Mechanical performances and durability analysis of sand concrete modified with nano-silica

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Received: 05/2023 **Published: 10/2023**

Abstract:
This work consists of the study of the evolution of the durability of sand concrete containing two mineral additions (crushed dune sand and nano-silica (NS)) in four storage media (free surface, plastic film, tap water and ground water).The potential negative effects of adding these alternative materials can be reduced by adding nanosilica to the cementitious system at very low quantities. This study evaluates the feasibility of using these alternative materials and nano-silica (NS) in producing lightweight aggregate concretes .The first step of our study is the characterization of the constituents used in the perfection of the sand concrete, then we study the effect of the additions of nano-silica (NS)with a percentage of 2% and dune sand powder from the region of Ouargla (5%, 10%) and the combination between two additions (2%NS+5%SDP; 2% NS +10%SDP). Thus, tests of flexural and compressive strength at 7, 28, 90 and 120 days are carried out in order to estimate and evaluate the durability. The results obtained in this experimental study allow us to say that sand concrete with 5SDP 2 NS or 10SDP 2 NS has a stable compressive strength after 90 days in tap water and groundwater. These sand concretes show a positive improvement in strength at all times in the storage medium "plastic film".

Keywords: **durability, sand concrete, mineral additions, crushed dune sand, nano-silica (NS), preservation media, strength.**
DOI Number: 10.48047/nq.2023.21.7.nq23039 **NeuroQuantology2023;21(7):420-431**

Introduction

The durability of reinforced concrete structures is a very important factor in the field of civil or industrial engineering, because the alterations of concrete are varied; they reach either the cement matrix or the reinforcements, and sometimes both. The origins of these alterations are numerous, including: the placing, the mechanical strength of the concrete at 28 days, the cracks formed under the effect of the stresses applied to the structure and the aggressive agents of the external environment.

Algeria, especially the south, is rich in natural materials, which can be used directly in the construction field. Their properties should be studied in order to extend their use. Among these materials, which can be exploited, and which we are going to study, sand of dune is available in great quantity and the studies of the valorization of this material is inexistent in the field of construction, and we also add in this study the silica smoke. The main objective of this study is to make a contribution to the evaluation of the effects of mineral additions such as crushed dune sand and nano-silica (NS)on the durability of sand concrete.

Methods and materials

Construction sand

The construction sand used is from Djamaa -El Oued located 211 km north of Ouargla.

The following table and curve represent the results of the different tests on the sand.

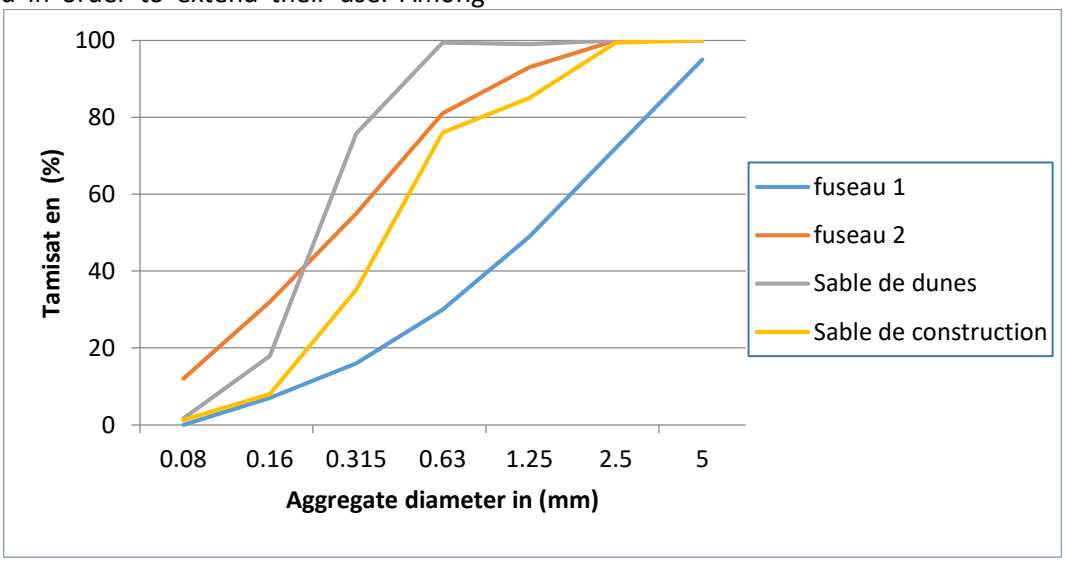

Figure 1. Trigonometrical curve of the sand of Djamaa -El Oued.

Physical characteristics of the construction sand used

Table 1. Characteristics of building sand

M_f	$M_{app}(g/cm^3)$	$M_{abs}(g/cm^3)$	ES_v (%)	ES_p (%)	F (%)	C_u	C_c
2.08	1.65	2.54	71.14	73.43	1.99	3.15	1.96

Crushed dune sand

Sand is a product of the slow disintegration of rocks under the action of erosive agents such as air, rain, etc. This material is found in large quantities in the Saharan regions. Dune sand has long been used in the execution of embankment works, foundations and road works.

We used a dune sand from SidiKhouildOuargla, which is a fine golden sand whose maximum dimension of the large grains is 2mm. We used the sand in the form of powder through a crusher of the university OUARGLA and sieving with a sieve of diameter 0.08mm.

Figure 2. The crushing stages of dune sand.

- Apparent density: 0.960 g/cm^3.
- Absolute density: 2.55 g/cm^3.
- Blaine's specific surface: 5304 cm^2/g.

The chemical analysis of the powdered dune sand which is carried out at LTPS Ouargla is represented in the table below:

Table 2. Chemical analysis of dune sand powder.

	NaCl %	$CaSO_4$ %	SO_3^{-2} %	SO_4^{-2} %	$CaCO_3$ %	Insoluble%
SDP	0.418	6.263	1.166	1.400	0.00	102.2

Nano-silica (NS)

In this study, NS having 99.5% SiO2 content, were utilized. The NS were synthesized in the laboratory of KasdiMerbahOuargla University. The properties of NT and NS are given in Table 3.

Figure 3. Nano-silica (NS)used.

The chemical analysis of the nano-silica (NS)which is carried out at LTPS Ouargla is represented in the table below [GUEMMOUDA,K and ZOUZOU,L.2019]:

Table 3. Chemical analysis of silica fume. [GUEMMOUDA,K and ZOUZOU,L.2019]

Properties	OPC	**Nano silica**
Physical		
Form	Powder	Powder
Specific gravity	3.15	2.2
Bulk unit weight (kg/m^3)	1140	2200-2600
Initial setting time (min)	85	-

Final setting time (min)	265	-
Specific area (cm^2/g)	3390	-
Particle size (nm)	-	20± 5
Melting point (°C)	-	1600
Boiling point(°C)	-	2230
Molecular weight (g/mol)	-	60.08
Color	Gray	White
Chemical compositions (%)		
SiO_2	20.86	99.5
Al_2O_3	6.17	-
Fe_2O_3	3.05	-
CaO	61.89	-
MgO	2.88	-
SO_3	2.67	-
K_2O	0.86	-
Na_2O	0.83	-
LOI	0.97	-

The chemical composition of the cement used is shown in the table below:

Table 4. Physical properties of cement.

Normal consistency (%)	Blaine fineness(cm^2/g) (NA231)	Absolute density g/cm^3	Bulk density g/cm^3	Time to set (min)	End of set time (min)
27.5	3454	3.14	1.0374	180	285

Table 5. Chemical analysis of cement [data sheet].

Fire loss (%) (NA5042)	Sulphate content (SO_3) (%)	Magnesium oxide content MgO (%)	Chloride content (NA5042) (%)
0.5 à 3%	1.8 à 3	1.2 à 3	0.01 à 0.05

Table 6. Compressive strength of cement [data sheet].

2 days (MPa)	28 days (MPa)
≥ 10	≥ 42.5

Compositions used

In our work, we prepared about 144 specimens for the physical and mechanical characterization of sand concrete made with different percentages of nano-silica (NS)and dune sand powder. The nomenclatures named in the work are given:

- **C**: Cement.
- **SDP**: Powdered dune sand.
- **NS**: nano-silica
- **E**: Mixing water.
- **SC:** Construction sand.

According to the studies carried out by GUEMOUDA K and ZOUZOU L, the following compositions give the best results in terms of resistance

Table 7. compositions used for sand concrete.

Composition	E/L	C %	SDP %	NS %
C1	0.48	100	0.0	0.0
C2	0.5	93	5	2
C3	0.5	88	10	2

The following table shows the quantities of the compositions in cubic metres (m3) of sand concrete:

Table 8. The quantities of sand concrete compositions (m^3).

Composition	C (kg)	SC (Kg)	E (Kg)	NS (Kg)	SDP (Kg)
C1	491.07	1473.21	235.71	0	0
C2	454.68	1466.70	244.44	9.78	24.44
C3	430.22	1466.70	244.44	9.78	48.88

Preparation of the specimens

The specimens are prismatic in shape with a square cross-section (40 x 40 x 160) mm. They must be molded as soon as possible after the sand concrete has been made. With the three-cell metal mould and its riser firmly attached to the impact table, the first of two layers of sandcastle is introduced. The layer is spread evenly using the large spatula and then tightened with 60 impacts. The second layer is then introduced, level with the small spatula and clamped again with 60 impacts.

The mould is removed from the impact table, and after the rise has been removed, the excess sandcastle is removed by leveling. The surface of the specimens is then smoothed.

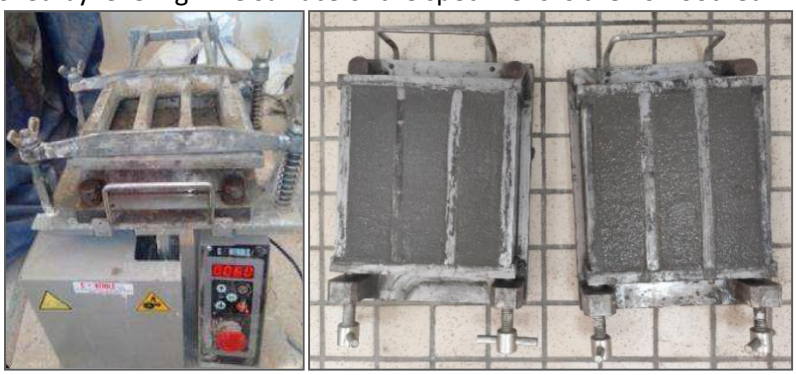

Figure 4. Impact table and specimen moulds (40x40x160) mm.

Specimen storage media

After the demoulding of the specimens after 24 hours, the specimens (40x40x160) mm were stored in the different media "open air, plastic films, tap water, and ground water" for 7, 28, 90 and 120 days.

Results and Interpretations

In this part, the results of the mechanical resistance tests (extramural and compressive), which were carried out on sand concrete in the dry state using the equipment available in the laboratory of the Civil and Hydraulic Engineering Department, are presented and analyses. The following abbreviations were used:

AL: the storage medium of the "free area" specimens.

FP: storage medium for "plastic film" specimens.

ER:the storage medium for "tap water" specimens.

5SDP 2NS: sand concrete with 5% dune sand powder plus 2% nano-silica (NS)

10SDP 2NS:sand concrete with 10% dune sand powder plus 2% nano-silica (NS)

Table 9. Bending strength results.

Conservation area	Composition	Flexural strength (MPa)			
		7 days	28days	90 days	120days
	M C	6.01	6.95	5.94	5.41
Free air	5SDP 2NS	5.39	5.86	5.39	5.39
	10SDP 2NS	4.53	4.61	5.24	4.69
Plastic film	M C	5.24	5.78	6.80	7.11
	5SDP 2NS	4.45	6.10	6.10	7.26

	10SDP 2NS	3.44	5.47	5.63	7.34
Flush water	M C	6.95	10.00	9.14	8.44
	5SDP 2NS	6.25	7.73	7.81	8.67
	10SDP 2NS	6.09	7.5	8.70	8.70

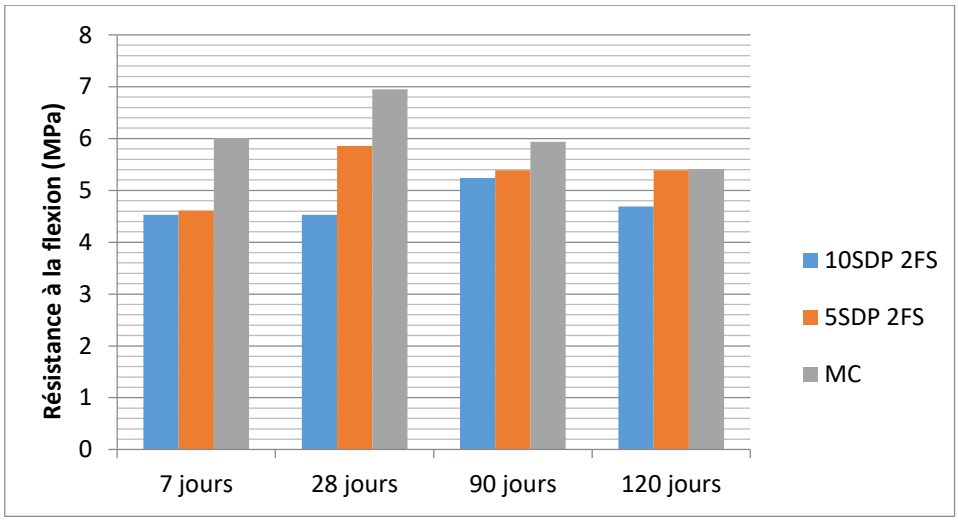

Figure 5. Extramural strength of specimens kept in free area.

From figure 5, we notice that there is a positive evolution of all the sand concretes in the 7 to 28 days, but we notice a drop in stress of the MC and 5SDP 2 NS after 28 days. Although the 10SDP 2 NS sandcastle showed an improvement in mechanical strength at 90 days, at 120 days we notice a drop in mechanical strength of all the sandcastles. This may be due to the dryness of the sandcastle due to the temperature rise in July, although the 5SDP2 NS sandcastle shows a stability in strength.

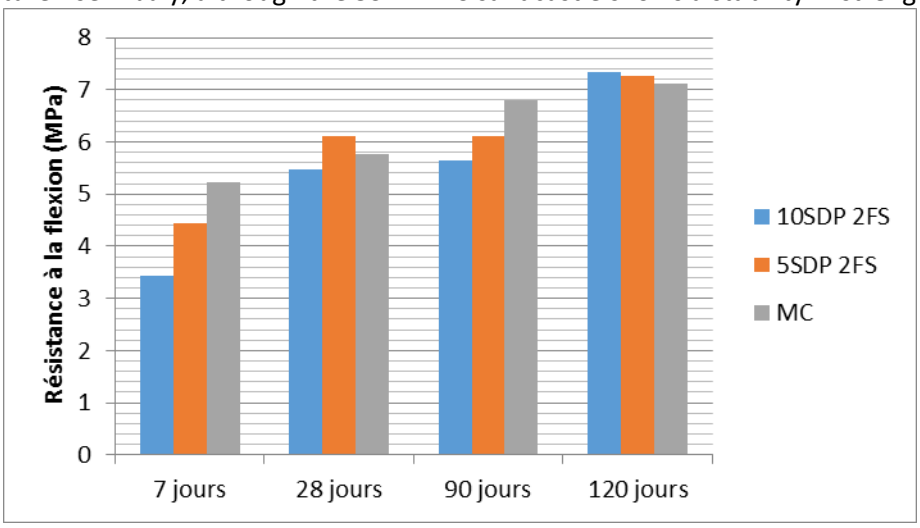

Figure 6. Extramural strength of specimens retained in plastic film.

From Figure 6, we can see that there is a positive stress evolution of all sandcastle in the period 7-28 days and 90-120 days. While we observe the stability of strength of sand concrete with 5SDP 2 NS and 10SDP 2 NS in the period 28-90 days, and for the classical sand concrete we notice a positive evolution of the stress in the period 28-90 days.

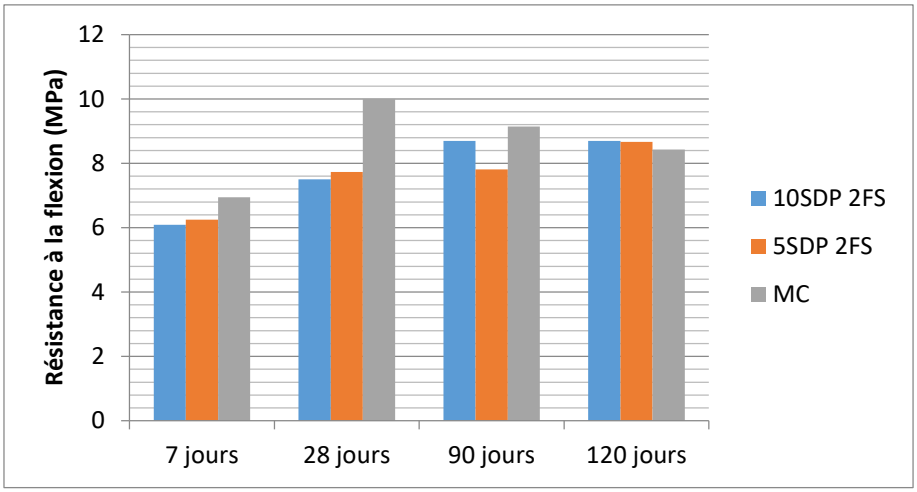

Figure 7. Extramural strength of specimens stored in tap water.

According to figure 7, we notice that there is a positive evolution of mechanical resistance of all the sand concrete in the period of 7-28 days, but after 28 days we observe that there is a fall of constraint for MC on the other hand 5SDP2 NS presents an improvement of resistance and 10SDP2 NS presents a stability of mechanical resistance.

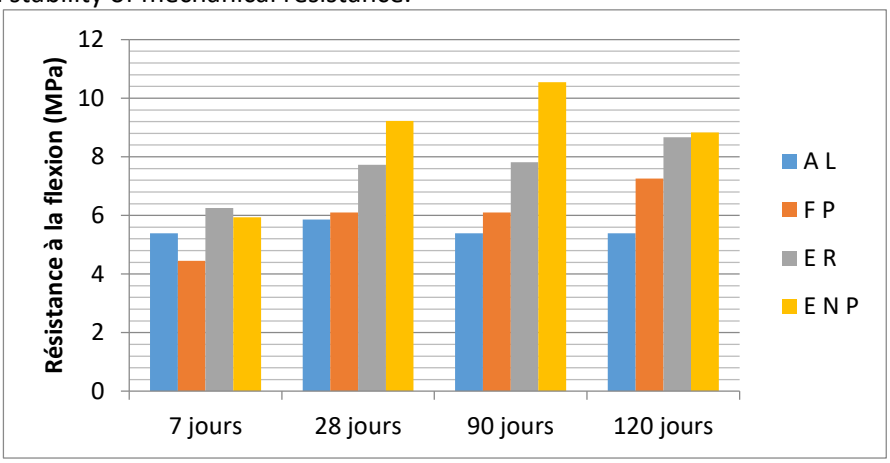

Figure 8. Extramural strength of sandcastle specimens with 5% SDP and 2NS in different media.

From figure 8, we notice that the sand concrete specimens with 5% SDP and 2% NS in the ENP medium at 90 days give the best result from the strength point of view, but there is a drop in stress after 90 days. While the specimens in E R or F P show a positive evolution of the mechanical strength at all ages. When the specimens in A L give the lowest stress values but they are almost stable after 28 days.

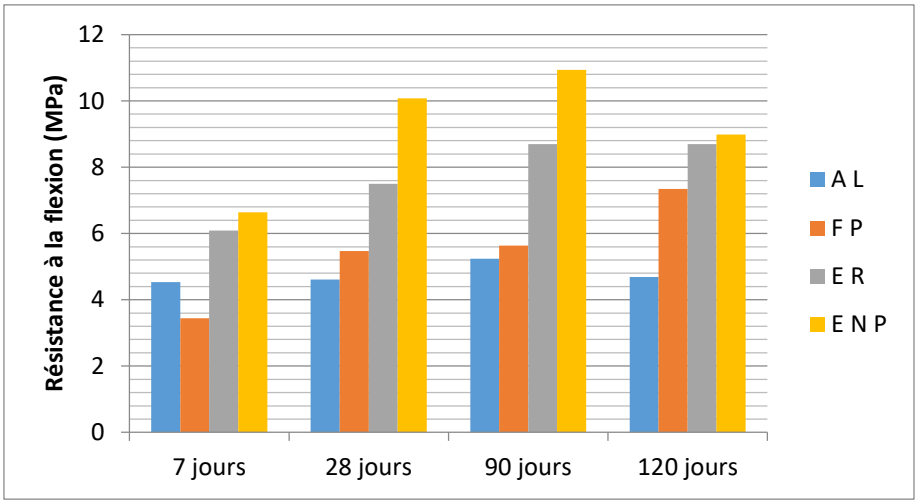

Figure 9. Extramural strength of sand concrete specimens with 10% SDP and 2NS at different media.

From Figure 9, we observe that there is a positive evolution of the specimens in ER at the period 7-90 days, after 90 days there is a stabilization of the stress. Although the specimens kept in ENP show the good result compared to the others, we notice a drop in stress at the period 90-120 days. The specimens in the F P storage medium show an improvement in mechanical strength at all ages. It can be seen that the specimens at A L give the lowest stress values.

It can be seen that the conventional sand concrete and the sand concrete with 10SDP 2FS give the best result in extramural strength, but a drop in strength of all sand concretes can be seen, although the sand concretes with 5SDP 2 NS and 10SDP 2 NS show strength stability at 90-120 days.

Table 10. Compressive strength results.

Milieu de conservation	Composition	Compressive strength (MPa)			
		7 days	28 days	90 days	120 days
	M C	21.25	22.06	17.52	16.46
Free air	5SDP 2NS	16.20	18.91	21.86	23.09
	10SDP 2NS	16.65	18.33	22.39	17.79
Plastic film	M C	20.51	22.29	15.48	12.70
	5SDP 2NS	15.31	15.42	20.48	20.65
	10SDP 2NS	16.29	17.36	18.76	27.89
Flush water	M C	28.50	31.66	32.76	30.90
	5SDP 2NS	29.47	30.52	34.48	34.48
	10SDP 2NS	25.78	34.24	37	36.98

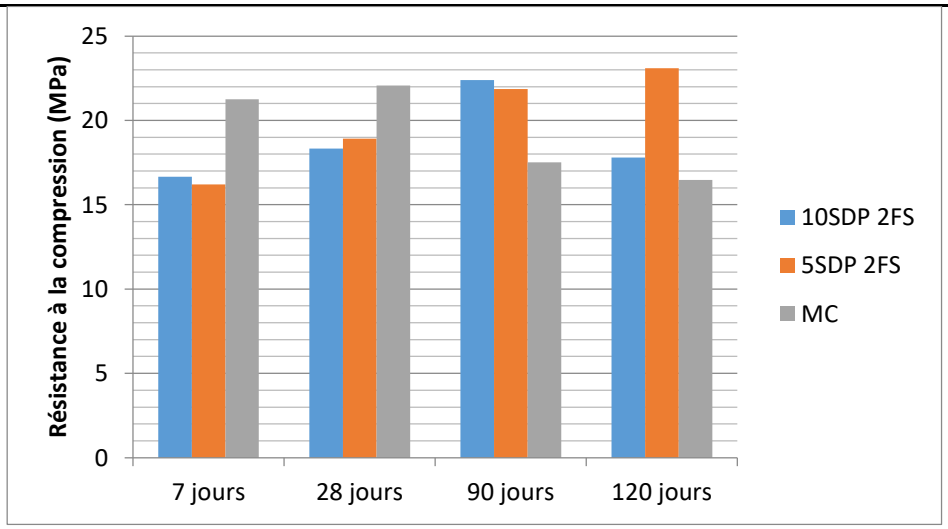

Figure 10. Compressive strength of the specimens kept in free area.

From figure 10, we notice that there is a positive evolution of strength for all the sand concretes at the period 7-28 days, but we notice a drop in stress of the MC after 28 days and we notice a drop in stress of the 10SDP2 NS sand concrete after 90 days, on the other hand the 5SDP 2NS sand concrete showed a positive evolution of stress at the period 90-120 days.

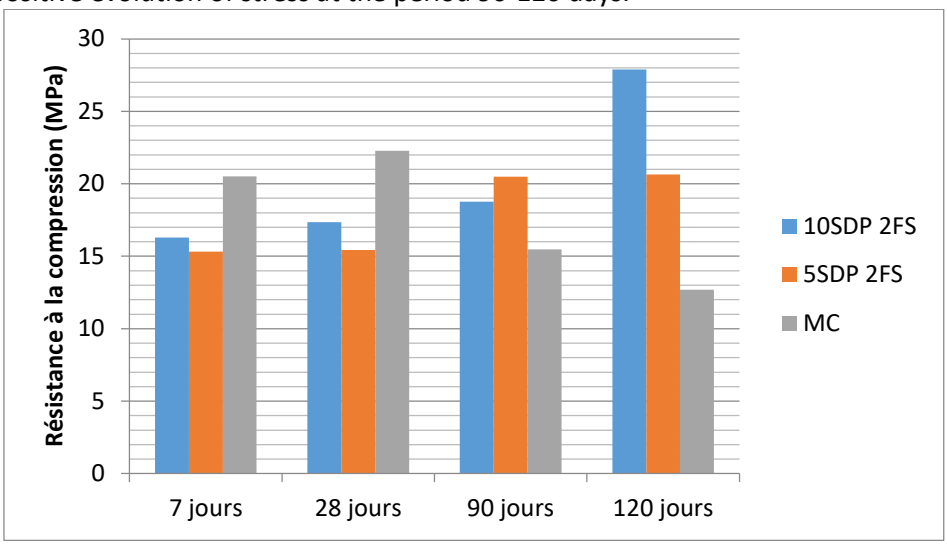

Figure 11. Compressive strength of specimens retained in plastic film.

From figure 11, we notice that the sand concrete with 5% SDP+2% NS and 10% SDP+2%NS gives a positive strength evolution at all ages. An improvement in the mechanical strength of M C is noticed, but there is a drop in stress after 28 days.

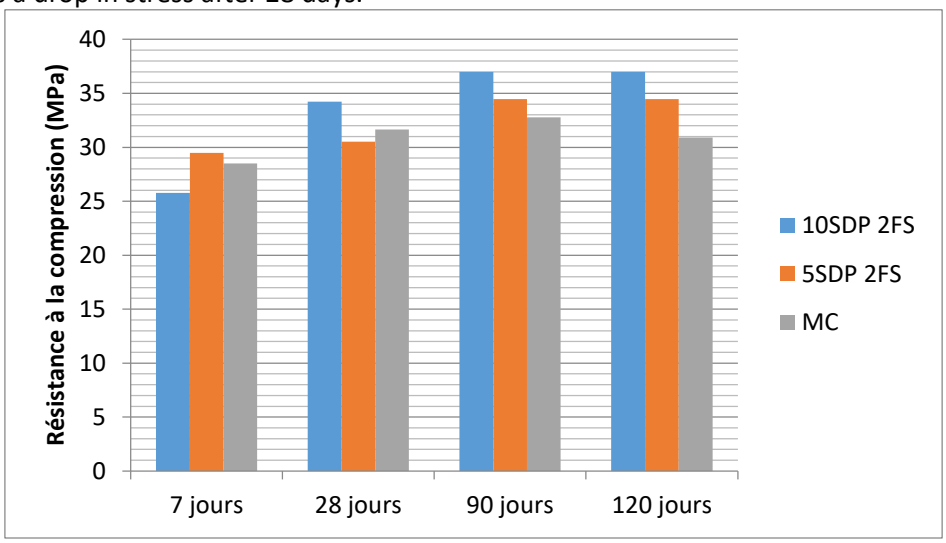

Figure 12. Compressive strength of specimens stored in tap water.

From figure 12, we notice that there is a positive evolution of strength of all the sand concrete at the period 7- 90 days. After 90 days, we notice that there is a drop in MC stress, and for the 5SDP2 NS and 10SDP2 NS sand concrete, we observe that there is a stability of stress at this period.

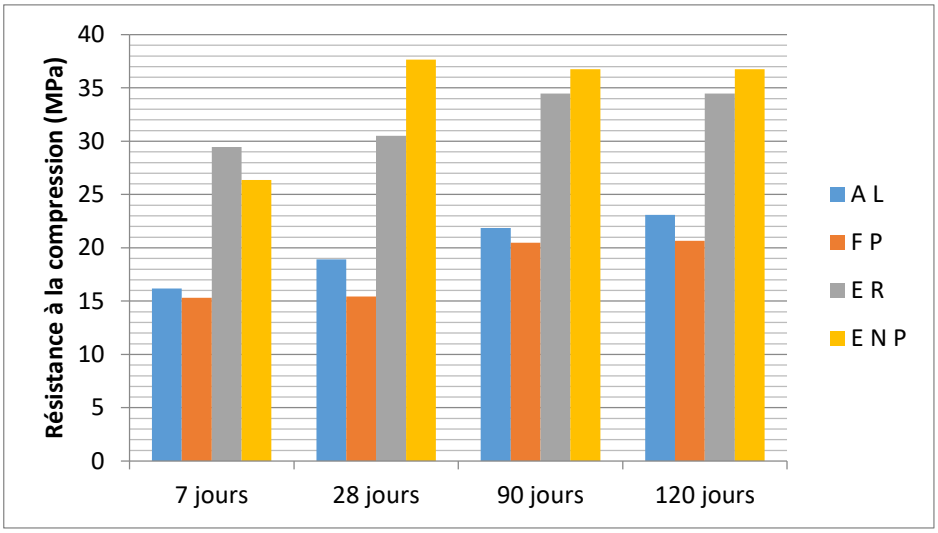

Figure 13. Compressive strength of sand concrete specimens with 5% SDP and 2NS at different media.

From figure 13, we observe that the specimens kept in A L, F P, and E R give a positive evolution of the mechanical strength at all ages, except for the specimens in ENP which give an improvement of the strength at 28 days, but we notice a drop in stress after 28 days with a stability of stress at the period 90-120 days.We note that the OE medium gives the best mechanical strength results at all ages.

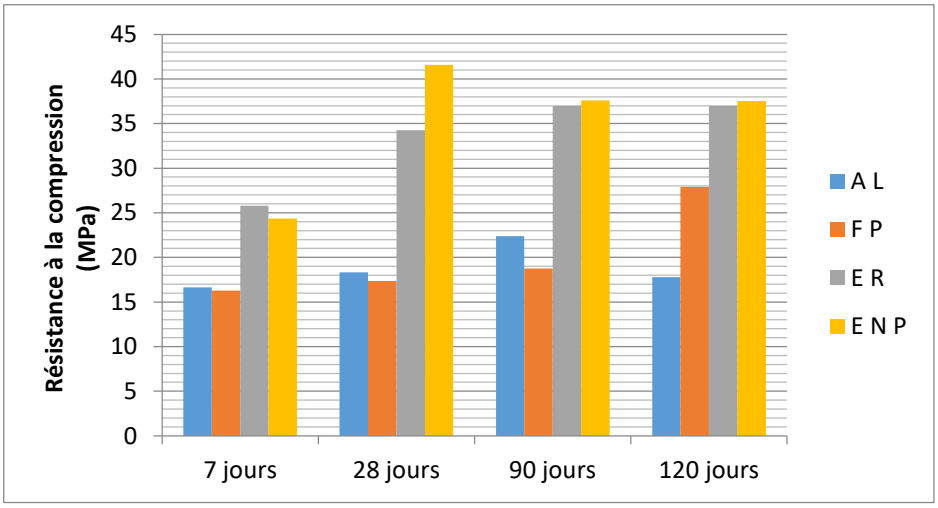

Figure14. Compressive strength of sand concrete specimens with 10% SDP and 2NS at different media.

From Figure 14, we notice that the specimens in FP and ER give a positive evolution of the mechanical strength at all ages with a stable stress for the specimens in ER at the period 90-120 days.Although the specimens in ENP have the highest strength values at 28 days, we observe a drop in stress after 28 days with a stable stress at 90-120 days.

We note that the specimens in AL show an improvement in stress at 7-90 days, but after 90 days there is a drop in strength. We note that the OE medium gives the best strength results at all ages.

Sand concrete with 5SDP 2 NS or 10SDP 2 NS has a stable compressive strength after 90 days in the "tap water and groundwater" media. These sand concretes show a positive improvement in strength at all times in the storage medium "plastic film". Conventional sandcastle and sandcastle with 10SDP 2 NS give the best compressive strength result.

Conclusion

This experimental work is a contribution to the improvement of durability of sand concrete by mineral addition, we used four preservative media and two compositions with nano-silica (NS)and dune sand powder.

The objective of this work is to study experimentally the influence of the use of natural products existing in the country on the durability to make a durable locally composed cement.The results obtained in this experimental study allow us to draw the following conclusions:

Sand concrete with 5SDP 2NS and 10SDP 2 NS has a strength stability of 90-120 days. The addition of powdered dune sand and nano-silica (NS)improves the durability of sand concrete. sand concrete stored in the medium (groundwater) shows the best mechanical results compared to other media used. sand concrete stored in the medium (free area) shows the worst mechanical results compared to other media used. In the storage medium (plastic film), sand concrete with 5SDP 2 NS and 10SDP 2 NS show a positive evolution of mechanical strength in the long term.

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