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PERFORMANCE OF GREEN CEMENT COMPOSITE CONTAINING BLAST FURNACE SLAG AND DUNE SAND POWDER

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The use of supplementary cementitious materials (SCMs), such as silica fume (FS), granulated blast furnace slag (GGBS), and fly ash (FA), is becoming increasingly popular in the cement industry due to the various benefits they bring to the table, such as reducing the construction costs, decreasing the energy consumption, and reducing greenhouse gas emissions. Therefore, the objective of this study is to test a new eco-friendly composite cement using local granulated blast furnace slag (GGBS) and dune sand powder (DSP). In this study, plain and tow blended mixtures were fabricated for the blended mixtures, 15 % GGBS by weight of the total binder materials and different percentages of dune sand powder (5 and 10 %) were incorporated as partial cement replacement materials. The physical, mechanical, and durability characteristics were evaluated by determining setting time and consistency by measuring the compressive strength, chemical resistance, water permeability, drying shrinkage and water swelling. The results showed that partial substitution of cement with (15 % GGBS + 5 % DSP) increases the compressive strength at 90 days, providing comparable strength to ordinary Portland cement concrete at 28 and 60 days. The study also showed that the partial substitution of cement with GGBS and DSP increases the setting time of the cement and improves the mix consistency. The results indicate that the composite cement with GGBS and DSP exhibits excellent resistance to chemical attacks and has lower water permeability than Portland cement concrete. The results also show that the composite cement has better resistance to water swelling and a slightly higher drying shrinkage compared to Portland cement.

INTRODUCTION

The production of cement is one of the most damaging to the environment due to the release of CO_2 gas into the atmosphere. It is estimated that the production of one tonne of Portland cement clinker produces approximately one tonne of CO_2 and other greenhouse gases [1-4]. These findings demonstrate that the cement manufacturing sector is responsible for climate change, which is a detrimental component for the development of the cement and concrete industry. In addition to its negative environmental impact, cement is one of the most expensive materials compared to other concrete components. The raw materials required for cement production, such as calcium carbonate ($CaCO_3$), are also extracted in large quantities, which can lead to depletion, as projected in certain regions of the world.

Although many efforts are being made to reduce CO_2 emissions, it is estimated that global human-induced CO_2 emissions will continue to increase in the coming years, primarily in developing countries [5-13]. Among the solutions considered by the cement manufacturing industries in order to reduce their CO_2 emissions is the use of various supplementary cementitious materials (SCMs), such as fly ash, slag, and silica fume.

Recent research on the study of the influence of the properties of supplementary cementitious materials has shown that these SCMs, due to their fineness, have variable reactivity with cements. Therefore, they can lead to significant modifications in the rheological and mechanical properties of concrete in certain cases. The mechanisms behind these modifications appear to be particularly complex, but several conducted studies have agreed in distinguishing three main effects that accumulate to influence the properties of cementitious materials in their fresh or hardened state: the granular effect, the physicochemical effect, and the chemical effect [14-27].

Blast furnace slag (BFS) has been successfully used in mud-to-cement conversion worldwide due to its economic, technical, and environmental advantages, as well as its stable properties compared to other industrial by-products [28]. BFS is a by-product obtained in the manufacturing of pig iron in the blast furnace. It taps out from the blast furnace as a molten liquid at a temperature of 1400 – 1500 °C and occurs either in a crystalline or granulated form depending on the treatment method for the molten liquid slag. When the slag is allowed to cool slowly in the air, it solidifies into a grey, crystalline, stony material, or dense slag of angular aspect that can be used as coarse aggregate in concrete production [29]. Granulated slag is composed of calcium and magnesium silico-aluminates. It is primarily composed (more than 90 %) of four oxides: SiO_2, Al_2O_3, CaO, and MgO. It also contains negligible amounts of oxides, such as TiO_2, MnO, FeO, as well as sulfides like CaS, MnS, and FeS [30]. The oxides (Al_2O_3 and CaO) increase the hydraulic activity of the slag, whereas the oxides (SiO_2) decrease it. An increase in MgO up to 18 % is beneficial, as there is no risk of swelling caused by the free MgO during hydration, unlike Portland cement [72]. A high content of Al_2O_3 leads to an increase in resistance, while the titanium oxide and manganese protoxide content is limited. On the other hand, the FeO content is quite low and does not have a considerable effect on the quality of the slag. A small amount of calcium sulfide, up to 7 %, does not stimulate the slag activity [31].

Many researchers have shown great interest in the use of granulated slag as mineral additives in the production of cement or cementitious materials. All types of blast furnace slag can be used, but the most common is granulated or vitreous slag due to its ease of handling and faster reactions with cement constituents [32].

Wedding et al. [33] studied cement mixes with 40, 50 and 65 % of slag. In general, the mixtures between 40 and 50 % gave the highest strengths at ages ranging from 28 days to 1 year. The rate of strength gain was inversely proportional to the slag content.

Gee [34] reported that the initial strength development of slag cement is affected by the chemistry of the clinker. This is because the way in which the clinker releases calcium where alkali cations affect the slag's rate of hydration. Clinker can be formulated with high lime content for use in high slag content mixes. Similarly, Royand Idorn [35] also reported similar results. However, it was reported that the strength improvement of concrete containing 20 – 60 % Ground granulated blast-furnace slag (GGBS) occurs only after 28 days of curing. After 28 days of curing, the long-term strength was similar or better than that of normal Ordinary Portland Cement (OPC) concrete [36-38].

Li and Zhao [39] studied the influence of combination of GGBS and fly ash (FA) on the compressive strength of high-strength concrete. Three types of concretes; GGFAC (concrete incorporating GGBS and FA) incorporating a combination of 25 % FA and 15 % GGBS, HFAC (high-volume FA concrete) (containing 40 % of FA), and PCC (control Portland cement concrete) were made and their strength was determined up to the age of 360 days. It can be seen that there is a general trend of increasing strength with the age up to 1 year for all the concretes. As expected, the behaviour of HFAC at the early ages is different from that of PCC and GGFAC. Though HFAC had the highest strength at the end test age, its strength was the lowestbefore 56 days. The strength development of GGFAC is similar to that of PCC, but with only slightly lower values before 28 days. This indicates that GGFAC can achieve adequate early compressive strength, while maintaining high long-term strength.

In addition to the above SCMs, there are also other variants, such as dune sand powder (DSP). Dune sand is one of the most common minerals on earth and is composed of tiny grains of quartz. Quartz is composed of silicon dioxide (SiO_2), which is also known as silica. An analysis by X-ray diffraction (XRD) shows that dune sand powder is composed of well-crystallised SiO_2, of a "low-quartz" type, in contrast to silica fume which has an amorphous structure [40-42]. The analysis by X-ray diffraction revealed the pozzolanic role of dune sand powder. Indeed, the low quantity of portlandite detected by X-ray diffraction (XRD) in cement pastes containing dune sand indicates the partial pozzolanic reaction of this addition, which contributes to the increase in the mechanical strength and improves the compactness of the paste [40].

According to de Larrard [43], ultrafine quartz is not inert. Therefore, crushed quartz, assumed to be of a crystalline nature, is found to be amorphous on the surface. As a result, it can potentially react with lime according to the classical pozzolanic reaction. Similarly, S. Guettalla and B. Mezghiche [44] and Larrard [43] showed that dune sand powder can have the same physical and pozzolanic advantages as other additives, despite its crystalline nature.

Similarly, Cheikh-Zouaoui [45] showed the beneficial role of introducing silica-based mineral additions (silica fume, ground silica sand and ground silica sand with cement) in improving the mechanical strength in the medium and long term. Indeed, it seems that the introduction of quartz sand with the mixing-grinding process gives mechanical strengths higher than those of the reference mixes and with the same order of mag-nitude as that of the introduction of silica fumes. Indeed, the addition of minerals in the form of SiO_2 leads to the formation of additional C-S-H, which also contributes to increasing the mechanical strength of the mixes.

In the same context, Wang and Ye [46], showed that the presence of about 20 % of crushed dune sand in Portland cement paste increases the degree of hydration of the cement at all ages. Furthermore, the degree of hydration is increased with the fineness of the DSP. There is also a significant influence on the total porosity and water permeability of cement paste premixed with crushed dune sand.

The main objective of this study is to investigate the combined effect of ground granulated blast furnace slag (GGBS) and dune sand powder (DSP) on the physical properties of cement and the mechanical strength and durability of mortar and concrete.

EXPERIMENTAL

Raw materials

The materials used in this study were ordinary Portland cement (OPC), principally composed of clinker, the potential mineralogical composition of the OPC clinker is calculated according to the empirical formula of Bogue [47]. The chemical analysis of the cement conformed to the European standard EN 197-1 [48]. The chemical and mineralogical composition of the OPC clinker is presented in Table 1.

In this study, two types of supplementary cement are used, granulated slag was obtained primarily by milling by-products in a steel industry blast furnace in El-Hadjar Algeria. The chemical composition and the physical properties of the addition are shown in Table 1. The second addition is finely crushed dune sand that comes from the Biskra region, Algeria. The dune sand powder had a bulk specific gravity of 2.7, a specific surface of 3500 $cm^2 \cdot g^{-1}$, and the chemical analysis is represented in Table 1. The fine aggregate employed for manufacturing the mortar and concrete specimens was less than 5 mm. The specific gravity, sand equivalent and fineness modulus of the fine aggregate were 2.5, 76.38 % and 2.37, respectively. The coarse used aggregate is composed of fractions of crushed stone (7/15 and 15/25 mm) that come from the Biskra region, Algeria. The apparent density was measured as 1420.0 $kg \cdot m^{-3}$, the specific density was 2610 $kg \cdot m^{-3}$, with a Los Angeles coefficient of 21.02 %.

The water employed for manufacturing the paste, mortar and concrete specimens is drinking water that contains a tiny amount of sulfate and had a temperature of 20 ± 2 °C. Its quality conforms to the requirements of standard NFP 18-404 [49].

Details of the mixture proportions and casting the specimens

In this study, 27 specimens were prepared with a w/b ratio of 0.50. Three types of concrete were studied and compared in all the tests. In addition, three mixes were designed. The first was a reference mix that did not contain granulated blast furnace slag or dune sand powder and was designated as BT. Two mixes containing (15 % GGBS + 5 % DSP), and (15 % GGBS + 10 % DSP) by weight relative to the Portland cement, were designated as BSI and BSII, respectively. The complete proportions of the BT, BSI, and BSII mixes are provided in Table 4.

The concrete mixtures were prepared in the laboratory using a pan mixer. Cubes measuring 100 × 100 × 100 mm in dimension were cast in a steel mould and compacted on a vibrating table. The cubes were removed from the moulds 24 h after being cast.

The mortar mixes had a proportion of 1:3 of binder to sand. The binder consisted of cement and slag and dune sand powder. The cement was formulated varying the replacement of the slag and dune sand powder. The water binder (w/b) ratio was kept constant at 0.5. GGBS and DSP were used as the cement replacement on a weight-to-weight basis. The details of the mortar mixtures are given in Table 3. The mortar mixtures were prepared in the laboratory using a pan mixer. Prisms measuring 40 × 40 × 160 mm in dimension were cast in a steel mould and compacted on a vibrating table. The prisms were removed from the moulds 24 h after being cast.

The cement pastes were prepared in a mixer using standard EN 196-1 [50] by following the procedure described by EN 196-3 [51]. The water binder (w/b)

Table 1. Chemical composition of the Portland cement (OPC) and mineral addition using slag (GGBS) and dune sand powder (DSP).

Item	Portland cement (OPC)	Slag (GGBS)	Dune Sand Powder (DSP)
SiO_2 (%)	22.0	40.80	74.16
Al_2O_3 (%)	5.30	5.20	1.35
Fe_2O_3 (%)	3.38	0.53	0.86
CaO (%)	65.16	43.01	17.30
MgO (%)	1.77	6.40	0.29
SO_3 (%)	-	0.80	0.04
Na_2O (%)	-	-	-
K_2O (%)	-	-	0.47
Insoluble residue (%)	1.40	-	-
Loss on ignition (%)	0.48	-	5.04
Free lime (%)	2.32	-	-
C_3S (%)	58.09	-	
C_2S (%)	23.32	-	
C_3A (%)	8.32	-	
C_4AF (%)	10.27	-	
Specific gravity ($g \cdot cm^{-3}$)	3.03	2.73	2.77
Specific surface area ($cm^2 \cdot g^{-1}$)	3500	3500	3500

Table 2. Mixture proportions of the pastes.

Mixture code	W/b* ratio	Mix description	Cementitious materials (%)		
			OPC	GGBS	DSP
P0	0.45	100 % OPC	100	0	0
PSDI	0.45	80 % OPC + 15 % GGBS + 5 % DSP	80	15	5
PSDII	0.45	75 % OPC + 15 % GGBS + 10 % DSP	75	15	10

OPC = 95 % Clinker + 5 % Gypsum
* (OPC+GGBS+ DSP)

ratio was kept constant at 0.45. Details of the mixture proportions of the used paste to the compressive strength are given in Table 2. Cubes measuring 20 × 20 × 20 mm in dimension were cast in a steel mould and compacted on a vibrating table. The cubes were removed from the moulds 24 h after being cast.

To evaluate the strength characteristics, concrete based on Portland cement alone and with slag and dune sand powder was used for the compressive strength test on the cubes (100 × 100 × 100 mm). The compressive load was applied using controlled compressive machine with a capacity of 1500 KN, at a rate of 2400 $N \cdot s^{-1}$ according to NFP18-406 [52], The strength measurements of the concrete were performed at the ages of 28, 60 and 90 days. Three specimens were used for each measurement age.

Table 3. Mixture proportions of the mortar (g).

Mixture code	Cement (g)	GGBS (g)	DSP (g)	Sand (g)	Water (g)
M0	450.0	0	0	1350	225
MSDI	360.0	67.5	22.5	1350	225
MSDII	337.0	67.5	45.0	1350	225

Table 4. Mixture proportions of the concretes ($kg \cdot m^{-3}$).

Materials	Unit	BT	BSDI	BSDII
Cement (OPC)	$kg \cdot m^{-3}$	385	308.0	288.75
Slag (GGBS)	$kg \cdot m^{-3}$	-	57.75	57.75
Dune Sand Powder (DSP)	$kg \cdot m^{-3}$	-	19.25	38.50
w/b	-	0.5	0.5	0.5
Fine aggregate (0/5)	$kg \cdot m^{-3}$	555.1	555.1	555.1
Coarse aggregates (7/15)	$kg \cdot m^{-3}$	807.83	807.83	807.83
Coarse aggregates (15/25)	$kg \cdot m^{-3}$	434.98	434.98	434.98

Test methods

A Vicat apparatus mould was used to determine the standard consistency of the different pastes per ASTM C 187 [53] and ASTM C191 [54]. The consistency was recorded when the plunger of the Vicat apparatus penetrated into the paste 5 to 7 mm above the bottom of the mould. The consistency was determined by taking an average of three tests. Once the standard consistency was established, the setting time was determined. The initial and final setting time was conducted using the Vicat apparatus. A 1 mm square needle was used to penetrate into the paste at 10 min intervals till the index scale showed 5 + 0.5 mm from the bottom of the mould. For determining the final setting time, the Vicat apparatus needle was replaced by a needle with an annular attachment. The needle was released at 30 min intervals till the needle made an impression on the test block. The initial and final set values were recorded as the average of three tests.

For the sulfate and acid attack tests, the mortar specimens were immersed in sodium sulfate (5 % Na_2SO_4) and the other part was immersed in a solution of chloride magnesium (5 % $MgCl_2$); the paste specimens were kept in water solution at laboratory temperature (23 ± 2 °C). The sulfate and acid solution was renewed every 15 days. The sulfate and acid resistance was evaluated by measuring the compressive strength of the paste specimens, measuring 20 × 20 × 20 mm, exposure to the sulfate and acid for a period of 28 and 90 days. The coefficient of quality (A) was calculated as follows:

$$A = \frac{Rs}{R_{ep}} \quad (1)$$

where R_S is the average compressive strength of three paste cement samples immersed in the aggressive solution; R_{ep} is the average compressive strength of three paste cement samples immersed in the water solution.

The water permeability tests were carried out on cylindrical specimens 150 mm in diameter and 150 mm in height according to GOST12730 5-84 [55], the specimens were demoulded after 24 hours of being cast and then placed in water at (23 ± 2 °C) up to the time of the test, the tests were carried out at 28 and 60 days of being cast. The principle of the test is to place the specimens in such a way that they are crossed from bottom to top according to their height, by the water under pressure (unidirectional flow), then to measure the variation in the quantity of the water crossing the specimens as a function of time, which makes it possible to determine the coefficient of permeability to the water of the material Kp. The water permeability coefficient can be calculated by the following equation:

$$K_p((m/s)\times 10^{-5}) = \frac{Q.H}{F(P_1 - P_2)\tau}\mu k \quad (2)$$

where Q is quantity of water which crosses the specimens (m^3), H is height of the specimens (m), (P_1 - P_2) is the difference in the pressure between the two faces of the specimens (bars), τ is time of test (s), μ is viscosity of water, k is coefficient which takes the diameter of the specimens into account, F is section of the specimens (m^2).

The drying shrinkage and swelling were measured according to NF P15-433 [56]. The length variation was measured using a dial extensometer with a gauge length of 160 mm. Measurements were taken after 3, 7, 14 and 28 days of drying (at 23 ± 2°C with a relative humidity of 50 ± 5 %). The swelling measurements were started 24 hours after being cast, once the specimens had been demoulded and stored in water, and for each property the average of three prism specimens was taken.

RESULTS AND DISCUSSION

Setting time and normal consistency OPC – GGBS – DSP

The most important part in the field of concrete construction is the concrete's setting properties [57]. It helps in the development of different types of concrete construction operations, such as the transportation, placing, compacting, and finishing of the concrete. Indeed, the placement of the concrete in the formwork is related to its setting, which gives it its stiffness [58]. Previous research [59-62] indicates that concrete setting times are influenced by the ambient temperature, water-binder ratio, total binder content, type of admixtures, and chemical composition of the cement used.

Figure 1 shows the experimental values of the initial and final setting times of plain Portland cement, as well as with various proportions of slag and dune sand powder. It was observed that the pure cement paste had an initial and final setting time of 125 and 200 minutes, respectively. In the case of the cement with the slag and dune sand powder, the initial and final setting times were 145 and 320 minutes for (80 % OPC 15 % GGBS + + 5 % DSP), and 155 and 340 minutes for (75 % OPC + + 15 % GGBS + 10 % DSP), respectively. The results indicated that the partial substitution of cement with slag and dune sand powder in the proportions of (80 % OPC + + 15 % GGBS + 5 % DSP) and (75 % OPC + 15 % GGBS + + 10 % DSP), by weight of Portland cement, resulted in the extended setting time of the cement. This is mainly due to the dilution effect of the cement by the dune sand powder and granulated slag, and the slow pozzolanic reaction of the dune sand powder and latent hydraulic reaction of the granulated slag. These results are consistent with those of several researchers [63-65] who studied the setting times of concrete containing GGBS. They observed that increasing the percentage replacement of cement by GGBS resulted in longer concrete setting times.

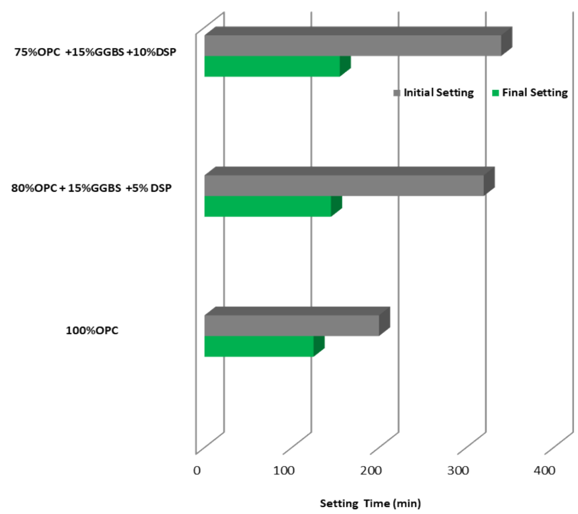

Figure 1. Effect of the GGBS and DSP content on the setting time of the cement blends.

Figure 2 shows the amount of water required to reach the normal cement consistency with different percentage additions of GGBS and DSP. It is also observed that the addition of slag and milled dune sand reduces the amount of water required to achieve the normal consistency of the cement paste, resulting in a more fluid mixture. This is due to the morphology of the dune sand powder particles, which act as lubricating bubbles between the slag and cement particles, thus promoting the better dispersion of the cement particles. In addition, the surface properties of the slag, such as its flexibility and density, have beneficial effects on the workability of the mix, allowing the mix to absorb less water during the mixing of the slag particles [66-67].

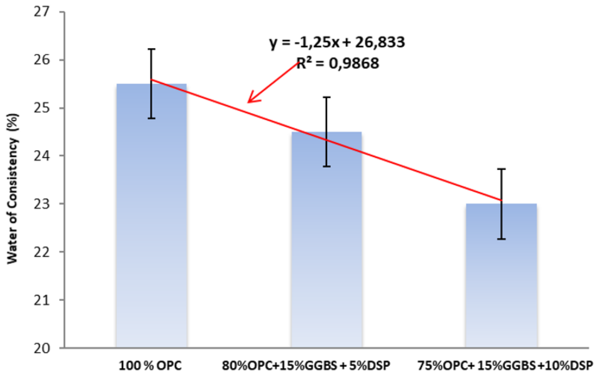

Figure 2. Effect of the GGBS and DSP content on the water normal consistency of the cement blends.

Compressive strength OPC – GGBS – DSP

The compressive strength of the cement concrete (w/b = 0.45) as a function of the percentage replacement of cement by the GGBS and DSP blend is shown in Figure 3. For the three types of concrete, the compressive strength increased with the curing time. The re-sults also show that the control concrete (BT) developed compressive strengths of (34.5 MPa and 43.5 MPa), while the concretes containing the ternary cement (BSDI, BSDII) with (80 % OPC + 15 % GGBS + 5 % DSP) and (75 % OPC + 15 % GGBS + 10 % DSP) developed compressive strengths ranging from (33.5 to 45.12 MPa) and (32.35 to 38.5 MPa), respectively. The results show that concrete (BSDI) with a ternary cement blend containing (80 % OPC + 15 % GGBS + 5 % DSP) exhibited a comparable compressive strength at 28 and 60 days to that of the reference concrete. Additionally, the compressive strength at 90 days was slightly higher (+ 3 %) than that of the reference concrete. This can be attributed to the densification of the hardened cement paste microstructure due to the formation of additional C-S-H gel, which is attributed to the synergistic effect of slag and dune sand powder. On the other hand, the concrete (BSDII) containing (75 % OPC + 15 % GGBS + 10 % DSP) exhibited a lower compressive strength compared to that of the BST and BSI concretes. This decrease in strength is attributed to the reduced amount of active cement components (C_3S and C_2S) due to the dilution effect caused by the addition of granulated slag and dune sand powder (DSP).

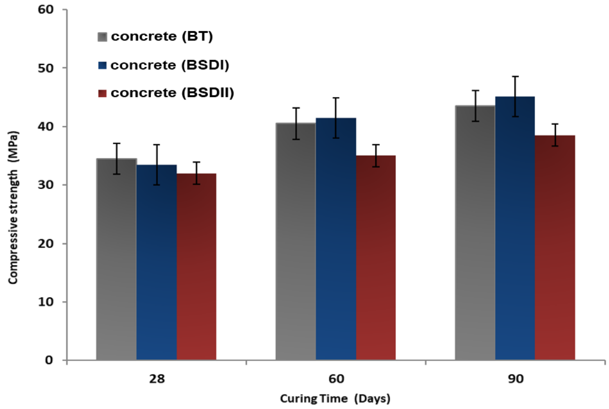

Figure 3. Compressive strength of the concrete containing OPC with the different GGBS and DSP contents as a function of the curing time.

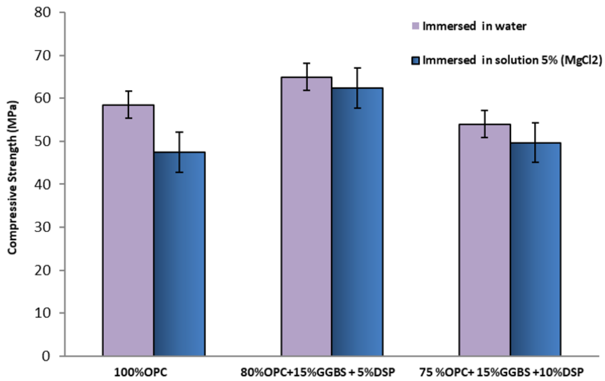

Figure 4. Compressive strength of the cement pastes immersed in water and the 5 % magnesium chloride ($MgCl_2$) solution.

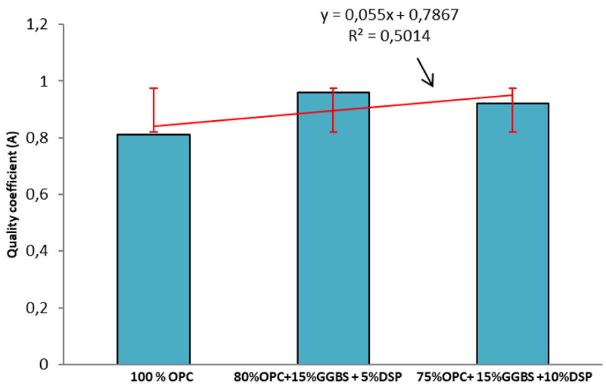

Figure 5. Quality coefficient of the cement pastes immersed in the 5 % magnesium chloride ($MgCl_2$) solution.

Sulfate and acid attack resistance OPC – GGBS – DSP

Figures 4 and 5 respectively show the compressive strength of the pastes cement immersed in water and the solution magnesium chloride 5 % ($MgCl_2$) and the variation in the quality coefficient (A) as a function of the immersion time of the cement pastes in the magnesium chloride solution (5 % $MgCl_2$), respectively, for a storage time of 90 days. The results obtained show that the cement containing granulated slag and dune sand powder for the mixture (80 % OPC + 15 % GGBS + 5 % DSP) and (75 % OPC + 15 % GGBS + 10 % DSP) showed good chemical resistance to the magnesium chloride solution (5 % $MgCl_2$) compared to that of Portland cement (OPC). Furthermore, the paste cement containing (80 % OPC + 15 % GGBS + 5 % DSP) showed the best resistance to the (5 % $MgCl_2$) solution compared to the mixture containing (75 % OPC + 15 % GGBS

+ 10 % DSP). This phenomenon can be explained by two reasons. The first reason is that the cement paste with GGBS and DSP contains a small amount of $Ca(OH)_2$ compared to the ordinary Portland cement paste, which reduces the leaching of $Ca(OH)_2$, resulting in a lower reduced of strength. Second, the low resistance of Portland cement to magnesium chloride compared to the cement paste with GGBS and DSP can also be attributed to the decalcification of hydrated calcium silicate (C-S-H). This decalcification occurs due to the progressive transformation of C-S-H into the hydrated magnesium silicate (M-S-H), which lacks binding properties [68-71]. However, in cement containing granulated slag and dune sand powder, the calcium hydroxide is consumed by the pozzolanic reaction of dune sand powder and the hydration of granulated slag, leading to the formation of additional hydrated calcium silicates (C-S-H), which could also increase resistance to salt damage.

On the other hand, the results obtained in Figures 6 and 7 showed that cements containing slag and dune sand powder have a better chemical resistance to sulfates (Na_2SO_4) than Portland cement (OPC). The cement composite containing (75 % OPC + 15 % GGBS + 10 % DSP) showed excellent resistance to a sodium sulfate attack which is due to an increase in the alkalinity of the cement medium related to the formation of sodium hydroxide (NaOH) following the chemical reaction between sodium sulfate and calcium hydroxide $Ca(OH)_2$, which promotes the hydration of the slag and, on the other hand, allows the formation and stabilisation of the gel (C-S-H).

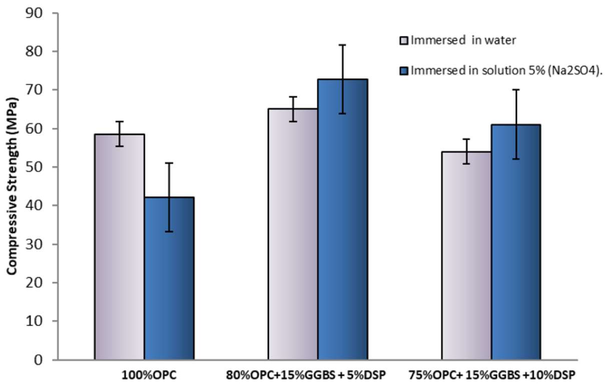

Figure 6. Compressive strength of the cement pastes immersed in water and the 5 % sodium sulfate (Na_2SO_4) solution.

Water permeability OPC – GGBS – DSP

Figure 8 shows the variation in the water permeability coefficient for the reference concrete (BST) and the concretes with cement containing dune sand powder and slag, designated as BSDI and BSDII concrete, as a function of curing time. The results obtained show that the water permeability of the concrete based

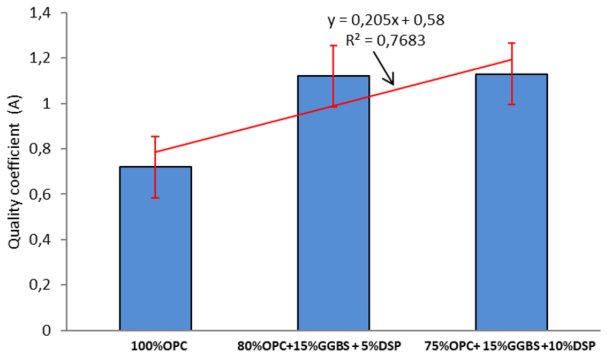

Figure 7. Quality coefficient of the cement pastes immersed in the 5 % sodium sulfate (Na_2SO_4) solution.

on the cement containing (80 % OPC + 15 % GGBS + 5 % DSP) is comparable to that of the reference concrete at 28 days. However, the concrete containing (75 % OPC + 15 % GGBS + 10 % DSP) exhibits a slightly higher water permeability coefficient compared to both the reference concrete and concrete made with (80 % OPC + 15 % GGBS + 5 % DSP). On the other hand, it is observed that, after 60 days of curing, the permeability coefficient of the concrete incorporating cement with (75 % OPC + 15 % GGBS + 10 % DSP) is lower than that of the reference concrete. The decrease in the permeability coefficient can be explained by the filling of the capillary pores in the cementitious matrix due to the formation of additional new (C-S-H) gel resulting from the pozzolanic reaction of dune sand powder and the latent hydraulic properties of the granulated slag with their hydration progress over time. These reactions lead to a reduction in the permeability coefficient and a lower diffusion of concrete containing slag and dune sand powder compared to ordinary Portland cement concrete. These results are consistent with the findings of S. Guettalla and B. Mezghiche [27, 38], which demonstrated the positive effect of dune sand powder on the mechanical

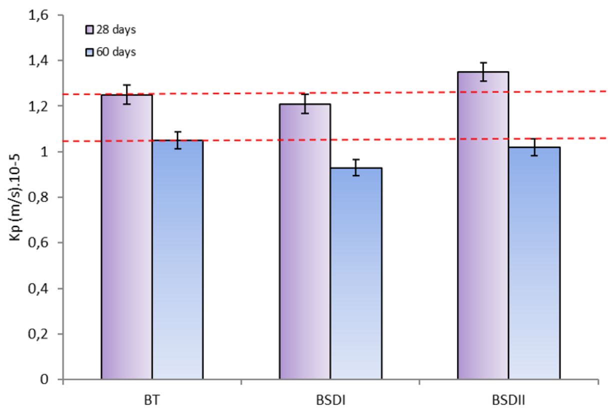

Figure 8. Variation in the water permeability coefficient (KP) for the different types of concrete as a function of the curing time.

and durability properties of concrete, resulting from its higher pozzolanic reactivity at later ages and the fineness of the dune sand powder used.

Stability volumetric

The swelling of concrete is the deformation of hardened concrete caused by swelling materials in the cement. The drying shrinkage of concrete is caused by the evaporation of the internal water of the hardened concrete. Swelling and drying shrinkage are two properties that depend on the concrete's properties most of the time.

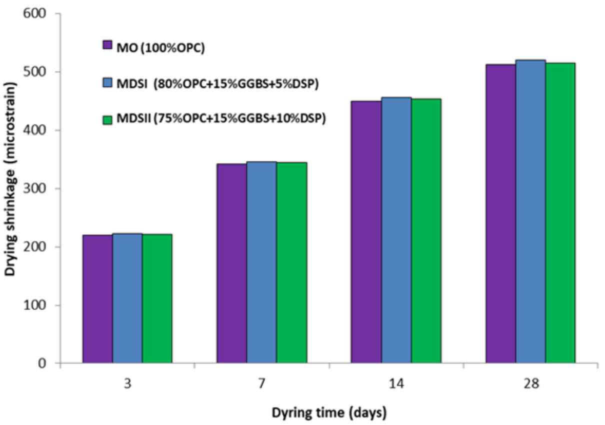

Figure 9. Drying shrinkage vs. drying time of the plain cement mortars and with GGBS and DSP.

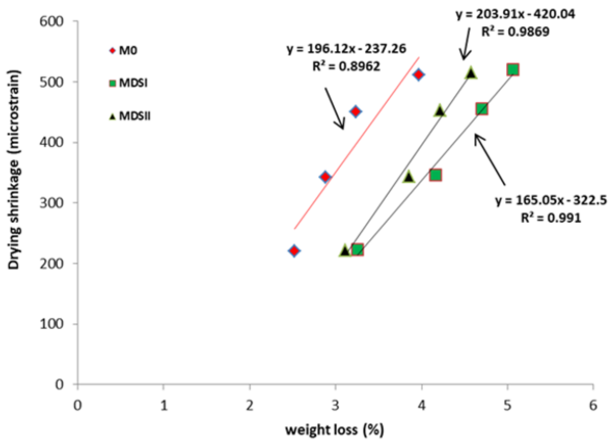

Figure 10. Relationship between the shrinkage and weight loss.

The evolution of the shrinkage drying and the swelling of the various mixtures according to time are presented by Figure 9 and Figure 11, respectively. From Figure 9, it can be observed that mortar-based cement on (80 % OPC + 15 % GGBS + 5 % DSP) and (75 % OPC + 15 % GGBS + 10 % DSP) has a slight increase in shrinkage drying compared to the reference mortar. In Figure 10, the drying shrinkage is presented as a function of the corresponding

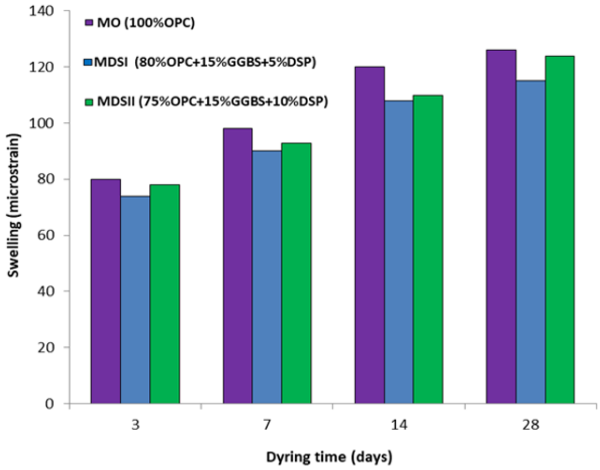

Figure 11. Swelling vs. time of the plain cement mortars and with GGBS and DSP.

weight loss for all the studied mixtures in order to obtain the relationship between them. For all the mixtures, it can be seen that the shrinkage is proportional to the water loss. Contrary to the reduction observed in the drying shrinkage (Figure 11), it can be remarked that the partial substitution of the cement by the slag and dune sand powder leads to a lower decrease in the swelling compared to the reference mortar. Indeed, the Portlandite $Ca(OH)_2$ released during the hydration of cement causes an increase in the volume of the mortars (swelling, expansion). However, the pozzolanic reactions in MDSII mortar (75 % OPC + 15 % GGBS + 10 % DSP) absorbed an important amount of $Ca(OH)_2$ and, therefore, diminished the probability of volume expansion in the mortars (75 % OPC + 15 % GGBS + 10 % DSP).

CONCLUSIONS

In this study, the effect of ground slag and dune sand powder as supplementary cementitious materials on the mechanical and physical properties and durability of cement and mortars was investigated. After discussing the results, the following conclusions can be drawn:

- The study showed that the partial substitution of cement by granulated slag and dune sand powder has the effect of extending the setting time; on the other hand, the results showed that the consistency of the fresh mixture containing slag and dune sand powder becomes more fluid compared to the control mixture without the addition;
- The study showed that partial substitution of Portland cement by (15 % GGBS + 5 % DSP) revealed improvements in the compressive strength of the concrete in the long term and comparable compressive strengths to the control concrete in the short and medium term (28 and 60 days). On the other hand, the results show that increasing the percentage of cement substitution

by DSP beyond 10 % leads to a slight decrease in the short and long-term strength.

- The study showed that replacing cement with blast furnace slag (GGBS) and dune sand powder (DSP) was very effective in improving the resistance of cement to sulfate attack. The sulfate resistance of the cement increased with the increasing cement replacement (DSP), the cement containing (75 % OPC + 15 % GGBS + 10 % DSP) showed excellent durability to sulfate attack.
- The results of the magnesium chloride acid resistance tests of the cement revealed that the cement replacement with slag (GGBS) and dune sand powder (DSP) provided better resistance to an acid attack than cement without replacing the slag and dune sand powder. The cement containing (80 % OPC + 15 % GGBS + 5 % DSP) showed excellent durability to the acid attack compared to the ordinary Portland cement and cement composite (75 % OPC + 15 % GGBS + 10 % DSP).
- The concrete mixtures containing cement with blast furnace slag and dune sand powder showed lower water permeability than the control concrete with ordinary Portland cement, the concrete mixture containing (75 % OPC + 15 % GGBS + 5 % DSP) showed the lowest water permeability, than the concrete mixtures containing (80 % OPC + 15 % GGBS + 10 % DSP) and 100 % OPC.
- The tests also showed that mortars containing cement with slag and dune sand powder (DSP) developed a slightly higher drying shrinkage than the mortar containing cement without the additions; on the other hand, the obtained results showed that the substitution of cement with the blast furnace slag and dune sand powder revealed lower water expansion than the cement--based mortar alone.

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