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Study on Flexural and Shear Behaviour of Hybrid Fibre Reinforced Self-Compacting Concrete using Recycled Aggregates as Replacement Material

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***Abstract*— In this world of rapid urbanization the demand for naturally available construction materials is increasing day by day which has created a necessity for alternative construction materials. Recycling of materials is a possible way of eradicating the acute shortage of materials. Considerable work has been done in the area of self-compacting concrete (SCC) by partial replacement of coarse aggregate (CA) with recycled coarse aggregate (RCA) obtained from construction and demolition debris. Many research works carried out in this area have proved that the role of chemical admixtures is inevitable in achieving good fresh state properties of SCC.**

In my study the flexural and shear behaviour of hybrid fibre (steel fibre and polypropylene fibre) reinforced SCC using recycled aggregate such as crushed Class I red brick to a size range of 10 - 12.5 mm as a replacement material by adding suitable proportion of chemical admixture and flyash were studied. The concept of hybridization with two different fibres incorporated in a common concrete mix, can offer more attractive engineering properties. This study were conducted using concrete mixes with fly ash of 30% as a replacement of cement and recycled aggregate such as crushed red brick of 0%, 10%, 20%, 30%, 40% and 50% as a replacement of coarse aggregate, with addition of steel fibre at various percentage as 0%, 0.25%, 0.5%, 0.75%, 1% and 1.25% along with polypropylene fibre at various percentage as 0%, 0.05%, 0.1%, 0.15%, 0.2% and 0.25% by the volume of concrete on M30 grade of SCC. Also a detailed investigation has been conducted to study the flexural and shear behaviour of hybrid fibre reinforced self-compacting concrete beams in terms of ultimate load, first crack load, energy absorption and ductility characteristics.

Keywords—Self compacting concrete, hybrid fibre, energy absorption, steel fibre, flexural strength, shear strength

I. INTRODUCTION

Concrete is the most common construction material used throughout the world for infrastructure, civil engineering and housing applications followed by wood, steel and a number of miscellaneous materials. One of the major problems is to preserve maintain and retrofit these structures. Concrete gives considerable freedom to mould the structural component into desired shape or form.

A new trend in designing complex and heavily reinforced structures showed that compaction of concrete by vibrating may be difficult in some cases. It is commonly noticed many times that after the formwork is removed; the fresh concrete had not spread to all the points, uniformly and perfectly. A homogenous property of the structure has thus been adulterated. These reasons prompted to the development of self-compacting concrete. The main aim of environmental protection agencies and the government is to seek ways to reduce the problems of health hazards posed by industrial by-products and way of disposal. Every year huge quantities of industrial by-products are being produced by various industries. Some industrial by-product like fly-ash is needed for self-compacting concrete and also it reduces the usage of cement particles. Fly ash had an excellent strength property and also reduces the requirements of cement. And addition of fibre improves the mechanical properties of self-compacting concrete. The addition of fibre especially steel fibre in self-compacting concrete improve its structural properties, especially the flexural and tensile strength makes advantages of its high performance in fresh state. The dosage of the chemical admixtures is an important parameter which influences the fresh state properties of SCC. The hardened concrete is dense, homogeneous and has the same engineering properties and durability as traditional vibrated concrete.

The main objectives of the study are:

- To develop M30 grade concrete mix
- To study the workability using slump flow, L-box, J-ring, and V-funnel tests
- To study the compressive strength
- To study the splitting tensile strength
- To study the flexural strength
- To study the impact resistance
- To study the flexural behaviour of beams
- To study the shear behaviour of beams

II. EXPERIMENTAL INVESTIGATION

The aim of the project is to find the ultimate strength and behaviour of hybrid fibre reinforced self compacting RC beams under two point loading. So the experimental programme is divided in to two groups. First programme is to find the mechanical properties of concrete and second is to find flexural and shear behaviour of RC beams. This chapter deals with the experimental programmes conducted which include material characterisation, mix design, properties of fresh concrete, mechanical properties, shear and flexural properties of RC beams under two point loading.

A. Material properties

Cement: Ordinary Portland cement of 53 grade conforming to IS 12269:1987 was used for the study The specific gravity was obtained as 3.12.

Fly Ash: Class F, dry fly ash obtained from the silos of Mettur Thermal Power Plant in Tamil Nadu was used as mineral admixture. The specific gravity of fly ash was 2.13.

Fine aggregate: Commercially available river sand with 4.75mm maximum size was used fine aggregate. All physical properties were tested as per IS 383: 1970. Specific gravity and fineness modulus of river sand used were 2.65 and 2.85 respectively.

Coarse aggregate: Coarse aggregate used in this study were 20mm nominal size. The properties of coarse aggregate conformed to the IS 383:1970. The coarse aggregate used was found to belong to standard zone. Specific gravity and fineness modulus of coarse aggregate used were 2.81 and 6.70 respectively.

Crushed red brick: Coarse aggregate was partially replaced with recycled crushed red brick. Recycled aggregates were obtained from a demolished residential building in the adjacent locality, and crushed to obtain suitable sizes for being used in SCC. Crushed red brick used for this study consists of nominal size 12.5 mm with specific gravity 2.66 and absorption of 1.9%. Fineness modulus of crushed red brick obtained is 6.43.

Steel fibre: Crimped steel fibres having diameter 0.5mm and length 30mm were used for the present study.

Polypropylene fibre: Polypropylene fibre of length 12 mm was used for the study.

Superplasticizer: Cera Hyperplast XR–W40 was used as the superplasticiser.

Viscosity Modifying Agent (VMA): Ceraplast-300 was used as viscosity modifying admixture.

Water: Portable water is generally considered as being acceptable. Hence water available in the college water supply system was used for casting as well as curing of the test specimens.

Reinforcing bars: Two numbers of 10mm diameter HYSD bar at the bottom and two numbers of 8mm diameter HYSD bar at the top were used as main reinforcement. Two legged stirrups of 6mm diameter bar are provided.

B. Mix Proportioning

The present study is based on the Japanese method of SCC mix design proposed by Okamura and Ozawa. In this method the coarse aggregate content in concrete is generally fixed at 50 percent of the total solid volume, the fine aggregate content is fixed at 40 percent of the mortar volume and the water/powder ratio is assumed to be 0.9-1.0 by volume, for the trial mix. Then depending on the properties of the powder and the superplasticiser dosage, the required water/powder ratio is determined. The final proportion is arrived by conducting a number of trials. Based on the mix design method proposed by Okumara (1995) several trial mixes were taken. The characteristic compressive strength expected was 30 N/mm^2 at 28 days. From the trial mixes taken, one mix having required compressive strength and self compactability is selected as the base mix for further studies. Test specimens in the form of 150 mm × 150 mm × 150 mm cubes were made, so as to evaluate the compressive strengh of the trial mix. Finally an optimum mix for SCC was selected from among these trial mixes for M30 grade concrete. The mix proportion of the hybrid fibre reinforced SCC using recycled aggregate as a replacement material with 70% cement and 30% FA is shown in the Table 1, which gives the range of values for SCC mix as per EFNARC guidelines.

TABLE 1: DETAILS OF MIX PROPORTION FOR SCC M30 GRADE

Mix	Cement (kg/m^3)	Fly ash (kg/m^3)	FA (kg/m^3)	CA (kg/m^3)	S P (kg/m^3)	W/ P
NSCC	315	135	919	649	0.4	0.57

Hybrid fibre (steel fibre and polypropylene fibre) reinforced SCC using recycled aggregate such as crushed Class I red brick to a size range of 10-12.5 mm as a replacement material of coarse aggregate by adding suitable proportion of chemical admixture and fly ash will be studied. This study will be conducted using concrete mixes with fly ash of 30% as a replacement of cement and recycled aggregate such as crushed red brick of 0%, 10%, 20%, 30%, 40% and 50% as a replacement of coarse aggregate, with addition of steel fibre at various percentage as 0%, 0.25%, 0.5%, 0.75%, 1% and 1.25% along with polypropylene fibre at various percentage as 0%, 0.05%, 0.1%, 0.15%, 0.2% and 0.25% by the volume of concrete on M30 grade of SCC.

TABLE 2: MIX DESIGNATION FOR DIFFERENT MIXES WITH DIFFERENT % OF CRUSHED CLASS I RED BRICK AND FLY ASH

Mix designation	NSC C	HSC CR-1	HSC CR-2	HSC CR-3	HSC CR-4	HSC CR-5
Cement (kg/m^3)	315	315	315	315	315	315
Fly ash (kg/m^3)	135	135	135	135	135	135
FA (kg/m^3)	919	919	919	919	919	919
CA (kg/m^3)	649	584.1	519.2	454.3	389.4	324.5
Crushed red brick(kg/m^3)	-	64.9	129.8	194.7	259.6	324.5
SP (kg/m^3)	0.4	0.6	0.8	1	1.2	1.4
VMA	0.2	0.2	0.2	0.2	0.2	0.2
Water (% of powder)	0.57	0.57	0.57	0.57	0.57	0.57

C. Specimen details

Cubes of size 150 mm × 150 mm × 150 mm were cast for compressive strength tests. Cylinders of size 300 mm × 150 mm were cast for cylinder compression tests and splitting tensile strength tests. Beam specimens of size 500 mm × 100 mm × 100 mm were cast for performing flexural tests on beams. Tests were performed for compressive strength at ages of 7 and 28 days. Splitting tensile strength and flexural strength were found out at 28 days. Table 3 gives the details of number of specimens.

TABLE 3: SPECIMEN DETAILS

Sl. No	Specimen	Property	Size (mm)	Numbers
1	Cube	Compressive strength	150 × 150 × 150	54
2	Cylinder	Splitting tensile strength	300mm height and 150mm diameter	18
3	Beam	Flexural strength	500 × 100 × 100	18
4	Disc	Impact resistance	64 mm height and 150 mm diameter	18
5	Large beam	Flexural and shear behaviour	1200 × 100 × 150	24
Total number of specimens				132

D. Preparation and casting of specimens

For each mix nine concrete cubes of size 150x150x150mm were casted for compressive strength test, three cylinders of 150mm diameter and 300mm height for splitting tensile strength test and and three beams of size 500x100x100mm for flexural strength test were casted. Also for each mix three concrete disc of 64 mm height and 150 mm diameter were casted for Impact resistance test.

To study the flexural crack pattern and shear crack pattern, total of 24 reinforced concrete beams of 1200x100x150mm were casted in which 12 are used for testing the flexural characteristics and remaining 12 are used for testing the shear characteristics.. For each type, four reinforced concrete beams were casted. The beam details are shown in Table 4. The reinforcement details of the beams for flexural and shear are shown in Fig. 1 and Fig. 2 respectively.

Concrete was mixed in a concrete mixer in the laboratory. All the specimens were vibrated with a mechanical vibrator and were stored at temperature of about 23^{0}C in the cast in room. They were demoulded after 24 hours and were cured in a water curing tank. After 28 days, the large beams were white washed for easy detection of cracks.

TABLE 4: BEAM DETAILS

Sl. No	Flexural behaviour	Shear behaviour	Steel fibre volume (%)	Polypropylene fibre volume (%)
1	FNSCC	SNSCC	0	0
2	FHSCCR-1	SHSCCR-1	0.25	0.05
3	FHSCCR-2	SHSCCR-2	0.50	0.1
4	FHSCCR-3	SHSCCR-3	0.75	0.15
5	FHSCCR-4	SHSCCR-4	1.00	0.2
6	FHSCCR-5	SHSCCR-5	1.25	0.25

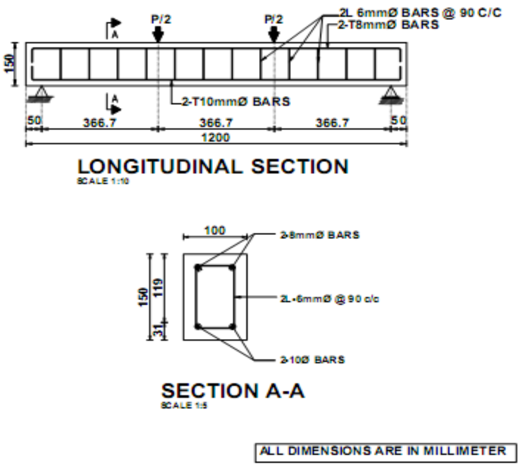

Fig.1 Reinforcement details (flexural)

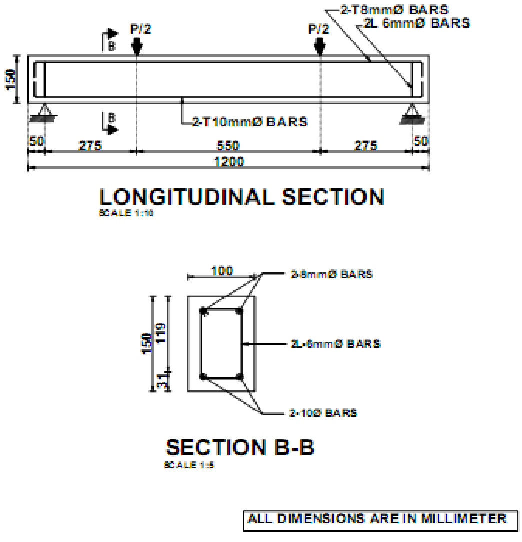

Fig. 2 Reinforcement details (shear)

E. Tests on specimens

Testing of concrete specimens plays an important role in controlling and confirming the quality of concrete. Thus the experimental investigation carried out was divided into three main headings. They are as follows:

1. Study on workability
   - Slump test
   - V-funnel test
   - J-ring test
   - L-box test
2. Study on strength
   - Compressive strength test
   - Splitting tensile strength test
   - Flexural strength test
   - Impact resistance test
3. Study on flexural and shear behaviour of RC beam

F. Test setup for studying flexural and shear behaviour

A two point flexural bending system is adopted for the tests. Specimens were tested in aloading frame of 2000kN (200t) capacity with an effective span of 1100mm. Load cell of 200kN capacity with a least count of 1kN is used to measure the applied load. Fig. 3 shows the test setup. The load was increased in stages till the failure of the specimen and at each stage of lading the following observations was made.

1. First crack load
2. Displacement at mid span
3. Ultimate load
4. Crack pattern and failure mode
5.

Fig. 3: Test setup for RC beam

III. RESULTS AND DISCUSSION

A. Properties of fresh concrete

Studies conducted on fresh properties are given in Table 5. From the results obtained it can be concluded the workability decreases with percentage increase of hybrid fibre.

TABLE 5: PROPERTIES OF FRESH CONCRETE

Mix Designation	Slump flow diameter (mm)	T_{50} (s)	J-Ring (mm)	V-Funnel test (s)	L-Box ratio (H_2/H_1)
NSCC	740	2	7.3	8.31	1.0
HSCCR-1	731	2.18	7.5	8.96	0.95
HSCCR-2	727	2.95	7.9	9.13	0.91
HSCCR-3	723	3.05	8.3	9.47	0.89
HSCCR-4	721	3.61	8.8	10.22	0.86
HSCCR-5	716	3.85	9.4	10.89	0.84

B. Properties of hardened concrete

1. Cube compressive strength: Compressive strength of all concrete mixes was determined at 7, 14 and 28 days of curing. From test results it can be concluded that there is an increase in early age compressive strength due to the addition of hybrid fibres in SCC. Comparing to NSCC, HSCCR-3 have showed an increase in strength of 1% at 7 days, 7% at 14 days and 8% at 28 days.

2. Splitting tensile strength: Splitting tensile strength of cylinder was determined at 28 days of curing. From results, it can be seen that the splitting tensile strength of cylinder of HSCCR-3 was higher than NSCC. Percentage increase in strength of HSCCR-3 was 4%.

3. Flexural strength: Flexural strength was determined at 28 days of curing. From results, it can be seen that the flexural strength of HSCCR-3 was higher than NSCC and HSCCR-4. Percentage increase in strength of HSCCR-3 was 4%.

4. Impact resistance

Dynamic energy absorption or strength is called as impact resistance and is one of the major attributes of concrete. Here the repeated impact test or drop weight test was conducted to determine the number of blows to achieve a prescribed level of distress of the specimen. To determine the impact resistance of concrete the first crack and ultimate failure of specimens were determined. The resistance offered by the concrete was found out using this test.

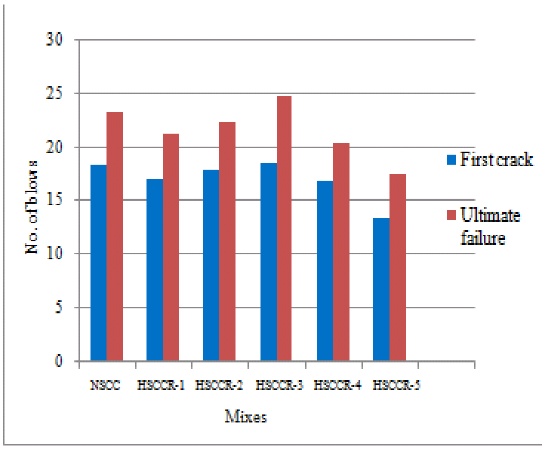

Fig. 4: Impact resistance for various mixes

Among the mixes HSCCR-3 showed greater impact resistance.

C. Test results on Beams

1) First crack load and ultimate load

The test results show that the first crack load for FNSCC beam was 12 kN and the first crack load for FHSCCR-4 beam was 17.2 kN. The addition of hybrid fibres increases the first crack load by 43%. The fibres distribute the strains more evenly in concrete and thereby cause the increase in the first crack load. The addition of hybrid fibres increases the ultimate load by 21%. The Maximum first crack load and ultimate load was observed for specimens (FHSCCR-5) with 8% volume fraction of hybrid fibres.

TABLE 6: TEST RESULT FOR FLEXURAL BEAM SPECIMENS

Sl. No	Beam Designation	First Crack Load (kN)	Ultimate Load (kN)	Deflection at Ultimate Load (mm)
1	FNSCC	12	46	9.7
2	FHSCCR-1	13.97	48.89	10.35
3	FHSCCR-2	15.93	51.79	10.5
4	FHSCCR-3	16	54	10.97
5	FHSCCR-4	16.5	55	11
6	FHSCCR-5	17.2	56	11.5

Ultimate load also increases with the addition of hybrid fibres to the beams when compared to control specimen SNSCC. When fibres are added to concrete, they intercept the cracks and this causes deviation of cracks from its initial propagation. This results in the demand of more energy absorption, which in turn improves the load carrying capacity. Maximum ultimate load was obtained in SHSCCR-5 and the percentage increase in ultimate load was 47%.

TABLE 7: TEST RESULTS FOR FIRST CRACK AND ULTIMATE LOAD OF SHEAR BEAM SPECIMENS

Sl. No	Beam Designation	First Crack Load (kN)	Ultimate Load (kN)	Deflection at Ultimate Load (mm)	Ultimate shear capacity (N/mm^2)
1	SNSCC	8	30	4.47	1
2	SHSCCR-1	10	34	5.47	1.13
3	SHSCCR-2	12.5	40.35	6.2	1.34
4	SHSCCR-3	14	42	6.27	1.4
5	SHSCCR-4	16	43	6.3	1.45
6	SHSCCR-5	17	44	6.42	1.47

2) Load deflection behaviour

Mid span deflection was noted at every 2kN load increment. Defection of all specimens was observed to increase considerably after the first crack was observed. Deformations corresponding to each increment of load for all specimens were noted. The load deflection graph for all the flexural specimen is shown in Fig. 5 and shear specimens is shown in Fig. 6.

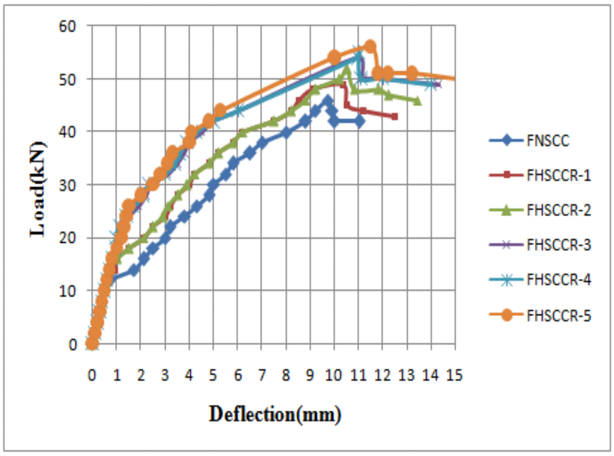

Fig. 5: Influence of fibre on the flexural behaviour of beam under loading

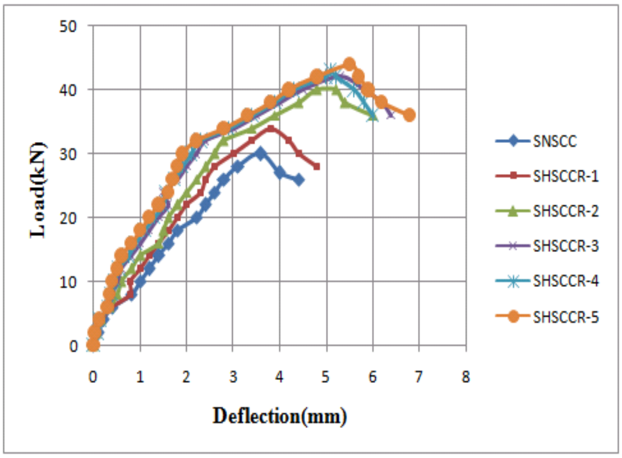

Fig. 6: Influence of fibre on the shear behaviour of beam under loading

3) *Crack pattern and failure mode*

The typical crack pattern of the flexural beam specimen is shown in Fig. 6 and shear beam specimen are shown in Fig.7

Fig.7 Typical crack pattern of flexural beam specimen

Fig.8 Typical crack pattern of shear beam specimen

4) *Energy absorption capacity*

In general energy absorption capacity of a given material could be obtained from area under the load deflection plot of the specimen. Concrete will be effective in resisting the load until the formation of the first crack. At this stage concrete is relieved of its tensile stress and steel becomes effective at the cracked section. Energy absorbed at ultimate load can be obtained by calculating the area under load deflection curve up to the ultimate load. Energy absorption capacity of all flexural specimens is shown in Table 8 and shear beam specimen is shown in Table 9.

TABLE 8: ENERGY ABSORPTION CAPACITY FOR ALL FLEXURAL BEAM SPECIMENS

Sl. No	Beam Designation	Energy absorption (kNm)	Ductility index
1	FNSCC	0.213	1.27
2	FHSCCR-1	0.216	1.63
3	FHSCCR-2	0.237	1.83
4	FHSCCR-3	0.244	2.00
5	FHSCCR-4	0.245	2.07
6	FHSCCR-5	0.246	2.14

TABLE 9: ENERGY ABSORPTION CAPACITY FOR ALL SHEAR BEAM SPECIMENS

Sl. No	Beam Designation	Energy absorption (kNm)
1	SNSCC	0.06
2	SHSCCR-1	0.081
3	SHSCCR-2	0.134
4	SHSCCR-3	0.137
5	SHSCCR-4	0.158
6	SHSCCR-5	0.161

From the results obtained it can be seen that energy absorption capacity was maximum for FHSCCR-5 and SHSCCR-5. Ductility is an important parameter in the design of structures subjected to large deformation. Ductility is the property of the material by which it undergoes large deformation without any reduction in load carrying capacity. Generally ductility of members subjected to flexure can be obtained from ductility factor.

V. CONCLUSION

The major conclusions of my thesis work are presented below:

- The recycled aggregates show higher water absorption compared with conventional normal aggregates and have low specific gravity.
- When fibre is added to concrete, the mix becomes stiff. So the workability is decreased with addition of fibre.

The workability can be improved by adding super plasticizer to some extent.

- The concrete mix starts clogging with the addition of steel and polypropylene fibre percentage beyond 0.75% and 0.15% volume of concrete respectively. So the mechanical properties are decreased above this percentage.
- The fibre distributes the strain more evenly in concrete and improves the tensile strength, thereby causing the increase in first crack load and ultimate load.
- When fibres are added to concrete, crack propagation is arrested and this results in improving load carrying capacity and energy absorption capacity. So the toughness and ductility is improved with the addition of percentage of hybrid fibre.
- Load deflection behaviour curve shows that ductility of fibres increases and the stiffening effect occurred in the tension zone reducing widening of crack and the diagonal crack are reduced to hair line crack..

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