Mechanical properties of high-performance concrete made incorporating dune sand as fine aggregate.

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Abstract. *The main objective of this research is to contribute to an experimental study of the behavior of high-performance concrete (HPC) based on dune sand of Taghit (Bechar-Algeria). This work also optimizes the formulation of HPC based on local materials. We used Taghit's dune sand to formulate HPC as fine sand substituting the fine amount of quarry sand fines. This substitution makes it possible to improve the distribution of the granular skeleton, the microstructure (size and network of the pores), the mechanical strength of the hydrated cement pastes in the short and long term, and consequently the performances of these concretes. The results show that the modification of sand quarry (0 <0.315) by dune sand in the composition of HPC Contributes to a slight improvement of properties in the fresh state. The mechanical behavior (strength and compressive modulus of elasticity) increased slightly with control concrete (about 5%) at 28 days for all proportions (25%, 50% and 100%). Finally, we can say that our study has shown that it is possible to realize a HPC based on dune sand, and that the development of dune sand can provide a solution for some work in the desert regions.*

Key words: High-Performance Concrete, Dune sand, Compressive strength, Modulus of elasticity

1. Introducere

The Algerian desert contains inexhaustible quantities of dune sand, is an abundant natural material that has never been seriously used in constructions. According to the chemical properties it has high quartz silica content, it is a very clean and fine sand, its cost of extraction almost nil except the cost of transport [1-3].

Many researchers [2-4], in various scientific themes, seek to exploit this type of sand, clean and present to abundance. And use in different areas of construction, hence the interest is related to its very high silica content, and rising demand for construction sand in Algeria, the inability of Algerian quarries to provide fine sand and the planned stoppage of the use of beach sand, which leads to a major ecological and tourist problem for Algeria, they are all reasons which lead to the valorization of this product and also presents a great economic and environmental interest which could present the use of sand dunes for the formulation of concretes of which it would be the main constituent.

This work aims to valuing dune sand by their uses in the field of civil engineering (study the behavior of high-performance concrete (HPC) made from sand dune in the fresh and hardened state), and look for solutions to optimize a HPC formula based on local materials.

The modulus of elasticity is absolutely necessary for the calculation of stresses and deformations in a structure in service. In addition, both the compressive strength and the elastic modulus change over time depending on the degree of hydration of the cement paste. The predicting models generally link these two properties. To make it easier to compare the various models, each of which uses its own system of notation, a unified notation based on that of Eurocode 2 is adopted: fcm and Ecm are respectively the average compressive strength and the modulus of elasticity in compression of concrete at 28 days. The modulus of elasticity can be estimated from the equations of the various models listed in Table 1.

Table 1 **Prediction of the modulus of elasticity by the five models**

Model	Modulus of elasticity in GPa
Eurocode 2 [6]	$E_{cm} = 22.(\frac{f_{cm}}{10})^{0.3}$ (1)
ACI 318 [7]	$E_{cm} = 43.10^{-6}.\rho^{1,5}\sqrt{f_{cm}}$ (2)
FIB Model [8]	$E_{cm} = 21.5.\alpha_E.(\frac{f_{cm}}{10})^{1/3}$ (3)
B3 Model [9]	$E_{cm} = 4.734.\sqrt{f_{cm}}$ (4)
GL2000 Model [10]	$E_{cm} = 3.5 + 4.3\sqrt{f_{cm}}$ (5)
with f_{cm} in MPa, ρ the concrete density in kg/m3 and αE a parameter that depends on the mineralogical nature of the aggregates (1.2 for basalt or compact limestone, 1.0 for quartz, 0.9 for limestone, 0.7 for sandstone)	

The estimation of the modulus of elasticity depends only on the compressive strength value for most of these models. The confrontation of experimental values of the Young's modulus with those calculated using these empirical relationships often shows notable variations [4-5]. The fib Model Code 2010 is the only model that takes the influence of the aggregate mineralogy on modulus of elasticity into account, through the α_E parameter.

2. Materials and experimental procedures

The cement used is Portland cement Composed CEM II / B resistance real Matine 42.5 MPa (under its trade name).

Dune sand coming from the commune of Taghit, wilaya of Bechar (Algeria) 0 <0.315). Sand rolled of class (0/3mm), (3/8 mm, 8/15 mm) were used in the formulation of concrete.

Table 2 present a Physical properties of Portland cement and dune sand.

Table 2 **Physical properties of cement and dune sand [2]**

Parameters	Cement	Dune Sand	Regulatory
Absolute density	3.05	2.8	NF P 18-558
specific surface (cm^2/g)	3200	3000	EN 196-6
Unit weight (kg/m^3)	1120	1300	NF P 18-554

The results of DRX analysis carried out on the dune sand of Taghit and Portland cement are presented graphically on Figure 1. It was noticed a peak of approximately 100 % of silica with dune sand and calcite for cement which translated the predominance of SiO_2 and $CaCO_3$, the others revealed elements present at small percentages.

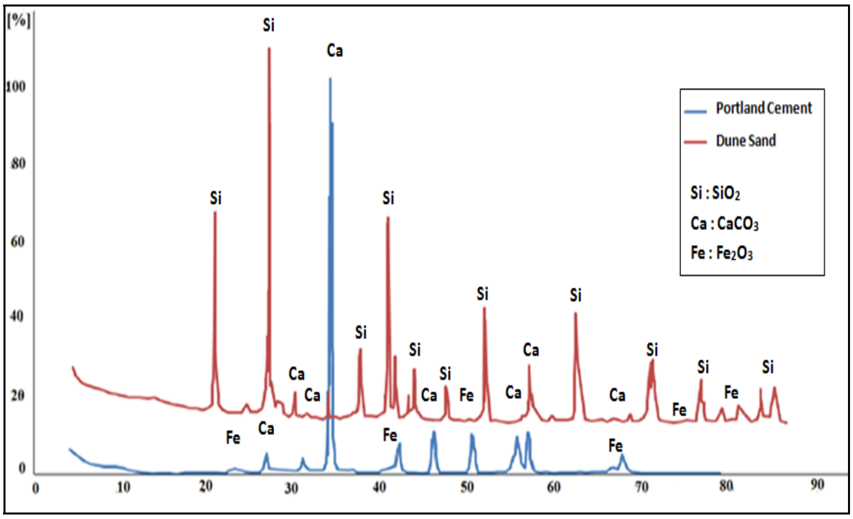
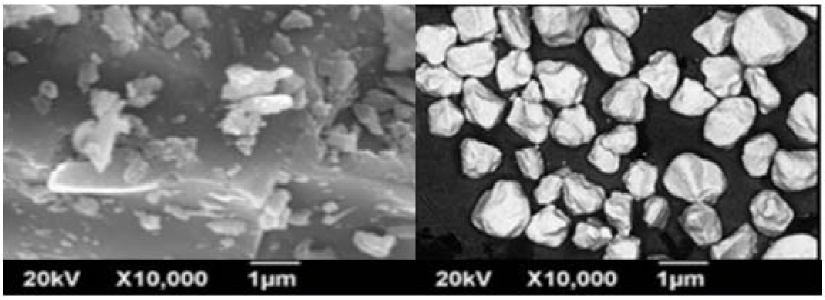


Fig. 1. XRD analyze of Portland cement and dune sand [2].

From the figure 2, it was observed that the shape of Portland cement particle is angular, dappled, broken or round forms observed for dune sand.



(a) Portland cement (b) Dune sand

Fig.2. SEM photographs of additions used [1].

Figure 3 represents the particle size distribution curves of the aggregates used.

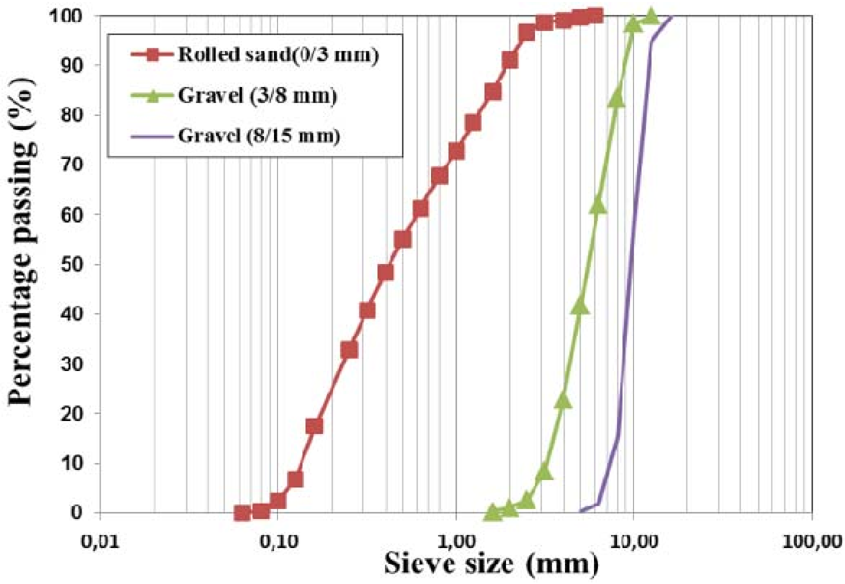


Fig.3.Particle size distribution curves of the aggregates used.

The superplastifiant SIKAPLAST 5045 / high reductive self-timer of water / for ready to use concrete and HPC are compliant with NF en 934-2.

The concrete mixtures were designed with a W/C ratio of 0.35 and a cement content of 405 kg/m^3 and G/S ratio of 1.5. The proportions of concrete value may be considered a little low for GC according to Dreux composition [11]. The final formulation HPC is given in Table 3.

Table 3 **Reference Composition of High Performance Concrete (kg/m^3)**

Composition	Dosage (kg/m^3)
Cement	450
Sand 0/3	687
Gavel 3/8	1125
Water	157
Superplasticizer (2%)	9
G/S	1.5
W/C	0.35

The sequence of mixing was as follows:

- Mixing during 30s of the dry components (aggregates, fine and cement).
- Introduction of mixing water with part of the adjuvant and to continue mixing during 1 min 30 s.
- Introduction of the remaining part of the additives and mixing during 2 min.

In this study, the dune sand is used as a fine sand (0 <0.315) has been prepared and examined to quantify the properties of HPC for the modification of sand quarry (0 <0.315) by dune sand by sand dune (0%, 25%, 50%, 100%).The mixtures having a fixed water / cement of 0.35 ratio and a constant total amount of binder of 450 kg/m3 (Table 4).

Table 4. **Mix proportion of High Performance concrete (kg/m^3)**

Dosage (kg/m^3)		HPC0%DS	HPC25%DS	HPC50%DS	HPC100%DS
Cement		450			
Dune Sand		0	103	206	412
Sand 0/3	Sand<0.315	412	309	206	0
	Sand 0.315-3	275			
Gavel 3/8		1125			
Water		157			
Superplasticizer		9			

A slump test, an air content test and a unit mass test will be done on the fresh concrete (figure 4). As the air content is known as a percentage of the mix volume, it is necessary to calculate the volume in litres of each ingredient in order to know exactly the final composition of concrete.

(a) (b)

Fig.4. Tests on fresh HPC: (a) Air content, (b) slump test.

For assessing mechanical compressive strength with RILEM standard [12], the compression test (fig.5a) breaks the test specimen between the two plates of a compression press. The press used is the ELE AUTOTEST compression machine.

(a) (b)

Fig. 5. Compression machine for (a) compressive strength test (b) Extensometric system to measure axial strain.

The modulus of elasticity corresponds to the secant modulus at 30% of the rupture stress. It is assessed with an “extensometric” system with two induction sensors which measure axial strains between two rings (12 cm of distance between the two rings). The extensometric system is shown in Fig 5b.

3. Results and discussion

The first hours of fresh concrete are very important for the performance of the concrete structure because it controls the long-term behaviour (ultimate strength compressive, elastic modulus, shrinkage, creep, and durability). A slump test, an air content test and a unit mass test will be done on the fresh concrete (Table 5).

Table 5. **Fresh properties of self- compacting mixes**

SCC mixes	Fresh properties of HPC			
	HPC0%DS	HPC 25% DS	HPC 50%DS	HPC 100% DS
Density of fresh concrete	2.450	2.456	2.464	2.474
Air content (%)	2.8	2.6	2.5	2.2
Slump (cm)	22.5	23.2	24.4	25.7

The compressive strength is an indicative feature of concrete which allows us to consider other properties. Generally, enhanced durability properties can be obtained with concretes of higher compressive strength [13]. The Fig. 6a presents the compressive strength of HPC mixes determined at different ages (7 and 28 days). Mostly, the compressive strength of HPC increased with age.

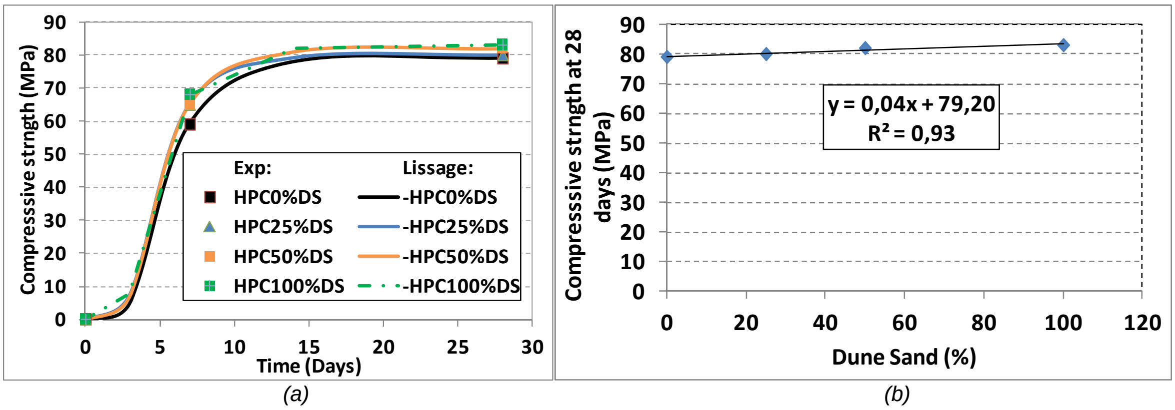


Fig. 6. Evolution of HPC compressive strength with different percentage of DS.

As can be observed, the compressive strength slightly increased with increase of amount of dune sand. This is due to the physical nature of better packing, as addition of dune sand governs the compressive strength due to the denser matrix and the better dispersion of cement grains [2,3]. The fine dune sand has improved the properties of HPC such as porosity reduced and better bonding in inter transition zone.

The Figure 6b presents the evolution of compressive strength with different percentage of fine dune sand of High performance concrete, good relationship exists between compressive strength and dune sand percentage for various mixtures of HPC which can be inferred from Figure 6b.

R^2= 0.93. R^2 = A number that reveals how closely the estimated values of equations corresponds to actual data. The compliance of above equation is justified since they were found to have R^2 = 1.

The modulus of elasticity is a parameter necessary in structural analysis for the determination of the strain distributions and displacements, especially when the design of the structure is based on elasticity considerations. This is why it was interesting to quantify its value from the influential parameters by offering a predictive model useable by engineers. However, we limited the study of its value to the date of 28 days since this corresponds to the value taken in most cases when designing concrete structures.

Models code prediction correlates directly the modulus of elasticity to the compressive strength. In order to verify the accuracy of its formula, Figure 7 presents a comparison between the increasing evolution of modulus of versus the compressive strength calculated from this model code and the experimental results obtained in this study and data collated from the available literature [5, 14, 15, 16, 17].

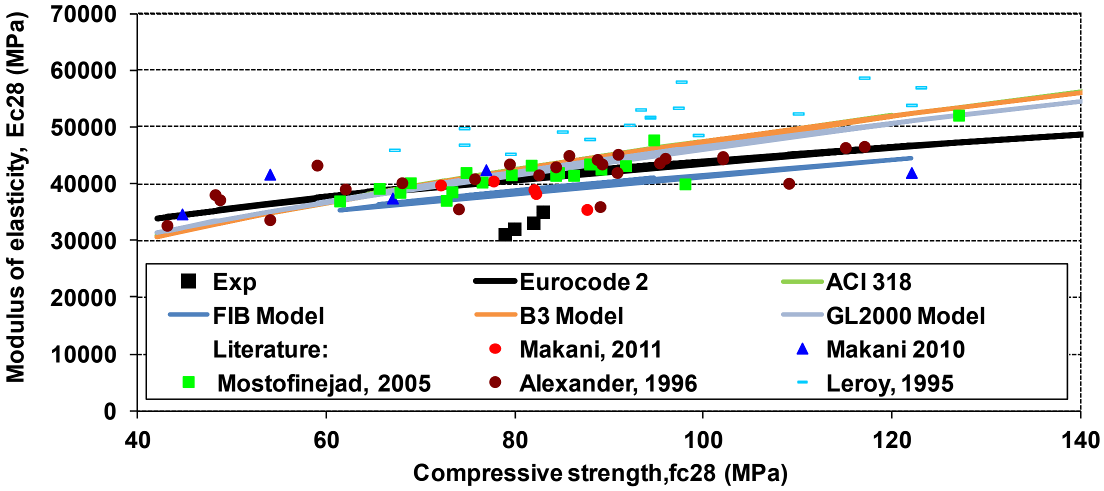


Fig. 7. Evolution of modulus of elasticity of HPC with different percentage of dune sand.

The Figure 7 illustrate a correlation between the modulus of elasticity measured at 28 days with different level of dune sand (DS).good relationship exists between both the modulus of elasticity and DS percentage for various mixtures of high performance concrete are obtained.

The models GL2000, B3, FIB 99, ACI-318, Eurocode2 are used as a model for predicting the Modulus values. The B3 model is the latest version in a number of deformation models. The first version was developed by Bazant and Baweja [9].The ACI-318 model recommended by the American concrete Institute. The model is purely empirical, based on deformations testing data representing the mean behavior for hundreds of tested specimens. The Eurocode2 is applicable for concretes having a compressive strength at 28 days lower or equal to 90 MPa. It is based mainly on code AFREM [8].

It may be noted that only the model Eurocode 2 (EN 1992-2) considering the presence / absence of mineral addition. Indeed, it is considered in this model, specifically developed for high performance concretes [6], the presence or absence of mineral addition in the concrete composition plays a major role compared to the type of cement. The ACI model takes into account in particular the density of concrete. The FIP model presents as well as mineralogical nature of the aggregates. The model B3 GL2000 considers the content of cement, aggregates and water. Although all the models use geometrical size factor translating the Specimen size, it should be noted that this one is defined differently according to the codes.

The Figure 8 shows a comparison between the accuracy of different models which is according to following equation:

$$Error\ coefficient(\%) = \sum \frac{E_{cal} - E_{exp}}{E_{exp}} x100 \qquad (6)$$

E_{cal} : Modulus value calculated by proposed models.
E_{exp} : Value of measured Modulus.

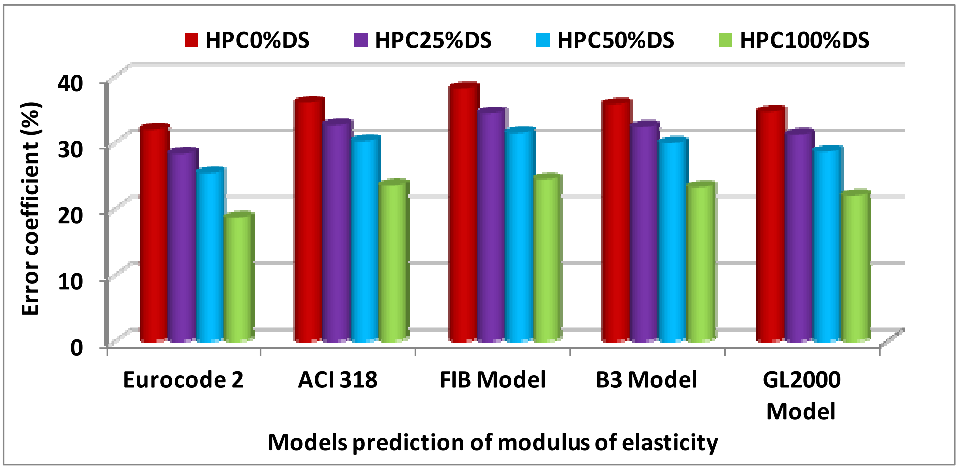


Fig.8. Error coefficients for prediction models.

The comparison between the experimental results and calculated according to FIB, ACI-318, B3 and GL 2000 model shows a similar prediction for HPC mixture. From this Figure 8 it can be observed that Eurocode 2 model has a good prediction compared to the data base of HPC mixture for HPC 100%DS (error coefficient is very low).

The error coefficient is the lowest for the Eurocode 2 models as compared to the other models for all concrete. They are more accurate model than the other models.

6. Conclusions

The experimental results of this research some known conclusions have been confirmed:

- It is necessary to estimate the workability fresh concrete (slump, air content and density test) are very important for the performance of the concrete structure.
- Linear relationships between compressive strength and fine dune sand percentage with acceptable coefficients of correlation show that by increasing the dune sand percentage compressive strength increases. The significant effect of HPC is obvious at high level of HPC100DS%.

- The value of modulus of elasticity of HPC is compared with the prediction model. It was noted difference between the experimental and estimated results for each model (Eurocode 2, FIB, ACI-318, B3 and GL 2000 model). On the other hand, the error coefficient is the lowest for the Eurocode 2 models as compared to the other models for all concrete.

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