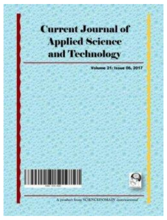

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Mechanical Characterisation of Concrete Beams Filled with Different Amounts of Nanosilica and Coir-Human Hair Fibre

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Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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ABSTRACT

The study concentrates on the cyclic behaviour of concrete grade M25 with the addition of nanosilica powder and equal amounts of waste coir fibres and human hair. The results indicate that the improvement of cyclic flexural and number of cycles to failure, other than compressive, split tensile and static flexural properties, are effective and consistent up to a global 1.5% volume of the two waste fibres and 3% volume of nanosilica. Also crack patterns appear neater and suggest a higher ductility of the material, up to this limit of content filler, indicating that to increase it further work on the repeatability and consistency of introduction would be required.

Keywords: Concrete; coir fibres; human hair fibres; nanosilica; ductility; cyclic behaviour.

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1. INTRODUCTION

Introducing fibres into concrete is a procedure able to reduce its total volume and the amount of steel required to produce a structural element. Fibres in concrete perform the action of improving the tensile characteristics by inhibiting crack growth and increasing energy absorption capacity, flexural strength and ductility: even a polymer fibre would achieve this effect [1]. A large number of fibres were used in concrete, including artificial fibres, metallic fibres, glass fibres, lathe fibres, polymeric fibres, mineral fibres, and naturally occurring fibres [2]. In some cases, hybrid composites were produced that are capable of offering more attractive engineering properties, because the presence of one fibre enables the more efficient utilisation of the potential properties of the other one: this has effect both on rheology and durability, provided the respective amounts are carefully selected for the purpose [3].

A recent possibility that is investigated is the introduction of different kinds of waste, such as that produced from agricultural or non-differentiable use, into concrete, which has also environmental benefits [4]. Moreover, the use of nanomaterials, such as nanosilica, as additional fillers to concrete proved largely beneficial in order to increase the compression strength of the concrete and reduce the porosity between the cement particles [5].

In this work, two fibres were introduced in a hybrid concrete composite, which are obtained as readily available waste materials: these are coir fibres from the fruit skin, and human hair fibres. In addition, as secondary reinforcement, nanosilica has been used, with the idea that the combined use of these fillers could improve the ductility of concrete. To prove this effect, mechanical (compressive, split tensile, flexural and cyclic flexural) tests have been performed on concrete with different amounts of the fillers, also observing the crack patterns obtained with filler introduction.

2. MATERIALS AND METHODS

2.1 Mix Design

The reference material used is concrete grade M25, in which the respective quantities were:

Cement = 425 Kg/m^3
Fine aggregate (sand) = 650 Kg/m^3
Coarse aggregate (gravel) = 1175 Kg/m^3

A water/cement ratio of 0.45 was applied for mix design, with the result that water content was equal to around 211 Kg/m^3

To enhance plasticity, a naphthalene-based superplasticizer was also added in the reason of 0.8% by weight of cement.

The proportion for M25 grade concrete had been designed using Indian standards (IS). The slump obtained was 165 mm, the degree of workability is high as per IS 456-2000.

2.2 Concrete Hybrid Composites Produced

Three different types of fillers were added to concrete for testing, which are represented in Fig. 1. Their characteristics are given in Table 1, also with data obtained from literature when necessary.

a) nanosilica **b) coir fibres** **c) human hair fibres**

Fig. 1. Different materials used in this study for concrete reinforcement

Table 1. Characteristics of coir and human hair fibres used as filler

Properties	Coir fibres	Human hair fibres
Length (after cutting) (mm)	60	60
Diameter (μm)	10-450	100-120
Aspect ratio	150-6000	500-600
Density (g/cm³)	0.7-1.4 [6]	1.3-1.5 [7]
Young's modulus (GPa)	3.5-6 [6]	5-7 [7]
Tensile strength (MPa)	15-500 [6]	45-125 [7]

Hairs are varying by a variety of factors like ethnicity, cleaning, grooming, chemical treatments and environment; they have been carefully selected in order to ensure they had approximately the same thickness. On the other side, coir fibres were used as obtained from waste from the fruit skin, therefore not yet carded or chemically treated. In the case of coir, for the nature of the material and its tendency to fibrillate, it was difficult to obtain a limited range of diameters, as from Table 1. Also, nanosilica particles with maximum dimension 200 nanometers were used.

Adding to concrete different amounts of fillers, a number of series of samples were produced for testing, as reported in Table 2, and considering that series A is the basic concrete with no fillers. Content in volume and in weight of the fillers are reported, the second one being in parenthesis.

2.3 Mechanical Tests

Compressive (according to ASTM C109/C109M-16a standard), split tensile (according to ASTM C496/C496M–17 standard), flexural center point loading (ASTM C293/C293M–16) and cyclic flexural tests were performed. With this aim cubes of size 150 x 150 x 150 mm were used for compression, cylinders of 300 mm height x 150 mm diameter were used for split tensile tests, and prisms of size 500 x 100 x 100 mm for both flexural static and cyclic tests, respectively.

Table 2. Different amounts of filler in concrete samples (bulk being concrete)

Sample series	Coir fibres vol. % (wt. %)	Human hair fibres vol. % (wt. %)	Nanosilica vol.% (wt. %)
A	0	0	0
B	0.25 (0.11)	0.25 (0.14)	2 (0.6)
C	0.5 (0.22)	0.5 (0.28)	2.5 (0.9)
D	0.75 (0.33)	0.75 (0.42)	3 (1.2)
E	1 (0.44)	1 (0.56)	3.5 (1.5)
F	1.25 (0.55)	1.25 (0.7)	4 (1.8)

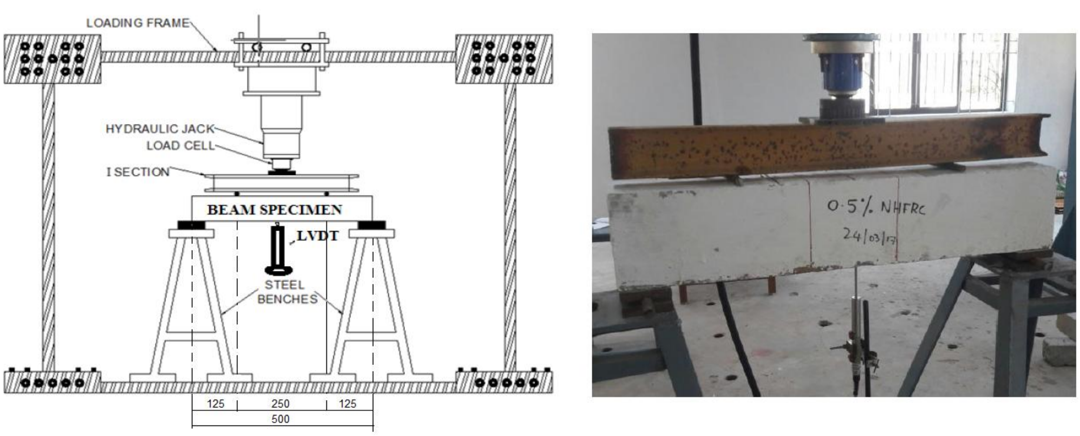

Fig. 2. Cyclic testing

In particular, experimental set-up for four-point flexural cyclic testing, with 12.7 mm diameter cylindrical supports at a mutual distance of 125 mm, has been reported in Fig. 2: cycles were performed by increasing load on the beam by 10 kN each time, then reverting back to zero after each cycle.

Testing was carried out on concrete cured for 7 days and 28 days in moist air, for compression and split tensile tests, whereas only the latter curing condition, corresponding to most likely final use for the compression properties achieved, was used for flexural testing.

3. RESULTS AND DISCUSSION

3.1 Static Mechanical Test Results

During compression testing on cubic specimens, the cubes bulged outwards, the crack originated from the bottom then propagated. Following this, spalling and crushing of concrete occurred. Cubes with filler addition did not show splitting due to the presence of fibre bonding. In particular, strength increased up to a volume of hybrid fibres of 1.5% with 3% of nanosilica, with sample D showing after 28 days of curing the maximum compressive strength of 33.23 N/mm^2. During split tension testing, the cylinder bulged and formed into elliptical cross-section during failure. No spalling of concrete occurred due to the presence of fibre. In this test, again the best performance was observed in the case of sample D, which showed maximum split tensile strength of 4.1 N/mm^2. During flexural tests, the prism specimens developed flexural cracks and no spalling of concrete occurred due to the presence of fibres, while the fibre bonding was clearly seen. Once again sample D proved the best among all the combinations, namely showing a maximum flexural strength of 6.79 N/mm^2. Results are summarised in Fig. 3.

It can be suggested that the presence of fibres is effective until they come to a 1.5% volume, after which the effect of nanosilica is deemed to become predominant. This is indicated by the fact that compression showed a limited decrease, whereas split tensile and flexural strength were much more affected. It is suggested that nanosilica can offer its advantages in the penetration through concrete pores and the relevant reduction of permeability and porosity would result in maintaining a sufficient level of compressive strength even in the presence of a higher amount of fibres [8]. On the other side, it is well known that the addition of coir into concrete bears limited effect on compressive and tensile strength while offering more limited shrinkage and higher ductility [9]. This is true for coir fibres treated with sodium hydroxide already for textile use, and is likely to be even more relevant for the secondary raw material used in this study, which has a large variation of diameters, hence of aspect ratios. What is questionable at this point is the influence of their use together with human hair fibres.

In reality, it can be suggested that the use of coir waste enables to slightly increase the amount of hair to be able to be introduced in the hybrid concrete composite. The main problem with hair fibres is that the characteristics of hair depend on a large number of factors, including age, color, ethnical differences and also the place in which they are cut, since they may have for example split ends. In practical terms, previous experiments were performed on concrete with a maximum amount of hair fibres of 0.5%, larger quantities being detrimental after concrete cure of 28 days [10]. Of course, there is still the issue of controlling the effective random introduction of hair into concrete, which may the object of further studies.

3.2 Cyclic Testing Results

In the case of cyclic testing, once again the results for sample D were the highest, approaching almost a 50% of increase in maximum strength at mid-span, as reported in Table 3. The load carrying capacity of the beams increased in each cycle, as reported in Fig. 4 for sample D. As reflected from Fig. 5, which aims to summarise the results of cycling on the different samples, B, C and D samples can be all suitable for use, since they all show a very similar behaviour, whereas for higher amounts of filler deflection tend to become more uncontrolled. Despite the limitations of this study, crack patterns observed in Fig. 6 do indicate their concentration at the extremities of the beam and their neater aspect in the presence of higher amounts of filler, even for sample E, whereas sample F appears quite badly damaged, which suggests the need to address the introduction of different fillers with more repeatable or less empirical methods.

3.3 Discussion

Another aspect to be considered is that in future work the disaggregated effect of the three fillers

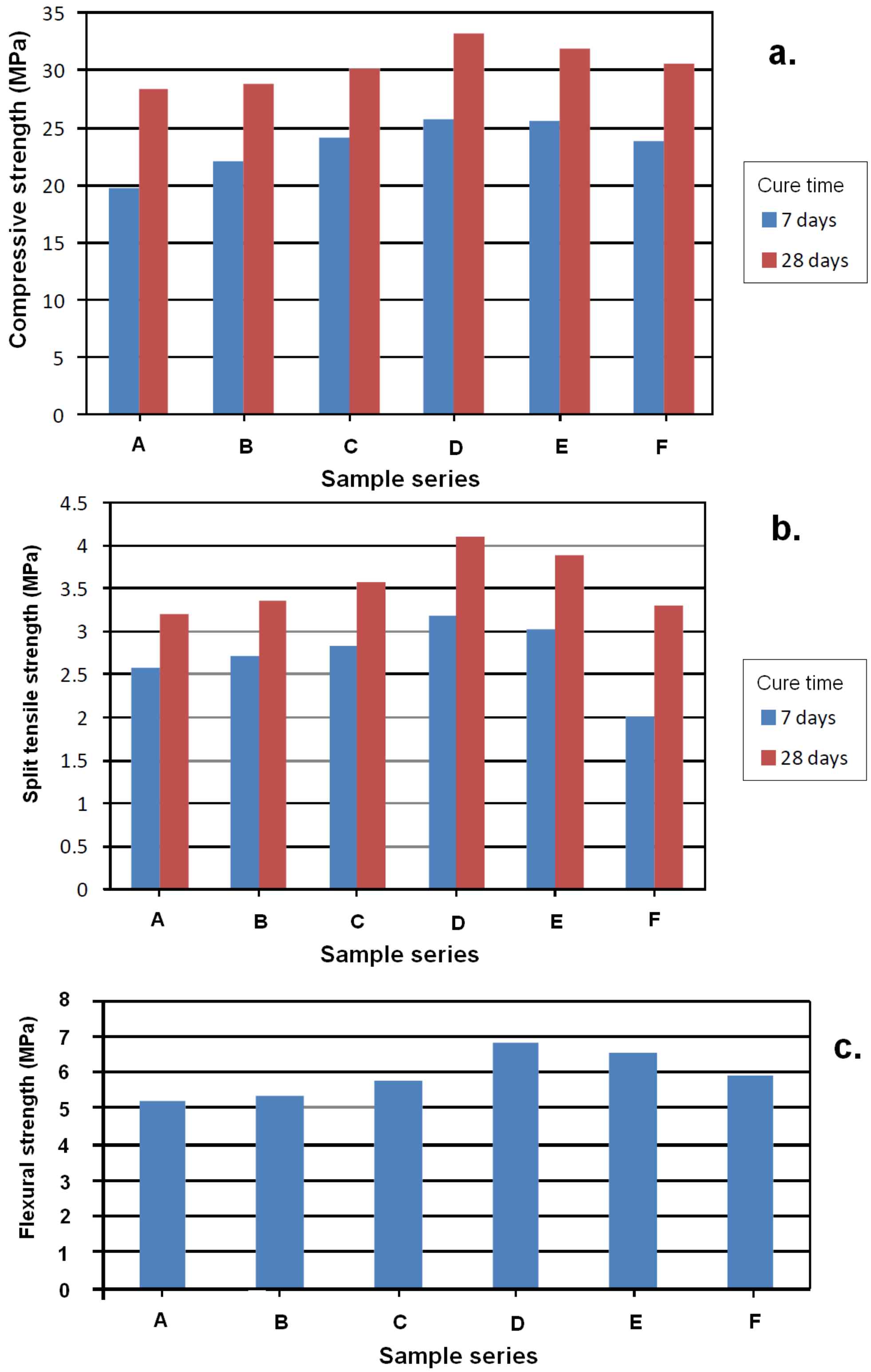

Fig. 3. Static mechanical properties for the different samples (a. for compressive strength, b. for split tensile strength and c. for flexural strength)

would need to be considered by introducing one of these in concrete, although some literature exists already, as discussed above for coir and hair fibres in concrete, even if the depart conditions of concrete, as far as e.g., grade and water/cement ratio, needs to be comparable too. On the specific case of nanosilica of similar size introduced in concrete, some results were provided already in [11], albeit with different objectives. This analysis has not be performed so far, because of limitation of the number of samples, which suggested to insist on performing different kinds of tests on the samples, yet only having one sample per condition. It is worth considering that, also in this case, the total number of 36 samples was to be fabricated already. The combined introduction of the three fillers allowed establishing what was supposed to be the best content for mechanical improvement, which is, as discussed before, that of sample D.

Table 3. Results of cyclic flexural tests on different sample series

Sample series	Number of cycles to failure	Maximum load (kN)	Maximum deflection (mm)
A	6	60.70	5.2
B	7	70.65	7.4
C	8	80.50	8.6
D	9	90.40	9.8
E	7	70	12.6
F	6	61.20	12.1

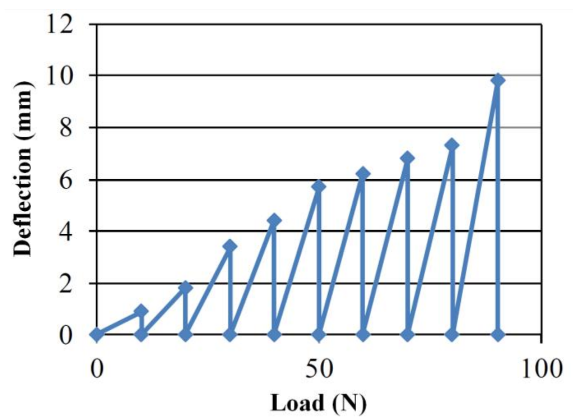

Fig. 4. Example of cyclic load deflection curve for sample type D

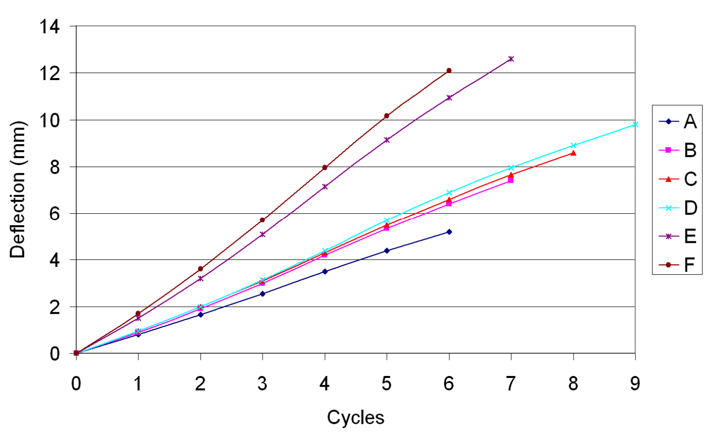

Fig. 5. Deflection vs. cycles curve for all samples (each cycle= 10 kN)

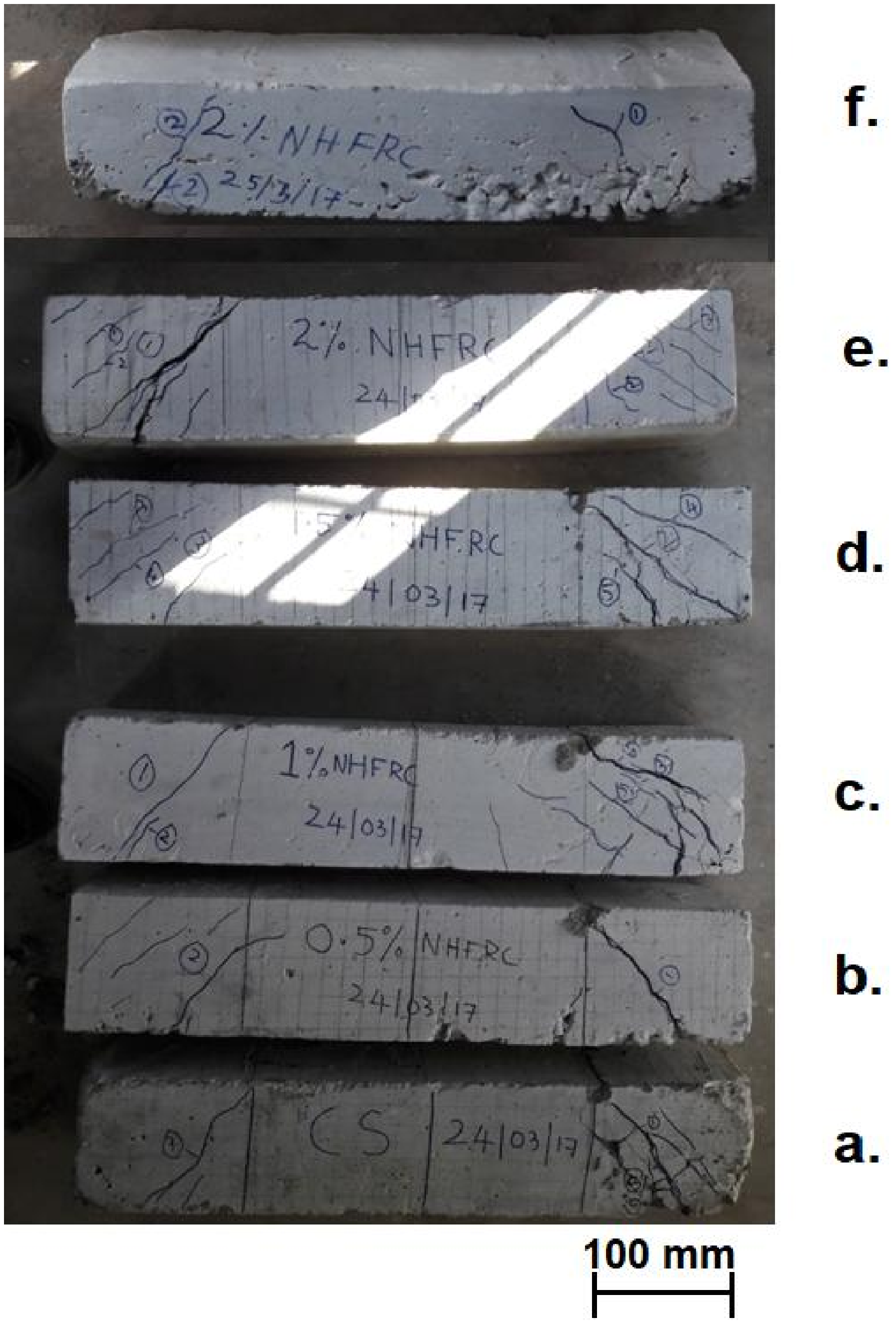

Fig. 6. Crack patterns in fractured beams after cyclic tests (from top to bottom, samples F to A)

4. CONCLUSION

These preliminary results indicate that the improvement of cyclic flexural and number of cycles to failure, other than compressive, split tensile and static flexural properties, are effective and consistent up to a global 1.5% volume (0.75% each) of the two waste fibres and 3% volume of nanosilica. Also, the ultimate deflection for the hybrid beams with added filler was found to be increasing when compared to the bare concrete beams, which is likely to be due to the increase in ductility of the beams. Also crack patterns appear neater and suggest a higher ductility of the material, up to this limit of content filler. Further work would require acting on the repeatability and consistency of introduction would be required, as well as on the selection and careful examination of the characteristics of waste to reduce as much as possible dispersion of properties.

COMPETING INTERESTS

Authors have declared that no competing interests exist.

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