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Tests of steel fibre reinforced concrete beams under predominant torsion

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ABSTRACT

The use of steel fibres in plain concrete helps in improving the mechanical properties of concrete structure. Thus the aim of present study is to investigate the effect of steel fibres on torsional strength improvement of concrete. The research evaluates the torsional strength and combined torsional-shear-bending strength. In this study, 20% of fly ash (class-C) is added as a replacement of binder to its weight and 1.5% steel fibres by weight of concrete. Experimental results show an improvement in torsional strength, combined torsional-shear-bending strength and crack resistance of concrete by addition of steel fibres in the concrete and a decrease in the deflection. Based on the experimental results the modified coefficient of the empirical formulae has been suggested to predict the torsional strength and torsional stress of steel fibre reinforced concrete.

1. Introduction

Beams are one of the structural members which take up transverse loads. Torsion failure is more frequently observed in the structure along with flexure, shear, axial tension and axial compression. Thus it is important to study the torsional behaviour of beams along with flexural behaviour. Failure of beam structure occurs mainly due to tensile stress developed because of pure shear which develops due to torsion. Due to advances in the material technology the inclusion of steel fibres in concrete improves the characteristics of concrete such as stiffness, toughness and ductility. This inclusion of steel fibres may mainly increases the tensile strength of the matrix to the moderate level but it increases the toughness to a greater extent. This has mainly inspired the researchers to study the mechanical properties of steel fibre reinforced concrete under different loading conditions.

At the initial stage researchers have found that the addition of fibres improves the ductility of the member and torsional strength [1–4]. Thus, the torsional behaviour of reinforced concrete beams should be compared with that of plain concrete. It is seen that the addition of fibre may cause decrease in compressive strength and considerable increase in tensile strength of concrete after split cylinder tests [5]. It is also seen that the increase in the fibre volumetric ratio increase the compressive strength of the concrete but the increase in the strength becomes less after certain level of volumetric ratio [6,7]. It is observed that increase in the volumetric ratio of fibre increases the energy absorption of concrete in bending [8]. Even some of the researchers noted that these improvements affect the torsional strength of concrete. Hence, researchers begin investigating the torsional strength of the concrete beam with the inclusion of steel fibres. Researchers found no difference up to first crack and ductility increases with volume content of steel fibres [9–11]. Researchers have observed that the unit angle of twist of plain concrete ranges from 0.002 to 0.003 rad/m whereas the unit angle of twist of steel fibre reinforced concrete increases up to 0.006–0.007 rad/m [12]. Empirical models are proposed to estimate the torsional strength of concrete by various researchers in terms of addition of the concrete capacity and reinforcement [13]. Single type of steel fibre reinforcement in concrete gives satisfactory results compared to plain concrete [14]. In some cases researchers have used carbon fibre sheets as reinforcing materials which showed improved torsional strength as compared to plain concrete [15–17].

The ability of steel fibres to replace stirrups in torsional-dominated (or shear-critical) concrete elements and, to some extent, to convert their brittle behaviour to a ductile one is an important issue. It is known that cracking of fibrous concrete requires debonding and pull-out of the randomly distributed steel fibres in the concrete mass. Thus, due to the tensile stress transfer capability of the steel fibres across crack surfaces (known as crack-bridging) and also to the fact that fibres provide significant resistance to shear across developing cracks, SFC demonstrates a pseudo-ductile tensile response and enhanced energy dissipations capacities, relative to the brittle behaviour of plain concrete. Based on this concept and aiming to a ductile response of the examined member, a recently proposed methodology [18] calculates the flexural and shear capacities of SFC elements and evaluates the minimum steel fibres required in order that a SFC beam to satisfy pre-set strength and ductility requirements.

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The well-known fibre factor F that equals to: $F=\beta^{*}V_f^{*}(L_f/df)$, where β is the fibre bond factor considering shape and surface characteristics of the fibre, V_f is the volume fraction of the fibres and (L_f/df) is the fibre aspect ratio [18–20].

The well-known elastic theory of Saint Venant for the problem of torsion in plain concrete elements has been extended in order (a) to include the influence of steel fibres in SFC beams [20] and (b) to acquire rational and accurate predictions of the torsional strength and the entire elastic behaviour of plain concrete members using a smeared crack analysis [21]. This model has extensively been verified by Karayannis and Chalioris [22] and proved to be a precise and well-established analytical tool for the torsional problem. It is based on the observation that, in reality, tensile concrete cracking consists of systems of parallel cracks that are continuously distributed over the concrete mass. Cracks are considered to be adequately represented by parallel micro cracks distributed (smeared) over the finite elements and are merely represented as a change in the material property of the element over which the cracks are assumed to be smeared. Thus, crack propagation takes place with the formation of a fracture process zone (crack band) that is defined as the boundary of the strain softening region that is caused not only by micro cracking but also by any bond ruptures, so the fracture process zone is assumed wider than the region of visible micro cracks. The analytical technique of this method employs constitutive relations expressed in terms of normal tensile stress and crack width for the behaviour of this crack process zones. Thus, in the case of SFC the contribution of steel fibres on the torsional capacity is important since steel fibres greatly improve the tensile stress versus crack width response of material.

But little information is available in the literature about the behaviour of steel fibre reinforced concrete under pure torsion and combined torsional-bending. Based on the literature review, it can be seen that steel fibre reinforced concrete has attracted the most to the researchers due to improved mechanical properties. Thus, the aim of present study focuses on the casting of steel fibre reinforced concrete with fly ash to improve the torsional properties of M40 grade of concrete. This work includes the experimental determination of pure torsional strength and combined torsional-shear-bending strength of steel fibre reinforced concrete beam.

2. Materials and methodology

For the present study M40 grade of concrete is designed as per the IS-456:2000 code [25]. The mix proportion obtained was 1:1.30:2.37 with W/C ratio of 0.4. And water reducing admixture (Flowcon-PC 163 JK) of 1% by weight of cement was used. Table 1 shows the concrete mix proportion for plain and steel fibre reinforced concrete.

A total of 12 beam samples were casted with each having cross-sectional area of 140 mm × 140 mm with 1500 mm length. Plain concrete specimens consist of 20% fly ash by weight of cement. Steel fibre reinforced concrete specimens consist of 20% fly ash by weight of cement and 1.5% steel fibres by volume of concrete. Steel fibres used in the study have tensile strength of 1050 MPa, aspect ratio (length of fibre to its diameter) of 80, length of fibres of 60 mm and diameter = 0.75 mm. For the present study it was decided to consider percentage fibres as 1.5%, by considering workability and to avoid balling of fibres to suit the available facilities in the laboratory.

Dramix type of fibres was selected for use in the present study based on literatures review, as it mixes properly, thoroughly in the matrix. Even in the literature review the strength parameter achieved by concrete matrix was also better when dramix type of steel fibres was used. Balling or curling of fibres was found least when compared with other types of steel fibres. The fibres were relatively stiff and glued into bundles. The glue dissolved in the water during mixing, thus dispersing the fibres in the mix.

The concrete mix was prepared in a single lift and consolidated using tamping rods. After setting, the beam specimens were covered with wet gunny bags. The burlap was kept for 3 days. At the end of the third day, the forms were stripped and the beam specimens were kept for curing up to 28 days.

The casted specimens were tested for pure torsional strength using the experimental setup shown in Fig. 1(a). The beam was restrained for torsion with one end free for rotations. From the figure it is clear that pure torsional force is applied through a 0.3 m lever arm. Further the casted samples were tested for combined torsional-shear-bending strength using experimental setup shown in Fig. 1(b). The beam specimen supports were restrained for torsion with the help of 0.3 m lever arm. The eccentric load was applied on lever arm at mid span of specimen for combined torsional-shear-bending load condition.

3. Results and discussion

The casted beam specimens were subjected to pure torsion and combined torsional-shear-bending loading. For each mix, six specimens were casted and two different tests were carried out on two mix. Following terminologies are used in the graphs and

Table 1
Concrete mix proportion.

Sr. no.	Mix proportion per cubic metre
Mix-1 (Plain concrete)	Cement:412.8 kg/cu.m,(IS: 12269-1976,IS: 2720-part-3,IS: 4031-1968,IS: 12269-1976,IS: 12269-1976). 43 grade, Specific gravity of cement = 3.15 (IS: 2720-part-3) Batch type: concrete mixing (IS: 4634:1968) was carried out. Coarse aggregate: 1223.89 kg/cu.m. (IS: 2386-Part-4,IS 283-1970). Fine aggregate(river sand): 673.5 kg/cu.m (IS 2386-(Part-I)-1963). Water: 206.4 kg/cu.m(IS: 456-2000). Water/cement (W/c) ratio was 0.40 < 0.6 (IS 456-2000). Fly Ash: 103.2 kg/cu.m Class-C (IS 3812 Part I– 2003). Water reducing Admixture: 5.16 kg/cu.m.
Mix-2 (Steel fibre reinforced concrete)	Cement:412.8 kg/cu.m,(IS: 12269-1976,IS: 2720-part-3,IS: 4031-1968,IS: 12269-1976,IS: 12269-1976). 43 grade, Specific gravity of cement = 3.15 (IS: 2720-part-3) Batch type: concrete mixing (IS: 4634:1968) was carried out. Coarse aggregate: 1223.89 kg/cu.m. (IS: 2386-Part-4,IS 283-1970). Fine aggregate(river sand): 673.5 kg/cu.m (IS 2386-(Part-I)-1963). Water: 206.4 kg/cu.m(IS: 456-2000).Water/cement (W/c) ratio was 0.40 < 0.6 (IS 456-2000). Fly Ash: 103.2 kg/cu.m Class-C (IS 3812 Part I– 2003). Water reducing Admixture: 5.16 kg/cu.m. Steel fibres: 39.37 kg/cu.m. Dramix type- Bekaert company (ISO-9001 certified)