Flexural and Shear Behaviour of RC Beams Using SCC by Partial Replacement of Fine Aggregate with Granite Fines

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Abstract— Global consumption of natural river sand is very high due to the extensive use of concrete. The non-availability of sufficient quantity of ordinary river sand for making concrete structures is affecting the growth of construction industry in many parts of the country. The present work is aimed at developing a concrete using the granite scrap an industrial waste, as a partial replacement for fine aggregate in self-compacting concrete. The percentage of granite fines addition by weight of fine aggregate is in the increment of 5%. The workability tests and hardened concrete tests has been conducted to determine the optimum percentage replacement of fine aggregate (M Sand) with granite fines in SCC. The optimum percentage replacement of fine aggregate by granite fines in SCC was found to be 15%. Behaviour of RC beams was also studied. From the various observations, it can be concluded that granite fines (GF) can be used for the production of structural SCC

Index Terms— Granite fines, Self-Compacting Concrete, Slump flow test, L-box, V-box, U-box, RC beams.

1 INTRODUCTION

HARSH exploitation of natural resources by humans has been harshly criticized in recent years. Every year millions of metric tons of granite waste pile is produced in Borba, and the Vila Vicosa region (the most important Portuguese marble quarrying area), a by-product of the local quarrying industry. Fig. 1 shows enormous waste of granite fines produced 80–90% of the total volume of rock extracted [1].

It has therefore become necessary to create sustainable destinations for the waste material to mitigate. Using waste generated by the granite quarrying industry to produce fine aggregates for production of structural concrete has therefore been studied as a useful alternative from the perspectives of environmental protection and sustainability of natural resources [1].

The granite stone industry generates different types of waste such as solid waste and stone slurry. This stone slurry is collected and processed to produce fine cakes. The compacted granite fine cakes are transported and disposed in landfills. Its water content are drastically reduced approximately 2% and the granite fines resulting from this will have environmental impacts. The factories were used to dispose these granite fines around their own factories. Disposal of these granite fines leads to health hazards like respiratory and allergy problems to the people around. It also decreases the fertility of soil and yield. It also causes Air and Water pollution. Cost of concrete can be reduced through the use of granite fines as an alternative measure to partially replace fine aggregates in SCC with granite fines thus reducing the impacts caused by the fine particles [1].

Self – compacting concrete (SCC) is a fluid mixture, which is suitable for placing concrete at difficult conditions and also in congested reinforcement, without vibration. The necessity of using concrete was proposed by Prof. Okamura in 1986 [2]. The size of dust particles is compatible with the purpose of filling up the transition zone (measuring between 10 to 50 microns) and the capillary pores (which range from 50nm to 10microns of diameter) this acts as micro filler in concrete [1].

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Fig. 1. Granite waste pile

2 Experimental Investigation

2.1 Materials Used

Cement: Portland pozzolana cement (Ultra tech cement) conforming to IS 4031 is used for the study [6], [7], [8].

Fine aggregate: Manufactured sand (MSand) belonging to zone II of IS 383-1970 with a specific gravity of 2.64 is used as fine aggregate throughout the work [9].

Granite fines: Granite fines brought from Benoy Marbles and granites ambalamukku, is used as fine aggregate for partial replacement of Manufactured sand. Tested physical properties are shown in Table 1.

TABLE 1
PROPERTIES OF GRANITE FINES

Properties	Results
Specific gravity	2.556
Fineness modulus	2.55

Coarse aggregate: Well graded crushed ballast stones of maximum size 12.5 mm size were used as coarse aggregate in concrete for the work.

Super plasticizer: Cerahyperplast XR-W40 from ElkemPvt. Ltd. is used as the mineral additive in this study.

Water: Potable water was used in the present investigation for both casting and curing.

TABLE 2
DETAILS OF SPECIMENS CAST

Type of specimen	Mould size	Total no. of specimens
Cubes	150mmX150mmX150mm	63
Cylinders	150mm dia and 300mm ht	18
Prisms	100mmX100mmX500 mm	6
Beams	150mmX100mmX1000mm	12

3MIX PROPORTION

Based on the results of material properties, the mix design was carried out. The SCC design mix calculations were carried out as per the Japanese Method prescribed by Nan Su, et al. which strictly adheres to the EFNARC recommendations [4], [5]. SCC trial mixes were prepared with varying percentages of silica fume, coarse aggregate, manufactured sand as fine aggregate and water to obtain SCC of M50 grade with target strength of 58.25N/mm^2. For each prepared mix, the slump flow tests were carried out and after 28 days of curing, they were tested for target strength for M50 grade concrete. Accordingly, the mix proportion was adopted. Table 3 shows the various notations used for concrete mixes.

TABLE 3
NOTATIONS FOR CONCRETE MIXES

Control mix	Notation
SCC with fine aggregate	NSCC
SCC with 5% FA replacement	GFSCC-5
SCC with 10% FA replacement	GFSCC-10
SCC with 15% FA replacement	GFSCC-15
SCC with 20% FA replacement	GFSCC-20
SCC with 25% FA replacement	GFSCC-25

Table 4 shows the trial mix conducted for finding the control mix (NSCC) in SCC.

4 DETERMINATION OF OPTIMUM REPLACEMENT PERCENTAGE OF GRANITE FINES

As per the mix proportion selected, various SCC mixes were prepared with 5%, 10%, 15%, 20% and 25% partial replacement of manufactured sand with granite fines. From these, the mix that gave slump flow results and adequate cube compressive strength after 28 days of curing was selected as the optimum replacement percentage. Table 5 shows the mix proportion details conducted for finding the optimum percentage replacement of fine aggregate with granite fines.

4.1 Workability Tests

The influence of granite fines on the workability traits of SCC was determined with respect to slump cone test, U-box test, V-funnel test and L-box test. The tests were carried out as per the guidelines prescribed by EFNARC [5].

Based on the slump flow test and cube strength results, with reference to the EFNARC limits and target strength respectively, the mix that produced acceptable slump flow result and target strength was adopted as the optimum granite fine replacement percentage to manufactured sand in SCC.

Table 6 shows the workability properties of NSCC control mix and GFSCC-15 optimum mix found out. All the workability values were within the limit for the NSCC control specimens and GFSCC-15 specimens.

4.2 Evaluation of Mechanical Properties of NSCC and GFSCC-15 Mixes

Various mechanical properties of NSCC and mix containing 15% partial replacement of fine aggregate by granite fines (GFSCC-15) were evaluated. Table 7 shows the mechanical properties of NSCC and GFSCC mixes.

TABLE 7
MECHANICAL PROPERTIES OF NSCC AND GFSCC-15 MIXES

Mix Designation	Cube strength (N/mm^2)	Cylinder strength (N/mm^2)	Split tensile strength (N/mm^2)	Flexural strength (N/mm^2)	Modulus of elasticity (N/mm^2)
NSCC	57.01	47.96	3.96	5.2	$3.87x 10^4$
GFSCC -15	55.96	47.66	3.78	5.1	$3.70x 10^4$

GFSCC-15 specimens shows a slight decrease in all the mechanical properties of concrete as compared to the NSCC specimens.

4.3 Flexural and Shear Behaviour of RC Beams

The effect of granite fines on the flexural strength and shear characteristics of SCC beam specimens was evaluated by conducting two point loading test on beam specimens of size 100mm X 150mm X 1000mm on Universal Testing Machine of 1000kN capacity. Observations were recorded from the LVDTs for every 2.5kN load increments. The detailing of RC beams under flexural and shear behaviour test is asshown in Fig. 2 and Fig. 3. The detailing of beam specimens are done as per IS 456-2000 [10].

TABLE 6
WORKABILITY CHARACTERISTICS OF NSCC AND GFSCC-15 MIXES

Mix Designation	Slump (mm)	T50 cm slump Flow (sec)	L-box (H1/H2)	V-funnel (sec)	U-Box (mm)
NSCC	708	4.5	0.82	12	30.50
GFSCC-15	715	4.5	0.84	12	30.40

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TABLE 4
MIX PROPORTION FOR NSCC

Mix Designation	Cement (kg/m^3)	FA (kg/m^3)	CA (kg/m^3)	SF (%)	SP (%)	Water (kg/m^3)	Slump (mm)	Comp. stress (N/mm^2)
NSCC 1	540	1008.20	751.93	5	1.3	162.54	695	37.67
NSCC 2	540	1008.20	751.93	5	1.4	167.40	700	33.47
NSCC 3	540	1008.20	751.93	5	1.5	156.60	690	38.99
NSCC 4	530	1008.20	751.93	5	1.5	164.30	700	44.21
NSCC 5	530	1008.20	751.93	7.5	1.5	159.53	685	46.67
NSCC 6	520	953.21	802.05	5	1.5	153.51	680	49.68
NSCC 7	520	953.21	802.05	5	1.5	166.40	705	47.23
NSCC 8	520	953.21	802.05	5	1.5	156.52	695	49.90
NSCC 9	510	953.21	802.05	5	1.5	158.10	710	54.99
NSCC 10	**510**	**953.21**	**802.05**	**5**	**1.5**	**153.51**	**705**	**57.01**
NSCC 11	500	953.21	802.05	5	1.6	150.50	690	51.11

TABLE 5
MIX PROPORTION FOR GFSCC-15

Mix Designation	Cement (kg/m^3)	GF replacement percentage (%)	FA (kg/m^3)	GF (kg/m^3)	CA (kg/m^3)	SF (%)	SP (%)	Water (kg/m^3)	Slump (mm)	Comp. stress (N/mm^2)
NSCC	510	-	953.21	-	802.05	5	1.5	153.51	705	57.01
GFSCC-5	510	5	905.72	42.66	802.05	5	1.5	153.51	690	35.56
GFSCC-5	510	5	905.72	42.66	802.05	5	1.6	153.51	695	38.15
GFSCC-10	510	10	857.88	85.32	802.05	5	1.6	153.51	690	42.23
GFSCC-10	510	10	857.88	85.32	802.05	5	1.7	153.51	700	45.92
GFSCC-15	510	15	810.22	127.99	802.05	5	1.6	153.51	700	52.92
GFSCC-15	**510**	**15**	**810.22**	**127.99**	**802.05**	**5**	**1.7**	153.51	**710**	**55.96**
GFSCC-20	510	20	953.21	170.65	802.05	5	1.6	153.51	685	50.71
GFSCC-20	510	20	953.21	170.65	802.05	5	1.7	153.51	690	50.92
GFSCC-25	510	25	762.56	213.32	802.05	5	1.6	153.51	675	45.11
GFSCC-25	510	25	762.56	213.32	802.05	5	1.7	153.51	670	46.45

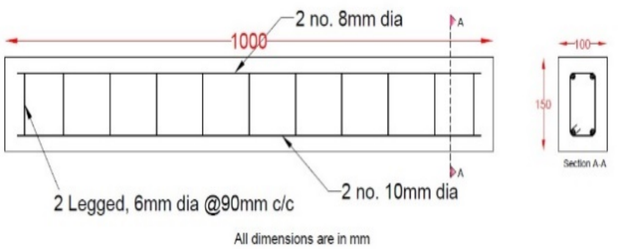

Fig. 2. Beam detailing for flexural study

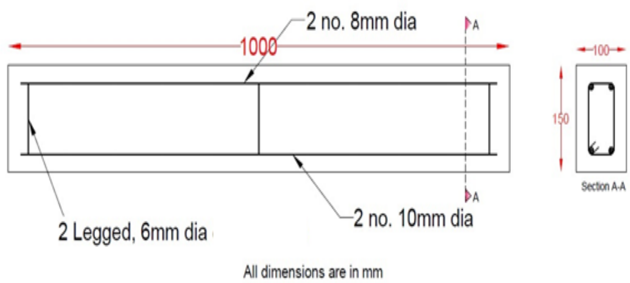

Fig. 3. Beam detailing for shear study

Fig. 4. Testing of Beam

The ultimate load, deflection at increasing load intervals and crack width were recorded and the load-deflection curves and moment-curvature graphs were plotted for the specimens. Initial crack load, yield load, energy absorption, stiffness index, toughness and displacement ductility, curvature ductility indices of the specimens were calculated from the graph and the crack patterns were analysed to study the failure characteristics.

5 TEST RESULTS OF RC BEAMS

5.1 Failure Mode, Crack Pattern and Crack Propagation

The failure and crack patterns in each specimen is as shown in Fig. 5 and Fig. 6. It was observed that for GFSCC flexure specimens with 15% fine aggregate replacement by granite fines (GF), flexural cracks developed while in the case of GFSCC shear specimens with 15% FA replacement, shear cracks developed before failure. The average crack width was however, smaller for both flexural and shear specimens with 15% fine aggregate replacement by granite fines (GF) as compared to the control specimens. Fig. 7 shows the crack propagation of the GFSCC-15 flexure and shear beam specimens with respect to the control beam specimens. It was observed that for GFSCC-15 flexure and shear beam specimens the crack propagation was almost similar as compared to the control beam specimens.

Fig. 5. Crack pattern and failure of NSCC and GFSCC-15 flexure beam specimens

Fig. 6. Crack pattern and failure of NSCC and GFSCC-15 shear beam specimens

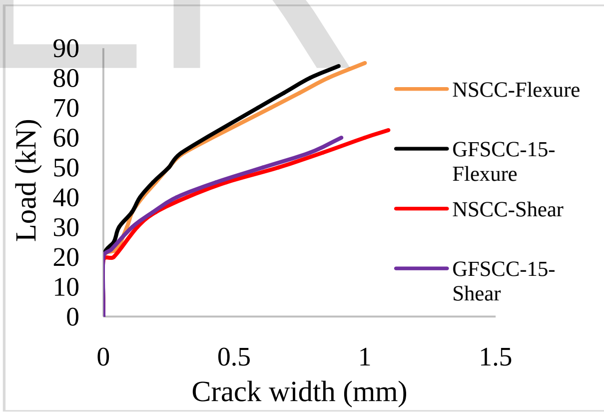

Fig. 7. Crack propagation

5.2 Load-Deflection Characteristics

Fig. 8 shows the load deflection graph of NSCC and GFSCC-15 beam specimens. It was observed that the curves for specimens with 15% granite fines and control specimen showed similar load-deflection behaviour with a linear portion till initial cracking and thereafter, non-linearly varying traits till the yield load.

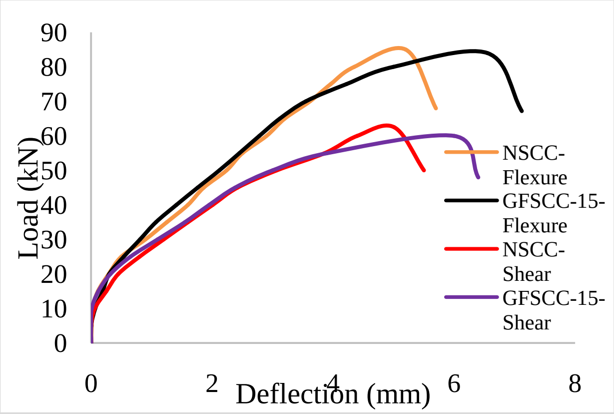

Fig. 8. Load-deflection graph

Beyond the yield point, the deflection of the beams increased considerably until the ultimate load was reached. Deformation of GFSCC-15 flexure and shear beam specimens was more as compared to the control beam specimens.

5.3 Evaluation of First Crack Load, Yield Load and Ultimate Load

TABLE 8
LOAD CARRYING CAPACITY

Specimen	First crack load (kN)	Yield load (kN)	Ultimate load (kN)
NSCC-Flexure	22.5	68.4	85
NSCC-Shear	20	50	62.5
GFSCC-15-Flexure	25	67.2	84
GFSCC-15-Shear	22.5	48	60

Table 8 shows the similar load carrying capacity of GFSCC-15 mix with reference to the control mix under flexure and shear behaviour. However, the yield load slightly decreases with increase in fine aggregate replacement by granite fines (GF) due to the proportional decrease in compressive strength.
The load taken by GFSCC-15 mix before the first crack under flexure behaviour was about 10% greater than the control mix and the corresponding ultimate load taken was about 1% lower as compared to the control mix. Similarly the load taken by GFSCC-15 mix before the first crack under shear behaviour was about 15% greater than the control mix and the corresponding ultimate load taken was about 4% lower than that of control mix.

5.4 Energy Absorption, Stiffness and Toughness

Although, GFSCC-15 flexure and shear beam specimens was capable of taking slight lower load than the control specimen, the energy absorption was higher than that of the control specimen for both the beams.
This was due to the larger deflection carried by the GFSCC specimens in flexure and shear. However, the stiffness of GFSCC-15 flexure and shear beam specimens was lower as compared to the control beam specimens.

TABLE 9
ENERGY ABSORPTION, STIFFNESS AND TOUGHNESS

Specimen	Energy absorption (kNmm)	Stiffness index (kN/mm)	Toughness
NSCC-Flexure	320.70	47.92	31.03
NSCC-Shear	239.32	43.56	33.47
GFSCC-15-Flexure	435.74	40.33	41.99
GFSCC-15-Shear	291.70	41.97	49.97

5.5 Moment-Curvature Characteristics

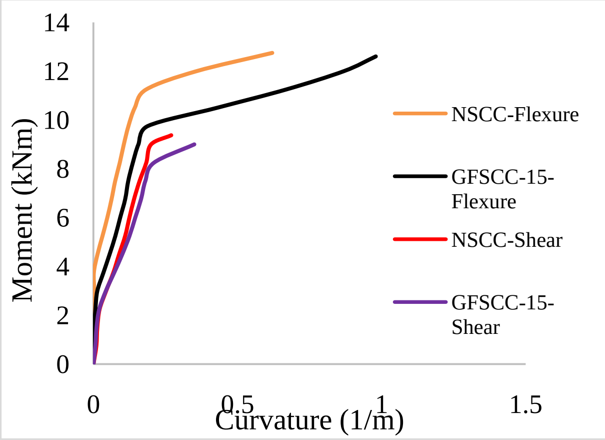

Fig. 9. Moment curvature graph

Fig. 9 shows the moment curvature graph of both specimens. Both the graphs clearly describes a higher load carrying capacity of SCC mix with 15% fine aggregate replacement by granite fines (GF) with respect to the control specimen. The curvature was more for GFSCC-15 flexure and shear beam specimens as compared to the control beam specimens.

5.6 Displacement Ductility and Curvature Ductility

From Table 10 the displacement and curvature ductility values was more for 15% fine aggregate replacement with granite fines (GF) specimens under flexure and shear behaviour as compared to normal specimens, indicating similar load carrying capacity at smaller loads.

TABLE 10
DUCTILITY VALUES

Specimen	Displacement ductility	Curvature ductility
NSCC-Flexure	1.44	4.59
NSCC- Shear	1.63	1.68
GFSCC-15-Flexure	1.90	4.76
GFSCC-15-Shear	1.99	2.00

5.7 Summary of Flexural and Shear Behaviour

From the above results, it was concluded that the flexural and shear capacity of GFSCC-15 specimens are comparable with that of control specimens. This is due to the reason that the voids present in the concrete is filled up by the optimum amount of granite fines and also due to the effect of silica fume which fills in the micro-cracks thereby imparting greater strength characteristics. In the case of GFSCC-15 specimens, the larger surface area of the granite fines may enhance the bond strength characteristics with the reinforcing steel and also be the reason for smaller crack width, which induces effective interlocking property while bending thereby increasing the ability to resist loads.

6 CONCLUSION

1. The workability and hardened properties of GFSCC were comparable as that of NSCC specimens
2. Optimum percentage replacement of fine aggregate by granite fines was found to be 15%
3. Reduction in compressive strength was observed with increase in replacement percentage of fin aggregate due to lower strength of GF. Decrease of 2% was obtained for GFSCC-15 specimen for modulus of rupture
4. The load taken by GFSCC-15 specimens before the first crack under flexure and shear behaviour was about 10% and 15% greater than that of the control mix and the corresponding ultimate load taken was about 1% and 4% lower than that of the control mix
5. The crack pattern and crack width propagation developed for GFSCC-15 flexure and shear specimens were similar as compared to the control mix
6. The load deflection and moment curvature curve of GFSCC-15 beam specimens showed similar pattern as compared to the control specimens. The Energy Absorption Capacity and toughness was improved for GFSCC-15 flexure and shear beam specimens, while the stiffness decreased
7. Partial replacement of manufactured sand by 15% granite fines can be used for the production of structural SCC with the help of admixtures

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