TORSIONAL BEHAVIOR OF HYBRID FIBER REINFORCED LIGHT WEIGHT CONCRETE BEAM.

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Abstract— Structural components can fail due to severe torsional effects, particularly in vertical resisting components where torsion in the horizontal plane greatly amplifies seismic effects. If the member is not adequately reinforced for torsion, a sudden brittle failure can occur. Lightweight concrete has gained high demand recently due to its reduced weight and being sustainable. The use of lightweight concrete can reduce the self-weight of the members and thereby decreasing the cross-sectional area of the members on the load transfer path to the ground. As lightweight concrete has lower density and reduced mechanical properties comparing to concrete with natural aggregates, fibers can be added to enhance the torsional behavior of concrete. This project work is intended to study the torsional behavior of hybrid fiber reinforced lightweight concrete beam members with partial replacement of natural coarse aggregates with lightweight expanded clay aggregates (LECA). Steel fibers and polypropylene fibers are added to the concrete matrix to enhance the properties of the concrete. Cement is replaced with silica fume to improve the mechanical properties of concrete. Torque versus angle of twist response of each specimen is to be monitored and studied.

Keywords— Torsion, Angle of twist, LECA, steel fiber, polypropylene fiber

I. INTRODUCTION

Reinforced concrete members in a structure may be subjected to axial forces, shear forces, bending moments, torsion, or a combination of these effects. When external loads act far away from the vertical plane of bending, the beam gets subjected to twisting about its longitudinal axis which is known as torsion. Shear stresses due to torsion create diagonal tension stresses that produce diagonal cracking. Torsion becomes primary effect, however, for situations as in, where beams curved in plane, staircases, balcony beams, eccentrically loaded beams, curved bridges, beams supporting a secondary beam and beams in supporting sunshades and canopies are used. Light weight aggregate concrete is one which is having 28 day compressive strength more than 17 MPa. Fibre hybridization means addition of two or more different type of fibre especially, metallic and non-metallic fibres, to concrete which will result in a new composite that derives benefits from each of the individual fibers and exhibits a synergistic response. Inclusion of steel fibers imparts pseudo-ductility to brittle concrete with a significant increase in the tensile strain capacity which increases the flexural strength, cracking resistance and toughness characteristics. Polypropylene fiber is a long chain of synthetic polymer which is normally tough and flexible, especially when co-polymerized with ethylene. It has high tensile strength, wrinkle resistance and abrasion resistance.

II. OBJECTIVES

- To study the torsional behavior of hybrid fiber reinforced light weight concrete beam.

III. LITERATURE REVIEW

Various research studies are carried out on the torsional behavior of steel fiber reinforced concrete beam. Hassan et al. (2020) examined the torsional strength of synthetic and steel fibre reinforced hollow concrete beam. Fibre content of 1% with three different lengths of synthetic fibre, 19, 38, and 57 mm, along with 13 mm of steel fibre was used. Enhancement in the performance was relative to the fibre type and length because with increase in length of SY.F, the ultimate load capacity of beams increased. Hadhood et al. (2020) studied the torsional behaviour of RC beams with GFRP spirals. Rectangular spirals and rectilinear stirrups were employed to reinforce concrete beams in the transverse direction under pure torsion loading. The rectangular spiralled GFRP beam outperformed in terms of post-cracking stiffness and ultimate torque and reduced angle of twist. Reducing the pitches of the rectangular spirals, enhanced the post-cracking stiffness and ultimate torsional capacity. Kandahar et al. (2019) studied the torsional behaviour of reinforced concrete beam wrapped with aramid fibre. The moment carrying capacity of the strengthened beam fully wrapped with aramid fibre was found to be maximum compare to all the beams. RC beams strengthened with fully wrapped aramid fibre and aramid fibre strips of 100 mm has taken 140% and 80% more moment at first crack when compared with controlled beam.

Nitesh et al. (2019) investigated on torsional behaviour of recycled aggregate based steel fibre reinforced self-compacting concrete. With the addition of steel fibres, the ultimate torsional strength and angle of twist were increased. Results showed that with the increase in aspect ratio of the steel fibre from 50-70, there is an increment in torsional toughness, ultimate torsional strength and twist at ultimate torque.

George et al. (2018) studied the torsional and cracking behaviours of normal weight and coconut shell lightweight concretes. Steel fibres enhance the torsional strength of reinforced concrete beams subjected to torsion. Coconut shell concrete produces beams of higher torsional resistance than normal weight concrete. Crack width was found to be decreasing as the percentage of steel fibres increased.

Teixeira et al. (2018) studied the ductility of RC beams under torsion. Results showed that the torsional ductility increases as the compressive strength increases in case of plain RC beams, whereas opposite tendency is observed for hollow RC beams. Torsional ductility decreases notably as the total torsional reinforcement ratio increases.

Zhou et al. (2017) investigated on torsional behaviour of FRC and ECC beams reinforced with GFRP bars. Polypropylene fibres could inhibit the crack propagations on the beams effectively. The torsional toughness of the beams were improved by the fibres significantly.

IV.MATERIAL PROPERTIES AND MIX DEIGN

Mix selected for this investigation was M20 grade concrete. Portland Pozzolana Cement of specification IS 1489 (Part 1) [17], crushed stones of 20 mm coarse aggregate, manufactured sand passing through sieve of size 4.75 mm and confirming to zone II of IS 383-1970 (reaffirmed 2002) as fine aggregates, water were used [18]. The mix design was done as per IS 10262-2009 and the mix proportion that obtained was 1:2.02:3.55.40% of the coarse aggregate was replaced by LECA to develop light weight concrete. Silica fume is varied by 15% of the cement in all the LECA replaced mixes. For fibre reinforced light weight concrete steel fibre of 25% and polypropylene fibre of 75% is adopted.

V.EXPERIMENTAL PROGRAMME

A. Reinforcement Work and Casting

Reinforcement was placed inside the beam mould with an effective cover of 25mm. The concrete was then poured inside and compacted well. It was demoulded the next day and covered with moist rags for 28 days for curing. The reinforcement detail is as shown in Fig.1. There are total 12 specimens divided into four groups, each having three specimens each.

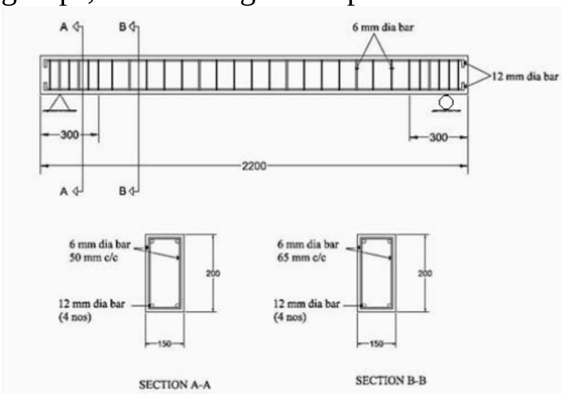

Fig.1: Layout of beam(all dimensions are in mm)

First one is the control beam (CB). The second specimen is light weight beam (LWB) in which 40% of the coarse aggregate is replaced with LECA. The third specimen is light weight beam with silica fume (LWBS). The fourth specimen is hybrid fibre reinforced light weight beam which has both steel fibre and polypropylene fibre and silica fume.

B. Test setup and Testing

Two shot put balls of eight pounds each are used to create the simply supported condition. Two metal plates are placed above and below the shot put balls having CNC done on the contact surface. One shot put ball is bolted to the plate below it to give the hinge effect to the plate placed above it while the other shot put ball is placed in between the CNC's to give the roller effect.

Fig.2: Simply Supported Condition (Hinge and Roller)

Concrete pillars were made (Fig.3) having centre to centre distance of 2 metres and the height of the pillars were fixed according to the height required for the test setup. The shot put balls with plates were then placed on the pillars. After that the test specimen to be tested was placed on the simply supported condition (Fig.4).

Fig.3: Pillar supports

Fig.4: Specimen placed on supports

The beams were placed on metal plates above the shot put balls and fabricated lever arms of 1m length are fixed on to the ends of the beam. One lever arm is connected to a universal load cell which is connected to a push pull jack connected to a loading frame. This push pull jack pulls down the lever arm to create torsional force on the beam. The second lever arm is connected on the other end of the beam in the opposite direction and the reaction is transferred through turn buckles hooked to the anchor bolt provided on the floor. The loading is done by using the push pull jack and as the lever at the loading end is pulled down, the other lever arm being fixed to ground using turn buckles resists the load. Since the support condition is simply supported, it allows free rotation of the lever arm which in turn ends up in twisting the beams. The loading is done by using push pull jack. Loading of 0.2kN interval was applied with the hydraulic jack, having a universal load cell attached on it, until the specimen failed to take further load. Deflections were noted by dial gauges of least count 0.01mm and angle of twists were found out for the corresponding loads. Crack patterns were also noted while testing.

Fig.5: Loading end

Fig.6: Reaction end

Fig.7: Torsion Test Setup

VI. RESULTS AND DISCUSSIONS

A. *Torsion and Angle of Twist*

Fig.8 shows the torque versus angle of twist curve. From the graph it can be seen that by replacing 40% of the natural coarse aggregate by LECA in light weight beam, there has been a significant decrease in the torque carrying capacity and the angle of twist. But on the addition of silica fume to the light weight beam, the graph shows an improvement in the torque values because silica fume improves the cohesiveness of the concrete and minimizes the induction of micro-cracks. Also it can be clearly seen that addition of steel fibres and polypropylene fibres have significantly increased the torque carrying capacity and the angle of twist.

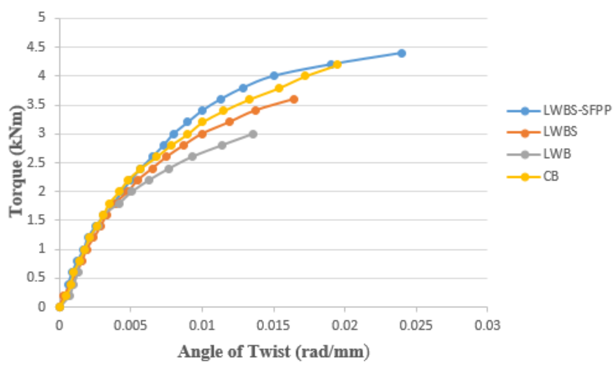

Fig.8: Torque vs angle of twist curve

TABLE I: INITIAL AND ULTIMATE TORQUES AND CORRESPONDING ANGLE OF TWISTS

Specimen	Initial cracking torque T_{cr} (kNm)	Angle of twist for initial cracking torque ϕ_{cr}(rad/mm)	Ultimate cracking torque T_u (kNm)	Angle of twist for ultimate torque ϕ_u (rad/mm)
CB	3.2	0.01	4.2	0.0195
LWB	2.2	0.0063	3	0.0136
LWBS	2.8	0.0087	3.6	0.0164
LWBS-SFPP	3.2	0.009	4.4	0.024

B. *Crack Patterns*

The crack patterns for the four specimens are shown below. In the case of control beam and hybrid fibre reinforced light weight concrete beam the cracks were formed such that they circulated along the periphery of the beam like a continuous spiral crack. . In the control beam the number of cracks were less compared to the beams having steel fibres and polypropylene fibres and the space between the adjacent cracks were less in hybrid fibre reinforced light weight beam.

i) Control Beam

The first crack of the control beam occurred on the deeper side of the beam at an initial torque of 3.2kNm and the ultimate cracking torque was 4.2kNm. The cracks developed all around the section and severe cracking was observed on the mid faces of sides of the rectangular section. The average number of cracks occurred were 7 and the average space between the adjacent cracks were 20cm.

Fig 9. Crack patterns on the sides and top face of control beam

As the cracks formed it connected and they circulated along the periphery of the beam like a continuous spiral crack. Fig.10 shows the continuous spiral pattern of cracks of control beam.

Fig 10. Continuous spiral cracks of control beam

ii) Light weight beam

The first crack of the light weight beam occurred at an initial torque of 2.2kNm and the ultimate cracking torque was 3kNm. The mechanical properties of the lightweight concrete are comparatively less than that of the concrete with natural aggregates. This is due to the weak strength properties of the lightweight aggregates. The number of cracks were limited on the light weight beam compared to the control beam as the beam was brittle. Spalling of concrete was observed at the end of light weight beam.

Fig 11. Crack patterns on the sides and top face of light weight beam

iii) Light weight beam with silica fume

The first crack of the light weight beam with silica fume occurred at an initial torque of 2.8kNm and the ultimate cracking torque was 3.6kNm. The torque vales were improved due to the addition of silica fume. This is because silica fume improves the cohesiveness of the concrete and minimizes the induction of micro-cracks. The cracks were observed at the end side of the beam and and the cracks were limited as similar to the light weight beam.

Fig 12. Crack patterns on the sides and top face of light weight beam with silica fume

iv)Hybrid fiber reinforced light weight beam with silica fume

The first cracks occurred at the middle of the longer side at an initial cracking torque of 3.2kNm. Then the cracks connected with the cracks on the shorter side forming spiral cracks. The addition of steel fibers delayed the initial crack formation. The number of cracks increased and the spacing between the cracks were less as compared to the cracks in the control beam. This is due to the bridging effect of steel fibre and polypropylene fibre. Even due to the weak strength properties of LECA, addition of steel fibre, polypropylene fibre and silica fume improved the ultimate torque of fibre reinforced light weight beam to 4.4km as compared to the control beam.

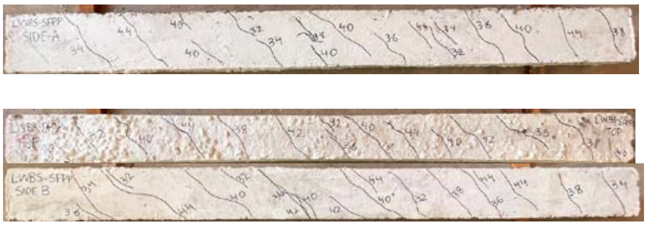

Fig 13. Crack patterns on the sides and top face of hybrid fibre reinforced light weight beam with silica fume

Fig 14. Continuous spiral cracks of hybrid fibre reinforced light weight beam with silica fume

VII. CONCLUSIONS

From the experimental investigation conducted and the analysis of results obtained, the following conclusions were obtained.

- LECA can be used to develop lightweight concrete of grade M30 by replacing 40% of natural coarse aggregates with LECA in addition with silica fume, steel fiber and polypropylene fiber even due to the weak strength properties of LECA.
- A reduction of 25% in the weight of concrete with lightweight aggregate was observed while comparing with the weight of concrete with natural aggregates
- The load carrying capacity was more for fiber reinforced light weight beam with silica fume and greater load was required to produce the same angle of twist when compared to the light weight beam with only LECA.
- Addition of steel fibers and polypropylene fibers decreased the widths of cracks, whereas an increase in the number of cracks.
- Addition of silica fume to the light weight beam improved the torque values as it improved the cohesiveness of concrete and prevented the induction of micro-cracks.

VIII. REFERENCES

[1] **Hassan, R.F., Jaber, M.H., Salim, N.H.** and **Hussein, H.H.,** (2020), Experimental research on torsional strength

of synthetic and steel fibre-reinforced hollow concrete beam, *Engineering Structures*, 220, p.110948.

[2] **Peedikayil,J.J.** and **George,T.,** (2017), Torsional behaviour of steel fibre reinforced concrete beams, *International Journal of Engineering and Technology(IJEAT),* ISSN:2249-8958,Volume-7,Issue-ICMSC17.

[3] **George, A.** and **Sofi, A.,** (2018), Torsional and cracking behaviours of normal weight and coconut shell lightweight concretes, *Journal of Engineering Science and Technology (JESTEC)*, 13(12), pp.4104-4117.

[4] **Ragab, K.S.** and **Eisa, A.S**.,(2013), Torsion behaviour of steel fibered high strength self-compacting concrete beams reinforced by GFRP bars. *International Journal of Civil Science and Engineering*, *7*(9), pp.218-228.

[5] **Nitesh, K.S., Rao, S.V.** and **Kumar, P.R.,** (2019), An experimental investigation on torsional behaviour of recycled aggregate based steel fibre reinforced self-compacting concrete, *Journal of Building Engineering*, 22, pp.242-251.

[6] **George, A.** and **Sofi, A.,** (2018), Torsional and cracking behaviours of normal weight and coconut shell lightweight concretes, *Journal of Engineering Science and Technology (JESTEC)*, 13(12), pp.4104-4117.

[7] **Teixeira, M.M.** and **Bernardo, L.F.A**., (2018), Ductility of RC beams under torsion. *Engineering Structures*, 168, pp.759-769.

[8] **Zhou, J., Shen, W.** and **Wang, S.,** (2017), Experimental study on torsional behaviour of FRC and ECC beams reinforced with GFRP bars, *Construction and Building Materials*, 152, pp.74-81.

[9] **Alabdulhady, M.Y., Sneed, L.H.** and **Carloni, C.,** (2017), Torsional behavior of RC beams strengthened with PBO-FRCM composite – an experimental study, *Engineering Structures*, 136, pp.393-405.

[10] **Zhou, J., Shen, W.** and **Wang, S.,** (2017), Experimental study on torsional behaviour of FRC and ECC beams reinforced with GFRP bars, *Construction and Building Materials*, 152, pp.74-81.

[11] **Behera, G.C., Rao, T.G.** and **Rao, C.B.K.,** (2016), Torsional behaviour of reinforced concrete beams with ferrocement U-jacketing—Experimental study. *Case Studies in Construction Materials*, 4, pp.15-31.

[12] **Mastali, M.** and **Dalvand, A.,** (2016), Use of silica fume and recycled steel fibers in self-compacting concrete (SCC), *Construction and Building Materials*, 125, pp.196-209.