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The behavior of the concretes and mortars reinforced by metallic fibers wastes as substitution of cement

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Abstract

The main objective of this work is to study the behavior of the mortar and the concretes obtained by substituting the cement by the metallic fibers wastes. Several materials were carried out by substituting the cement with different amount of fibers (0, 10, 20 and 30 wt %). Mechanical properties of the two obtained materials (mortar and concrete) as flexural and compressive strengths were studied. Physical properties as shrinkage, the swelling effect, loss in mass, slump concretes and porosity were evaluated. However, the addition of 10 wt % of the fibers in the mixtures of the mortar and the concretes is possible, due that its compressive strengths are respectively 40.9 and 27.4 MPa. The environmental risks of the incorporation of the metallic fibers rich in heavy metals (Zn and Cu) into the mixtures were evaluated by leaching tests of the obtained materials. The results indicated a very slight release of the pollutants. The obtained materials have a good performance and they are suitable for use in practice.

Keywords: Concretes, Mortars, Metallic fibers, Mechanical properties, Shrinkage, Environment

1. Introduction

The use of the fibers in the building materials; particularly in mortars and concretes is a technique increasingly used for several reasons, either ecological or economic, or to improve some properties of in fresh or hardened states. In Fact, the use of metallic fiber as a cement substitution reduces the consumption of clinker by contributing in a huge way, reduce energy costs and address problems related to environmental pollution by CO_2 emissions [1]. The projections for the global demand of Portland cement show that in the next 40 years, it will have a twofold increase reaching 6 Gt/year [1]. Considering all the greenhouse gases emitted by cement manufacture, this production is responsible for 3% of greenhouse gases emission in the world [2]. It is estimated that the production of cement is responsible for 5–7% of the world CO2 emissions [2–3]. The life cycle of cement shows that 95% of the CO2 emissions occur during the production and only 5% during transportation of raw material [3]. Thus, 0.37 kg/kg clinker are emitted during the production of the energy necessary to the manufacturing of cement and 0.53 kg/kg clinker CO2 during the decarbonation of CaCO3 [2]. The concrete is a composite material with a low tensile strength and a low voltage [4-5]. The fiber-reinforced concrete is one of the most appropriate innovations in the field of special concrete. [6] This compound proved to be competitive equipment in many types of structures [7-8].Generally the addition of fibers to the concrete mix can significantly improve concrete properties such as; bending, fatigue and abrasion strength, formability, toughness and load-bearing capacity after cracking [9-10]. However, under the tensile stress, the concrete cracks easily and almost no ductility [11]. The classic way to solve this problem may be the application of fiber reinforcement [12-13]. The alternative is the application of different types of fibers in concrete [11]. The additions of randomly distributed fibers of steel in concretes improve the practical properties such as resistant static flexural strength, ductility and bending hardness [14]. In fact, by varying the amount and types of fibers in the concrete mix also the mechanical behavior varies [15]. The addition of the steel fibers in the mixture can improve the brittle behavior of the material. [16-17]. Reinforcing hybrid systems can be used in concrete [18], which depends on several parameters that include assays for fiber [19]. These compounds systems can improve not only the flexural strength and tensile strength, but can also lead to a change of cracking mechanisms [20-21]. The ultra high strength concretes provide very high compressive strength and are highly durable partially. However ,their behavior and fragile trend for withdrawal. These concretes have been built using high strength steel fibers to improve their resistance to cracking and increase their hardness, thus reducing withdrawal [22]. In order to show the influence of metal fibers on the properties of concretes and mortars, cement has been substituted by different percentages of fibers (0, 10, 20 and 30 wt %) where M(00%), M(10%) M(20%) and M (30%) are the different samples of the mortar mixtures and BT(00%), BT(10%) BT (20%) and BT (30%) the different samples of the concrete mixtures. The other aim of this work is to find the optimum in cement substitution rate by metallic fibers that give both a good compressive strength and flexural strength, and acceptable shrinkage and swelling.

2. Experimental

2.1. *Materials and mix proportions*

The cement used in this study is the Algerian Portland cements CEM II 42.5/A according to European standard EN 197-1[23]. Four different size fractions as 0/3 mm (fine quartz sand), 0/3 mm (crushed limestone sand), 8/15 mm and 15/25 mm (limestone gravel) of aggregates were used. Additionally, wastes of metallic fibers (Cu and Zn) from the treatment surface industry (Figure 1) with a length and a cross section of 40 and 0.5 mm respectively were added into the mix as substituent of cement. In the first time with 0 wt % of metallic fibers wastes, the second time with 10 wt% of metallic fibers, after20 wt% and than 30 wt%. The mortars are prepared by mixing cement, demineralized water and standard sand NF EN 196-1.

Figure 1: Photo of metallic fibers waste.

The preparation of formulations of mortar is generally based on the NF EN 196-1 standard [24] and the amount of waste used. To make our results comparable two blank matrixes (without the addition of waste) were prepared; one for the case of mortars and the other for the case of pastes. Each material is prepared in a mixer of 3 kg. First, the sand and the waste are mixed at medium speed for 10 min to obtain a homogeneous mixture. The cement is then added and the mixture is mixed for a few minutes. The addition of demineralized water is to avoid the addition of metallic fibers in trace amounts, it is necessary then to stop the mixing for scraping the bottom of the mixer with a spatula to ensure the hydration of the total mixture. Then, the cement mixtures are molded to prepare samples (Table 1) (three samples for each test) with dimensions of 40 mm X 40 mm X 160 mm for mechanical testing at 28 days. Specimens of 40 mm X 40 mm X 40 mm are made to prepare the monolithic blocks for TLM test. pH and electrical conductivity are measured from the preservation solution.

2.2 *Formulation of the concrete*
The formulation method is that of DREUX-GORISSE [23], which has the advantage of being after many formulations have been tested on site, and having given satisfaction and this is a method that is suitable for concrete based fibers. The proportions of the different compositions of concrete are shown in Tables 2 and 3. The sample preparation is carried out according to the NF P 18-400 standard. The concrete mixing is carried out in a concrete mixer of 30 liter capacity. The fibers are introduced as a granular component. The specimens produced are cylindrical samples of size (16 * 32) cm^2 and 06 concrete specimens for each series are realized. After mechanical tests, the samples of concrete having the best resistance are prepared in the form of pellets 63 mm in diameter and 20 mm thick to achieve the TLM test for a period of 64 days; (6H, 18H, 1day, 2d, 5d, 7d, 20d and 28d). These monoliths are held in two (02) different environments which are:

- A neutral environment (pure water);
- Sulphated environment (05% de Na_2SO_4).

2.3 *Mineralogical Analysis*
Mineralogical analysis were carried out by X-ray diffraction (XRD) technique (X'Pert MPD PANalytical; CuKα, 2°-99° 2θ, 0.017° 2θ step and the counting time of 10 s per step).
2.4 *Compressive and flexural strengths*
Compressive and flexural strengths were measured out on a press of type 65-L11M2 according to the NF EN 196-1 standard [24].

3. Results and discussion

3.1. Mineralogical analysis of the raw materials
The XRD patterns of the metallic fibers wastes (Figure 2.a) shows the mineralogical phases of CuZn associated with some iron and nickel to compose (Fe, Ni)P. Thus, as it is shown in figure 2.b, the sand is mainly composed by quartz (SiO_2) and some associated mineralogical phases as calcite ($CaCO_3$).

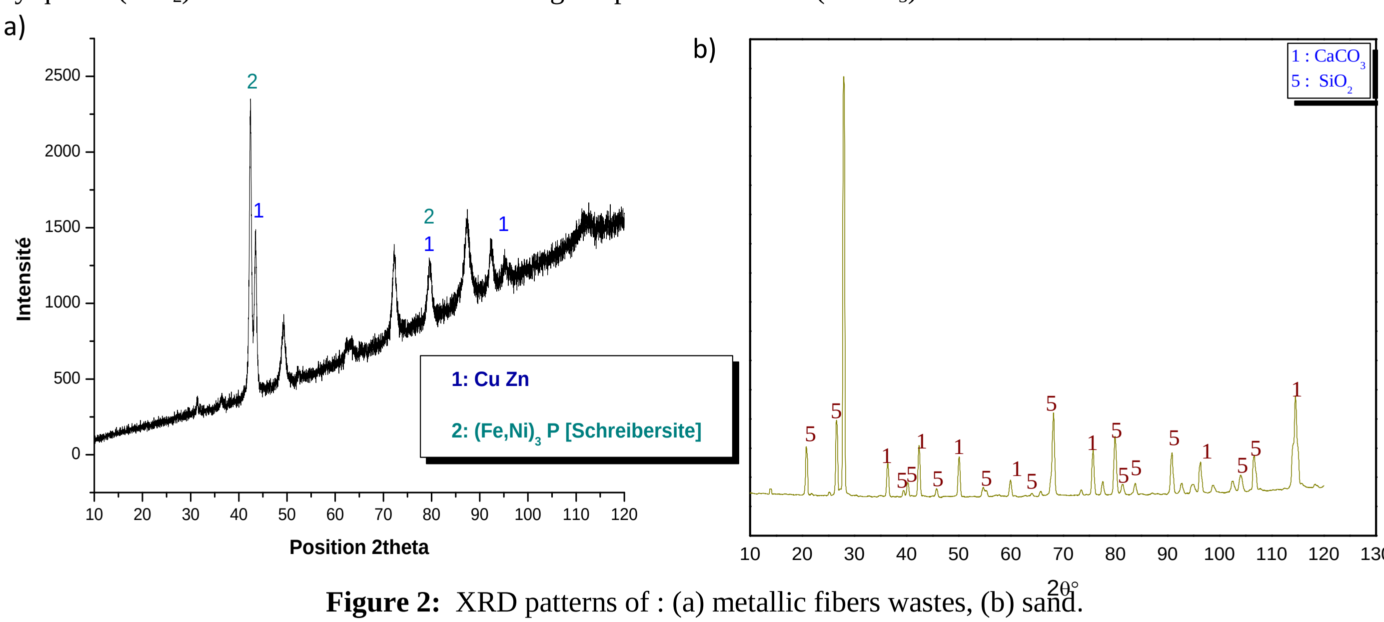

Figure 2: XRD patterns of : (a) metallic fibers wastes, (b) sand.

The figure 3 shows that all the spectrums obtained introduce a series of peak of diffraction well defined and they are largely identical that is to say a shift of peak was not noticed, for these samples studied mortars the appearance of new peaks in those containing metallic fibers is explained by the creation of new phases between the chemical elements of metallic fibers and those of the cement matrix.

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Concretes used are made according to standard NF-P-18-400; they are cylinders of (16x32) cm^2. The formulation method used is that of DREUX GORISSE (figure 4). The various mixtures obtained for 1 m^3 of concrete are given in table 2, and for the various wasted of six (06) samples for each series are given in table 3.

Table 1: Mix proportion of mortar mixtures

samples	Metallic fibers wt (%)	Metallic fibers (gr)	Cement (gr)	Standard sand (gr)	Water (gr)
M 00%	0	0	450	1350	225
M 10%	10	45	405	1350	225
M 20%	20	90	360	1350	225
M 30%	30	135	315	1350	225

Table 2: Mix proportion of concrete mixtures

Components	Aggregates Wt (%)	Absolute volume of components (L)	ρ_s (g/m^3)	Proportioning of the components (Kg/m^3)	ρ_p (g/m^3)	volume of the components (L/m^3)
Water	nd	175.00	1	175.00	1	175
Cement	nd	113.00	3.1	350.00	nd	nd
Sand 0/3	34	232.56	2.72	632.56	1.16	545.31
Gravel 8/15	34	232.56	2.64	613.95	1.28	479.64
Gravel 15/25	32	218.88	2.81	615.05	1.38	445.68

Table 3: Proportioning of the various batches of concretes

Specimens	Gravel 15/25 (Kg)	Gravel 8/15 (Kg)	Sand 0/3 (Kg)	Cement (Kg)	Water (Kg)	Metallic fibers (Kg)
BT 00%	32.37	32.31	33.29	18.42	9.21	-
BT 10%	32.37	32.31	33.29	16.58	9.21	1.84
BT 20%	32.37	32.31	33.29	14.74	9.21	3.68
BT 30%	32.37	32.31	33.29	12.89	9.21	5.53

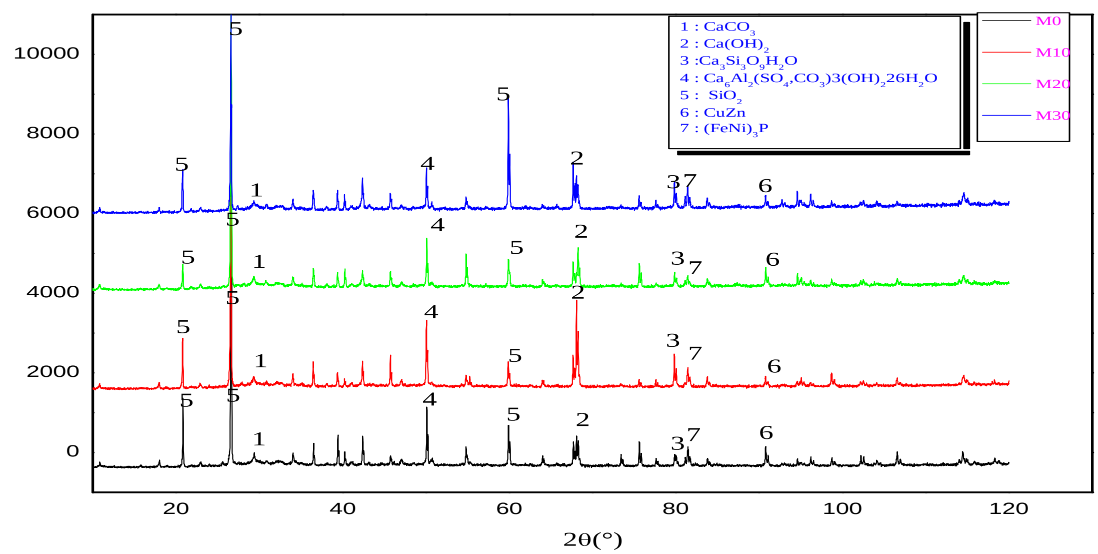

Figure 3: XRD patterns of the mortar samples

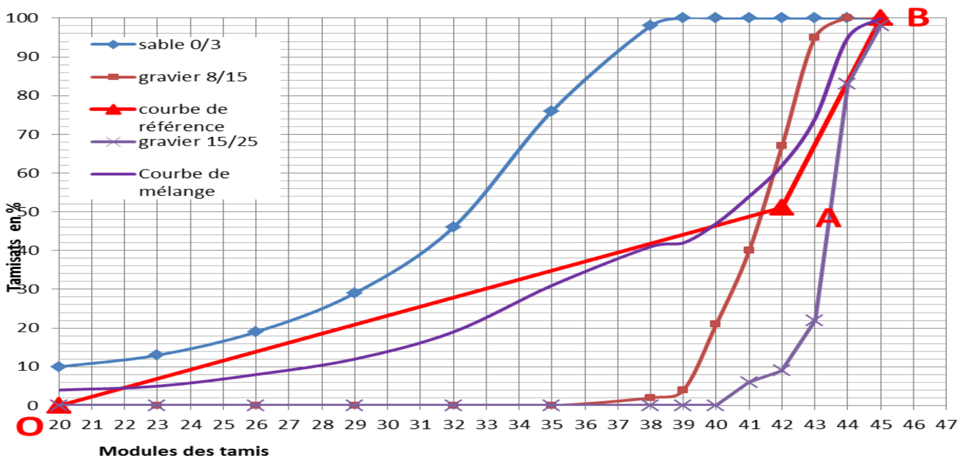

Figure 4: Curve of mixture according to Dreux-Gorisse

3.2. *Compressive strength and flexural strength of mortar*

The value of the flexural strength obtained is the average of three prisms for each series of specimens. The half-prisms of each test-tube obtained break in inflexion will be broken in compression, thus the value of the compressive strength obtained is the average of six half prisms for each series of test-tubes. The results of these resistances are illustrated on the following figure.

From this histogram, it is shown that the compressive strength and traction by inflexion at the age of 28 days decreases progressively increasing the percentage of metallic fibers, but those of the mortars with 10 and 20 wt% fibers are good resistances. This diminution is due to the presence of the metallic fibers, and in the reduction in the quantity of cement in the mixture, thus increasing the W / C ratio which reduces the compactness of mortars that influences their resistance.

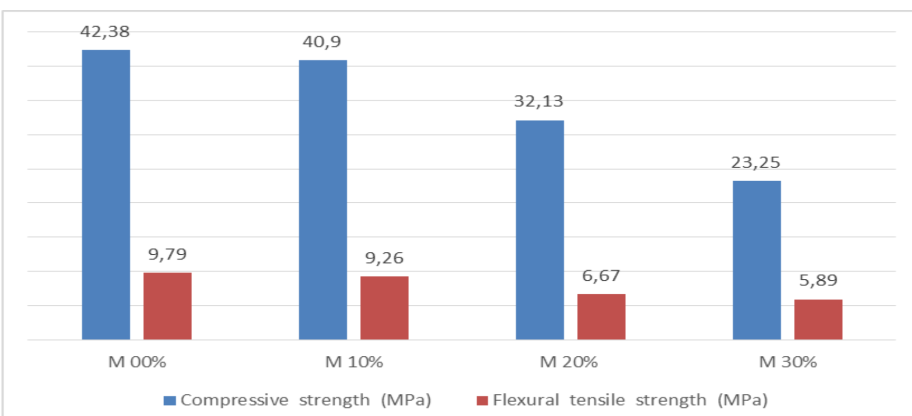

Figure 5: Mechanical strength of mortars at 28 days.

3.3. *Measure the shrinkage of mortar specimens*

It is known that the reaction of hydration is accompanied by a reduction of volume, called shrinkage. Water evaporates of a mortar preserved at the free air causing the shrinkage, which is the consequence of the loss of free water,when this water leaves the material, acontraction(shrinkage) occurs automatically.Results introduced above show a behaviour of shrinkage of test specimens at different ages of measure (1 day, 3 days, 7 days, 14 days, 21 days, 28 days, 60 days, 90 days, 120 days, 150 days, 180 days, 210 days, 240 days, 270 days, 300 days, 330 days, 360 days, 3900 days, 420 days, 450 days, 480 days, 510 days, 540 days, 570 days, and 600 days), and in different percentages of metallic fibers (00 wt %, 10 wt %, 20 wt %, et 30 wt %), the volume changes occur after hardening .

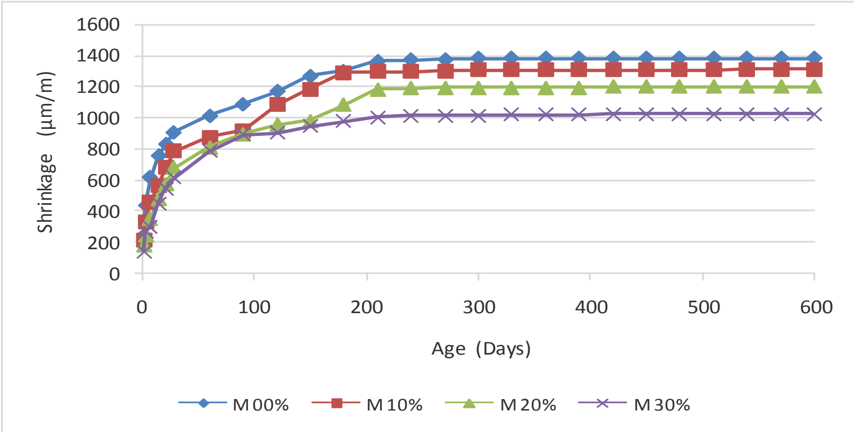

Figure 6: Evolution of the shrinking of the mortars in function times

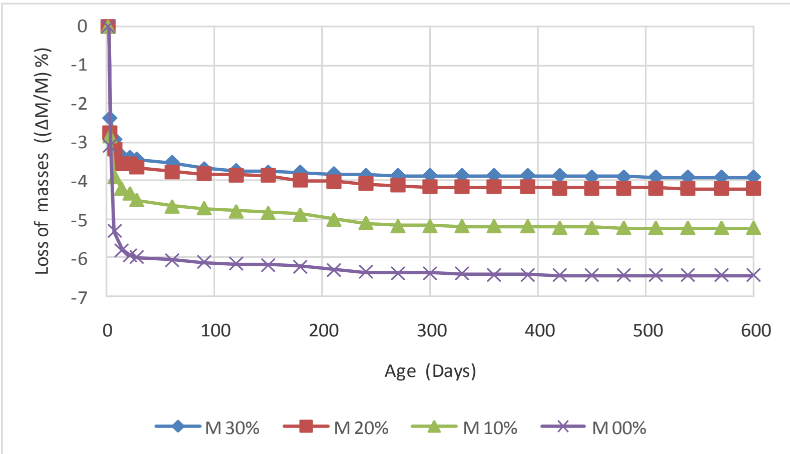

Figure 7: Loss of the mortars masses according to time

The variation of shrinkage of mortar specimens at different percentages of fibers have almost the same pace (the representative curves have the same evolution). However, we note that the shrinkage evolves according to time by evaporation of the water imprisoned in the mortars and by desiccation, beyond 200 days this evolution becomes stable. The shrinking of the mortar witnesses remains the biggets, therefore the use of the metallic fibers reduces the shrinkage; and that is due to the reduction in the quantity of cement which induces with the lowering of its hydration what translated by consequent in the reduction of shrinking. It is known that the shrinking is accompanied systematically by a reduction or a loss of mass, the figure 7 shows us that the loss of mass increases according to time, and starts to stabilize from 240 days for all the mortars with various percentages of metallic fibers. The mortars without metallic fibers have a loss of more important mass; however they have more evaporation of water, which is due to a more important hydration of cement.

3.4. *Measure of swelling on specimens of mortar*

The figure 8 shows that the swelling increases with time and the percentage of metallic fibers in substitution of cement, and it starts to be stabilized as from 270 days. This stabilization and increasing the swelling depending on the fibers can be explained by the saturation of the voids created by the addition of fibers. In fact, by substituting the cement by fibers metallic, there will be more voids inside the mortar, who promotes the birth of additional pocket of water who induces more swelling. As it is shown on Figure 9 the variation of the masses for swelling is proportional to that of swelling itself; the increase in mass is due to the quantity of water absorbed by the mortar specimens.

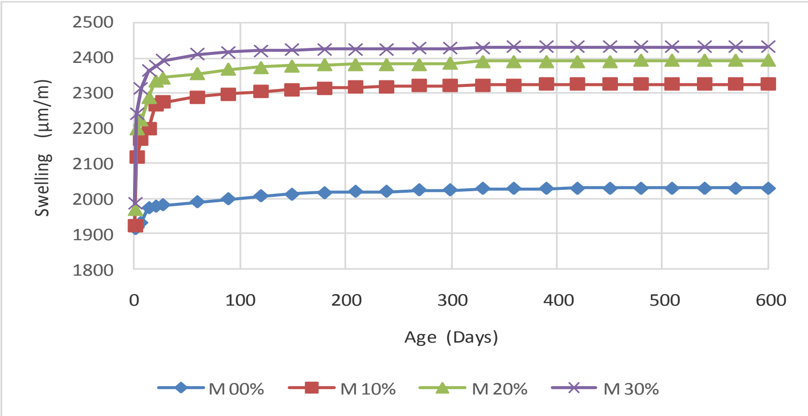

Figure 8: Evolution of swelling according to time

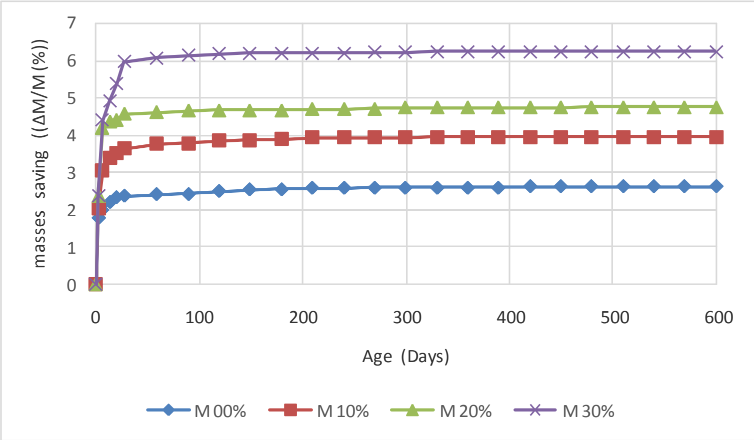

Figure 9: Variation of the masses of the mortars according to time

3.5. *Physico-chemical analysis of the preservation solutions (solutions concerning swelling)*

3.5.1**.** *Evolution of pH*

Accordingly to the figure 10, all mortars have a basic pH , which varies from 8 to 12, and this pH increases according to the time and with the increase of the percentage of fibers in the mortars; this alkalinity is due to progressive and continuous salting out elements of zinc (Zn^{2+}) and copper (Cu^{2+}) present in the fibers, and which form with the water the alkaline bases.

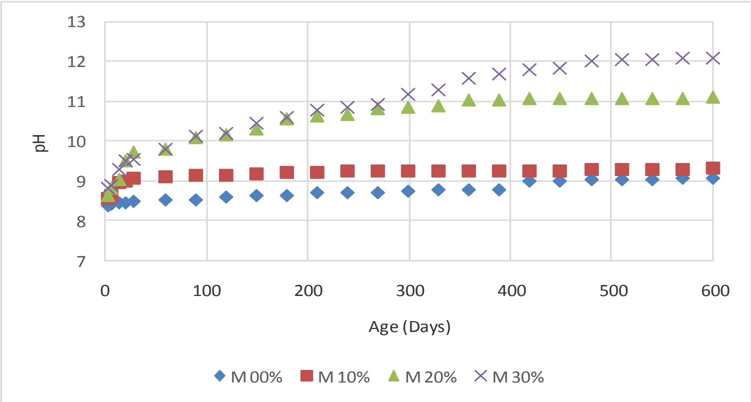

Figure 10: Evolution of the pH according to time mortars.

3.5.2. *Measure of the electrical conductivity*

From Figure11, it is noticed that there is an increase of the electrical conductivity as a function of time and as a function of increasing the percentage of the fibers, this increase is due to the salting out of the chemical species (Zn^{2+} and Cu^{2+}) and immigration of these elements of material towards the solution of conservation. The continuous salting out is gradually.

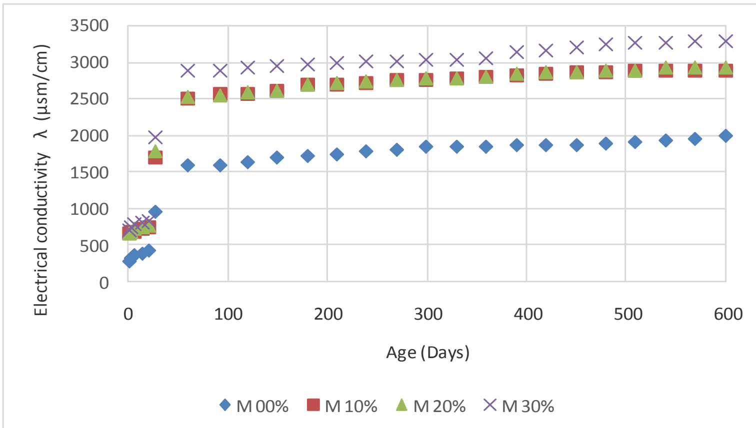

Figure 11: Evolution of the electrical conductivity according to time.

3.6. *Test on freshly-mixed concretes*

3.6.1. *Slump test*

The values of subsidence made four series of concrete specimens presented in figure 12. It is noted that the concretes with 00 wt %, 10 wt % and 20 wt % of metallic fibers are plastic concrete (subsidence lower than 9 cm), on the other hand that of 30% is a fluid concrete. Through these results, it is found that the introduction of the metallic fibers in substitution of cements increases the subsidence of the concretes, because by increasing the percentages of these fibers in the concretes, there will be more empties and less firm concretes.

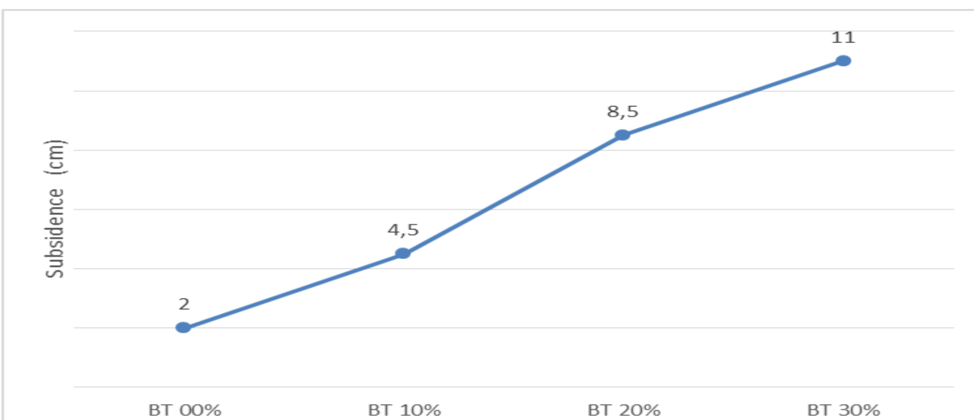

Figure 12: Subsidence for different concretes

3.6.2. *Test of control of occluded volume of air*

The results are given by the curve of the figure 13 below. When the raw materials composed the concrete are mixing, there has been creation of air bubbles, and the concrete still form a certain some quantity of occluded air .Through the results obtained and shown in the figure above, it is found that the inclusion of metallic fibers in cement substitution increases the quantity of voids in the concrete because the cement is a fine powder and has the property of closing the existing voids between the grains. Therefore the reduction of cement in the concretes decrease the compactness and strength of concrete, and this can be confirmed in the compressive strength test.

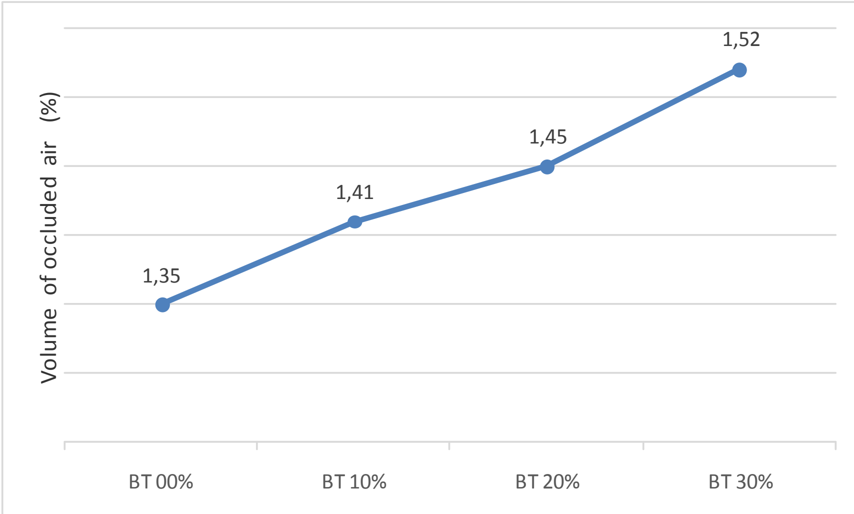

Figure 13: Evolution of the volume of air of the different concretes.

3.7**.** *Test hardened concrete (compressive strength test)*

The compressive strength is an essential characteristic and fundamental parameter of our study. Therefore, measuring at the age of 7 days, and at the age of ripening (28 days) was made on different compositions of concrete and the results thus obtained are graphically shown in figure 14. It is observed that the dosage to 00 wt % of metallic fibers (concrete witness) gave a better compressive strength

For the proportion in 10 wt % of metallic fibers has a slight decrease in strength relative to the concrete witness.

These results were predictable; because the W / C ratio was increasing, which is respectively: 0.5, 0.55, 0.62, and 0.72, thus by increasing the proportioning of metallic fibers in cement substitution, the compactness of the concretes decreases, which generates a lowering of the compressive strength.

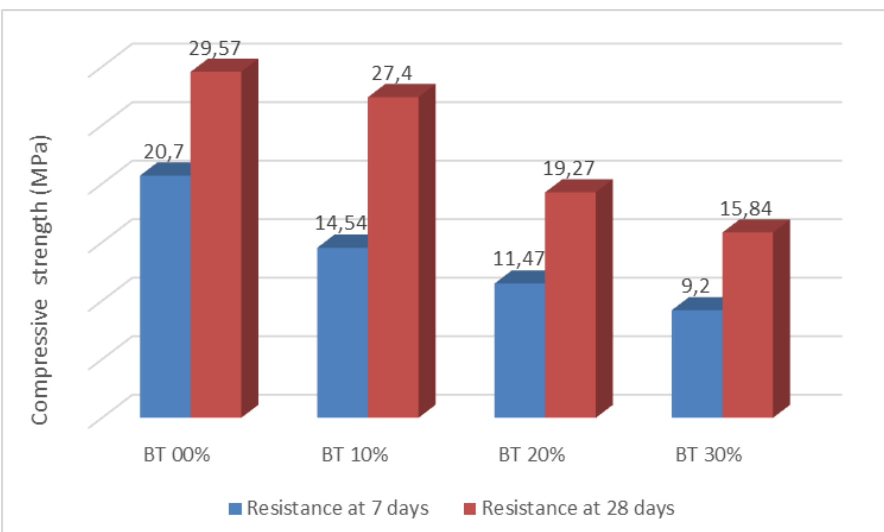

Figure 14: Compressive strength of concrete.

3.8**.** *Characteristics of materials by X-rays*

According to this spectrum (Fig. 15), the compounds of Co,Fe,Ni_8S_8 et Zn_2SiO_4 increased in the concrete after leaching , and this is duo to salting out of heavy metals contained in metallic fibers, and calcite is a dominant phase in both cases.

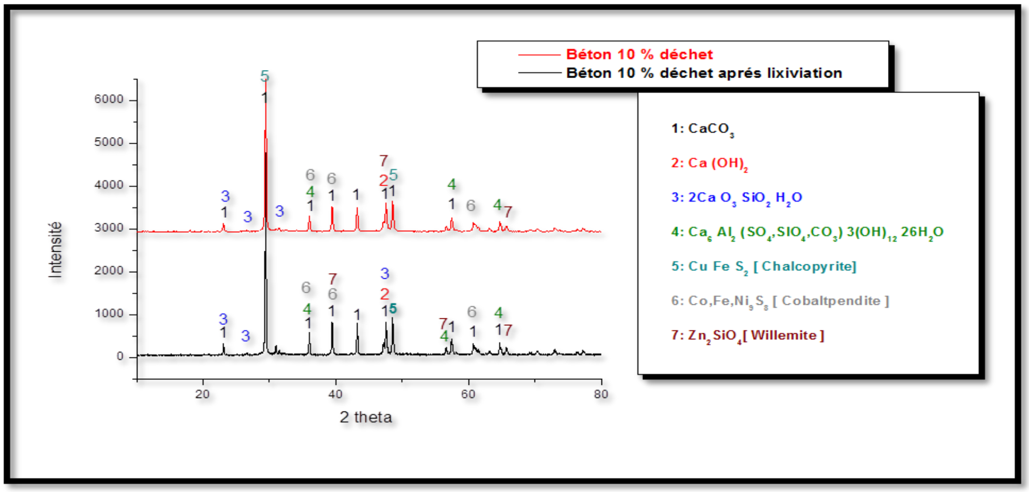

Figure 15: XRD patterns of the concrete with 10 wt % of metallic fibers before and after leaching.

3.9**.** *Test of Leaching (lixiviation) on Monolith (TLM)*

The variations of the rate of the leached metals into the different solutions are given by the figures 16 and 17.

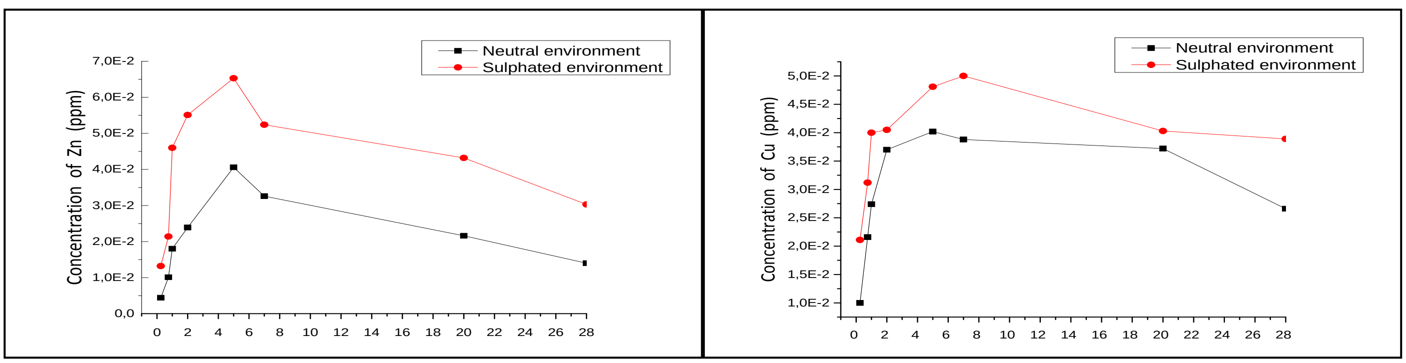

Figure 16: Evolution of the concentrations of Zinc and Copper as a function of time in mortars

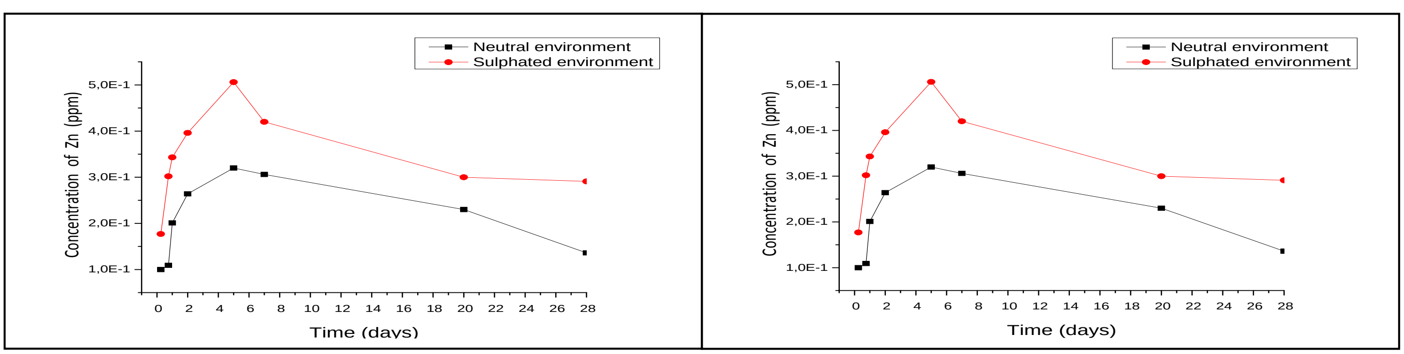

Figure 17: Evolution of the concentrations of Zinc and Copper as a function of time in concretes

The curves of the salting out of the chemical elements contained in the mixtures of concretes and mortars have the same pace, there are two (02) stages:

- The first (1^{st}) stage where there is an increase in salting out until the 5 days age which can be explained by the swelling of the monolithic and consequently an increase in release of these metals.
- The Second (2^{nd}) stage where there is reduction in salting out from the 5th day which can be explained by the depletion of metals which are on the surface of monoliths.

The curves obtained show clearly that the quantity of the metals salted out in the sulphated solutions is more important than that salted out in the neutral solutions, because the sulphates penetrate inside the monoliths which will give rise to the étringite which will create an increase in porosity, consequently important salting out of metals, but these quantities remain weak. Salting out in the concretes is more important than that of the mortars, and that returns to the porosity which is greater in the concretes. These figures also show that the salted out quantity of Zinc (Zn^{2+}) is weaker than the salted out quantity of Copper (Cu^{2+}), and that returns to its quantity which is initially weak in fibers.

Conclusions

The main interest of this study is to evaluate the influence of use of the metallic fibers in cement substitution on the mechanical and physico-chemical behavior of mortars and concretes. The results showed that the metallic fibers can be used as a substitute for 10 wt % of cement in concrete and mortar. Due that they give similar resistance to those of mortars and concretes without cement substitution (mortar and concrete of reference).The use of these fibers in cement substitution reduced the shrinkage and the swelling increasing slightly. Therefore, the formulation with 10 wt % of metallic fibers wastes in cement substitution is interesting. The results show good compressive and flexural strengths and acceptable shrinkage and swelling. Moreover it is an economic gain concerning cement. The tests of TLM carried out on mortars and concretes immersed out of pure water and sulphated solution highlighted for the sulphated solution of the significant amounts of heavy metals (Zn^{2+}, Cu^{2+}). But these quantities of salting out remain always weak; because this test of leaching in two different solutions made it possible to evaluate the quantities of salted out heavy metals.

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