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*Technical Note*

# MECHANICAL RESPONSE OF MORTAR MADE WITH NATURAL AND ARTIFICIAL FINE AGGREGATES

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## Abstract

This work presents on the one hand the possibility of the use of the industrial waste of mineral origin (calcined clay bricks) for the manufacture industry of a mortar based on mixed fine aggregates (natural and artificial) and on the other hand a contribution to the improvement of the mechanical properties of the mortars containing mixed sands (dune sand and calcined clay).

The purpose of this initiative is the analysis of the physical and chemical properties of sands used (dune sand and calcined clay sand), as well as the characteristics of the mortar made with mixed sand such as, the workability, the density and the mechanical responses (compressive and flexural strengths: $R_c$ and $R_f$). In this work, we substituted the natural sand (dune sand) by artificial sand (waste bricks) at various ponderal contents (0, 25, 50, 75 and 100%).

The results obtained show that the substitution of the natural fine aggregates (dune sand) by 25% of calcined clay (artificial sand) by ratio to the ponderal weight gives an acceptable mechanical strength in relation to the mortar of reference (0% of clay sand substituted).

**Keywords:** Artificial fine aggregates; natural fine aggregates; mortar; mechanical response

## 1. Introduction

Sand is the fine aggregate more used for the manufacture of the mortar. Unfortunately, the majority of the natural sands used (rolled sands: sand of river, dune sand or sand of sea and crushed sands) are selected for reasons of the price and the availability [1].

Fine aggregates are inert granular materials such as sand, along with water and Portland cement, are an essential ingredient in mortar. For a good mortar mix, fine aggregates need to be clean, hard, strong particles free of absorbed chemicals and other fine materials that could cause the deterioration of mortar [2].

The demand for aggregates knows a considerable growth in connection with the

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development of construction in Algeria. To surmount it, it is be necessary to ensure a rational exploitation of the artificial aggregates available to the country by a valorization of mineral waste available: blast furnace slag, calcined clay, etc...

The quality of aggregates strongly influences mortar's freshly mixed, hardened properties, mixture proportions 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 [3].

The Algerian clay industry (bricks, tiles, ceramics, etc ….) has particular problems (mineral wastes) with its very high level of mineral waste which remains without being to exploit until now.

Mineral waste represents residue that could be used with minimal processing, largely as construction material, low value industrial mineral [4].

The Use of the artificial resources (waste industrials) such as the slag and waste bricks (calcined clay) makes it possible to increase the manufacture of building materials, to limit the use of natural aggregates and to value the waste products and being able to find valuable solution of the protection of the environmental [5].

The purpose of this paper is to analyze the influence of partial or complete substitution of natural aggregates (dune sand) by artificial aggregates (calcined clay) at different proportions (0, 25, 50, 75 and 100%) on the mechanical response of mortar.

## 2. Characteristics of the Used Materials

### *2.1 Natural sand (fine aggregates)*

The fineness modulus calculated was $M_f$ = 1.65. The information on the physical properties of the natural sand (dune sand) used is given in Table 1. Its chemical composition is shown in Table 2.

Table 1. Characteristics of the dune sand used for the tests

| Materials | Absolute density (Kg/l) | Apparent density (Kg/l) | Water content (%) | Porosity (%) | Sand equivalent value (sight/test) |
|---|---|---|---|---|---|
| Dune sand | 2.58 | 1.80 | 1.52 | 30.23 | 74.77 |

Table 2. Chemical composition (%, by weight) of dune sand used for the test

| Oxides % | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $K_2O$ | $Na_2O$ | $SO_3$ | LOI* |
|---|---|---|---|---|---|---|---|---|---|
| Dune sand | 87.85 | 0.98 | 0.69 | 6.12 | 0.19 | 0.35 | 0.01 | 0.04 | 2.62 |

**(*Loss on ignition)**

### *2.2 Artificial sand (Waste Bricks)*

In this study the calcined clay (artificial sand) used is waste bricks obtained by calcination of the clay to 850°C and used in the proportions of 0, 25, 50, 75 and 100% by the mass (weight) of natural sand to study its effect on mortar properties. The waste bricks before their use as sands artificial were crushed and to sift. The information on the physical properties of the natural sand used is given in Table 3. Its chemical composition is shown in Table 4.

Table 3. Characteristics of calcined clay used for the tests

| Materials | Absolute density (Kg/l) | Apparent density (Kg/l) | Water content (%) | Porosity (%) |
|---|---|---|---|---|
| Clay sand | 2,32 | 1,30 | 2,35 | 43,96 |

Table 4. Chemical composition (%, by weight) of calcined clay used for the tests

| Oxides (%) | $SiO_2$ | $Al_2O_3$ | $Fe_2O_3$ | CaO | MgO | $K_2O$ | $Na_2O$ | $SO_3$ | LOI* |
|---|---|---|---|---|---|---|---|---|---|
| Clay sand | 63.65 | 10.32 | 5.37 | 11.54 | 2.11 | 1.44 | 0.40 | 2.35 | 282 |

**(*Loss on ignition)**

### *2.3 Cements*

The Portland cement (CEM II) with mineral addition was used in this experimental study. The information on the physical properties of the cement used is given in Table 5. Table 6 presents the chemical composition of the cement studied.

Table 5. Physical characteristics of cement used for the tests

| Materials | Absolute Density (Kg/l) | Apparent Density (Kg/l) | Porosity (%) | Fineness (Specific surface area) ($cm^2/g$) |
|---|---|---|---|---|
| Cement | 3.10 | 1.80 | 41.93 | 3807 |

The finenesses (specific surface area) of the cement with mineral admixture studied was determined by Air Permeability Apparatus.

Table 6. Chemical composition of cement used for the tests

| Constituents % | $SiO_2$ (%) | $Al_2O_3$ (%) | $Fe_2O_3$ (%) | CaO (%) | MgO (%) | $K_2O$ (%) | $Na_2O$ (%) | $SO_3$ (%) | LOI (%) |
|---|---|---|---|---|---|---|---|---|---|
| Cement | 22.51 | 5.76 | 3.52 | 57.58 | 1.92 | 0.38 | 0.07 | 1.77 | 5.67 |

The chemical composition of the cement used in this research is determined by the testing method "X-ray Fluorescence Spectrometry (XRF)".

## 3. Mechanical Tests (Flexural and Compressive Strengths)

The mortars samples were subjected to flexural and compressive mechanical tests. Mechanical strength was determined at 7.14 and 28 days on 4×4×16cm$^3$ prisms specimens with 65% water-cement ratio and 1:3 cement/Sand (By mass). The moulds with fresh mortar test specimens were cured for 24h at relative humidity of 95% RH. Three specimens were tested per specimen age.

Tables 7 and 8 give the mixes of the sands made (dune sand and clay sand) by partial and full substitution of the natural sand (dune sand) by artificial sand (waste bricks) at various ponderal contents (0, 25, 50, 75 and 100%) and the ponderal composition of the mortars used in this experimental work.

Table 7. Mix composition of mixed sands studied

| Mix of sands substituted | Artificial sand "Clay sand" % | Natural sand "Dune sand" % |
|---|---|---|
| $S_{0\%}$ | 0 | 100 |
| $S_{25\%}$ | 25 | 75 |
| $S_{5O}$ | 50 | 50 |
| $S_{75\%}$ | 75 | 25 |
| $S_{100\%}$ | 100 | 0 |

Table 8. Ponderal composition of mortars studied

| Mix of mortars studied | Mixed sands (g) | | Cement (g) | Water (ml) |
|---|---|---|---|---|
| | Clay sand | Dune sand | | |
| $M_{0\%}$ | 0 | 1350 | 450 | 292.5 |
| $M_{25\%}$ | 337.5 | 1012,5 | 450 | 292.5 |
| $M_{5O}$ | 675 | 675 | 450 | 292.5 |
| $M_{75\%}$ | 1012.5 | 337,5 | 450 | 292.5 |
| $M_{100\%}$ | 1350 | 0 | 450 | 292.5 |

## 4. Results and Discussion

### *4.1 Effect of the quantity of clay sand substituted on the workability of mortar*

Water is a very important part of the mix and the volume of water used can dictate the strength of the finished mix. On site, a apparatus "slump test" of mixed mortar is used to test the water content of the mortar. A cone made of steel is used for this test. The mixed mortar is placed into the cone through the top, a bar is used to compact the mortar, and remove air voids, within the cone. During the substitution of natural sand by artificial sand, water-cement ratio was maintained constant.

The figure 1 presents the effect the quantity of clay sand substituted on the workability of mortar. From the results obtained (Figure 1), the following conclusions may be drawn:

- a significant difference of the workability (slump test) beyond 25% of the substitution between the various mortars tested.
- a significant decrease of the workability (slump) beyond 25% of the replacement of the clay sand (waste bricks) in relation to the weight of the dune sand.

The difference observed between the workability of mortars tested, depends of the content of the artificial sand incorporated in the sand natural (difference of the density and the porosity between the two sands studied). The Substituted artificial sand (clay sand) presents a high porosity compared to the natural sand (dune sand), this is mainly due at the variation of the physical properties for each type of sand (natural and artificial sands).

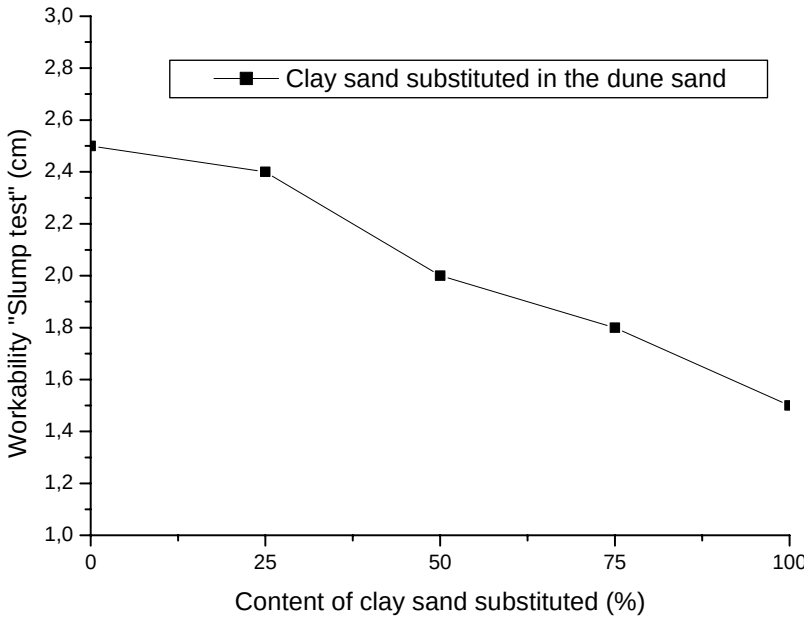


Figure 1. Variation of workability as a function of the quantity of clay sand substituted

### *4.2 Effect of the quantity of clay sand substituted on the density of mortar*

Figure 2 shows the effect of the clay sand substituted on the density of mortar. The

substitution method by the incorporation of the calcined clay in the dune sand influences the density of the mortars studied. The increase of the percentage of the clay sand at different percentages (50, 75 and 100%) in relation to the weight of the dune sand strongly decreases the density of mortar (variation of the porosity of sand). The difference observed between the density of mortars, depends of the percentage of the clay sand (lightweight density) incorporated in the dune sand (low density of the calcined clay). The best result of the workability is obtained for the substitution of 25% of clay sand.

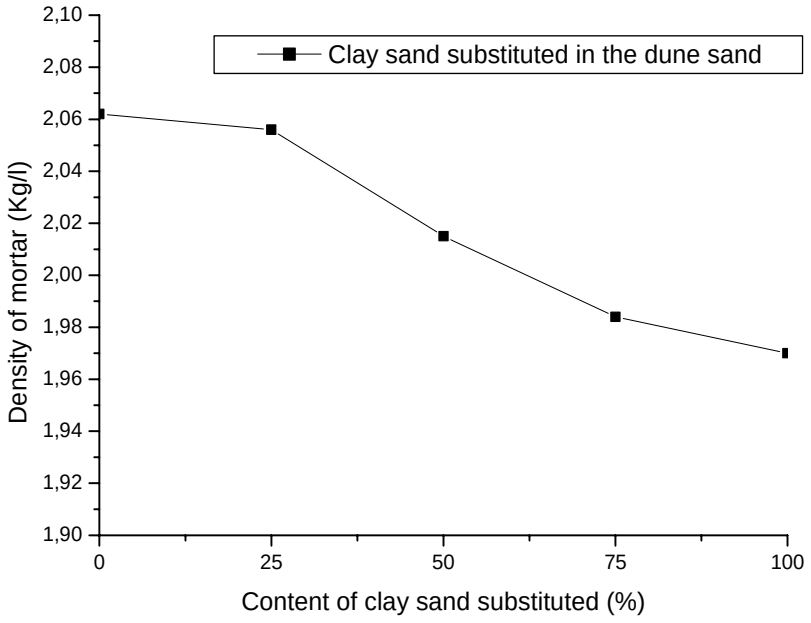


Figure 2. Variation of density as a function of the quantity of clay sand substituted

***4.3 Effect of the quantity of clay sand substituted on the mechanical strengths of mortar***

The developments of compressive and flexural strengths of the test specimens are shown in Figures 3 and 4. The compressive and flexural strengths increase with curing time for all hardened mortars. The increase of the percentage of the clay sand beyond 25% by the substitution method in relation to the weight of the dune sand decreases the mechanical strengths for all samples tested (the chemical composition and the granulometry of fine aggregates). The difference observed between the mechanical responses of mortars, depends of the percentage of the clay sand (lightweight density) incorporated in the dune sand (low density of the calcined clay), the porosity and the chemical composition of calcined clay. The results obtained show that the substitution of the fine aggregates by 25% of calcined clay (artificial sand) by ratio to the ponderal weight of sand gives a acceptable mechanical strengths of the examined mortars.

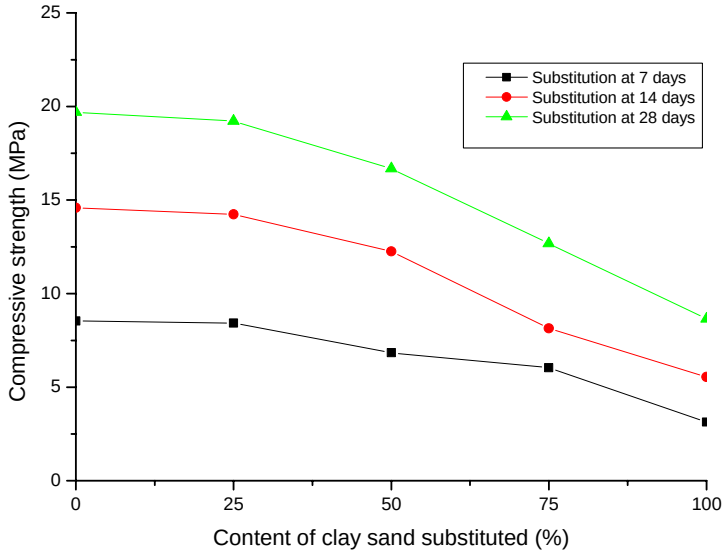


Figure 3. Evolutions of compressive strength of mortars as a function of the quantity of clay sand substituted

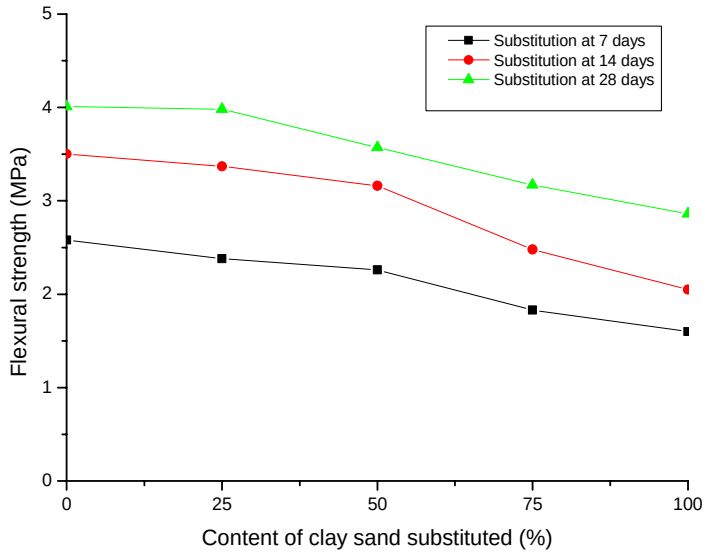


Figure 4. Evolutions of flexural strength of mortars as a function of the quantity of clay sand substituted

## 5. Conclusions

The main conclusions of this study are summarized as follows:

* The substitution of the dune sand by the clay sand (calcined clay) influences

appreciably on the water demand necessary to have a acceptable workability (fluidity or consistency) of fresh mortar.

* a significant difference of the workability (slump) beyond 25% of the substitution between the various mortars tested.

* a significant decrease of the workability (slump) beyond 25% of the replacement of the clay sand (waste bricks) in relation to the weight of the dune sand.

* The increase of the percentage of the clay sand at different percentages (50, 75 and 100%) in relation to the weight of the dune sand strongly decreases the density of mortar (variation of the porosity of sand).

* The difference observed between the density of mortars, depends of the percentage of the clay sand (lightweight density) incorporated in the dune sand (low density of the calcined clay).

* The best result of the workability is obtained for the substitution of 25% of clay sand.

* The increase of the percentage of the clay sand beyond 25% by the substitution method in relation to the weight of the dune sand decreases the mechanical strengths for all samples tested (the chemical composition and the granulometry of fine aggregates).

* The difference observed between the mechanical responses of mortars, depends of the percentage of the clay sand (lightweight density) incorporated in the dune sand (low density of the calcined clay), the porosity and the chemical composition of calcined clay.

* The results obtained show that the substitution of the fine aggregates by 25% of calcined clay (artificial sand) by ratio to the ponderal weight of sand gives a acceptable mechanical strengths of the examined mortars.

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