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Technical Note

MECHANICAL CHARACTERISTICS OF FIBER REINFORCED SELF COMPACTING MORTARS

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Abstract

In modern day construction practice, repair and rehabilitation of structures has taken a prominent role. Mortar plays a vital part in these works. As such, the flowability of mortar can be an added advantage when inaccessibility comes into picture like in case of congested reinforcement or narrow cracks or fissures. Due to the application easiness and mechanical advantages, Self Compacting Mortar is preferred for repair purposes especially in reinforced concrete structures these days. The cement as well as the ingredients of the paste, mineral admixtures (pozzolanic or inert nature) and plasticizing chemical admixtures should be carefully chosen in order to obtain a suitable paste composition to enrich the granular composition of the mix. There is no universally accepted agreement on the effect of these factors due to the complexity of combined action; thus, it is hard to make a generalization. The objective of the study is to evaluate the effect of fiber and mesh in Self Compacting Mortar from the viewpoint of fresh state behaviour and mechanical performance. For this purpose two fibers (Polypropylene and Glass fiber) and two types of mesh (Chicken mesh and G.I. wire mesh) were used. The results of 54 panels, 54 cubes and 54 cylinders for flexure, compressive strength and split tensile strength are presented.

Keywords: Self-compacting mortar; mechanical characteristics; fiber reinforced

1. Introduction

Mortar serves as one of the basis for the workability properties of self-compacting concrete (SCC) and these properties could be assessed by Self Compacting Mortars (SCM). In fact, assessing the properties of SCM is an integral part of SCC design. As a new technology product, SCMs are especially preferred for the rehabilitation and repair of reinforced concrete structures. The repair mortar applied to concrete is usually hard to consolidate, and in most cases vibration is not possible. From this point of view, the self compactability of repair mortars may bring considerable advantages at narrow mould systems such as coating.

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With the development of new generation plasticizers, it is possible to obtain high filling rates even for complex mould systems. Self Compacting Mortar [1] is a relatively new area of research. Fly ash and limestone powder significantly increase the workability of SCM's. Smooth surface characteristics and spherical shape of the fly ash is important to improve the workability characteristics of SCM mixtures. Fly ash increases the setting time of the mortars the most, due to a spherical geometry and a coarse particle size, causing a reduction in the surface area to adsorb free water. Mixes incorporating fly ash give higher strength values than the control mixtures beyond 28 days due to the pozzolanic effect of fly ash [2]. A paste made with any particular powder, the relative flow area and the water powder ratio by volume are linearly related [3]. The objective of this study is to evaluate the effect of fiber, mesh reinforcement and aggregate composition on the mechanical characteristics of SCM.

The optimal volume content of sand in the mortar varies between 40–50 % depending on paste properties. Target values are slump flow of 24 to 26 cm and V-Funnel time of 7 to 11 seconds. As per EFNARC guidelines [4], the dimensions of the test apparatus for finding the fresh state properties (slump flow and V-funnel time) is shown in Figures 1(a) and 1(b).

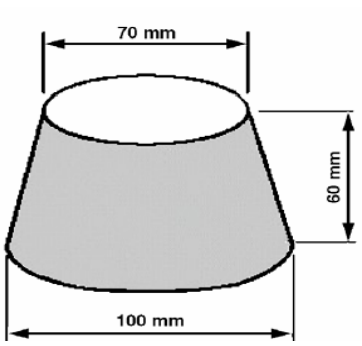


Figure. 1(a) Mini slump

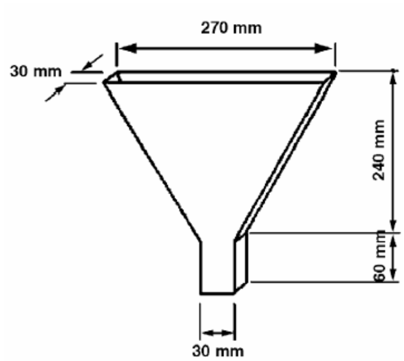


Figure. 1(b) Mini V-funnel

2. Experimental Program

The experimental program consisted of casting and testing 54 panels (500×150×25mm), 54 cubes (100×100mm) and 54 cylinders (100 mm diameter and 200 mm height). Workability of the fresh mortar was determined using mini V-funnel and mini slump flow tests[5]. Fly ash significantly increased the workability of SCMs when used as a replacement for about 33%. In the present study, the Self Compacting Mortars (SCM) were developed using Natural (NA) and Recycled-Natural aggregate (RN) and was checked for the mechanical characteristics in the presence/absence of fibers. The parameters in the study include the type of aggregate (Natural and Recycled-Natural sand), type of fiber (No fiber, Polypropylene and Glass fiber) and type of mesh (No mesh, Chicken mesh and G.I. wire mesh). In the present investigation Recycled–Natural (RN) sand represents fine aggregate having a composition of 50% Natural sand and 50% Recycled sand.

2.1 Materials

(a) Cement: Ordinary Portland cement of 53 grade confirming to IS: 12269 (1987) [5] was used. The specific gravity, standard consistency and the initial setting time of the cement were 2.9, 32% and 76 minutes, respectively.

(b) Fine Aggregate (Natural sand): The fine aggregate was procured from a nearby river source. The sand was confirming to IS: 383-1970 [6]. In the present investigation, sand confirming to Zone II was used. Tests were conducted on the sand used. The details of the physical properties of Natural and Recycled sand are shown in Table 1.

Table 1. Physical properties of NA and RA

Property	Natural Aggregate	Recycled Aggregate
Fineness Modulus	2.723	2.808
Bulk Density	1.274	1.274
% Air Voids	50%	48%
Voids Ratio	0.87	0.90
Specific Gravity	2.55	2.29
Water Absorption	1%	8.75%

(c) Fly ash: The fly ash used in this investigation was obtained from a nearby source. The reactive silica available was about 88-90%.

(d) Fiber: Two types of fibers were used in the present investigation, (Polypropylene and Glass).

(i)Glass fiber: Specific gravity is 2.6; length of the fiber is close to 12 mm, aspect ratio 857:1, and Specific surface area is105m^2 /kg.

(ii)Polypropylene: Length of the fiber is close to 12 mm, melting point is greater than 250^{o}C. The details of both Polypropylene and Glass fiber are shown in Table 2.

Table 2. Details of Polypropylene and Glass Fibers

Fiber	Density (kg/m^3)	Elastic modulus (GPa)	Tensile strength (MPa)	No. of fibers (Million/kg)
Mortar	2000	25-35	0-5	0
Polypropylene fiber	900	3.5-5	400-600	15
Glass fiber	2600	73	1700	220

(e) Mesh: Two types of mesh were used namely Chicken mesh and G.I. wire mesh. Both the meshes were having strength of 250 MPa. The diameter of G.I. wire was 0.72 mm and the spacing between the wires is about 6.35mm. The diameter of the Chicken mesh was about 0.1 mm.

(f) Water: Potable water was used in the experimental work for both mixing and curing**.**

(g) Superplasticizer: High range water reducing admixture confirming to ASTM C 94 [7] commonly called as Superplasticizer is used for improving the flow or workability for decreased water-cement ratio without sacrifice in the compressive strength. These admixtures when they disperse in cement agglomerates significantly decrease a viscosity of the paste by forming a thin film around the cement particles.

2.2 Evaluation of mix proportions

Since there is no proper design procedure is available for SCM, the final mix proportions were designed based on the trial and error method in which various proportions of fly ash and superplasticizer have been tried to arrive at the mix giving the appropriate workability which meets the self compacting standards. The final design mix was adopted for both the mixes with and without the presence of fibers and is as given below:

Cement: sand = 1:3 Powder: sand = 1:2, % fly ash replacement = 33% of powder, w/c ratio = 0.595, w/p ratio = 0.41, Superplasticizer dosage (for natural sand mix) = 25 ml/kg of powder; Superplasticizer dosage (for Recycled-Natural sand mixture) =30 ml/kg of powder; Fiber dosage = 60g/50kg of cement; The ingredients considered per m^3 of mortar are worked out as shown in the Table 3.

Table 3. Proportion of Self Compacting Mortars per m^3

Cement (kg)	Fly ash (kg)	Powder (kg)	Sand (kg)	Water (liters)	Superplasticizer (liters)		Fiber (gms)
					Natural sand	Recycled-natural sand mixture	
454.55	204.55	659.10	1363.63	270.23	16.48	19.77	545.45

2.3 Preparation and casting

A standard mixer of rotating drum type of half bag capacity was used for mixing the mortar. To begin with, all the dry materials (Fine aggregate, Cement and Fly ash) were mixed for about two minutes. Superplasticizer was thoroughly mixed with water and the liquid component was added to the dry material mixture. This wet composition was allowed to mix for another four minutes. During the process, fiber was sprinkled uniformly in the wet mixture. Care has been taken in allowing all the materials to get mixed up uniformly and avoiding the materials to get stuck up to the walls of the mixer. After the mixing was completed, tests were conducted on fresh mortar to determine setting time, mini slump flow diameter and mini V-funnel flow time. Segregation and bleeding were visually checked during the slump flow test and was not observed. The fresh properties of the Self Compacting Mortar which were found out include wet density; Mini Slump and Mini V-Funnel time. These are shown in Table 4.

Table 4. Fresh properties of SCM

Mix	Wet Density (kg/m^3)	Mini Slump (mm)	EFNARC Specifications[3]	Mini V-funnel (sec)	EFNARC Specifications[3]
NAW	2607	255	Between 240mm to 260 mm	3.0	Less than 11 seconds
NAP	2460	253		3.6	
NAG	2363	250		4.0	
RNW	2367	253		5.7	
RNP	2300	250		7.3	
RNG	2340	245		6.7	

Note: NA-Natural Aggregate, RN-50% Recycled and 50% Natural sand, W- With out Fiber P-Polypropylene fiber, G- Glass fiber

The standards wooden moulds were fitted such that there are no gaps between the plates of the moulds. If there are small gaps they were filled with plaster of Paris. The wet mortar was directly poured into the panel moulds as shown in Figure 3(a) and the mesh was kept after filling the mould up to a level of 20 mm from the bottom surface leaving 5 mm for cover as shown in Figure 3(b). Then the mortar was filled up to the brim level. Along with the panels companion cubes and cylinders were also cast. At the end of casting the top surface was made plane using trowel and a hacksaw blade to ensure a top uniform surface.

Figure 3(a). Placing of mortar into moulds

Figure 3(b). Placing of mesh

2.5 Testing

2.5.1 Compressive Strength

The cube specimens of SCM were tested on compression testing machine of capacity 200 tones under strain control mode. The maximum load applied on the specimens was recorded. The detail of a cube specimen under test is shown in Figure 4.

2.5.2 Split Tensile Strength

The axis of the specimen was carefully aligned with center of the loading frames of the 200 ton Tinius Olsen Testing Machine. The load was applied and increased continuously till the specimen breaks. The maximum load was recorded. The details of a cylinder tested for split tensile strength is shown in Figure 5.

2.5.3 Flexural Tensile Strength

The flexural strength of the SCM specimen is expressed as the modulus of the rupture. The method used in testing is third point loading. The test specimen should be placed in such a way that the mesh reinforcement which was placed in the top surface during casting should be at the bottom to care of the tensile stresses. Then the panel should be centered on bearing blades. The load applying blades shall be brought in contact with the upper surface at the third points between the supports. The strength in the bearing is the extreme fiber stress on the tensile side at the point of the failure. The details of a specimen tested for flexural strength is shown in Figure 6. The test was carried as per ASTM C 947-03 [8].

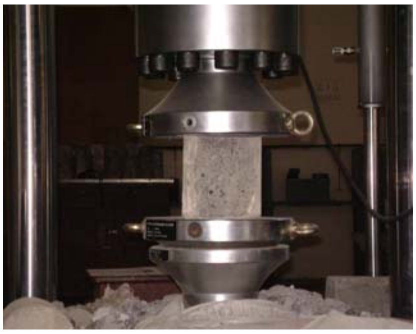


Figure 4. Compressive strength test of cube

Figure 5. Split tensile strength test of a cylinder

Figure 6. Flexural strength test setup

3. Results and Discussion

3.1 Compressive strength

Figure 7 shows the plot of the average compressive strength of Self Compacting Mortar (SCM) with Normal and with RN sand and with and without Polypropylene / Glass fiber. It can be noted from the plot that there is a marginal increase in the compressive strength with fiber addition in mortars. The percentage increase in fibrous Natural aggregate (sand) specimens is 3.52% and 7.96% respectively in Polypropylene Fiber (PPF) and Glass Fiber (GF). The trend is same in RN (sand) specimens with respect to fiber additions. In general all the RN aggregate (sand) specimens yielded low compressive strength values as compared to pure Natural sand specimens. The increase in Compressive Strength in fibrous RN aggregate (sand) specimens was 9.87% and 15.8% in PPF and GF respectively. It is clear that the role of fibers (both Polypropylene and Glass) seems to be more effective in RN sand SCM's as compared to NA sand SCM's.

3.2 Split tensile strength

Fig.8 shows the plot of the average split tensile strength of Self Compacting Mortars with Normal and with RN sand and or with and without polypropylene / Glass fiber. It can be noted from the plots that there is an increase in the split tensile strength with the addition of fibers in both the specimens cast in the Natural sand as well as with 50-50% RN sand. The percentage increase in Polypropylene Normal sand SCM is 3.83 % while that with Glass fiber is 5.23%. In case of RN sand specimens in general the values are lower than Normal sand specimens both without and with fiber. But it is to be noted that the percentage increase in Split Tensile Strengths in Polypropylene and Glass fibrous SCM developed using RN sand are 6% and 14.2% respectively. From this it is evident that the effect of fibers in Recycled sand SCM's is more as compared to Natural sand SCM's.

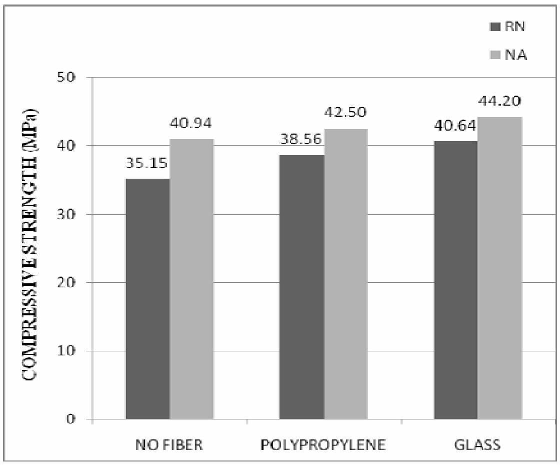


Figure 7. Compressive strength of SCM

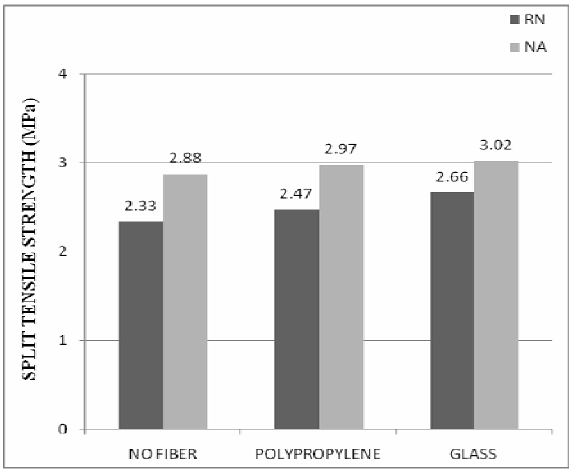


Figure 8. Split Tensile strength of SCM

3.3 Flexural strength

In order to determine the flexure strength of the Normal and RN aggregate Self Compacting Mortars, standard panels of dimensions 500 × 150 × 25 mm confirming to ASTM C947-03 [8] were prepared and tested using a loading frame set up and the deflections were recorded using dial gauge of 0.01 least count. The load-deflection curves are plotted for Plain, Chicken and G.I. wire mesh specimens as shown in Figures 9 (a), (b) and (c) respectively for Natural aggregate and Figures 10 (a), (b) and (c) respectively for RN aggregate.

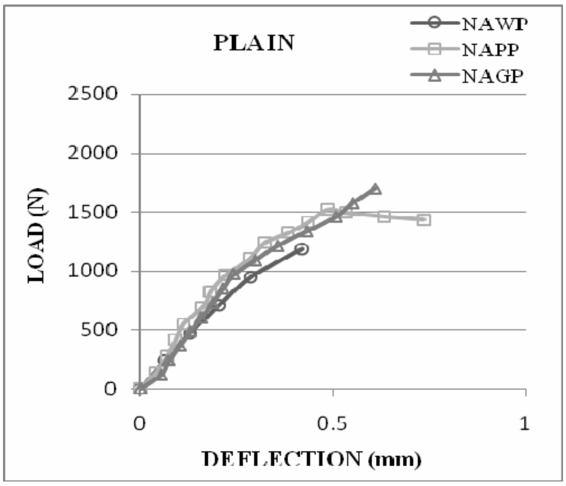


Figure 9(a). NA sand specimens without mesh

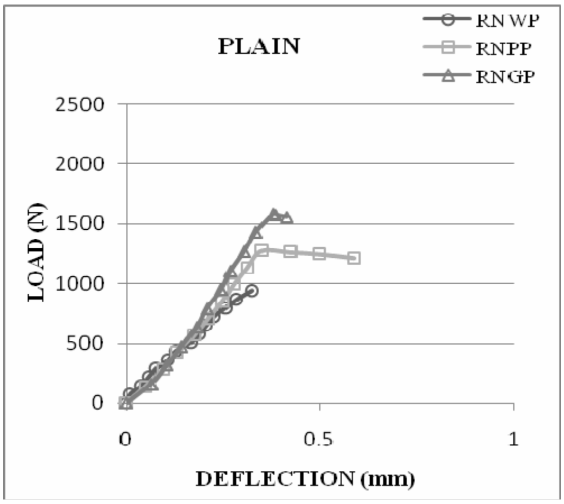


Figure 10(a). RN sand specimens without mesh

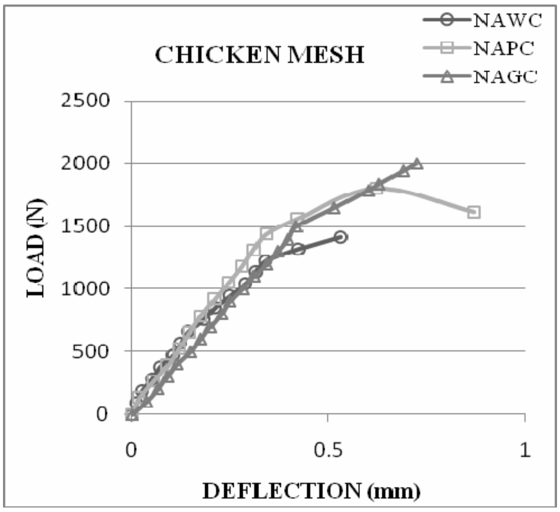


Figure 9(b). NA sand specimens with chicken mesh

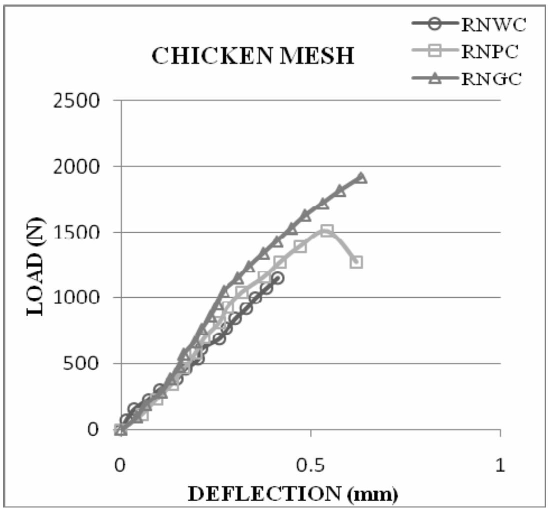


Figure 10(b). RN sand specimens with chicken mesh

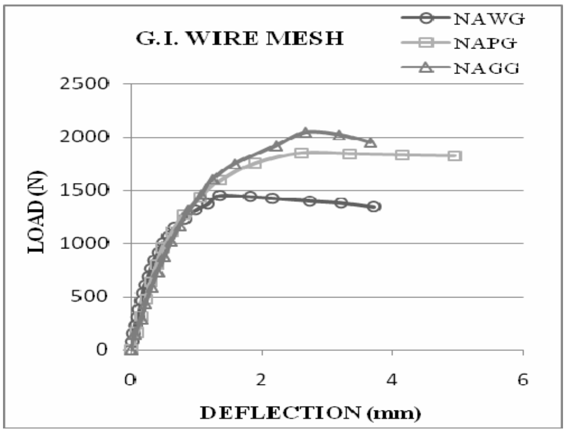


Figure 9(c). NA sand specimens with G.I. wire mesh

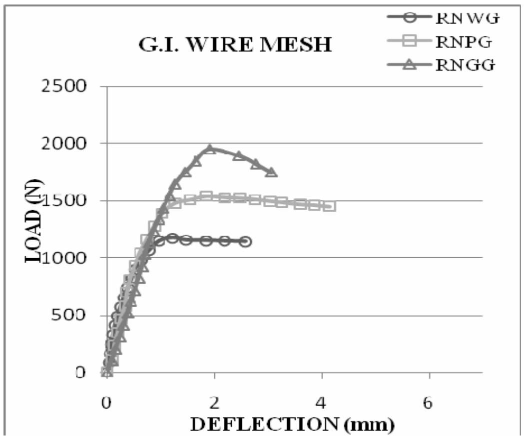
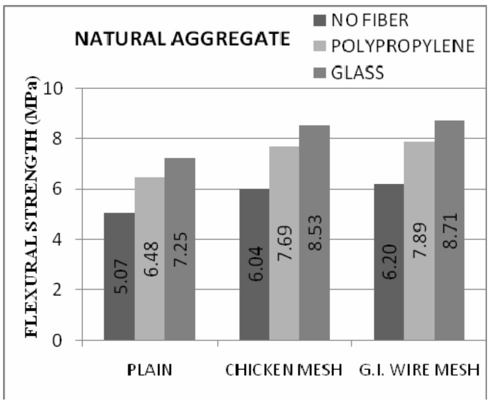


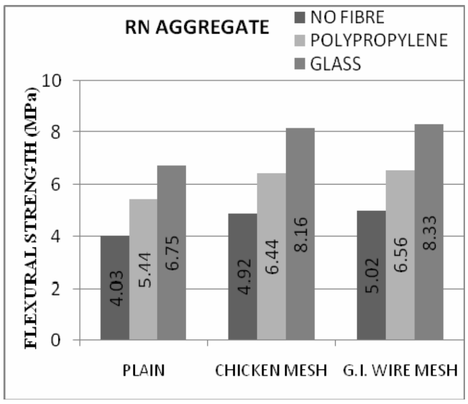
Figure 10(c). RN sand specimens with G.I. wire mesh

The peak values of the load-deflection curves are taken and the flexural strength has been estimated based on the formula given in ASTM C947-03[8]. The flexural strength values for estimating the effect of fiber and the effect of mesh are shown in Figure 11 and Figure 12. It can be noted from Figure 11(a) in case of SCM made with NA that there is an increase in the flexural strength in both Polypropylene fiber and Glass fiber as compared to no fiber mortar specimens. This increase was also noted in the presence of chicken mesh and G.I. wire mesh in the panels. The increase in flexural strength of panels consisting of G.I. wire mesh is more than that of non fibrous, no mesh panels and also panels with chicken mesh. The percentage increase in flexural strength is more in G.I. wire mesh panels as compared to Chicken mesh panels (Figure 12(a)).

From Table 4 it can be noted that the flexural strength is higher in case of Natural aggregate panels, also the deflections at ultimate loads are also more as compared to Recycled– Natural aggregate panels indicating the higher ductility of the Natural aggregate SCM.

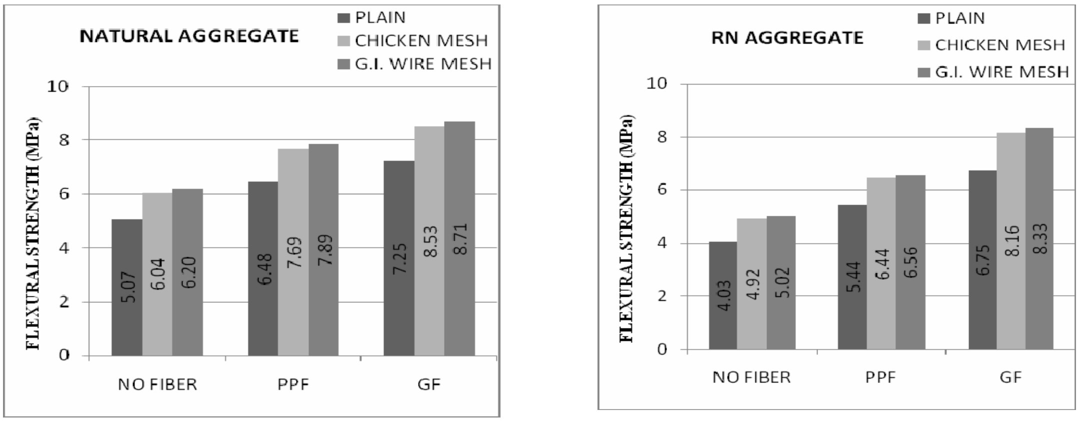


(a)



(b)

Figure 11. Effect of fiber on flexural strength (a) Natural aggregate (b) RN aggregate



(a) (b)

Figure 12. Effect of mesh on flexural strength (a) Natural aggregate (b) RN aggregate

4. Conclusions

The following are the conclusions obtained from the mechanical studies on fiber reinforced SCM.

1. The compressive strength, split tensile and flexural strength of Natural Aggregate SCM is greater than Recycled–Natural aggregate SCM irrespective of fiber addition/mesh reinforcement.
2. There was no considerable change in compressive strength with optimum fiber addition but addition of fiber is effective in split tensile and flexural strength, with Glass fiber giving higher strength than Polypropylene fibers.
3. Natural Aggregate SCM exhibited higher ductility corresponding to Recycled-Natural SCM.
4. The post peak strains are more for polypropylene based specimens as compared to Glass fiber based specimens, but they carried lower flexural strength. This was observed to be the same in natural and recycled aggregate specimens and with chicken and GI wire mesh.
5. Flexural strength of specimens with GI wire reinforcements and Chicken wire reinforcement were on higher side than that of no reinforcement panels. In particular G.I. wire mesh gave higher values of strengths and also exhibited greater ductility.

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