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Effect of Dune Sand on the Properties of Reactive Powder Concrete Reinforced with Metal Fibers

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ABSTRACT

Dune sand is widely available in Algeria. Unfortunately, it is not adequately exploited, despite the interesting properties this material may exhibit. It was revealed that using this new material could significantly alleviate the pressures on the construction sector; it may also contribute to the development of the Algerian southern regions, which contain huge amounts of dune sand. It is worth mentioning that the reactive powder concrete is a novel type of concrete that possesses a high compressive strength of up to 800 MPa. This sort of concrete uses a fine particulate matter or powder that is needed for the reactions occurring between all the constituents and hence allows manufacturing high density and high-strength sand-based concrete. It should be noted that preparing reactive powder concrete requires various materials such as cement, sand, water and some additional constituents. The major part of the concrete mixture consists of fine aggregates whose characteristics play an important role in the physical and mechanical properties of the resulting material. The present study aims primarily to investigate the effects of using dune sand on the mechanical and physical properties of fiber-reinforced reactive powder concrete. In this work, river sand has been replaced by dune sand at three different substitution ratios, i.e., 40%, 50% and 60%, successively. Then, the flexural strength, ultrasonic pulse velocity, compressive strength and modulus of elasticity (dynamic and static) were examined and assessed. The experimental findings indicated that the characteristics of the resulting material were significantly enhanced when using dune sand. This allows concluding that dune sand can be employed as an effective substitute in the formulation of reactive powder concrete. Finally, the test results indicated that the ideal dune sand replacement ratio was 60%.

1. INTRODUCTION

The southern region of Algeria possesses significant renewable natural reserves of dune sand that is characterized by a fine grain size and a chemical and mineralogical composition rich in silicon. According to Diago et al. [1], the quantity of this material has not been estimated and therefore remains unknown. It has been reported that the dune sand of the western erg occupies about 6% of the Sahara desert of Algeria. It is widely admitted that sand is an essential material for making concrete. It makes up about 30% to 40% of the total mass of the concrete mixture Zenati et al. [2]. Sand plays a strategic role in ensuring the required granular continuity between cement and aggregates (gravel); it helps to produce high-strength concrete. In addition, the ever-increasing demand for aggregates has engendered a rapid depletion of sandpits and has encouraged the anarchic exploitation of sea sands, thus causing serious damage to the sensitive beach environment, along with the bad impact on natural resources (depletion) and advance of the sea over land. According to Elat et al. [3], practices in the concrete industry are conditioned by local resources and are relatively customary processes.

The reactive powder concrete (RPC) contains fine particle materials that play an essential role in minimizing voids and hence realizing high density and high strength concrete. In this context, Chadli et al. [4] found out that the materials that make up RPC ought to be smooth and must be able to interact with each other. Moreover, this reactive powder concrete is lighter than ordinary concrete because the RPC does not include coarse aggregates or stones. The average weight of ordinary concrete can vary between 2320 and 2400 kg/m^3. In this context, Richard and Cheyrezy [5] found out that the weight of RPC might be within the interval extending from 1900 to 2100 kg/m^3. As for Chadli et al. [6], they found out that the finalized concrete exhibits homogeneity, compactness, and high durability because it is made of microfine aggregates such as is silica which is able to react with other constituents at higher temperatures, during the manufacturing process. This would certainly enhance the compressive strength of concrete. Based on all these advantages, it can be said that RPC products can be made with smaller and thinner sections and without any reinforcement Mounira et al. [7]. In addition, in 2018, these same authors indicated that RPC could also be used for the implementation of prefabricated constructions [8].

Furthermore, an experimental study was carried out by Meziane et al. [9] for investigating the effect of crushed limestone sand content on the workability and compressive strength of concrete. In this regard, the performance of concrete including crushed limestone sand was compared with that of siliceous sand concrete. Later on, it was found that although the characteristics of crushed limestone sand concretes were lower than those of siliceous sand concretes, they remained comparable in terms of performance. In this context, Intaboot and Charboot [10] showed that crushed sand fines have a significant impact on the physical and mechanical properties of concrete. In this study, four different types of cement were used for the preparation of concrete, while the water-to-cement (W/C) ratio was kept constant. Then, the influence of finely crushed limestone sand on the concrete compressive strength was examined. The findings indicated that it is possible to use up to 15% of finely crushed sand without any adverse effect on the compressive strength of concrete. In addition, the possibility of using crusher dust, stone chips, and fly ash in the manufacturing of self-compacting concrete (SCC) was also experimentally investigated. Regarding Djedid et al. [11], they explored the potential of utilizing local sand that is found in large quantities in sandcrete blocks. These same authors indicated that correcting the granular distribution using a mixture of two local sands in fixed ratios allows making a sandcrete with better workability, higher compactness, and higher strength. It should be noted that when designing concrete, the properties of concrete in the fresh and hardened states significantly depend on the content and fineness of the aggregates used. In this regard, Mundra et al. [12] found out that using rock flour as fine aggregates rather than river sand could help to improve the compressive strength. With regard to Chandar et al. [13], they announced that the compressive strength of quarry rock dust concrete was relatively greater than that of similar conventional concrete mixes. As for Ali and Saikrishnamacharyulu [14], they investigated the effect of crushed stone dust as fine aggregate. They then reached the conclusion that the flexural strength of the resulting concrete was greater than that of ordinary concrete (natural sand). However, the flexural strength values started decreasing as the crusher dust content went up. On the other side, Pilegis et al. [15] revealed that if natural river sand is completely (100%) replaced with quarry rock dust, it is very likely to have similar or even better properties, such as the compressive and flexural strengths, compared with those of reference concrete (natural sand). They finally concluded that replacing fine aggregates with 50% marble powder and 50% quarry rock dust gives very good results in terms of tensile strength.

Furthermore, Chadli et al. [6] indicated that the mechanical strength of concrete incorporating 0.23% of steel fibers, 15% of slag and 23% of quartz powder exhibited the highest mechanical performance.

On the other hand, Rasheed and Aziz [16] investigated the effects of varying the steel fiber content on the properties of concrete. They announced that the optimum amount of steel fibers in the concrete mixtures changed. Indeed, it was found that when the amount of steel fibers was increased from 0% to 3%, the compressive strength of RPC rose slightly. However, when that amount was greater than 3.5%, the compressive strength of RPC remained unchanged and did not increase any further. Moreover, it was revealed that the splitting tensile strength augmented as the steel fiber content went up to 2%; however, this strength remained constant for fiber levels above 2%.

This study aims primarily to determine the physical and mechanical properties of RPC incorporating both dune sand and river sand. The main purpose of this work is to develop a fiber-reinforced reactive powder concrete (RPCF) including dune sand, which is quite abundant locally, either in a single granular phase or mixed with river sand, in various proportions. It is useful to remember that one of the main objectives is to analyze the influence of dune sand on the physical and mechanical properties of fiber-reinforced reactive powder concretes, in the fresh and hardened states.

2. EXPERIMENTAL PROGRAM

2.1 Characterization of constituent materials

This section presents the properties of the materials that are used in this study. These are mainly cement, fine aggregates (sand), waste marble powder, crushed quartz, superplasticizer, water and metal fibers.

Cement: The Portland cement (C) of type 42.5 MPa class CEM I, which was used to manufacture our reactive powder concrete (RPC), was brought from the Biskria Cement Plant located in the region of Biskra (Algeria). Its bulk density and absolute density are respectively equal to 1.01 g/cm^3 and 0.82 g/cm^3. Its chemical characteristics are summarized in Table 1.

Sand: In this study, two types of sand were used. First, the local river sand (RS) that was brought from the region of Lioua. Its apparent density, absolute density, and sand equivalent are respectively equal to 1.56 g/cm^3, 2.60 g/cm^3, and 91.01%. Second, the fine siliceous dune sand (DS) was brought from the region of Elhajeb. Its apparent density, absolute density, and sand equivalent are respectively equal to 1.50 g/cm^3, 2.61 g/cm^3, and 94.74%.

Crushed quartz: The crushed quartz (CQ) is in the form of a powder. Its grains have an average diameter between 10 and 15 μm, resulting from the grinding of highly rich silica sand (SiO_2>98%). Note that silica is generally used in glassmaking. Crushed quartz is mainly used in the formulation of ultra-high-performance fiber-reinforced concrete (UHPFRC) treated at a temperature above 90°C; it is used as a chemical supplement. It has a bulk density of 1.80 g/cm^3, absolute density of 2.64 g/cm^3 and a specific surface area of 5714.7 cm^2/g. Its chemical characteristics are reported in Table 1.

Marble powder: The marble powder (MP) was used in our tests as a mineral addition. The marble powder used is the waste from marble works, such as cutting, shaping, engraving, and grinding of white marble pieces. Its apparent density is equal to 0.97 g/cm^3, with an absolute density of 2.65 g/cm^3 and a specific surface of 5150 cm^2/g. Its chemical characteristics are given in Table 1.

Additives: The adjuvant used in our study is a new generation superplasticizer high range water reducer.

Metallic fibers: The metal fibers used are SIKA® METAL FIBERS RL-45/50-BN and are manufactured from drawn steel wire. They are certified to ISO 9001 standard. They are free and unglued.

Mixing water: Tap water, which is supplied by the drinking water network of the city of Biskra (Algeria), was used.

Table 1. Chemical characteristics of cement, marble powder and crushed quartz

Oxides (%)	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	K_2O	LOI
Cement (g)	20.62	5.31	4.94	64.24	2.01	-	1.65
Marble powder (g)	1.24	0.382	0.174	39.43	2.55	-	-
Crushed quartz (g)	94.33	1.171	1.044	1.622	0.184	0.386	1.582

Table 2. Mix proportions

Mix	RPCF1	RPCF2	RPCF3	RPCC1	RPCC2	RPCC3
Cement (g)	622.08	622.08	622.08	622.08	622.08	622.08
Marble powder (g)	62.208	62.208	62.208	62.208	62.208	62.208
Super plasticizer (g)	20.736	20.736	20.736	20.736	20.736	20.736
Fiber (2%)	12.471	12.471	12.471	0	0	0
Water (g)	136.86	136.86	136.86	136.86	136.86	136.86
Crushed quartz (g)	168.96	168.96	168.96	168.96	168.96	168.96
40%RS 60%DS	313.344 470.016	0	0	313.344 470.016	0	0
50%RS 50%DS	0	391.68 391.68	0	0	391.68 391.68	0
60%RS 40%DS	0	0	470.016 313.344	0	0	470.016 313.344

1. RS is for river sand and DS for dune sand; 2. Without fibers: control or reference RPCC and with 2% of metallic fibers: RPCF include 2% fibers; 3. RPCC1 includes 40% river sand and 60% dune sand, RPCC2 contains 50% river sand and 50% dune sand and RPCC3 includes 60% river sand and 40% dune sand; 4. RPCF1, RPCF2 and RPCF3 include 2% fibers.

2.2 Mix proportions

The formulation of RPCF is more delicate and more complex than the other types of concrete. Several concrete mix design methods exist. Some of these are the Dreux - Gorisse method, the Faury method and the Japanese method. Unfortunately, the three are not adaptable to RPCF. However, some formulations, previously recommended by companies and associations such as LAFARGE and AFGC, could eventually be applied to this type of cement. Mix proportion given in Table 2.

2.3 Mixing and sample preparation

This operation was carried out as follows:

- Put the cement, additions and dry sand in the mixer;
- Mix these dry components for 2 minutes;
- Add water and half of the superplasticizer, and then mix for 3 minutes;
- Add the remaining half of the superplasticizer, and mix again for 6 to 8 minutes at high speed until fluidization;
- Afterwards, add the metal fibers, and mix for 1 minute at low speed. Figure 1 shows the stripping and naming of specimens during fabrication.

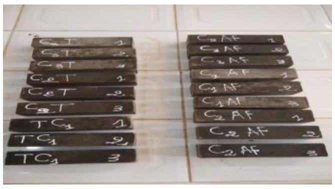

Figure 1. Stripping and naming specimens

2.4 Tests conducted

2.4.1 Testing the masses of hardened concrete

First, three specimens of dimensions (4×4×16) cm^3 were made, for each formulation of RPCF. Afterwards, following demolding, at 7 and 28 days, the specimens were taken out of the water and weighed (wet); they were next subjected to the ultrasonic non-destructive measurement test, and then to the destructive bending and compression tests. The average of the masses of the different RPCF specimens was calculated using the following formula:

$$\text{MAverage} = \sum \frac{\text{Mi}}{3} \tag{1}$$

where, $M_{Average}$ is the corresponds to the mass of the test specimen measured in [g].

2.4.2 Ultrasonic testing

Figure 2. Ultrasound device

The ultrasonic pulse velocity (UPV) test is a powerful non-destructive (NDT) technique for testing and controlling the quality of concrete materials. It also allows assessing a number of concrete characteristics in the hardened state, such as the degree of compaction, cracking, and the uniformity of pouring. The principle of the ultrasonic method consists in measuring the propagation time of the ultrasonic pulses passing through the concrete specimen as shown in Figure 2. The interpretation of the results obtained depends on the type of measurement method applied. Considering the positions of the transducers of the ultrasonic device, one can calculate the speed of propagation of the sound waves using the following equation:

$$\nu = \frac{d}{t} \tag{2}$$

where, ν is the propagation speed in [m/s] and d is the distance traveled by the signal [m], and t is the time [s].

2.4.3 Mechanical tests

Compressive strength test according to Standard NFP 15-451 [17]. Each half-test piece, which was placed between two hard metal plates at least 10 mm thick and (40 mm + 0.1) mm wide, was subjected to compression testing on the side faces of the mold, under a section of dimensions (4×4) cm^2. These plates are made of tungsten carbide. The half-test piece was placed between them so that its intact end protrudes by at least 1 cm, and the longitudinal edges of the test pieces are perpendicular to those of the plates. The plates can be guided during the test, without appreciable friction, so as to have the same horizontal projection. One of them can be slightly tilted to allow for a perfect contact between the plate and the specimen faces. Then, the compressive strength could directly be calculated using the following formula:

$$Rc = \frac{F}{A} \quad (3)$$

where, Rc is the compressive strength in [KgF/cm^2], F is the load applied in [KgF] and A is the area of the specimen in [cm^2].

Flexural tensile strength test according to Standard NFP15-451 [17]. The *flexural* and splitting *tensile strength* testing device comprises two supports with semi-cylindrical sections, 10 mm in diameter and 100 or 106.7 mm apart, on which the prismatic specimen is placed according to a lateral molding force. A third semi-cylindrical support of the same diameter, equidistant from the first two and transmitting the load F, allows applying the forces on the specimen in a uniform manner. In addition, two of the supports must be able to be slightly rotated around their centers, in the vertical plane, perpendicular to the axes of the specimens. For a concrete material not having an elastic behavior in the vicinity of rupture, it is advisable to use a corrective term of 0.6 (σt=0.6 σRf) when calculating the tensile strength of the concrete sample. Then, the flexural tensile strength is calculated according to the expression given below:

$$Rf = \frac{3PL}{2bh^2} \quad (4)$$

where,
Rf: flexural tensile strength [KgF/cm^2];
P: the load at the fracture point [KgF];
L: the length of the support span [cm];
b: is width [cm];
h: is thickness [cm].
The Figure 3 shows the pressure testing machine.

Figure 3. Pressure testing machine with bending compression and tensile device

Modulus of Elasticity. The speed of propagation of the ultrasonic wave in a concrete depends on the modulus of elasticity of the concrete and its density Khattab et al. [18]. To determine the modulus of elasticity according to the speed of sound and the density [19].

The dynamic modulus of elasticity (Ed) can be determined by Eq. (5), while the static modulus of elasticity (Ec) can be determined by Eq. (7).

$$Ed = \frac{(1+\mu)(1-2\mu)}{(1-\mu)} \times \gamma \times \nu^2 \quad (5)$$

where,
γ: concrete density (experimental);
μ=0.2 (Poisson's ratio);
ν: speed of sound [Km/s].
The density can be estimated by:

$$\gamma\nu = 1.67 + 0.155 \quad (6)$$

$$Ec = \kappa \times \nu^2 \quad (7)$$

$\kappa = 1.68$ for t ≥ 180 days
$\kappa = t^{0.1}$ for t < 180 days
with t: age of the concrete in days;
ν [Km/s]: speed of sound in concrete.
Ec [GPa]: secant static modulus of elasticity according to SIA 162/1.

3. RESULTS AND DISCUSSIONS

3.1 Masses of hardened concrete

The prismatic specimen masses obtained before and after storage in water are shown in Figure 4.

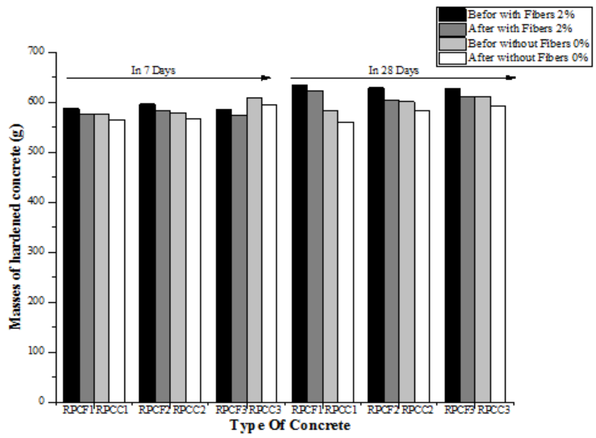

Figure 4. Histogram representing the masses of prismatic specimens before and after storage in water, at 7 and 28 days

This figure indicates that the first formulation of RPCF1 and RPCC1 (40% RS and 60% DS), with and without fibers, at 7 days and 28 days, presents the greatest masses after storage in water. These masses are equal to 634.14 g for RPCF1 with 2% fiber and 583.25 g for the control specimen (without fibers) at 28 days, and 587.49 g for RPCF1 with 2% fiber and 577.66 g for the control specimen at 7 days. The same remark is made for the second formulation (50% RS and 50% DS) and third formulation (60% RS and 40% DS).

This histogram clearly show that the masses of the different RPC specimens increased over time after their storage in water. This mass increase was certainly due to the penetration of water into the specimen and the filling of the available pore space by water of the conservation medium. It should be noted that the greater the quantity of water is absorbed, the more significant the porosity of the material is. This result was also confirmed by Kewalramani and Khartabil [20].

3.2 Non-destructive testing

After the weighings, the prismatic specimens were tested by ultrasound, on the 7th and 28th days. The ultrasound pulse velocity measurements were carried out by evaluating the time of travel of the pulse on a series of three specimens, for each RPCF formulation. In addition, the ultrasound velocity measurements were performed in direct transmission mode. It should be noted that this mode provides the maximum energy. These measurements were conducted using an ultrasonic tester. For the sake of accuracy, it was decided to repeat each test three times on each specimen. Then, the average of all three measurements was calculated for each RPCF specimen. In order to better appreciate the speed results, it was deemed interesting to calculate the average speeds obtained for the three specimens, and for each formulation. The findings are illustrated in Figure 5.

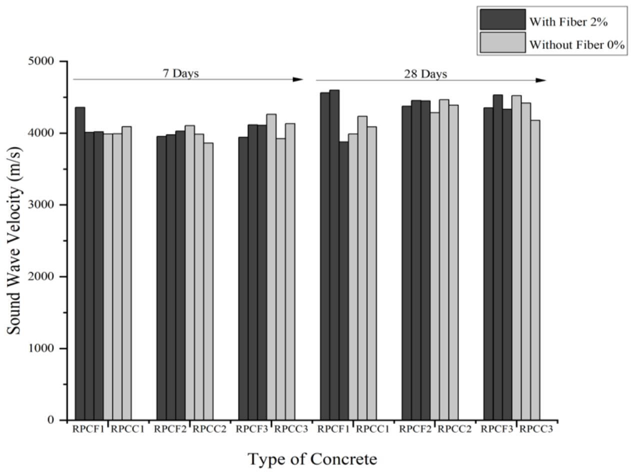

Figure 5. Evolution of the sound wave velocity of the different RPCFs at 7 and 28 days

The results shown in Figure 5 allowed making the following observations:

For the first formulation (40% RS-60% DS), a significant velocity increase took place in RPCF1 with 2% fiber as compared to that of RPCC1 (control specimen);

For the second formulation (50% RS-50% DS), a considerable increase in the sound wave speed was noted for RPCF2 with 2% fiber. Similarly, a high increase in the sound wave speed was reported for the control specimen RPCC2 as compared to that of the first formulation.

Similar remarks were also noted for the third formulation (60% RS-40% DS) at 28 days. However, this third formulation RPCF3 with 2% fiber showed a wave velocity decrease at 7 days; it is smaller than that of the control specimen RPCC3.

Furthermore, the behavior of compositions 1, 2, 3 could also be explained by the high or even optimal compactness of the RS and DS mixtures. It should be noted that the finer dune sand grains filled the voids between the coarse aggregates of the river sand.

It should also be mentioned that the results obtained for the RPCFs under study are of the same order of magnitude as those found for RPCFs with a very good compactness.

All these findings were observed when the river sand was replaced by dune sand. It can therefore be concluded that the dune sand provides the concrete with a good compactness, as its fine grains fill the voids that are present within the cementitious matrix. These results were also confirmed by Lorenzi et al. [21] and Climent et al. [22].

3.3 Compressive strength

The compressive strength test was conducted on RPCF concrete specimens of dimensions (4×4×16) cm^3. For this, nine samples were tested, for each formulation, and at different ages. The results obtained are presented in Figure 6.

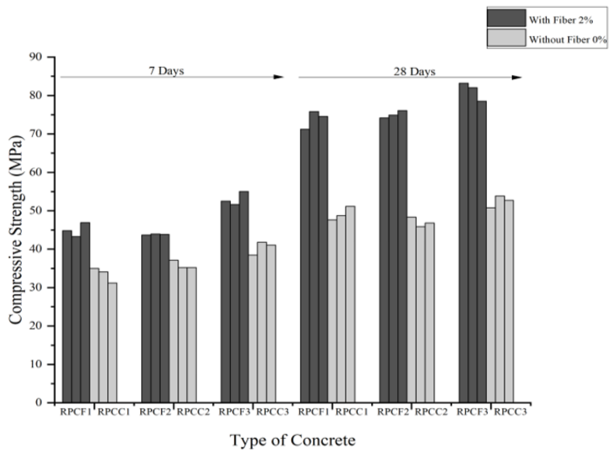

Figure 6. Effect of varying the river sand (RS) content on the compressive strength of RPCF, at 7 and 28 days

It should be mentioned that the RPC, with and without fibers, for each variant, was taken from the nine samples that had previously been manufactured. The average compressive strength was assessed at 28 days and was found between 49.18 and 81.26 MPa. The results obtained indicated that the greatest compressive strength value was found for RPCF3, which contained 60% of river sand and 40% of dune sand, while the lowest value was for RPCF1, which included 40% of river sand and 60% of dune sand. Moreover, Figure 6 clearly indicate that the compressive strength of fiber-reinforced reactive powder concrete increased between the ages of 7 and 28 days. These results were also confirmed by Indrayadi et al. [23] and Ait Medjber et al. [24].

Similarly, Mounira et al. [7] found out that the addition of 2.5% of metallic fibers causes a compressive strength increase of 18.12% over that of non-fibered concrete, at 28 days.

3.4 Flexural strength

It is useful to remember that the purpose of adding metal fibers in the concrete mixture is to improve the flexural tensile strength.

According to the results shown on the histograms represented in the Figure 7, the introduction of fibers into concrete allows increasing the mechanical resistance of concrete to traction, for the different dune sand contents. This would also enhance the actual tensile strength value.

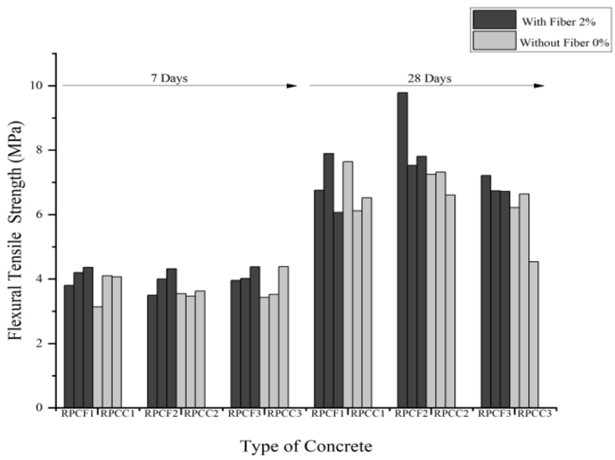

Figure 7. Effect of sand percentage variation on the flexural tensile strength of RCPFs, at 7 and 28 days

It is worth noting that the fiber-free concrete systematically exhibited strength values lower than those of the fiber-reinforced concrete. Regarding the effect of the granular composition on strength, a quasi-similarity between the different compositions was noted. According to Tebbal et al. [25] and Hachemi et al. [26], the best strength value was recorded for the RPCF sample incorporating 50% RS and 50% DS, at 28 days, which indicates that both types of sand give good results. In order to confirm the positive effect of dune sand on the mechanical performance of concrete, we can mention the improvement in the flexural strength of the concretes under study in comparison with that of the control concrete. Indeed, the average flexural strength passed from 30 to 40%. This is certainly due to the fact that the addition of finely ground dune sand affects the pozzolanic reaction and hydration reactions of the previously well-dispersed cement grains with portlandite hydroxide; this would certainly modify the growth rates and morphology of the finely ground dune sand. This result confirms the findings of Ahmed et al. [27] and Cai et al. [28].

3.5 Modulus of elasticity

Through equations, it is possible to apply the data previously available from the results of the compression and the speed of the sonic waves. We obtain the following histograms.

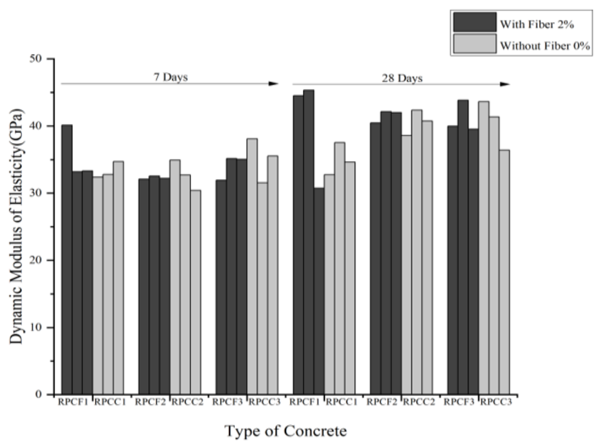

Figure 8. Effect of sand percentage variation on the dynamic modulus of elasticity of RCPFs, at 7 and 28 days

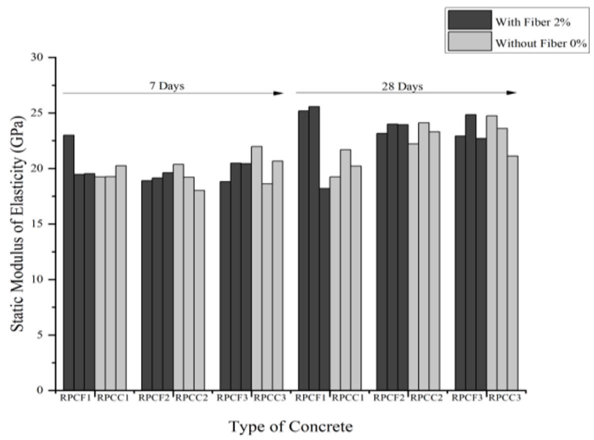

Figure 9. Effect of sand percentage variation on the static modulus of elasticity of RCPFs, at 7 and 28 days

It is clearly shown in Figures 8 and 9, which includes the effect of river sand on the Elasticity modulus, that the addition of fibers clearly increases the value of the E modulus.

Whether in 7 days or in 28 days, it turns out that all types of concrete have a lower modulus of elasticity than fiber-reinforced concrete.

The highest value in 7 days to the dynamic modulus of elasticity is given for concrete with 40% RS, 60% DS, 2% fiber, while the lowest value is given for concrete with 50% RS, 50% DS, by the same principle, the highest value is given after 28 days for the same concrete (40% RS, 60% DS), while the minimum value varies to become concrete with 60% RS, 40% DS.

In this order, the values remain in relation to the static modulus of elasticity - when we talk about the difference between the dynamic and static E coefficient, we see that it is always and for all types of concrete that the dynamic modulus is greater than the static modulus, and this was proven by Nematzadeh and Poorhosein [29], where he explained that this is due to Concrete components do not behave like flexible linear materials and are therefore negatively affected by compression and stress applied and hence on the static modulus, but these effects are less important for the dynamic modulus because RPC concrete has a homogeneous material nature, Washer et al. [30].

Raza et al. [31] say that a-fibers providing confinement to the binder matrix which controls axial strain and confining the binder matrix to specification vertical strain under compressive loads. The way the elastic method of RPC with the incorporation of fibers and since the modulus of elasticity and the compressive strength are strongly dependent on each other allows a high degree of accuracy to be achieved.

Nematzadeh and Poorhosein [29] also found that the trend of UPV variations is very similar to that of the static modulus of the samples, suggesting that the velocity of the ultrasonic pulses is part of the elastic properties of materials since the more fibers there are of steel. The more the samples contain, the larger the volume for fibers, both types of dynamic and static modulus increase. Contrary to what is known, Simões et al. [32] found that for steel fibers the dynamic Young's modulus is close to the value measured in the reference mixture, except at the highest dose where a decrease of 5% (compared to the reference mixture) was observed. His results agreed with results reported by Sahin and Köksal [33] and Olivito et al. [34], where the modulus of elasticity did not appear to change significantly with the presence of steel fibers.

4. CONCLUSIONS

This study allowed us to highlight the potential use of dune sand, which is available in abundance in Algeria, for the development of fiber-based reactive powder concretes that are well known for their very interesting mechanical behavior when they incorporate dune sand. The use of dune sand as a constituent, in different proportions, in addition to river sand in the manufacture of RPC was thoroughly assessed. Examination of different formulations allowed us to better appreciate the effects of the nature and percentage of sand used on the physical and mechanical characteristics of the formulated RPCs. For this, three compositions were selected, namely (40% RS-60% DS), (50% RS-50% DS) and (60% RS-40% DS), in order to be able to identify the content levels of dune sand that are acceptable for the manufacture of RPCs with and without metal fibers.

Based on the results obtained, the following conclusions can be drawn:

The use of dune sand in the formulation of RPC gives strength values higher than those obtained with river sand. As dune sand is available in abundance in our country, it can then be considered as a natural resource that can contribute to national economic growth. It is also noteworthy that choosing very small aggregates allows achieving an optimized granular skeleton with good compactness and better mechanical resistance.

Moreover, the addition of fibers in the concrete mixture makes it possible to systematically obtain better compressive and bending strength values. Adding metal fibers to the mix increases the value of dynamic and static modulus of elasticity. Moreover, UPV differences show a similar trend to these changes, indicating that the ultrasonic pulse velocity is an elastic property of materials, all the concretes studied. All the concretes studied in this work showed sound propagation velocity values greater than 3200 m/s, which indicates that they all have a good compactness and a high mechanical strength. Note also that the best compressive strength value was obtained for RPCF3 (60% RS + 40% DS). It was found that replacing part of river sand by dune sand in the mixture could significantly enhance the mechanical performance of UHPCs. This would also contribute to saving an overexploited material (river sand) by replacing it with an abundant and underexploited material (dune sand).

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NOMENCLATURE

M Average	Mass of average of 3 samples of concrete, g
Mi	Mass of each sample, g
ν	Speed of sound, $Km.s^{-1}$
d	Distance, m
t	Age of the concrete, days
Rc	Compressive strength, $KgF.cm^{-2}$
F	Load applied, KgF
A	Area, cm^2
Rf	Flexural tensile strength, $KgF.cm^{-2}$
P	Load at the fracture point, KgF
L	Length of the support span, cm
b	Width, cm
h	Thickness, cm
Ed	Dynamic modulus of elasticity, GPa
Ec	Static modulus of elasticity, GPa

Greek symbols

ɤ	Concrete density, t. m^{-3}
μ	Poisson ratio

Subscripts

RPC	Reactive Powder Concrete
RPCF	Fiber-reinforced Reactive Powder Concrete
CEM I	Portland cement type
SiO_2	Silicon dioxide
Al_2O_3	Aluminum oxide
Fe_2O_3	Ferric oxide
CaO	Calcium oxide
MgO	Magnesium oxide
K_2O	Potassium oxide

LOI	Loss-on-ignition	NDT	Non-destructive technique
RS	River Sand	UPV	Ultrasonic Pulse Velocity
DS	Dune Sand		