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THE EFFECT OF PLASTIC WASTE FIBERS ON MORTAR PERFORMANCE

Wassila MOUATS [a], Assia ABDELOUAHED [a], Houria HEBHOUB [b*], Wassila BOUGHAMSA [a]

[a] PhD; Faculty Technology, LMGHU Laboratory, Skikda University, Algeria

[b] Prof.; Faculty Technology, LMGHU Laboratory, Skikda University, Algeria

*E-mail address: *hebhoubhouria@yahoo.fr*

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Abstract

This paper studies the possibility of using plastic waste fiber in the mortar, and aims to find the optimum percentage of fiber to improve the properties of mortar. The plastic fiber is used as a volume substitution in dune sand and it used with rates of 5%, 10%, 15%, 20%, 25%, and 30%. Specifically, the mechanical properties as compressive and tensile strength and durability performance as capillary and immersion absorption, the depth of chloride penetration and the loss of weight were measured. The results show that the incorporation of waste plastic fiber reduces the compressive strength and enhances the flexural tensile strength. The use of waste plastic fibers indicates the good behavior to mortars in aggressive environment.

Keywords: **Cement; Durability; Mortar; Plastic fibers; Performance; Substitution; Waste.**

1. INTRODUCTION

The introduction of fibers from recycled materials and in particular plastic waste as reinforcement in construction materials field is the subject of several researches, in order to solve several problems due to their mechanical, thermal and acoustic characteristics, their renewable aspect, as well as their low density.

The recovery of plastic waste and its reuse in construction materials is the best choice for transforming the waste into useful products, which can be used, especially in the rehabilitation of old buildings field. The main advantages of waste recycling are reducing waste volume that can be a problem for the environment, and preserving natural resources (Senhadji and al., [1]. It also allows waste, to be eliminated by recycling, thus protecting the environment. That helps to solve the problems related to the lack of aggregates (Hebhoub and Belachia.,) [2]. Recycled fibers from industrial wastes can offer economic and environmental advantages to the construction industry sector [3].

The possibility to use waste plastic in concrete or mortars has been studied by many researchers. The use of plastic waste as aggregates in cement mortar and concrete was studied by Saikia and de Brito [4]. They replaced the recycled aggregates with ordinary aggregates in mortar and concrete, the results obtained show that there was a reduction in the density and workability of concrete, a drop in mechanical strength which is due to the weak bond between the surfaces of the plastic particles and the cement paste. Abdulrahman and al., [5], used the fine aggregates from polypropylene waste to partially replace aggregates in mortar and concrete low density. The results show a reduction in density and compressive strengths and a decrease in the ultrasonic pulse velocity of samples containing polypropylene waste, however, the introduction of this type of waste changes the type of failure from brittle to ductile.

Azad and Puneet., [6] introduced plastic waste aggregates in the composition of concrete. The substitution of natural coarse by the recycled aggregates with rates ranging from 0 to 10% has been studied. The results obtained indicate an increase in compressive and flexural strength up to a rate of 2.5%, beyond this rate the effect is reversed and the best workability is recorded for a rate of 5%. Yin and al., [7] carried out a study on the use of recycled plastic macro fibers to reinforce a concrete or steel plate. They found that plastic macro-fibers decrease the workability of fresh concrete, and the cracking caused by plastic shrinkage. The use of plastic macro-fibers leads to increasing the ductility, flexural tensile strength, and high resistance in alkaline media.

Benosman and al., [8] studied the effect of polyethylene terephthalate (PET, from beverage bottles and other packaging products) on the mechanical performance of mortar-PET composite materials. They noted that the compressive strength of the reference mortar is higher, but beyond 180 and 360 days all the compressive strengths of the composites are brought together. They also found that the use of PET, enhances the durability of different composite materials (such as resistance to acids and bases, sulphate attack and chloride ion penetration).

Sam and Tam., [9] studied the use of PET (from the packaging) as a binder, to produce polymer concrete. The plastic is transformed in the presence of glycols, into unsaturated polyester resins which is then mixed with sand and gravel. The concrete obtained is more resistant in compression and in bending compared to the concrete formulated with Portland cement. Ghernouti and Rabehi., [10] claimed that, the substitution of recycled aggregates (waste from plastic bags) by sand up to a rate of 40%, reduces chloride penetration and improves the behavior of mortars in acidic medium. Al-Tulaian et al. [11] indicated that the use of the recycled plastic waste fibers can influence the flexural strength, flexural toughness and plastic shrinkage cracking characteristics of Portland cement mortar. They found that the flexural toughness shows a substantial increase, about 26 to 61 times. And a considerable increase in flexural strength ranging from 6% to 8% of mortars reinforced with recycled plastic fiber compared to plain mortar. They also found a significant reduction in width, and total area of plastic shrinkage cracks of slabs reinforced with an increased amount of recycled plastic fibers.

Jay Kim et al. [12] studied the effect of the geometry of reinforcing fibers on plastic shrinkage cracking in cementitious composites. At a fraction of 0.25%, the plastic shrinkage was reduced, but no further improvement was seen when the fiber fraction was increased to 0.5%. The geometry of the fibers also affected the control of plastic shrinkage cracking down to a fiber fraction of 0.25%.

Plastic bags are a considerable source of pollution, throughout their life cycle; their recycling is limited in the field of construction. In this investigation, we are interested in flour plastic bags.

This paper aims to valorize a new type of waste plastic fibers from flour sacks for enhancing the performance of mortar. The plastic fiber is used to partially replace sand in mortar with rates of 0, 5, 10, 15, 20, 25 and 30%. Different results of this research indicate that the introduction of plastic fibers in mortar is very interesting, mostly in the durability.

2. MATERIALS

2.1. Cement

The cement CPJ-CEM II 42.5, from the cement company of Hdjar Soud- Skikda. East of Algeria.

2.2. Sand

Ordinary sand of class 0/1, rolled nature from Oued Zhor, Skikda, East of Algeria. The grain size curves are given in Figure 1. The physical and chemical properties cement and sand are given in Table 1.

Table 1.
Properties of sand and cement

Designation	Sand	Cement
Apparent density g/cm^3	1.53	2.97
Absolute density g/cm^3	2.608	--
Value of bleu methylene %	1	--
Fineness modulus %	1.78	--
Sand equivalent %	93.97	--
Absorption %	2.5	--
Blaine specific surface cm^2/g	--	3500
Initial setting time min	--	184
Final setting time min	--	304
CaO %	0.80	66.46
Al_2O3%	2.36	5.40
Fe_2O3%	1.15	3.92
SiO_2%	94.09	21.63
MgO %	0.14	1.29
Na_2O %	0.2	0.21
K_2O %	0.58	0.57
SO_3%	0.01	0.46
Cl^-%	--	0.01
CaO free %	--	0.5
MS %	--	2.32
MAF %	--	1.38
LSF%	--	94.18
MH%	--	2.16
C3S %	--	62.18
C2S %	--	15.13
C3A %	--	7.68
C4AF %	--	11.23
PAF %	--	0.30

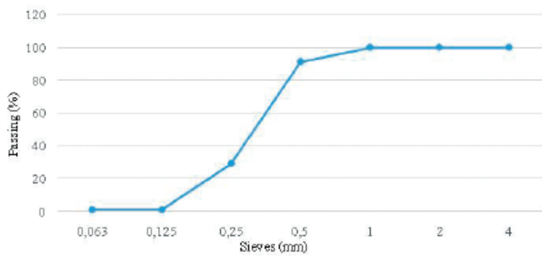

Figure 1.
Granulometric curve of the sand

2.3. Plastic waste fibers

The plastic waste fibers used in this research come from a woven plastic bag (bag of flour), with polypropylene nature. After the flour is finished, these bags are discarded as waste. We brought the bags from the baker and prepared them to use as fibers.

2.3.1. Preparation of fibers

After washing and drying the bags, they are traced in square of 5 × 5 cm and cut to obtain fibers with dimensions 2 mm × 5 cm. This is the final material that we will use in different mortars (Fig. 2). The fibers have an absolute density of 0.32 g/cm^3 (we can observe that the fibers have a very low density).

2.4. Water

Potable water was used in all the mixes and curing of the specimens.

According to the properties tests, we can note that:

The results of the particle size analysis of ordinary aggregates are common;

- The sand equivalent shows that the sand dune is clean and allowable for quality concretes, with a value of 93.97%.
- The sand used is characterized by a continuous particle size distribution.
- The sand density is greater than that of fibers.
- Value of bleu methylene is lower than 1.5; this indicates that dune sand is a sand with a low percentage of fine clay;
- The dune sand contains a high percentage of silica (SiO_2) 94.09%, which indicates silica sand.

3. EXPERIMENTAL PROGRAM

This study aims to valorize plastic waste as fibers partially replace rolled sand in the formulation of a mortar to produce an ecological material. The objective is to achieve a more ductile mortar. The control mortar is a 1/3 mortar made according to the EN 196-1 standard, consisting of one (01) part of cement, three (03) parts of rolled sand. Mortars with addition are obtained according to the same standard by replacing a volume fraction (rate of substitution) of ordinary sand by plastic waste fibers. The different substitution rates are: 5, 10, 15, 20, 25 and 30%. In these various tests, the fixed parameters are the dosage of cement and water, while the variable parameters are the substitution rates of plastic waste fibers.

The control mortar (CM) specimen (0% of plastic waste fibers) was used as a reference. Three specimens were used for each age. The test specimens produced from the fresh mortar were stored for 24 hours in ambient laboratory conditions (20° ± 1°C). After 24 hours the samples are unmolded. The test specimens of flexural tensile and compressive strength, chloride penetration and chemical attack tests are kept in water (20° ± 1°C), while those of absorption by immersion and that of capillary absorption are

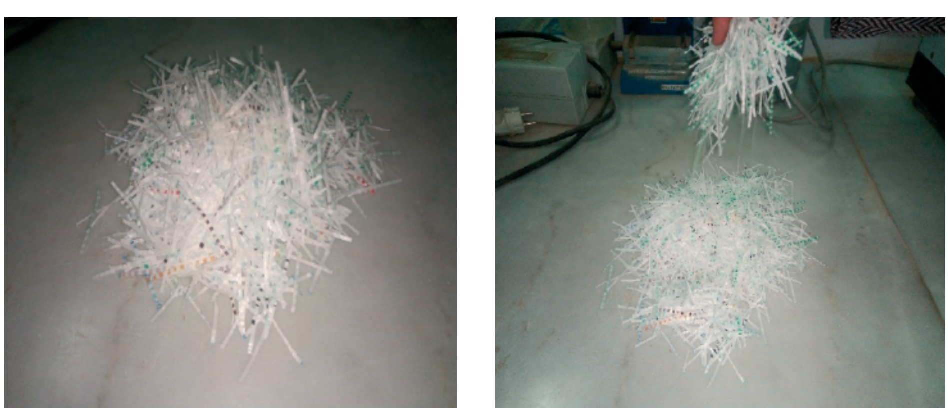

Figure 2.
Plastic fibers

kept in the open air until the day of the test.

The test specimens used for the compressive and flexural strength test, capillary absorption and chloride penetration test had dimensions of 4 × 4 × 16 cm^3. Those used for the absorption by immersion and weight loss test had dimensions of 5 × 5 × 5 cm^3.

Table 2 presents the different constituents and their designations.

Table 2.
Constituents of the samples

Designation	Cement	Dune sand	Plastic waste fibers	Water
CM (0%)	1V	3V	0	1V
M (5%)	1V	2.85V	0.15V	1V
M (10%)	1V	2.7V	0.3V	1V
M (15%)	1V	2.55V	0.45V	1V
M (20%)	1V	2.4V	0.6V	1V
M (25%)	1V	2.25V	0.75V	1V
M (30%)	1V	2.10V	0.9V	1V
Notation	V		Volume	

The tests carried out based on the different formulations are:

- Density in the fresh state according to standard NF EN 1015-6.
- Consistency, measured by the mini slump test in accordance with standard NF EN 1015-3.
- Flexural tensile and compressive strength at the age of 7, 14, 28 and 90 days, measured on 4 × 4 × 16 cm^3 prismatic specimens preserved in water in accordance with standard EN196-1.
- Water Absorption by immersion measured by Neville, 2000.
- Capillary absorption according to standard NF EN 480-5.
- Chloride penetration according to standard NBN B 15-215.
- Chemical effect tests with solutions of 5% HCl and 5% H_2SO_4 on cubic specimens of size 5 × 5 × 5 cm^3 according to ASTM C-267-96 standard.

4. RESULTS AND DISCUSSIONS

4.1. Density of mortars

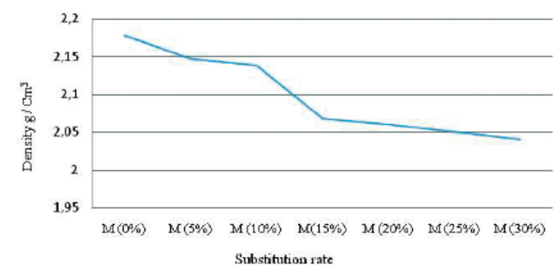

Figure 3.
Density of different mortars

The Figure 3 shows the effect of the introduction of plastic waste fibers on the density of mortars. According to the results of density, it should be noted that the incorporation of plastic fibers decreases fresh density of mortars due to the lightweight nature of plastic waste fibers; it was shown by some researchers either on concrete or mortar [13, 14 and 15].

4.2. Consistency

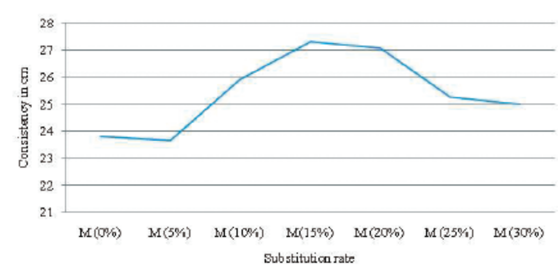

Figure 4.
Consistency of different mortars

Figure 4 indicates the effect of the introduction of plastic waste fibers on consistency of mortars. There was a slight decrease of slump values with increasing percentage of plastic waste fibers (5%). It must be noted that the consistency of mortar increases with the increase of plastic waste fibers percentage, where the maximum value is registered for M(15%), so this increase is possibly due to the nature of plastic waste fibers and has tendency to not absorb water. When the percentage of fibers exceed the 15% it can be observed that the consistency decreases with the increase of plastic waste fiber content, it can be explained by the sharp edges and angular particle size of plastic waste fiber [4].

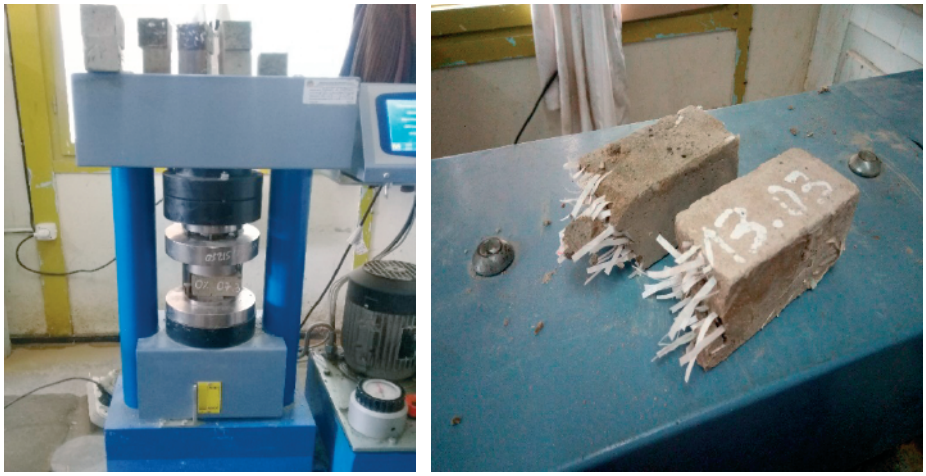

Figure 5.
Compressive strength test

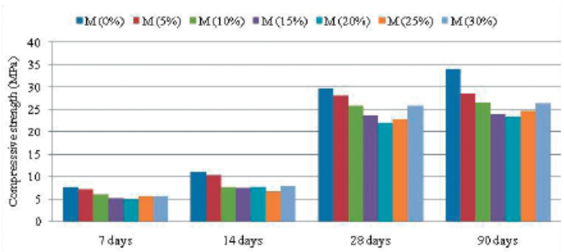

Figure 6.
Compressive strength of different mortars

4.3. Compressive strength

After 7, 14, 28 and 90 days of water curing, the $4 \times 4 \times 16\ cm^3$ samples were used for compressive strength tests (Fig. 5). The results are shown in Fig. 6.

After 7 days, the compressive strength decreases with the increase of plastic waste fibers content, but the difference in strength is not large. Control mortar M(0%) showed the best compressive strength.

After 7, 14 and 28 days, it can be observed that the introduction of waste plastic fibers reduces compressive strength, but there is not significant changes in compressive strength of M(0%) and M(5%), their values are very close. Then the plastic fibers show a clear influence on the compressive strength of the mortars, a similar result was given by Luiz et al., [16].

After 28 days, the compressive strength varied between 22.06 MPa and 29.75 MPa. It can be noted that the best results match always CM (control mortar). It can be observed that the plastic fibers did not enhance the compressive strength. The decrease in compressive strengths due to the substitution of plastic waste fibers can be explain by the poor bond between the matrix and plastic fibers [17]. The nature of waste plastic fiber (hydrophobic nature) can inhibit cement hydration reaction by restricting water movement [4].

It can be also noted that the variation on compressive strength after 90 days is the same to that after 28 days. All specimens mark an increase of compressive strength as a function of the time.

4.4. Flexural tensile strength

The results of flexural tensile strength test (Fig. 7) are presented in Fig. 8. It shows the variation of flexural tensile strength as a function of the time.

From Fig. 8, it can be observed that the introduction of plastic waste fibers in mortar leads to an increase in flexural tensile strength at all the ages. It can be also noted that the tensile strength increases over time for all mortars. The best strength is given by mortar with 30% of plastic waste fibers M(30%), while control mortar M(0%) presents the lowest strength. These results are similar to the results given by authors in reference [18–19] and [20]. The fibers can stop the propagation of macro-cracks resulting during test, which helps to improve the flexural tensile strength [20]. Flexural tensile strength is influenced by the elastic nature and non-brittle characteristics of plastic waste fibers in mortar. In the control mortar (0%), when the first crack occurs, the specimen cracks and then suddenly collapses, with small deformation and without prior warning. However, in mortar with waste plastic fibers, the rupture progresses with bending, but without sudden collapse as in the control mortar (without plastic fiber). When the mortar gives way, the charge is transferred to the plastic fibers. The fibers prevent the propagation of

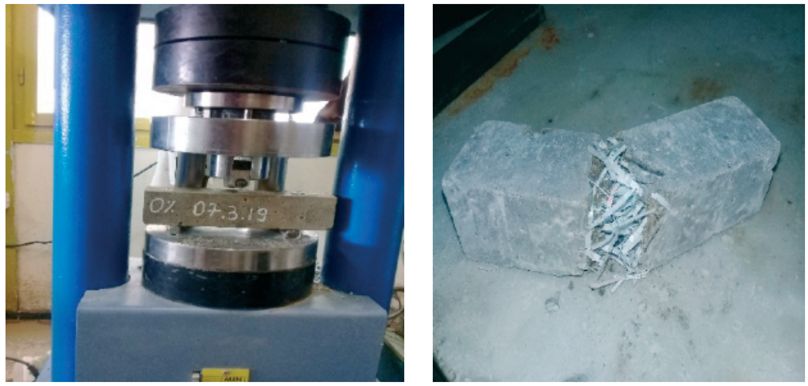

Figure 7.
Flexural tensile strength test

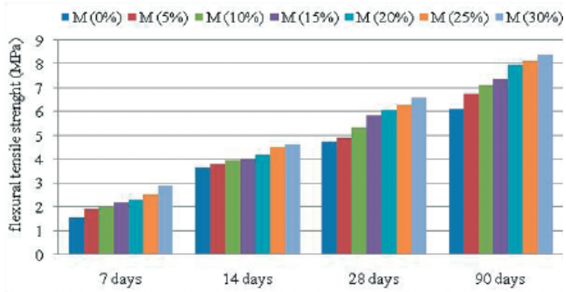

Figure 8.
Flexural tensile strength of different mortars

cracks and thus delay collapse.

The strength augmentation is more significant at 90 days, where the mortar strength can attain more than the double of 7 days strength obtained with mortars (30%) waste plastic fiber [20–21].

4.5. Water absorption by immersion

The absorption of water by immersion allows estimating the volume of open pores of mortar by water penetration through the structure of these pores. Fig. 9 shows the results of absorption coefficient as a function as the substitution rate.

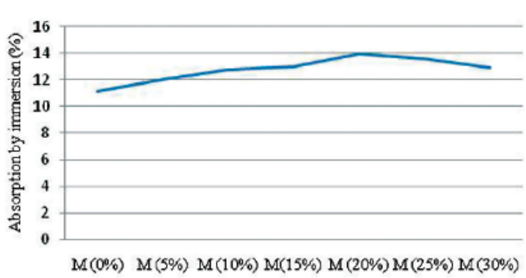

Figure 9.
Absorption coefficient as a function as the substitution rate

It can be seen that the absorption coefficient of mortar increases with the increase of plastic waste fibers percentage until 20% of plastic waste fibers, when the absorption coefficient presents the highest coefficient 13.95%. It can be also observed that there are not large differences between the results, not more than 2.8%, but all mortars present lower absorption coefficient than control mortar. The substitution of a part of natural sand by plastic waste fibers, creates a clean porosity different from that created by the sand since its shape is plane and elongated.

4.6. Capillary absorption

The capillary absorption coefficients are related to the durability of mortars; it allows estimating the volume of open pores of mortar by the rising of water through the structure of these pores.

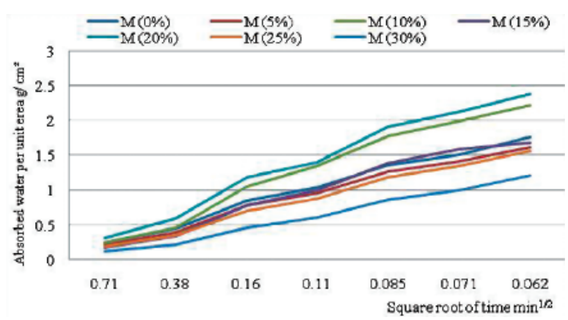

Figure 10.
The capillary absorption coefficients

The absorption of water by immersion coefficients for all the dosages is shown in Fig. 10 can be observed that the capillary absorption coefficient of mortar with 30% of plastic waste fibers is the lowest coefficient. It can be concluded that the introduction of fibers into the mortar is responsible for a slight reduction in the capillarity coefficient of water absorption, this reduction can be explained by the air found in the pores which acts as a barrier, preventing the water from rising through the matrix [20]. The plastic waste fibers can be an obstacle which slow down the rise of the water.

4.7. Chloride penetration

The depth of penetration of different mortars is taken at 28 days of conservation in NaCl solution. The different results are mentioned in Figure 11.

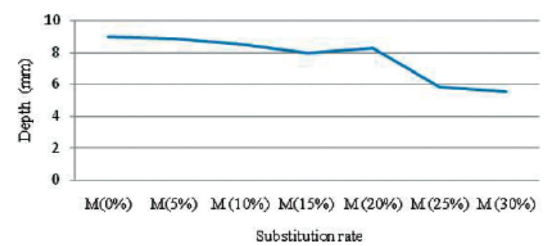

Figure 11.
Depth of chloride penetration

From the results obtained (Figure 11), it is found that the lowest depth of chloride penetration is given by the mortar with 30% of plastic waste fibers, that is the mortar with the highest content of plastic waste fibers. On the other hand, the control mortar presents a very high depth of around 9 mm. The results indicate that the resistance of chloride penetration of the mortar increased with increasing plastic waste fibers content. The result can be explained by the effect of the plastic waste fibers to block the passage of chloride ions in the cement matrix. These results are similar to the results obtained by Kou et al., [22] who worked on PVC-based aggregates.

4.8. Weight loss

The weight losses of different specimens are measured according to the standard ASTMC267-96. The results are given below fibers.

4.8.1. In sulfuric acid (H_2SO_4)

The chemical resistance test of sulfuric acid consisted of the immersion of different specimens (after 28 days of water curing) into 5% of H_2SO_4 solution for 90 days. The whole solution was changed every 14 days. Then the weight loss was tested after 3, 7, 14, 21, 28, 56 and 90 days of immersion, the results are given in Figure 12.

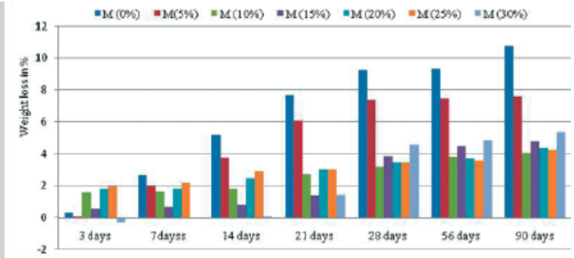

Figure 12.
Weight loss of different mortars stored in H_2SO_4 solution

From the Figure 12, it can be noted that all specimens had a loss in weight in all the ages except after 3 days, where mortar M(30%) had a gain in weight, this gain is due to the deposit of gypsum which is leached then (during the first week).

The loss of weight decreases according to the increase of the plastic waste fibers percentage, after 7 days of attack, the control mortar (0%) has the heights weight loss. This indicates the good behavior of mortars with plastic waste fibers towards the sulfuric medium.

After 7, 14 and 21 days of immersion, the lowest weight loss is given by mortar (15%), after 28 days of immersion the mortars with fibers waste plastic have the results slightly similar. In general way, the plastic waste fibers enhance the chemical resistance of mortars, those results are similar to the results given by Ghernouti and Rabehi [10].

4.8.2. In chloridric acid (HCl)

The same steps determine chemical resistance test of chloridric acid. Then the weight loss is tested after 3, 7, 14, 21, 28, 56, and 90 days of immersion, the results are given in Figure 13.

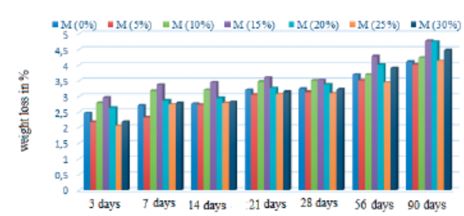

Figure 13.
Weight loss of different mortars stored in HCl solution

Chloridric acid, attacks the surface of specimens and produces the loss of weight. From different results, it can be seen that the weight loss increased with the time of immersion, the different results were slightly similar, the mortar with 20% of plastic waste fibers had a best chemical resistance in all ages, it presented about 3.44% in 56 days of immersion where the reference mortar presented 3.70%. The use of plastic waste fibers in mortar in chloridric medium can be accepted.

5. CONCLUSION

The recovery of this waste allows the production of new ecological and sustainable materials used either in the new construction or in the rehabilitation of old buildings.

As this study shows that the introduction of plastic waste fibers into the mortar can influence the performance of the mortar, so from the experimental study we can draw the following conclusions:

- The incorporation of plastic waste fibers as partial replacement of sand, reduces fresh density of mortars, due to the lightweight nature of plastic waste fibers. Consistency is also affected by the addition of waste plastic fibers, where it decreases when the content of waste plastic fibers exceeds 15%.
- At all ages, the compressive strength decreases with plastic waste fiber content in the mixtures. A decrease of 32.8% for mixtures of 25% with plastic waste fiber is observed after 28 days, and attain 52.1% after 90 days for the same mortar. This drop in compressive strengths can be explained by the poor bond between the matrix and plastic waste fiber.
- The introduction of plastic waste fibers in mortar leads to an increase in flexural tensile strength at all the ages. The fibers prevent the propagation of cracks and thus delay collapse where the flexural strength will be enhanced.
- Chloride penetration depth decreases with increasing fiber content of plastic waste, because plastic fibers block the passage of chloride ions. And about the chemical resistance, the use of plastic waste fibers indicates the good behavior to mortars in acidic environment.

The results given in this research are a part of useful information for reusing the plastic bags in mortar mixes. They show that the plastic fibers have potential to be used as substitution in sand.

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