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Concretes properties made with machining reject (foundry sand)

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Abstract

The use of waste materials in the building industry is a major challenge for construction and environment. This industry is that of concrete which is highly intolerable concerning the high dependence on natural resources. In the present study, the effects of using foundry sand as fine aggregates (quarry sand) on the mechanical properties and durability of concretes and mortars is investigated. The ordinary sand was replaced with four (04) percentages (25%, 50%, 75% and 100%) of foundry sand by weight. Used Foundry Sand is the high quality silica sand by-product from the production of nonferrous metal casting industry comes from the BCR unit of Ain El kbira (Setif, Algeria). The obtained materials are compared to those without substitution (00 wt% of machining reject). The test results showed that the best percentage is reached with 25% of foundry sand. The specimens tested have good performance and are suitable for practical uses.

1. Introduction

The preservation of the environment is becoming more and more of a major concern. It is only from the years 60-70 that one becomes aware of the scale of the problem. The danger of the environment is becoming a global issue, particularly in the field of waste, but it should be pointed out that the question of waste at the historical level is much less important than it is today [1]. For a long time, waste supplied several sectors of valorization. Faced with this problem, sectors of valorization in civil engineer were sought. This recovery operation brings together an economic advantage and an environmental issue. Waste recovery serves to protect the environment since it tends to reduce the quantities of waste to be stored.

Valorization recoverable materials and reducing the amount of waste to be disposed of have important environmental benefits [2]. For economic and ecological reasons, the recovery and recycling of industrial by-products for the birth of new building materials appears as one of the most interesting solutions for the elimination or reduction of these rejections [3]. It is shown that the valorization of the "useful" fraction of waste and the reduction of the polluting or dangerous character can ensure good waste management [4]. Population growth and rapidly increasing globalization have brought about a shift in the building sector that has led to an increase in the demand for building materials. River sand and quarry sand are basic materials used as fine aggregate in concrete manufacturing. High demand for this fine aggregate (sand) has led to overexploitation of the sand of the river and aggregate career, this overexploitation has negative consequences for the environment. In addition, the limitation of sand extraction by government organizations has increased the price of this major ingredient, which significantly affects the stability of the construction sector and building industry [5]. The use of recycled aggregates is constantly increasing, their reuse in the building sector (mortar and concrete) leads to an economy of aggregates and the preservation of the environment.

For these reasons, finding an alternative material to sand has become indispensable. In recent years, much research has been conducted into the use of industrial waste, including granite and marble waste [6-11], wood waste [12], palm oil ash [13], tire waste [14] and foundry sand as a replacement or substitute material for fine aggregates.

Several recent studies have been conducted on the exploitation of this foundry sand [15-19]. Foundry sand is sub-angular to round in shape [20-21]. About 85–90% of its particles are smaller than 100 mm. Since it is basically fine aggregate so it can be expected to be used in many applications as substitute of natural sand [21,22]. However, this type of sand is too fine to be used as complete replacement of regular sand. Fineness modulus of WFS has been found in the range of 0.9–1.6 compared to 2.3–3.1 for normal sand. Hence, only partial replacement with coarser sand is recommended to meet the standard specifications of fine aggregate [21,23]. Currently, this type of sand is valued mainly in three sectors in France: recycling into backfill and road underlay, the bi treatment then backfilling and finally cement manufacturing [24]. The Algerian foundry industry uses many types of sands that are used to make molds and cores for molding metal parts, most often is the foundry sand; knowing that the latter is a clean sand, of uniform grain size, having a high quality which is bond by binders to form molds for molding ferrous or non-ferrous metal parts. In Germany, Finland, Sweden, and the United Kingdom, used foundry sand can be recovered after analytical characterization in public works in the manufacturing of concretes, in the filling of disused mining cavities and in the construction of landfill sites [25]. Recycling is always recommended in terms of environmental sustainability; following a waste recovery approach [26,27].

The present experimental study was developed to see the influence of foundry sands on the mechanical and physical characteristics of concretes and their durability. Le quarry sand has been substituted by different percentages of foundry sand (00, 25, 50, 75 and 100 wt %) where M(00%), M(25%), M(50%), M(75%) and M (100%) are the different samples of the mortar mixtures and C(00%), C(25%), C(50%), C(75%) and C(100%) the different samples of the concrete mixtures. The foundry sand was recovered from Ain El Kebira's BCR plant in the city of Setif, Algeria, and was used for the manufacture of concretes and mortars. Our goal is to determine the best optimal substitution rate of foundry sand by conventional sand (quarry sand).

2. Experimental program

2.1. Materials and mix design

2.1.1. Cement

Five (05) specimens of concrete and mortar were realized: a concrete and a mortar were made without sand of foundry and four (04) series of concretes and mortars based on this sand of foundry in substitution of the quarry sand. Concretes and mortars are prepared in the laboratory; the materials used are listed below:
The cement used is an Artificial Portland Cement CPA (CEM I 42.5) according to European standard EN 197-1[28,29], its absolute density is 3.1 g / cm3 and its specific surface area measured with the Blaine method is 3200 cm^2 / g. The X-ray diffraction pattern of the cement is shown in Figure .1. Mineralogical and chemical compositions of cement are listed in table .1.

Table 1: *Chemical and mineralogical compositions of cement*

Chemical composition(%)		Composition of clinker (%)	
SiO_2	23.30	C3S	57.55
Al_2O_3	6.10		
Fe_2O_3	3.99	C2S	19.95
CaO	61.60		
MgO	1.6	C3A	3.20
SO_3	1.8		
Na_2O	0.24	C4AF	15.00
K_2O	0.39		
Loss On Ignition	1.18		

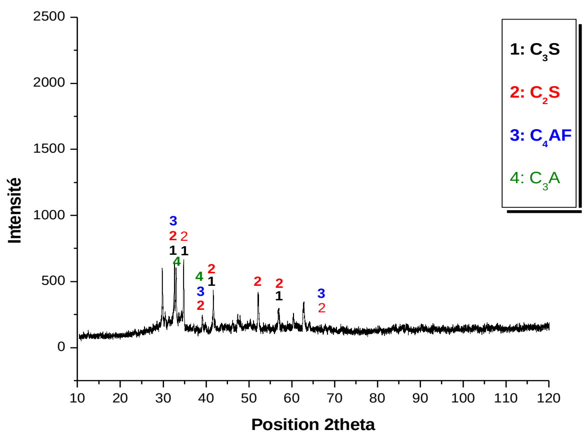


Figure 1: *XRD patterns of the used cement.*

2.1.2. Aggregates

Locally available natural aggregates from the quarry of ENOF Setif, Algeria; a natural sand with the size of 0/4 mm, and two crushed stone aggregates having sizes of 8/15mm and 15/25 mm are used for the manufacture of

concretes. The chemical composition and physical properties of aggregates 0/4, 8/15 and 15/25 mm are given in Tables 2 and 3. The X-ray diffraction pattern of the crushed sand 0/4 is shown in Figure 2 below.
On the other hand, for the manufacture of mortars, standard sand is used NF EN 196-1.

2.1.3. Foundry sand

The foundry sand used in this study is a by-product of the BCR foundry industry in Ain el Kebira Setif, Algeria, and its characteristics are summarized in tables 2 and 3. As shown on Figure.3, the foundry sand is mainly composed by quartz besides calcite as auxiliary mineral; this indicates that the sand has a siliceous nature. However, the fraction 0/2 of the foundry sand is cleaner than that of the crushed sand 0/4, the MB <1 so it is a non-clayey sand.

Table 2: *Chemical composition of crushed, standard and foundry sands*

Constituents (%)	Sand 0/4	Standard sand	Foundry sand
$CaCO_3$	93.00	-	03.00
SiO_2	03.00	97.22	90.00
Cl	00.00	-	00.00
SO_4^{2-}	00.00	-	00.00
Al_2O_3	-	nd	07.00
Fe_2O_3	-	nd	-
CaO	-	01.34	-
MgO	-	nd	-
Na_2O	-	nd	-

Table 3: *Results of physical properties of aggregates*

Physical characteristics	Sand 0/4	Aggregate 8/15	Aggregate 15/25	Foundry sand
Density ρ_p (NF P 18-554) (g/cm$^{3)}$	1.58	1.42	1.40	1.44
Density ρ_s (NF P 18-555) (g/cm$^{3)}$	2.62	2.69	2.70	2.20
Porosity	0.39	0.47	0.48	0.34
Content of impurities (NF P 18-598, NF P 18-591) (%)	ES = 60	0.78	0.34	ES=78
Module of finesse	3.47	-	-	1.93
MDE (NF P 18-572) (%)	-	13	15	-
LA (NF P 18-573) (%)	-	25	25	-

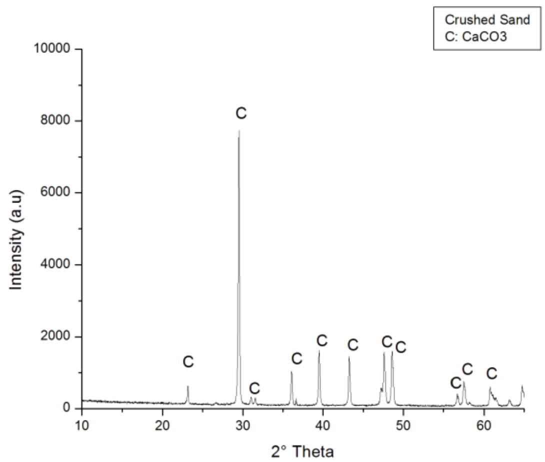


Figure 2: *XRD patterns of the crushed sand 0/4.*

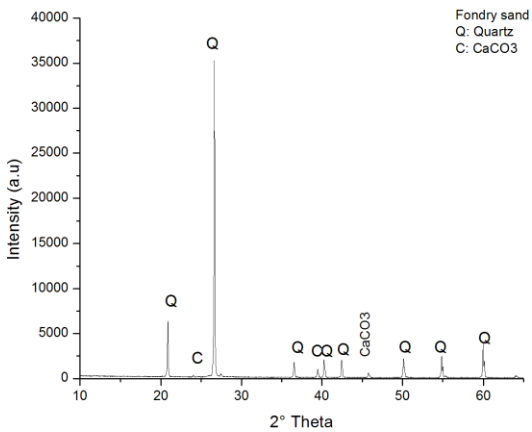


Figure 3: *XRD patterns of the foundry sand.*

2.1.4. Water

The water used is the drinking water of the city of Bejaia, so it does not require any test. It complies with the requirements of the standard (NF EN 1008).

2.2. *Specimen preparation*

Five (05) different mortar and concrete mixtures were prepared to compare the effect of foundry sand as a crushed sand (of quarry) replacement material. The first was the control, without foundry sand, and the four (04) other mortar and concrete mixtures were made by replacing crushed sand with 25%, 50%, 75% and 100% foundry sand by mass.

2.2.1. Mortar

The preparation of formulations of mortar is based on the NF EN 196-1 standard [30-32]. The formulation is given for five (05) sets of three (03) prismatic test pieces of (4 x 4 x 16 cm) for mechanical testing at 28 days its dosage is shown in Table .4 follows:

Table 4: *Compositions of fresh mortars.*

Sample	Foundry sand (%)	Foundry sand (gr)	Crushed sand (gr)	Cement (gr)	Water (gr)	W/C
M 00%	00	00.00	1350.00	450	225	0.5
M 25%	25	337.50	1012.50	450	225	0.5
M 50%	50	675.00	675.00	450	225	0.5
M 75%	75	1012.50	337.50	450	225	0.5
M 100%	100	1350.00	00.00	450	225	0.5

2.2.2. Concrete

The prepared concretes are manufactured according to standard NF-P-18-400; they are 16x32 cm cylinder specimens. The formulation method used in this study is that of DREUX GORISSE (Figure .4.) [33]. Three (03) concrete cylinders are manufactured for each series; the different mixtures obtained are indicated in the Table .5.

Table 5: *Proportions of fresh concretes.*

Specimen	Foundry sand (%)	Foundry sand (Kg)	Crushed sand 0/4 (Kg)	Cement (Kg)	Water (Kg)	Gravel 8/15 (Kg)	Gravel 15/25 (Kg)
C 00%	00	00.00	18.359	8.75	4.375	14.59	12.74
C 25%	25	04.589	13.77	8.75	4.375	14.59	12.74
C 50%	50	09.179	9.179	8.75	4.375	14.59	12.74
C 75%	75	13.77	4.589	8.75	4.375	14.59	12.74
C 100%	100	18.359	00.00	8.75	4.375	14.59	12.74

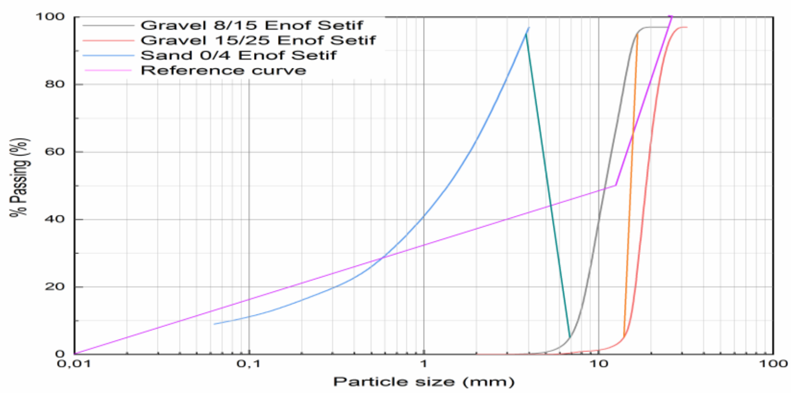


Figure 4: *Curve of mixture of concrete according to Dreux-Gorisse method.*

2.3. *Test Methods*

The different tests performed on the concrete and mortar samples made are:

2.3.1. Compressive strength and flexural strength of mortar
The EN 196-1 standard describes in detail the procedure for this test; it's about defining the qualities of resistance.

Figure 5: *Conservation of concrete specimens.*

2.3.2. Shrinkage of mortar specimens
The shrinkage is defined in accordance with standard NF P 15-433. In this work, the evaluation of the shrinkage was carried out by taking the average of three identical test pieces for each mixture according to a well-defined schedule, namely: 3, 7, 14, 21, 28, 60 and 90 days.

2.3.3. Compressive strength test of concrete
The compression test is carried out according to standard NF P 18-406, the studied test piece is subjected to an increasing load until rupture.

2.3.4. Durability tests
*The durability of concretes is determined on (*4 x4 x 4 cm^3) mortar cubes and on (6.3 cm in diameter and 2 cm thickness) concrete discs. The samples are subjected to chemical attack: external sulfate attack (5% Na_2SO_4) [34-36] and acid etching (5% HCl), according to ASTM C 1012-96 and ASTM C 267-96, respectively.
The notion of durability of concretes is tested by external sulfate attack, because of that the Algerian environment is potentially conducive to development of this pathology like building on land very wet gypsum during the winter [37], on the other hand, the chloride ion present in the concrete can have harmful affect on concrete as well as on the reinforcement [21].

3. Results and discussions

3.1. Compressive strength and flexural strength of mortar
Flexural and compressive strength are presented in Figure.6.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.

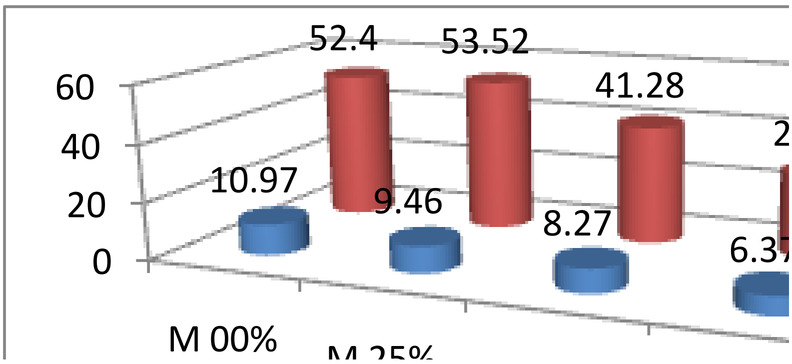


Figure 6: *Effect of foundry sand on the flexural and compressive strength of mortars at 28 days.*

From the histogram, it is shown that the compressive strength and traction by inflexion at the age of 28 days decreases progressively increasing the percentage of foundry sand, but, those of the mortars with 25 wt% foundry sand are good and better resistances. The reduction in strength is due to the lowering of the fineness rate obtained in the foundry sand which makes mortar less compact and therefore less resistant.

3.2. 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, a contraction (shrinkage) occurs automatically. Results introduced above show a behavior of shrinkage of test specimens at different ages of measure (1 day, 3 days, 7 days, 14 days, 21 days, 28 days, 60 days and 90 days), and in different percentages of foundry sand (00 wt %, 25 wt %, 50 wt %, 75 wt% and 100 wt %).

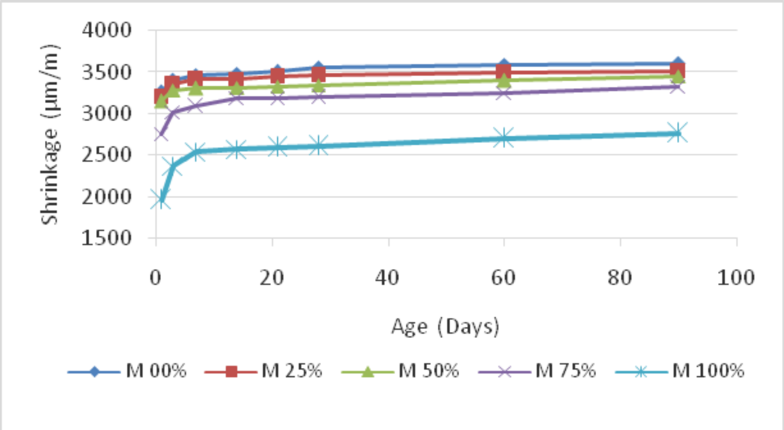


Figure 7: *Evolution of the shrinking of the mortars in function times.*

From the plotted curves (figure 7), it is clear that the shrinkage in the mortars decreases with the increase in the dosage of the foundry sand, and this amounts to the quality of this sand which contains few of the fine element sand fewer voids; therefore reduced shrinkage. However, we note that the shrinkage evolves according to time by evaporation of the water imprisoned in the mortars. The shrinking of the mortar witnesses remains the most important.

3.3. Compressive strength test of concrete specimens

The compressive strength is an essential characteristic and fundamental parameter in our study.

The compressive strength of concrete specimens prepared with and without foundry sand was determined at the age of 28 days. It is found that the optimum compressive strength of concrete is reached at 25% of the foundry sand (figure .8.). From this percentage, a decrease in resistance is clearly noted as a function of the increase in the percentage of foundry sand, this reduction of resistance is due to the reduction of the rate of the fine fraction obtained in the foundry sand which makes the mortar less compact and therefore less resistant as reported in [38-41] and as was shown by P.R. de Matos and al [42].

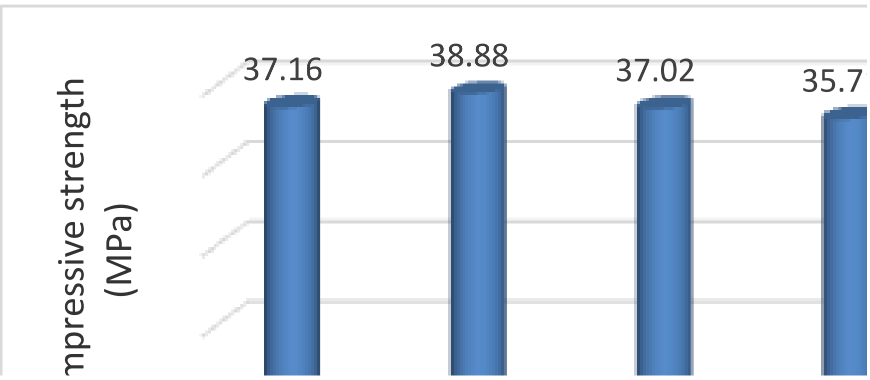


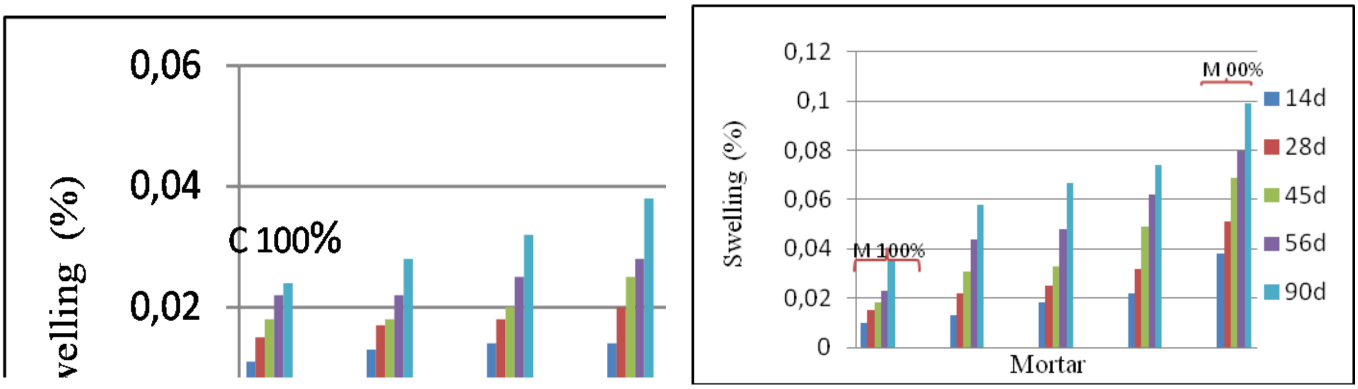
Figure 8: *Compressive strength of concrete at 28 days*

3.4. Durability

3.4.1. Resistance to Sulfate Attack Tests

Concrete and mortar samples were cured in water for 28 days at 20 °C ±2°C before being subjected to a sulfate attack. Mass variation and compressive strength were evaluated in these tests.

The degree of damage of the tested samples is evaluated by a visual check of the cracks, and a diagnosis of the degradation. Sulfate attack clearly has an influence (deterioration) on mortars and concretes. It is noticed that mortars are more prone to deteriorate compared to concrete specimens (large expansion of mortars) (Figure .9). And this mainly comes down to the initial composition of these mortars and concretes, as they contain aggregates that slow down the phenomenon of degradation.



a)-concretes b)-mortars

Figure 9: *Evolution of the expansion*

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 sulfate solution up to 90 days. This behavior is attributed to the formation of gypsum and secondary ettringite following the reaction between the hydrates and particularly the portlandite and sulfates of the solution. Sulfates cause swellings by reaction with tricalcium aluminate [43], which generally increases the rate of concrete degradation [44].

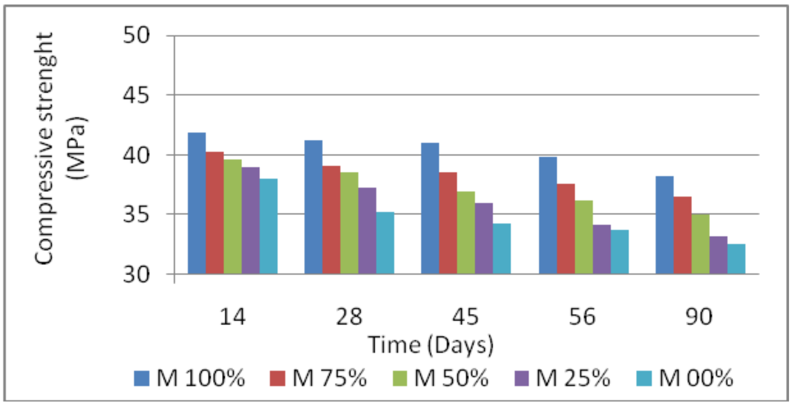
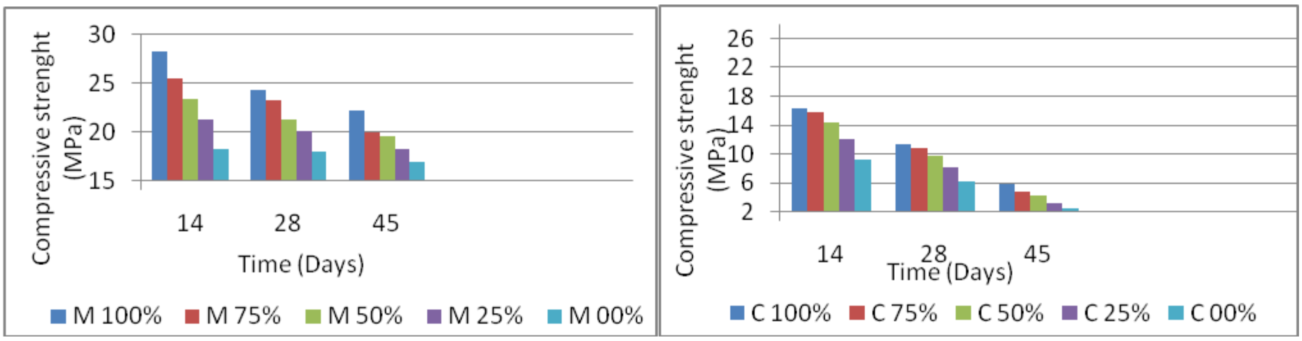


Figure10: *Compressive strength of mortars kept in a sulfated environment.*

The variation of the compressive strength of the mortars immersed in a solution of 5% of Na_2SO_4 up to 90 days was not in the same step of the expansion (Figure .10).The samples lose their resistance; this is due to their relatively high expansion. For the M 100% samples, the resistances are slightly better compared to other samples. Hence, this resistance tends to decrease as a function of the reduction of the foundry sand. Addition of foundry sand had no negative effect on the resistance of mortar and concrete against sulfate attack; as it has been reported by B. Bhardwaj and P. Kumar [21].

3.4.2. Resistance to acid attack

After demolding the test pieces, they are stored for 28 days in water at a temperature of 20 °C ± 2 °C. The samples were weighed, before being placed in the attack solution; the attack solution is renewed according to the pH value.



a)- Mortars b)- Concretes

Figure 11: *Compressive strength of mortars kept in acid environment*

According to the study of R. Siddique and al [45], the ability of concrete to resist the penetration of chloride ions is a critical parameter in determining the service life of steel-reinforced concrete structures exposed to deicing salts or marine environments. The properties of concrete have been well documented; however, no documentation of foundry sand as replacement of fine aggregates in concrete mixes is available.

Figure .11.shows the results of the compressive strength of mortars preserved in acid environment, in terms of mass losses, mortar performance is better than that of concrete, because the attack in concrete is faster than that of mortars, this is due to limestone sand and gravel. Since concrete is an alkaline medium, it is very susceptible to acid attack. Generally, chemical reactions concern two elements, which are mainly: calcium hydroxide (Ca $(OH)_2$) in the cement paste and limestone CaCO3 in the aggregates, according to the following equations:

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

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

After 45 days of attack, the samples are too damaged and continuity of measurement is not possible.

Conclusion

This paper contributes to the reuse of foundry sand (considered as an industrial waste) in building materials as concrete and mortar. The main conclusions that can be drawn from this investigation are:

1. The reuse of 25% of foundry sand which gives better mechanical resistance of mortar and concrete compared to the reference (without foundry sand addition).
2. Replacement of more than 25% of ordinary sand with foundry sand decreases the compressive strength of concretes and mortars.
3. The reuse of foundry sand has a positive effect on shrinkage, since it decreases as the foundry sand amount increases.
4. Foundry sand plays a positive role in the handling of concrete, as its use makes concrete more fluid (more manageable). Thus, increasing the foundry sand amount leads to crease in workability of concrete which is attributed to the finer particles of the foundry sand.
5. The results on acid and sulfate attacks have shown good durability for concretes and mortars made with foundry sand.

Hence, foundry sand of BCR factory (Ain El Kebira, Setif. Algeria), could be reused with 25 % ratio in mortars and concretes

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