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TORSIONAL AND CRACKING BEHAVIOURS OF NORMAL WEIGHT AND COCONUT SHELL LIGHTWEIGHT CONCRETES

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Abstract

Modern-day structures using conventional concrete, which is tall and aesthetically pleasing is in need of torsional strengthening. The ability of a structure to withstand twisting forces about a longitudinal axis is called torsional strength. In this study, torsional behaviour of normal weight concrete (NWC) and lightweight concrete (LWC) is analysed. Coconut shell aggregate is used instead of broken granite to make lightweight concrete. Torsional strengthening is done using crimped steel fibres. A torsion-loaded member will result in torsional cracking commencing before the flexural failure, as the torsional strength is highly dependent on the tensile strength, which is the weakest component in brittle concrete. Steel fibres in optimum amount can impart homogeneous tensile properties in concrete, which in turn increases torsional capacity. Fibres are added in 0.5%, 0.785% and 1% by volume to both NWC and LWC. Basic mechanical properties such as compressive strength, split tensile strength and flexural strength are analysed using cubes, cylinders and prism for 7 days and 28 days. Torsional strengthening studies are carried out on beams of size 1100x150x100 mm. Comparative study of results in NWC and LWC is done with control mixes of corresponding mixes. Comparison between torsional behaviour of NWC and LWC is also done. Torque-Angle of twist responses of all mixes is also found. LWC showed more torque value and angle of twist than NWC. Steel fibres enhanced these properties in both mixes.

Keywords: Coconut shell concrete (CSC), Fibre reinforced concrete, Normal weight concrete (NWC), Torsion, Steel fibre.

1. Introduction

Concrete has a relatively high compressive strength, but much lower tensile strength, limited ductility and little resistance to cracking. When a load acts tensile stresses are induced in concrete resulting in the cracking of concrete. The recent building trends are focused on the concepts of being more economical and space efficient and aesthetic design in which, the structural members are designed to be irregular or curved in shape. The curved members will be eccentrically loaded, which will induce torsion in the members. Typical examples of torsion-loaded structures include utility poles, eccentrically structures, spiral staircases, spandrel beams and curved beams. Thus, it is understood that modern buildings are in need of torsional strengthening.

Steel reinforcement is used to absorb tensile stresses and to prevent the cracking to some extent. The addition of steel reinforcement significantly increases the tensile strength of concrete but to produce concrete with homogeneous tensile properties the microcracks developed in concrete should be suppressed [1]. As commented by Mahadik and Kamane [2], it has been found that the addition of fibres to concrete would act as crack arresters and would substantially improve its static and dynamic properties. Steel fibre reinforced concrete has superior resistance to cracking and crack propagation. They will impart homogenous tensile properties to concrete and thus improve torsional capacity also.

Construction using LWC has more future potential due to its low density and cost reduction. Structural LWC offers design flexibility and cost savings due to weight reduction, improved seismic response, and lower foundation costs. Coconut Shell Concrete (CSC) could be used in places where coconut is abundant and may also be used where the granite aggregates are costly. Researches proved that wood-based materials, being hard and of organic origin, will not contaminate or leach to produce toxic substances once they are bound in concrete matrix [3]. Addition of fibre to concrete will enhance the flexural behaviour as well as other mechanical properties [4, 5]. Since torsion is phenomena that occur on all faces of a concrete member, the steel fibres will induce tensile behaviour on all sides and thereby will improve torsional capacity [6]. Studies by Sofi and Phanikumar [7] on fibre reinforced concrete proves that it is more durable than conventional concrete.

As explained by Gunasekaran et al. [8], long-term studies on CSC confirms that there is good bond strength between coconut shell and cement paste [8]. Torsional studies on normal concrete, ultra high-performance concrete and squared beams emphasise the strengthening requirements of concrete beams [9, 10]. Presence of steel fibres will reduce the brittleness of concrete, which is attributed to the crack bridging effect [11]. Rao and Seshu [12] found that steel fibre is very effective in improving the torsional strength of higher brittleness. Crack widths of concrete with fibre is also found to be less [13].

The study on the torsional behaviour of concrete is limited, especially in the case of lightweight concrete. This study aims at the understanding the effect of steel fibres in normal weight concrete (NWC) and coconut shell concrete (CSC).

2. Experimental Program

2.1. Materials used

To carry out experimental investigation various material were used. The following section explains the materials used in this study.

2.1.1. Cement

Ordinary Portland Cement (OPC) of 53 grade was used. The specific gravity of cement was found to be 3.15.

2.1.2. Aggregates

Sand from Palar River was used as fine aggregate. The specific gravity of fine aggregate was found out to be 2.59. Locally available crushed granite was used as coarse aggregate in NWC mixes. The size of granite aggregate used was between 20 mm and 12.5 mm. Coconut shells (CS) were collected from market waste and was broken into 12.5 mm size using a hammer. According to Rahal [14], since coconut shells have high water absorption, CS aggregates were used in saturated surface dry condition to avoid water absorption in the concrete matrix. Table 1 shows the physical properties of CS and granite aggregates.

Table 1. Physical properties of CS and granite aggregates.

	Maximum size(mm)	Moisture content	Specific gravity	Water absorption
Coconut shell	12.5	9.7%	1.31	23.7 %
Granite	20	0.3%	2.78	0.5%

2.1.3. Water and superplasticizer

Potable water with a pH value of 6 was used for both the mixing and curing processes. A high-end superplasticizer (Cera Hyperplast XR-W40) was added to the CSC mixes to improve the workability, at a constant amount of 0.7% of the binding material by weight [1].

2.1.4. Fibres

Grooved steel fibres of 50 mm length and 1 mm diameter was used to produce fibre reinforced NWC and CSC mixes. Fibres were used in 0.5%, 0.75% and 1% by volume of concrete.

2.2. Mix Design

Total of eight mixes were made for this investigation. Four of the mixes were normal weight concrete (NWC-0%) using granite aggregates and four were coconut shell concrete (CSC-0%) using coconut shell as coarse aggregate. 0.5%, 0.75% and 1% steel fibres by volume of concrete were added to NWC-0% and designated as NWC-0.5%, NWC-0.75% and NWC-1%.The same percentage of fibres were added to CSC-0% and was designated as CSC-0.5%, CSC-0.75% and CSC-1%. NWC was designed as per IS 10262-2009. CSC was designed based on works of Gunasekaran et al. [8] and Yap et al. [1]. Silica fume was added at 10% by weight of cement to compensate for the reduction in strength due to the replacement of granite with coconut shell [1]. The mix designs obtained are tabulated in Table 2.

Table 2. Mix design.

Mix	OPC (kg/m^3)	Silica fume (kg/m^3)	Water (kg/m^3)	Sand (kg/m^3)	Granite (kg/m^3)	CS (kg/m^3)
NWC-0%	384	-	192	678	1190	-
CSC-0%	550	55	186	830	-	550

2.3. Specimens for tests

For testing the mechanical properties of each mix proportion, 100 mm cubes, 200 mm length 100 mm diameter cylinders and flexural testing on 500 mm × 100 mm × 100 mm prisms were cast for a compression test, split tensile test and flexural test respectively as per IS specifications. The specimens were removed from the moulds after 24 hours and were put in a curing tank. Tests were conducted on 7 days and 28 days. For torsion studies, beams were cast of size 1100 mm × 150 mm × 100 mm with an effective length of 1m as shown in Fig. 1. As in the case of mechanical properties, beams were water cured for 28 days. Reinforcement details of the torsion beam are shown in Fig. 1.

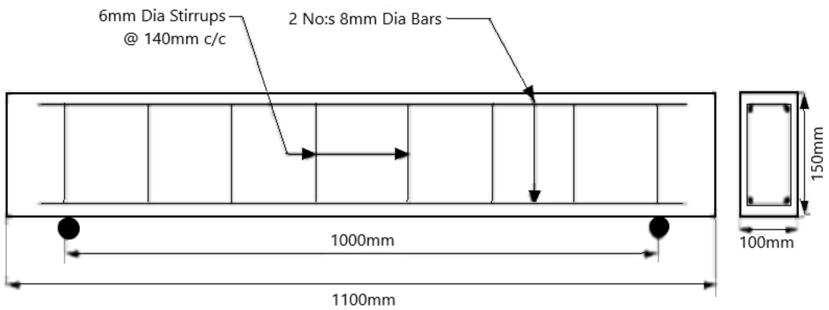

Fig. 1. Reinforcement details of beam.

2.4. Test procedures

For compressive strength, split tensile strength and flexural strength methods where followed as per IS specifications. Torsion testing was done on a Universal Testing Machine. The test setup was made using channel sections and flat plates [6]. The torsion test setup and schematic setup of end support are shown in Fig. 1. The angle of twist was measured with the help of a dial gauge [9]. Arc supports were provided for the end support systems to facilitate twisting motion laterally. The load was applied at an eccentricity from the arc support for creating the torsion effect. This was made possible by transferring the load from UTM to both ends on opposite sides using a spreader beam. Figure 2 shows the actual torsion test setup and the schematic diagram of the end support setup.

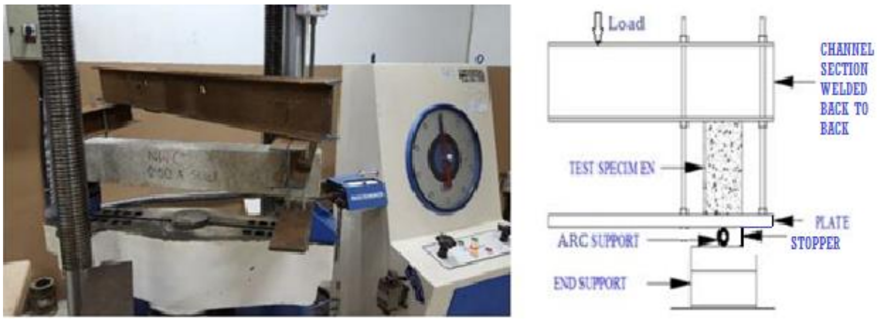

Fig. 2. Torsion test setup in UTM and schematic setup of end support.

3. Results and Discussions

3.1. Workability

NWC-0% mix exhibited higher workability of 75 mm against the 50 mm workability of CSC-0% mix. A high amount of cement paste is required for the formation of CSC aggregate-cement paste bond, which reduces the flowability of the mix. When 0.5% fibre was added the workability of both mixes reduced. NWC-0.5% mix had workability of 55 mm and CSC-0.5% had workability of 20 mm.

Further addition of fibre at 0.75% and 1% to NWC mixes reduced workability to 45 mm and 40 mm respectively. The same amount of steel fibres in CSC mixes provided slumps of 15 mm and 10 mm. Figure 3 shows the variation of workability with a change in the percentage of steel fibres.

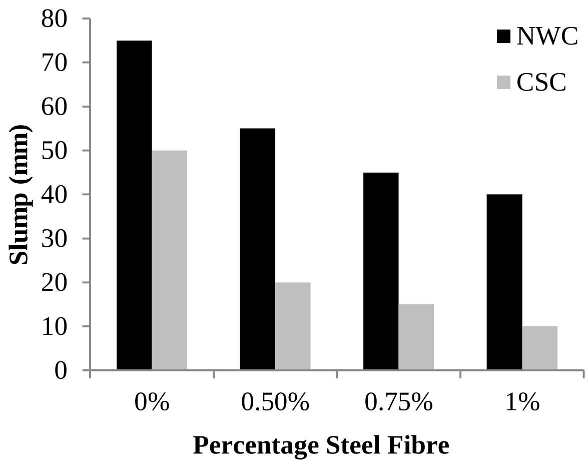

Fig. 3. Workability chart.

3.2. Density

The density of NWC mix was found to be 2398 kg/m3 and that of CSC was 1995 kg/m3, hence classified as structural lightweight concrete. By the addition of 0.5% steel fibre, the densities increased to 2493 kg/m3 and 2089 kg/m3 for NWC-0.5%

and CSC-0.5% respectively. Maximum density obtained at 1% steel fibre was 2601 kg/m3 for NWC and 2193 kg/m3 for CSC mixes. At 0.75% steel fibre NWC mix had a density of 2544 kg/m3 and CSC mix had a density of 2142 kg/m3.

The workability and density results obtained were satisfactory. The work of Yap et.al [1] says that lower slump values of lightweight concrete is comparable to medium slump values of normal weight concrete. Workability and density had an inverse relation, that is, workability of mixes in both series decreased when the density increased. Figure 4 shows the density change in both NWC and CSC series to the change in steel fibre percentage. Workability and density of both mixes were inversely related [14].

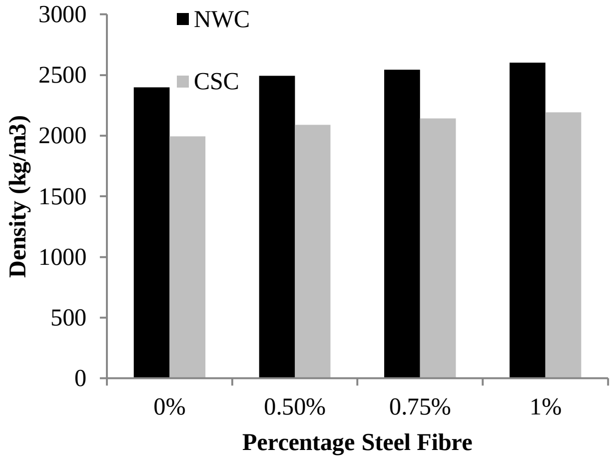

Fig. 4. Density of mixes.

3.3. Mechanical properties

Table 3 shows the test results of compressive strength, split tensile strength and flexural strength. The mixes were compared on the basis of strength. Hence the 28-days compressive strengths of both the mixes were made approximately same. This was done to obtain an exact comparison between normal weight concrete and lightweight concrete of the same grade.

Compressive strength showed a steady increase by the addition of fibres. However, the rate of increase was less when fibre content was increased from 0.75% to 1%. On the contrary, the flexural strength and split tensile strength decreased when fibre content was increased from 0.75% to 1%.

The decreases in flexural and split tensile strengths were 13.3% and 2.5% respectively in the case of normal weight concrete. For coconut shell concrete, for the same variation in the percentage of steel fibres, the decreases in flexural strength and split tensile strength were 1.69% and 0.96% respectively.

Table 3. Mix design.

Mix	Compressive strength (N/mm²)		Split tensile strength (N/mm²)		Flexural strength (N/mm²)	
	7-days	28-days	7-days	28-days	7-days	28-days
NWC-0%	23.9	32.2	2.01	2.69	8.67	9.42
NWC-0.5%	37.7	44.2	2.643	3.206	9.67	10.417
NWC-0.75%	43.2	58.97	3.067	3.678	9.08	10.67
NWC-1%	50.67	59.97	2.99	3.56	8	9.25
CSC-0%	21.9	30.167	1.83	2.34	5.5	7.25
CSC-0.5%	27.6	35.36	2.632	3.46	6.5	9.583
CSC-0.75%	30.33	35.36	2.908	3.46	8.58	10
CSC-1%	32.83	36.6	2.88	3.32	8.25	9.83

3.4. Torsional behaviour

The cracking torque and ultimate torque values of all the mixes are given in the table. The angle of twist was also measured for all beams. For every mix torque versus angle of twist, graph was plotted. The torsional strength of both controls mixes increased on addition of fibres. However, torsional strength slightly reduced when fibre content was varied from 0.75% to 1%. Maximum torsional resistance was shown by 0.75% fibre in both mixes. Therefore, 0.75% of steel fibre by volume can be considered as the optimum fibre dosage. Table 4 shows the cracking and ultimate torque of all mixes. Figures 5 and 6 show the torque versus angle of twist graph for NWC and CSC mixes.

From the graph, it is clear that 0.75% fibre content in both mixes gave maximum values for torque and angle of twist. Cracking torque is the torque at which, the first crack was formed. After cracking torque, the rate of increase in torque with respect to the angle of twist is less. This is the yielding stage of the beam. It undergoes twisting without a considerable increase in load. All mixes with fibre exhibited considerably good torsional strength compared to control mixes of both types of concretes. Comparison between each mix is based on the percentage of fibre is also carried out in this paper.

Table 4. Cracking and ultimate torque.

Mix	Cracking torque (kNm)	Ultimate torque (kNm)
NWC-0%	2.146	2.55
NWC-0.5%	3.825	4.05
NWC-0.75%	5.994	6.512
NWC-1%	5.624	6.216
CSC-0%	4.35	4.8
CSC-0.5%	5.1	5.325
CSC-0.75%	6.734	7.252
CSC-1%	6.142	6.512

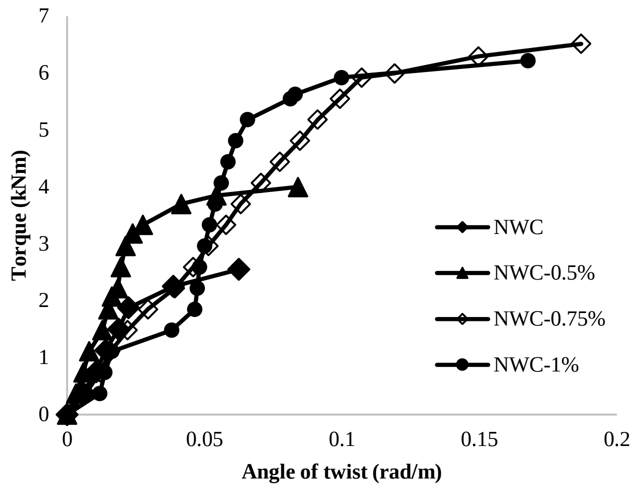

Fig. 5. Torque vs. angle of twist in NWC.

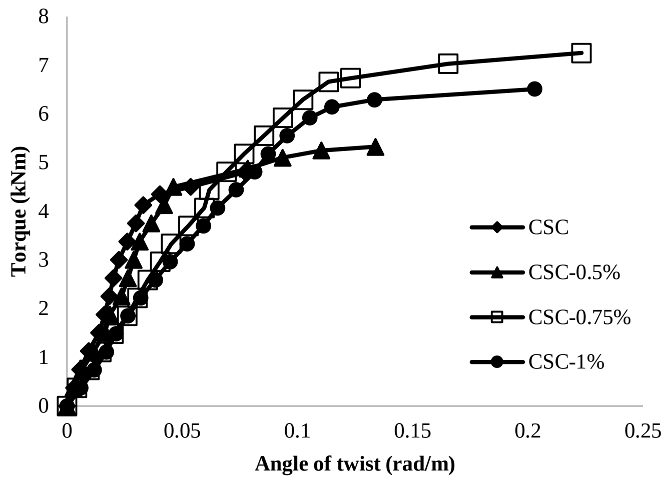

Fig. 6. Torque vs. angle of twist in CSC.

3.5. Crack analysis

After torsion testing crack analysis was carried out on all the beams. A digital microscope was used to measure the crack widths. All the cracks in each beam were measured for its width. The sum of all the crack widths in a beam divided by the number of cracks in that beam gave the average crack width. For beams of both types of concretes, the average crack width was maximum for control mix. In NWC series, beams control mix had an average crack width of 1.4583183 mm, which decreased to 0.922472773 mm, 0.86430037 mm and 0.81941628 mm on the addition of 0.5%, 0.75% and 1% steel fibre respectively.

The CSC series mixes had comparatively lesser crack width than NWC series mixes. In CSC series for 0%, 0.5%, 0.75% and 1% fibre content the crack widths were 1.0512206 mm, 0.73295015 mm, 0.56759068 mm and 0.55317806 mm respectively. Figures 7 and 8 shows the maximum and average crack width of beams versus the percentage of steel.

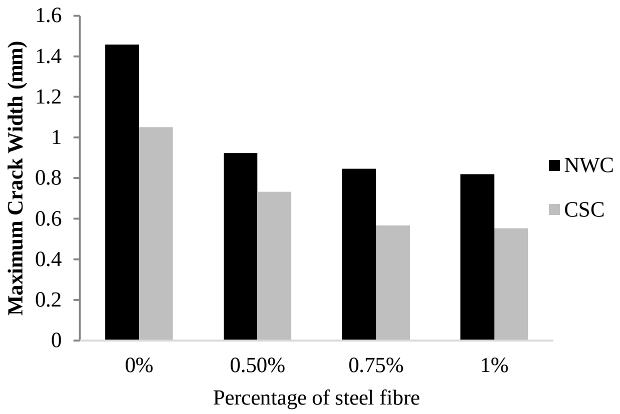

Fig. 7. Maximum crack width.

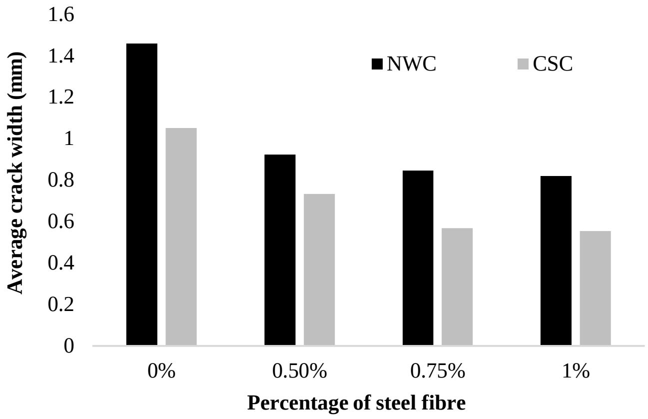

Fig. 8. Average crack width.

3.6. Comparison of behaviour of beams

3.6.1. Comparison between NWC-0% and CSC-0%

NWC-0% beam exhibited the first crack at the torsional moment of 2.146 kNm. The ultimate torque was 2.55 kNm and angle of twist was 0.0624 rad/m. The CSC mix showed more torsional strength than NWC mix. It had a cracking torque of 4.35 kNm and ultimate torque of 4.8 kNm. The angle of twist at ultimate load was 0.077 rad/m. There was an increase of 88.43% in the strength of CSC-0% beam when compared to NWC-0% beam.

In the crack analysis, though NWC-0% beam exhibited a maximum crack width of 3.456 mm, which is only 8.95% more than the crack in CSC-0% beam, the average crack width of NWC-0% beam was 38.72% more than CSC-0% beam. Figure 9 is the Torque versus angle of the twist response curve for 0% steel fibre.

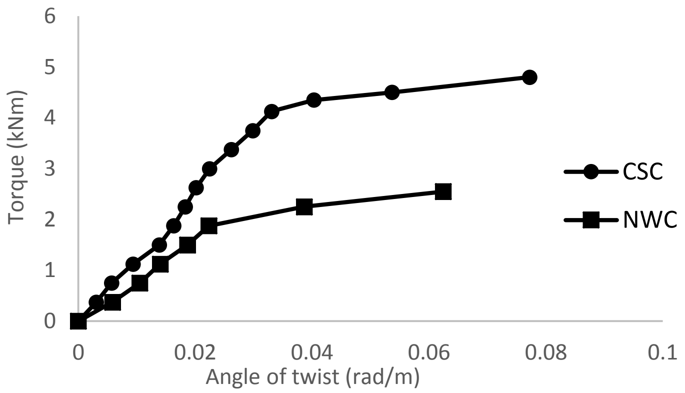

Fig. 9. Torque v/s Twist for 0% fibre.

3.6.2. Comparison between NWC-0.5% and CSC-0.5%

The NWC-0.5% mix beam had a cracking torque of 3.825 kNm and ultimate torque of 4.05 kNm with an angle of twist of 0.084 rad/m. The CSC-0.5% mix exhibited more values for cracking and ultimate torque than NWC-0.5% mix. The cracking toque was 5.1 kNm and ultimate torque was 5.325 kNm. The angle of twist was 0.134 rad/m. The increase in strength of CSC-0.5% beam was 31.48%, which is much less when compared to the increase in the control mix strength. This increase in strength of NWC mix is attributed to the presence of steel fibres.

The maximum crack width reduced from 2.33216 mm in NWC mix to 1.766 mm in CSC mix. The average crack width of NWC mix is only 25.8% more than that of CSC mix. This is due to the presence of steel fibres, which will impediment the development of cracks. Figure 10 is the Torque versus angle of the twist response curve for 0.5% steel fibre.

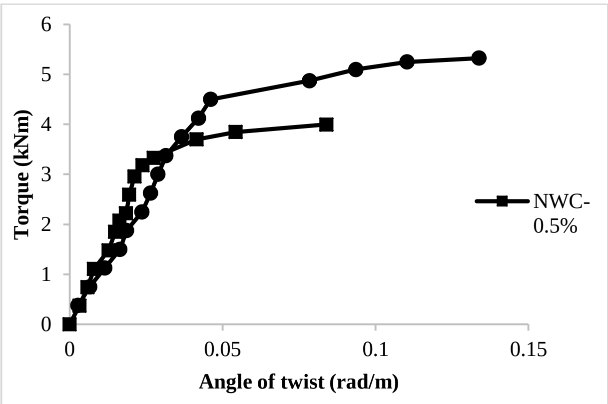

Fig. 10. Torque vs. twist for 0.5% fibre.

3.6.3. Comparison between NWC-0.75% and CSC-0.75%

The beams with 0.75% steel fibre in both mixes had a maximum value of torsional strength. The CSC mix had ultimate torque of 7.252 kNm and cracking torque of 6.734 kNm. Ultimate torque and cracking torque in NWC mix were 6.512 kNm and 5.994 kNm respectively. The strength of CSC mix only 11.36% more than NWC mix. The angle of twist in CSC mix was 0.2239 rad/m and that of NWC mix was 0.187019 rad/m.

The torsional strength of CSC beam is 11.36% more than NWC beam. From this, it is evident that steel fibres improved the torsional capacity of NWC beam significantly so that the margin between the strengths of NWC and CSC mixes is reduced by the increase in fibre content. The maximum crack width of CSC mix is 23.1% less than that of NWC mix. However, the average crack width of NWC mix exceeds only by 0.278705 mm. Figure 11 is the torque versus angle of twist response of 0.75% steel fibre.

The NWC-1% beam exhibited the first crack at the torsional moment of 5.624 kNm. The ultimate torque was 6.216 kNm. The angle of twist was 0.167642 rad/m. With an increase of strength of 4.76%, CSC had a maximum torque of 6.512 kNm and the cracking torque was noted to be 6.142 kNm. The angle of twist at ultimate torque was 0.20301 rad/m.

The maximum crack width of CSC mix is 1.453399 mm, which is 29.7% less than that of NWC mix, which comes up to 2.066458 mm. The difference in average crack width is 0.266 mm, which is similar to the average crack difference in 0.75% mixes. Figure 12 shows the torque versus angle of twist response of 1% steel fibre.

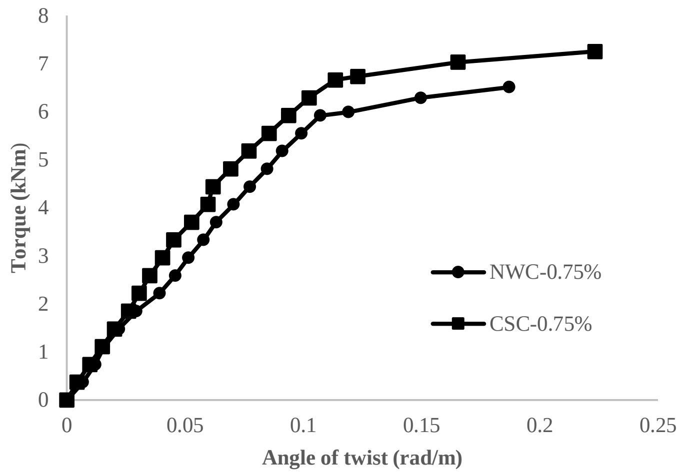

Fig. 11. Torque vs. twist for 0.75% fibre.

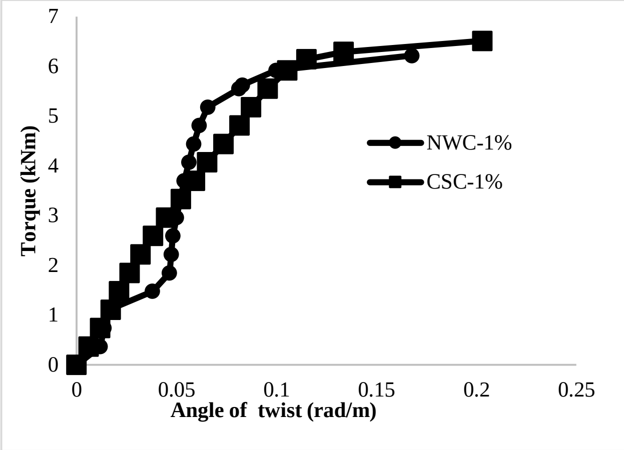

Fig. 12. Torque vs. Twist for 1% fibre.

3.6.4. Comparison between NWC-1% and CSC-1%

The NWC-1% beam exhibited first crack at torsional moment of 5.624 kNm. The ultimate torque was 6.216 kNm. The angle of twist was 0.167642 rad/m. With an increase of strength of 4.76% CSC had a maximum torque of 6.512 kNm and the cracking torque was noted to be 6.142 kNm. The angle of twist at ultimate torque was 0.20301 rad/m. The maximum crack width of CSC mix is 1.453399 mm which is 29.7% less than that of NWC mix, which comes up to 2.066458 mm. The difference in average crack width is 0.266 mm, which is similar to the average crack difference in 0.75% mixes. Figure 12 shows the torque versus angle of twist response of 1% steel fibre.

3.6.5. Comparison between NWC-0% and NWC-0.75%

NWC-0.75% expressed maximum torsional strength in all NWC mixes. By the addition of steel fibre of 0.75% by volume, the strength changed from 2.55 kNm to 6.512 kNm. This corresponds to an increase in strength by 155%. The maximum crack width was reduced by 40%. The angle of twist was increased by 200%.

3.6.6. Comparison between CSC-0% and CSC-0.75%

The CSC-0.75% mix outperformed all other mixes in the case of torsional strength. The angle of twist in CSC-0.75% mix was 190% more than 0.077 rad/m of CSC-0% mix. The CSC-0.75% mix had ultimate torque of 7.252 kNm and cracking torque of 6.734 kNm. The ultimate torque is 51% more than the control mix of CSC series. The maximum crack width reduced by 49.8% by the addition of fibres and average crack width reduced by 46%.

4. Conclusions

The present experimental study is made on the torsional behaviour of rectangular concrete beams strengthened by steel fibres. All beams had same reinforcement detailing and was designed to fail in torsion and are cast and tested till ultimate load. During testing, deflections were observed with the help of dial gauges. Following are the conclusions drawn from this study:

- 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.
- Maximum torsional strength was observed at 0.75% by volume of steel fibre in both concrete.
- 0.75% steel fibres caused an increase of torsional resistance by 155% in NWC and 51% in CSC.
- The cracking torque values of fibre reinforced concretes are closer to ultimate torque because fibres prevent crack formation at early stages.
- The angle of twist values is more for fibre reinforced concretes. CSC-0.75% mix underwent maximum twist and was able to resist maximum torque. The angle of twist in CSC-0.75% mix was 190% more than the control mix of CSC series. In the case of NWC series, this increment was found to be 200%.
- Crack width was found to be decreasing as the percentage of steel fibres increased. Least crack width was found in CSC-1% mix. However, it was observed that the number of cracks increased as the percentage load acting on the beam increased.
- The maximum crack width reduced by 49.8% and 40% in CSC and NWC mixes respectively by the addition of 0.75% fibre.
- Mechanical properties of all mixes were also enhanced by the addition of fibre.
- Coconut shell can be grouped under lightweight aggregate because 28-days air-dry densities of coconut shell aggregate concrete are less than 2000 kg/m3. Actual Density of coconut shell is in the range of 550-650 kg/m3
- From the experimental results and discussions of above researches on coconut shell, the coconut shell has potential as lightweight aggregate in concrete. Also, using the coconut shell as aggregate in concrete can reduce the material cost in construction because of the low cost and its availability in abundance.
- The amount of cement content may be more when coconut shell is used as an aggregate in the production of concrete compared to conventional aggregate concrete.
- It can be concluded that the Coconut Shells are more suitable as a low strength-giving lightweight aggregate when used to replace granite aggregate in concrete production.
- Test result reveals that strengthening using 1% steel fibre had not enhanced the ultimate strength than 0.75%.
- Initials cracks were generated at higher loads in case of torsional strengthened beams compared to normal concrete beams.

Abbreviations

CS	Coconut Shell
CSC	Coconut Shell Concrete
LWC	Lightweight Concrete
NWC	Normal Weight Concrete
OPC	Ordinary Portland Cement

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