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Properties of steel fibrous concrete containing mixed fibres in fresh and hardened state

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Abstract

The paper presents results of an experimental investigation carried out to study the properties of plain concrete and steel fibre reinforced concrete (SFRC) containing fibres of mixed aspect ratio. An experimental programme was planned in which various tests such as inverted cone time, Vebe time and compaction factor were conducted to investigate the properties of plain concrete and fibre reinforced concrete in the fresh state. Compressive strength, split tensile and static flexural strength tests were conducted to investigate the properties of concrete in the hardened state. The specimen incorporated three different volume fractions, i.e., 1.0%, 1.5% and 2.0% of corrugated steel fibres and each volume fraction incorporated mixed steel fibres of size $0.6 \times 2.0 \times 25$ mm and $0.6 \times 2.0 \times 50$ mm in different proportions by weight. Complete load deflection curves under static flexural loads were obtained and the flexural toughness indices were obtained by ASTM C-1018 as well as JCI method. A fibre combination of 65% 50 mm + 35% 25 mm long fibres can be adjudged as the most appropriate combination to be employed in SFRC for compressive strength, split tensile strength and flexural strength. However, better workability was obtained as the percentage of shorter fibres increased in the concrete mix.

Keywords: Plain concrete; Fibre reinforced concrete; Toughness

1. Introduction

Due to increasing structural applications placing greater demand on material performance, the need for more fundamental information on the behaviour of concrete and fibre reinforced concrete under different types of loads is of paramount importance. The addition of fibres to concrete considerably improves its structural characteristics such as static flexural strength, impact strength, tensile strength, ductility and flexural toughness. The degree of improvement depends upon many factors such as size, type, aspect ratio and volume fraction of fibres.

Many researchers have conducted investigations to study different characteristics of fibre reinforced concrete in the past. The mechanical properties of concrete and mortar reinforced with randomly distributed smooth steel fibres were investigated by Shah and Rangan [1]. It was observed that the post-cracking resistance of the material was considerably influenced by the length, orientation and stiffness of the fibres used. Batson et al. [2] tested conventional reinforced concrete beams in flexure wherein the shear stirrups were replaced by fibrous concrete containing steel fibres of various shapes, sizes and volume fractions. In an investigation, Shah and Naaman [3] conducted tensile strength, flexural strength and compressive strength tests on mortar specimens reinforced with different lengths and volume fractions of steel and glass fibres and observed that the tensile or flexural strength of steel fibre reinforced mortar was at least two to three times than that of plain mortar, while the corresponding strains or deflections were at least ten times than that of plain mortar specimens. Hughes

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and Fattuhi [4] investigated the effect of fibre type (polypropylene, steel), fibre shape (straight, duoform, crimped, hooked), specimen size (cube, prismatic) and age on the compressive stress–strains curves of steel fibre reinforced concrete. The factors influencing flexural strength measurement of SFRC such as specimen span, width, depth and mode of loading was investigated by Johnston [5]. Analysis of the experimental data showed that the variation of flexural strength with the volume parameters of fibres was similar for both fibre reinforced concrete and plain concrete. The test results of Nagarkar et al. [6] indicated that the compressive, split tensile and flexural strength increase by addition of fibres, but the workability of concrete was reduced. The compressive, split tensile and flexural strength increased by 13–40% for steel fibrous concrete containing fibres with aspect ratio of 105 at 0.5% volume fraction and 10% to 45% for nylon fibres with aspect ratio 100 at 0.5% volume fraction. The results of an investigation of plain concrete and fibre reinforced concrete subjected to compressive loads at three different strain rates were presented by Otter and Naaman [7]. The influence of fibre addition to plain concrete was found to be comparable to that of confinement effect of reinforcement. The strength and toughness of the composite were found to increase at higher loading rates. Nakagawa et al. [8] reported the results of an investigation on the mechanical properties of concrete reinforced with carbon, aramid and high strength vinylon fibres. Toutaji and Bayasi [9] investigated the effect of manufacturing techniques on the mechanical properties of steel fibre reinforced concrete. The effect of curing environment and testing direction relative to the casting direction on the mechanical properties of the steel fibre reinforced concrete were reported. It was observed that the flexural behaviour of steel fibre reinforced concrete is strongly affected by the testing direction. Ramanalingam et al. [10] presented the results of an experimental investigation on fibre reinforced mortar incorporating different combinations of fibres to exhibit strain-hardening under flexural loading. The micro-mechanical parameters such as fibre, matrix and fibre–matrix interface properties were controlled by proper selection of reinforcing fibres, water/binder ratio and percentage replacement of cement by fly ash.

2. Research significance

Review of literature indicates that a number of investigations have been conducted to study the behaviour of steel fibrous concrete under statically applied loads. In all these investigations, single size fibres have been used. Many researchers have started using mixed steel fibres with the understanding that the longer fibres are more effective in arresting macro-cracks whereas, shorter fibres are effective in arresting micro-cracks. This investigation was, therefore, planned to study the properties of fresh concrete as well as hardened concrete containing mixed steel fibres. Tests such as inverted cone time, compaction factor and Vebe time were conducted on fresh concrete whereas, compressive strength, split tensile strength and static flexural strength were conducted on hardened concrete. Complete load deflection curves were obtained under static flexural loading and toughness indices were evaluated as per ASTM C-1018 and JCI method to quantify the flexural toughness of steel fibre reinforced concrete.

3. Experimental program

The concrete mix used for casting the test specimens is shown in Table 1. Ordinary Portland cement, crushed stone coarse aggregates having maximum size 12.5 mm and river sand were used. The specimens incorporated two different aspect ratios of corrugated steel fibres, namely 40 (fibre size $0.6 \times 2.0 \times 50$ mm) and 20 (fibre size $0.6 \times 2.0 \times 25$ mm) by weight of the longer and shorter fibres in mix proportions of 100–0%, 65–35%, 50–50%, 35–65% and 0–100% at each of the fibre volume fractions of 1.0%, 1.5% and 2.0%. The tensile strength of 25 mm and 50 mm long fibres was 826 MPa and 801 MPa, respectively. The specimens used for compressive strength tests were $150 \times 150 \times 150$ mm cubes, for split tensile strength tests -150 mm $\times$ 300 cylinders and for static flexural strength tests -100 mm $\times$ 100 mm $\times$ 500 mm beams. The specimens were cast in different batches.

3.1. Tests on fresh concrete

The inverted slump cone test was used to measure the workability of the steel fibre reinforced concrete. This test has been specifically developed to obtain the workability of fibre reinforced concrete and measures its mobility or fluidity under internal vibrations. The test was conducted by loosely filling the inverted cone with concrete, the concrete being struck off at the top level. A 25 mm diameter vibrator needle was inserted at the centre of the cone and the material was allowed to fall freely into the yield bucket placed below it. The time taken to empty the cone from the instance the needle was inserted is recorded as the inverted cone time. In addition to inverted cone time test, tests such as compaction factor and Vebe consistometer were also conducted as per Indian Standard Codes of Practice.

3.2. Tests on hardened concrete

Tests such as compressive strength, split tensile strength and static flexural strength were conducted on specimens of plain concrete as well as steel fibre reinforced concrete containing different fibre mix combinations (see Table 2).

Table 1
Concrete mix proportion

Water/cement ratio	Sand/cement ratio	Coarse aggregate/cement ratio
0.35	1.35	2.12