Performance of hybrid waste fibrous materials in high strength concrete

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Abstract. Concrete is naturally a brittle material and it can withstand high compression load but fails to withstand the tensile load. In order to improve the tensile strength in concrete, concrete composites are modified by adding steel fibers in volume fraction. However, discontinuous micro cracks are developed in plastic state of concrete. The drawback can be overcome by modifying the fibrous composites in the form of hybrid fibres. In this experimental work, a triangle series of fibres are selected to establish the hybrid fibres through steel fibers, nylon fibre and coir fibre. The total fibre dosage was restricted to 2% by volume and the hybrid fibre combination was developed by replacing one-third of fibre by other one for making high strength concrete. The performance of hybrid fibre reinforced high strength concrete (FRHSC) were analysed by studying the fresh and hardened properties.

1. Introduction
Concrete is a well-known manmade material and it is strong in compression and weak in tension. The brittle nature of concrete had been utilized in various structural elements where the flexural stresses and combined stresses condition are developed and hence making ductile to brittle nature of concrete to withstand under all sorts of stress condition is an inevitable requirement to develop a sustainable structural elements. Normally, the tensile strength of concrete was observed as one tenth of its compressive strength [1, 2]. Because of these characteristics, flexural members are unable to bear certain loads that usually occur throughout their service life [3]. The extension of concrete cracks leads to reduce the service life and abrupt failure without warning [4, 5]. Making ductile concrete by means of substituting small amount of fibres enhancing the concrete properties and able to solve the structural problem during service period [6, 7]. In addition, steel fibres are utilized at critical location in concrete member to overcome highly potential tensile stresses and shear stresses [8]. In the present era, solid waste management has become one of the biggest problems due to the rapid development of urbanization [9-11]. There are actually two main approaches for disposing of waste in operation. The first one is filling the low level land and burning in open atmosphere is the other one [12, 13]. The first needs more valuable land while the second pollutes the atmosphere. Therefore, alternative methods should be found to dispose of solid waste. Keeping these conditions into consideration, an attempt is...
made to research the possibility of reusing waste materials from steel, coir and nylon fiber as concrete fiber composites in FRHSC [14-16].

2. Experimental program

2.1 Materials used

The materials used in this investigation are 53 grade Ordinary Portland cement (OPC), coarse aggregate of crushed granite rock, river sand as fine aggregate, portable water and super plasticizer. The physical properties of aggregates are mentioned in Table 1. Fibres used in this investigation are steel fibre, nylon fibre and coconut coir which are collected from the waste stream and converted into fibres of required length and diameter [17]. The properties of fibres are listed in Table 2.

2.2 Mix proportioning

M50 grade high strength concrete was considered in this study and the mixture proportion was mentioned in Table 1 [18]. The water cement ratio is maintained at 0.40. The total fibre dosage was maintained by 2% by volume of concrete. The fibres were combined in triangle combinations such that the mix ID (SF1/3+NF2/3)2.0 denotes 1/3 of steel fibre and 2/3 of nylon fibre with 2% of total fibre. The mix combinations are specified in Table 1 [19]. Superplastizer dosage was selected to achieve desirable workability as 1.2% by weight of cement.

3 Testing methods

3.1 Workability, casting and curing

A laboratory type concrete mixer machine was used to prepare the concrete. In order to prepare homogeneous mix, aggregates and cement were mixed in dry state for one minute, water being added within two minutes [20, 21]. Then fibres were dispersed throughout the mass in slow increment. The ingredients were allowed to mix thoroughly for three more minutes [22]. Slump test was conducted to ascertain the workability of FRHSC. All the specimens were well compacted using a table vibrator. The specimens were de-moulded after 24 hours and cured in a water tub for sufficient duration before testing.

Table 1. Mix Proportioning of FRHSC

| Mix ID | Cement (kg/m³) | Fine Aggregate (kg/m³) | Course Aggregate (kg/m³) | W/C ratio | SP (kg/m³) | Fibre dosage (%) |
|--------|----------------|------------------------|--------------------------|-----------|------------|------------------|
|        |                |                        | 20 mm | 10 mm |               | Steel | Nylon | Coir |
| CC     | 422            | 641                    | 726  | 484   | 0.4           | 5.064 | --    | --   |
| SF     | 422            | 641                    | 726  | 484   | 0.4           | 5.064 | 2.0   | --   |
| NF     | 422            | 641                    | 726  | 484   | 0.4           | 5.064 | --    | 2.0  |
| CF     | 422            | 641                    | 726  | 484   | 0.4           | 5.064 | --    | --   |
| (SF1/3+NF2/3)2.0 | 422 | 641 | 726 | 484 | 0.4 | 5.064 | 0.67 | 1.33 | --  |
| (SF1/2+NF1/2)2.0 | 422 | 641 | 726 | 484 | 0.4 | 5.064 | 1 | 1 | --  |
| (SF2/3+NF1/3)2.0 | 422 | 641 | 726 | 484 | 0.4 | 5.064 | 1.33 | 0.67 | --  |
| (SF1/6+CF2/3)2.0 | 422 | 641 | 726 | 484 | 0.4 | 5.064 | 0.67 | -- | 1.33 |
| (SF1/2+CF1/2)2.0 | 422 | 641 | 726 | 484 | 0.4 | 5.064 | 1 | -- | 1 |
| (SF2/3+CF1/3)2.0 | 422 | 641 | 726 | 484 | 0.4 | 5.064 | 1.33 | -- | 0.67 |
| (NF1/3+CF2/3)2.0 | 422 | 641 | 726 | 484 | 0.4 | 5.064 | -- | 0.67 | 1.33 |
| (NF1/2+CF1/2)2.0 | 422 | 641 | 726 | 484 | 0.4 | 5.064 | -- | 1 | 1 |
| (NF2/3+CF1/3)2.0 | 422 | 641 | 726 | 484 | 0.4 | 5.064 | 1.33 | 0.67 | --  |

3.2 Testing methods

The compressive strength of FRHSC was determined by testing the cube specimen of 150 mm dimension in accordance with IS: 4031-Part 6 [23]. The split tensile strength was determined with 150 mm diameter and 300 mm height specimens as per the specification prescribed in IS: 5816 -1999 [24].
The prism specimen with 100 x 100 x 500 mm size was used for finding the flexural strength as per IS: 516-1959 [25]. The results mentioned in this report was the mean value of three specimens.

4 Results and discussion

4.1 Slump value
The slump value of CC was observed as 95mm. The substitution of steel fibre in concrete reduced the slump value up to a maximum extend. The slump value of steel mono fibre added FRHSC was found as 50 mm which is 47% lower than CC. The reduction of slump value is due to the increasing the surface area of the fibres and extra mortar required to apply coating over the steel fibre and the insufficient mortar fraction in concrete affect the workability. Meantime, the slump value of FRHSC with nylon and coir mono fibre were relatively higher than the steel fibre reinforced concrete. The slump variations of all mixes considered in this experiment is shown in Figure 1. As expected, the steel fibre added hybrid FRHSC was lower than CC and higher than the steel mono FRHSC [26]. In comparison with nylon and coir fibres, coir fibre had shown higher slump value than nylon fibre based FRHSC.

4.2 Compressive strength
The compressive strength results for the 28 days cured FRHSC specimens are presented in Figure 2. From the Figure 2, it was found that on comparing control concrete (CC) with mono fibres, steel fibre (SF) has the highest compressive strength which is 16.6% higher than control concrete (CC). The higher compressive strength in steel fibre reinforced concrete was reported due to the transverse confinement effect of steel fibres in concrete which restrict the lateral expansion when load was applied longitudinally [26]. The improvement in compressive strength of steel fibre reinforced concrete can be credited to the bridging of micro cracks presence in the high strength concrete [27]. Reduction in compressive strength in waste material based fibre reinforced concrete was noticed than the steel fibre reinforced concrete due to the poor interface of waste fibre in cement matrix [27]. However nylon and coir fibre based hybrid FRHSC had shown higher compressive strength than the CC. While considering the various hybrid fibre combinations selected in this investigation, the composition of 2/3 SF and 1/3 CF mixed FRHSC had shown higher compressive strength among all other hybrid combinations which is 12.98% higher than the CC. Poongodi et al, (2020) found that the hybrid fibre combination with agro based fibres such as coir fibre and banana fibre increased the compressive strength up to 5% than that of M60 grade control concrete [28, 29]. From this investigation it was noticed that mono waste fibre had contributed an insignificant higher compressive strength than CC and the hybrid combinations with steel fibres enhanced the compressive strength of hybrid FRHSC.
Figure 1. Slump value of FRHSC

Figure 2. Compressive Strength of FRHSC

4.3 Split tensile strength

The split tensile strength results for all the specimens are shown in Figure 3. From the figure, it was found that the SF had yielded the maximum split tensile strength which is 44.2% higher than CC with mono fibres. Whereas considering hybrid fibre combination, the mix (SF2/3+CF1/3)2.0 showed highest split tensile strength which is 40% higher than CC. The higher dosage of waste fibre had shown insignificant lower split tensile strength due to the relatively lower tensile strength of nylon and coir fibres when compared to steel fibres. When both the waste fibres were employed for hybrid fibre compositions, 1/3 CF had shown better results.Murthi et al (2020) found that the presence of more than 1% coir fibre in high strength concrete reduced the splitting tensile strength [30]. Increasing the split tensile strength evidenced that the FRHSC had better ductility than the normal HSC.
4.4 Flexural strength
The flexural strength results for all the specimens are shown in Figure 4. From the figure, it was found that the SF has the highest flexural strength when compared to nylon and coir mono fibre reinforced concrete and also found that SF added FRHSC was 40.5% higher than CC. The hybrid fibre combination with 2/3 SF and 1/3 CF showed the maximum flexural strength which is 37.1% higher than CC and other hybrid combination. The waste fibres based hybrid FRHSC evidenced relatively lower flexural strength among the other fibre reinforced combinations.

5 Conclusion
The following conclusions are derived from the above investigation,
1. The SF reinforced HSC was evidenced poor workability than other fibre reinforced combinations due to the restriction offered against the free flow of concrete by the steel fibres.
2. The compressive strength of concrete which is Hybridization with 2/3 of Steel Fibre and 1/3 of Coir Fibre Reinforced Concrete with 2.0% volume fraction is 16.6% higher than the conventional concrete mix.
3. The split tensile strength of concrete which is Hybridization with 2/3 of Steel Fibre and 1/3 of Coir Fibre Reinforced Concrete with 2.0% volume fraction is 40% higher than the conventional concrete mix.
4. The flexural strength of concrete which is Hybridization with 2/3 of Steel Fibre and 1/3 of Coir Fibre Reinforced Concrete with 2.0% volume fraction is 37.1% higher than the conventional concrete mix.

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