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Formulation and characterisation of micro and macro polypropylene fibre reinforced mortar

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Abstract. The objective of this work is to study the physical and mechanical characteristics of mortars reinforced by synthetic fibres. The work is carried out on mortars, using limestone crushing sand, composite cement and synthetic fibres. The fibres used as reinforcement of these mortars are synthetic fibres of polypropylene coming from industrial wastes; micro fibres having a diameter of 0.25 mm and macro fibres with a diameter of 0.45 mm. The used fibres have the same length of 30 mm. The results revealed that the addition of polypropylene fibres has a negative effect on the workability of the mixture, especially micro fibres. However, the mechanical properties of mortars have been enhanced. The weight loss is close in all mortars.

Key words: Mortar, Polypropylene fibres, Micro fibre, Macro fibre, Workability, Mechanical strength, Weight loss.

1. Introduction

Based on statistic studies, the concrete is considered as the most used material in the world after water. Concrete is a durable material, with a high compressive strength and stiffness and it can be moldable into complicated shapes. However, concrete has a low tensile strength and a low ductility (Manaswini, 2015). To improve this weakness, many technical solutions are proposed; such as the introduction of fibres in its mass. During the mixing process, fibres are distributed throughout the concrete in all directions. Consequently, the concrete tensile strength as well as modulus of elasticity is thus increased. The problem of the addition of fibres to concrete is the decrease of its workability, thus for improving this property, mixing water volume should be increased or water reducing super plasticizers will be added to the mixture.

In construction, there are several types of fibres used for the reinforcement of concrete, such as metallic (Hadjoudja et al., 2019; 2021; Ammari et al., 2020), synthetic (Bendjillali and Chemrouk, 2018), mineral and vegetable fibres (Krobba et al., 2018). It has been established that the addition of metallic or polypropylene fibres to cement based materials can increase their fracture toughness, ductility and their mechanical resistance. Synthetic fibres are non-biodegradable and their presence in the nature cause environmental pollution. In order to reduce the air, water and ground pollution, synthetic fibres are used in concrete and their use represents an economic gain in the field of civil engineering. Synthetic fibres of polypropylene or polypropylene-based are often preferred over steel fibres due to their lower production cost, lower weight and their high deformation and also because they do not absorb water or react chemically with cement. The presence of synthetic fibres in concrete reduces the workability and improves efficiently the mechanical strength, and can significantly affect the lifespan of the structure by reducing the permeability, the amount of shrinkage and the expansion of concrete. According to the same authors, polypropylene fibres increase the fire resistance of the structure due to the low melting point of the polymers and inferential formation of water vapour capillaries in the structure of concrete (Antoš et al, 2017). Polypropylene fibres have a good resistance to degradation and sufficient mechanical properties, such as tensile strength and toughness and they have the ability to disperse easily in the concrete and to control plastic shrinkage cracks (Banthia and Gupta, 2006).

Sand is the essential aggregate used in the composition of the mortar. The river sand is the most commonly used for construction in Algeria. The excessive extractions of this sand have contributed significantly to the depletion of resources and have caused adverse effects on the environment. Many parts of the world are experiencing this situation and must now look for alternative materials to meet the growing demand for concrete and mortar aggregates. Crushing sands are very often the only alternative. However, they must meet their own quality criteria and be available in sufficient quantities at reasonable prices.

In this experimental work, crushing limestone sand produced by Ouazzane station (situated in the north of Laghouat city) is used for preparing the test's mortars. The fibres used as reinforcement of these mortars are synthetic fibres of polypropylene coming from industrial wastes; macro fibres with a diameter of 0.45 mm produced by PLAST BROS factory of Bordj Bou Arreridj (Algeria) and micro fibres with a diameter of 0.25 mm obtained from the market. The used fibres have the same length of 30 mm. The valorization of these materials as reinforcement seems to be a good solution for the economic, environmental and technical problems of concrete constructions. The present investigation is carried out to study the physical and mechanical characteristics of mortars reinforced by synthetic fibres of polypropylene.

2. Experimental programme

2.1. Material and formulation

For the realisation of this work, we have used limestone crushed sand as fine aggregate in the mortar composition. It is a crushing residue obtained from the fabrication of limestone gravel in Ouazzane station in the north of Laghouat. The sand has a particle size ranging between 0 and 3.15 mm. The size graduation and the characterization of the used sand are presented in Figure 1 and Table 1.

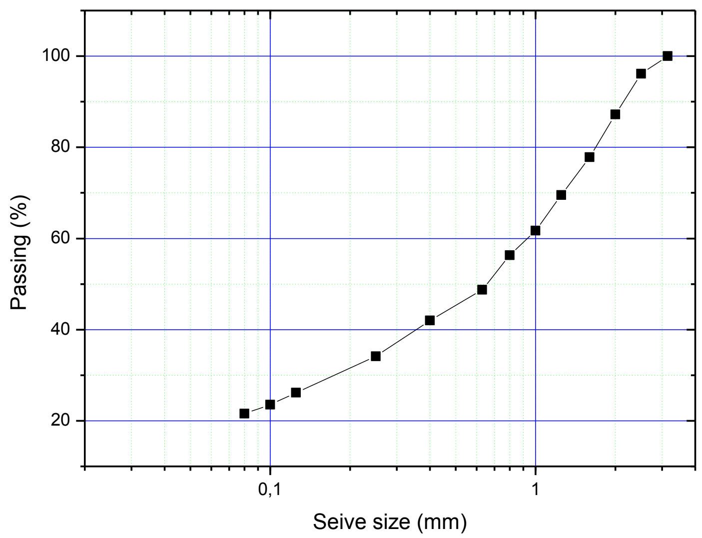


Fig 1. Size graduation of sand.

A Portland cement CEM II/B-L 42.5 N was used; it is produced by M'Sila cement factory (Algerian company). Table 2 gives the different properties of the used cement. A superplasticizer type SIKA VISCOCRETE TEMPO12 and a potable water were used for the mixing. The employed fibres are of polypropylene (PP) with two different diameters, micro (Figure 2.a) and macro fibres (Figure 2.b). Micro fibres are obtained from the market and macro fibres are produced by PLAST BROS factory of Bordj Bou Arreridj (Algeria), Table 3 illustrates their properties.

Table 1. Sand characterisation results.

Properties	Results	Interpretations
Specific gravity	2.60 g/cm^3	Current aggregates (Neville, 2002)
Bulk density	1.49 g/cm^3	
Fineness modulus	2.45	Medium sand (Dreux and Festa, 2006)
Esv / Esp	64 % / 59 %	Crushed sand contains many fines (Dreux and Festa, 2006)
VB	0.14 ml/g	(VB < 1) Satisfactory sand and fines are not harmful for material (Dreux and Festa, 2006)

Table 2. Cement characterisation results.

Properties	Results
Specific gravity	3.1 g/m^3
Bulk density	1.13 g/m^3
Fineness	3700 cm^2/g
Consistency	26.5 ± 2.0 %
Cement setting	150 ± 30 min
7th Compressive strength	37.89 ± 1.88 MPa
7th Flexural strength	6.45 ± 0.44 MPa

a. Micro fibre

b. Macro fibre.

Fig 2. Polypropylene fibres.

Table 3. Fibres characteristics.

Characteristics	Micro fibres	Macro fibres
Diameter(mm)	0.25	0.45
Length (mm)	30	30
Specific gravity	0.99	0.99
Absorption to water	None	None
Tensile strength (MPa)	235	204
Elongation (cm)	14	4

In this work mortar mixes are prepared with a sand to cement ratio (S/C) equal to 1/3 (C = 450 g), a fibre dosage of 1 % by weight, which is previously fixed (Bendjillali, 2015). Mixtures are prepared as follows:

- Vary the water to cement ratio (W/C) to achieve a desirable workability, without the use of admixture.

- Find out the percentage of superplasticizer SP, which gives the desirable workability of mortars for a given W/C ratio.

- Find out the percentage of superplasticizer which gives the desirable workability of fibre mortar, for a given W/C and a percentage of fibres of 1 %.

Mixing process is carried out with a mortar mixer as below:

- Cement and sand are mixed for 60 sec,
- 70% of water is added; the wet mixing is kept for 30sec,
- The rest of water (30 %) is added with the superplasticizer; mixing is kept for another 30sec,
- Fibres are added to the wet mortar and mixed for 90 sec.

During the first 210 sec, the mixing is realised with a slow speed and then with a fast speed during another 30sec to ensure that the fibres can evenly disperse throughout the mortar. After, the mixture is relaxed for 90sec and then remixed for 60 sec with a fast speed.

2.3. Preparing and curing of specimens

Starting with the measure of workability of the fresh mortar then, filling in prismatic moulds (40×40×160) mm (Figure 3.a), which are covered with a plastic film (Figure 3.b). Samples are demoulded after 24 h and conserved in controlled chamber (T = 22°C, RH = 92 %) for mechanical tests or in uncontrolled chamber (T = 20 ± 5°C, RH = 20 ± 5 %), for weight loss test

a. Molding mortar

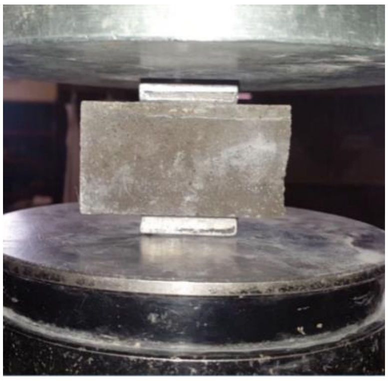
b. Curing of samples under a plastic cover

Fig 3. Molding and curing of samples

2.4. Tests

The measure of the workability was yielded according to NFP18-452 by a Maniabilimeter B, which is consists of a parallelepiped mould with a mobile wall and a vibrator. The principle of the test consists after removing the mobile wall, to measure the time taken by the mortar under vibration to reach a mark engraved on the inner face of the mould. Numerous mixes were prepared and tested until obtaining a good workability, which corresponding to a flow time of 16 ± 4 seconds. According to EN 196-1, compressive and flexural strength were measured after 28 days of age. The flexural strength was tested on prismatic specimens (40×40×160) mm (Figure 4.a) and the half-prisms(Figure 4.b) were utilized for the compressive test using “CONTROLS” testing machine(Figure 4.c), with a maximum charge load of 100 kN. For the evaluation of the weight loss, prismatic specimens (40×40×160) mm were prepared and exposed to the atmospheric air (T = 20 ± 5°C, RH = 20 ± 5 %) during 28 days then a daily measure of weight is made using a0.01g balance precision. The weight loss is the ratio of the mass difference, between the initial mass and the daily mass to the initial mass.

a. Three point flexural test.



b. Compressive test.

c. Testing machine.

Fig 4. Mechanical test

3. Results and discussions

3.1. Formulation of control mortar without superplasticizer

The experimental results of this test are shown in table 4. The Figure 5 confirms the practical reality that the flow time decreases with the addition of water. To reach a good workability, mixtures need a high W/C ratio which is between 0.60 and 0.69. The high W/C ratio is due to the important absorption of the used sand (= 6.23 %).

Table 4. Composition and flow time of control mortar without superplasticizer

Mortar	C (g)	S (g)	W (g)	W/C (%)	Flow time (s)	Visual observations
M’0	450	1350	270.0	0.60	45	Very dry mix
M’1	450	1350	292.5	0.65	30	Dry mix
M’2	450	1350	301.5	0.67	10	Wet mix
M’3	450	1350	310.5	0.69	6	Self-levelling mix

3.2. Formulation of control mortarwith superplasticizer

For respecting the practical recommendations, the W/C ratio is reduced to 0.55 and then to 0.50. For each W/C ratio, the percentage of superplasticizer is measured. According to the table 5, the mixes M2 and M7 give the good workability. Figure 6 illustrates the variation of the flow time with the percentage of superplasticizer. The figure confirmed the roleof the used superplasticizer, which is a water-reducer, to reduce the water dosage. This conclusion is in accord with the study of Kheribet et al. (2011) established on the effect of the superplasticizer on the rheological properties of concrete. The viscosity of the mixture decreases that means that the utilisation of superplasticizer reduces water requirement to have a workable mixture, this can be explained by the dispersing effect of the superplasticizer, which, causes a steric repulsion between the cement particles, reducing their agglomeration (Kheribet et al., 2011).

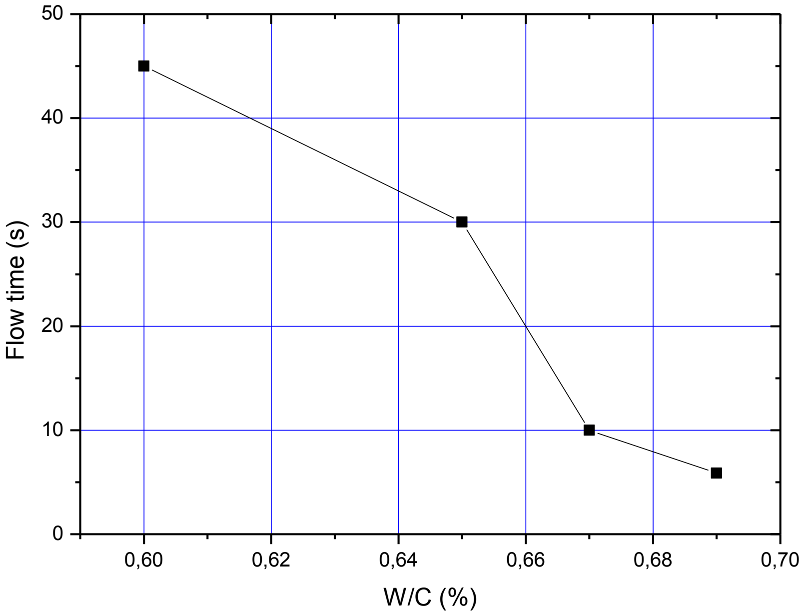


Fig 5. Variation of flow time of mortars in function of W/C ratio.

The mixture M7 is chosen as control mortar MC, because it requires an acceptable water dosage and a superplasticizer percentage (= 0.93 %) lower than that required by M2 (= 1.2). Since the superplasticizer is a commercial material, it is very important to use lowest dosages for not increasing the mortar cost. We note that control mortar gives a good strength at the 28th day. The Table 6 gives the final formulation of control mortar.

Table 5. Composition and flow time of control mortar with superplasticizer.

Mortars	C (g)	S (g)	W (g)	W/C (%)	SP (%)	Flow time (s)	Visual observations
M1	450	1350	225	0.50	1.0	28	Very dry mix
M2	450	1350	225	0.50	1.2	16	Plastic mix
M3	450	1350	225	0.50	1.3	9	Wet mix
M4	450	1350	247.5	0.55	0.6	35	Very dry mix
M5	450	1350	247.5	0.55	0.8	30	Very dry mix
M6	450	1350	247.5	0.55	0.9	25	Dry mix
M7	450	1350	247.5	0.55	0.93	15	Plastic mix
M8	450	1350	247.5	0.55	0.95	10	Wet mix
M9	450	1350	247.5	0.55	1.0	7	Wet mix
M10	450	1350	247.5	0.55	2.0	1	Self-levelling mix

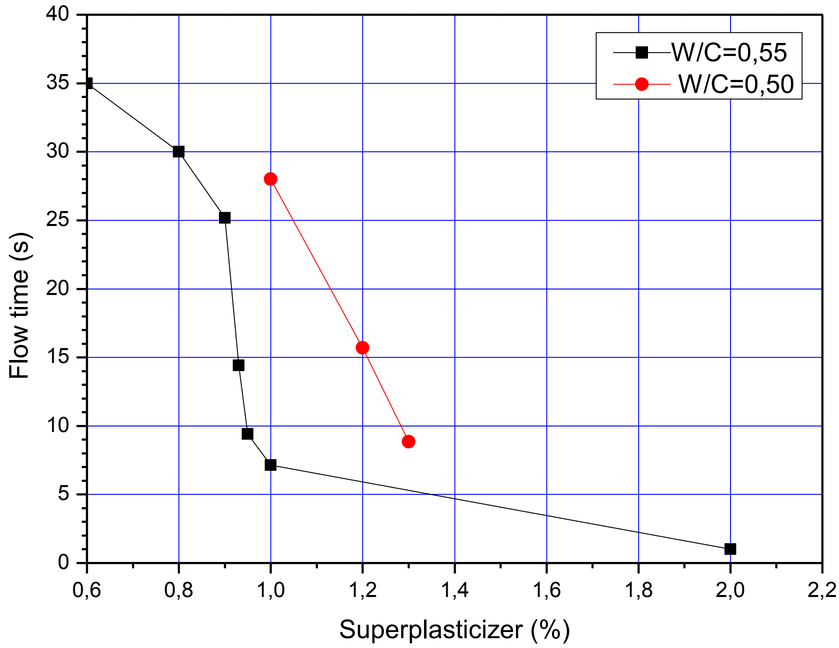


Fig 6. Variation of the flow time in function of the superplasticizer percentage.

Table 6. Final composition of control mortar

Mortar	C (g)	S (g)	W (g)	W/C (%)	SP (%)	R_{C28d} (MPa)	R_{f28d} (MPa)
MC	450	1350	247.5	0.55	0.93	43.83 ± 2.10	9.36 ± 0.62

3.3. Formulation of fibres mortars

With the same composition of control mortar (C = 450 g, S = 1350 g and W/C = 0.55), fibre mortars are prepared with a new optimisation of superplasticizer. For each mixture, numerous tests are conducted to look for the superplasticizer dosages Sp, which give the desirable workability. Table 7 illustrates the composition of the workable mixtures.

Table 7. Composition of fibres mortars.

Mortar	C (g)	S (g)	W (g)	W/C (%)	Micro fibre (g)	Macro fibre (g)	SP (%)	Flow time (s)
MC	450	1350	247.5	0.55	00	00	0.93	15
Micf	450	1350	247.5	0.55	20.5	00	1.60	19
Macf	450	1350	247.5	0.55	00	20.5	1.28	14

3.4. Workability of fibres mortars

Figure 7 presents the variation of superplasticizer dosage of fibres mortars. It is remarked that fibres mortars need higher dosage of superplasticizer compared to control mortar, while micro fibres mortars require the most important dosage compared to macro fibres mixes this could be due to their high specific surface. The majority of the literature studies confirmed that the addition of fibres to concretes and mortars negatively affect their workability and increase their viscosity (Sebaibi et al., 2014; Söylev and Özturan, 2014; Manaswini and Deva, 2015; Bendjillali and Chemrouk, 2017; Abdullah et al., 2020).

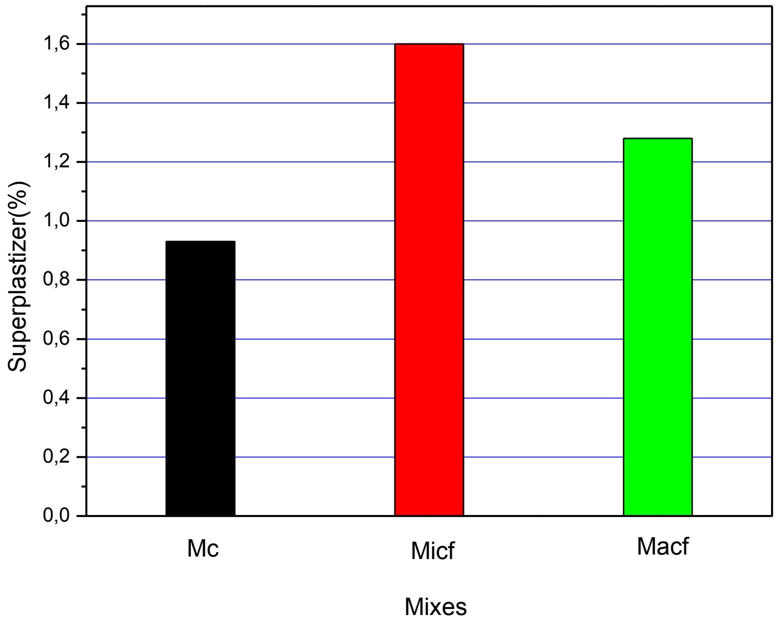


Fig 7. Variation of superplasticizer dosage of fibres mortars.

3.5. Flexural strength of fibres mortars

The flexural strength of all mortars is measured at 28 days and schematized in the figure 8. For a good discussion, the strength gains of the flexural strength offibres mortars (Figure 9) is calculated compared to control mortar as following:

$$\Delta Rf = \frac{Rf - Rf0}{Rf0} 100 \qquad (1)$$

With:
ΔRf: strength gain of the flexural strength (%)
Rf: flexion strength of fibre mortar (MPa)
Rf0: flexion strength of control mortar (MPa)

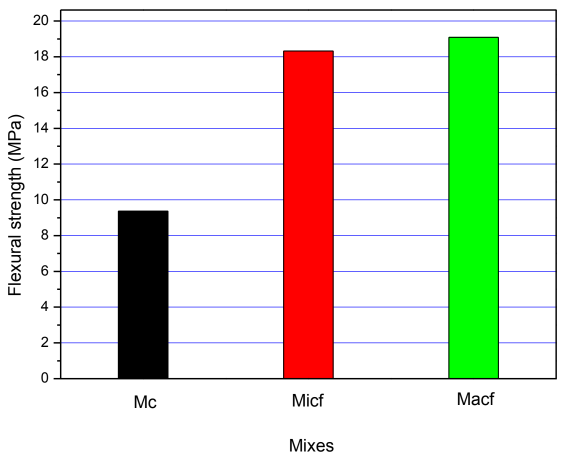


Fig 8. Flexural strength of mortars.

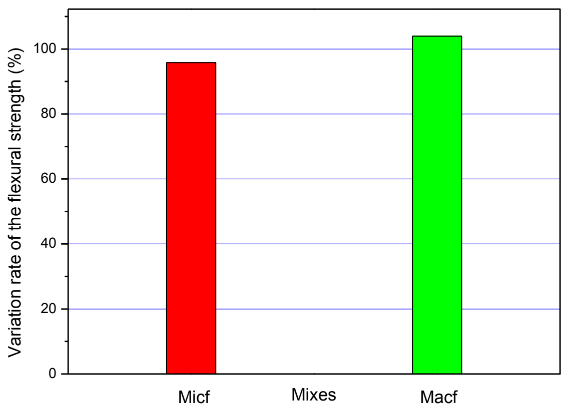


Fig 9. Strength gain of the flexural strength.

It is very important to note that fibres mortars produce higher flexural strengths (Figure 8), compared to the control mortar that means that the addition of polypropylene fibres to mortar enhances its flexural behaviour. This result is found in the most of the literature studies

(Mamlouk and Zaniewski, 2011; Pereira de Oliveira et al., 2011). This increase in flexural strength is due to the fibre bridging properties, as reported by some authors (Hasan et al., 2011). According to the same authors, under flexural test, the load is transferred to the fibres when the matrix began to crack. Fibres with high tensile strength transfer higher tensile stresses from a cracked matrix to the fibres (Song et al., 2005). It is remarked through the figure 9, that the effect of macro polypropylene fibres is slightly more important than micro fibres, with a strength gain of 104 %. Macro fibres disperse better in the matrix than micro fibres, which explain their positive effect. The good dispersion of fibres in the matrix can affect positively the mechanical performance of the materials as reported by other studies (Akkaya et al., 2001; Ozyurt et al., 2007).

3.6. Compressive strength of fibres mortars

The variation of the compressive strength of mortars at 28 days is given in figure 10. In figure 11, the strength gain of the compressive strength of fibres mortars is presented. This strength gain is calculated by comparison to control mortar with the following relation:

$$\Delta Rc = \frac{Rc - Rc0}{Rc0} 100 \qquad (2)$$

With:
ΔRc: strength gain of the compressive strength (%)
Rc: compressive strength of fibre mortar (MPa)
Rc0: compressive strength of control mortar (MPa)

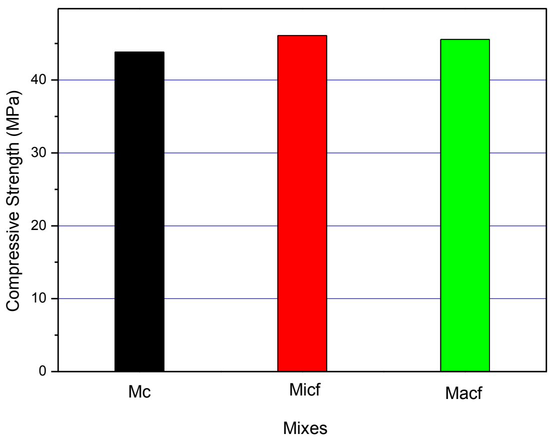


Fig 10. Compressive strength of mortars.

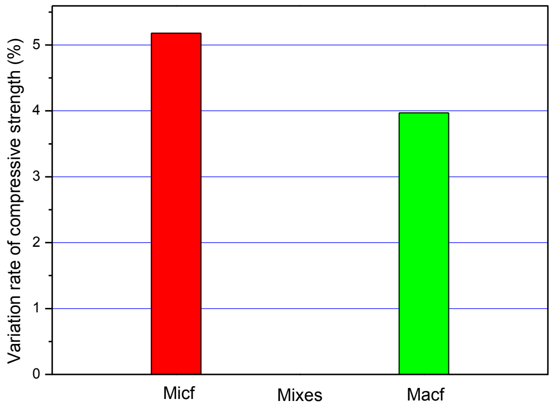


Fig 11. Strength gain of the compressive strength.

The figure 10 shows that all mortars give a good mechanical behaviour. The maximum values of the compressive strength are recorded in micro fibres mortar. By comparison with control mortar, the fibre mortar shows amelioration about 5 % (Figure 11). The highest compressive strengths are produced in polypropylene fibres mortars, as in flexural strength, which shows the positive effect of the addition of polypropylene fibres to mortar. Some researchers (Hasan et al., 2011; Alengaram et al., 2013; Bendjillali and Chemrouk, 2016; Sohaib et al., 2018) have reported a compared conclusion.

3.7. Weight loss of fibres mortars

Figure 12 presents the variation of weight loss with time. It can be remarked that the weight loss develops rapidly with age, especially during the first two weeks from around 2 % to 7 %; then it continuous to evolve slowly until the stabilisation nearly to 7.5 %. In general, the weight loss measurements are close during all tests. That means that scattered fibres in the matrix did not affect negatively the size of pores (increase) in the material as well as their volume, by increasing the capillary intensity, and obstructing the evaporation of water contrary to what other authors found (Mesbah and Buyle-Bodin, 1999).

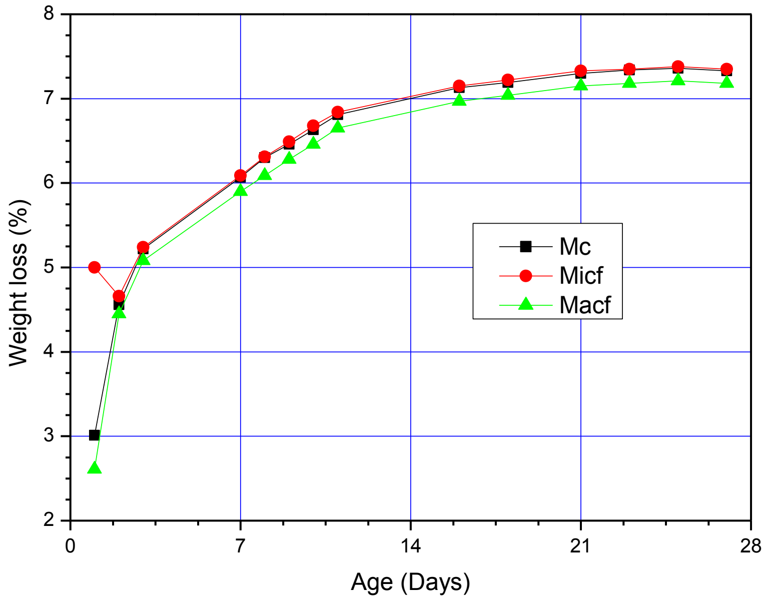


Fig 12. Variation of weight loss of different mortars.

4. Conclusions

This paper has been concerned with the investigation of workability, mechanical behaviour and weight loss of mortar reinforced with macro and micro synthetic fibres. Hence, the conclusions summarized as:

- The used VISCOCRETE TEMPO 12 efficiently improves the workability of fibres mortars.
- The workability of mortars is reduced by the addition of polypropylene fibres.
- The addition of polypropylene fibres enhanced significantly the flexural strength of mortar. The enhancement is mainly attributed to the fibre bridging process that allowed additional stress to develop for the cracks to propagate.
- Macro fibres mortar presents the highest flexural strength with an amelioration of 104 %.
- Micro fibres mortar gives the highest compressive strength and the most important variation rate is about 5 %.
- The weight loss is very close in all mortars until the age of 28 days.
- By the addition of polypropylene fibres to mortar, we can improve its mechanical properties and certainly increase the chance to use it as composite material for more strong and durable structures in the future, which can open a new area in the field of construction materials.

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