Shear Performance of Steel Fibrous Concrete Beams

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Abstract

The influence of steel fibres in shear reinforced concrete beams subjected to monotonic and cyclic loading is experimentally investigated. Seven steel-fibre-reinforced concrete beams and conventionally reinforced beams without steel fibres, used as control specimens, were constructed for the purposes of this study. Hook-ended steel fibres with two different volume fractions (0.5% and 0.75%) have been used in the fibrous concrete beams of the test program as shear reinforcement. Two beams were tested in monotonically increasing four-pointed loading up to total failure of the specimen, and five beams were tested under cyclic deformations.

The dimensions and the flexural reinforcement of all the beams examined were the same. Hook-ended steel fibres with an aspect ratio equal to 75 were used. The loading was imposed consistently in low rate, and the values of the load and the corresponding crack widths and deformation at the mid-span of the beams were reported. The conclusions drawn from the experimental results of the tested beams imply that the steel-fibre-reinforced beams exhibited improved shear performance with high shear capacities, enhanced energy dissipation capabilities and ameliorated crack patterns.

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Selection

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1. Introduction

It has long been recognised that the addition of steel fibres in concrete is a non-conventional mass reinforcement that improves the mechanical properties of concrete and provides for crack propagation control (ACI 544 1998). This ability is attributed to the tensile stress transfer capability of the steel fibres across crack surfaces that provide significant resistance to shear across the developing cracks (Chalioris and Karayannis 2009). This phenomenon is also known as crack-bridging. Cracking of steel-fibre-reinforced concrete requires a debonding and pulling out process of the randomly distributed steel fibres in the concrete (Karayannis 2000). Therefore, fibrous concrete demonstrates a pseudo-ductile tensile response and enhanced energy dissipation capacities, regarding the brittle behaviour of plain concrete (Nanni 1991; Economou et al. 1994).

Concerning the shear failure of concrete members, it is well known that when principal tensile stresses exceed the tensile strength of concrete, diagonal cracks occur in the shear span. This way, the behaviour of a concrete element under shear is fully characterized by the behaviour of the material in direct tension (Chalioris 2003; Zararis et al. 2006). Thus, in order to enhance the shear capacity of concrete beams, the improvement of the brittle and poor performance of concrete in tension by incorporating steel fibres has been proposed and studied in the last few decades (Adhikary and Mutsuyoshi 2006). The experimental studies reported in the paper of Adhikary and Mutsuyoshi (2006) have shown that the use of steel fibres improves the cracking characteristics and the overall behaviour of shear concrete beams under monotonic loading. Further, this had inspired some investigations to study the possibility of partially replacing stirrups (conventional transverse steel reinforcement) with steel fibres, especially in cases where design criteria recommend a high steel ratio, which leads to limited stirrup spacing (Cucchiara et al. 2004; Lim and Oh 1999).

In this paper, the influence of the steel fibres on the shear response of concrete beams under monotonic and cyclic loading is experimentally investigated. This study contributes to the rather limited existing literature on shear testing of fibrous concrete beams under cyclic deformations. Furthermore, the use of steel fibres as the only shear reinforcement is also examined herein, in an attempt to examine the effectiveness of steel fibres as a potential replacement for stirrups.

2. Experimental Program

The experimental program includes 7 shear beams subjected to monotonic and cyclic loading. Tested specimens were constructed with plain concrete (control beams) and steel-fibre-reinforced concrete with two different volume fractions ($V_f = 0.5\%$ and $0.75\%$) of the fibres used.

2.1. Specimen characteristics

All beams have the same height and width; $h/b = 300/100$ mm. The effective depth, the length and the longitudinal reinforcement of all the specimens were also the same; $275$ mm, $1.60$ m and six longitudinal bars of diameter $8$ mm ($3\bar{8} \text{ top and } 3\bar{8} \text{ bottom}$) respectively (see also Figure 1). Hook-ended steel fibres (DRAMIX ZC 60/.80) with a length of $60$ mm and a diameter of $0.80$ mm (aspect ratio $l_f/d_f = 75$) were added in the fibrous concrete beams of the test program as non-conventional shear reinforcement. Two beams were tested in monotonically increasing four-pointed loading up to total failure of the specimen and five beams were tested under cyclic deformations. Furthermore, five specimens had no conventional shear reinforcement (practically without stirrups) whereas two beams had closed steel stirrups with a diameter of $8$ mm at a uniform spacing of $200$ mm. The characteristic yield strength of the steel bars and stirrups was $400$ MPa. The characteristics of the tested beams are also presented in Figure 1.
The cement used in this work was locally-manufactured, general-purpose ordinary Portland type cement (type 35IIa, Greek type pozzolan cement containing 10% fly ash). Sand with a high fineness modulus and coarse aggregates with a maximum size of 9.5 mm was used. The concrete mixture was made using cement, sand and crushed stone aggregates in a proportion 1:1.92:2.88 respectively, and a water-to-cement ratio equal to 0.57. Cement, sand and crushed stone aggregates were first dry-mixed. Afterwards, clump-free steel fibres were dispersed by hand, gradually and slowly in small amounts to avoid fibre balling, while mixing continued. Finally, water was added and mixed gradually, to ensure that the produced mixture would obtain uniform material consistency, adequate workability and homogeneous fibre distribution. The prepared fresh fibrous concrete mixture was placed in the specimens’ moulds and vibrated. Sufficient time of vibration was provided to guarantee suitable consolidation and to prevent fibre protrusion. The compression strength of the plain concrete and the steel-fibre-reinforced concrete mixtures with $V_f = 0.5\%$ and $0.75\%$ were 23.0, 28.4 and 30.3 MPa respectively (mean values from three standard $150\times300$ mm cylinders).

2.2. Test rig and instrumentation

The experimental setup is shown in Figure 1. Beams were edge-supported on roller supports 1.45 m apart. The imposed loading was applied in two points in the midspan of the beam (four-point bending). Loading was imposed consistently in low rate and was measured by a load cell with an accuracy of 0.05 kN. Midspan deflection of the tested beams was measured by linear variable differential transducers (LVDT) with an accuracy of 0.01 mm. Measurements of load, deflection and crack widths were read and recorded continuously.

| Beam code name | Loading | Stirrups | $V_f$ (%) |
|----------------|---------|----------|-----------|
| MP             | monotonic | -        | -         |
| MF50           | monotonic | -        | 0.50      |
| CP             | cyclic   | -        | -         |
| CF50           | cyclic   | -        | 0.50      |
| CF75           | cyclic   | -        | 0.75      |
| CP-S           | cyclic   | $\varnothing8/200$ mm | -         |
| CF50-S         | cyclic   | $\varnothing8/200$ mm | 0.50      |

Figure 1: Characteristics, test setup and steel reinforcement of the tested beams.
3. Test Results

Diagonal cracks formed in the shear span of the tested beams that exhibited typical shear failure. Figure 2a presents the applied load versus the crack widths of the monotonically tested beams. The ultimate deflection of these beams at failure is also reported in this Figure. The entire shear response of the beams subjected to cyclic deformations is presented in Figures 2b & 2c in terms of the applied load versus midspan deflection experimental hysteretic curves.

4. Concluding Remarks

Based on the experimental results it can be deduced that fibrous beams showed improved overall shear performance since they exhibited increased shear strengths, ultimate deflections and energy dissipation capacities regarding to the corresponding non-fibrous control specimens. The contribution of steel fibres on the shear behaviour is mainly observed after concrete cracking. The addition of steel fibres was essential to the beams without stirrups since fibres were the only shear reinforcement and proved capable of providing enhanced shear capacities and deformations.

Figure 2: Test results.
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