

Experimental and Analytical Study on Moment-Curvature (M- ϕ) Response for Graded Fiber Reinforced SCC Beams

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Abstract: Homogeneous mixing of similar type of fibers from micro to macro (with short length to long length) in concrete is termed as graded fiber reinforced concrete. Research shows addition of micro fibers improves the ultimate strength whereas macro fibers improve the post – crack deformation of concrete. An attempt has been made to study the flexural performance and obtain the moment curvature relationship of graded fiber reinforced self-compacting concrete (SCC). Experimental work is carried under flexural loading test for 16 beams of size 150mm x 200mm x 1800mm for M30 and M40 grade SCC with a constant volume fraction of 0.5% graded steel fibers. The steel fibers used in the study are 0.75mm diameter x 60mm length, 0.5mm diameter x 30mm length and 0.25mm diameter x 15mm length. The addition of graded fibers showed significant improvement in moment carrying capacity and deformation capacity compared to conventional SCC and mono fiber reinforced SCC beams. An analytical moment – curvature relationship is developed using the stress- strain characteristics of conventional and graded fiber reinforced SCC. A satisfactory co-relation is observed between experimental and analytical moment-curvature relationship.

Keywords: graded fibers, moment-curvature, micro and macro fibers, self-compacting concrete, volume fraction.

1. INTRODUCTION

Self-Compacting Concrete is a boon to building industry where high rise and complex structures are to be built which have difficult concreting conditions due to placement of heavy and congested reinforcement in the structural members. SCC is one of the best solutions to improve the durability of concrete structures. SCC is termed as that concrete which flow on its own weight and fills the formwork without any voids, segregation and honey combs, under any obstructions like closely spaced reinforcement. SCC was developed in late 1980's [1]. This method of concreting showed improved product quality and efficiency of structural members. The European federation of natural trade associations representing produces and applications of specialist building products (EFNARC) [2] has given specifications and guidelines for developing SCC mix design to maintain quality standards during 2002. A Number of mix

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proportion models were developed [3]. Mix proportioning using compressive strength model based [4-5] is used to develop M30 and M40 grade SCC.

Addition of steel fibers to SCC will improve the post cracking behavior by bridging the cracks in the concrete in addition to the advantages of SCC in the fresh state [6-7]. Fiber reinforced concrete showed a technical support for improving the brittle nature and tensile strength of concrete. Fibers are small pieces of reinforcing material added to the concrete. The most common types of fibers used are glass, asbestos, polypropylene and steel. When concrete members are loaded to failure, cracks propagate rapidly, fibers placed in concrete helps in arresting these cracks to grow further. Addition of steel fibers in concrete members is encouraged to increase the properties of concrete such as strength, ductility and toughness [8-10].

The process of mixing two different fibers to a concrete mix is named as hybrid fiber concrete and blending of same type of fibers from shorter length to longer length is named as graded fiber reinforced concrete [11]. Short (or) micro fibers resist the propagation of micro cracks which improves the pre-cracking behavior and strength of concrete. The contribution of micro fibers in delaying the initial cracks is high and its effects are ceased when micro cracks are converted to macro cracks on further loading of the member. The macro fibers resist the propagation of macro cracks by bridging them. The post crack performance of concrete increase with increase in number of macro fibers. Hence a homogeneous mixture of fibers from micro level to macro level can improve the pre and post-performance of concrete [12-16].

The failure modes of a structural member play a major role in showing the ductility of a member. Very few researchers have developed moment-curvature relationships for fiber and graded fiber reinforced concrete members [17-19]. To develop analytical moment-curvature curves for a concrete member, stress-strain characteristics are essential. Several authors have developed stress-strain models of fiber reinforced concrete [20-22]. The models developed by samer ezeldin [20] are used in this study to develop the analytical moment-curvature curves of graded steel fiber reinforced concrete.

Considering the advantages of graded fibers and SCC, an attempt has been made to investigate the fresh, hardened properties and flexural behavior of graded steel fiber reinforced self-compacting concrete.

2. EXPERIMENTAL PLAN

2.1 Materials Used

Ordinary Portland Cement (OPC) of 53 grade (with compressive strength of 53 MPa after 28 days of curing) confirming to IS 12269-2013 [23] is used as the binder. River sand sourced locally was used for the experimental work as fine aggregate and the material was confirmed according to the standard of zone II as per IS 383-2016[24]. The specific gravity and fineness modulus of the fine aggregate used were 2.67 and 2.4 respectively. Locally available coarse aggregate with a maximum size of 10mm obtained from crushed stone was selected for use in preparing the concrete mix. The determination of the specific gravity of coarse aggregate was carried out as per IS 2386-1963[25] and the value was found as 2.81. Mineral admixture GGBS was obtained from JSW cement, tested and satisfied with the recommendations of IS 12089-1987[26]. Tap water of potable quality is used for mixing and curing concrete mixes [27] during the experimental procedures.

Hiforza 405, a PCE-based super plasticizer (SP) with a solids content of 40% and a pH value of 5, is used in this study. Super plasticizer is obtained from hi bond chemicals in Vijayawada, India. Hooked steel fibres with dimensions of 0.75mm diameter (dia) – 60mm length, 0.5mm dia – 30mm length and 0.25mm dia – 15mm length tested to have a tensile strength of 1100 N/mm² and yield strength of 400 N/mm² supplied from Chennai, India have been used in this

study. The steel fibres at 0.5% by volume are used in all concrete mixes. Figs. 1 and 2 show the different steel fibres used in the work.

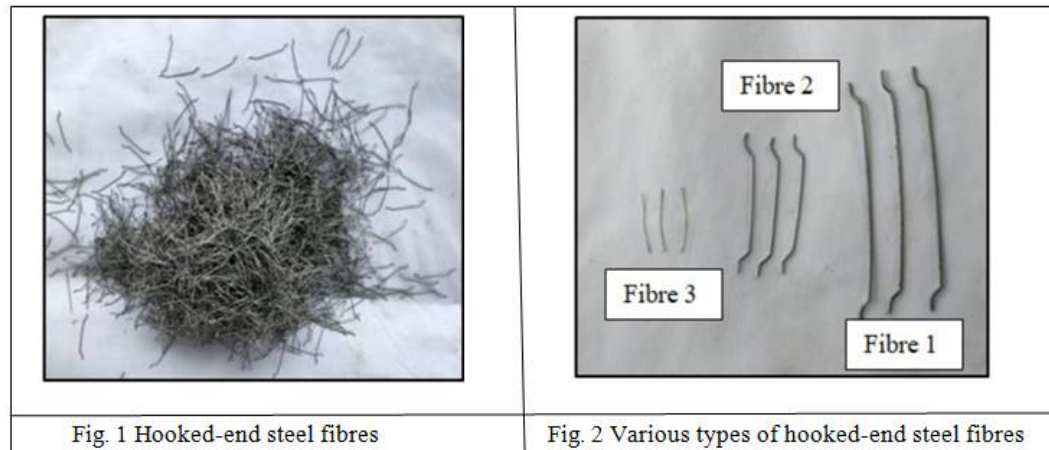


Table 1. Properties of fibres

Description	Fibre 1	Fibre 2	Fibre 3
Type of Fibre	Hooked end steel	Hooked end steel	Hooked end steel
Length of Fibre	60mm	30mm	13.5mm
Diameter of Fibre	0.75mm	0.5mm	0.25mm
Aspect Ratio	80	60	50
Specific Gravity	7.8	7.8	7.8
Modulus of	200GPa	200GPa	200GPa
Tensile Strength	2000N/mm ²	2000N/mm ²	2000N/mm ²

2.2 Proportioning of concrete mixes

To carry out the experimental work, a Self-compacting concrete mix was prepared using Cement, Fine Aggregate (FA), Coarse Aggregates (CA), Ground Granulated Blast Furnace Slag (GGBS), super plasticizer (SP), steel fibres, and water following EFNARC [23] specifications and guidelines. Two SCC mixes (M30 and M40) were prepared, and their proportions are specified in Table 2.

Table 2. Mix Proportions of prepared SCC mixes.

Grade of Concrete	Cement Kg/m ³	Fine aggregate Kg/m ³	Coarse aggregate Kg/m ³	GGBS Kg/m ³	SP Lts	Water Lts
M 30	346	832.63	800	210	2.78	190
M 40	427	839.31	799	148.4	3.45	183.5

2.3 Casting and curing of concrete mixes

The work prepares four types of SCC mixes with plain and graded steel fibres for each grade of concrete accounting for a total of 8 mixes are prepared in this work. These mixes are designated as M-30, MF1-30, MF2-30, MF3-30; and M-40, MF1-40, MF2-40, MF3-40. MF refers to Mix with Fibre and 1(mono), 2(double blended), 3(triple blended) represent the types of blending fibres in two grades of concrete. Table 3 shows the percentage of each fibre added to the mix for each proportion.

Table 3. SCC mix proportions with steel fibres

	Specimen	Fibre 1	Fibre 2	Fibre 3	Total
1	M-30	0	0	0	0
2	MF1 -30	39	0	0	39
3	MF2 -30	27.3	11.7	0	39
4	MF3 – 30	27.3	9.36	2.34	39
5	M – 40	0	0	0	0
6	MF1 – 40	39	0	0	39
7	MF2 – 40	27.3	11.7	0	39
8	MF3 – 40	27.3	9.36	2.34	39

A laboratory mixer was used for mixing concrete by systematically adding required amount of materials in dry state and then, water is added. To attain required flow to the mix, super plasticizer is added. The addition of steel fibres is done as the last step in proportions as listed in table 3. This method of concrete mix is adopted to ensure resistance to segregation. The fresh concrete properties of the mixes were determined followed by pouring the fresh mix in moulds (1800 mm in length, 200 mm deep and 150 mm wide) by carefully scrapping off excess concrete mix on the top surface. The self-compacted samples were removed from the mould after 24 hours and allowed for curing by immersion in potable water.

2.4 Fresh properties of steel fibres in SCC

The difference between SCC and the conventional concrete mix is that SCC fulfils the three placement requirements i.e., the capability to fill, pass through the reinforcement, and resist segregation. The capability of SCC to above-mentioned requirements is observed based on tests namely slump flow test, T-50, and V-funnel test [1-2]. All these tests were conducted as per the methods stipulated in EFNARC [2].

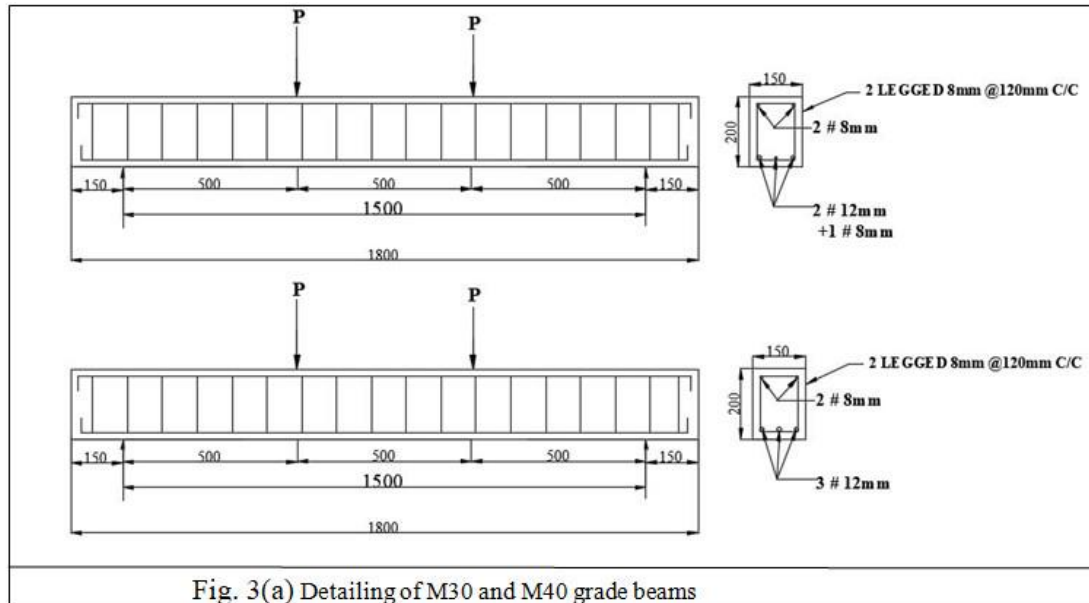
2.5 Hardened properties of concrete mixes

Compressive strength, splitting tensile strength, and flexural strength tests were determined at the age of 28 days. Specimens were tested as per the stipulations mentioned in IS 516(1959), IS 5816(1999) [28-29].

2.6 Design Details of Beams

The concrete beams of size 1800 mm long, 150 mm wide and 200 mm deep, with an effective depth of 170 mm were cast using M30 and M40 grades of SCC are shown in Fig. 3(a). All the beams are designed as under-reinforced with 2#12mm and 1#8 mm dia bars as main steel for M30 grade SCC beams, 3#12 mm dia bars as main reinforcement for M40 grade

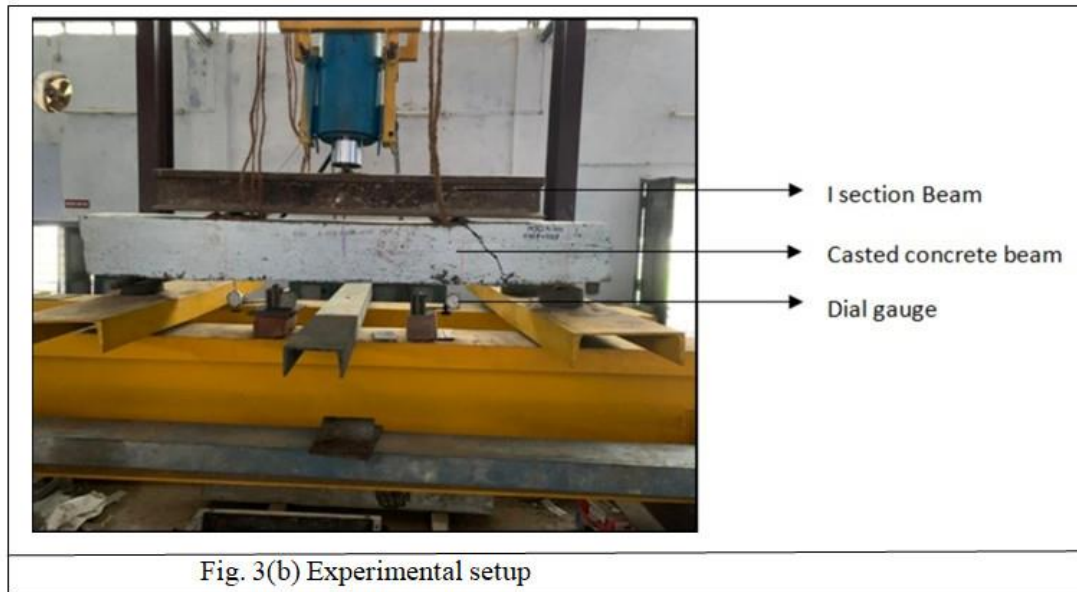
beams. 2#8 mm dia bars are provide as hanger bars to support the transverse reinforcement, which is made of two-legged 8 mm dia bar spaced at 120 mm c/c such that no shear failure occurs during testing.



2.6 Test set-up

All the specimens were air-dried and then whitewashed before testing after a curing period of 28 days each specimen was tested on a loading frame unit having a capacity of 100 tons. The beams are simply supported with location of supports marked to have a span of 1500mm. The position of deflection gauges under the load points were marked on it with a pencil and kept ready for testing. A rolled steel I section is used to transfer the load from the equipment to the beam and the I beam is supported with two rollers, which in turn act as point loads on the testing specimen. The roller supports are placed at 500mm from the simple support of the beam. The deflections at point loads, central deflection and the crack patterns are marked when the beams are loaded to failure. The total setup is shown in Fig. 3(b).

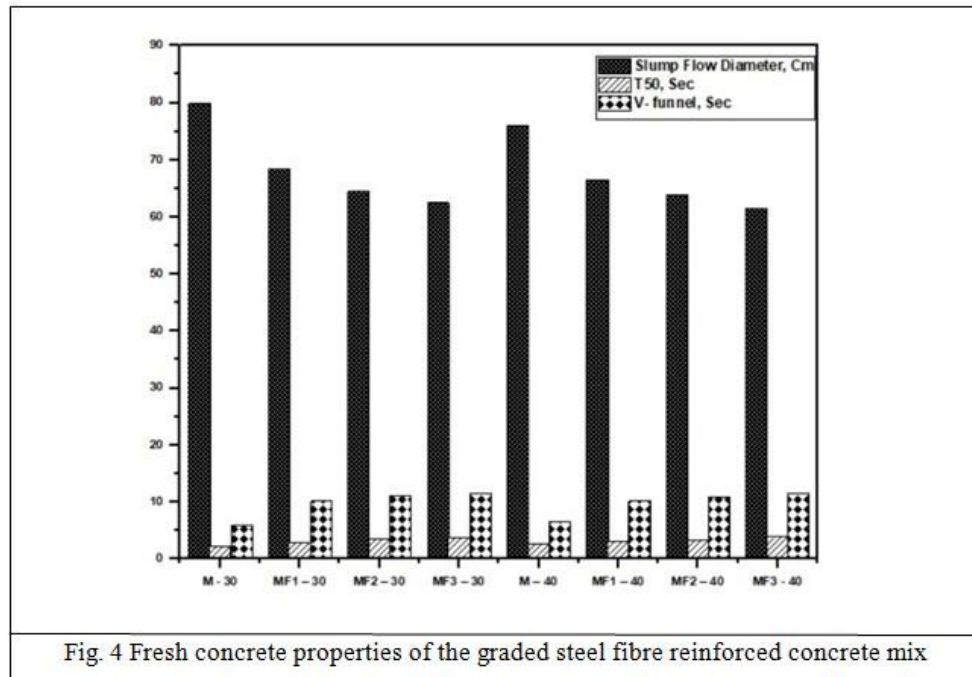
The displacement control loading was obtained by carefully adjusting the inlet valve of the loading frame machine such that the valve moment of the crosshead is controlled and is maintained at 1 mm per minute which is nearly simulated as displacement loading.



3. RESULTS AND DISCUSSION

3.1 Fresh Properties of concrete

EFNARC developed various workability methods to evaluate the fresh properties of SCC, the ability to flow, passing ability and segregation resistance. Checking for consistency is the primary test to evaluate the filling ability; it is done by slump test. The V- Funnel test is for assessing the Flowability, segregation resistance and viscosity. The volume fraction of fibers in the mix plays a major role in deciding the fresh properties of SCC. The fresh properties obtained and tabulated as shown in Fig. 4. With fibers of length 13.5mm and 0.25mm dia the inclusion of fibers reduces the slump flow value by up to 20 to 22% in M30 and M40 grade concrete. The time required by fresh concrete mixes to empty the V-funnel increase with the reduction in the length and diameter of steel fibers. This can be attributed to the additional friction offered by fibers against each other along with the friction between the fibers and aggregates. The inclusion of fibers provides resistance, which increase the time to flow 50cm diameter (T_{50}). The resistance to flow and T_{50} increase as the number of fibers l increases with the addition of micro fibers. The blending of fibers imparts interlocking and increases friction between the aggregates and the fibers, which is accepted to increase the resistance to flow.



3.2 Hardened Properties

The mechanical properties to evaluate the performance of the graded steel fiber reinforced SCC includes compressive strength of cube specimens with 150mm x 150mm x 150mm size and split tensile strength on cylinder specimens with 150mm diameter and 300mm height.

The compressive strength variation with variation in concrete mix and steel fibres is shown in Fig. 5. There is a significant increase in the compressive strength of M30 with the addition of steel fibres in the range of 34%, 45%, and 53% with fibres of type mono, dual and triple respectively. The strength increase in M40 follows a similar trend but the percentage increase is comparatively lesser than that observed in M30 SCC. The increase in compressive strength can be attributed to the curing-induced hydration products and the integrity offered by the uniform dispersion of steel fibres.

As shown in Fig. 6 the splitting tensile strength also increased with variation in steel fibres length and diameter. The effect of steel fibre in M30 was higher resulting in about a 48% increase in tensile strength with the fibre of type 3 whereas the percentage increase in M40 concrete was about 43%. The steel fibres are attributed to restraining the formation of internal micro cracks and hence contributing to an increase in tensile strength.

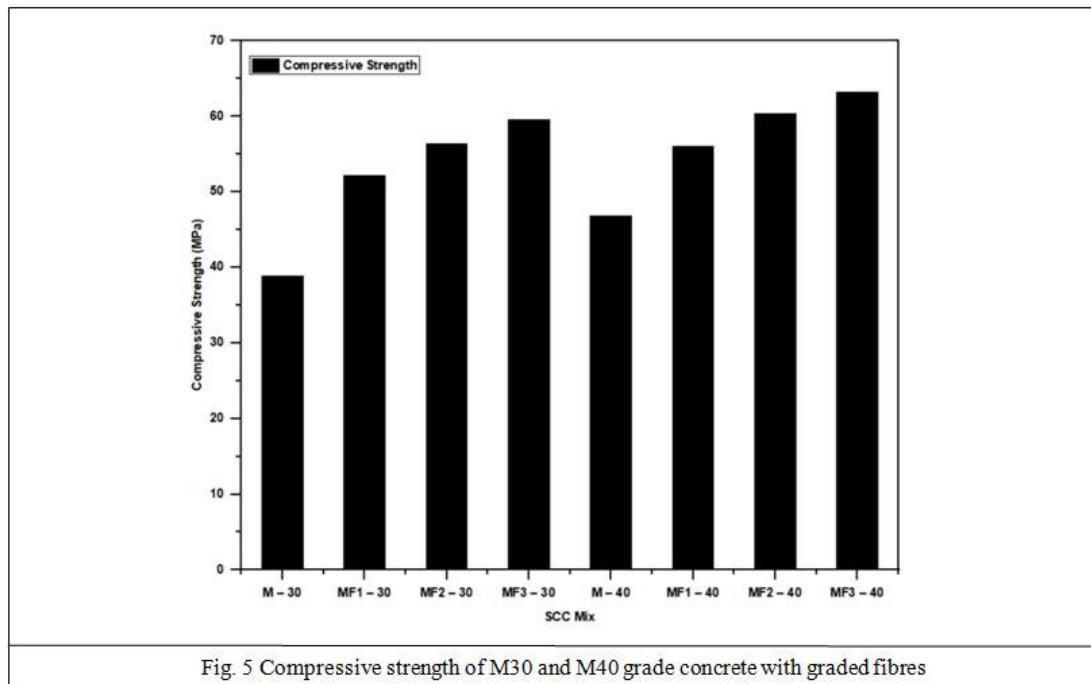


Fig. 5 Compressive strength of M30 and M40 grade concrete with graded fibres

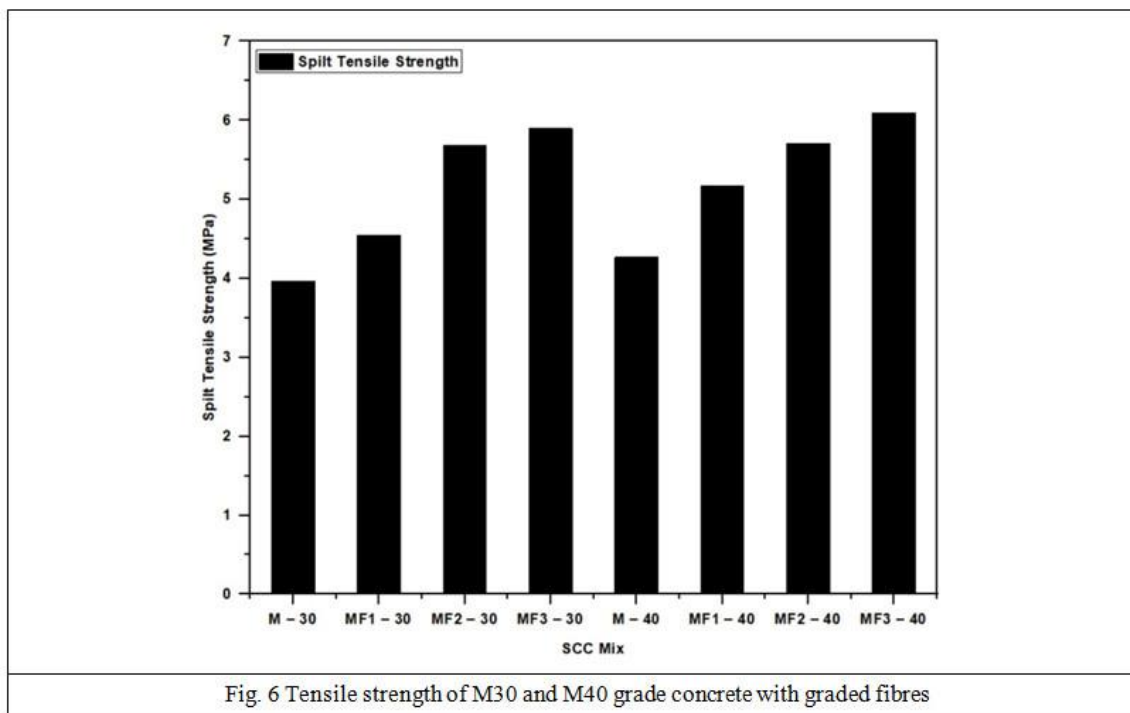


Fig. 6 Tensile strength of M30 and M40 grade concrete with graded fibres

3.3 Influence of graded fibres on the bending response of SCC beams

Table 4 shows the load at first crack, corresponding deflection, ultimate load and ultimate mid span deflection for all the beams when tested and loaded to failure. A total of 16 beams, two for each set were cast and tested for M30 and M40 grade mix. The addition of single fiber 0.75mm dia- 60mm length to the conventional concrete has resulted in the increase in first crack load by 6.78% and decrease in first crack central deflection by 11.11% for M30

grade concrete. An increase in first crack load of 9.96% and decrease in first crack deflection of 14.29% is observed for M40 grade concrete. An increase in ultimate load of 12.3% and 10.77% is observed for M30 and M40 beams.

With the replacement of second fiber 0.5mm dia – 30mm length to the first fiber by 30% of its weight, an increase of 17.23% for first crack load with respect to conventional mix and 9.84% with respect to mono fiber concrete is observed for M30 grade concrete. A decrease of 27.7% and 18.75% for first crack displacement with respect to conventional M30 SCC and mono fiber SCC is observed. An increase of 14.37% and 4.01% for first crack load is observed for M40 grade concrete while a decrease in first crack displacement by 28.57% and 16.66% is observed. An increment of 14.97%, 2.37% and 14.24%, 3.69% for ultimate loads of M30 and M40 grade beams with respect to conventional and mono fiber reinforced beam are observed.

With the replacement of micro fiber 0.25mm dia – 15mm length by 20% weight of second fiber 0.5mm dia – 30mm length, an increase in first crack load by 21.36%, 13.65%, 3.47% with respect to the conventional concrete, single fiber and dual fiber M30 grade concrete beams while a decrease in first crack displacement is observed with respect to other beams. With the grading of fibers, an increase in ultimate load of 19.68%, 6.56%, 4.09% and 18.4%, 7.48%, 3.65% for M30 and M40 grade SCC beams is observed with respect to conventional, mono fiber and dual fiber concrete beams.

With the addition of fibers to the concrete an increase in the first crack load is observed, this is attributed to the fibers bridging the space between micro cracks. When micro cracks originate in the transition zone of the concrete matrix, the micro fibers near to the vicinity of such cracks tend to sease these cracks resulting in preventing the propagation of crack. This increases the initial load carrying capacity of the member. The increase in ultimate load carry capacity of the member is due to presence of macro fiber which bridge the cracks, this demands more energy for further propagation of cracks which intern increases the load carrying capacity of the member. The similar behavior is observed in all types of beams.

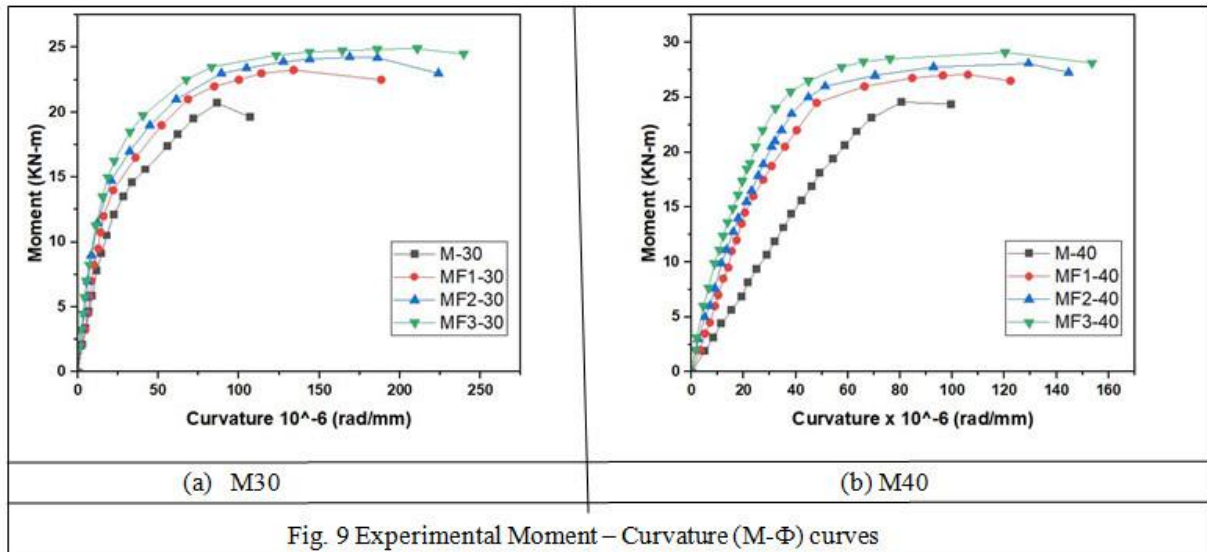
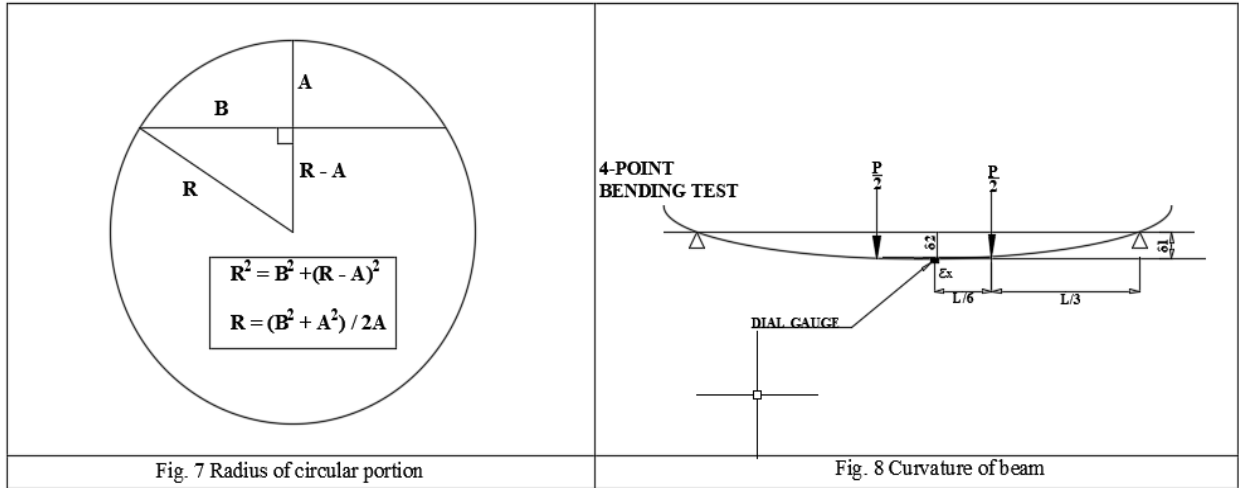
A decrease in deflection at load points and at the mid span is observed when the blending of fibers is done. This is due to the flexural stiffening of elements there by reducing the member deformation, increase in its ultimate strength and controlling the deflection. The above results show an evidence of improving the load carrying capacity and lower deflections by grading of fibers with normal SCC concrete. Thus grading of fibers can be an effective method of controlling deflections, propagation of macro and micro cracks in structural members.

Table 4. Load & Deflection

S.No	Sample Identification	First crack load kN	Central Deflection mm	Ultimate Load kN	Central Deflection mm
1	M - 30	11.8	0.18	41.4	5.43
2	MF1 - 30	12.6	0.16	46.5	5.94
3	MF2 - 30	13.84	0.13	47.6	6.225
4	MF3 - 30	14.32	0.12	49.55	6.79
5	M - 40	14.06	0.14	49.15	6.28
6	MF1 - 40	15.46	0.12	54.15	7.5
7	MF2 - 40	16.08	0.10	56.15	7.98
8	MF3 - 40	16.46	0.09	58.2	8.625

4. EXPERIMENTAL MOMENT-CURVATURE RELATION

As four-point bending setup is used, the mid portion of beam is under pure bending, hence it is assumed the central part of the beam is like a circular arc. Using the deflections obtained during the tests, the curvature of the beam is estimated using a simple mathematical expression of finding radius of circle as shown in Fig.7 The curvature of the beam is inverse of radius. The term “A” as shown in Fig. 7 is estimated by the difference of deflections obtained from the dial gauge readings, which is as shown in Fig. 8 and the term B indicates the distance between the load point and midpoint of beam which is 250mm and is constant for all tested beams. The experimental moment-curvature relations obtained are shown in Fig. 9.



5. ANALYTICAL STRESS-STRAIN CURVE RELATION

To study the behavior of RCC element, we need to understand the stress – strain characteristics for the material. Park and Paulay [22] described the following equations for stress – strain curve of conventional concrete loaded under uniaxial compression.

$$\text{For strain } \leq 0.002 \quad f_c = f_c'' \left\{ \frac{2\varepsilon_c}{\varepsilon_o} - (f_c''/\varepsilon_o)^2 \right\} \quad (1)$$

$$\text{For strain } > 0.0035 \quad f_c = f_c'' \{1 - 100 (\varepsilon_c - \varepsilon_o)\} \quad (2)$$

The stress – strain curves for any fiber reinforced concrete can be drawn for known values of reinforcing index (RI), β and ultimate strain of the fiber concrete. The following equation is used to draw the stress – strain of fiber reinforced concrete suggested by A. Samer Ezeldin [20].

$$\frac{f_c}{f_{cf}} = \frac{\beta \frac{\epsilon_c}{\epsilon_{uf}}}{\beta - 1 + (\epsilon_c / \epsilon_{uf})^\beta} \quad (3)$$

$$\beta = 1.093 + 0.7132(RI)^{-0.926} \quad (4)$$

$$\epsilon_{uf} = \epsilon_o + 446 \times 10^{-6} (RI) \quad (5)$$

Where f_{cf} compressive strength of fibre is concrete; ϵ_{uf} is strain corresponding to the compressive strength; ϵ_o is stain corresponding to maximum stress f_c'' ; f_c, ϵ_c are stress and strain values from the curve; β is material parameter.

$$RI = W_f * (l / \phi)$$

$$W_f = 3 * V_f$$

$$l = l_1 \quad \text{for Single Fiber}$$

$$l = (l_1 + l_2)/2 \quad \text{for Dual Fiber}$$

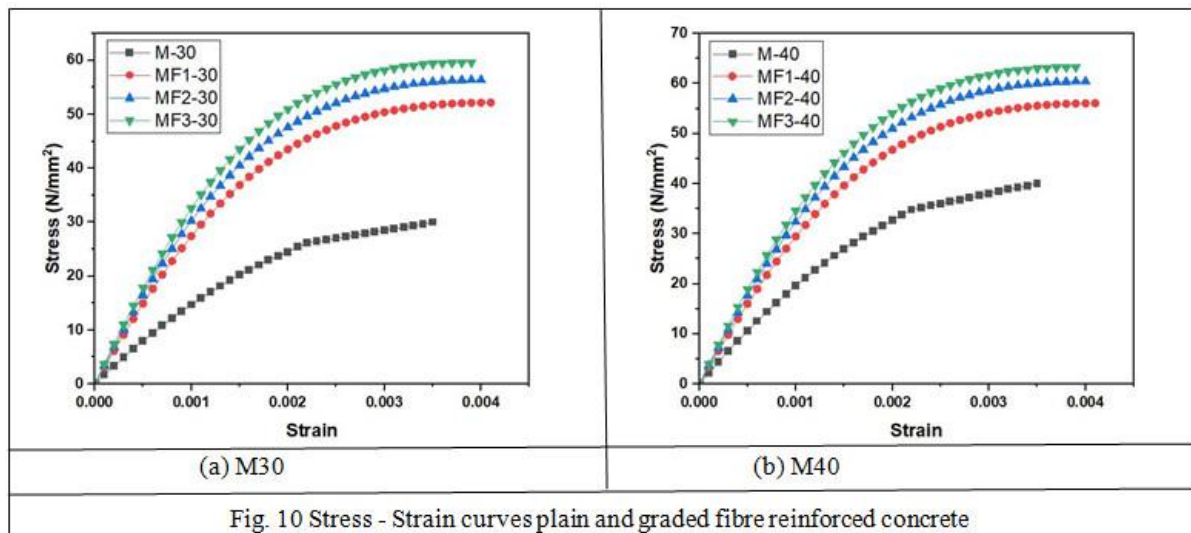
$$l = (l_1 + l_2 + l_3) / 3 \quad \text{for Triple Fiber}$$

$$\phi = \phi_1 \quad \text{for Single Fiber}$$

$$\phi = (\phi_1 + \phi_2)/2 \quad \text{for Dual Fiber}$$

$$\phi = (\phi_1 + \phi_2 + \phi_3)/3 \quad \text{for Triple Fiber}$$

Fig.10 shows the stress – strain curves for conventional SCC, single fiber, dual fiber and triple fiber reinforced SCC.



6. ANALYTICAL MOMENT-CURVATURE RELATION

To calculate the complete moment-curvature relationship for any cross section of a given member, discrete values of concrete strains ϵ_c were selected such that even distributions of points on the plot both before and after the maximum were obtained. The procedure [22] used in computation is given below

1. The extreme compressive strain ϵ_c is assumed. In present investigation the values of ϵ_c are in the range of 0.0001 to the failure strain.
2. The neutral axis depth, nd , is assumed initially as 0.5 times the effective depth.
3. For this value of N.A depth, the compressive force in the concrete, C_c was calculated from respective stress – strain model.
4. The strain in tension and compression steel is calculated based on the strain compatibility.
5. Based on the strain in tension steels the corresponding stresses were taken from idealized stress – strain curve of steel specimens.
6. The total tensile force (T) in tension steel is calculated.
7. Same process is repeated for compression steel to calculate the compressive force in compression steel (C_s).
8. The total compressive force C acting in the section is calculated as $C = C_c + C_s$.
9. If $C = T$ then the assumed value of N.A depth (nd) is correct, and the moment (M) and the corresponding curvature (Φ) is calculated. Otherwise the N.A. depth is modified until the condition $C = T$ is achieved.

The total moment about N.A. is given by

$$M = M_t + M_c + M_{cs}$$

And the corresponding curvature is given by

$$\Phi = \epsilon_c / nd$$

Where

M_t = Moment of force in tensile steel about the N.A.

M_c = Moment of compressive force in concrete about the N.A.

M_{cs} = Moment of force in compression steel about the N.A.

Φ = Curvature in radian/mm

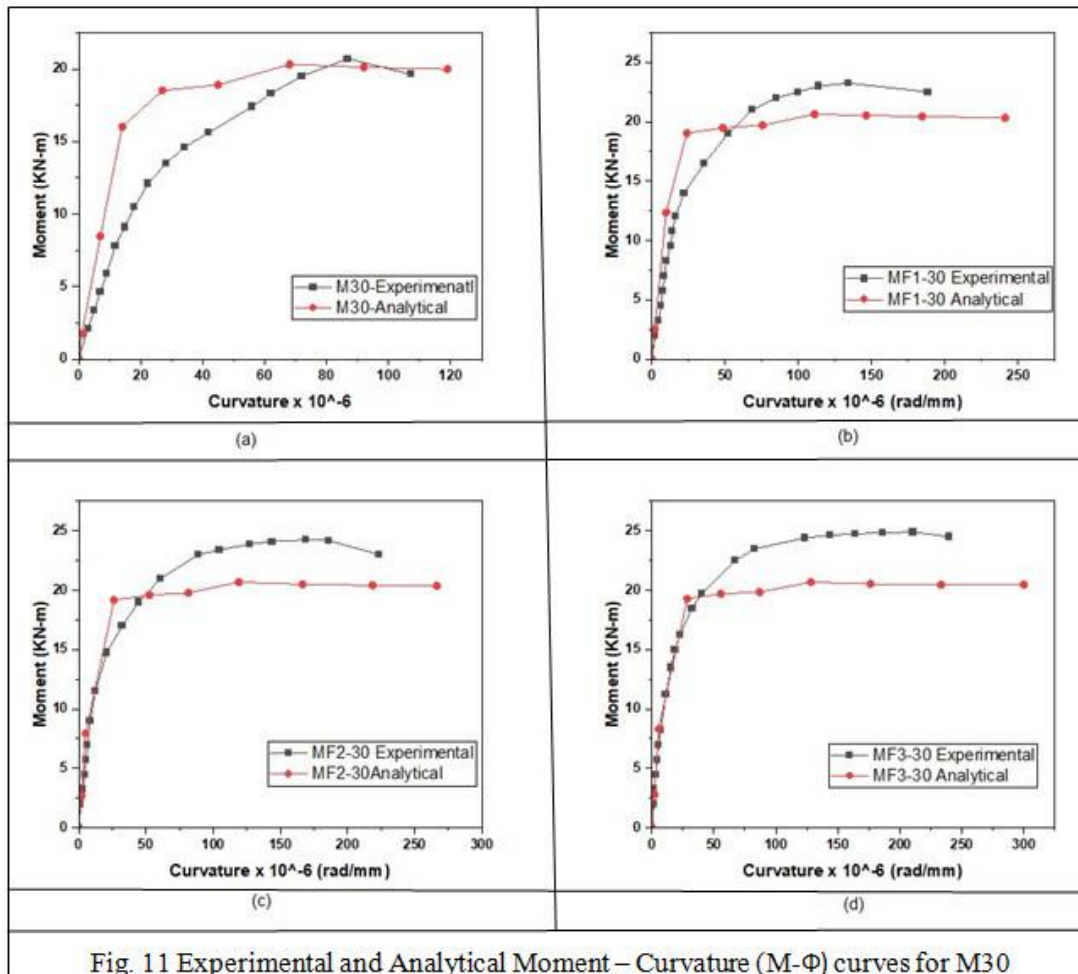
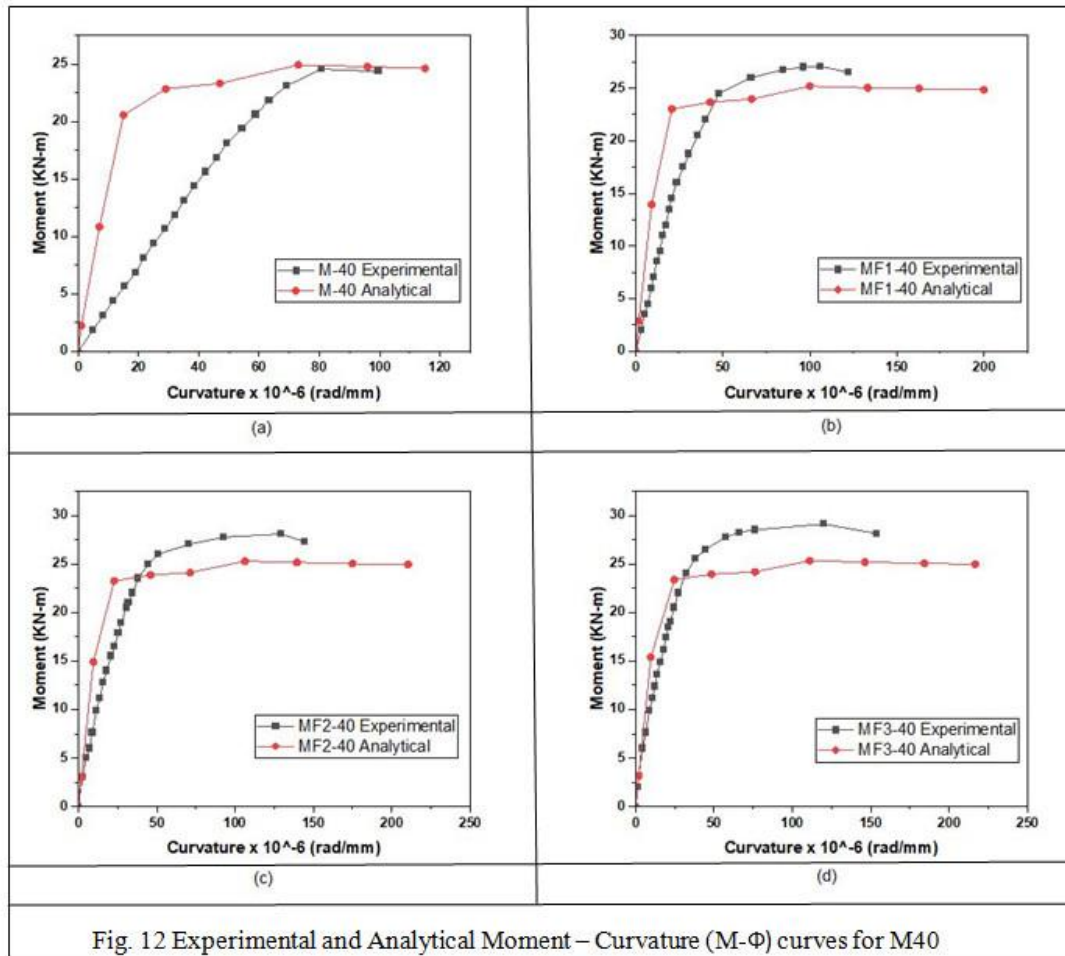


Fig. 11 Experimental and Analytical Moment – Curvature (M-Φ) curves for M30



7. COMPARISON OF EXPERIMENTAL AND ANALYTICAL MOMENT-CURVATURE RESPONSE

The moment-curvature response predicted using analytical model with those of the experimental data is shown in Figs. 11 and 12. The ratios of experimental to analytical ultimate moment carrying capacity and curvature are tabulated in Table 5. From Figs. 11(a) and 12 (a), it can be clearly observed that the ultimate moment and curvature for conventional SCC beams are almost similar for experimental and analytical data. With the addition of fibers, an increase in ultimate moment carrying capacity is observed. This shows the efficiency of fibers in resisting the cracks which in turn make it necessary to change the path of crack thereby increasing the load carrying capacity. A decrease in ultimate curvature of concrete is observed in experimental data compared to analytical prediction when mono, dual and triple fibers are blended, this is due to the assumptions made in the analytical modeling that a homogeneous dispersion of fibers is carried which in reality may differ during the process of mixing, placing along with the resistance offered by reinforcement which make some fibers to change the orientation. These fibers can speed up the propagation when they are oriented parallel to the crack.

Table 5. Comparison of analytical and experimental moment-curvature

S.No	Designation of the Beam	Ultimate moment experimental M_{ue} kN.m	Ultimate moment analytical M_{ua} kN.m	M_{ua} / M_{ue}	Curvature Experimental $\phi_e \times 10^{-6}$	Curvature Analytical $\phi_a \times 10^{-6}$	ϕ_a / ϕ_e
1	M-30	19.63	19.99	1.02	107.20	199.00	1.86
2	MF1 - 30	22.50	20.32	0.90	188.40	241.18	1.28
3	MF2 - 30	23.00	20.38	0.89	223.90	266.67	1.19
4	MF3 - 30	24.50	20.48	0.84	239.50	300.00	1.25
5	M-40	24.38	24.63	1.01	99.60	115.00	1.15
6	MF1 - 40	26.50	24.68	0.93	122.40	200.00	1.63
7	MF2 - 40	27.25	24.93	0.91	144.63	210.53	1.46
8	MF3 - 40	28.13	24.96	0.89	153.59	216.67	1.41
			Mean	0.92		Mean	1.40
			Standard Deviation	0.06		Standard Deviation	0.24
			Coefficient of variance %	6.79		Coefficient of variance %	17.15

8. FAILURE MODES

Figs. 13(a) and 13(b) show the failure modes of all the beams tested. Flexural cracks initiated in the pure bending zone of the beam and propagated vertically towards the top of the beam. Numbers of cracks were formed in conventional SCC and mono fiber SCC beams, this denser crack network is reduced when fibers are graded. The initiation of flexural crack is delayed with the blending of fibers which is due to the addition of micro fibers, resisting the formation of crack in the transition zone. As predicted all the beams failed in flexural mode with cracks originating in the pure bending zone. The beams with fibers blended showed an increase in deflection under constant loading which is a sign of ductile behavior and is attributed to the yielding of tensile steel along with fibers. When beams are loaded to failure, crushing of concrete in compression zone is observed with widening of all the cracks initiated and development of finer cracks is observed.

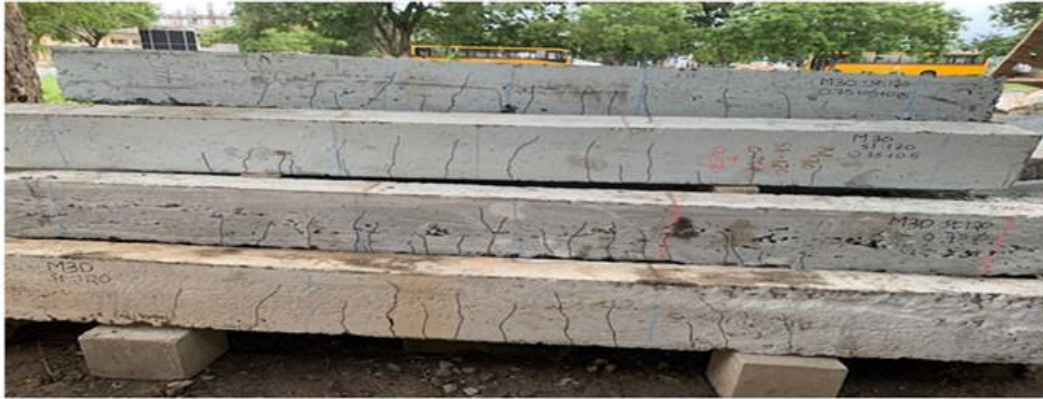


Fig.13 (a) Crack Patterns of M30 SCC Beams



Fig. 13(b) Crack Patterns of M40 SCC Beams

9.CONCLUSIONS

The experimental and analytical study was carried to understand the flexural performance of graded steel fiber reinforced self-compacting concrete by testing 16 beams of M30 and M40 grade. The following are the conclusions drawn from the study

- The workability of triple, dual and mono fibers in two grades of SCC is reduced by 10-22% with plain SCC mixes.
- The increase in compressive strength of mono, dual and triple blended M30 grade mixes are 30%, 44% and 53% respectively. Similar behavior is observed in M40 grade concrete with 26%, 38% and 44% improvement in compressive strengths.
- The tensile strength of triple blended fiber reinforced concrete for two grades showed improvement of 48% and 43% compared to corresponding plain mixes.
- The initial crack load is increased and its corresponding displacements are reduced with the blending of single, dual and triple fibers.
- A direct fall in moment – curvature plot was observed for conventional SCC beams, with the addition of single, dual and triple fibers the curve has straightened showing a yield point which is a sign of increase in stiffness for the members.
- Numbers of cracks were observed in conventional SCC and mono fiber beams, this crack density is reduced when micro fibers are blended to concrete.

- Moment-curvature curves developed using analytical models are almost similar to experimental curves for both M30 and M40 grade SCC. There is an increase in ultimate moment capacity and decrease in curvature experimentally for beams with graded fibers.
- A need to develop the stress-strain equations analytically is essential to predict the exact behavior of graded fiber reinforced SCC.

Acknowledgments

The authors have no relevant financial or non-financial interest to disclose.

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