Effect of Addition the Dune Sand Powder on Development of Compressive Strength and Hydration of Cement Pastes

S. Guettala, B. Mezghiche

Abstract—In this paper, the effect of addition the dune sand powder (DSP) on development of compressive strength and hydration of cement pastes was investigated as a function of water/binder ratio, was varied, on the one hand, the percentage of DSP and on the other, the fineness of DSP. In order to understand better the pozzolanic effect of dune sand powder in cement pastes, we followed the mixtures hydration (50% Pure Lime + 50% DSP) by X-ray diffraction. These mixtures the pastes present a hydraulic setting which is due to the formation of a C-S-H phase (calcium silicate hydrate). The latter is semi-crystallized. This study is a simplified approach to that of the mixtures (80% ordinary Portland cement + 20% DSP), in which the main reaction is the fixing of the lime coming from the cement hydration in the presence of DSP, to form calcium silicate hydrate semi-crystallized of second generation. The results proved that up to (20% DSP) as Portland cement replacement could be used with a fineness of 4000 cm²/g without affecting adversely the compressive strength. After 28 days, the compressive strength at 5, 10 and 15% DSP is superior to Portland cement, with an optimum effect for a percentage of the order of 5% to 10% irrespective of the w/b ratio and fineness of DSP.

Keywords—Ordinary Portland Cement; Pure Lime; Dune Sand Powder; Compressive Strength; Hydration.

I. INTRODUCTION

SINCE 1970, a major research effort has been provided on the use of the cementing additions as a partial substitution to Portland cement. These additions come from natural sources, or by-products of other industries [1] The additions present an increasing binding activity with their amount, their fineness, their mineralogical composition and the type of cement also influence into practical terms, this activity results in a profit of strength [2]. The compactness of the cement paste can be improved by the formation of calcium silicate hydrates. The latter are obtained by the introduction of fine siliceous particles, equipped with a certain pouzzolanic role and contribute to the increase in the strength and the durability of the concretes to which they are built-in [3],[4]. The recent studies which considered the influence of the mineral additions on the properties of cementing materials showed that those additions by their fineness are more or less significant reactivity with the cement can generate in certain cases significant modifications in the rheological and mechanical properties.

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The mechanisms at the origin of these modifications appear particularly complex, but several studies in this field agree to distinguish three principal effects which are superimposed to influence the properties of the cementing materials in the fresh or hardened state: [5]-[17].

A granular effect relates to all the modifications, induced by the presence of the mineral additions in the granular structure, of the cementing materials in a fresh state. These modifications can result from the capacity of stacking fine or ultra-fine particles of the addition, with other solid components of the mixture and/or the intensity of frictions between particles. Several studies showed the existence of an optimisation of the granular structure properties by the incorporation of mineral additions, of different natures and amount. A granular effect becomes positive and leads either to improve the consistency of fresh mixture to constant content of water or decrease the water content for a given consistency by improving the compactness of the mixture and the mechanical performance of hardened material [18]. Similarly Kronlof [19] showed by studying the effect of ultra-fine aggregates on concrete strength, the incorporation in concrete three additions of different fineness of quartz leads to the decrease of water requirement in relation to the amount and fineness. Kwan [20] showed that the workability of a concrete increases with the percentage of silica fume for the *w/b* ratio constant.

In the same way, De Larard [21] showed that the workability of a mortar varies according to the amount of built-in silica fume.

Similarly Bessa [5] showed that the granular effect of the mineral additions on the formulations of mortars could involve an increase or decrease of the water requirement with standardised workability and depends initially on the fineness and amount of the introduced addition.

In the same way, Kara [12] showed that the introduction of additions with great proportions into the cement pastes with a standardised workability generates a higher water requirement. Then, when the addition particles modify lightly the frictions between the grains and fill the porosities of the granular structure (cement and aggregates) by releasing the water in these pores, the granular effect becomes favourable and leads to improving the workability of the fresh mixtures with a constant amount of water, or to the reduction of water for a given workability and to improving the compactness of the mixture and the mechanical performances. However, when the particles of the addition modify considerably the frictions between the grains in the cementing mixtures or do not fill porosities of the granular structure, the granular effect becomes unfavourable.

A physico-chemical effect relates to all the modifications generated by the multiple interactions between the mineral additions particles on the hydration process of cement, and on structuring the hydrated products. Other authors argue that the presence of mineral additions in a cement mixture leads to the acceleration of hydration process, or that it provided a better dispersion of cement grains, leading to a structure of cement matrix more efficiently [5],[16]. Similarly Lilkov et al. [22] have showed that the amount of the hydrates formed during the first 24 h in a cementing paste is more significant in mixtures with additions of silica fume and fly ashes that in mixtures without additions. Similarly Jiang and Van Damme [23] have confirmed these results by studying the action of the siliceous and limestone additions on the process of hydration of the pure C_3S. In the same way, Cheng-Yi and Feldman [24] have showed that the mineral additions play a role of preferential sites of nucleation during the cement reactions, allowing a better distribution of the hydrated products and thus lead to more effective structuring the cementing matrix. Thus, it results that the physico-chemical effect of the mineral additions acts primarily on the evolution of the mechanical strengths at earty-age and on the physical and microstructural properties of the hardened cementing materials. In the same way, Care et al. [25] have also shown by studying the effect of inert mineral additions on hydration of mortars, the degree of hydration for short-term of mortars containing chemically inert additions were always higher than that of the reference mortars and have confirmed the improvement of the hydration of cement with inert additions. In the same context, the mineral additions play a role of nucleation sites during reactions of cement, this nucleation is a physical process, causes a chemical activation of cement hydration and depends on the fineness of particle additions, the content addition into the mixture and nature of the addition powder with the cement hydrates [14],[24]. The physico-chemical effect concerns on a general all additions of their mineralogical nature.

A chemical effect relates to the capacity of the additions characterised by pozzolanic and/or hydraulic properties, to react with water and the anhydrous or hydrated components of cement, to form new mineral phases which can contribute to the evolution of the mechanical strengths, as well as the hydrated products of cement [12]. Similarly Appa Rao [26] showed that for a (w/b) ratio constant equal to 0.5 the incorporation of a silica fume in a mortar in the limit of 30% of the cement substitution by the addition, leads to an increase in the compressive strengths independently of the age of mortar. Similarly Kwan [20] showed that independently of the w/b ratio, the incorporation of a silica fume in a mortar in the limit of 15% of the cement substitution by the addition, leads to an increase in the compressive strengths in 28 days. In the same way, Benezet and Benhassaini [27] have shown by studying the influence of particle size of quartz in the pozzolanic reaction the quartz crystal powder can react with portlandite to form stable hydrates. The reactivity of quartz powder measured in a static medium (not activated) heat (test at 20° C), hitherto attributed to amorphization of the grain surface, resulting from the presence of very fine grains adsorbed on the surface of larger grains.

In the same way, Lawrence et al. [14] have shown that the degree of hydration of mortars containing additions of quartz was more significant than that of the mortars without additions.

Similarly Cyr et al. [11] have confirmed the chemical reactivity of the limestone additions by comparing the evolution of the mechanical strengths of mortars, made with two fly ashes and a limestone addition. It results that the chemical effect, when it is favourable, is complementary to the physico-chemical effect.

Similarly the analysis by X-ray diffraction highlighted the role of pozzolanic dune sand powder. Indeed, the small content of portlandite detected in the cement pastes in the presence of dune sand powder, translated the partial pozzolanic reaction, which contributes to increasing the strength and improves the compactness of the paste, and also shows that the DSP consists of SiO_2 quartz well crystallized of type low-quartz [28],[29].

The dune sand is a material of a great availability in Algeria. This material is practically not exploited, in spite of the possible characteristics which it presents. The contribution of addition the dune sand powder (DSP) in the cement binding activity results primarily from two effects: a physico-chemical effect and a chemical effect.

On the one hand it changes the hydration process of cement as well as the structuring of hydrated products; on the other, it reacts in the cementing medium and develops new hydrated products. These effects act simultaneously and in a complementary way on the final properties of cement pastes. A third physical effect which is the granular effect related to the changes induced by the presence of the fine particles in the solid skeleton of the mixture [34],[35].

However, to ensure the development of this vital building material, the approach of sustainable development should be incorporated into the production of cement, which will enable it to reach a balance between the constraints of environmental protection and the economic, technical and social considerations [34]. The required objective is to evaluate through experiments the combined contribution of the physical, physico-chemical and chemical effect of addition the DSP at cement, on development of compressive strength and hydration of cement pastes.

II. EXPERIMENTAL PROGRAM

Studying in parallel the effect of different percentages of dune sand powder, effect of fineness ($F_1 = 3000$ and $F_2 = 4000$ cm²/g) and the effect of the water/binder ratio (w/b = 0.40, 0.30 and 0.25) on the compressive strength of cement pastes, we selected four mass percentages (5%, 10%, 15% and 20%) for the addition to ordinary Portland cement (OPC) and obtain a new variety of compound cement (optimisation of the cement content in dune sand powder).

We used cubic specimens (2×2×2 cm) pure pastes for six specimens per test. The cement pastes were prepared in a mixer standard EN 196-1 by following the procedure described by EN 196-3 relative the normal consistency of pure pastes [30].

The hardening was under natural conditions, the specimens are subjected to a curing in drinking water at 20 ± 1°C until the time of testing.

This work is to analyse by X-ray diffraction (XRD), using the powder method, its main use is identifying minerals. Each body crystalline product indeed is a spectrum or X diffractogram, which reflects its internal structure and nature of minerals. You can treat any X diffractogram which is a specific kind of (fingerprint), which can distinguish another mineral. To identify a body from its X diffractogram, it has a file or ASTM minerals are classified according to their three main line, the intensity of the strongest line being set at 100. If several mineral species are combined in the powder studied, the diagram is the juxtaposition of elementary diagrams.

To this end, we analyzed by X-ray diffraction:

Firstly, the dune sand powder, to highlight its mineralogical nature.

Thereafter, we followed the fixing kinetics of lime as a function of time in pastes mixtures, previously stored in PVC tubes at 20 ± 1 °C sealed hermetically. In order to understand better the pozzolanic effect of this addition in the cement pastes, we followed the mixtures hydration (50% Pure Lime + 50% DSP). This study is a simplified approach to that of the mixtures (80% OPC + 20% DSP), in which the main reaction is the fixing of the lime coming from the cement hydration in the presence of dune sand powder (pozzolanic reaction), to form calcium silicate hydrate C-S-H semi-crystallized of second generation.

At a given age, a portion of the paste is crushed into a fine powder, whose maximum diameter of grain is less than 40 μm, to be tested by XRD.

For reactivity analysing dune sand powder, we studied: the evolution of mixtures hydration (50% Pure Lime + 50% DSP) and (80% OPC + 20% DSP) as a function of time.

III. Materials and Mix Proportions

This is a crushing of dune sand and clinker. The crushing is carried out using a conventional ball crusher (horizontal metal cylinder rotated and filled with 1/3 steel balls that crush the material into a cascade movement).

A. Dune Sand Powder

The choice of an addition relative to another is generally following the local availability at acceptable costs, focused on the high silica content. We used dune sand in the region of Biskra. Apparent density = 1300 kg/m^3 and specific density = 2770 kg/m^3.

TABLE1 contains the chemical analyses which were carried out in the laboratory of the cement factory of Ain Touta (Batna, Algeria).

TABLE I
CHEMICAL ANALYSIS OF DUNE SAND POWDER (%)

SiO$_2$	Al$_2$O$_3$	Fe$_2$O$_3$	CaO	
74.61	1.35	0.86	17.3	
MgO	SO$_3$	K$_2$O	Cl	LOI
0.29	0.04	0.47	0.005	5.04

From a chemical stand point, the important observation to note is the presence of a high percentage of silica SiO$_2$; is greater than 74%, and therefore the dune sand is siliceous sand. Fig.1 shows that the DSP presents a crystalline structure siliceous (low-quartz) [34].
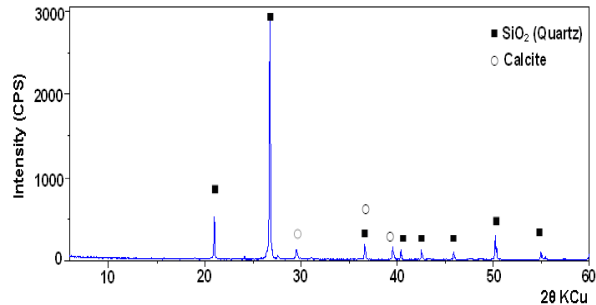

Fig. 1 X Diffractogram (DSP)

The crystalline silica presents a regular three-dimensional structure; the basic reason is a tetrahedron, an oxygen atom and the centre occupies each summit by a silicon atom. Its atomic structure is changed if the temperature reaches over 870 °C [31]. According to De Larrard [21] (nothing is ultra-fine inert. Thus quartzes crushed deemed crystal, are amorphised on surface. They can therefore be associated with lime according to reactivity pozzolanic classic). The dune sand powder is siliceous, can have the same physical benefits and pozzolanic than other additions, despite its crystalline character [32].

B. Portland Cement

The Cement that was used is an ordinary Portland cement (OPC) class 42.5 Mpa; it is composed of 95% clinker and 5% gypsum, for the regularization of the setting. The clinker is from the cement factory of Ain Touta (Batna). Apparent density = 1120 kg/m^3 and specific density = 3050 kg/m^3. The potential mineralogical composition of the clinker is calculated according to the empirical formula of Bogue [33].The chemical analysis of cement shows that it is in conformity with standard NFP 15-301. Chemical and mineralogical compositions of clinker are presented in Tables II and III, respectively.

TABLE II
CHEMICAL COMPOSITION OF CLINKER (%)

SiO$_2$	Al$_2$O$_3$	Fe$_2$O$_3$	CaO	
22.00	5.02	2.94	64.36	
MgO	SO$_3$	Free CaO	IR	LOI
2.07	1.94	0.30	0.73	0.64

IR: Insoluble residue, *LOI*: Loss on ignition

TABLE III
MINERALOGICAL COMPOSITION OF CLINKER (%)

C$_3$S	C$_2$S	C$_3$A	C$_4$AF
51.28	24.68	8.33	8.94

C. Water

The water is drinking water that contains little sulphate and having a temperature of 20 ± 1 °C. Its quality conforms to the requirements of standard NFP 18-404.

D. Mix Proportions

Details of the mixtures proportions are given in Table IV.

TABLE IV
MIXTURES PROPORTIONS

Mixture code	w/b Ratio	Fineness DSP (cm²/g)	Cement type	Mass Dosage (%)		
				Clinker	Gypsum	DSP
M1	0.25	-	OPC	95	5	0
M2	0.30	-	Fineness			
M3	0.40	-	3200 cm²/g			
M4	0.25	$F_1 = 3000$	95%OPC	90	5	5
M5	0.25	$F_2 = 4000$	+			
M6	0.30	3000	5%DSP			
M7	0.30	4000				
M8	0.40	3000				
M 9	0.40	4000				
M10	0.25	3000	90%OPC	85	5	10
M11	0.25	4000	+			
M12	0.30	3000	10%DSP			
M13	0.30	4000				
M14	0.40	3000				
M15	0.40	4000				
M16	0.25	3000	85%OPC	80	5	15
M17	0.25	4000	+			
M18	0.30	3000	15%DSP			
M19	0.30	4000				
M20	0.40	3000				
M21	0.40	4000				
M22	0.25	3000	80%OPC	75	5	20
M23	0.25	4000	+			
M24	0.30	3000	20%DSP			
M25	0.30	4000				
M26	0.40	3000				
M27	0.40	4000				

IV. RESULTS AND DISCUSSIONS

A. Compressive Strength

The results obtained are clearly exposed on the (Figs.2,3,4 and 5).

According to these results one notices that the evolution of compressive strengths as function of time (7, 28 and 90 days) shows that during the first seven days, the compressive strengths is low for all samples, whereas the following periods, the compressive strengths increases significantly.

This is due to the kinetics of the reaction of cement hydration and reaction of dune sand powder with portlandite as a function of time.
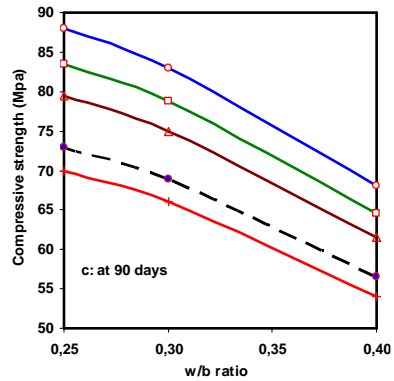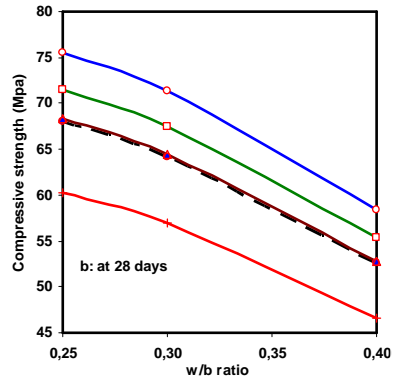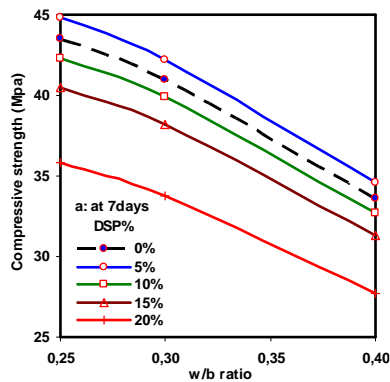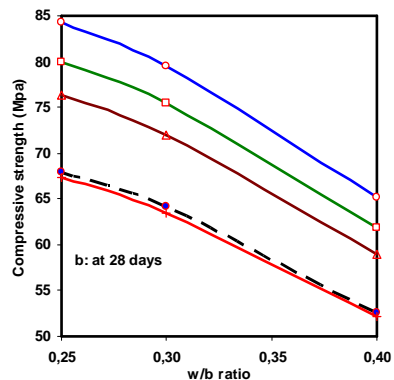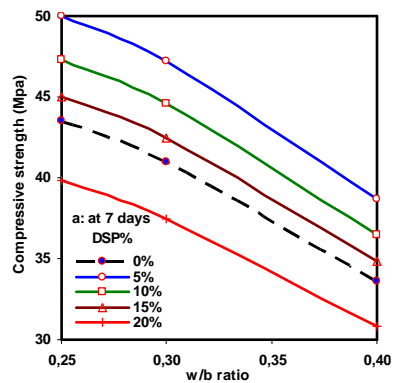

Fig. 2 Variation in compressive strength as a function of time and w/b ratio ($F_1 = 3000$ cm²/g)
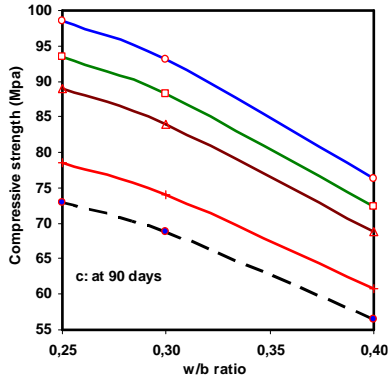
Fig. 3 Variation in compressive strength as a function of time and *w/b* ratio ($F_2 = 4000 \text{ cm}^2/\text{g}$)
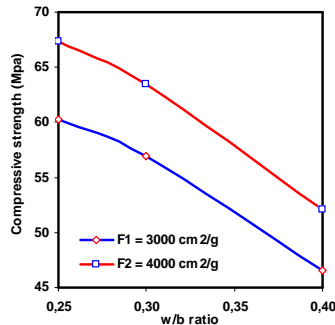

Fig. 4 Variation in compressive strength at 28 days of cement pastes with 20%DSP as a function of fineness and *w/b* ratio
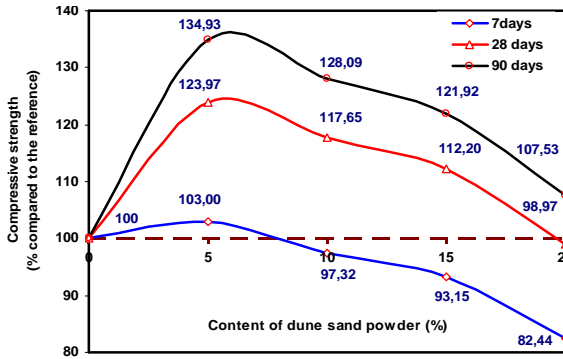

Fig. 5 Effect of content of dune sand powder on the compressive strength ($F2 = 4000 \text{ cm}^2/\text{g}$, *w/b* = 0.25)

The rate of development of the compressive strength of OPC alone to 28 and 90 days, compared to 7 days, is 56% and 68% respectively, the compressive strengths of the binders to 5 and 20% of dune sand powder develop a rate equal to 69% for 28 days and 97% to 90 days respectively, that translated the chemical effect played by dune sand powder in the long-term, therefore confirms the pouzzolanic activity.

The results obtained show that contribution of addition the dune sand powder to the cement binding activity resulted primarily from three effects: physical, physico-chemical and chemical. These effects act simultaneously and in a complementary way on the compressive strengths of cement pastes: [34],[35].

Physical effect: an improvement of the compressive strengths by a thickening of the cement pastes and even the consistency of fresh mixture (the pastes become more fluid).

Physico-chemical effect: a physical process produces a chemical activation of cement hydration and depends on the content and fineness of the dune sand powder, which acts on the evolution the compressive strengths at earty-age. The presence of dune sand powder accelerates the reaction of cement hydration. This accelerating effect of dune sand powder on the hydration combined with the physical effect, due to their fineness, can lead to better compressive strengths short-term.

Chemical effect: lime provided in the case of Portland cement and consumed by the pozzolanic reaction, caused by the addition of dune sand powder to cement, it improved the compressive strengths of cement pastes at average and especially at long-term.

This also makes it possible to reduce the content of cement for strength and a given slump. This last characteristic is very interesting from an economic standpoint seeing that cement is the most expensive ingredient in the composition of the concrete. Another advantage is that it makes it possible for cement to continue its development of compressive strength even after the 28 days period. Concerning the influence of *w/b* ratio, we see clearly that the compressive strength of all hardened cement pastes at any age, decreased with the increase of *w/b* ratio. The *w/b* ratio exerts a great influence on the porosity of the cement paste hydrated (network of pores finer and more discontinuous).

That is why cement pastes with *w/b* ratio low: developing very quickly their compressive strength by a high concentration in C-S-H. The DSP can change the structure of the pores, to reduce the number of the large pores and increase the small pores. This change is a function of fineness, more particles are fine and their role is more effective.

The results showed that by increasing the fineness of 3000 at 4000 cm²/g, the compressive strengths at all ages were improved by 12%. One can generally observe that after 28 days, the compressive strength at 5, 10 and 15% DSP is superior to Portland cement, with an optimum effect for a percentage of the order of 5% to 10% irrespective of the *w/b* ratio and fineness of DSP.

The incorporation of (20% DSP) with a fineness of 4000 cm²/g, in the form of substitution at OPC provides a new variety of compound cement with a compressive strength comparable to those of OPC.

B. Consistency and Setting Time

Table V gives the consistency, initial and final setting time of mixtures. According to the results obtained one notices that the content of the addition, DSP% did not generate significant modifications on the setting time of mixtures.

TABLE V
CONSISTENCY AND SETTING TIME OF MIXTURES

Tests ($T = 27 \,°C$)	Mixture				
	M1	*M5*	*M11*	*M17*	*M23*
Normal Consistency (%)	27	26.7	26.5	26.3	26
Setting Initial (min)	95	100	105	105	105
Setting Final (min)	240	229	227	225	225

By cons the addition significantly decreased their initial consistency (the pastes become more fluid). Because of their superior fineness than that of cement OPC the intergranular vacuum reduce. Therefore the dune sand powder plays a role of lubricant [34],[35].

The amount of water necessary to obtain a normal consistency of the cement paste varies from 23% to 35% (ASTM C 187-86). The granulometry has a prevalent influence on the demand for water of the cement. More the granulometry distribution is (tight), with few particles of small and of large dimensions; higher is the demand for water. This cement comprises a great proportion of vacuums, which should be filled by water before setting part in the handiness of the cement paste. Therefore, for decrease the demand for water of cement, it is necessary to increase the proportions in small and large particles in order to decrease the intergranular vacuum.

According to TABLE 5 one notices that dune sand powder will fill intergranular vacuums and decrease the demand for water.

C. Reactivity Pozzolanic of Dune Sand Powder

The superposition of X diffractograms shows that the dune sand powder does not change the nature of hydrates after 14 days of hydration. Fig.6 shows that the portlandite formed during reactions of cement hydration in the presence of the DSP has been partially consumed. Indeed, the peak corresponding decreased compared to the reference (peak appearing at 9°θCu Kα (P is centered in the reticular distance d = 4.9Å)). The choice of this stripe is the fact that it is distinct from those of other minerals. The higher the percentage of DSP content in the paste increases the intensity of the line corresponding to 4.9Å increases [35]. This result confirms that the DSP is not inert and participates in training new C-S-H that make the paste thicker and more compact. The dune sand powder, despite its crystalline nature, presents a partial pozzolanic reactivity [34],[35].
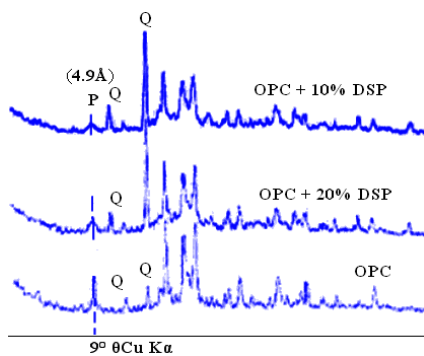

Fig. 6 X Diffractograms of cement pastes in the presence of DSP in 14 days

1. Evolution of Mixtures Hydration (50% Pure Lime + 50% DSP) as a Function of Time

The evolution of the pozzolanic reaction as a function of time was considered by X-ray diffraction on pastes containing (50% Pure Lime + 50% DSP).
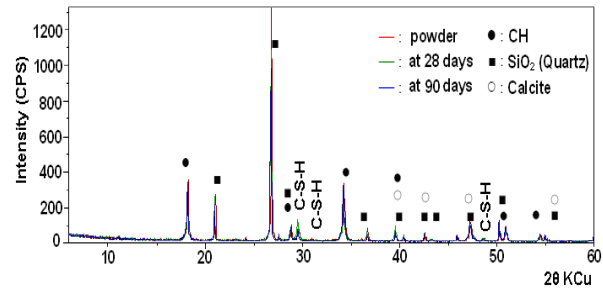

Fig. 7 X Diffractograms of mixtures hydration (50% Pure Lime + 50% DSP) as a function of time

An examination of X diffractograms (Fig.7) shows that: [34]. The line intensities of lime (4.90 Å, 2.62 Å and 1.92 Å) decreased as a function of time, which explains the fixing of the lime by the grains of silica, to form the calcium silicate hydrate C-S-H semi-crystallized (partial pozzolanic reactivity of DSP).

2. Evolution of Mixtures Hydration (80% OPC + 20% DSP) as a Function of Time

In the same way, we followed by XRD the evolution mixtures hydration pastes (80% OPC + 20% DSP) as a function of time. The changes in hydration kinetics of Portland cement, in the presence of dune sand powder are highlighted by X-ray diffraction.
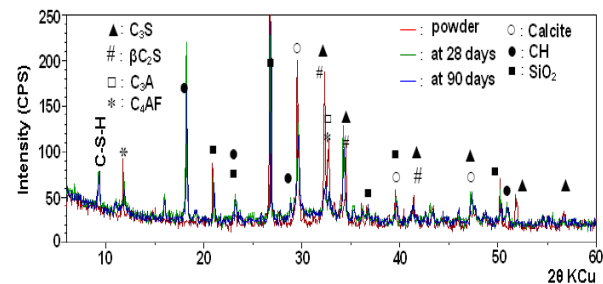

Fig. 8 X Diffractograms of mixtures hydration (80% OPC + 20% DSP) as a function of time

An examination of X diffractograms (Fig.8) presents the following observations: [34]. At 28 days of hydration, the line intensities of lime and calcium silicate hydrate C-S-H appearances and the line intensities of C_3S and βC_2S decreased which explains the hydration of calcium silicate. In the presence of DSP and at 28 days of hydration, the line intensities of quartz decreased, as compared to that of powder mixture, so the partial pozzolanic reaction of DSP, which confirmed the results found previously. At 90 days of hydration, the line intensities of lime and cement minerals, as well as that of quartz, decreased significantly, this shows the partial pozzolanic effect.

V.CONCLUSION

Based on the results of this experimental study, the following conclusions could be drawn:

The use of dune sand powder in substitution of the clinker in Portland cement is an excellent example of reducing carbon

dioxide CO_2 emissions. The results obtained show that contribution of addition the dune sand powder to the cement binding activity resulted primarily from three effects: physical, physico-chemical and chemical. These effects act simultaneously and in a complementary way on the compressive strengths of cement pastes. The compressive strengths at earty-age develop due to the acceleration of cement hydration, combined with the physical effect, while those at average and especially long-term develop through the partial pozzolanic effect, which cause the replacement of lime by the calcium silicate hydrate (C-S-H) semi-crystallized of second generation.

One can generally observe that after 28 days, the compressive strength at 5, 10 and 15% DSP is superior to Portland cement, with an optimum effect for a percentage of the order of 5% to 10% irrespective of the *w/b* ratio and fineness of DSP. The results proved that up to (20% DSP) as Portland cement replacement could be used with a fineness of 4000 cm²/g without affecting adversely the compressive strength.

The dune sand powder does not change the nature of hydrates after 14 days of hydration. The portlandite formed during reactions of cement hydration in the presence of the DSP has been partially consumed. The dune sand powder, despite its crystalline nature, presents a partial pozzolanic reactivity.

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