine the permeability of mortars.

Sorptivity

Sorptivity, an index of moisture transport into unsaturated specimens, has been recognized as an important indicator of mortar durability, as the test method employed for its determination reflects the manner that most mortars will be penetrated by water and other injurious agents. This test evaluates the sorptivity by capillary water absorption of the tested mixtures. The sorptivity test[19] was conducted on cube specimens of size 100 × 100 × 100 mm, after 28 days of conventional wet curing. The sorptivity was determined by the measurement of capillary rise absorption rate and water was used as the test fluid. The quantity of absorbed fluid in a time period of 1, 3, 6, 12, 24, 48, and 72 hours was measured by weighing the specimen before and after the test. Sorptivity value is calculated using the following formula

Sorptivity $s = I/t^{1/2}$ Eq. (1)

where *s* is sorptivity in mm/√ (min); *t* the elapsed time in min; and *I* =Δ*W/Ad*; Δ*W* the increase in weight; *A* the surface area of specimen through which water penetrates; and *d* is the density of water.

RESULTS AND DISCUSSION

The results of the hardened properties and sorptivity of different GFRSCM mixes with varying type and size of fine aggregate are presented in Tables 3 and 4.

Table 3. *Mechanical Properties of GFRSCM Mixes.*

Design of the mortar mix	Mix proportion	MSA (mm)	Fly ash content (%)	28 day-strength (MPa)		
				Compressive	Split tensile	Flexural
GS1	1:1	–4.75	20	58.56	3.85	6.67
GS2	1:2	–4.75	20	39.50	2.34	6.35
GS3	1:1	–2.36	20	55.50	3.24	6.47
GS4	1:2	–2.36	20	38.25	2.24	5.68
GS5	1:1	–1.18	20	33.50	3.21	4.90
GS6	1:2	–1.18	20	22.80	1.99	4.51
GC1	1:1	–4.75	20	58.25	3.33	6.27
GC2	1:2	–4.75	20	38.50	2.18	6.00
GC3	1:1	–2.36	20	35.95	2.31	5.88
GC4	1:2	–2.36	20	26.75	1.90	5.10
GC5	1:1	–1.18	20	28.30	2.15	5.68
GC6	1:2	–1.18	20	21.50	1.78	4.70
GF1	1:1	–4.75	20	43.75	2.76	6.10
GF2	1:2	–4.75	20	38.25	1.92	5.10
GF3	1:1	–2.36	20	40.75	2.37	5.88
GF4	1:2	–2.36	20	23.25	1.54	3.92
GF5	1:1	–1.18	20	27.25	2.02	4.50
GF6	1:2	–1.18	20	19.50	1.34	3.53

Table 4. *Sorptivity of GFRSCM Mixes.*

Sl. no	Mix designation	MSA (mm)	Sorptivity of SCRMs (mm/√min)						
			1 hour	3 hours	6 hours	12 hours	24 hours	48 hours	72 hours
1	GS1(1:1)	–4.75	0.0129	0.0149	0.0105	0.0074	0.0052	0.0037	0.0030
2	GS2(1:2)	–4.75	0.0258	0.0149	0.0105	0.0074	0.0052	0.0037	0.0030
3	GS3(1:1)	–2.36	0.0129	0.0149	0.0105	0.0074	0.0052	0.0037	0.0030
4	GS4(1:2)	–2.36	0.0258	0.0149	0.0105	0.0074	0.0052	0.0037	0.0030
5	GS5(1:1)	–1.18	0.0387	0.0223	0.0158	0.0111	0.0105	0.0074	0.0060
6	GS6(1:2)	–1.18	0.0516	0.0298	0.0210	0.0149	0.0105	0.0074	0.0060
7	GC1(1:1)	–4.75	0.0258	0.0149	0.0105	0.0074	0.0052	0.0037	0.0030
8	GC2(1:2)	–4.75	0.0387	0.0223	0.0158	0.0111	0.0105	0.0074	0.0060
9	GC3(1:1)	–2.36	0.0129	0.0074	0.0052	0.0037	0.0026	0.0018	0.0015
10	GC4(1:2)	–2.36	0.0387	0.0298	0.0210	0.0149	0.0105	0.0074	0.0060
11	GC5(1:1)	–1.18	0.0129	0.0149	0.0105	0.0074	0.0052	0.0037	0.0030
12	GC6(1:2)	–1.18	0.0516	0.0372	0.0263	0.0186	0.0184	0.0130	0.0106
13	GF1(1:1)	–4.75	0.0258	0.0149	0.0105	0.0074	0.0052	0.0037	0.0030
14	GF2(1:2)	–4.75	0.0774	0.0447	0.0316	0.0223	0.0184	0.0149	0.0136
15	GF3(1:1)	–2.36	0.0258	0.0149	0.0105	0.0074	0.0052	0.0037	0.0030
16	GF4(1:2)	–2.36	0.0774	0.0521	0.0421	0.0335	0.0263	0.0204	0.0167
17	GF5(1:1)	–1.18	0.0129	0.0149	0.0105	0.0074	0.0052	0.0037	0.0030
18	GF6(1:2)	–1.18	0.0258	0.0149	0.0105	0.0074	0.0052	0.0037	0.0030

Workability of Glass Fiber Reinforced Self-Compacting Mortars

Table 3 shows the details of the mix proportions for two mortar mixes 1:1/0.4 w/c and 1:2/0.4 w/c and optimum Glass Fiber dosage i.e., 0.034% by weight of cement. The size of aggregates and type of aggregates was the parameters of investigation. It can be noted that the mini slump and V-funnel values were satisfied. It can also be observed from Table 2 that there is a decrease with decreasing size of fine aggregate. The range of spread of mini-slump cone and mini V-funnel test values have been 252–260, 250–265, and 250–260 mm and 9–10, 9–12, and 9–11 seconds, respectively, for GFRSCMs with NS, CSFA, and FS. The smaller the particle size, less is the chance of obtaining highly workable mortar due to less paste content necessitating use of admixture for obtaining the required workability.

Effect of Size and Type of Fine Aggregate on Compressive Strength

Figure 1 depicts the variation of compressive strength of GFRSCMs of proportions1:1 and 1:2 with w/c=0.4. There is a decrease in compressive strength of GFRSCMs with decrease in the size of aggregate due to lower paste content. This suggests that for better mechanical properties it is important to have all the aggregate proportions. For identical mix proportions NS based mortars gave higher strengths followed by these are the mortars with CSFA and FS. This shows the superiority of NS, however, all the other mixes with CSFA and FS could also satisfy the strength properties.

The highest compressive strengths of 58.65 and 39.5 MPa are obtained for 1:1 and 1:2 mortars containing NS of 4.75 mm down size, among all the mortars studied. GFRSCMs of 1:1 proportion, containing NS of 4.75, 2.36, and 1.18 mm down sizes, recorded compressive strengths that are 0.7 and 25.4%, 35.22 and 26.57%, and 13.59 and 16.79% higher than those of corresponding mortars containing CSFA and FS as fine aggregates. Similarly, the corresponding values in respect of GFRSCM of 1:2 proportions have been, respectively, 2.53 and 3.16%, 30 and 39%, and 5.7 and 14.47% more than those of mortars with CS and FS as fine aggregates.

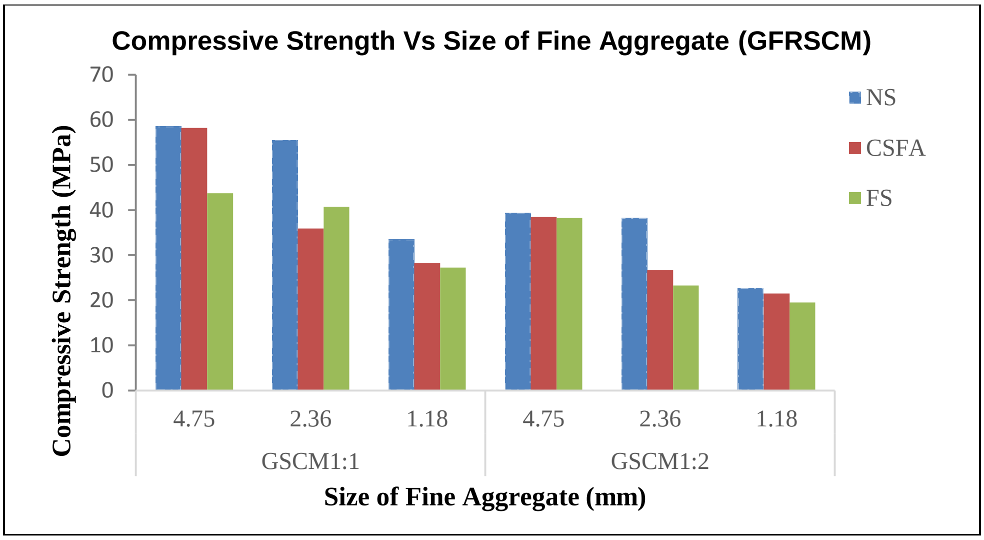

Fig. 1. *Compressive Strength versus Size of Aggregate.*

Influence of Size and Type of Aggregate on Split Tensile Strength

Figure 2 shows the variation of Split Tensile Strength with maximum size of fine aggregate used in GFRSCMs of 1:1 and 1:2 proportions. A decrease is observed in split tensile strength of GFRSCMs with decrease in the size of aggregate. The highest split tensile strengths of 3.85 and 2.34 MPa are obtained for 1:1 and 1:2 with 0.4 w/c ratio, containing NS of 4.75 mm down size, among all the mortars studied. GFRSCMs of 1:1 proportion, containing NS of 4.75, 2.36, and 1.18 mm down sizes, measured the split tensile strengths, respectively, 13.5 and 28.3%, 28.7 and 26.85%, and 33% and 37% higher than those of corresponding mortars containing CSFA and FS as fine aggregates. Similarly, the corresponding values of GFRSCMs of 1:2 with 0.4 w/c ratio proportion have been, respectively, 6.83 and 17.94%, 15.17 and 31.25%, and 10.55 and 32.66% more than the mortars with CSFA and FS as fine aggregates.

Flexural Strength of Glass Fiber Reinforced Self-Compacting Mortars

Figure 3 presents the variation of Flexural Strength with the maximum size of fine aggregate used in the making of GFRSCMs of 1:1 and 1:2 with 0.4 w/c proportions. There has been a decrease in the flexural Strength of GFRSCMs with decreasing size of fine aggregate. The higher values of flexural strengths of 6.67 and 6.27 MPa are obtained for 1:1 and 1:2 containing NS of 4.75 mm down size. GFRSCMs of 1:1 proportion, containing NS of 4.75, 2.36, 1.18 mm down sizes, measured the flexural strengths that are, respectively, 6 and 8.55%, 9.12 and 9.12%, and 13.6 and 10% higher than those of corresponding mortars containing CSFA and FS as fine aggregates. On the other hand, the corresponding values for GFRSCMs of 1:2 proportions have been, respectively, 6.83 and 17.94%, 15.17 and 31.25%, and 10.55 and 32.66% more than the mortars containing CSFA and FS as fine aggregates.

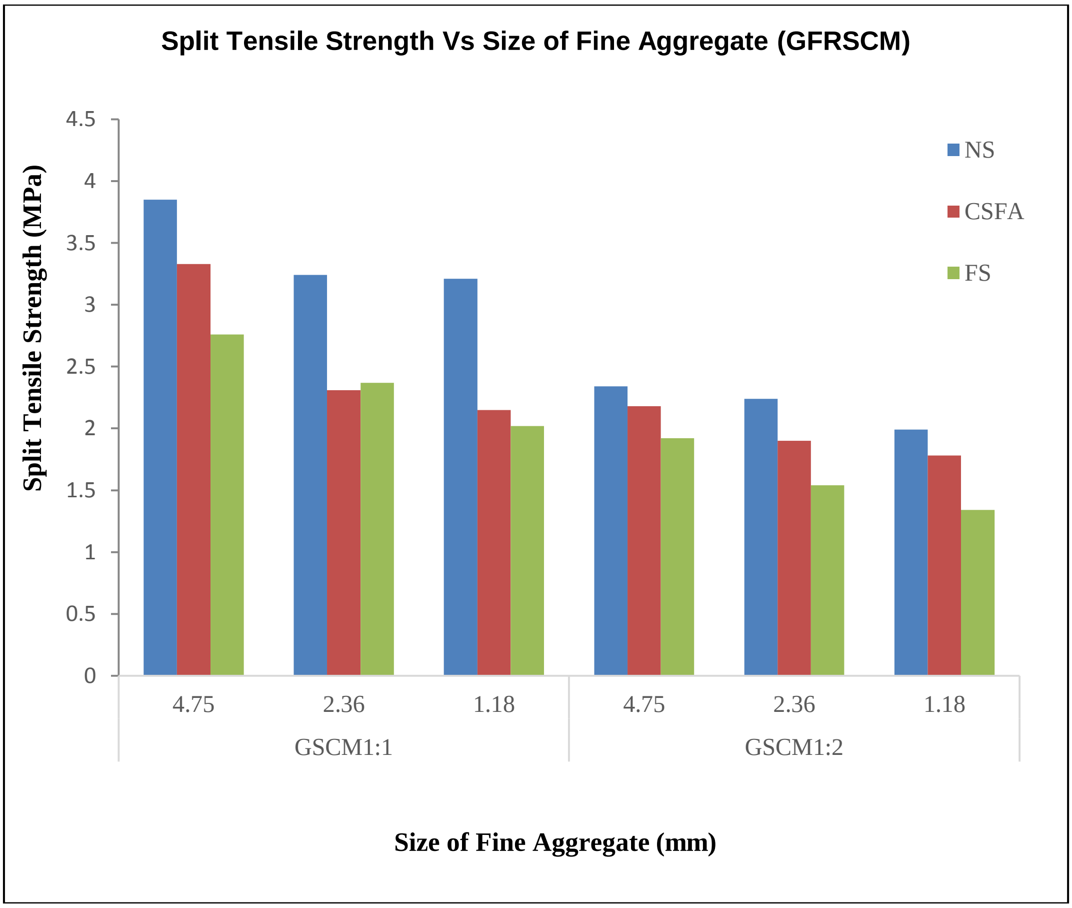

Fig. 2. *Split Tensile Strength Versus Size of Fine Aggregate.*

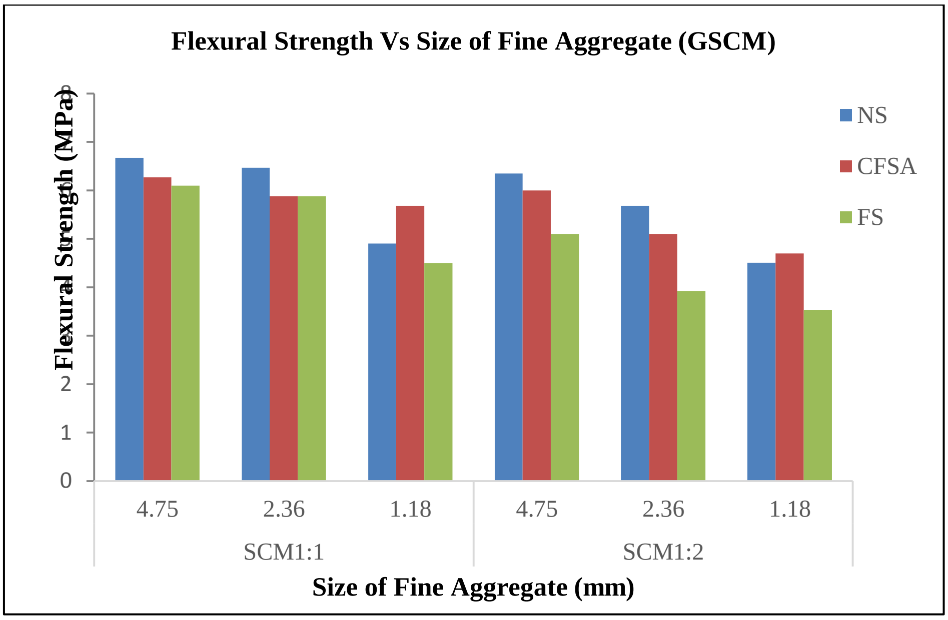

Fig. 3. *Flexural Strength Versus Size of Fine Aggregate.*

SORPTIVITY OF GLASS FIBER REINFORCED SELF-COMPACTING MORTARS

Table 4 represents the variation of sorptivity of GFSCMs with time for three different types of aggregates (FS, CSFA, and FS) and three sizes (4.75, 2.36, and 1.18 mm down) of fine aggregate considered in this study. Test results have shown that sorptivity increases with decrease in the size of aggregate and decreases with increase in the immersion period and richness of the mix as well. In GFSCMs of 1:1 and 1:2 proportions, using NS, CSFA, and FS of 4.75, 2.36, and 1.18 mm down sizes, it can be observed that FS has higher sorptivity compared to those of mortars with CSFA and NS. Mortar with NS has lesser sorptivity compared to those of mortars with CSFA and FS. Sorptivity values are higher for 1:2 mortar mixes with different types of fine aggregates. The sorptivity value is higher for mortar of 1.18 mm size of aggregate in comparison to those of 2.36 and 4.75 mm maximum size of aggregates.

CONCLUSIONS

In the present study two SCM mixes with 1:1/0.4 and 1:2/0.4 w/c ratios, three types of aggregates (NS, CSFA, and FS) and three sizes of aggregates (4.75, 2.36, and 1.18 mm down) were considered. The following are the broad conclusions from the study.

1. Use of alternate fine aggregates as CSFA can address the demand for rapid depletion of NS and hence can contribute to sustainability. GFRSCM are very useful for repair and retrofitting works.
2. Workability of such mortars decreased with decrease in maximum size of fine aggregate and resulted in consumption of higher dosage of admixtures to maintain the fluidity.
3. Compressive, tensile and flexural strengths of GFSCMs decreased with decrease in size of fine aggregate. GFRSCM's with 4.75 mm down aggregate yielded maximum strength with NS. This is true with CSFA and FS as well.
4. The GFSCM's with NS resulted in superior compressive strength followed by mortars of CSFA and FS with 4.75 mm down size for 1:1 and 1:2 mortar mixes.
5. Sorptivity of mortars increased with decrease in the size of aggregate. Sorptivity of GFRSCM with 1.18 mm down size of aggregate has been high

compared to those with 4.75 and 2.36 mm sizes of aggregates. Although mortars with NS exhibited more imperviousness than those with CSFA and FS, these mortars were also better.
6. GFRSCM's of 1:1 proportion exhibited better performance in respect of strength and sorptivity characteristics as well.

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