Recycled Polypropylene Fibres for Reinforcing Cement Mortar under Arid Conditions

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Abstract

Concreting in arid environment is a delicate operation, due to many problems, such as the premature evaporation of mixing water, which affects the material consistency and the shrinkage cracking which threatens its durability. The present experimental work is conducted to investigate the physical and the mechanical behaviour of cement mortar reinforced by recycled polypropylene fibres under arid conditions, at 45 °C and 30% RH. The used polypropylene fibres are recycled from a domestic plastic waste. The tests realized in this investigation include the workability, the total shrinkage, the flexure and the compression tests. Through this investigation, the beneficial effect of recycled polypropylene fibres as reinforcement of cement mortar is well demonstrated, particularly under arid environmental conditions. The obtained results showed a substantial increase in the flow time of about 53% in mortar reinforced by 1% of recycled polypropylene fibres (1RPFM). It is also shown that under arid conditions, the presence of 1% of recycled polypropylene fibres in cement mortar leads to a considerable decrease in total shrinkage of about 46% and an increase in the flexural and compressive strength of about 24% and 26%, respectively, compared to control mortar (CM) at the age of 194 days. Overall, the used recycled polypropylene fibres have presented a high capacity to improve the different properties of cement mortar and make it a suitable composite for concreting in arid environment.

Keywords: Cement mortar; Recycled polypropylene fibres; Arid conditions; Shrinkage; Mechanical strength

1 Introduction

Algeria is the largest country in Africa; it comprises 2.4 million square kilometres of land, more than 80% of which is occupied by the Sahara Desert. The Sahara is covered by immense areas of sand dunes and it is characterised by hot and dry climate, especially during summer, with high temperature (50 °C), low humidity, frequent and violent winds and intense solar radiations. The properties of concrete and mortars are significantly affected by these climatic conditions. Construction materials are subjected to high risk of evaporation of their mixing water, which can affect even constitution water, if their exposure to arid climate is long. In hot and dry climate, the evaporation is about 10 times, than in hot and humid climate (Almusallam, 2001). The premature loss of water causing by this accelerate evaporation increases the cracking risk in cement materials and reduces their mechanical strength at later ages and also their durability performances. To improve the materials quality and prevent their cracking, when exposed to arid and hot climate, several standards, as ACI 308R-16 and studies (Al-Amoudi et al., 2007; Khan & Abbas, 2017; Khan et al., 2021) recommend the application of an immediate curing technique. The incorporation of fibres in the mass of cement materials is considered by many authors (Zhang & Zhao, 2012; Cifuentes et al., 2013) as a good solution to reduce cracking risk and increase their ductility. Today, polypropylene fibres are among the most used fibres in concrete, because they have many qualities, such as their low price, their low density, their high chemical resistance, their non-water absorption and as reported by (Bin et al., 2020), their high ability to improve the fire resistance of concrete. The recycling of fibres coming from waste for the fabrication of some construction materials has become an important ecologic challenge as well as a major technological advantage (Bendjillali et al., 2013; Sengul, 2016; Pešić et al., 2016; Borg et al., 2016; Mohammad Hosseini & Tahir, 2018; Mohajerani et al., 2019; Adnan & Dawood, 2020; Faraj et al., 2020; Jain et al., 2021; Mohammed & Mohammed, 2021).

In the present paper, an experimental work is made on the re-use of recycled polypropylene fibres, as fibrous reinforcement, in cement mortar exposed to arid conditions (T = 45 °C and 30% RH). The used fibres are obtaining from a plastic waste of polypropylene resulting from the fabrication of domestic sweeps, which ends up in landfills. The valorisation of this waste in construction materials can improve their performances and participate in the protection of the environment. The work consists to measure the workability, the flexure and the compression strength and the total shrinkage of cement mortars reinforced by these recycled fibres.

2 Materials and Tests

For the preparation of tested mortar, Portland cement (CEM II/A 42.5), crushed limestone sand (0/2 mm), potable water, recycled polypropylene fibres, a superplasticizer (SIKA VISCOCRETE TEMPO12) are used. The sand characteristics are shown in Table 1. The fibres having the properties given in Table 2 are recycled from a domestic plastic waste (Figure 1).

Mortar mixtures are prepared according to the Standards EN196-1 (2005), with a water/cement and a sand/cement ratio of 0.55 and 3, respectively. The amount of the admixture, which is the same in all mortars is about 2.88%. The fibres are added in the last of mixing operation with weight contents of 0.5 and 1%. Three mortar mixes are tested, control mortar fabricated without fibres, noted CM, mortar prepared with 0.5% of recycled polypropylene fibres, noted 0.5RPFM and mortar prepared with 1% of recycled polypropylene fibres, noted 1RPFM. For each mixes, prismatic samples 40x40x160 mm are prepared and immersed in water for 14 days, immediately after their demoulding and then conserved under arid conditions, at 45 °C and 30% RH until testing day. Due to their very small size, compared to real structural elements that are already protected by the formwork, mortar samples if not protected will be exposed to a rapid evaporation of mixing water, immediately after their demoulding (24 hours) that can touch even the water required for cement hydration. Therefore, this initial curing of samples in water is an essential procedure that must be applied before exposure to arid conditions to prevent the premature water evaporation and allow the achievement of a sufficient strength for resisting to the various environmental conditions. The workability of the mixtures is estimated by the measure of the flow-time, according to the Standards P 18-452. Strength tests are conducted at different ages, 14, 21, 28, 42, 70, 105, 134 and 194 days. The strengths reached after 14 days in water conservation are considered as reference values. The total shrinkage is measured during 190 days of age of mortars.

Table 1: Characteristics of crushed limestone sand

Specific density	Fineness modulus	Sand equivalent	Methylene blue value	Water absorption
2.52 g/cm^3	1.80	63%	0.13 ml/g	4.50%

Table 2: Properties of recycled polypropylene fibres

Specific density	Diameter	Length	Water absorption	Elasticity modulus	Tensile strength
0.99 g/cm^3	0.38 – 0.51 mm	20 ± 2 mm	Nil	4 - 5 GPa	230 MPa

Fig.1: Recycled polypropylene fibres

3 Results and Discussions

3.1 Flowability

The flow-time of cement mortar has a significant effect on the facility of their production and also on their performances. It is well noted that mortars with recycled polypropylene fibres need more flow-time than control mortar (Figure 2). The increase of the flow-time will be interpreted in construction site by implementation difficulties of the material that requires additional finishing work. In composite materials, the cement paste may be trapped by fibres, giving the impression that the material is less workable. The negative effect of fibres on materials flowability is mentioned in many experimental works (Silva et al., 2013; Al-Hadithi & Hilal, 2016; Belferrag et al., 2016; Zeyad, 2019). This effect is less important with polypropylene fibres, by comparison to others (Dreux & Festa, 2002).

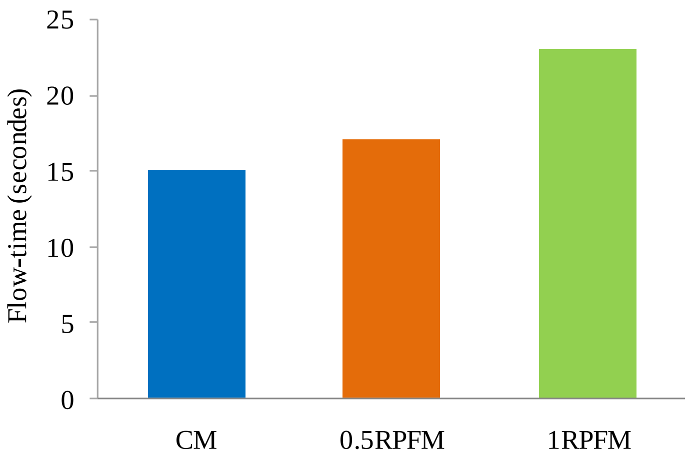

Fig.2: Variation of flow-time in cement mortars

3.2 Flexure Behaviour

Until 194 days of aging, the flexure strength of all mortars is the highest, compared to reference strength values (Figure 3). It is well observed that there is a quick strength evolution during the first 28 days of aging (14 days in water following by 14 days in arid conservation), where the evolution ratio reaches 116, 86 and 101% in mortars CM, 0.5RPFM and 1RPFM, respectively, compared to reference values. Kriker et al. (2008) have already concluded that the conservation of fibre concrete in hot-dry environment positively affects its performances at early age. A flexure strength reduction is detected beyond the age of 28 days; at 194 days, this reduction reaches 46% in CM, 37% in 0.5RPFM and 38% in 1RPFM, by comparison to maximum strengths obtained at 28 days. The decrease of flexure strength of mortars is probably due to the conservation conditions (T = 45 °C, 30% HR) that negatively affect the hydrated cement quality produced at early ages which in turn, weakens their long-term mechanical strength. These results are in agreement with others' studies (Park & Noguchi, 2017; Tang et al., 2017) who reported that the hot temperature favours early strength evolution but decreases the long-term strength. It is well known that the effect of hot temperature on the mechanical behaviour of cement materials becomes more influential with the low humidity. With the use of more recycled polypropylene fibres, the flexure strength becomes more important. By comparison, to control mortar, the flexure strength at the age of 194 days is increased by 19% and 24% in 0.5RPFM and 1RPFM, respectively. In this regard, it is very important to note that the recycled polypropylene fibres used in this investigation have a great ability to reduce the strength fall of cement mortars conserved in arid environment, which encourages their use for reinforcing concrete in arid climates. As other types of fibres, the used recycled fibres have improved the ductility of mortars by absorbing more energy, during flexure tests. These findings were mentioned in many literature studies (Oliveira et al., 2011; Yin et al., 2015; Caggiano et al., 2016).

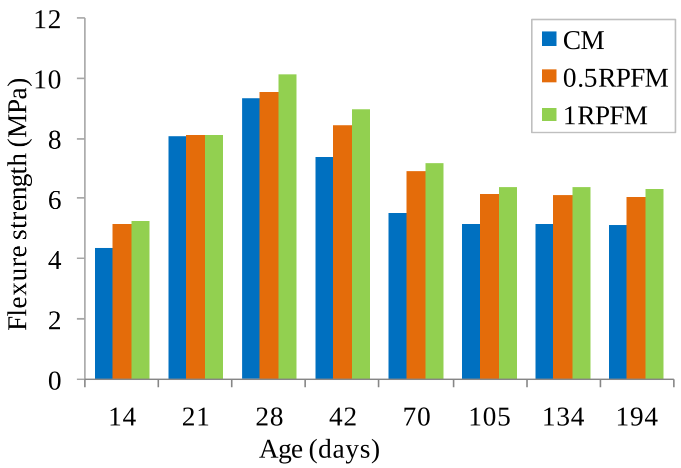

Fig.3: Variation of flexure strength of cement mortars

3.3 Compressive Behaviour

As with flexure behaviour, the compressive strengths of mortars in any age are higher than reference values (Figure 4). After a conservation of one week under arid conditions, a compressive strength increase of about 76, 63 and 49% is reached in CM, 0.5RPFM and 1RPFM, respectively, compared to reference values. These important percentages reflect the good effect of the temperature (T = 45 °C) associated with a low humidity (30% HR) to accelerate the evolution of the compressive strength by the activation of hydration reaction, during early time. The conservation conditions continue to affect positively, the compressive behaviour of mortars reinforced by recycled polypropylene fibres until 42 days of aging (14 days in water and 28 in arid conditions) and then a decline of about 20% in 0.5RPFM and 15% in 1RPFM in the compressive strength will take place at 194 days of aging. Gallucci et al. (2013) justify the low final strengths of materials exposed to a temperature of 60 °C by the coarser and the porous microstructure of the cement paste, resulting from the increase of the C-S-H apparent density. After a conservation of 180 days (194 days of age) under arid conditions, the compressive strength increase reaches 39% in CM, 47% in 0.5RPFM and 45% in 1RPFM, by comparison to reference mortars. Recycled polypropylene fibres have improved also the compressive behaviour of cement mortars conserved under arid conditions; where an increase of the compressive strength of about 14% and 28% is detected at 28 days aging, in 0.5RPFM and 1RPFM, respectively, by comparison to CM. At the age of 194 days, the compressive strength increases from 15% in 0.5RPFM to 26% in 1RPFM, by comparison to CM. According to some previous studies (Santos et al., 2005; Ramezanianpour et al., 2013; Alaskar et al., 2021), the use of polypropylene fibres as reinforcement in cement composites, reduces their compressive strength. Bentur & Mindess (2007) justify the compressive reduction by the difficulties to achieve a full compaction, which encourages the creation of porosity in the material, particularly by using high amount of fibres. The positive effect of the recycled polypropylene fibres is not limited only to mechanical strength of mortars, but also to their post-cracking, when the high capacity of these fibres to bridge cracks and to prevent their opening is well observed during all crush concrete tests.

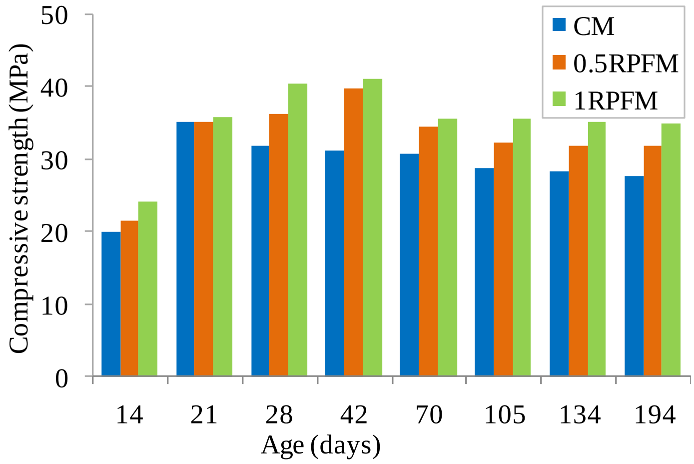

Fig.4: Variation of compressive strength of cement mortars

3.4 Total Shrinkage

The total shrinkage in all tested materials is in continuous evolution with the time, as seen in Figure 5. It is well observed that the shrinkage evolution is more important at early age, due to the effect of the conservation conditions (45 °C and 30% HR) on the evaporation of mixing water. The heat generated by the hydration reaction of cement during the first time of the preparation of mortars is also other parameter accelerating the water evaporation, which increases the risk of shrinkage. Several studies (Tolêdo Filho et al., 2005; Bouziadi et al., 2016), confirmed that the curing conditions do not affect only the initial rate of shrinkage, but also its magnitude. A stabilization of the values of shrinkage is observed at 78 days in CM and at 108 days in 0.5RPFM and 1RPFM. Furthermore, the presence of recycled polypropylene fibres in cement mortar considerably reduces the evolution and the amount of the shrinkage; in 1RPFM, the shrinkage is reduced by 74%, 56% and 46% at 1, 28 and 190 days of aging respectively, compared to CM. In other study (Branch et al., 2002), the reduction of the shrinkage reached up to 85% compared to ordinary concrete. It is remarked through these results that the used fibres act as a barrier against any shrinking movement in cement mortar. The efficiency of recycled polypropylene fibres to reduce the total shrinkage can also be due to their good dispersion into the mortar mass. Jafarifar et al., (2014) confirmed that in fibre reinforced concrete, the evolution of free shrinkage is more uniform than in unreinforced concrete. Nevertheless, some authors (Mesbah & Buyle-Bodin, 1999) see that the ability of fibres to reduce cracking width is more than their ability to reduce free shrinkage value in mortars. Other researchers (Ma et al., 2004) have confirmed that polypropylene fibres decrease the number of larger cracks in cement mortar, but they increase the finer ones.

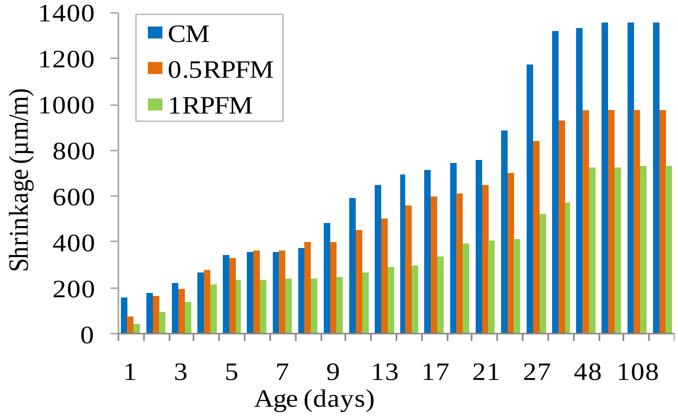

Fig.5: Variation of total shrinkage in cement mortars

4 Conclusion

From the present study, the following conclusions can be drawn:

- As many other types of fibres, the recycled polypropylene fibres have an adverse effect on the mortar consistency, particularly under arid conditions.
- The arid conditions which are characterised by low humidity and high temperature improve the early age mechanical strength of cement mortars, while their effect on the long-term strength is negative. At 28 days aging, the increase percentage of the flexure strength is about 116%, 86% and 101% in CM, 0.5RPFM and 1RPFM, respectively, compared to reference values; for the compressive strength, it reaches 76%, 63% and 49%, respectively. At the age of 194 days, the percentage decreases to 18% in CM and 0.5RPFM and 20% in 1RPFM for the flexure strength and to 39%, 47% and 45%, respectively, for the compressive strength.
- The recycled polypropylene fibres improve both the flexure and the compressive strength of mortars under arid conditions; in the mortar 1RPFM, the improvement is about 24% and 26% for the flexure and the compressive strength respectively, compared to CM, at the age of 194 days.
- The mortars conserved under arid condition rapidly develop more shrinkage with high values.
- The presence of recycled polypropylene fibres into the mass of mortars conserved under arid conditions shows down the evolution of their shrinkage and reduces its final values, when the reduction exceeds 46% in 1RPFM, by comparison to CM.
- The recycled polypropylene fibres improve the failure mode of tested mortars, by bridging cracks.

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