Experimental study of the influence of the incorporation of combined recycled steel and polypropylene fibres on the compressive behaviour of self-compacting cementitious composites

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Abstract

The majority of fibre-cement composites are made from a single type of fibre. However, using a several types of fibers in the composite, with different proportions, canbe improve the properties of the material, such as impact strength, tensile strength, compressive strength and increased stiffness. This study aims to valorise the recycled steel fiber, obtained from steel wool production waste, and the polypropylene fiber, as reinforcement, and a cementitious matrix, based from local materials, to devlope a new self-compacting cementitious composite with combined fiber. Several matrix/combined reinforcement proportions are considered to evalueted the effect of the quantity of combined reinforcement on destructive tests, such as compressive strength, and non-destructive tests, such as sound propagation velocity and rebound index on the the quality of these composites. The results suggest that the combination of th recycled steel fiber and the polypropylene fiber improve the mechanical properties of the self-compacting cementitious composites.

Keywords: *self-compacting cementitious composite; recycled steel fibers, polypropylene fibers , Combined fiber , destructive tests, non-destructive tests.*

1. Introduction

Cementitious composites, which are essential in today's structural applications, represent a significant advance in construction materials and materials technology. From the literature, the cementitious matrices, such as concrete and mortar have a low strength to tensile and break easily [1-2]. To improve the tensile strength, it is usual to use metal reinforcements. This technique request makes the cost of construction expensive. For this reason, the incorporation of fibers into cement-based composite structures has a significant economic impact on the construction costs, particularly in terms of labour hours. The construction process is improved when all or part of these conventional reinforcements are replaced by fibers [1]. This technique offers a variety of solutions to composite technology such as the use of fiber-reinforced self-compacting cementitious composites (FRCCC) [2]. Reinforced cementitious composites are frequently used in a variety of advanced applications. The sprayed cementitious composite and tunnel lining industries account for the majority of FRCCCs in most countries [3].

At present, nylon, glass and polypropylene fiber are added to cementitious composite to improve its qualities in the fresh state and reduce early cracking. Although they do not have as much impact on post-cracking behaviour as steel fiber, these non-metallic fiber can also be used [4]. Steel fiber, glass fiber and micro-polypropylene fiber (MPP) are just a few examples of the many fiber that can be used. Fiber are often added to FRCCCs to make them more resistant to breakage [5]. It has been shown that the inclusion of fiber, such as the use of hardwood pulp [5], the addition of glass fiber [6] and the addition of plant fiber [7], [8], can improve mortar performance. The cementitious composite has been reinforced with various types of fiber, including steel, synthetic fibers and natural fibers. [9] Jute, coir and sisal fibers are used to reinforce reinforced cementitious composite structures. [10]. The results of the experiments carried out by the researchers revealed that the resistance of the cementitious composite to liquefaction decreased, while its resistance to compression, traction and flexion increased with the volume of the fiber.[11]. When fiber are added, the flow value also decreases compared to a mixture without fiber [12]. At present, steel and polypropylene fibers are the two most common types of fiber used in cementitious composites. The shrinkage of cementitious composite reinforced with polypropylene fiber has been greatly reduced by increasing the fiber content up to 0.5% of the composite volume, but the rate of shrinkage reduction became relatively minor as the percentage of fiber increased [13]. The use of fiber, particularly fine synthetic fiber with a volume of less than 0.5%, is the best and most acceptable way of preventing the creation of cracks. [14-15]. Self-compacting with hooked steel fibers, $f = 0.38\%$, has an axial compressive strength 19% higher, according to [16-17]. The axial compressive strength of self-compacting FRCCCs did not change when steel fibers with a fraction $Fv = 0.5\%$ and 1.0% were added, according to [18]. However, some studies have been carried out on the addition of two different fiber to the cementitious composite may be a suitable compromise for obtaining the desired qualities of the cementitious composite both fresh and hardened [16], [19]. The researchers [20]and [21] found that the workability of FRCCCs is not affected by the inclusion of mixed steel fiber up to 1.5%. However, some workability parameters are significantly affected by the inclusion of additional steel fiber above 1.5%. The mechanical characteristics of the standard cementitious composite reinforced with mixed steel-PP fiber have, however, been the subject of a few studies [22]. Adding 2% mixed steel fiber gives a box L value of less than 0.8 and does not meet the standards [23].

A study of the mechanical behaviour of a self-compacting cementitious composite contaned a short and long mixed steel fiber was also carried out [24].
Several studies have been carried out to find the ideal mixing ratio for adding steel or polypropylene fiber to FRCCCs.

This experimental study presents the discovery of the qualities in the hardened state du FRSCCC material. In the elaboration of FRSCCC material two types of fibers was combined (recycled steel fibers and polypropylene fibers), used as reinforcement, and mixed with a cementitious matrix, based from local materials. Several fractions of the combined reinforcement were carried out (Maximun 2%). An experimental method was carried out to determine the mechanical properties of FRSCCC and evaluate the mechanical qualities over time (7, 14, 21 and 28 days). In addition, the FRSCCC material was tested in the fresh state (J-ring test, V-Funnel test, U-box test and L-box test), furthermor, its quality in the hardened state using some destructive tests (compressive strength) and non-destructive tests (sound propagation velocity test and rebound index).

2. Methodology

2.2 Materials and mix design

Ordinary Portland cement, limestone fillers, aggregates, colloidal agent, superplasticizer and water were used in this study. Their properties are shown in Table 1. In this experiment, ordinary Portland cement (CEM I 42.5 R) is made from gypsum and Portland cement clinker. Crushed limestone is available from most quarries in Biskra in the form of limestone fill. We used crushed stone. We used crushed limestone gravel sourced locally from the Ain-Touta deposit located 80 kilometres north of Biskra. Sand from the Lioua region (wilaya of Biskra), which is often used to manufacture cement composite in this locality. For the gravel grains and sand, a particle size distribution with maximum (7/15) and minimum (0/5) sizes was determined. In order to obtain optimum workability (fluidity) of our cementitious composite, a colloidal agent, a white powder soluble in water, generally used to prepare cementitious composites and mortars, designated "MEDACOL BSE", was added. To improve the workability of the mix, a water-reducing superplasticizer was added. We prepared our mixes using tap water. People often think that drinking water is sufficient for mixing cementitious composite.

. **Table. 1** Test data for materials

N°	Designation	Property	
		Absolute density	Apparent density
01	Cement	3.150	1.215
02	Fillers	2.50	1.09
03	Coarse aggregate	2.59	1.33
04	Fine aggregate	2.572	1.678
05	Colloidal agent	0.5	/
06	Super-plasticizer	1,20 ± 0,01	

Table 2 shows the proportions of the composite composition. These proportions were calculated using a minimum slump flow diameter of 650 mm and a compressive strength of 35 MPa or greater for a standard self-compacting cementitious composite. In this study, different fiber (recycled steel fiber and polypropylene fiber) with varying combinations were used to reinforce the composites with constant fiber volume fractions of 0%, 0.5% and 1%. Five alternative blend compositions were created taking into account the different combinations, contents and types of fiber. Table 3 shows the chosen fiber combinations.

Table. 2 Details of Mix design ratio

Cement	Fillers	Coarse aggregate	Sand	Water
1	0.43	1.77	1.84	0.4

Table. 3 Designation and details of the report on fibers of different compositions

Designation	Recycled steel fiber	Polypropylene fiber
CCO	0%	0%
CRA	0.5%	0.5%
CRB	1%	0.5%
CRC	0.5%	1%
CRD	1%	1%

Several tests characterising rheological properties are available in the literature. However, in our study, we rely on the characterisation tests on fresh cementitious composites summarised in Figure 1:

J-Ring Test V-Funnel Test U-Box Test L-Box Test

Figure 1. characterisation tests on fresh concrete

The development of composites reinforced with recycled steel fibers is currently the subject of extensive research. To be used in a range of applications, recycled fiber need to have specific mechanical properties, such as improved tensile strength. Our composite is reinforced with recycled steel fibers produced from steel wool production waste, as shown in Figure 2. The irregular lengths and diameters of the recycled steel fiber revealed some diversity in their corrugated architecture. Statistical analysis was therefore used to characterise the geometric parameters of the recycled fiber. Further details and information are available in the study [25].

The mechanical properties of the recycled steel and polypropylene fiber. The recycled steel fiber used in this study are corrugated with a semi-spherical cross-section and lengths of approximately 50 mm and 12 mm respectively, as shown in Figure 3.

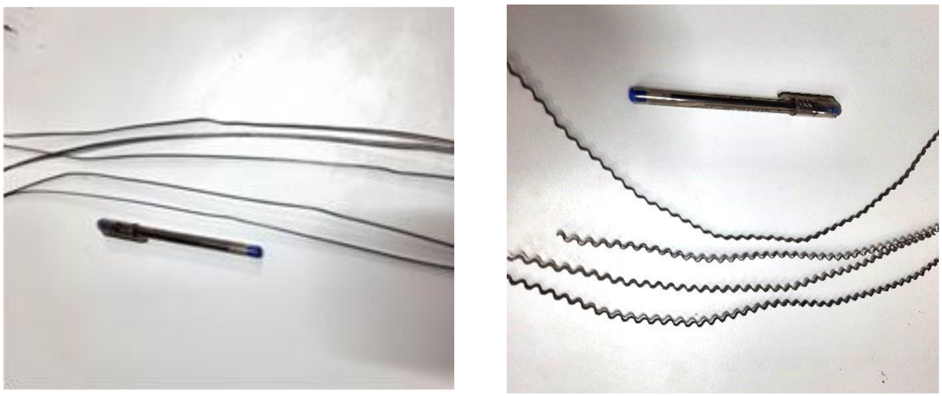

Figure 2. Production of recycled steel fiber

-a **-b**

Figure 3. the fibers used-a. Polypropylene fiber, -b. Recycled steel fiber

3.results and discussion

3.1. Compressive strength tests

From the results obtained in Figure 4, we can see that:

Air voids in mixes increase when fibers are added, and at the same time fibers can reduce fracture propagation. As a result of the interaction between these two processes, compressive strength can increase or decrease. The addition of the fiber combination effectively increased the air void content. On the other hand, the results showed that the ability of the fiber to block crack propagation led to an increase in the compressive strength of the mixtures including fiber compared with the ordinary composite at a young age.

Compressive strength decreases at a young age when the PP fiber is increased. This is mainly due to the use of a PP fiber with a smooth surface, which results in a weak bond at the contact between the matrix and the fibers. In addition, it was observed that the greatest increase in compressive strength was recorded, of around 20%, in the 28-day CRA sample of mixes reinforced with the mixed combination of 0.5% PP and 0.5% recycled steel fiber.

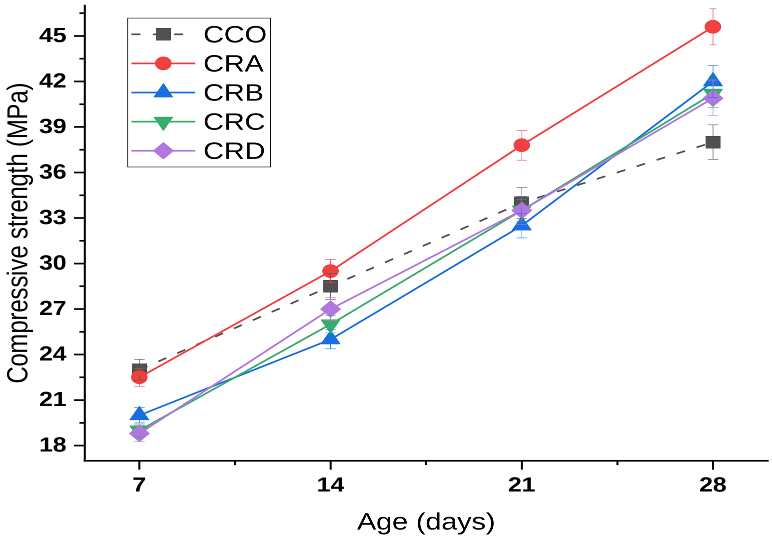

Figure 4. Compressive strength of composites as a function of age

3.2. UPV tests

From the results obtained in figure 5 and 6, we can see that:

The sound propagation velocity in the cementitious composite increases with increasing age of the cementitious composite, regardless of the type of cementitious composite.

The speed of sound propagation in the cementitious composite decreases with an increase in the percentage of both types of fiber , regardless of the type of cementitious composite.

The speed of sound varies according to the measured position (top, middle and bottom) of the cubes.

The speed of sound at seven days of age is greater than at seven days of age, due to the presence of water in the cementitious composite, whatever the percentage of fiber (0%, 0.5%, 1%) for combinations of the two types of fiber . This increase in sound speed is attributed to the fact that the ultrasonic pulses travel through the water-filled pores, whereas in the dry state the ultrasonic pulses travel around the edges of the pores.

So, as the travel distance decreases, the time decreases and the speed of sound propagation increases. It can be seen that using a percentage of fiber (0.5% metal fiber and 0.5% polypropylene) gives us a higher speed of sound than the ordinary cementitious composite, while using a percentage of fiber (1% metal fiber and 1% polypropylene) gives us a lower speed of sound than the ordinary cementitious composite. The estimation of compressive strength as a function of sound velocity has a certain reliability, whatever the type of cementitious composite, and reflects the reality of the behaviour of the cementitious composite as a function of the measurement position and the age of the samples used.

The speed of sound propagation decreases as the percentage of fiber combination increases. This behaviour is explained by the porosity aspects (voids created by the amount of fiber added), above 0.5% for the types of fiber used.

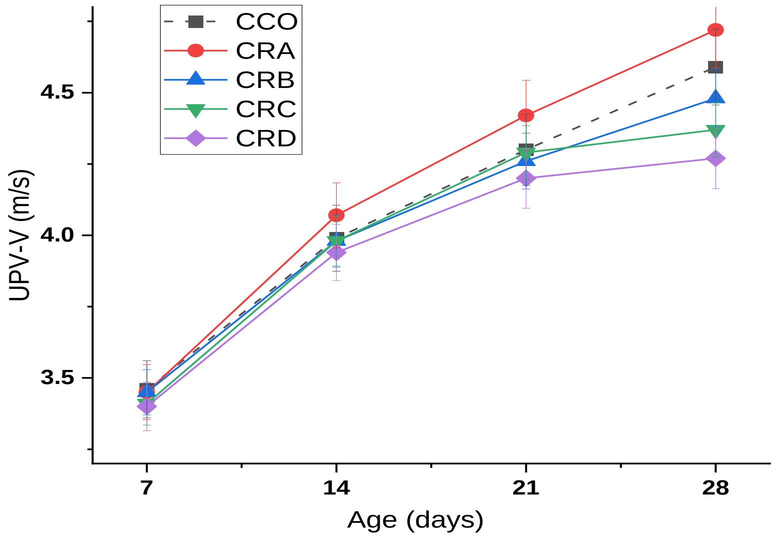

Figure 5. UPV-V of composites as a function of age

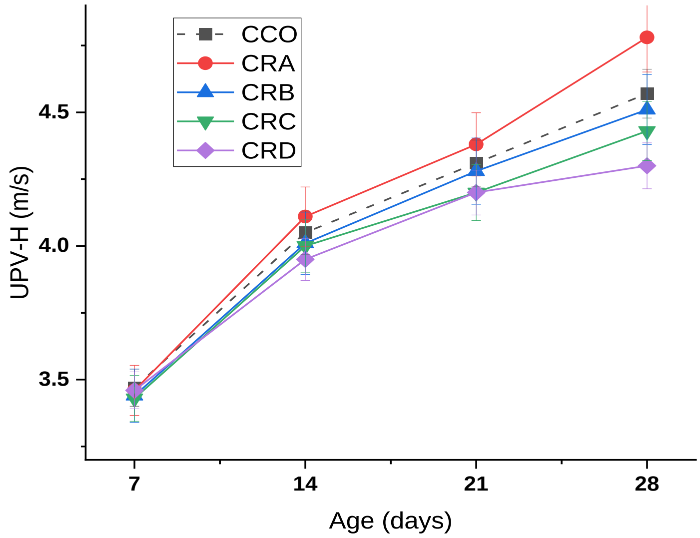

Figure 6. UPV-H of composites as a function of age

3.2. Sclerometer index tests

From the results obtained in figure 7 and 8, we can see that:

The sclerometric index increases as the age of the cementitious composite increases.

At a young age (seven days after demoulding the cubes), the sclerometric index is almost zero (no reading is mentioned on the device). The sclerometric index values vary according to the measurement position (casting face, opposite face (Rv) and lateral faces (Rh)). We note that the variation in the sclerometric index between the pouring face and the opposite face of each cube is variable. This can be explained by the fact that one side is in contact with the soil, which prolongs the hydration time. The pouring face loses more water than the opposite face, which does not allow similar hydration on both sides, and sometimes due to segregation. Estimating compressive strength based on the sclerometric index has a certain reliability, as it reflects the reality of the behaviour of the cementitious composite as a function of its age and the measurement position. It is not possible to assess the strength of the cementitious composite at a young age (seven days) using the sclerometer.

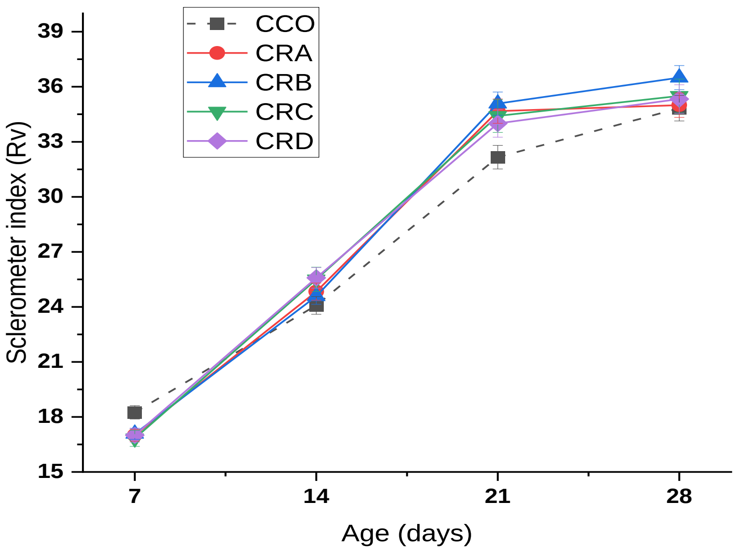

Figure 7. Sclerometer index (RV) of composites as a function of age

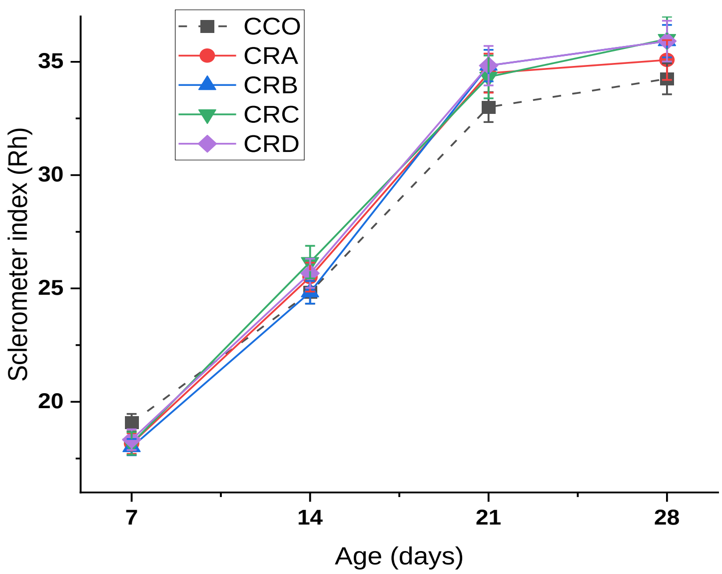

Figure 8. Sclerometer index (RH) of composites as a function of age

4. Conclusion

In this study the valorisation of the recycled steel fiber and the polypropylene fiber are used as reinforcement with a cementitious matrix, based from local materials, to elaborate a new self-compacting cementitious composite with combined fibers. Mechanical characterisations on the self-compacting cementitious composites with combined fibers were carried out such as compressive strength, sound propagation speed and rebound index, to determine the mechanical properties of the composite material. According to the results obtained, the following conclusions can be distinguished:

- By adjusting the type and the proportion of fibers, it is possible to develop a cementitious composite which meets the desired rheological criteria while taking into account economic constraints.
- The use of combined fibers, with percentages of 0.5% recycled steel and 0.5% polypropylene, provides good mechanical strength compared with ordinary cement-based composites.
- Above 0.5% of fibers (steel and polypropylene), the compressive strength of the cementitious composite decreases for any type of used fibers.
- Sound propagation velocity and rebound index have proved to be promising indicators for estimating the strength of self-compacting cementitious composite with combined fiber. These measurements are reliable for any type of cementitious composite, the measurement position and the age of the samples.
- The speed of sound propagation increases with increasing the age of the cementitious composite, On the other hand, if the quantity of fiber increases beyond 0.5%, the speed of sound propagation decreases.
- The hydration of the cementitious composite can vary between the faces of specimens, which explains the difference in sclerometric index between the casting face and the opposite face.
- The sclerometer index increases with the age of the cementitious composite, however, testing at a young age is not reliable.
- Non-destructive tests, such as the measurement of the sclerometer index, can provide a reliable estimate of the strength of the cementitious composite as a function of age and measurement position, but are not suitable for assessing the strength of the cementitious composite at a young age.
- Finally, to increase the life of the cementitious composite and reduce the risk of macro-cracks, the incorporation of fiber in the cementitious composite formulation is proving promising. However, the optimum dosage must be taken into account to avoid an excessive reduction in strength.

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