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THE EFFECT OF HYBRID STEEL FIBER ON CONCRETE PERFORMANCE

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ABSTRACT
This study is aimed at examining the possible improvements on the fracture properties of concrete containing more than one fibre type. Several mixtures were elaborated in this study. To study the fracture properties and load resistance at various scales, discrete short brass fibres and double-hooked steel fibres were added in concrete. Different types of concrete mixtures were prepared and tested which contained varying proportions of steel and brass fibres up to 0.4% volume fraction. The effects of different hybrid fibre combinations at low and high dosages were investigated for compressive strength, splitting tensile strength and flexural strength. Test results indicated that the different hybrid fibre combinations played a significant crack arresting properties depending upon the fibre properties (size and fibre availability). The presence of steel fibres provided post crack resistance properties whereas the shorter brass fibres delayed the crack origination resulting in significant increase in mechanical strength. The hybrid fibre concretes containing steel fibres (0.3% Vf) and brass fibres (0.2% Vf) showed a consistent increase in the ultimate stress capacity up to 7.75% (in compression) and 37.98% (in fracture strength). Microscopic studies showed the effectiveness of different hybrid fibres during crack formation and subsequent propagation at different loading stresses. The use of steel fiber hybrid offers several economical and technical benefits.

Keywords: Compressive strength, Flexural strength, Steel fiber, Hybrid fiber, Concrete.

INTRODUCTION
The advancement in hybrid steel fibers improves the mechanical properties and the ductility of concrete structures. Fibre addition to concrete is a potential approach for enhancing the properties of hardened concrete. In recent years, there has been significant research conducted to study the effect of different fibres on the characteristics of hardened concrete. Steel fibres have traditionally been employed to improve crack resistance behaviour at various crack scales. The same factors that affect shrinkage strain in plain concrete also affect shrinkage strain in fibre reinforced concrete, including temperature and relative humidity, material properties, curing time, and structural size (Cunha et al 2009).
Studies have shown that adding fibres, particularly steel, to concrete has positive benefits in balancing the movements brought on by volume changes in concrete and tends to stabilize the volumetric changes sooner when compared to plain concrete. Steel fibres allow concrete to support several cracks, delay the onset of the first crack, and greatly reduce crack widths (Ding et al 2010). Brittle tension failure with micro-level strains occurs in cement-based matrices. The tensile qualities of the FRC are significantly enhanced when discrete fibres are added to such matrices, whether continuous or discontinuous, as compared to the characteristics of

the unreinforced matrix (Brouwers et al 2005). The characteristics have greatly improved because of a larger number of fibres present in the matrix along with a consistent load sharing system. To implicitly deduce the composite's tensile properties, the majority of FRC research relies on experimental observations from flexural or split cylinder tests (Petit et al 2010). The present study is conducted on the fracture resistance of brittle concrete composites using hybrid fibre combinations of steel and brass fibres. Fibres were also traditionally used in spatial distribution of concrete to achieve homogenous mechanical properties.

Objective of study

(1) To conduct investigation on the fracture and ductile response of steel-brass hybrid fibre concretes at different volume fraction of fibres.

(2) To systematically analyse the load carrying capacity of concretes containing different hybrid fibre combinations to evaluate its fracture efficiency and the optimal steel-brass fibre combination.

(3) To analyse and interpret crack growth in various steel-brass hybrid fibre concrete system under monotonic flexural loading and fractured surfaces are interpreted with the advanced digital image analysis technique.

EXPERIMENTAL PROCEDURE

Materials

Concrete materials used consist of ordinary Portland cement, river sand as fine aggregates and crushed coarse aggregates from nearby source of granite rocks. Proportioning of concrete mixtures was done carefully in the ratio of 1:1.42:2.35 (Binder: Sand: Aggregate) at w/c ratio of 0.34. To achieve a high workable concrete mix up to 100 mm slump super-plasticizing admixtures were added. The various concrete mixtures are proportioned by varying the fibre content in terms of volume fraction of fibre dosage (% by volume of concrete). Short cut brass fibres of 6.54 mm long (average size) and double hooked steel fibres of 32 mm long were used in concrete mixes to evaluate the fibre synergy in the hardened concrete. The concrete manufacturing materials are provided in Table 1.

Table 1: Concrete manufacturing materials used.

Materials	**Grade of material**	**Specific gravity**	**Particle size**	**Density (Kg/m3)**	**Tensile Strength (N/mm2)**
Cement	43	3.12	0.0435	3215	-
Sand	3.12	2.45	2.61	2205	-
Crushed granite Aggregates	0.013	2.36	6.45	2415	-
Steel fibres	Double Hooked steel	7.34	L=32mm, D=0.35mm, Aspect ratio = 91	7450	440
Brass fibres	Loose stranded filaments	8.12	L=6.54mm, D=0.04mm, Aspect ratio = 164	8230	325

The various design concrete mix proportions for different hybrid fibre concrete mixes are as follows:

CASE 1: Plain Cement Concrete (PCC 1):

Cement - 342, Sand - 694, Coarse Aggregate - 1194, Water/Concrete ratio (w/c ratio) - 0.34, Water - 175, Superplasticizer – 24

CASE 2: Hybrid Steel Brass Fiber Concrete Two (HYSBFC-2):
Steel - 0.4% Vf , Brass - 0.1%Vf, Cement - 342, Sand - 694, Coarse Aggregate - 1194, Water/Concrete ratio (w/c ratio) - 0.34, Water - 175, Superplasticizer – 24

CASE 3: Hybrid Steel Brass Fiber Concrete Three (HYSBFC-3):
Steel - 0.3% Vf , Brass - 0.2%Vf, Cement - 342, Sand - 694, Coarse Aggregate - 1194, Water/Concrete ratio (w/c ratio) - 0.34, Water - 175, Superplasticizer - 24

CASE 4: Hybrid Steel Brass Fiber Concrete Four (HYSBFC-4):
Steel - 0.2% Vf , Brass - 0.3%Vf, Cement - 342, Sand - 694, Coarse Aggregate - 1194, Water/Concrete ratio (w/c ratio) - 0.34, Water - 175, Superplasticizer – 24

CASE 5: Hybrid Steel Brass Fiber Concrete Five (HYSBFC-5):
Steel - 0.1% Vf , Brass - 0.4%Vf, Cement - 342, Sand - 694, Coarse Aggregate - 1194, Water/Concrete ratio (w/c ratio) - 0.34, Water - 175, Superplasticizer - 24

Special chemical admixtures such as sulphonated melamine formaldehyde was added at 1% by weight of cement to reinstate the loss in consistency of fresh concrete. Fibres added in concrete mixes were known to show loss in consistency during fibre addition and this is effectively addressed by using super-plasticizing admixtures. Freshly prepared concrete mixes were placed and compacted in the steel moulds as shown in Fig. 2 and allowed for normal drying in room temperature. After sufficient curing for a day, the moulds were removed to separate the hardened concrete and further kept under water curing for 28 days.

Fig. 2: Layered casting of concrete using steel-brass hybrids.

Laboratory testing of hybrid fibre composite beams

The specimens were tested in a universal compressive strength testing machine of 2000KN capacity which has an electronic digital controller for actuating the rate of loading, Also, the crack propagation in beams can be electronically tested using ultrasonic pulse velocity (UPV) measurements. The visual observations during first crack origination on the surface of concrete specimens were captured using digital recording machine for fracture assessment. Flexural testing of beam specimens of size 150×150×1000mm were carried out using a third point loading setup. Gradual loading rate of 0.5 mm/min was maintained throughout the bending test for maintaining a stable crack propagation and further crack bridging ability of brass fibres in the concrete matrix. To monitor the crack growth at the centre it was intended to place the ultrasonic sensors using transducers at the middle third point of beam specimens. Digital images of concrete specimens were recorded to observe the crack propagation pattern in each type of concrete specimens. Fracture characteristics of concrete were assessed in terms of first crack origination and the fracture energy**.**

Digital images of sliced concrete specimens were taken at the fractured surfaces to assess the crack propagation patterns and fibre bridging mechanism. A digital USB Microscope of 1000x magnification with a resolution of 1280 × 960 pixels was used in this study to analyse the cracked surfaces in different concrete specimens. Microscopic images of failed concrete specimens were captured initially from cracked concrete sections and further image analysis were carried out.

RESULTS AND DISCUSSIONS

The influence of hybrid fibres in different failure loads of concrete are discussed in this section and the experimental values are represented in Fig. 3**.** It clearly indicated that compared to plain cement concrete, all fibre concretes showed controlled failure without any sudden cracking sound. A maximum compressive strength increases of 7.75% was noted in the case of steel-brass fibre concretes (HYSBFC-3). Also, the other hybrid fibre concretes reported a marginal increase in compressive strength without any abrupt strength loss. Fracture strength of all fibre incorporated concretes resulted in appreciable increase owing to additional reinforcing mechanism contributed by fibres. Maximum fracture strength of 7.12 N/mm2 and 6.89 N/mm2 was obtained for steel/brass hybrid concretes (HYSBFC-3 and HYSBFC-4 respectively) with an increase of 37.98% compared to plain concrete. It can be noted that hybrid fibre addition in concrete systems provided an appreciable increase in fracture strength. However, the presence of optimal fibre combination of 0.3% steel fibres and 0.2% brass fibres reported maximum strength up to 37.98%. Similar test observations were made by Cunha et al (2009) that high volume fraction of micro fibres may affect the post elastic strain hardening properties up to 60% in the strain capacity of composites. This was observed in the present study when the crack opening was unstable leading to increased crack width and hence the smaller micro brass fibres were not effective enough to bridge the widening cracks. Hence, it can be evident that the pre-peak strain hardening part is greatly influenced by short/micro brass fibres than longer steel fibres. This effectively provides matrix strengthening leading in delay in the origination of micro cracks. This also reveals that synergy of steel-brass hybrid fibre combinations are profoundly observed in all fibre combinations. The maximum ductility was observed for steel-brass hybrid fibre concrete **(HYSBFC-5)** up to 3.87mm with a maximum peak deflection of 2.13 mm. Since the post elastic deformation characteristics of fibre concretes were found to be dependent on the straining/yielding of fibres completely after failure. However, the straining of composite was found to be dependent on the number of fibres bridging the wider cracks as well as crack localization. In this study, it was apparently evident that maximum availability of brass fibres at crack opening provided adequate ductility leading to significant post elastic deformation.

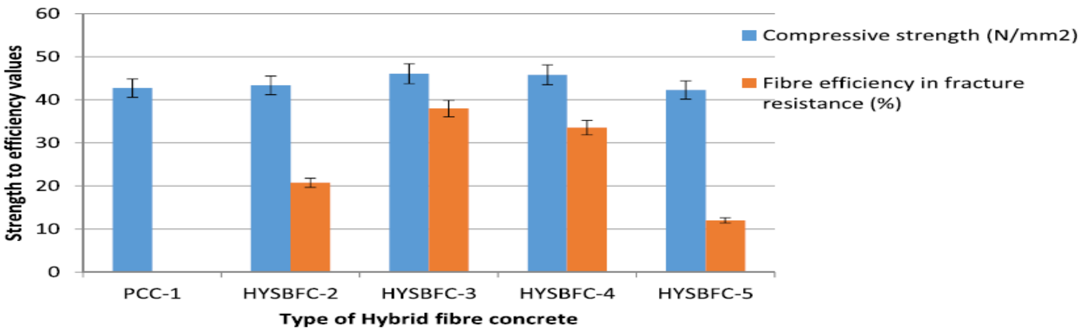

Fig. 3. Compressive strength to efficiency of hybrid fibre concretes.

However, the hybrid fibre efficiency in compression was found to be maximum of 7.75% and 7.23% for hybrid fibre concretes **HYSBFC-3** and **HYSBFC-4** respectively. Similar strength improvement upto 10% in flexural bending and fracture properties were reported in earlier studies [2,5,8,9] depending upon the type of hybrid fibre combinations used. Mechanism of hybrid fibres provide evidence that dual action of short and long fibres in arresting crack propagation at different scales and at different stress levels. Fibre effectiveness is also visibly observed depending upon the number of micro cracks appearing at maximum bending stress. This was visibly higher for steel-brass hybrids containing 0.1% steel fibres and 0.4% brass fibres as seen in Fig. 4. It can be inferred that by increasing fine brass fibres volume in the matrix comparatively to steel fibres, may result in higher bending resistance due to effective fibre bridging by shorter fibres. Many research studies conducted earlier support the hybrid fibre mechanism in concrete in terms of the careful selection of fibre types (length, aspect ratio, elastic modulus) and its volume fraction [10]. The dual fibre action noticed in this study proceeds at every crack interception and the effectiveness in synergistic crack arresting mechanism depends upon optimum volume fraction of steel (0.3%) and brass (0.2%) fibres.

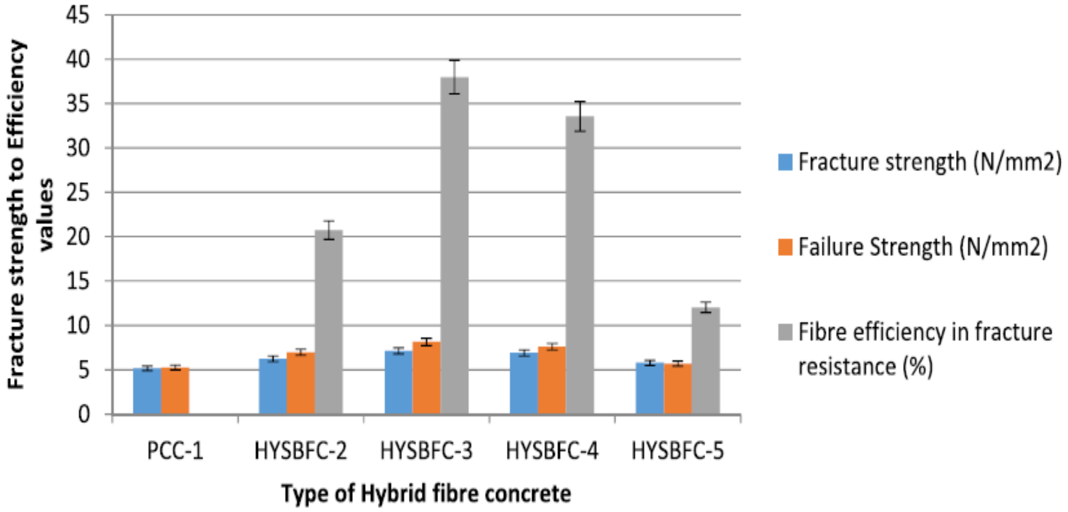

Fig. 4. Fracture strength to efficiency of hybrid fibre concretes.

The use of advanced image analysis at 500x magnification has provided distinctive fibre reinforcements in matrix phase and analysed for each type of hybrid fibre concrete specimen. The origination of steady state cracks occurs at the weak boundary of ITZ and propagates to the matrix phase. The various load levels were given to each concrete specimen to identify the potential cracking pattern as well as to observe the crack coalescing in the crack vicinity. It can be evidently seen that the crack coalescence occurs with either crack joining or leading to the origination of multiple cracking**.** At low stress levels up to 30% of ultimate load, the crack formation is slightly visible in the plain concrete specimens**.** The influence of fibres during crack origination is observed when the direction of propagation is controlled by the intercepting steel fibres**.** During stress transfer from the matrix to the fibres the interfacial shear stress is taken by fibres which may show debonding failure. The fibre effectiveness is pronounced when number of fibres provides crack bridging properties and has enhanced the load carrying capacity. In another research study, similar microscopic observations were made to analyse the fibre orientation and spacing on the fracture properties of concrete (Srinivasa et al 2009).

CONCLUSION

The experimental observations for different hybrid fibre concretes consisting of steel-brass fibre concretes were typically investigated in this study and summarized as given below.

(1) Compressive strength of concrete is marginally improved depending upon the different hybrid substitutions and showed a maximum strength of 46.03 N/mm2 (HYSBFC-3) with an increase upto 7.75%.

(2) Hybrid Fibre efficiency in compressive performance was found to be marginal in the case of longer steel fibres which does not undergo required straining, whereas the presence of shorter/fine brass fibres in large availability provide adequate matrix strengthening leading to strength improvement.

(3) The inclusion of hybrid fibres substantially increased the flexural performance and post crack performance of all hybrid fibre concretes without sudden cracking. Most notably a maximum failure strength up to 8.14 N/mm2 was obtained for steel (0.3%) and brass (0.2%) hybrid concretes (HYSBFC-3).

(4) A maximum efficiency of 37.98% and 33.53% in fracture resistance of hybrid fibre concretes was noticed in HYSBFC-3 and HYSBFC-4 concretes respectively. This showed effective synergistic combinations due to dual fibre mechanism played at different cracking scales. As the short and large availability of finer brass fibres provided high crack control mechanism at smaller micro-cracks and steel fibres provide adequate bridging mechanism upon increased crack widths.

(5) The most important contribution of hybrid fibres mechanism was observed in terms of maximum ductility (3.87 mm) which was noticed in the case of steel-brass hybrids (HYSBFC-5) which exhibited a good post elastic deformation characteristics of hybrid fibre composites.

(6) Microscopic image analysis showed convincing evidence of the dual role played by hybrid fibres during crack formation at low and high stress levels with a multi scale crack arresting properties in cementitious system.

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