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Performance Evaluation of a Self-Compacting Mortar Altered with Dune Sand

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Abstract: In this paper, a laboratory-performed study relating to the evaluation of a self-compacting mortar (SCM) made initially from crushed quarry aggregates and modified by the addition of fine dune sand (DS) is presented. The aim was to show the modification of the rheological, acoustic, and mechanical properties of the SCM brought about by this very fine aggregate, whose use is deemed to be unsuitable for the production of cementitious materials. Though, its valorization could save the overexploited natural resource that is crushed quarry sand (CS). For this purpose, different mortar mixtures made with DS rates of 0%, 25%, 50%, 75%, and 100% by volume of CS were prepared, and subjected to mini-cone flow, ultrasonic pulse velocity (UPV), and destructive compressive and flexural tensile strength tests. The results showed the improvement of several of the parameters studied after the addition of DS, as well as the possibility of using DS in the design of such kinds of mortars even at very high substitution rates. The study also concludes that DS could serve as a viable alternative to CS, in the sense that it could allow to manage in a more sustainable way the otherwise depleting and overexploited supply of quarry sand.

Keywords: Self-compacting mortar, Dune sand, Crushed sand, Ultrasonic pulse velocity, Sustainability

Introduction

Self-compacting mortar (SCM) is a specifically engineered type of mortar that has the ability to flow and consolidate in a confined volume without the need for any type of settlement aid. This remarkable property is a result of its high flowability (Turk et al., 2022; Yon et al., 2022). The concept of self-compacting mortar SCM derives from that of self-compacting concrete SCC which was introduced in the late 1990s, before raising widespread interest among researchers as concrete technology improved.

The primary focus when developing SCC has been to achieve the best possible workability performance - through the usage of high-range water-reducing agents - in addition to the high flowability required for excellent workability. To be in line with the viscosity requirements of such mixtures, mineral additions are often used in the form of inert or active supplementary cementitious materials such as limestone filler (inert), fly ash, silica fume,..etc (active). These materials incur in the SCM in addition to an improved cohesion and flowability at the

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fresh state, the formation of a denser matrix and denser ITZ (Khelil, 2020) At the hardened state. One way to achieve the required flowability, instead of mineral additions, could be the use of very fine sand particles in the likes of dune sand (DS). Indeed, research has shown that dune sand particles, thanks to their morphological properties (near-spherical shape, smooth surface texture), have a positive impact on the rheological properties of cementitious materials (Khelil et al., 2023).

The present paper shows the results of an experimental study exploring the possibility of using dune sand in substitution of crushed sand in SCMs, with the objective on the one hand, to improve their rheological properties, and on the other hand, to reduce the usage of regular crushed sand and hence diminish its environmental impact.

Materials and Procedures

Materials

In this study, a CEM II/A-L 42.5R cement with a specific gravity of 3.1 supplied by SPA Biskria and conforming to standard EN 197-1 (British Standards Institution, 2011). Was used. Two types of sands were used to prepare the mortars. The first one is a crushed sand (CS) sourced from a local quarry in the region of Tizi-Ouzou, whereas the second originates from the mid-southern region of Touggourt, in the Algerian desert. The particle size distribution of both sands is presented in (Figure 1). From the graph, a difference in fineness can be observed between the studied sands. DS is finer than CS to the extent where its fineness modulus is measured at 1.94 whereas that of CS is at 3.09. In terms of absolute density, both sands share a near-similar density of 2.66 and 2.65 for CS and DS respectively. To complete the mix, tap water as well as a high-range water-reducer supplied by Granitex under the commercial designation of Medaplast SP 40 was used.

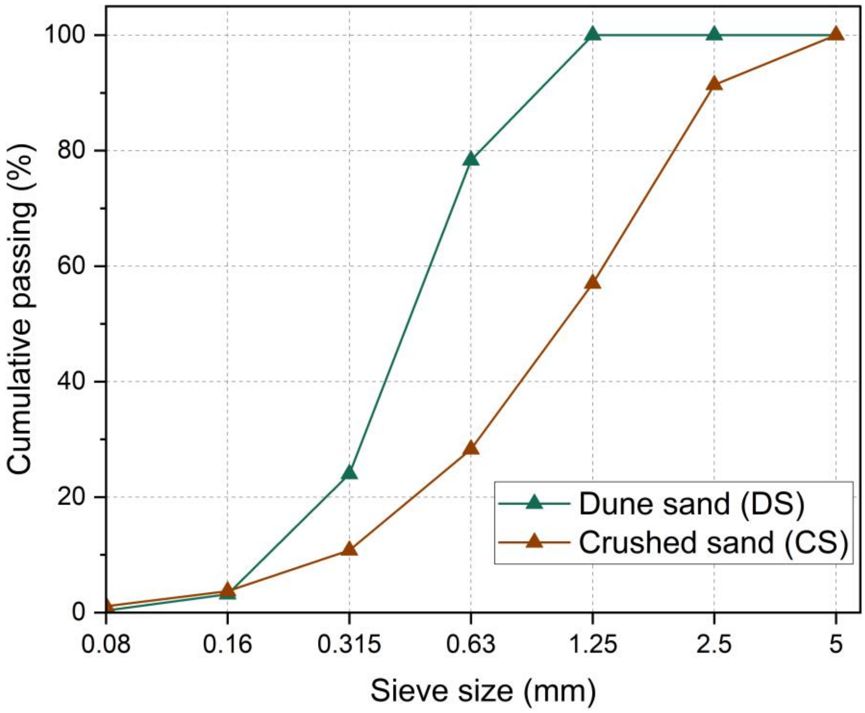

Figure 1. Particle size distribution of the tested sands

Mortars Mix Proportions

In total 5 SCM mixtures were prepared using the CEM II 42.5 R as the sole binding material. No supplementary material was included in the study. Playing the role of the supplementary material at least on the very fine and compaction-favoring aspect was the dune sand DS. Indeed, due to its fine particle size distribution along with its general near-spherical shape, DS could help achieve the rheological requirements of the SCM, while being quite cheap and easy to handle. The tested CS-DS sand blends in the mortars are presented in (Table 1). The mixing protocol is based on that of EN 196-1 (British Standards Institution, 2016). Dealing with regular mortar. It consisted of an overall mixing duration of 180s, comprising the following steps: Firstly, the water and cement are introduced into the mixing bowl, before the planetary mixer in switched on at a low speed for 30s. After that, the addition of the sand blend is performed during another 30s, right before switching to the higher speed for 30 more seconds. At this point, the mixer is paused for 30s to allow to scrape any material stuck to the bottom or the walls of the bowl. Lastly, mixing is resumed for 60s at high speed, before termination. After completion, the fresh SCM mixtures are tested for their flowability properties using a mini-slump cone. The mixtures are then introduced in 40 x 40 x 160 mm^3 prismatic molds for 24h at room temperature of around 25°C. After 24h, the specimens are demolded and allowed to age in a water tank at the same temperature for another 27d before further testing. For each SCM mixture, three prismatic specimens were cast, in order to be subjected to Ultrasonic Pulse Velocity testing (UPV), flexural tensile strength testing and finally compressive strength testing. The results displayed hereafter are the averaged values recorded on those three specimens.

Table 1. Mortars mix proportions

Mortar ID (%CS-%DS)	CS (g)	DS (g)	Cement (g)	water (g)	HRWR (%)	W/C
M0 (100CS-0DS)	1191.6	0	685.6	205.68	0.68	0.3
M1 (75CS-25DS)	893.7	299.24	685.6	205.68		
M2 (50CS-50DS)	595.8	598.49	685.6	205.68		
M3 (25CS-75DS)	297.9	897.74	685.6	205.68		
M4 (0CS-100DS)	0	1196.99	685.6	205.68		

Mini-Slump Testing

This is the most common test, as it is the easiest to implement. It allows to characterize mobility in an unconfined environment. This is a spreading test that is used to characterize the fluidity of the mortar. It is a variant of the slump test used for concrete but this time it is carried out on a truncated mini cone (mini slump test). It protocol consists in measuring on two perpendicular sides, the spreading diameter of the mortar pancake and comparing the results to the spreading values of an SCM that are usually set between 240 and 260 mm according to EFNARC (European Federation of Specialist Construction Chemicals and Concrete Systems) guidelines (2005). In detail, the test method consists in filling a mini-cone of base-diameter:100mm, top-diameter:70mm and height:60mm, in two steps, during which, the mortar is consolidated by performing 25 strokes using and tamping rod. The mini-cone is then lifted allowing for the fresh mixture to freely flow. The measurements are performed once the fresh SCM stops flowing and remains still, and no segregation and bleeding is observed.

Ultrasonic Pulse Velocity Testing

Ultrasonic Pulse Velocity Testing (UPV) is a non-destructive testing method used to determine the quality and integrity of materials, such as concrete or mortar. It works by transmitting high-frequency acoustic waves into the material and measuring the time it takes for these waves to travel through it, as described by BS EN 12504-4 (British Standards Institution, 2004). And ASTM C597-16 (American Society for Testing and Materials, 2016). The speed of the sound waves depends on the material's properties, such as its density, elasticity, and presence of cracks or voids. The testing of the mortar prismatic specimen was carried out using a UPV apparatus possessing two transducers, an emitting transducer and a receiving one. After setting the UPV frequency (150KHz) the specimen to be tested is placed between the transducers, before turning the apparatus on. For each mortar formulation, three specimens were tested, each one tested three times. The results shown in this paper are the averaged values of 9 tests.

Tensile and Compressive Strength Testing

The destructive tests were carried out using a computer-controlled hydraulic press. Each SCM specimen was initially subjected to a three-point flexural test at a constant loading rate of 50 ± 10 N/s, as outlined in EN 196-1

(British Standards Institution, 2016). This test determined the flexural tensile strength of the specimen. Subsequently, the two resulting half-prisms were crushed at a constant loading rate of 2400 ± 200 N/s following EN 196-1 prescriptions (British Standards Institution, 2016). Allowing for the measurement of compressive strength. The mechanical properties reported in this study represent the average values calculated from the three test specimens prepared for each mixture.

Results and Discussion

Mini-Slump Testing

The results of the mini-slump test carried out on the fresh mortars are presented in (Figure 2).

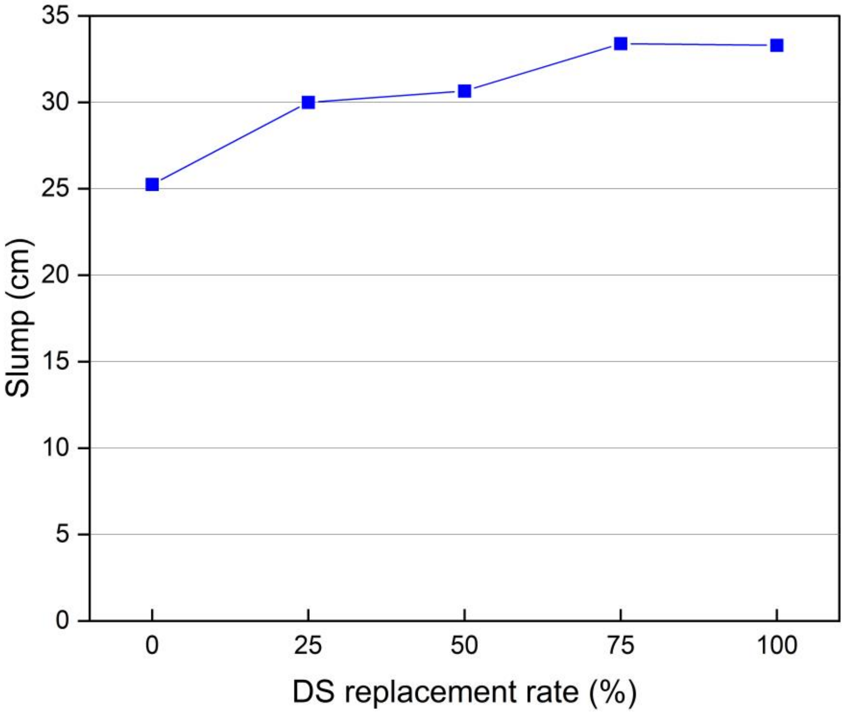

Figure 2. Slump values of the tested mortars

The data show the improvement of slump values as the amount of DS increases in the mortars. Indeed, slump values increase from 25.25 cm for the control specimen M0 to 30.0 cm, 30.65 cm, 33.4 cm and 33.3 cm for M1, M2, M3 and M4 respectively, representing an increase of 18.81%, 21.39%, 32.27%, 31.88%. These results show the positive effect of dune sand addition in amelioration the fresh mortar flowability performance. This improvement could be related as mentioned earlier, to the shape of DS particles, since they are mostly constituted of near-spherical particles. This particularity, makes it easier for the mortars constituents to flow under their own weight. DS particles in that case can be considered as playing the role of a lubricant, facilitating along with the HRWR, the motion of the cement and the CS particles at the fresh state, enabling their arrangement in a more compact configuration within the cementitious matrix.

Ultrasonic Pulse Velocity testing

The ultrasonic pulse velocity test results are shown in (Figure 3). It can be seen from the data that the presence of DS in the mortars in increasing proportions leads to the overall decrease of the acoustic velocity, transitioning from 5319m/s for M0 and M1 to 4990m/s, 4939m/s and 4799m/s for M2, M3 and M4 respectively. The decrease in the recorded data show the alteration of mortar properties brought about by DS particles, in the sense that, those particles seem to make the mortar somewhat less dense compared to the control. Indeed, as mentioned earlier, UPV testing is often used to assess the material compactness, and the higher the UPV recorded, the denser the material. This decreased compactness observed here could be indicative of a poorer material strength-wise and durability-wise, since those parameters are often correlated.

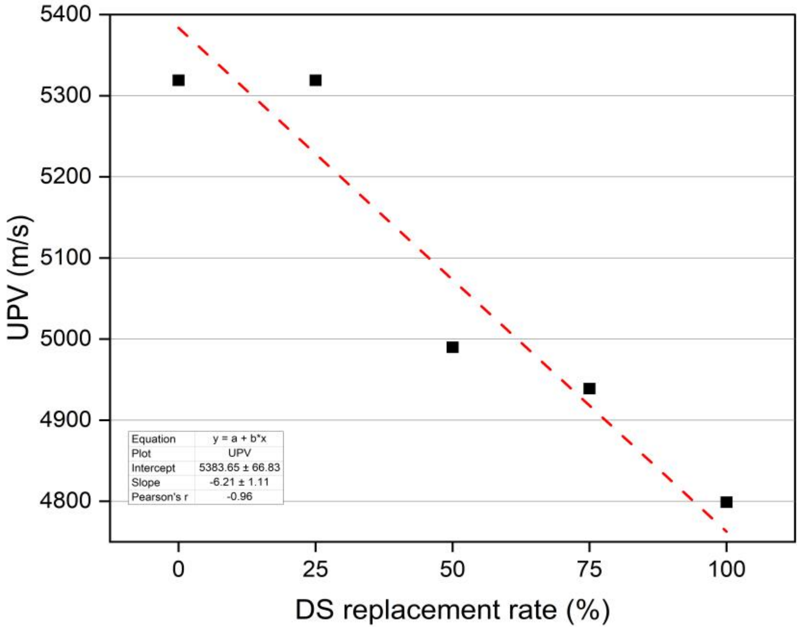

Figure 3. Ultrasonic pulse velocity test results at 28d

Tensile Strength Test Results

The following figure (Figure 4) presents the flexural tensile strength of the tested mortar specimens.

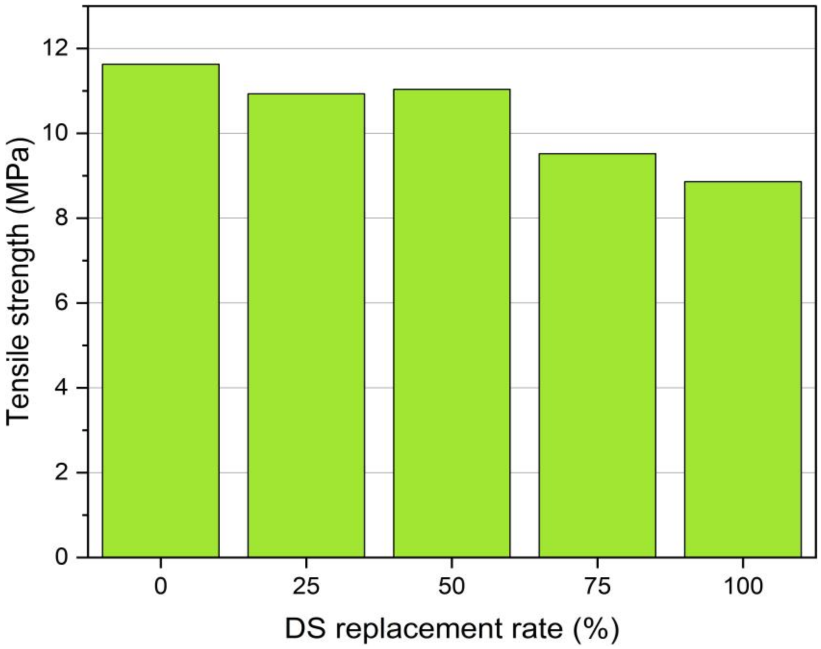

Figure 4. Tensile strength of the tested mortars at 28d

Globally, what is observed is a steady decrease of the tensile strength of the mortars as the amount of dune sand increases in the mixtures. From the control tensile strength value of 11.63MPa, the strength decreases down to 10.93MPa, 11.04MPa, 9.52MPa and 8.86MPa for M1, M2, M3 and M4 respectively, account for a decrease of 6.02%, 5.07%, 17.54% and 23.82%. These results seem to be accord with the UPV test results, which indicated that the mortar mixture becomes more porous with the increasing amount of dune sand. Indeed, it is well known that DS particles hold a spherical shape and a smooth surface texture (Khelil et al., 2023). This property as much as it allows to improve the mortars flowability and particles arrangement at the fresh state, at the hardened state however, it makes the particle bond to the cement matrix specifically at the porous ITZ weaker that its CS counterpart (Khelil, 2020). As a consequence, very little resistance to crack propagation during loading are observed on these mortars, making them less able to withstand loading compared to the control.

Compressive Strength Test Results

The compressive strengths of the tested mortars are presented in (Figure 5).

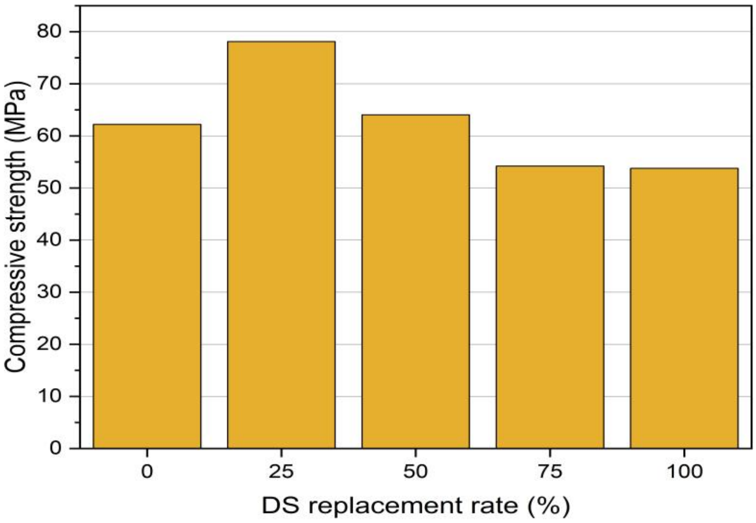

Figure 5. Compressive strength of the tested mortars at 28d

From the graph, one can note that the mortars containing DS particles exhibit two types of behaviors depending on the amount of DS in the mixtures. For mixtures M1 (25% DS) and M2 (50% DS), the compressive strengths are valued at 78MPa and 64.04MPa representing an increase of 25.51% and 2.92% compared to the control (62.22MPa). At higher DS amounts, namely M3 (75% DS) and M4 (100% DS), a decrease is recorded, valued at 15.78% and 13.56% at 54.2 and 53.75 MPa respectively. These results seem to indicate that there is a positive effect to adding DS to the SCMs up to a certain DS content valued at 50%. These observations are indicative of the improvement of the particles arrangement within the cementitious matrix during the mixing process and casting, making it possible to reduce inter-granular spacing and hence improve the granular phase interlocking. Beyond that value, lower strengths are observed. This could be explained by the high amounts of DS particles, which, exhibit a relatively easy debonding from the cement matric under loading and cracking, making the overall ability of the mortar less able to achieve high compressive strength. Nevertheless, it is noteworthy, that even though the high DS mortars are less performing, their strength remains significant enough (>50MPa), for them to be considered as appropriate building materials.

Conclusion

In light of the experimental data, the following conclusions may be inferred:

- DS addition improves the flowability of SCMs made of natural crushed sand particles, on all the DS-containing mixtures. The flow increases by up to 32.27% for Mixture M3 (75% DS).
- DS addition reduces the acoustic properties (UPV) of the SCMs, meaning that porosity of the cementitious matrix increases, and consequently so is the durability of the SCMs.
- Flexural tensile strength test results showed a slight decrease of resistance when DS content is lower or equal to 50%, whereas the decrease is steeper beyond.
- Compressive strength test results show that at low DS contents (below 50% DS), the SCMs behave better than the control, whereas beyond, poorer strengths are observed.

Overall, these findings show that dune sand DS could represent a viable alternative, capable of replacingordinary crushed sand in SCMs, while improving their properties provided that the replacement rate is low (around 25%).

Scientific Ethics Declaration

The authors declare that the scientific ethical and legal responsibility of this article published in EPSTEM Journal belongs to the authors.

Acknowledgements or Notes

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