Estudio de la durabilidad de Hormigones y Morteros reforzados por residuos industriales (Fibras Metálicas)
Study of the durability of Concretes and Mortars reinforced by industrial waste (Metallic Fibers)

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Resumen— **Durante mucho tiempo, los residuos han alimentado varias cadenas de valor. Ante esta problemática, se han buscado cadenas de valor en ingeniería civil. Esta operación de recuperación reúne una ventaja económica y una cuestión medioambiental. El proceso de valorización en el ámbito de la construcción permite dar respuesta a múltiples problemas, tales como: la preservación de las reservas naturales de áridos mediante la valoración de los materiales de sustitución de las obras de ingeniería civil, y la reducción del transporte y de las emisiones de CO$_2$. La gestión de los desechos sólidos es una de las principales preocupaciones ambientales del mundo. Con la reducción de los espacios para vertederos y debido a su elevado coste, el uso de residuos se ha convertido en una alternativa atractiva disponible para diversas aplicaciones. Por otro lado, la sostenibilidad es un objetivo de calidad para el ingeniero. La durabilidad del material de hormigón en su entorno se considera una preocupación importante en el sector de la construcción. El mecanismo de degradación química de este material es su descalcificación gradual en el tiempo en contacto con un entorno agresivo. Esta degradación provoca cambios en las propiedades fisicoquímicas y mecánicas del hormigón. Para evaluar experimentalmente la durabilidad del hormigón, hay que estudiar su comportamiento en relación con una serie de mecanismos que podrían degradarlo. El problema se puede tratar como la durabilidad del hormigón en ambientes agresivos. En este estudio se investigó el efecto de la adición de residuos industriales (fibras metálicas) sobre la durabilidad de hormigones y morteros que contienen un 10% de fibras en sustitución del cemento. Los resultados presentados se refieren a los obtenidos con las siguientes pruebas: Prueba de humectación-secado, prueba de lixiviación monolítica, ataque químico y evaluación de resistencia a la compresión mediante prueba de oscultación sónica.**

Palabras Clave— Fibras metálicas; Valorizaci

Abstract— **For a long time, waste has fuelled several value chains. Faced with this problematic, value chains in civil engineering have been sought. This recovery operation brings together an economic advantage and an environmental issue. The process of valorization in the field of building and construction makes it possible to answer to multiple problems, such as: the preservation of the natural reserves of aggregates by the valuation of the materials of substitution for the works of civil engineering, and the reduction of the transport and CO2 emissions. Solid waste management is one of the main environmental concerns in the world. With the shrinking of spaces for landfilling and because of its high cost, the use of waste has become an attractive alternative made available for various applications. On the other hand, sustainability is a quality goal for the engineer. The durability of the concrete material in its environment is considered**

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a major concern in the building sector. The mechanism of chemical degradation of this material is its gradual decalcification over time in contact with an aggressive environment. This degradation causes changes in the physicochemical and mechanical properties of the concrete. To experimentally evaluate the durability of concrete, one must study its behaviour in relation to a number of mechanisms that could degrade it. The issue can be treated as the durability of concrete in aggressive environments. In this study, we investigated the effect of the addition of industrial waste (metallic fibers) on the durability of concretes and mortars containing 10% of fibers in substitution of cement. The results presented concern those obtained with the following tests: Wetting-Drying Test, Monolith Leaching Test, Chemical Attack and Evaluation of Compression Resistance by Sonic Auscultation Test.

Index Terms—Metallic Fibers; Valorization; Durability; Concretes; Mortars.

I. INTRODUCTION

The concept of waste is always ambiguous because what is waste for one person can be considered as raw material for another. It is shown that the valorisation of the "useful" fraction of waste and the reduction of the polluting or dangerous nature can ensure good waste management (Imyim, 2000). The fibres, in the concrete, bring many advantages particularly on the mechanical behaviour. Metal fibre concretes, and high-performance metal fibre concretes, are increasingly used in construction and public works. Scientific studies have shown that the addition of fibres contributes to limit the development of cracks and possibly to improve durability (Maage, 1984; Rossi, 1998). A lot of research studies have shown improvements in the mechanical properties of fibre-based mortars and concretes. However, these studies have not been extended to the study of sustainability. The fibres used in this study are waste from a factory producing bolts, cutlery and taps (BCR, Algeria). They come from the surface treatment operation and are in the form of chips Fig.1. The objective here is to valorise this waste as building materials in mortars and concretes as a substitute for a part of the cement.

Fig. 1. The fiber chips used in this study.

These fibres are 0.5 to 1 mm thick and 0.2 to 1 cm in length and are CuZn40Pb2 type. Their characteristics are given in Table 1.

The study of the effect of the addition of these metal fibres, on the mechanical properties of concretes and mortars containing 10%, 20% and 30% of metallic fibres in substitution of cement, was the subject of our first study (Kherbache, 2018 ; Kherbache et al., 2016). This study has shown that the best mechanical strengths were obtained with a rate of 10% of fibres in substitution of cement Fig. 2 and Fig. 3. From these results, we are interested in this study by the effect of the addition of metal fibres on the durability of concretes and mortars

containing 10% of metal fibres in substitution of cement. The cement used is Artificial Portland Cement and the aggregates are aggregates of quarries with a high percentage of $CaCO_3$.

TABLE I
CHARACTRICS OF THE METALLIC FIBERS

Chemical composition (%)							
Cu	Al	Fe	Ni	Pb	Sn	Zn	Autres
57	0.05	0.3	0.3	1.6	0.3	40.25	0.2

Physical Characteristics		
Density (kg/dm^3)	Electrical conductivity (MS/m)	Elasticity module (kN/mm^2)
6.44	15	97

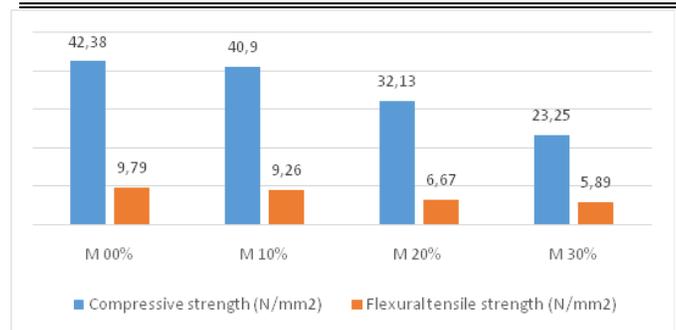| Mechanical characteristics	
Tensile strength (N/mm^2)	Elongation at break E (%)
410	25

Fig. 2. Evolution of the flexural and compressive strength at 28 days of mortars according to the percentages of fibers added in substitution of the cement study (Kherbache, 2018 ; Kherbache et al., 2016).
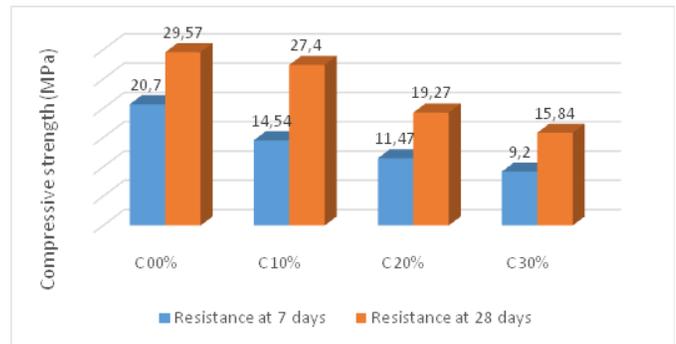

Fig. 3. Evolution of the compressive strengths of concretes whith fibers in substitution of the cements study (Kherbache, 2018 ; Kherbache et al., 2016).

II. EXPERIMENTAL DEVICE

A. Wetting-drying test (ASTM D559-57)

The wetting-drying test was carried out on 4x4x16 cm^3 mortar prisms kept in the open air at the laboratory. At the age of 28 days, these specimens undergo 5 accelerated aging cycles. This test is defined as an alternative continuation of a wetting period at 20 ° C and drying period at 105 ° C in a stove.

B. Monolith Leaching Test (MLT)

A recovered waste material can have an influence on the environment by the release of pollutants (heavy metals), contained in this waste. This is the reason why waste management methods must be adapted to the knowledge of long-term behaviour (Mayeux and Perrodin, 1996; Gobbey and Perrodin, 1999). A means of environmental assessment has been proposed by the European standard EN V 12-920 (European, 1997). The process of simple leaching is very long. According to Adenot (Adenot, 1992), to obtain 4 cm of degraded thickness on a cement paste with distilled water, it would take 300 years. It is therefore imperative to use processes to accelerate the leaching phenomenon. The kinetics of leaching depends mainly on the chemical equilibrium and the diffusion of the chemical species: it is thus necessary to accelerate the process of dissolution or diffusion. Several solutions can be implemented among themthe one proposed by Peycelon (Peycelon and Mazoin, 2004). It consists of increasing the temperature of the aggressive solution which speeds up the diffusion process.

1) Sample Preparation for TLM Testing

The monolithic blocks of mortar, subjected to the leaching test, are obtained by dry cutting the prisms 4 cm x 4 cm x 16 cm in order to have cubes of 4 cm side. For the monolithic blocks of concrete, they were obtained by coring and then by sawing specimens of 16 x 32 cm of concretes, in order to have disks 6.3 cm in diameter and 2 cm thick.

2) Leaching device

The waste leaching test is currently considered, as an indispensable tool for predicting the long-term behaviour of stored and / or recovered waste (Imyim, 2000). It consists of characterizing the transfer mechanisms by observing the fluxes of chemical elements, released by porous monolithic blocks of known dimensions. The block is contacted with a fixed volume of leach solution. The solution is renewed periodically and the dynamics of the release of certain elements is determined by the physicochemical analysis of the obtained eluates (Environment Agency, 2005; Conner, 1990). The experimental device is shown in Fig. 4.

The lixiviants used are: distilled water (neutral medium), a sulphated solution of 5% Na_2SO_4 (Yang et al., 1996; Wang, 1994) and a solution of 5% HCl. The rate of change of the solution is imposed by the monolith / solution contact times

which are: 6 hours, 18 hours, 1, 2, 5, 7, 20 and 28 days. The solutions obtained are then used for the analysis of the cations (Cu^{2+} and Zn^{2+}), while acidifying these solutions at pH <2 with 65% nitric acid (Imyim et al., 2000).
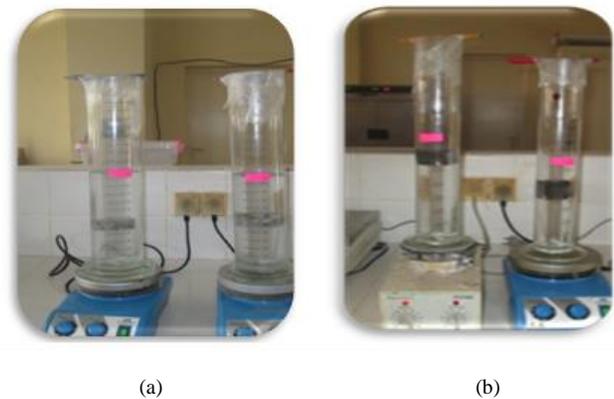

(a)   (b)

Fig. 4. Leaching device: a) On concrete disc; b) On cube of mortar.

3) Atopic Absorption Spectrophotometry (AAS)

Our leach solutions are analysed by AAS to detect the presence and the quantity of heavy metals. This method of analysis makes it possible to determine trace of chemical element in a solution and to measure the concentrations of other present elements (Rouessac and Rouessac, 2004).

4) X- Ray Diffraction Analysis (XRD)

XRD analysis of the powders, from the samples submitted to the leaching test, makes it possible to identify and estimate the mineralogical phases contained in these samples.

5) Chemical attacks and degradation mechanisms

The tests are carried out on samples of concrete and mortar at 0% of fibres and at 10% of fibres in substitution of cement. The main aggressive agents are sulphates, chlorides and acids.

a) External Sulphate Attack (ASTM C 1012-96)

We are interested in the study of external sulphate attacks, what is to say the sulphates which come from the conservation medium. The samples tested in this study are cubic (4x4x4 cm^3) for mortars, obtained after sawing prismatic specimens (4x4x16 cm^3), and cylindrical (10 cm in diameter and 2 cm thick) for concretes (Fig. 5).

Fig. 5. Concrete and mortar samples for sulphate attack

The sulphate resistances are determined from the specimens immersed in the solution of sodium sulphate with 5% Na_2SO_4 concentration and renewed every 30 days. This solution is

considered a severe condition for external sulphate attack for concrete (Tennich et al., 2017). The choice of this concentration is based on the bibliography (Ghrici et al., 2005; Ghrici et al., 2006).

b) Acid attack (ASTM C 267-96)

For the characterisation of the chemical resistance against the attack of hydrochloric acid, 4x4x4 cm^3 mortar specimens, 10 cm diameter and 2 cm thick concrete cylinders were made. After demoulding, these manufactured test pieces are stored for 28 days in water at a temperature of 20 °C ± 2 °C. After this curing time in water, the samples are weighed and then put in a solution of 5% HCl. This operation is carried out according to the following deadlines: 1, 3, 7, 14, 21, 28 and 45 days.
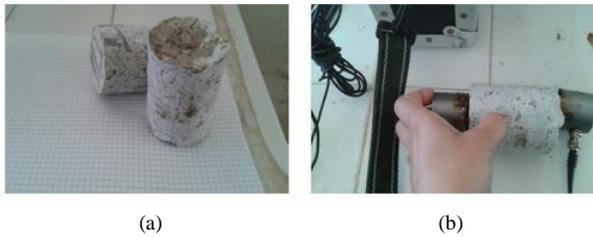

(a)   (b)

Fig. 6. Evaluation of the compressive strength by sonic auscultation: a) Minicylinders 5x10cm. b) Measurement of the propagation speed

c) Storage of test pieces in a neutral medium (drinking tap water)

To discuss the results obtained from the chemical degradation of our materials with respect to sulphates and the acid medium, we proceed to the conservation of these test samples in a neutral medium which is tap water. The manufactured specimens have the same geometrical characteristics as those manufactured for the different attacks. After demoulding, these manufactured test pieces are stored during 90 days in water at a temperature of 20 °C ± 2 °C after demoulding.

d) Chloride attack and penetration

Corrosion of concretes reinforcement is one of the main causes of the degradation of reinforced concrete structures, and the chloride ion diffusion coefficient is an essential quantity of the durability of concretes exposed to these chlorides. After a 28-day cure of $4 \times 4 \times 4$ cm^3 mortar cubes in water, the attack by the chloride ions consists in covering the lateral faces of these cubes with a resin in order to make all these faces impermeable. Thus, the penetration of Chloride ions will be made only in the one-way direction of the two prism bases (the top and bottom face), then these cubic samples are introduced into a 5% concentrated NaCl solution (UNI, 1978; JIS, 2000). The test consists in following the evolution of the penetration depth of chloride ions at 7, 28 and 90 days. At each test, the test piece was cut in half along both permeable faces in order to follow the flow of the chloride diffusion. A silver nitrate solution AgNO$_3$ is poured onto each cut section. The ends of the sections of the cubes change colour (whitish), it represents the degraded distance (depth of chloride penetration) and which is measured using a calliper.

C. Evaluation of the compressive strength by Sonic Auscultation Test (ultrasound): (NF P 18-418)

The characterisation of concretes by non-destructive testing (ultrasonic wave propagation), is a quick way to determine the elastic properties of concrete that can be related to its strength.

The speed of propagation is the parameter which makes it possible to obtain information on the quality of the concrete, the relation between these two parameters allows classifying a concrete (Carino, 2003). The determination of the propagation velocity of ultrasonic waves was carried out on six cylindrical samples of concrete (5x10 cm) (Fig. 6), (03 samples of each type of concrete: (C00% and C10%)). These samples were cored at the heart of the mass of cylindrical concrete (16x32 cm) stored during 28 days in water at a temperature of 20 °C ± 2°C.
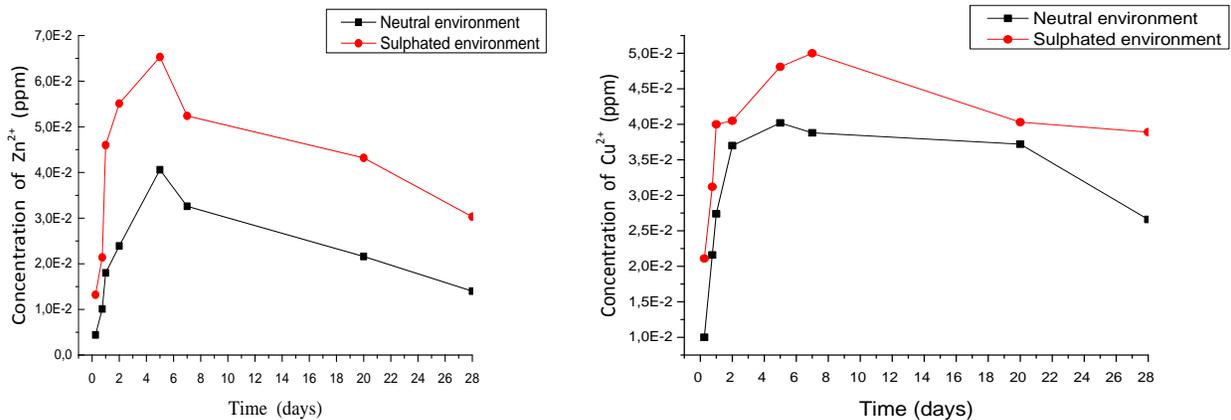

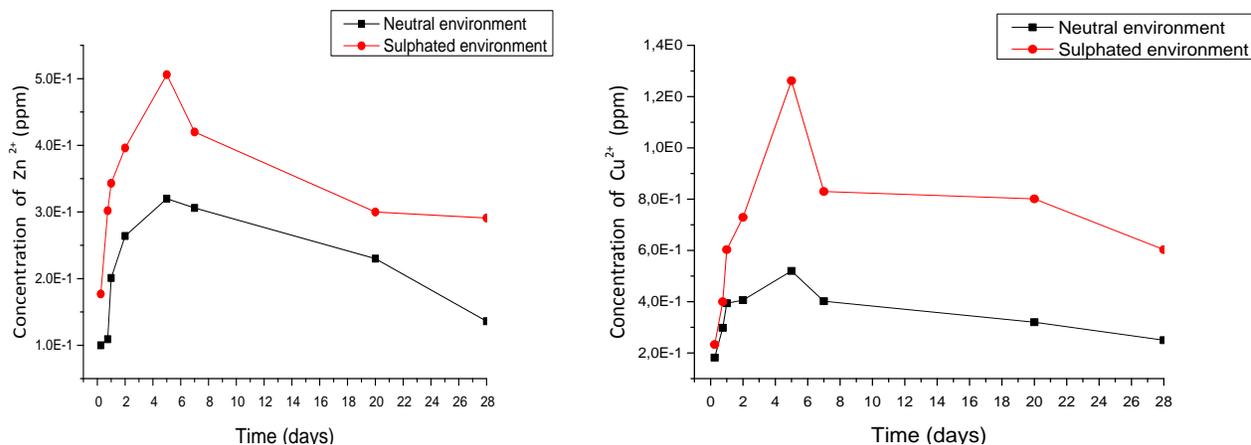Fig. 7. Evolution of zinc and copper concentrations in mortars.

Fig. 8. Evolution of zinc and copper concentrations in concrets.

III. RESULTS AND DISCUSSION

A. Monolith Leaching Test

All the curves (Fig. 7 and Fig. 8) of the release of the chemical elements contained in the mixtures of concretes and mortars have the same appearance, there are two (02) stages:

The 1st stage where there is an increase of the release until the age of 5 days, it can be explained by the swelling of the monoliths and consequently an increase of release of these metals. The 2nd stage where there is a decrease in the release from the 5th day, it can be explained by the depletion of the metals that are on the surface of the monoliths. The obtained

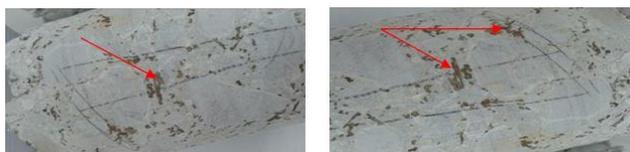Fig. 9. Color of the fibers on the surface of the mortars.

Fig. 10. Color of the fibers on the surface of the concretes.

curves clearly show that the quantity of metals released, in the sulphate medium, is greater than the one released in the neutral medium. It is due to the penetration of sulphates inside the monoliths giving rise to the ettringite which will create an increase of porosity and therefore, significant release of metals but these quantities remain low. The release in concretes is greater than that of mortars, and this amounts to the porosity which is greater in concretes. These figures also show that the released amount of Zinc (Zn^{2+}) is lower than the released

quantity of copper (Cu^{2+}). The various materials subjected to leaching tests, in the various environments, were damaged. These degradations are more importante in mortars, and this amounts to the matrix of these, which is more fragile than that of concretes, and also to the density of these two materials which is different.

B. Durability of fibres

The only durability problem, specific to concretes made of metallic fibres, is the corrosion of these fibres. Regarding our fibres, there is no surface corrosion of concretes and mortars (no corrosion), which will be harmful to the aesthetics of the structures (Fig. 9 and Fig. 10).

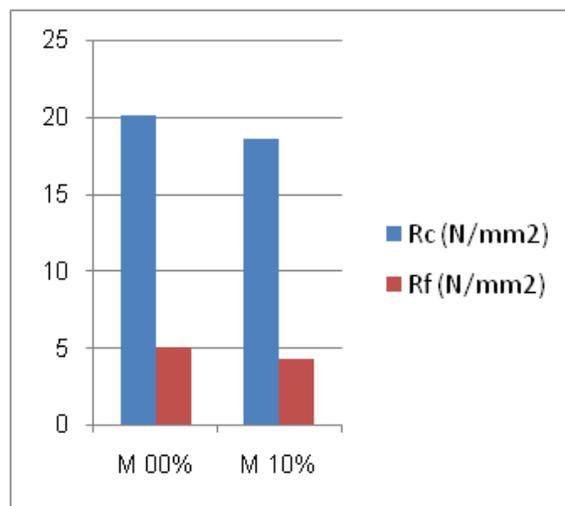Fig. 11. Loss of resistances of mortars subjected to the immersion/drying

The concrete surface does not show any traces or rust stains. A non-corrosive surface also increases the durability of the concrete. After storage of the fibres, in distilled water and in tap water, for a period of more than 180 days, given the life of these fibres, the latter are stainless and they remained intact which avoids corrosion problems.

C. Immersion/drying test

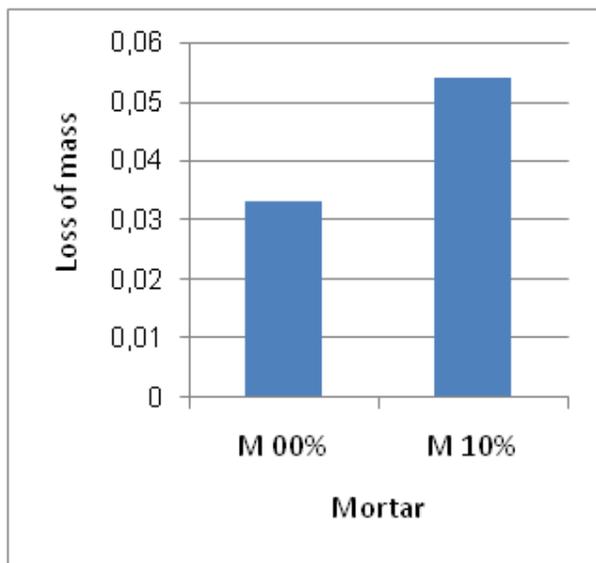We were interested in the determination of two parameters;

Fig. 12. Loss of mass of mortars subjected to the immersion/drying cycle.

the mechanical strength and the mass variation of the mortar prisms, containing 10% of fibres in substitution of the cement during this aging test (Fig. 11 and Fig. 12).

For both mortars the mechanical strengths are relatively low, compared to the initial resistances before the test. This diminution is more important for the mortars with 10% of fibres that amounts to the porosity existing in the specimens with fibres base. Mortars with dry wetting cycles lose their mechanical performance and this loss is even greater in fibre mortars. These explanations are also suitable for the loss of mass of these mortars subjected to the aging cycle, such that the loss of mass has the same variation as the loss of resistance. The presence of fibres creates a preferential path for the departure and absorption of water.

D. Chemical attacks

1) Sulphate attacks

The degree of damage of the tested samples is evaluated by a visual check of the cracks and by a diagnosis of the degradation. Sulphate attack has clearly an influence on mortars

Fig. 13. Samples after sulphate attack. (a) Mortar. (b) Concrete.

and concretes. In our sulphate attack tests, it was noted that mortars are more prone to deteriorate compared to concrete specimens (large expansion of mortars). Figure 13 clearly illustrates this phenomenon. This this mainly comes down to the initial composition of these mortars and concretes, as they contain aggregates that slow down the phenomenon of degradation. If we compare the effect of the attack on the control mortars and the mortars with 10% of fibres in substitution of the cements, the latter are more resistant (less expansion and without cracks) (Fig. 14) and this although the porosity is slightly important in the mortars with fibres. Sulphates react directly with the cement paste, that is to say less cement, less sulphate-cement reaction and less expansion.
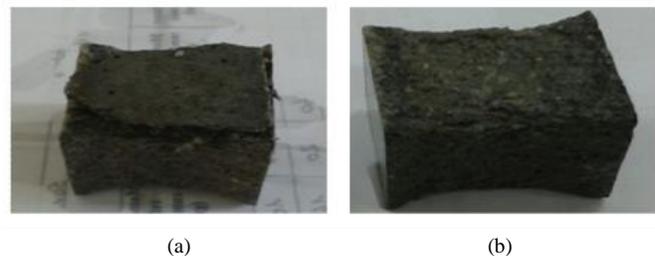
Fig. 14. Degradation of the mortars in the sulphated medium (5% Na_2SO_4, $10H_2O$): (a) Control Mortar. (b) Mortar with 10% fibers.

The crystals of ettringite and calcium sulphate accumulate in the matrix cement, producing internal pressures which generate cracks. Thus, the use of the 10% fibres in cement substitution has a beneficial effect on the durability of the concretes with respect to concentrated sulphates at 5%. The degradation of mortars by sulphates is particularly related to the formation of

Fig. 15. SEM photo of Portlandite and CSH in the mortar.

Fig. 16. XRD spectra of mortar with 10% fibers subjected to 5% Na_2SO_4 attack.

Fig. 17. Secondary ettringite in the control mortars.

ettringite, as Carde explains (Carde, 2007). During this sulphate attack, the constituent of the reacting cement is portlandite ($Ca(OH)_2$); the l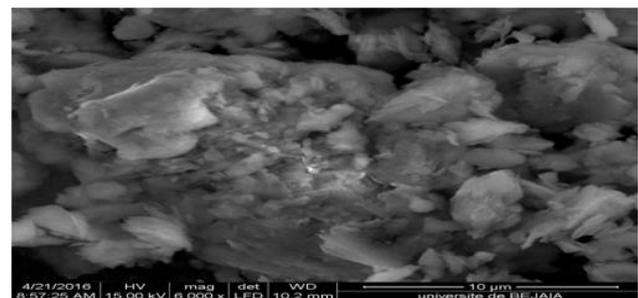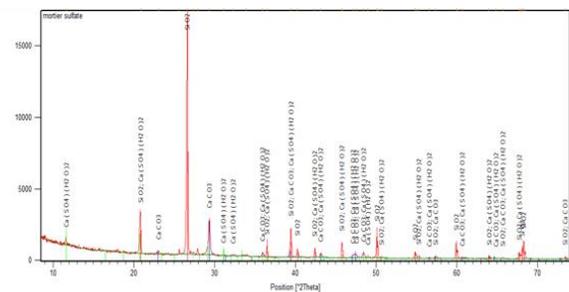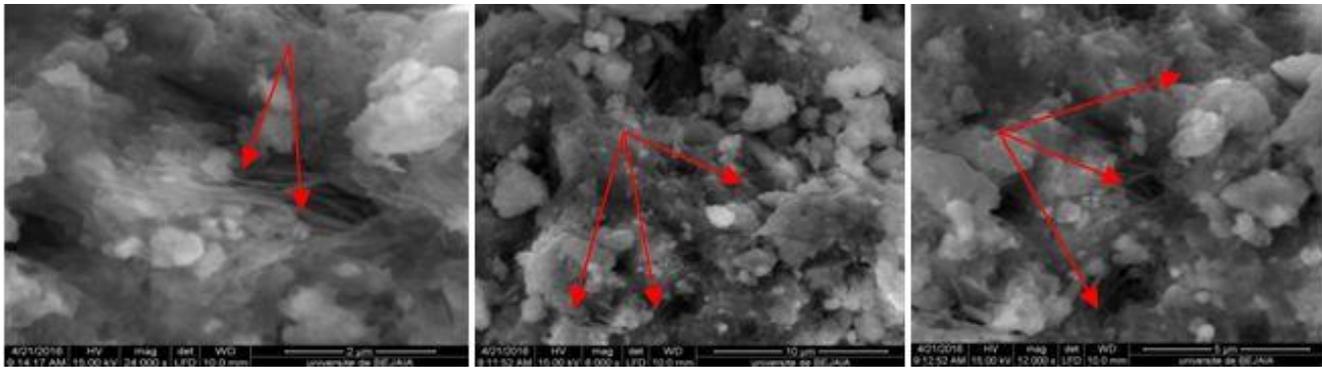atter being released during the hydration of tricalcium silicate C3S and the aluminates originating from the hydration of the Tricalcium aluminate C3A. The sulphates damage mortars by the mechanism of expansion and loss of binding properties of hydrated calcium silicates C-S-H, according to Gagne's explanations (Gagne, 2004). During sulphate attack, the basic reason for mortar expansion is the

Fig. 18. Evolution of the expansion of the cubes of mortars preserved in the solution of 5% Na_2SO_4.

formation of ettringite (ACI, 1992). This phenomenon is related to the formation of secondary gypsum, by the reaction between the sulphate and the calcium ions released during the hydration of the cement (LEA, 1971). The formation of secondary gypsum, by the reaction between sodium sulphate Na_2SO_4 and calcium hydroxide (Bhatty and Taylor, 2006), is carried out according to the following reaction:

$$Ca(OH)_2 + Na_2SO_4 + 2H_2O \rightarrow CaSO_4, 2H_2O + 2NaOH.$$

The existence of the NaOH element is the main cause of the alkalinity of our storage solutions which stabilizes the C-S-H crystals (Fig. 15). The presence of CaSO4, 2H2O makes our samples more expansive (Gagne, 2004). This is consistent with the XRD analysis of our mortars subjected to sulphated attack (Fig. 16).

In order to confirm the origin of the expansion and to deepen our study, we used the scanning electron microscopy of reference mortars (0% fibre), (Fig. 17).

The study is continued by measuring the swelling undergone by the mortar (Fig. 18).

In addition to visual observations, the expansion measurement results clearly show the increase in swelling (weight gain) as a function of the age of storage, in the sulphated solution up to 180 days. This gain is attributed to the formation of gypsum and secondary ettringite, following the reaction between the hydrates and particularly the portlandite and sulphates of the solution. Sulphates cause swelling by reaction with tricalcium aluminate (Baron and Ollivier, 1997) which generally increases the rate of concrete degradation (Zayed, 2004). If one analyses the values of the swellings, obtained during the expansion of our mortars in the solutions of the sulphates, one can classify the different behaviours with respect to the swelling according to the work achieved by Brunetaud (Brunetaud, 2005), as follows:

The expansion of the reference mortars (M00%) varies from 0.035 to 0.12%, between 30 and 180 days, the expansion remains less than 0.2%, so the swelling is considered low. For
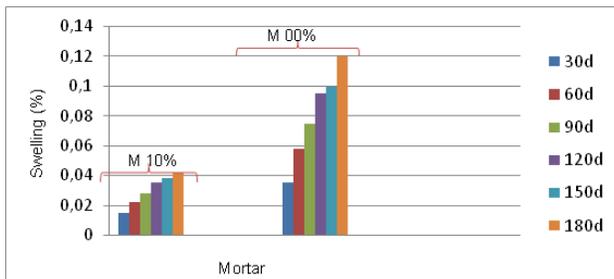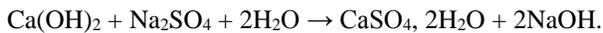

Fig. 19. Material formed on samples during sulphate attack.

mortars with 10% fibres (M10%), the expansions are of the order of 0.015 (30 days) to 0.042% (180 days), these values are much lower than the limit value 0.2%, so the swelling is also considered low. The fibres contained in the mortars have not reacted with the sulphates of the solution (according to the XRD), otherwise further analysis (ESM-EDS) would be needed to confirm.

The white powder layer formed on our samples of long-term concretes and mortars during this sulphate attack (Fig. 19) is analysed by XRD. The phase determination of the layer thus formed show that they are hydrated sulphates (Fig. 20).
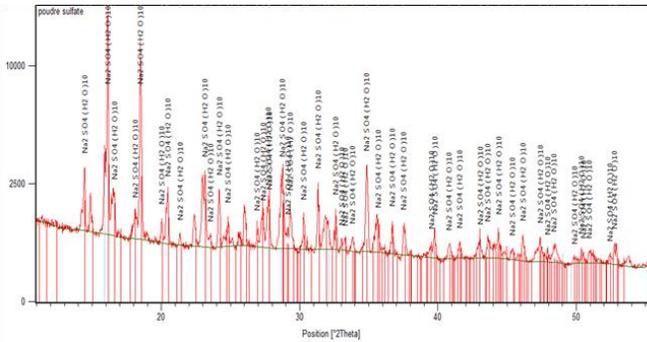

Fig. 20. XRD spectra of the sulphate powder.

The results of compressive strengths of the mortar cubes kept for 6 months in the 5% Na_2SO_4 solution are shown in Fig. 21.
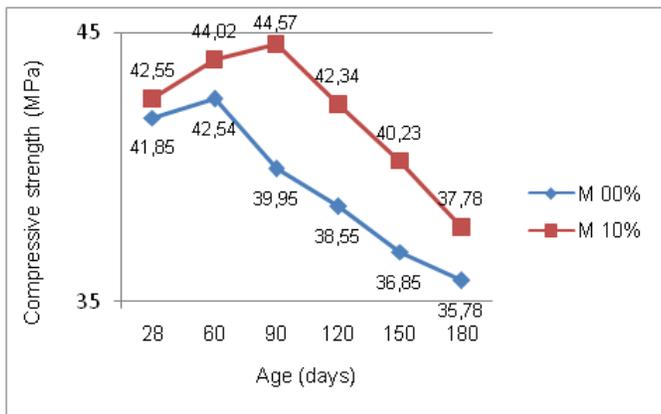

Fig. 21. Compressive strength of mortars preserved in sulphates as a function of time.

The curves look the same. The variation of the compressive strength of the cubes of mortars was not in the same step of the expansion. The M00% samples develop their resistance until the age of 60 days. Exceeded this age, the samples lose their resistance, the thing that was predictable since the expansion was relatively high. In addition the reaction between portlandite (Ca(OH)2) ,resulting from the hydration of cement with sulphates, to form gypsum and expansive ettringite causing microcracks that lead to the fall of resistance. For the M10% samples, the resistances are slightly better compared to those of the reference mortar.The compressive strengths increase as a function of time until the age of 90 days and then a resistance

loss is noted ranging from 44.57MPa (90 days) at 37.78MPa (180 days). The reason can be attributed to the early age resistance of these samples to this aggressive environment. This phenomenon is also attributed to the presence of fibres. It is possible that crystals of copper sulphates and zinc sulphates have formed, according to the following reactions:

$Na_2SO_4 + Cu \rightarrow CuSO4 + 2Na$; $Na_2SO_4 + Zn \rightarrow ZnSO_4 + Na_2$.
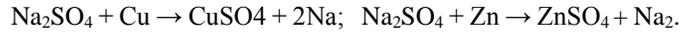
2) Acid attacks

Measurements of mass loss were made on three samples of the two types of concrete and mortar. They are cleaned 3 times with demineralized water and then wiped out, to eliminate the surface solution and the altered material. Figure 22 shows that, in terms of mass loss, mortar performance is better than that of concrete because the attack in concrete is faster than that of mortars; this amounts to sand and limestone gravel used in concretes. Since concrete is an alkaline medium, it is very susceptible to acid attack.

(a)   (b)

Fig. 22. Degraded state at 45 days of acid attack: (a) Mini-cylinders of concretes. (b) Cubes of mortars.

Generally, the chemical reactions concern two elements that are mainly: the calcium hydroxide (Ca (OH)2) in the cement paste and the limestone $CaCO_3$ in the aggregates, according to the following equations:

$CaCO_3 + 2HCl \quad\quad \rightarrow \quad\quad CaCl_2 + CO_2 + H_2O$.

$Ca(OH)_2 + 2HCl \quad\quad \rightarrow \quad\quad CaCl_2 + 2H_2O$

After 45 days of attack, the samples are too damaged and continuity of measurement is not possible. If we compare the specimens of reference with those of 10% of fibres in substitution of cement, one notes that their degradation is not really different. The copper contained in our fibres is not attacked by hydrochloric acid (Fig. 23).

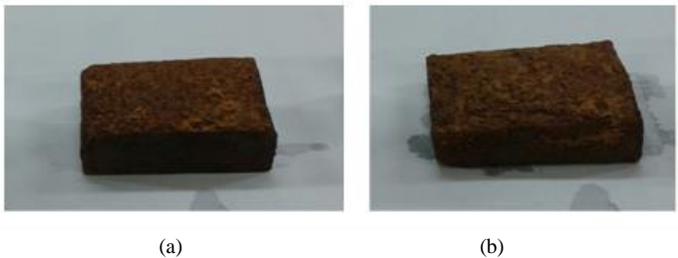
(a)   (b)

Fig. 23. Mortar after 45 days of attack: (a) Control Mortar. (b) Mortar with 10% fibers.

Every time, it is found that the pH of the attack solutions increases, especially that one of the samples with 10% fibres.That is to say the solutions become less acidic and this

amounts to the disappearance of hydrogen ions (H$^+$) responsible for the acidity. They have become hydrogen atoms which form the molecules of hydrogens (H$_2$), according to the following reaction:

Zn + HCl → H$_2$ + (Zn^{2+} + 2Cl$^-$)

Figures 24 and 25 show the loss of mass of the various samples of mortars and concretes preserved in the 5% HCl solution.

Fig. 24. Loss of mass of the mortars preserved in the acid solution (5% HCl, 2H$_2$O).

Fig. 25. Loss of mass of the concretes preserved in the acid solution (5% HCl, 2H$_2$O).

This loss increases as a function of time until almost the mass loss of half to 45 days of attack, such that this loss is significant starting from 28 days. The decrease in sample volume and weight is due to the decomposition and weathering of hardened cement paste in the mortars and the disintegration of the aggregates in the concrete. Comparing the reference specimens with those of 10% cement substitute fibres, we find that their degradation is almost similar with slight high values for those of 10% fibres which is normal, compared to the more porous texture of these. X-ray diffraction (XRD) analysis of the degraded portion of the 10% fibre mortar after drying, milling and sieving (passers at 80μm) gave the diagram shown in Figure 26.

Fig. 26. XRD spectra of the 10% fiber mortar subjected to 5% HCl attack.

The latter gives the formation of quartz and calcite. The intensity of the quartz peaks is greater. On the other hand, we did not detect minerals containing chlorides.

3) Neutral enviroment

The variations in mass and compressive strength are the average of three results of each type of studied material. These results are presented in the following figures 27, 28 and 29.

Fig. 27. Evolution of the mass of mortars preserved in water as a function of time.

Fig. 28. Evolution of the mass of concretes preserved in water as a function of time.

The masses of mortars and concretes increase significantly as a function of time. This increase is explained by the continuous hydration of the cement grains. We find that from 28 days the mass stabilizes (almost saturation). If we compare the masses of 10% fibre specimens to those of the reference, those made of fibres have a greater weight gain. These values indicate the created voids and occupied by water during storage.

The compressive strength tests on the mortar cubes gave a significant increase in mechanical compressive strength as a function of time (Fig. 29).
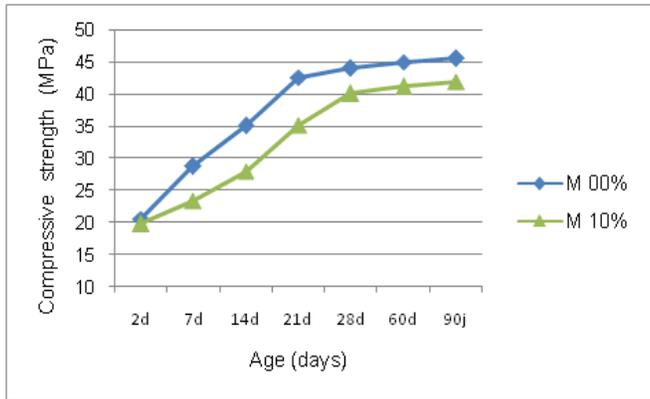

Fig. 29. Evolution of the compressive strength of mortars kept in water as a function of time.

This gain in resistance is attributed to the phenomenon of maturation of the cement matrix. The presence of water in the porosity of the sample favours the displacement of Ca^{++} ions and thus the crystalline growth of portlandite. The latter is transformed into calcite which also explains the resistance gain that has been recorded. The reference samples have a better resistance, compared to those of 10% of fibres in substitution of cement that amounts to the reduction of the compactness of the latter. SEM analysis were performed, observations made on the samples mortars provide information on the homogeneity of their morphology (Fig.30).
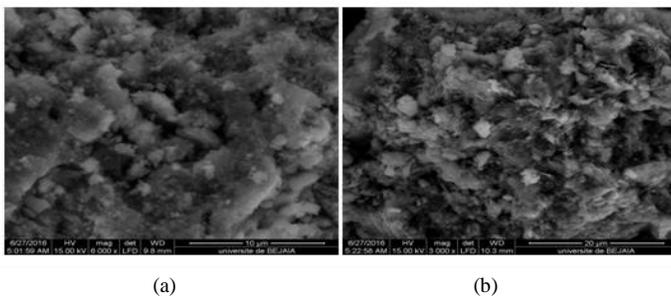

(a)   (b)

Fig. 30. SEM photo of the samples mortars: (a) Mortar with 10% fibers. (b) Reference mortar (0% fibers).

4) Resistance to chloride penetration

The white colour appeared on the faces of the cubes of mortars, which facilitated the measurement of the degraded thickness is due to the following reaction:

$AgNO_3 + NaCl \rightarrow AgCl + NaNO_3$

Silver Nitrate + Sodium Chloride → Silver Chloride + Sodium Nitrate

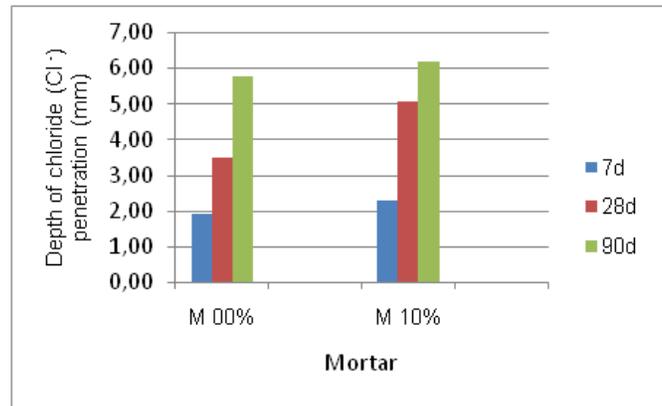The depth of chlorides penetration as a function of time is shown in Figure 31.

Fig. 31. Depth of penetration of Cl⁻ ions.

The penetration depth of the chloride ions of mortars at 10% fibre is higher than that of the reference mortars in the three deadlines. This is mainly due to the permeability of fibre-based mortars which is slightly larger. This infiltration increases with time. If we analyse the rate of variation of the crossing of chloride ions for the two types of mortars, the elevation of the depth is of the order of: 1.19%, 2.19% and 3.62% respectively at 7, 28 and 90 days, for reference mortars, and 1.44%, 3.19% and 3.87% for 10% fibre mortars. However, the depth of chloride penetration is important as a function of time.

E. Evaluation of ultrasonic wave velocity

Table 2 shows the results obtained by sonic auscultation of the wave propagation time of cylindrical concrete specimens (5 cm x10 cm).

TABLE II
WAVE PROPAGATION TIME

Concrete	Propagation time (μs)
C00%	4351.66
C10%	4111.84

From these results of the propagation time of the waves, through the masses of concretes given by the ultrasound, one can calculate the velocity of propagation of the waves by the formula:

$V = (L / T) \times 10^6$

with: V: velocity of propagation of waves (m/s), L: distance between probes (m)

T: wave propagation time given by ultrasound (μs). The results of the speeds and the resistances of the reference concretes and those with 10% of fibres in substitution of cement are given by the table 3.

TABLE III
WAVE PROPAGATION TIME

Conrete	Velocity (m/s)	Compressive Strength (MPa)
C00%	4351.66	33
C10%	4111.84	26.9

According to the results obtained, concretes have good performances and are classified as good quality concretes. The substitution of 10% of cement with metal fibres (C10%) caused a decrease in the order of 239.82 m / s of UPV (Ultrasonic wave Propagation Velocity). The study shows the sensitivity of the UPV parameter following the incorporation of a quantity of 10% of fibres in substitution of cement. This sensitivity can be explained by the increase of the porosity of the concrete, but it remains a concrete of good quality.

IV. CONCLUSION

In this paper, we presented an experimental study on the durability of concretes and mortars containing industrial waste (metal fibres containing heavy metals essentially Cu, Zn). The results obtained show a low presence of these metals in neutral medium. The level of these heavy metals leached for 64 days in the different aggressive mediums are below the limits given by the literature, which proves the effectiveness of using this valuation. Degradations in the acid medium are important for concretes compared to mortars. The degradation is slightly greater in the mortars and concretes of 10% fibres in substitution of cement. This is probably due to the porosity created by the introduction of fibres. Mortars with 10% fibre substitution cement have a better behaviour in the aggressive sulphates medium compared to mortars without fibres. At 10% of fibres in substitution of cement, the loss of resistance is of the order of 7.2%. This loss is small and is considered acceptable.

Finally, it can be concluded that taking into account the criteria of loss of strength and chemical degradation, the introduction of metal fibres in substitution of cement is possible with a rate of 10%. The incorporation of these metal fibres leads to materials whose physical and mechanical characteristics meet the criteria of use. Thus, the recovered waste will be valorized and will have a double impact on the environment, namely to avoid its storage in the nature and to reduce the quantity of cement used in the construction.

REFERENCES

ACI (1992). Commitee 201, "Guide to durable concrete", ACI manuel of concrete practice, 1992.

Adenot, F. (1992). Durabilité du béton : Caractérisation et modélisation des processus physiques et chimiques de dégradation du ciment, thèse de doctorat, Université d'Orléans, France, p.239, 1992.

Baron, J., Ollivier, J.P. (1997). " Les bétons : bases et données pour leur formulation", Association technique de l'industrie des liants hydrauliques, édition Eyrolles, 1997.

Bhatty, J., Taylor, P. (2006). "Sulfate resistance of concrete using cements or supplementary cementitious materials", Portland Cement Association, SN2916a, 2006.

Brunetaud, X. (2005). "Etude de l'influence de différents paramètres et leurs interactions sur la cinétique et l'amplitude de la réaction sulfatique interne au béton, thèse de doctorat, Ecole centrale des arts manufactures & Laboratoire Centrale des Ponts et Chaussées, 2005.

Carde, C. (2007). "L'Ettringite", édition no 09, Béton, p.75-76, 2007.

Carino, N.J. (2003). Non destructive test methods to evaluate concrete structures, 6th CANMET/ACI International Conference on Durability of Concrete, Thessaloniki, Greece, 2003.

Conner, J.R. (1990). Chemical fixation and solidification of hazardous wastes, Van Nostrand Reinhold, New York, 1990.

Environment Agency (2005) EA NEN 7375 :2004, Leaching characteristics of mouled or monolithic building and waste materials : determination of leaching inorganic components with the diffusion test 'the tank test, based on a translation of the Netherlands Normalisation Institute Standard, version 1.0, 2005.

European (1997) Committee for Standardisation Characterisation of Wastes Methodology for the determination of the leaching behavior of waste under specified conditions", European Standard. EN 12-920, Brussels: CEN, 1997.

Gagne, R. (2004). "Durabilité et réparation du béton", Cours maîtrise de génie civil, université de Sherbrooke, Canada, 2004.

Ghrici, M., Kenai, S., Mansour, M.S., Kadri, E. (2006). Some engineering properties of concrete containing natural pozzolana and silica fume, Journal of Asian Architecture and Building Engineering, November, 2006.

Ghrici, M., Kenai, S., and Meziane, E. (2005). Mechanical and durability properties of cement mortar with Algeria, natural pozzolana, Springer Science + Business Media, LLC, 2005.

Gobbey, A., Perrodin, Y. (1999). Ecocompatibilité des déchets In Wastes Stabilization & Environment, Edited by J. Méhu,

G. Keck and A. Navarro, Grenoble : Societé Alpine de Publications, pp 189-197, Lyon (France), 1999.

Imyim, A. (2000). "Méthodologie d'évaluation environnementale des déchets stabilisés /solidifiés par liants hydraulique", thèse de doctorat no 00 ISAL 0091, Institut National des Sciences Appliquées (INSA) de Lyon, France, 2000.

Imyim, A., Moszkowicz, P., Tiruta-Barna, L., Sanchez, F., Barna, R. and Méhu, J. (2000). Mise au point d'une boite à outils de tests de lixiviation pour l'évaluation du flux de polluants émis d'un déchet solide, Déchet-Science et Technique, no 18, 2ème trimestre, INSA (Lyon), France, 2000.

JIS (2000) A 1171 (E), Test methods for polymer-modified mortar, Japanese Industrial Standard, 2000.

Kherbache, S. (2018). Etude et caractérisation des déchets d'usinage (fibres métalliques) et leurs influences sur le comportement mécanique et la dégradation chimique des bétons, Thèse de Doctorat en Sciences, Université de Bejaia, 2018.

Kherbache, S., Bouzidi, N., Bouzidi, M. A., Tahakourt, A. and Moussaceb, K. (2016). The behavior of the concretes and mortars reinforced by metallic fibers wastes as substitution of cement, J. Mater. Environ. Sci. (2016) 7 (1) 18-29.

LEA, F.M. (1971). "The chemistry of cement and concrete", third edition, 1971.

Maage, M. (1984) "Effect of microsilica on the durability of concrete structures, Report STF65 A 84019, FCB/SINTEF, The Norwegian Institute of Technology, Tronddheim, Norway, march 1984.

Mayeux, V., Perrodin, Y. (1996). Ecocompatibilité des dechets: vers une prise en compte de la notion d'impact pour l'élimination et la valorisation des déchets, Déchets-Sciences et Techniques, no 3, p. 10-18, 1996.

Peycelon, H., Mazoin, C. (2004). Comportement à long terme des bétons : influence de la température et du matériau sur la dégradation (décalcification/hydrolyse) en milieu saturé, notes technique CEA NT SCCME 03-245-A, 2004.

Rossi, P. (1998). "Les bétons de fibres métalliques", Presses de l'École Nationale des Ponts et Chaussées, Paris, 1998.

Rouessac, F., Rouessac, A. (2004). "Analyse chimique: Méthodes et techniques instrumentales modernes", 6ème édition (Masson Ed), Paris, pp. 372, 2004.

Tennich, M., Ben Ouezdou, M. et al. (2017). Kallel, Durabilité des bétons autoplaçants à base des déchets de marbre et de carrelage exposés à l'attaque du sulfate, Journées nationales du Béton JNB'17, Hammamet, Tunisie, Mai, 2017.

UNI 7928 (1978), Concrete Determination of Ion Chloride Penetration, Ente Nazionale Italiano Di Unificazione-UNI, Milano, December, 1978.

Wang, J.G. (1994). Sulfate attack on hardened cement paste, Cement and Concrete Research 24, p 735-742, 1994.

Yang, S., Zhongzi, X. and Mingshu, T. (1996). The process of sulfate attack on cement mortars, Advanced Cement Based Materials 4, p 1-5, 1996.

Zayed, A. (2004). "Effect of sulfur trioxide content on concrete structures using florida materials", Research report, University of south Florida, 2004.