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Experimental evaluation of workability and compressive strength of concrete with several local sand and mineral additions

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HIGHLIGHTS

- The behavior of concrete is influenced by sand types.
- The contribution of river and dune sands to improve the behavior of concrete.
- Mineral additions influenced the behavior of concrete with crushed sand.
- The software Concrete Lab Pro 3 does not include the fines contents and coefficients of the particle shape.

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ABSTRACT

The evolution of civil engineering has recently resulted in new structural methods and greater consumption of aggregates, particularly sand. This evolution has led to an international dynamics of valuating local materials, such as crushed sand, which is not used sufficiently often due to the high rate of fine particles that it contains. The aim of this work is to study the influence of fine particles of crushed sands on the compressive strength and concrete slump. The experiments have been performed on crushed, river and dune sands and the results indicate that the behavior of concrete in the fresh and hardened states is different according to the composition and sands. The results were compared with "Concrete Lab Pro 3" outputs. The analysis of the resistances shows that the experimental values and the estimated values are not comparable, especially in concrete slump.

1. Introduction

In recent years, engineers and researchers in civil engineering have observed a depletion of aggregates. Among these aggregates, "crushed sand" plays an important part in the manufacturing of concrete because it influences the properties of fresh and hardened concrete (workability, mechanical strength and durability).The current standards have been adapted by increasing the limit of fine particles in crushed sand. For instance, the European standard EN-206 suggests 16% of fines, the British Standard (BS 882) allows 15% fine and ASTM C33 sets the limit at 7% [1]. However, there is no way to predict the impact of crushed sand on the behavior of concrete because the properties of crushed sand vary according to the source and the extraction method. Consequently, a large amount of research work has examined using crushed sand and has revealed that various parameters should be taken into account, such as the effect of the mineralogical source, the form of the particles and the fines content [2,3]. The behavior of concretes with crushed sand could be disturbed if the fines content exceeds a certain percent [3–8]. A threshold of (10–15%) of fines is considered optimal [9,10]. Researchers [9–13] explained this by the filling effect caused by crushed sands and the increase of the fine particles, which affects the water needs and the relationship of cement paste and aggregates. In Algeria [14,15], the content of fines is not always the most influential parameter that affects the behavior of concrete because sands with a high fines content also give good performance (workability and mechanical strength), which was explained by the difference in the grading curves between the sands.

Other researchers examined the combination of the crushed sand with other categories of sand, such as river and dune sands, [11,13,16] and showed that the use of river sand improves the workability and mechanical strength and decreases the water needs. These results were attributed to the reduction of the pore spaces (voids) in the mixture and the differences between form particles [17–20]. Other authors [13,17,21] reported that dune

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sand improves the workability as long as the limit is 30%. The best values of mechanical strength have been achieved at a threshold of 15% of dune sand.

Researchers have suggested the use of mineral additions to address the problem of using crushed sand and [22–25] found that the use of slag and natural pozzolan increases the water requirements and generates an improvement of the compressive strength at 120 days. Ilker et al. [26] found a variation of the compressive strength depending on the pozzolanic reaction between $Ca(OH)_2$ and mineral additions. The present study assesses the impact of fine particles on concrete slump and compressive strength of 270 specimens produced with 30 formulations. The main objective of this research concerns the combined effects of multiple sands (crushed sand, dune sand, and river sand) and mineral additions (pozzolan and slag) on the behavior of concrete. To our knowledge, no study has examined in literature, the influence of several crushed sands modified with river and dune sands, and with different percentage of additions. A comparison of the experimental and numerical (simulations) results given by the software "Concrete Lab Pro 3" is performed by observing the differences between the results.

2. Materials characterization

2.1. Cement

The cement used in this study is commercial Portland (CEM I) class 42.5 MPa from cement factory of SOTACIB Kairouan (Tunisia). The chemical and mineralogical compositions of the cement are presented in Tables 1 and 2. The potential mineralogical composition of the cements is calculated according to the empirical formula of Bogue [27].The physical properties of the cement are shown in Table 3.

2.2. Water

The water used in this study is tap water at a temperature of 20 ± 2 °C. Its quality conforms to the requirements of standard NFP 18-404.

2.3. Sand

The sand used (0/5 mm) in this study is from two different regions of Algeria (Biskra and Constantine), represented respectively by yellow limestone and white calcareous. In addition, 20% river sand ST and 10% dune sand SD were used as a crushed sand replacement for correction of the grading curves. The chemical analyzes have been conducted in cement factory of Ain touta (Batna). The significant finding to notice is the presence of a high percentage of silica SiO_2 which is higher than 86%, and therefore the sand dune of Biskra (Tolga) is silica sand. The chemical compositions and the physical properties of the sands are presented in Tables 4 and 5. All properties were measured by following standards NF P18-553, NF P18-555, NF P18-597 NF P18-598, and NF P18-560. The morphologies and grading curves of the different sands before and after correction are given in Figs. 1–3.

2.4. Gravel

We used fractions of crushed stone (8/16 and 16/25 mm) from the Biskra region (Algeria). Apparent density = 1435.5 kg/m^3, specific density = 2645 kg/m^3 and coefficient of Los Angeles = 26.04% (hard). The properties were measured by NF P18-560, NF P18-554, and NF P18-573. The grading curves of the gravels are given in Fig. 3.

2.5. Mineral addition

We used mineral additions of pozzolan (P) and slag (L), which are available at the national level. The additions were obtained respectively from cement factory of Ain Touta (Batna), and company ArcelorMittal (Annaba). The chemical compositions and the physical properties of the additions are presented in Tables 6 and 7. The significant finding to notice is a high fineness of slag in comparison with the pozzolan.

Table 1
Chemical composition of the cement (%).

Cement type	SiO_2	Al_2O_3	Fe_2O_3	CaO	SO_3	MgO	IR	LOI
CPA CEM I (42.5)	20.40	5.53	3.54	61.60	2.38	1.73	0.6	2.74

IR: insoluble residue.
LOI: loss on ignition.

Table 2
Mineralogical composition of the cement (%).

Cement type	C_3S	C_2S	C_3A	C_4AF
CPA CEM I (42.5)	51.19	19.88	8.667	10.773

Table 3
Physical properties of the cement.

Cement type	CPA CEM I (42.5)
Apparent density (kg/m^3)	1473.5
Specific density (kg/m^3)	3149.6
Fineness (cm^2/g)	3581.5

3. Mix proportions

An experimental program was conducted to study, with a constant ratio W/C (0.6), the effect of fine particles on the behavior of concrete. We prepared thirty formulations with two crushed sands without modification and modified with dune sand, river sand. Partial substitution of Portland cement with mineral additions (pozzolan and slag) will complete the study. The tests began with mixing materials and water during 2 min in a concrete mixer. The concrete was cast in metallic moulds (10 mm × 10 mm × 10 mm) in two layers, and subject to vibration on a table of shocks. After 24 h, the samples underwent curing with conservation in tap water at 20 ± 2 °C for 7 or 28 days.

The optimization of the formulation of concrete-based on several criteria often requires a compromise between the workability, strength, economy and durability. The method of B. Scramtaiv was used to determine the concrete and provided accurate results. This method relies on the fact that the sum of the absolute volumes of original material in a cubic meter is equal to the volume of the composition of tamped concrete [28]. The compositions of concretes are reported in Table 8.

4. Concrete Lab Pro 3

Concrete Lab Pro 3 is concrete formulation software. The Input parameters of this tool are tuned by carrying out several tests: These parameters are:

- Grading curves of constituents
- Densities of materials (cement, sand, gravel, mineral additions, etc.)
- The compactness of materials

After the tuning phase, the maximum compactness of granular mixture is measured by Compressible Packing Model (CPM), a large number of output values characterizing the concrete have been obtained (concrete slump, resistance). The details of the calculations by Compressible Packing Model (CPM) are given in reference [29]. An example of the simulations of concrete formulation with Concrete Lab Pro 3 is given in Fig. 4.

5. Results and discussion

5.1. Concrete slump

The test of concrete slump was performed in accordance with standard NF P 18-451. The experimental concrete slump was