PHYSICO-MECHANICAL PROPERTIES OF MORTAR MADE WITH BINARY NATURAL FINE AGGREGATES (DUNE SAND AND CRUSHED SAND) WITH AND WITHOUT CHEMICAL ADMIXTURE

M. Maza*, A. Naceri and S. Zitouni
Geo-Materials Development Laboratory, Technology Faculty, Civil Engineering Department, M’sila University, Algeria

Received: 4 October 2015; Accepted: 12 December 2015

ABSTRACT

This experimental study investigates the effect of using binary natural fine aggregates (dune sand and crushed sand) on mortar. This method is utilized to modify the particle size distribution of various sands used in mortar. For this investigation, two sands were used: a dune sand (DS) and crushed sand (CS) at different proportions in mortar. The effect of the quality and grain size distribution of natural fine aggregates (DS ad CS) on the physical properties of binary sand confected (apparent or bulk density, absolute or gravity density, porosity, fineness modulus, particle size distribution and water absorption). The properties of fresh and hardened mortar were also analysed. The results obtained showed that the mechanical strength of mortar depends on the nature and particle size distribution of sand studied. This study shows the potential of this method to make mortar with binary sand (dune and crushed fine aggregates) in order to improve the physical properties of sand. The increase in the quantity of mixing water generated by addition of quarry waste was modified by the addition of a superplasticizer or water reducing admixture (Medaflow 30) what led to the improvement of the physical and mechanical properties of the mortar. The inclusion of crushed sand (CS) at replacement levels of 40 % to 50% resulted in a increase in the mechanical strength of the mortar. However, the improved performance was observed when quarry waste as fine aggregate was used in presence of chemical admixture (1% of Medaflow 30).

Keywords: Crushed sand; dune sand; chemical admixture; mortar; physico-mechanical properties.

*E-mail address of the corresponding author: mekkimaza3@gmail.com (M. Maza)
1. INTRODUCTION

The demand for aggregates reflects the development of construction in Algeria. To surmount the demand, it was necessary to ensure a rational exploitation of the industrial waste aggregates available in the country by a valorization of mineral waste such as quarry wastes, blast furnace slag, wastes of bricks, tiles and ceramics wastes. Wastes and industrial by-products are until now rarely used in Algeria: it is thus necessary to use these materials in production of building materials.

In Algeria, natural fine aggregates have been traditionally used in mortars and concrete. However, growing environmental restrictions regarding the exploitation of sand from riverbeds have resulted in a search for alternative materials to produce fine aggregates, particularly near the larger metropolitan areas. Manufactured fine aggregates (crushed quarry sand) then appeared as an attractive alternative to natural fine aggregates (dune sand) for cement mortars and concrete.

Fine aggregates are inert granular materials used in the production of mortars and concretes. For a good mortar mix, fine aggregates need to be clean, hard, strong and free of absorbed chemicals and other fine materials that could cause the deterioration of mortar. Unfortunately, the majority of the natural sands used (rolled sands: sand of river, dune sand and sand of sea) are selected for reasons of the price and the availability [1-4]. Properties of sand affect the durability and performance of mortar. As fine aggregate are essential component of cement mortar. The shape and texture of crushed sand particles could lead to improvements in the strength of concrete due to better interlocking between particles [5,6].

Aggregates have a significant influence on both rheological and mechanical properties of mortars and concretes. Their specific gravity, particle size distribution and surface texture influence markedly the properties of mortars and concrete in the fresh state. On the other hand, the mineralogical composition, toughness and degree of alteration of aggregates are generally found to affect the properties of mortars and concrete in the hardened state [7-10].

The importance of using the type and quality of fine and coarse aggregates cannot be overemphasized. The fine and coarse aggregates generally occupy 60% to 75% of the concrete volume (70% to 85% by mass) and strongly influence the concrete’s freshly mixed and hardened properties, mixture proportions, and economy. Fine aggregates generally consist of natural sand or crushed stone with most particles smaller than 5 mm.

Aggregates quality strongly influences properties of fresh and hardened mortar and economy. Consequently, selection of aggregates is an important process. Although some variation in aggregate properties is expected, characteristics that are considered when selecting aggregate include: particle shape, surface texture, abrasion, unit weights, voids, absorption and surface moisture [11-14].

The present paper analyzes the performance of manufactured fine aggregates obtained from different quarries and containing different amounts of microfines in mortars, comparing them to natural fine aggregates. These mortars are analyzed in both fresh and hardened states. The use of waste quarry aggregate in construction can be useful for environmental protection and economical terms.

The granulometric composition is an important indicator of the physical properties and structure of a natural or manufactured aggregate.
The Algerian mineral waste industry produces high levels of waste which remains unused. Mineral waste (quarry sand, blast furnace slag and waste bricks) represents residue that could be used with minimal processing, largely as construction material, low value industrial mineral.

The use of the industrial solid wastes such as the quarry sand makes it possible to increase the manufacture of building materials, to limit the use of natural aggregates and to value the waste products offering valuable solution of the protection of the environmental [15-17].

In order to investigate the possibility of using crushed sand as fine aggregate in mortar, it was first necessary to investigate the physical properties of the aggregates themselves, as these properties will affect the properties of fresh and hardened mortar. The main fine aggregate properties influencing the mortar properties are: grading, strength, relative density, porosity and surface texture.

The Algerian quarry waste has many environmental problems (mineral wastes) as well as economic considerations. By using crushed sand as a partial replacement of natural fine aggregate in mortar or concrete is very beneficially. Two different types of fine aggregates (crushed and dune sands) were used in this investigation.

The present study has been attempted to evaluate the characteristics of cement mortar using quarry waste as fine aggregate and its compare with dune sand.

The objectives of this study are to investigate the effect of use of crushed sand as partial replacement of dune sand in various percentages (0%, 30%, 40%, 50%, 60% and 70%), on mortar properties such as compressive, flexural and tensile strengths, workability etc. and also the determine the optimum dosage of crushed fine aggregates in mortar having maximum compressive strength.

The main goals of this experimental work were to investigate the followings:
- The possibility of reusing quarry waste in mortar mixes as a partial replacement of fine aggregates in order to reduce the environment impact resulting from industrial waste disposal.
- The impact of solid wastes (crushed sand) on the physical properties of binary sand prepared (i.e., density, porosity, fineness modulus, particle size distribution and water absorption) and mechanical response (i.e., flexural, tensile and compressive strengths) of the mortars made with binary sand mixtures.

2. RESEARCH MATERIALS AND METHODOLOGY

The objectives of this study are to investigate the effect of use of quarry waste fine aggregates (crushed sand) as partial replacement of natural fine aggregates (dune sand) in various percentages (0%, 30%, 40%, 50%, 60% and 70%), on mortar properties such as compressive, tensile and flexural strengths, workability, etc. and also the determine the optimum dosage of crushed sand mortar having maximum mechanical strength. Apart from characterizing the properties of crushed stone sand, tests were performed on the mortars using crushed stone sand as well as natural dune sand.
2.1 Materials
The mortar mixtures were prepared at the laboratory of the Civil Engineering Department, Msila University (Algeria), using the following materials:

2.1.1 Dune sand (natural fine aggregate)
The natural fine aggregates used were dune sand with particles ranging from 0.08 mm to 3 mm in size. The fineness modulus, $M_f$, was calculated as 1.77. This natural sand was taken from Boussâada, Algeria. The absolute density and porosity were 2.61 g/cm$^3$ and 42%, respectively. The physical characteristics is summarized in Table 1.

The mineralogical composition (mineral phases) of the dune sand was investigated by the X-ray diffraction (XRD). Mineralogy was determined by X-ray diffraction (XRD) analysis using a diffractometer. The crystalline mineral phases identified for the dune sand (Fig. 1) is mainly composed of quartz ($\text{SiO}_2$), calcite ($\text{CaCO}_3$) and anorthite ($\text{CaSi}_2\text{Al}_2\text{O}_8$). It has a small but evident band ranging from 20° and 30°, indicating the presence of amorphous materials. Silicate and lime are predominant in terms of chemical composition (Table 2) that also indicates the presence of alumina, iron and magnesia in small quantities. The chemical composition is shown in Table 2.

![Figure 1. XRD of dune sand](image)

2.1.2 Crushed fine aggregate (quarry waste)
Crushed quarry waste (limestone sand) is obtained as a by-product during the production of aggregates through the crushing process of rocks in rubble crusher units. In this study the manufactured fine aggregate used is crushed sand generated by the quarry waste. The effect of quarry waste (angular crushed sand) replacement by normal weight dune sand (0%, 30%, 40%, 50%, 60% and 70% by volume) was investigated. The absolute density and porosity of crushed sand were 2.67 g/cm$^3$ and 44%, respectively.

Samples of the natural fine aggregates (crushed sand and dune sand) utilized in this study are shown in Figs. 2 and 3. The particle size distribution of the natural aggregate (siliceous dune sand) and quarry waste fine aggregate (calcareous crushed sand) used was determined using dry sieve analysis method. The granulometric composition is an important indicator of
the physical properties and structure of a fine aggregates used is this study. The grading and grading limits are usually expressed as the percentage of material passing each sieve.

There are several reasons for specifying grading limits and nominal maximum aggregate size; they affect relative aggregate proportions as well as cement and water requirements, workability, economy, porosity, shrinkage, and durability of mortar and concrete. Variations in grading can seriously affect the uniformity of mortar and concrete from batch to batch. Very fine sands are often uneconomical; very coarse sands can produce harsh, unworkable mixtures. In general, aggregates that do not have a large deficiency or excess of any size and give a smooth grading curve will produce the most satisfactory results.

The grain size distribution of natural aggregate (dune sand) and quarry waste fine aggregate (crushed sand) used is presented in Fig. 4 their physical properties and chemical compositions are summarized in Tables 1 and 2. The sieve analysis was obtained according to AFNOR standard NE EN 933-1. From the sieve analysis result, the studied samples of the two fines aggregates used (DS and CS) is out of limits of the fine sized-sand particles, fine upper limit (F.U.L.) and fine lower limit (F.L.L.). It needs slightly coarse particles to achieve the limits of the dune sand and fine particles of the crushed sand.

Based on the analysis of the results obtained concerning the physical properties of natural and artificial sands (Table 1):

- DS has a low porosity and a significant water absorption compared to the crushed sand, this is primarily with its fine particles (low fineness modulus).
- CS has a high porosity and water absorption compared to the dune sand, this may be attributed to its coarse particles (coarse fineness modulus).

According to particle size distribution and fineness modulus, the sands used in the study can be categorized as follows:

- The dune sand presents a fine particle size distribution,
- The crushed sand presents a coarse particle size distribution.

<table>
<thead>
<tr>
<th>Physical properties</th>
<th>DS</th>
<th>CS</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fineness modulus</td>
<td>1.77</td>
<td>3.16</td>
</tr>
<tr>
<td>Absolute density (g/cm³)</td>
<td>2.61</td>
<td>2.67</td>
</tr>
<tr>
<td>Apparent density (g/cm³)</td>
<td>1.52</td>
<td>1.49</td>
</tr>
<tr>
<td>Porosity (%)</td>
<td>42</td>
<td>44</td>
</tr>
<tr>
<td>Water absorption (%)</td>
<td>1.23</td>
<td>1.25</td>
</tr>
</tbody>
</table>

DS: dune sand and CS: crushed sand.
Table 2: Chemical composition (% by weight) of fine aggregates (crushed sand and dune sand) used

<table>
<thead>
<tr>
<th>Compounds</th>
<th>% (by weight)</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>CS</td>
<td>DS</td>
</tr>
<tr>
<td>Lime</td>
<td>51.43</td>
<td>02.94</td>
</tr>
<tr>
<td>Silica</td>
<td>03.31</td>
<td>88.25</td>
</tr>
<tr>
<td>Alumina</td>
<td>01.17</td>
<td>00.71</td>
</tr>
<tr>
<td>Iron oxide</td>
<td>01.09</td>
<td>00.96</td>
</tr>
<tr>
<td>Potassium oxide</td>
<td>00.09</td>
<td>00.30</td>
</tr>
<tr>
<td>Sodium oxide</td>
<td>00.01</td>
<td>00.01</td>
</tr>
<tr>
<td>Sulfite</td>
<td>00.55</td>
<td>00.08</td>
</tr>
<tr>
<td>Magnesia</td>
<td>00.91</td>
<td>00.17</td>
</tr>
</tbody>
</table>
Figure 4. Particle size distribution curve of the crushed and dune sands studied

2.1.3 Cements
The Portland cement type CEM II/A 42.5 from Hammam Dalâa local factory was used in this experimental study. The absolute density, bulk density and porosity were 3.1 g/cm³, 1.9 g/cm³ and 41.93%, respectively. The Blaine specific surface area (fineness) was 3800 cm²/g. The finenesses (specific surface area) of the cement studied was determined by Air Permeability Apparatus and the chemical composition have been determined by the testing method “X-ray Fluorescence Spectrometry (XRF)“. Chemical and mineralogical compositions of the cement used is shown in Table 3.

Table 3: Chemical analysis of the cement and the Bogue composition

<table>
<thead>
<tr>
<th></th>
<th>SiO₂</th>
<th>Al₂O₃</th>
<th>Fe₂O₃</th>
<th>CaO</th>
<th>MgO</th>
<th>SO₃</th>
<th>C₃S</th>
<th>C₂S</th>
<th>C₃A</th>
<th>C₄AF</th>
</tr>
</thead>
<tbody>
<tr>
<td>Value</td>
<td>22.10</td>
<td>04.57</td>
<td>03.95</td>
<td>66.34</td>
<td>01.60</td>
<td>00.54</td>
<td>65.70</td>
<td>16.85</td>
<td>5.42</td>
<td>12.03</td>
</tr>
</tbody>
</table>

2.1.4 Chemical admixture (superplasticizer or water reducing admixture)
In order to check the workability of the mortar it was used superplasticiser high reducer water manufactured by the company of Algerian Granitex marketed under the name of Medaflow30. Its normal use scale is fixed by the manufacturer’s recommendation of 0.5 to 2% of the cement weight. The percentage of the chemical admixture used was 1% by weight of cement for all mixes. The properties of the chemical admixture are represented in Table 4.

Table 4: Characteristics of the chemical admixture (superplasticiser)

<table>
<thead>
<tr>
<th>Superplasticiser</th>
<th>Color</th>
<th>Density</th>
<th>Form</th>
<th>PH</th>
<th>Dry extract</th>
</tr>
</thead>
<tbody>
<tr>
<td>Medaflow30</td>
<td>Yellowish</td>
<td>1.07</td>
<td>Liquid</td>
<td>6.0–6.5</td>
<td>30</td>
</tr>
</tbody>
</table>

2.1.5 Mixing water
Water is an important ingredient of Mortar as it actually participates in the chemical reaction
with cement. Since it helps to form the strength giving cement gel, the quantity and quality of water is required to be looked into very carefully. Potable tap water was used for mortar mixing all through the study and contains none harmful impurity.

2.2 Binary sand mixtures
The natural and manufactured fine aggregates used in this study were DS (dune sand) and CS (crushed sand). Five series of binary fine aggregate mixtures and one reference control mixture (100% DS) were prepared. The characteristics of binary sand mixtures are given in Table 5 and designated as: M₀ (0%CS + 100%DS), M₃₀ (30%CS + 70%DS), M₄₀ (40%CS+60%DS), M₅₀ (50%CS + 50%DS), M₆₀ (60%CS + 40%DS) and M₇₀ (70%CS + 30%DS). The sieve analysis of binary sand mixtures is shown in Fig.5 and their physical properties are summarized in Table 6.

<table>
<thead>
<tr>
<th>Mix notation M(CS/DS)</th>
<th>CS</th>
<th>DS</th>
</tr>
</thead>
<tbody>
<tr>
<td>M₀</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>M₃₀</td>
<td>30</td>
<td>70</td>
</tr>
<tr>
<td>M₄₀</td>
<td>40</td>
<td>60</td>
</tr>
<tr>
<td>M₅₀</td>
<td>50</td>
<td>50</td>
</tr>
<tr>
<td>M₆₀</td>
<td>60</td>
<td>40</td>
</tr>
<tr>
<td>M₇₀</td>
<td>70</td>
<td>30</td>
</tr>
</tbody>
</table>

The method to blend natural and manufactured sands (dune sand and crushed sand) improves the physical properties of prepared fine aggregate mix (Table 6):
✓ An improvement of porosity of the binary mixture (crushed and dune sands) using 30%, 40% and 50% of crushed sand combined.
✓ An improvement of the grading (grain size distribution) of the ternary sand prepared, this in order to correct the variation of the granulometric composition (particle sizes) of various sands used.

Water absorption capacity was determined from the decrease in weight of the specimens saturated by water and then dried at 105°C to constant weight. The results are expressed in weight percent (wt.%). Porosity was calculated from the absolute density and bulk density values using the formula:

\[ P(\%) = (1 - \frac{\rho}{\gamma}) \times 100 \]  

where \( P \) is the porosity as the content of pores and voids in the specimens (wt.%), \( \gamma \) is the absolute density (g/cm³) and \( \rho \) is the bulk gravity (g/cm³).

2.3 Tests
The following fresh and hardened properties of mortar were selected for testing:
  Slump test (Properties of fresh mortar).
Testing of dry density (Hardened mortar).
Testing of compressive, flexural and tensile strengths (Hardened mortar) at age 7, 14 and 28 days.

Table 6: Physical properties of the mixed fine aggregates (crushed and dune sands)

<table>
<thead>
<tr>
<th>Physical properties</th>
<th>$M_0$</th>
<th>$M_{30}$</th>
<th>$M_{40}$</th>
<th>$M_{50}$</th>
<th>$M_{60}$</th>
<th>$M_{70}$</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fineness modulus</td>
<td>1.77</td>
<td>2.59</td>
<td>2.59</td>
<td>2.75</td>
<td>2.91</td>
<td>3.02</td>
</tr>
<tr>
<td>Absolute density (g/cm³)</td>
<td>2.61</td>
<td>2.62</td>
<td>2.62</td>
<td>2.65</td>
<td>2.64</td>
<td>2.65</td>
</tr>
<tr>
<td>Apparent density (g/cm³)</td>
<td>1.52</td>
<td>1.60</td>
<td>1.59</td>
<td>1.56</td>
<td>1.53</td>
<td>1.50</td>
</tr>
<tr>
<td>Porosity (%)</td>
<td>42</td>
<td>39</td>
<td>39</td>
<td>41</td>
<td>42</td>
<td>43</td>
</tr>
<tr>
<td>Water absorption (%)</td>
<td>1.236</td>
<td>1.238</td>
<td>1.246</td>
<td>1.241</td>
<td>1.245</td>
<td>1.249</td>
</tr>
</tbody>
</table>

Figure 5. Grain size distribution (dry sieves analysis) of the mixed sand

2.4 Slump test (Properties of fresh mortar)
The slump test is a method of testing the workability of the fresh mortar. A standard metal slump cone is to be filled with 4 layers of mortar, each layer is to be thoroughly compacted with a steel rod. The last layer which fills the cone to the top is to be trowelled flat. The cone is then removed and the height reduction (slump) of the mortar is measured. The slump test is used for evaluation of rheological behavior of a mixture. The slump were fixed between 4 and 6 cm for all mixes in this study. Workability is a property of fresh mortar and it is measured by the slump test and is described as a measure consistency.

2.5 Mechanical tests
The mortars samples were subjected to flexural, tensile and compressive mechanical tests. Mechanical strength was determined at 7, 14 and 28 days on $4 \times 4 \times 16$ cm prisms specimens with 0.5 water-cement (W/C) ratio and 1:3 cement/sand by mass. The composition used is that of normal mortar prepared according EN 196-1 standard [15]. The value W/C is fixed at W/C = 0.5. The water used in this study was a potable drinking water.
After production of mortars, the moulded specimens were covered with a plastic sheets at 20 ± 2 °C for 24 ± 1 h. After 24 h the specimens were demolded and cured in water at 20 ± 2 °C until testing. The results reported in this paper are the mean values obtained. Table 5 shows the composition of the mortar mixtures produced and tested. M₀ is the corresponding control mortar made only with 100% of dune sand (control sample). M₃₀, M₄₀, M₅₀, M₆₀ and M₇₀ are the mortars made with a binary sand containing DS and CS.

The aim of this study is two-fold. One is to investigate the physical properties and chemical compositions of natural and quarry waste fine aggregates (100% DS and 100% CS) by the use of solid waste aggregate, which will provide the advantage of reducing of natural fine aggregate (dune sand). The second is to analyze the physical properties of binary sand mixture prepared (e.g. apparent or bulk density, absolute or gravity density, porosity, fineness modulus, particle size distribution and water absorption) and mechanical response (flexural, tensile and compressive strengths) of the mortars made with binary sand.

3. RESULTS AND DISCUSSION

3.1. Physical properties
3.1.1. Effect of crushed sand on the water cement ratio
The results of the variation of water cement ratio for various percentages of crushed sand of fresh mortar are presented in Fig.6. The mortar mixture without admixture has a high water-cement ratio. The mortar made with binary sand (natural and manufactured fine aggregates) presents a high water-cement ratio in comparison with the control mortar (M₀). The difference observed between the water-cement ratio of various mortars tested, depends of the content of the crushed fine aggregates (crushed sand) incorporated in the natural fine aggregate (difference of the density and the porosity between the different fine aggregates studied). The Substituted crushed fine aggregates presents a high porosity compared to the natural fine aggregate (dune fine aggregate), this is mainly due at the variation of the physical properties for each type of fine aggregate. The test results show that water cement ratio and water absorption values of crushed sand mortar mixtures decreased with the increase in level of fine aggregate replacement by crushed sand.

The Fig. 6 shows that increasing the percentage of crushed sand for all mortars studied is generated by an increase in the mixing amount of water. This is due primarily to cohesion force between the particles of angular shape of the sand and the presence of fines (high water absorption) that contains the crushed sand, this increase exceeds 8% for the mortar without chemical admixture, it reaches 3% for the mortar with adjuvant. The incorporation of water-reducing admixture (1% of Medaflow30) allows a significant reduction of mixing water for all mortars despite the high percentages of crushed sand used. This reduction even reaches and exceeds 27% for the chemical admixture allows defloculating fine particles of cement, which allows an increase in the compactness (geometric effect), lubricates the solid surfaces by reducing friction stress between particles (mechanical effect). Hence, it is concluded that increasing the use of a high percentage of crushed sand leads to an increase of the mixing water, but the incorporation of water-reducing admixture (1% of Medaflow30) allows to reduce significantly the increase of the mortar mixing water.
3.1.2 Effect of crushed sand on the density

The density tests for binary sand mortar mixture are shown in Fig. 7. The density at 28 days decreases with increasing the quarry waste fine aggregate (crushed sand) in mortar mixture. The use of crushed fine aggregate for each curing age reduced the densities of all mixtures with increasing the quarry waste fine aggregate, because the variation of density and water absorption of waste fine aggregate (WFA) is higher than that of natural sand (DS). The incorporation of water-reducing admixture (1% of Medaflow 30) allows the improvement of the dry density that is mainly due to the water reduction then the mortar becomes more compact. The dry density of hardened mortar as follow:

\[ \rho (Kg/l) = \frac{M}{V} \quad (2) \]

where, \( M \), weight of specimen (Kg); \( V \), volume of specimen (l).

On the other hand, the difference in the density of mortar mixes are mainly due to the difference in specific gravity of the used fine aggregates (crushed sand). Consequently, the density of crushed sand is higher than that of dune sand.

3.1.3 Effect of crushed sand on the water absorption

The 40 mm x 40 mm x 160 mm size prism after casting were immersed in water for 28 days curing. These specimens were then oven dried for 24 hours at the temperature 105°C ± 3 until the mass became constant and again weighed. This weight was noted as the dry weight (\( W_1 \)) of the specimen. After that the specimen was kept in water at 105°C ± 3 for 24 hours. Then this weight was noted as the wet weight (\( W_2 \)) of the specimen. The water absorption (\( W_{\text{abs}} \)) is calculated from the following equation:
The variation of water absorption of mortar for various percentages of crushed sand are shown in Fig. 8. The results show that the water absorption of mortar with or without chemical admixture increases with the content of crushed sand substituted, this is due to the difference of the density and the porosity between the different fine aggregates used (angular crushed and round dune sands). In fact, the porosity (voids and pores) is influenced by the packing characteristics of the entire mixture that includes fine aggregates, cement and water. Also, the water absorption values of mortar with water-reducing admixture (1% of Medaflow30) are lower (18%) than those of mortar without chemical admixture (24%). The use of the chemical admixture (1% of Medaflow 30) allows reducing the number of voids and pores existing in the mortar, which thus becomes more compact, more resistant and more waterproof. The water absorption is linearly proportional to the total porosity of the mortar.

3.1.4. Effect of water cement ratio on the water absorption of mortar tested

Figs. 9 and 10 show the relationship between water cement ratio and water absorption of mortar studied. It shows that the incorporation of crushed sand influences considerably the water/cement ratio and water absorption of mortar. The water of mixing is one of the main parameters which influences the workability of the fresh mortar and the strength and the compactness of the hardened mortar. The incorporation of the crushed sand engenders a variation of the water cement ratio and the water absorption capacity of the mortar with mixed sand (crushed and dune sands) with or without water-reducing admixture (1% of Medaflow30). In order to appreciate the effect of the sand substitution on the workability of the studied mortar, W/C was fixed at 0.5 and superplasticizer concentration was fixed at 1%. The workability tests lead to the conclusion that by increasing the amount of limestone

\[
W_{abs}(\%) = \left[ \frac{W_2 - W_1}{W_1} \right] \times 100
\]
crushed sand in the mortar, the mixing becomes increasingly. This can be explained on the one hand by the fact that a quantity of mixing water is absorbed by the limestone crushed sand (1.25% water absorption instead of 1.23% for dune sand), and on the other hand by the friction generated by these fine aggregates because of their angular shape and their external rough surface. Evidently, the water absorption values increase with the W/C ratio, this is due to that with the variation of the content crushed sand substituted and porosity. This effect is less significant in mortar with binary sand incorporating 1% of Medaflow 30 rather than mortar mixture incorporating 0% of Medaflow 30. The use of water reducing admixtures is not only to disperse the cement particles to make them more exposed to the water molecules for reaction, but also making the mix more workable (more fluidity) that will make the water more available to infiltrate the fine aggregates. Crushed fine aggregates surface has a higher porosity than natural fine aggregates. The water absorption values of mortar containing the crushed fine aggregates are higher than those of the dune fine aggregates.

Figure 8. Variation of water absorption for various percentages of crushed sand

Figure 9. Water cement ratio versus water absorption of mortar tested (without admixture)
3.1.5 Effect of water cement ratio on the porosity of mixed fine aggregates (crushed and dune sands)

The water cement ratio is one of the key factors effecting on mortar properties. Fig. 11 shows the relations between the water cement ratio and porosity of binary sand (crushed and dune sands). The presentation of data demonstrate that as the porosity of binary sand increased the water cement ratio increased. The water cement ratio of mortar depends on the porosity and type of fine aggregate substituted. Using of superplasticizer (water reducing admixture) decreased the water cement ratio and porosity of fresh mortar. The water cement ratio of the mortar depends on the porosity of the binary sand. We notice according to Fig. 11 that the increase of the porosity of the mixed sand engenders an increase of the water cement ratio of mortars without chemical admixture of more than 11 %. For mortars with chemical admixture the increase of the water cement ratio is 6.33 %. We note that the use of the water reducing admixture (1% of Medaflow30) decreases the water cement ratio, because the lubricates and facilitates the rearrangement of particles and thus the mortar becomes less porous more compact.
3.2 Mechanical properties

3.2.1 Effect of crushed sand on the mechanical strengths

The results of the compressive, flexural and tensile strengths of the mortars with and without crushed fine aggregates at 28 days are plotted in Figs. 12, 13 and 14. Each presented value is the average of three measurements. The partial replacement of natural sand (DS) by manufactured sand (30%, 40% and 50% of CS combined) results in an increase in compressive, flexural and tensile strengths of the mortars (M_{30}, M_{40} and M_{50}) compared to the control mortar (M_0). The use of crushed sand increases the mechanical strength of the mortar, depending on the percentage of crushed fine aggregates used. The increase in the mechanical strength of the mortars may be attributed to the chemical composition, type, grain size distribution and structure of the quarry waste fine aggregates (crushed sand). The results obtained specify in a clear way that the incorporation of crushed sand (30%, 40% and 50% of CS) in the dune sand (DS) improves the mechanical strengths (compressive, flexural and tensile strengths) of the mortars tested to base of the binary mixtures. This can be to explain by the fact why nature (chemical composition) and the grain-size distribution are the principal parameters which influence the increase in the mechanical behavior of the mortar tested. The strength gain of the mortar tested was superior for the mortar containing binary sand (M_{40} and M_{50}) for the compressive, flexural and tensile strengths to that of the control mixture (M_0) with or without water-reducing admixture (1% of Medaflow30). This, can be to explain by the fact why nature (chemical composition) and the grain-size distribution are the principal parameters which influence the increase in the mechanical behavior of the mortar tested. Indeed, the improvement of the mechanical strength is due to the correction of the physical properties (improved grading, low porosity, high compactness, etc....) of the mortar containing binary sand. Finally, one concluded that from 30% up to 50% of crushed sand we notice an improvement of the compressive, flexural and tensile strengths of mortars with or without chemical admixture. We notice that the use of the reducing admixture (1% of Medaflow 30) improves the mechanical strengths of the mortar of more than 24%.

Figure 12. Variation of compressive strength of mortars at 28 days as a function of the quantity of crushed fine aggregate substituted
3.2.2 Effect of porosity of binary sand on the mechanical strength

Figs. 15, 16 and 17 show the relationship between porosity of binary sand and compressive, flexural and tensile strengths of mortar studied. It shows that the increase of porosity of binary sand influences considerably the mechanical strengths of mortar tested. In general, an increase in porosity of binary sand results in a decrease in the compressive, flexural and tensile strengths of mortar, but such reduction was found to be very limited, particularly for mortar prepared with chemical admixture (1% of Medaflow30). Porosity and texture of fine
aggregate (sand) have an important effect on workability of fresh mortar and have an effect on mechanical strength and durability of hardened mortar. In fact, the effects of shape and texture of fine aggregate are much more important than the effects of Mortar characteristics. Porosity of binary sand also effects the mechanical strength, permeability, and water absorption of mortar, and it will affecting the behavior of both freshly mixed and hardened mortar. The mechanical strength of mortar also may depend on the porosity, water absorption, and pore structure of the fine aggregates. From the result of porosity of binary sand, it can be concluded that the sample incorporation with different percentage crushed sand replacement has lower percentage of porosity of the binary mixtures (M30, M40 and M50) compared with the control mixture (M0). The porosity of binary sand decreased with an increase in the replacement of 30%, 40% and 50% of crushed sand. This is due to the lower volume of voids inside the binary sand. Similar finding was also reported by other investigations [18, 19].

Figure 15. Compressive strength at 28 days versus porosity of binary sand

Figure 16. Flexural strength at 28 days versus porosity of binary sand
5. CONCLUSIONS

The results obtained specify in a clear way that the incorporation of crushed sand (30%, 40% and 50%) in the dune sand improves the mechanical strengths (compressive, flexural and tensile strengths) of the mortars tested to base of the binary mixtures ($M_{30}$, $M_{40}$ and $M_{50}$).

The improvement of the mechanical strength is due to the correction of the physical properties (improved grading, low porosity, high compactness, etc...) of the mortar containing binary sand for the mixtures ($M_{30}$, $M_{40}$ and $M_{50}$) for the compressive, flexural and tensile strengths.

This study shows the importance of this method to made mortar with binary sand (natural and manufactured fine aggregates) in order to correct the physical properties of sand. Using a mixture of dune and crushed sands in various proportions, allows to obtain a high strength mortar.

The main objective of this experimental work is to valorise local materials and quarry wastes by using them in construction. It aims at the study of the effect of use of crushed sand as partial replacement of dune sand in various percentages (0%, 30%, 40%, 50%, 60% and 70%) on the physico-mechanical properties of mortar made with binary natural fine aggregates (DS and CS). Starting from the test results, it can be concluded:

- Adding crushed sand improves the physical properties of binary sand (grading, low porosity, high compactness, etc ...);
- It also improves its mechanical strength (compressive, flexural and tensile strengths);
- Using crushed sand from 30% up to 50% replacement and chemical admixture (1% of Medaflow30) increase the compressive, flexural and tensile strengths about 24% at 28 days.

The best values of mechanical strength were obtained by using an optimum content of
crushed sand which were about 40% to 50%. It could be noted, finally, that it is possible to formulate mortar with binary sand having good physico-mechanical properties by using crushed fine aggregates extracted from wastes of local careers. The rate of the strength gain decreased as the percentage of crushed sand replacement increase more than 50 percent in mortar. The test results indicated that physico-mechanical properties of mortar would be better with crushed sand (CS) replacing natural sand (DS). The crushed sand may be used as a substitute to natural sand (dune sand). The manufactured crushed sand found to have good gradation and nice finish which is lacking in natural sand (dune sand) and this has been resulted in good cohesive cement mortar. The mortar with binary sand (manufactured crushed sand and Dune sand) can be recommended for masonry work.

REFERENCES


