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Effect of partial and total replacement of siliceous river sand with limestone crushed sand on the durability of mortars exposed to chemical solutions

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HIGHLIGHTS

- Effect of replacement of silica sand by limestone sand on the durability of mortar.
- With limestone sand, the mechanical strength is better whatever the environment.
- In lime, we recorded gains in mass and in strength while in acid we recorded loses.
- The lime is a non-aggressive environment; whereas the hydrochloric acid is aggressive.
- The resistance to HCl-acid of mortar based on limestone sand is better (compared to silica sand).

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ABSTRACT

This study presents a part of different works carried out on a context of local materials valorization and industrial wastes reuse. The main objective of this investigation is to substitute silica river sand (M'zi river) by crushed limestone sand (residues quarries) in the mortar, so as to valorize the crushed limestone sands that are found (in waste form) in large quantities in the region of Laghouat (Algeria), to protect the environment against this waste and to unlock the local construction projects, especially after the ban on local sand extraction from river for environmental reasons. Indeed, the aim of this work is to study the effect of this replacement on the durability of mortar exposed to different chemical environments. In fact, we have to study the behavior of the obtained mortars into three different environments: in open air, in a solution containing lime and in another one containing hydrochloric acid (HCl). For replacement 0%, 50% and 100%, the results showed that, compared to open air environment, conservation in a lime solution has a positive effect on the durability of mortars. In fact, it furthermore improves their physical and mechanical properties such as the mechanical strength, the dimensional variations, etc. In addition, and compared to silica sand, it has been noted that these properties were much higher in the presence of crushed limestone sand in mortar. Concerning the HCl-solution, it has been recorded a negative effect on the durability of mortars. But, it should be noted that this effect was considerably reduced in the presence of crushed limestone sand in the materials. Finally, with introduction of limestone sand in mortar, the improvements were higher: decrease in the permeability, reduction in the mass and strength losses, reduce in the phenomenon of capillary rise and less attack by acid.

1. Introduction

Mortar is one of the constituents of the anisotropic masonry material. In spite of this, mortar has been often neglected in terms of structural analysis of masonry structures, it is well known that it influences the final behavior of masonry such as compressive and bond strengths, and deformability [1]. Besides, durability of mortar has an important role on the construction process of masonry structures. It may be considered as one of the most important properties because it influences directly the brick layer's work in the long term. Indeed, the corrosion of cementitious composite due to their exposure to harmful chemicals that may be found in nature, such as in some ground waters, industrial effluents, acid rain, acid mist, and seawater is one of the main causes for deterioration in buildings structural elements [2]. Among the most aggressive chemicals that can affect the durability of concrete and mortar structures, we find the sulfates and chlorides. The damage mechanism and retained strength of concrete structures in chemical environment therefore have drawn increasing

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attention from material scientists and structural engineers [2–9]. Therefore, mortar, which is generally composed of a mixture of cement, sand and water, is required to have enough resistance to different aggressive agents to survive for long.

Moreover, the majority of buildings in many regions are made with alluvial sand. In the city of Laghouat (Algeria) it is the same case, almost all buildings are made of alluvial sand which is extracted from M'zi river (river passing through the city of Laghouat). However, the extraction of river sands in an uncontrolled and abusive manner is an aggression against the environment and, thus, jeopardizes the entire ecosystem. To better regulate this activity, a new law came in August 2005 to prohibit the extraction of river sands and beaches. Although this ban was reported and then after limited the problem still persists [10]. However, the shortage of sand constituted a disastrous impact on the various projects launched in this period. To overcome, therefore, these needs of sands, generated mainly by banning sand extraction from rivers, officials have proposed various mine sites around the country for the production of crushed sand and they have established the conditions prohibiting extraction of alluvial material from the river beds and river sections that present a risk of degradation as well as the arrangements operating in authorized sites. It should be noted that it is not only Algeria which suffers from this problem, several other countries in Europe and Africa, such as France, Turkey, Morocco, etc. have been passed by and have already developed new strategies for the extraction quarries [11–14]. Moreover, and for environmental reasons, projects have been launched in France, for the use of quarries dusts (fillers purely limestone) in concrete to protect nature [15]. It should be noted that in the perspectives of the next decade, many quarries production should be moved from alluvial exploitation to the exploitation of massive rocks. Elaboration of schemes of quarries exploitation must therefore be the subject of an important reflection. Indeed, limestone aggregates are characterized by good mechanical strength, the possibility of alkali-silica reaction and the decrease in drying shrinkage in concrete [16] and an effort of scientific and technological research is needed to effectively promote the total or partial replacement of the alluvial sand by limestone sand.

It is in this context that opened reflection on the replacement of the alluvial sand (extracted from valley (river), Laghouat region) by crushed limestone sand in the formulation of mortars.

The main purpose of this work is to study the effect of the replacement of silica sand by limestone sand on durability of mortars in three different environments: open air, lime solution and hydrochloric acid solution. According literature, only hydrochloric acid solution is aggressive [2,17].

We have therefore to replace the granular skeleton of siliceous nature and rounded shape by granular skeleton of limestone nature and angular shape, then to study the effect of this new skeleton on the durability of mortars.

Let's note that certain works have been already conducted in this way (sand concrete, limestone concrete, limestone mortar, etc.). The obtained results revealed that different valorized local materials respond well to the requirements of standards and can be used for the elaboration of hydraulic concretes and mortars [18,19]. The material studied in the present paper forms therefore part of the family of the previous studied composites. Indeed, by this sand substitution, we are moved from siliceous mortar to limestone mortar. By definition, limestone mortar is a mortar essentially constituted from aggregates of limestone nature [19].

2. Experiments

Mortar is consisting of a mixture of sand, cement, additives, and water. Besides these basic components, it typically includes one or more admixtures [20]. The various used components introduced during this work are characterized hereafter.

2.1. Sands

Two different sands have been used in this study: the first one is a river sand (RS) (Fig. 1a) from the river M'zi (around the city of Laghouat) and the second one is a crushed sand (CS) (Fig. 1b) brought back from local quarry waste, near the city of Laghouat. Their particle size distributions are shown in Fig. 2. It should be noted that "CS" is a waste of local crushing aggregates that we are going to valorise.

The RS presents a continuous particle size distribution ranging from 0.08 to 5 mm with a fraction of grains smaller than 0.08 mm below 2% (Fig. 2). The CS presents also continuous particle size distribution with a maximum grain diameter of approximately 5 mm but the proportion of grains smaller than 0.08 mm is below 14% (Fig. 2). It should be noted that this proportion of fine grains remains acceptable [21]. In a schematic manner, the particle size distribution of crushed sand is slightly more spread out than that of river sand. In addition, RS grains present rounded shapes (Fig. 1a) while CS grains present an angular shapes. Table 1 lists the set of physical characteristics for the two types of sand. It reveals that the density of CS is slightly higher than RS but the latter is slightly more compact. RS modulus of fineness is 2.45, however the CS fineness modulus is 2.30 which means that CS is slightly finer. The high values of the "RS sand equivalent", which are measured according to NF P 18-598 standard [22], show that RS is clean. While the "CS sand equivalent" is lower (76.46), but it remains above the limit value recommended for concrete and mortar.

EDX analysis of sands demonstrates the essentially siliceous nature of RS and the essentially limestone nature of CS (Fig. 3).

Finally, it should be noted that the basic difference between these two sands lies, therefore, in the nature, in the grain shape and the proportion of fine elements.

2.2. Cement

The used cement is a Portland cement of class 42.5 the denomination of which is "CPA-CEM II/A". The physical characteristics are the following: specific density 3100 kg/m^3 and specific surface area 330 m^2/kg and the chemical analysis are shown in Table 2.

2.3. Admixture

The admixture used is water-reducing plasticiser of SIKA VISCOCRETE 3045. This product is based on modified polycarboxylates. It allows to keep a long rheological maintaining (>1H30). It improves the stability and decreases segregation risks. The recommended proportion is 0.25–2.5% of cement weight according to the desired performances.

2.4. Preparation of specimens and test procedure

2.4.1. Composition

The composition used is that of normal mortar prepared according EN 196-1 standard [23].

The value W/C is fixed at $W/C = 0.5$.

The workability is fixed at (flow time = 5–7 s).

Used concentration of plasticizer: 2–2.5% by weight of cement.

Table 3 presents the different studied compositions.

2.4.2. Elaboration of mortars

For all physico-mechanical characterizations, prismatic specimens of $40 \times 40 \times 160$ mm were used. The material is cast in two layers. Each of the layers is set up by 30 shocks to promote the evacuation of air bubbles and then stitched to promote interlayer adhesion [24].

2.4.3. Curing

After elaboration of mortar, a part of specimens is conserved in open air and another part, which will be subjected to durability tests, is conserved in lime water during 28 days. It should be noted that this environment is considered as non-aggressive, because it is rich in calcium which results from the dissolution of lime in water, so it's an alkaline environment. Hydration reactions must take place in a normal manner, away from any leaching that may be due to acidic environments. In this environment, we chose a mass concentration of 10% [16]. Some authors took it as reference [19]. The considered compositions in this period are C0 (0% limestone +100 silica), C1 (25% limestone +75 silica), C2 (50% limestone +50 silica), C3 (75% limestone +25 silica) and C4 (100% limestone +0 silica).

Then, after 28 days, and during a period of 180 days, the samples are subjected to durability tests by placing them in different environments, A, B and C, as showed in Fig. 4a. Let's note that, according to literature, the last environment is aggressive and provokes an accelerated degradation [25]. In order to accelerate the degradation, the mass concentration of acid is taken equal to 3%. The considered compositions for this period are only C0, C2 et C4, in order to appreciate the case of river sand alone, the case of limestone sand alone and the case of the two sands mixing.