Magazine of Civil Engineering. 2020. 98(6). Article No. 9809

Magazine of Civil Engineering

ISSN 2712-8172

journal homepage: http://engstroy.spbstu.ru/

DOI: 10.18720/MCE.98.9

Behavior of heat treated self-compacting mortar cured in seawater

***R. Derabla*[*a, b], *F. Sajedi*[c]**

[a] *Department of Civil Engineering, University of 20 august 1955, Skikda, Algeria*

[b] *Laboratory of Civil Engineering and Hydraulic (LGCH), University of 8 May 1945, Guelma, Algeria*

[c] *Department of Civil Engineering, Ahvaz Branch, Islamic Azad University, Ahvaz, Iran*

** E-mail: rderabla@gmail.com*

Keywords: GGBFS, limestone, mortar, heat treatment, mechanical properties, seawater

Abstract. The acceleration of the hardening of self-compacting concrete (SCC) using the process of heat treatment is widely used in the field of prefabrication. Because mortar serves as the basis for the workability properties of SCC, these properties could be assessed by self-compacting mortars (SCMs). This paper has the purpose to study the behavior of heat-treated SCM based on two different mineral additions in marine environment. The additions are used as micronized powder to substitute 20 % and 40 % of cement. They are as ground granulated blast furnace slag (GGBFS) and limestone filler (LF). The cycle regime of heat treatment process used achieves a temperature of 60 °C and total duration of 24 hours. The research was conducted through the study of the physical and mechanical properties of elaborated SCMs under two curing regimes as freshwater and seawater. The obtained results indicate that the incorporation of LF seemed more effective in standard treatment process but it is advisable to limit its use to levels of less than or equal to 20 % as it develops resistance levels lower than those obtained by GGBFS. The incorporation of GGBFS especially with high amount of 40 % is very beneficial to improve physical-mechanical properties of heat-treated SCMs and it has many advantageous for obtaining stable and resistant SCMs against aggressive environment.

1. Introduction

According to the experimental researches, concrete subjected to high temperatures at early ages attains higher early-age mechanical strengths but has lower later-age mechanical strengths than concrete subjected to normal temperatures. This is because the higher curing temperatures which affect the physical characteristics of the cementitious system by altering the dormant period of hydration process. Many laboratory studies carried out on pastes, mortars or concretes under controlled conditions have shown that expansion does not occur if the material has not been subjected to a temperature above 70 °C [1, 2].

The use of some mineral admixtures in concretes has several interests. It can diminish the final cost of the production by reducing the cement content which is the most expensive component in the concrete, it can reduce the emission of CO_2 generated in the production of ordinary Portland cement and it is inevitable to improve concrete fresh and hardened properties and to enhance concrete durability [3].

The quality of the normal concrete (NC) and self-compacting concrete (SCC) elaborated with mineral admixtures e.g. silica fume (SF), fly ash (FA), pozzolans (PZ), limestone fillers (LF) and ground granulated blast furnace slag (GGBFS), is higher than that of the concrete made with pure cement [4−6]. When the hardening of the concrete is accelerated by heat treatment (HT), the researches [7−9] have proven the effectiveness of these additives. Under the heat curing, the high temperature will strongly enhance the reactivity of FA and GGBFS in NC and SCC and therefore the hydration action of mineral additions [10].

On the other hand, it is suitable that the building materials are as durable as resistant and economic to allow their use in aggressive environments such as marine environment. In seawater, there are large amount of chloride and sulfates where the reinforced concrete structures are often found to be deteriorated by corrosion. The chloride causes the Friedels Salt and the sulfate reacts with calcium hydroxide and calcium aluminate hydrate to form gypsum and secondary ettringite that are more voluminous than the initial reactants [11]. It can affect the long-term durability of concrete structures, and leads to expansion, cracking, and deterioration of concrete specimens.

Among of the mineral admixtures, the GGBFS has been widely used as successful replacement material with OPC in making durable concrete for improving some properties of concrete in marine environments and for achieving environmental and economic benefits since the beginning of 20th century [12]. GGBFS can effectively fill the pores of concrete which are very much helpful for reducing the permeability and then restricts the penetration of seawater inside the concrete. It has been observed that GGBFS can be effectively used to reduce the pore sizes and cumulative pore volume considerably leading to more durable and impermeable concrete and therefore increases the durability of concrete in seawater environments [13]. Although, the strength development of concrete made with GGBFS is remarkably reduced at early ages due to its low initial rate of hydration especially if it will be activated thermally as the case of precast [14]. Although low heat of hydration of slag, the structural benefit is that the decrease of the thermal cracking of mass concrete is significant and it is seen to be lower than ordinary Portland cement [15]. Concerning the LF, its use to replace cement has a positive effect on the development of mortar strength [16]. It confers flow-ability, viscosity and stability; however, it does not present pozzolanic or hydraulic properties [17]. According to [18–20], LF accelerates the hydration of C_3S and thereby increases the early compressive strength of the mortar. Medjigbodo et al. [21] explain this early acceleration by the chemical reaction between the calcium carbonate of LF and the aluminate supplied by cement.

Since the mortar serves as the basis for the workability properties of SCC, these properties could be assessed by SCM. The SCMs are especially preferred for the rehabilitation and repair of reinforced concrete structures. Several works have been studied the behavior of SCMs under different conditions. The authors [22] have determinate that the production of SCM with good rheological and strength properties could be successfully assessed using LF. The researchers [23, 24] have concluded that FA and LF powder increased significantly the workability and had an improved overall response on SCMs.

The characteristics of heat-treated SCC could also be assessed by the characteristics of heat-treated SCM. Safi et al. [25] showed that heat-cured SCMs (temperature of 60 °C) containing calcined silt of dams and ground brick waste (BW) have permitted to obtain a strength gains compared to reference SCM. Other authors have studied the heat curing of normal mortars. Famy et al. [26] showed that the heat curing at 90 °C lead to dimensional changes of mortars due to the formation of the expansive ettringite. Sajedi and Hashim [27] are found that 50 % level of slag with heat curing of 60 °C in duration of 20 hours is the optimum regime for compressive strength of cement-slag mortars studied. It has been proved as reported in our previous paper [28] that it is possible to produce a heat-treated-concrete (at 60 °C for duration of 9 hours) resistant to chlorides and sulphates existing in the marine environment by either combining 20 % of slag, with the use of water reducing plasticizer admixture and W/C rate limited to 0.35 or by the use of 40 % of slag, without admixture and a W/C slightly higher and equal to 0.5. Erdogdu [29] has been found that the type of cement and the preheating duration have an important influence on the flexural strength of heat-treated mortar. Thus, the fineness of the cementitious materials is a very interesting parameter to obtain high level of resistance of the elaborated materials, whether in standard treatment conditions or in thermal treatment conditions [30].

The durability of mortars in seawater environment has been also studied. Moinul et al. [31] have been revealed that GGBFS cement-mortar having mix ratio 70:30 with water binder ratios of 0.46 has better resistance against strength deterioration at different ages and all curing conditions. So, it was concluded by Boufenara et al. [32] that the cements with high content of GGBFS offer good chemical resistance against the aggression of sodium sulfate solution and seawater.

Following this short introduction and on the basis of our bibliographic research, few works that have been interested of the durability of elaborated concrete or mortar in seawater environments; but there is almost no work which studied the behavior of heat-treated concrete or mortar based on mineral admixtures in aggressive environments.

This paper investigates the effect of local mineral additions as GGBFS and LF on the physical and mechanical properties of SCMs in seawater environment. For this, the SCMs have been prepared with water to binder ratio of 0.42 for all binder mixtures which are based on various levels of mineral additions as 20 % and 40 %. The physical and mechanical tests were conducted on prismatic samples (4×4×16in) of SCMs subject to HT process at 60 °C and kept after demoulding in seawater medium (SW). The results of these tests were compared with those obtained with standard treatment process (ST) at 20 °C and kept in freshwater medium (FW).

2. Materials and Methods

2.1. Materials

The cement used is a Portland cement compound, CPJ CEM II 42.5, the limestone filler (LF) is a calcium carbonate powder ($CaCO_3$ = 98 %) and the GGBFS is obtained after grinding of blast furnaces slag to obtain a fine powder similar to that of common cements.

The chemical composition of the various cementitious materials is given in Table 1. The chemical composition of LF indicate that is inert product and that of GGBFS is near to that of the cement which indicate that is reactive product and its activity index (A_{GGBFS} = 0.96) indicates that it is basic [33].

The physical characteristics of the admixtures: absolute density, specific surface of Blaine (SSB) (EN 196-6), and specific surface by laser diffraction (SSDL) (NF X11-666), are shown in Table 2 and their particle size distribution is illustrated in Fig. 1.

The superplasticizer (SP) used is MEDAPLAST SP 40 which is a high water reducer for ready-mix concrete according to EN 934-2.

Two types of sand were used: Siliceous sand 0/1 (noted S1) and Crushed limestone sand 0/4 (noted S2) of fineness modulus of 1.66 and 3.51, apparent densities of 1.46 and 1.49 and absolute densities of 2.50 and 2.56 respectively. The chemical analyses of sands are given in Table 1.

2.2. Methods

2.2.1. Experimental program

The heat treatment cycle used in this study (Fig. 2) take into account the specifications of the norm NF EN13369 [34]. The characteristics of the adopted cycle of heat-treatment are near to the cycles used in precast concrete industry. Also, The T^{re} of treatment of 60 C was adopted to avoid the formation of delayed ettringite (DEF) which can be effected by the instability of ettringite crystals when they are exposed to temperatures above 65 C, phenomenon which causes internal damage and expansive behavior in concrete samples [35]. The cycle starts after 3 hours of the mixing and takes a total duration of 24 hours. It includes 3 hours of pretreatment (pre-setting at 20°C), a phase of temperature rise of 2.5 hours before stabilizing at 60 C for a period of 16 hours (isothermal stage) and finally a natural cooling phase of 2.5 hours. The demoulding of the SCM specimens was carried out just at the end of the cooling phase. The specimens were placed in two different curing regimes, i.e. the freshwater (FW) and the seawater (SW).

The characteristics of the heat-treated SCMs are compared to the characteristics of that of the control SCMs (without addition and/or standard treatment at 20 °C).

The effect of the amount of GGBFS and LF as 20 % and 40 % to substitute the cement is well studied by its effect on the characteristics of the elaborated SCMs in both fresh and hardened states. The amounts of GGBFS and LF of 20 and 40 selected in this work are within the actual rates usually adopted in the manufacture of Algerian composite cements: such as CPJ-CEM II/A (6–20 % of mineral additives) and CPJ-CEM II/B (21–35 % of mineral additives).

The tests realized are the bulk density (ρ_{bulk}), the slump flow (S_f) and the occluded air (Oa) at the fresh state. In hardened state they are as:

– The porosity (P) at the age of 28 days calculated as the ratio of the difference of the masses of specimen (saturated and dried) to the total volume of the specimen according to standard NBN B 15-215 [36].

– The shrinkage and the swelling at the age of 28 days calculated as described in the standard NF P15-433 [37].

– The compressive strength at the age of 1, 7, 28 and 180 days according to the standard NF EN 196-1 [38].

2.2.2. Mortar mixes-design

The composition of the SCMs given in Table 2 is that of the mortar which composes the SCC that formulated based on the recommendations of the AFGC [39]. The mixing and the preparation of SCMs specimens were carried out according to EN 196-1.

- Ratio Water to Binder W/B as 0.42 for all SCMs,
- Type of treatment: standard treatment (ST) (or untreated) and heat treatment (HT),
- Level of substitution of cement by the GGBFS and LF are as 20% and 40 %,
- Curing regimes are as freshwater (FW) and seawater (SW). The mineral composition of seawater is given in Table 3.

For the elaborated SCMs which W/B = 0.42, the parameters are as:

- Volume of the paste: Cement (C) + Water (W) + Admixture (A) + Occluded air = 397 liters,
- Volume of the sand equal to 42 % compared to the volume of the mortar,
- Ratio S1/S2 = 1 by volume and S1/S2= 0.97 by mass,
- Dosage of SP adopted which corresponds to the saturation dosage (SP_{sat}),
- Ambient air curing regime for the shrinkage test.

Table 1. Chemical composition of raw materials.

Oxides (%)	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	K_2O	Na_2O	SO_3	Loss on ignition
C	59−62	22−24	5.3–6.0	3.0−4.0	1.5−1.8	< 0.9	< 0.7	1.8−2.2	na
GGBFS	42.77	41.23	7.89	1.38	4.60	0.94	0.00	0.34	na
LF	56.18	0.43	0.08	0.09	0.26	0.01	0.07	0.03	42.85
S1	0.62	95.21	1.12	0.55	0.04	0.46	0.10	00	na
S2	56.73	3.71	0.23	0.20	1.18	0.02	0.07	0.09	37.77

Table 2. Composition of elaborated SCMs.

Mix type	C (kg)	A (kg)	W (kg)	S1 (kg)	S2 (kg)	W/C (%)	W/B (%)	SPsat (%)
SCM-R	530	0	220	360	369	0.42	0.42	1.85
SCM20GGBFS	440	88	220	360	369	0.50	0.42	1.60
SCM40GGBFS	377	151	220	360	369	0.58	0.42	1.70
SCM20LF	430	86	215	360	369	0.50	0.42	1.70
SCM40LF	362	145	211	360	369	0.58	0.42	2.00

SCM-R: Reference SCM
SCM20GGBFS: SCM having 20% of GGBFS
SCM40GGBFS: SCM having 40% of GGBFS
SCM20LF: SCM having 20% of LF
SCM40LF: SCM having 40% of LF

Table 3. Mineral composition of seawater [40].

T(°C)	S(‰)	pH	O_2 (%)	O_2 (mg/l)	rH (mV)	Condi (µS/cm)
20.2	37.1	7.7	66.1	6.1	− 38.6	55846

T: Temperature (°C) S: Salinity (‰)
pH: hydrogen potential (), O_2: oxygen saturation rate (%),
O_2: dissolved oxygen (mg / l), rH: reducing power (mV)
Condi: conductivity (µS / cm)

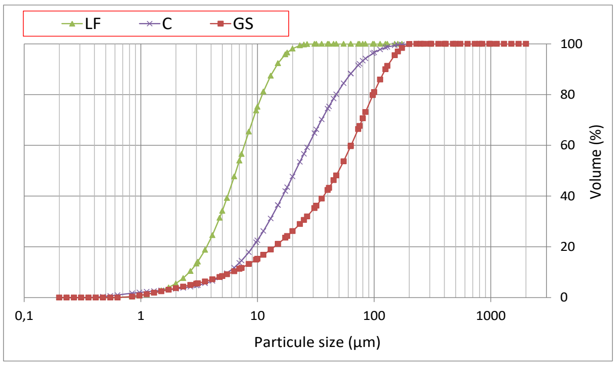

Figure 1. Particle Size Distribution of cement, GGBFS and LF.

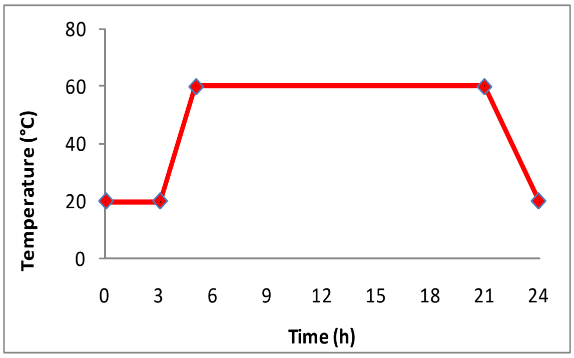

Figure 2. Heat treatment cycle.

3. *Results and Discussion*

The results of the tests carried out for the characterization of the SCMs in the fresh state are given in Table 4 and that of the hardened state are shown in Fig. 3 to 17.

It can be said that, in the fresh state, the incorporation of the GGBFS and LF causes a decrease of the measured values of the physical properties of SCMs. The increase in the content of the GGBFS is associated to a decrease of slump flow and an increase of occluded air. The opposite is observed in the case of LF for both characteristics.

The LF confers flow-ability due to the considerable fineness compared to that of cement which allows a good filling of the voids and a better understanding of the paste particles. Thus it does not present pozzolanic or hydraulic properties which allows to water to be free and this helps to minimize occluded air bubbles. The

GGBFS is characterized by its reactivity and its considerable absorption of water which needs a larger amount of water than is required by the cement. These characteristics of GGBFS lead to decrease the amount of Occluded air and to reduce the fluidity of the SCM paste and consequently its flow.

Table 4. Characteristics of SCMs in fresh state.

Mix type	SCM-R	SCM20GGBFS	SCM40GGBFS	SCM20LF	SCM40LF
ρ_{bulk} (kg/m^3)	2100	2103	2080	2217	2105
Oa (%)	6.0	4.0	5.9	4.4	3.7
S_f (cm)	32.5	29.0	27.5	31.5	32.5

3.1. Porosity

The porosities at the age of 28 days of the studied SCMs are presented in Fig. 3. Overall, the least porous SCMs are:

– In terms of nature and dosage of admixture, SCMs based on 20 % of GGBFS in FW medium and SCMs based on 20 % LF in SW medium,

– In terms of treatment process, heat treated SCMs based on GGBFS and untreated SCMs based on LF.

These results confirm the advantage of the incorporation of the mineral admixtures to reduce the porosity of SCMs. Also, the dosage of 20 % showed better yield than that of 40 % for both mineral admixtures used. The SCM20GGBFS which has a limited amount of air occluded (by 4 %) is also less porous than the reference mortar SCM-R. This is almost which has been reached by [41] where they found that at the age of 1 year, slag concrete with slag substitution ratio 20% has the least pore size. This benefit has been obtained by Pal et al. [42] who observed that slag can be effectively used to reduce the pore sizes and cumulative pore volume considerably leading to more durable and impermeable concrete. The slag is reactive and has a latent hydraulic power, which need to an activator as temperature to can be reactivated and then to have the ability to properly fill the space and existing voids. In seawater, the presence of slag gives birth to some expansive hydrates (aragonite, calcite and gypsum) which decrease size of the pores and the capillary absorption coefficient The SCM20LF is very beneficial in standard treatment and seawater curing regime. The limestone filler is inert and finer than the cement, which allows a good filling of the voids and a better understanding of the paste particles. The amount of 40 % of LF is useless and it is even harmful, for that we must limit the incorporation of this admixture to levels a little lower.

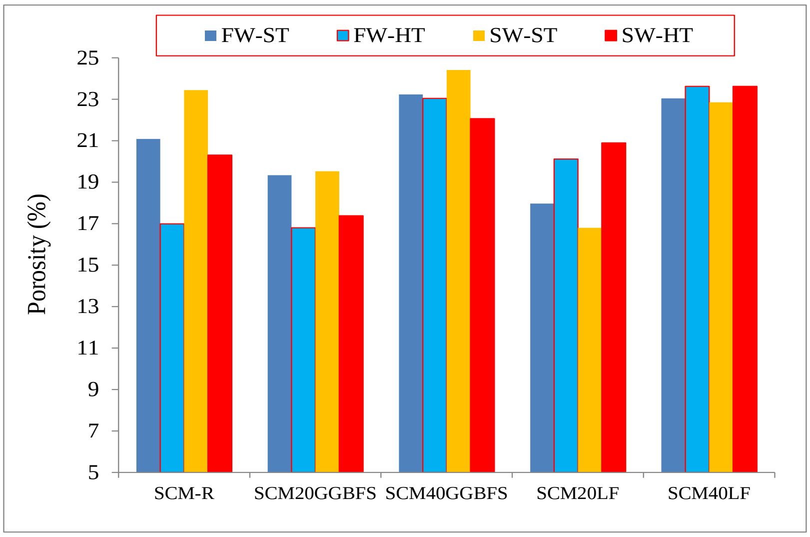

Figure 3. Porosity of SCMs.

3.2. Shrinkage and swelling

Regarding the test results of shrinkage (Fig. 4) and swelling (Fig. 5), the following comments can be given:

The HT process caused an increase in the shrinkage of elaborated Slag-SCM specimens and a decrease in that of LF-SCMs. The level of substituation of cement by 40 % of the additions is more advantageous, in both treatment cases. The SCM40LF is the less shrinking one among the others SCMs.

For the swelling test with both treatment process and compared to all studied SCMs, the SCM20GGBFS and SCM40GGBFS are that which give the lower swelling in FW and SW mediums respectively. With 40 % of LF, heat-treated SCMs are very advantageous than of 20 % in both curing regimes. These results prove that using GGBFS or LF could help to obtain stable heat-treated mortars against swelling in aggressive medium as marine environment especially with high replacement level (≥ 40 %).

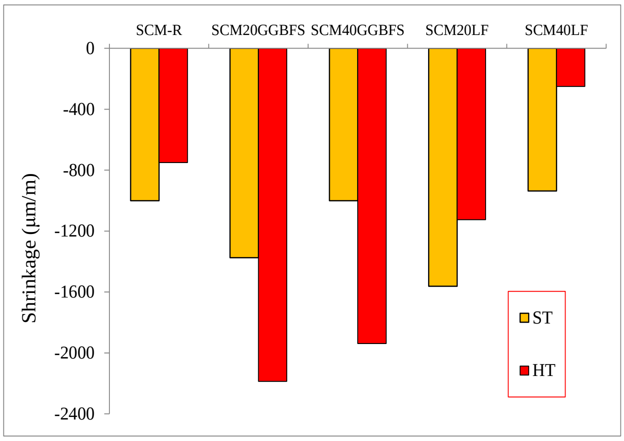

Figure 4. Shrinkage of SCMs.

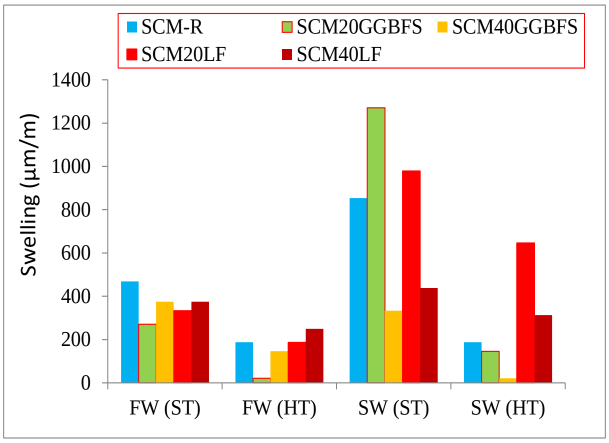

Figure 5. Swelling of SCMs.

3.3. Compressive strengths

The results of compressive strengths are schematized in Fig. 6 to 17.

3.3.1. Effect of the nature of the mineral addition

a. Dosage of 20 %

In fresh water (Fig. 6), LF and GGBFS allowed to obtain very close resistances in the first days. Beyond, GGBFS preponderates a little and shows its advantage due to its inherent hydraulic power and its distinctive reactivity at long-term. Thus, the SCM20GGBFS could be even more resistant than the SCM-R in HT process. In the SW medium (Fig. 7), the ST elaborated SCMs are more resistant than SCM-R but only heat treated SCM20GGBFS which predominates at the age of 180 days. These benefit results prove the advantage of GGBFS in the aggressive marine environment especially at very long term (180 days). Therefore, a good durability is ensured for the structures or the elements built with this eco-sustainable-product.

b. Dosage of 40 %

In both mediums, FW (Fig. 8) and SW (Fig. 9), the GGBFS is very beneficial while the LF is very harmful. We can notice here that GGBFS shows always its positive performance especially in SW environment and offers the possibility to have SCMs more resistant and more durable than those without GGBFS. This positive result using GGBFS remains valid for this level of substitution and even for levels above 40 %. Its according to the search results of Binici et al. [43] which came to conclude that the durability of concrete depending on the types and amount of additives and he was found that between (40 %, 60 % and 80 %) of GGBFS, the specimen based on high level of GGBFS (80 %) have the higher seawater attack resistance than that of the reference concrete.

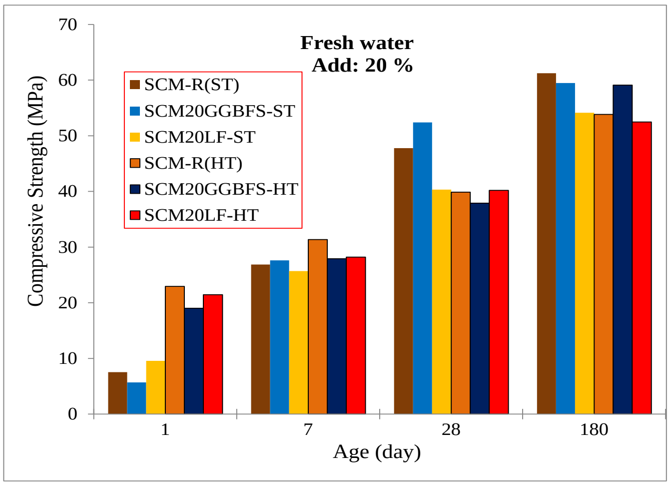

Figure 6. Effect of the nature of the mineral addition (20 %) on compressive strength of SCMs in freshwater.

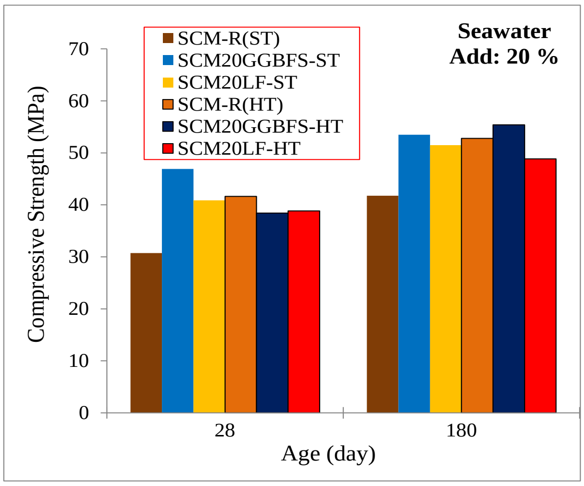

Figure 7. Effect of the nature of the mineral addition (20 %) on compressive strength of SCMs in seawater.

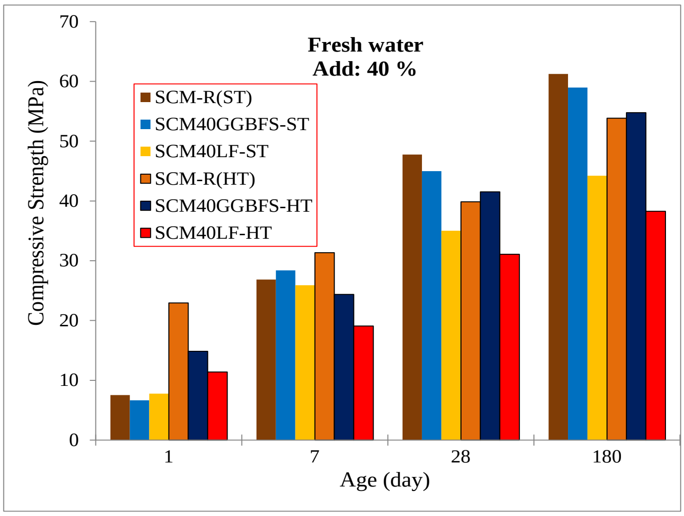

Figure 8. Effect of nature of the mineral addition (40 %) on compressive strength of SCMs in freshwater.

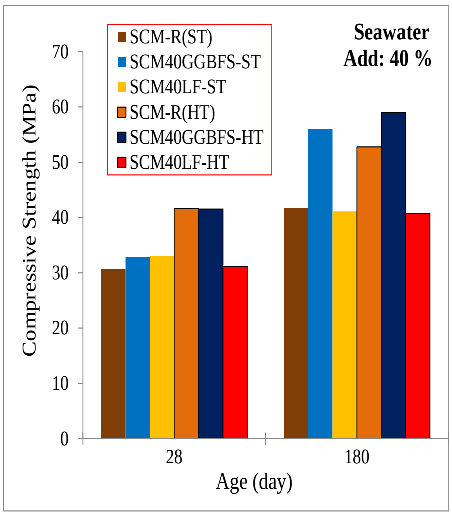

Figure 9. Effect of the nature of the mineral addition (40 %) on compressive strength of SCMs in seawater.

3.3.2. Effect of the dosage of the mineral addition

a. GGBFS

In fresh water (Fig. 10), the two dosages of admixture have allowed to have almost the same level of resistance except at the age of 28 days where the untreated SCM20GGBFS where could even preponderate the SCM-R.

In sea water (Fig. 11), except at the age of 28 days where the SCM20GGBFS has reached a resistance level higher than that of the SCM-R, it is very clear that SCM based on 40 % of GGBFS is very beneficial than that based on 20 %. This allows to consider that SCM40GGBFS as a stable material and thus more durable in the marine environment.

b. Limestone Filler

In fresh water (Fig. 12), except at early age (1 and 7 days) where the untreated SCM40LF has reached a level resistance almost the same of that of SCM-R and SCM20LF, the dosage of 40 % of LF is very harmful in all cases compared to that of 20 %. The same observations remain valid for SCMs cured in the SW medium (Fig. 13).

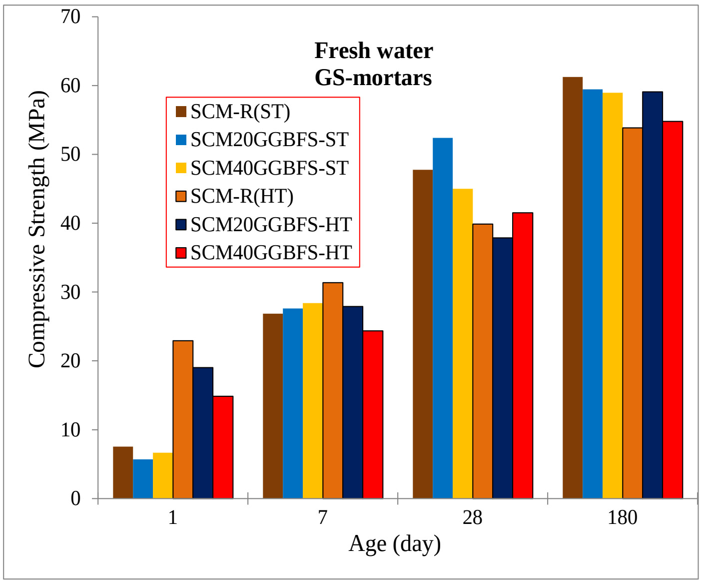

Figure 10. Effect of treatment process on compressive strength of Slag-SCMs in freshwater.

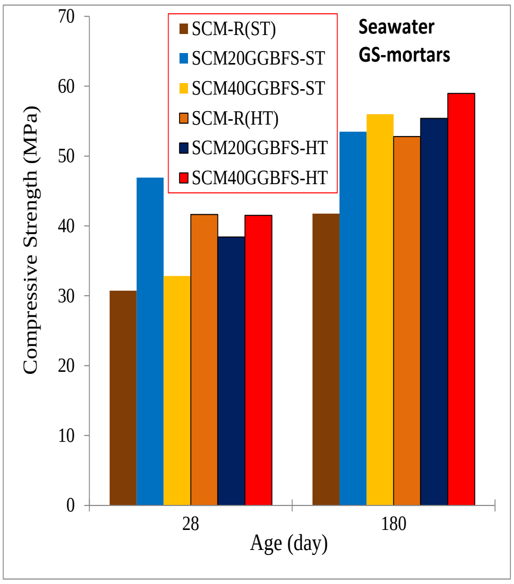

Figure 11. Effect of treatment process on compressive strength Slag-SCMs in seawater.

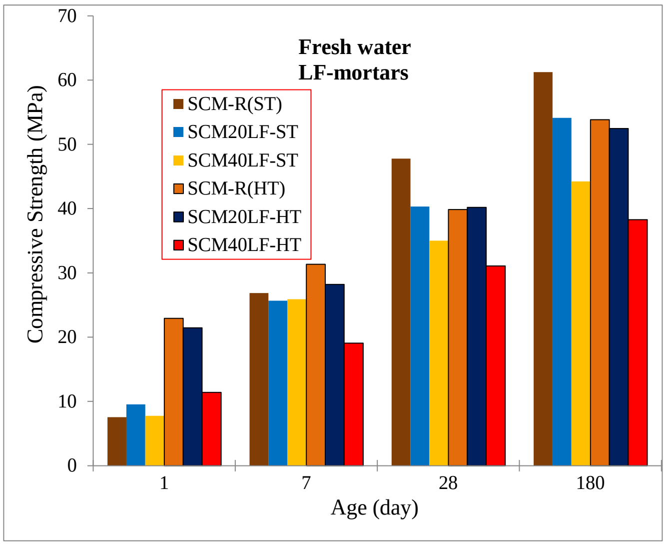

Figure 12. Effect of treatment process on compressive strength of LF-SCMs in freshwater.

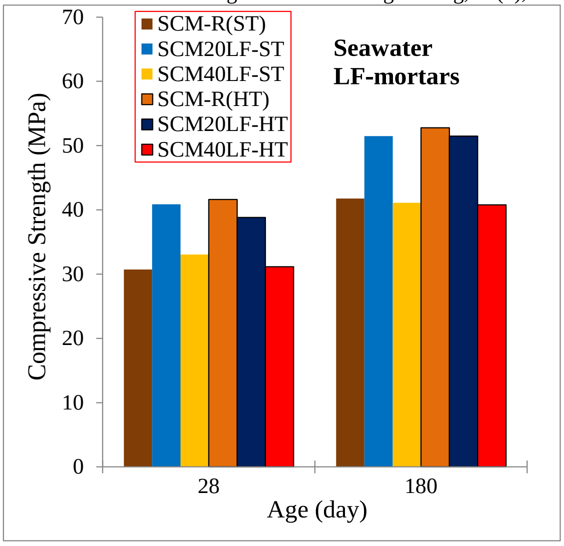

Figure 13. Effect of treatment process on compressive strength LF-SCMs in seawater.

3.3.3. Effect of treatment process

a. Using GGBFS

In fresh water (Fig. 10), at early age (1 day) all heat treated SCMs have higher strengths compared to untreated SCMs. The early age strengths of heat-treated mortars (SCM20GGBFS and SCM40GGBFS) achieved respectively, as 234 % and 123 % compared to their heat-treated strengths at 1 day, and reached respectively as 50 % and 36 % compared to their heat treated strengths at 28 days and attain respectively as 36 % and 33 % compared to their heat treated strengths 28 days.

At the age of 7 days, the resistances are nearly equal.

Beyond 28 days, the phenomenon reversed and the untreated SCFs had the high compressive strengths except for SCM20GGBFS where the results of the strengths are almost equal. Compared to the strength of heat-treated SCM-R at 28 days, SCM20GGBFS marks a loss of 5 % and SCM40GGBFS offers a gain of 4 %. Compared to the strength of untreated SCM-R at 28 days, the strengths of heat-treated mortars (SCM20GGBFS and SCM40GGBFS) at 28 days have respectively the losses as 21 % and 13 %.

At the age of 180 days, the elaborate SCMs have higher resistant compared to the heat-treated control mortar (SCM-R). Compared to the strength of heat-treated SCM-R at 180 days, heat treated SCMs (SCM20GGBFS and SCM40GGBFS) mark losses of 1 % and 7 % respectively. Compared to the strength of untreated SCM-R at 180 days, the strengths of heat-treated mortars (SCM20GGBFS and SCM40GGBFS) at 180 days have respectively the losses as 4 % and 11 %.

In sea water (Fig. 11), at the age of 28 days, the HT process leads to an increase of the strength of SCM40GGBFS (26 %), but a decrease for SCM20GGBFS (18 %). At very long-term (180 days), all heat-treated SCMs had the highest strengths compared to those of untreated SCMs. The slag-SCMs have higher resistant compared to the SCM made without slag. They are about 4 % and 5 % for SCM20GGBFS and SCM40GGBFS respectively.

b. Using LF

In fresh water (Fig. 12), at early age (1 day) all heat treated SCMs have higher strengths compared to untreated SCMs. The early age strengths of heat-treated mortars (SCM20LF and SCM40LF) achieved respectively, as 125 % and 47 % compared to their heat-treated strengths at 28 days and reached, respectively as 53 % and 37 % compared to their heat treated strengths at 28 days and attain respectively as 53 % and 33 % compared to their HT strengths at 28 days.

At the age of 7 days, the resistances are nearly equal.

Beyond 28 days, the phenomenon reversed and the untreated SCMs had the high compressive strengths except for SCM20LF where the results of the strengths are almost equal. Compared to the strength of heat-treated SCM-R at 28 days, SCM20LF offers a gain of 1 % and SCM40LF marks a loss of 22 %. Compared to the strength of untreated SCM-R at 28 days, the strengths of heat-treated mortars (SCM20LF and SCM40LF) at 28 days have respectively the losses of 16 % and 35 %.

At the age of 180 days, the elaborate SCMs have higher resistant compared to the heat-treated control mortar (SCM-R). Compared to their untreated at 180 days, SCM20LF and SCM40LF mark losses of 3 % and 13 % respectively. Compared to the strength of untreated SCM-R at 180 days, the strengths of heat-treated mortars (SCM20GGBFS and SCM40GGBFS) at 180 days have respectively the losses as 14 % and 38 %.

In sea water (Fig. 13), at the age of 28 days, the heat treatment process always leads to a decrease of the strength of SCM20LF and SCM40LF (5 % and 6 %). At very long-term (180 days), the HT process slightly influenced the strength of the elaborated SCMs and they have losses of about (5 % and 1 %).

The HT process leads to obtain promising early age strengths. These results allow demoulding concrete elements quickly (after some hours) and then a gain of time, money and high productivity. So, it is very important in the precast industry and has many advantages for arid regions to overcome curing of concrete structures. Beyond 28 days (long term), the HT process leads to losses in CS of all SCMs without SCM40GGBFS which offers a gain in CS of about 5 %. This confirms that the temperature supplied by HT process in our study was able to reactivate the GGBFS and consequently to increase its hydraulic power as obtained with other researches. Battagin [44] observed that the slag hydration increased systematically with temperature. This acquired property contributes to increase the CS of the developed SCM.

3.3.4. Effect of curing regime

From the results obtained for CS of untreated SCMs (Fig. 14), all SCMs kept in FW medium have higher resistant compared to those kept in SW medium. In the case of HT regime (Fig. 15), only SCM based on 40 % of GGBFS has the best result in SW compared to that stored in FW. With 20 % of GGBFS is even interesting in both process treatment (ST and HT). The same observations that have been made in the case of the use of GGBFS remain valid and right here with LF either with HT regime (Fig. 16) or with ST regime (Fig. 17). But the level of CS developed with GGBFS is superior to that obtained with LF and the amount of 20 % is much better compared to 40 %.

These results show the effectiveness of the incorporation of mineral additions into SCMs to enhance their resistance to seawater aggressively. It is clear that the increase of the substitution rate of the cement by GGBFS ensures a good durability of the SCM in SW medium. This finding has been confirmed by the researchers [31, 32] who concluded that the cements with high content of GGBFS offer good chemical resistance against the aggression of seawater. But the opposite using LF where it is preferable to limit its incorporation to levels less than or equal to 20 % and/or or if it is combined with other additions as MK.

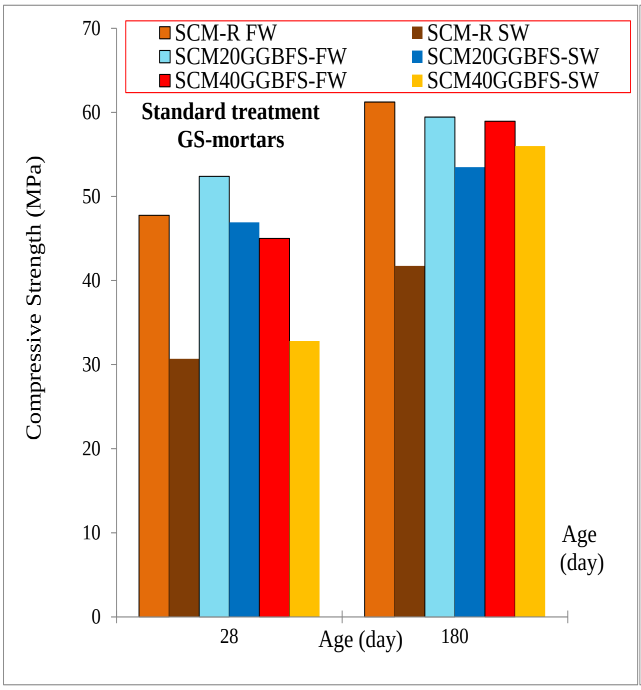

Figure 14. Effect of curing regime on the compressive strength of untreated Slag-SCMs.

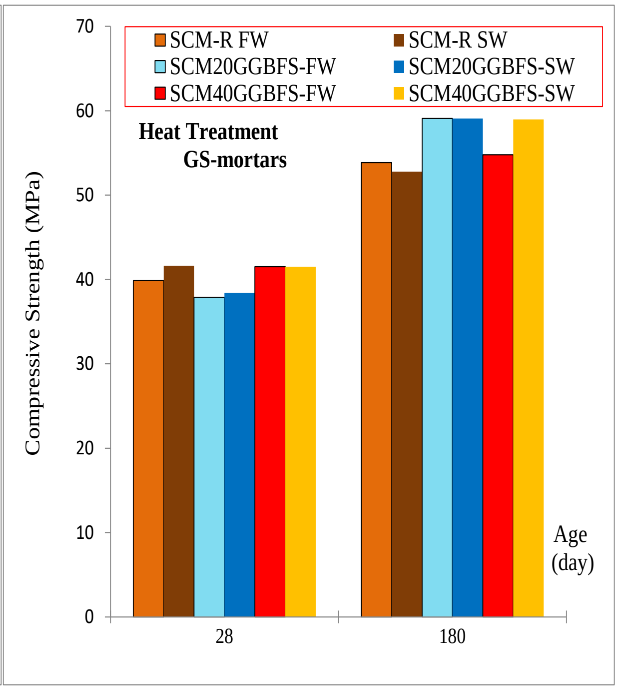

Figure 15. Effect of curing regime on the compressive strength of heat-treated Slag-SCMs.

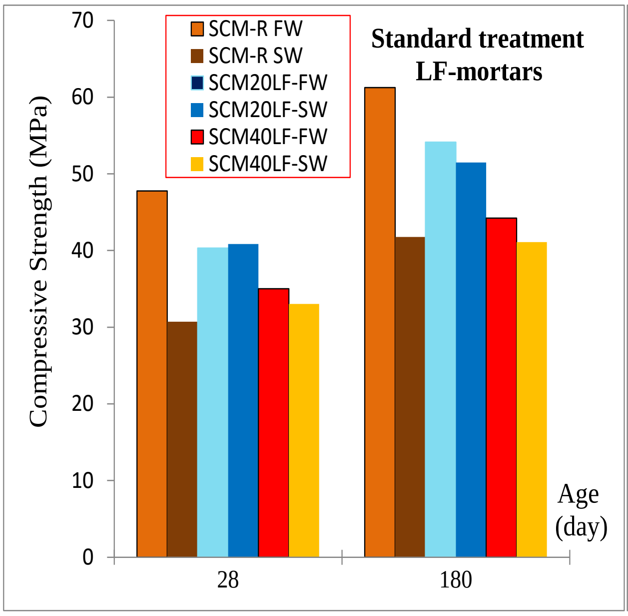

Figure 16. Effect of curing regime on the compressive strength of untreated LF-SCMs.

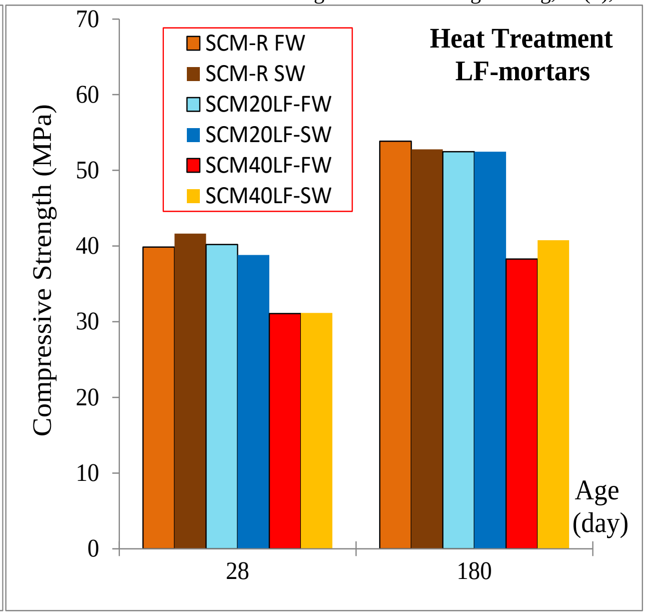

Figure 17. Effect of curing regime on the compressive strength of heat-treated LF-SCMs.

4. Conclusions

The main results derived from this study are as follows:

1. The heat treatment method has many advantageous especially at early ages where all the heat-treated SCMs could develop higher strengths than those of SCMs matured in normal conditions.

2. The incorporation of the mineral admixtures is very advantageous to improve physical-mechanical properties of heat-treated SCMs and almost to enhance its durability;

3. The nature and the dosage of the mineral admixture have significant impact on the behavior of SCMs with both HT and ST process and in both FW and SW mediums;

4. The dosage of 20 % LF seemed more effective than that with 40 %, so it is advisable to limit its use to levels of less than or equal to 20 %.

5. The incorporation of GGBFS has played a very important role in improving the behavior of SCM in the marine environment especially in the case of HT process where it could be reactivated by temperature and was able to show its long-term power.

6. The 40 % GGBFS dosage is more profitable than that of 20 % to provide a more stable SCM HT in the face of seawater aggression.

References

1. Heinz, D., Ludwig, U. Delayed ettringite formation in heat-treated mortars and concretes. Concr. Precast. Plant Technol. 1996. 55 (11). Pp. 56−61. http://dx.doi.org/10.1016/0958-9465(96)00012-1
2. Odler, Y., Chen, Y. On the delayed expansion of heat cured Portland cement pastes and concretes. Cem. Comp. Res. 1996. No. 18. Pp. 181−185. http://dx.doi.org/10.1016/0958-9465(95)00014-3
3. Victor, T. Effect of Mineral and Chemical Admixtures on Durability of Cementitious Systems. Graduate Theses and Dissertations, University of South Florida. 2015. http://scholarcommons.usf.edu/etd/6040
4. Gonen, S., Yazici, O., Gonen, T., Yazicioglu, S. The influence of mineral admixtures on the short and long-term performance of concrete. Building and Environment. 2007. No. 42. Pp. 3080–3085. http://dx.doi.org/10.1016/j.buildenv.2006.10.019
5. Tasdemir, C. Combined effects of mineral admixtures and curing conditions on the sorptivity coefficient of concrete. Cem. & Conc. Res. 2003. No. 33. Pp. 1637–1642. http://dx.doi.org/10.1016/S0008-8846(03)00112-1
6. Uysal, M., Yilmaz, K. Effect of mineral admixtures on properties of self-compacting concrete. Cem.& Conc. Comp. 2011. No. 33. Pp. 771–776. http://dx.doi.org/10.1016/j.cemconcomp.2011.04.005
7. Liu, B., Xie, Y., Li, J. Influence of steam curing on the compressive strength of concrete containing supplementary cementing materials. Cem. & Conc. Res. 2005. No. 35. Pp. 994–998. http://dx.doi.org/10.1016/j.cemconres.2004.05.044
8. Jacquemot, F., Rougeau, P., Flahault, N. Acceleration of hardening kinetics of SCC, Design, production and placement of self-consolidating concrete. RILEM Book series. 2010. No. 1. Pp. 307−316.
9. Felekoglu, B. Utilization of high volumes of limestone quarry wastes in concrete industry (self-compacting concrete case). Resources Conservation and Recycling. 2007. No. 51. Pp. 770–791. http://dx.doi.org/10.1016/j.resconrec.2006.12.004
10. Zhimin, H., Junzhe, L., Kangwu, Z. Influence of Mineral Admixtures on the Short and Long-term Performance of Steam-cured Concrete. Energy Procedia. 2012. No. 16. Pp. 836−841. http://dx.doi.org/10.1016/j.egypro.2012.01.134
11. Hooton, R.D. Influence of silica fume replacement of cement on physical properties and resistance to sulfate attack, freezing and thawing, and alkali silica reactivity, ACI Mater. J. 1993. 90(2). Pp. 143–151.

12. Eascalante, J.I., Gomez, L.Y., Johal, K.K., Mendoza, G., Mancha, H., Mendez, J. Reactivity of blast-furnace slag in Portland cement blends hydrated under different conditions. ACI Material Journal. 2001. 31(10). Pp. 1403−1409. http://dx.doi.org/10.1016/S0008-8846(01)00587-7
13. Pal, S.C., Mukherjee, A., Pathak. S.R. Corrosion Behavior of Reinforcement in Slag Concrete. ACI Material Journal. 2002. 99(6). Pp. 521−527. http://dx.doi.org/10.1016/j.cemconres.2003.12.029
14. Takashi, M., Iwaki, I., Strength Development of Concrete Incorporation High Levels of Ground Granulated Blast-Furnace Slag at Low Temperatures. ACI Material Journal. 2000. 97(1). Pp. 66−70.
15. Sajedi, F., Hashim, A.R. Thermal activation of ordinary Portland cement–slag mortars. Materials and Design. 2010. No. 31. Pp. 4522–4527. http://dx.doi.org/10.1016/j.matdes.2010.04.011
16. Antoni, M., Rossen, J., Martirena, F., Scrivener, K. Cement substitution by a combination of metakaolin and limestone. Cem. Concr. Res. 2012. 42(12). Pp. 1579–1589. https://doi.org/10.1016/j.cemconres.2012.09.006
17. Ye, G., Liu, X., De Schutter, G., Poppe, A. M., Taerwe, L. Influence of limestone powder used as filler in SCC on hydration and microstructure of cement pastes. Cem & Con. Com. 2007. No. 29. Pp. 94–102. https://doi.org/10.1016/j.cemconcomp.2006.09.003
18. Vuk, T., Tinta, V., Gabrovšek, R., Kaucic, V. The effects of limestone addition, clinker type and fineness on properties of Portland cement, Cem. Concr. Res. 2001. 31 (1). Pp. 135–139. https://doi.org/10.1016/S0008-8846(00)00427-0
19. Liu, S.H., Wang, L. Influence of limestone powder on hydration properties of complex binders, Mater. Res. Innov. 2014. 18(2). Pp. S2−186−S2−190. https://doi.org/10.1179/1432891714Z.000000000624
20. Qi, L., Liu, J., Liu, Q. Compound effect of $CaCO_3$ and $CaSO_4$_$2H_2O$ on the strength of steel slag-cement binding materials, Mater. Res. 2016. No. 19(scielo). Pp. 269–275. http://dx.doi.org/10.1590/1980-5373-MR-2015-0387
21. Medjigbodo, G., Rozière, E., Charrier, K., Izoret, L., Loukili, A.Hydration, shrinkage, and durability of ternary binders containing Portland cement, limestone filler and metakaolin. Con. & Buil. Mat. 2018. No. 183. Pp. 114–126. https://doi.org/10.1016/j.conbuildmat.2018.06.138
22. Benchaa, B., Kadri, H., Azzouz, L., Kenai, S. Properties of self-compacting mortar made with various types of sand. Cem. & Con. Com. 2012. No. 34, Pp. 1167–1173. http://dx.doi.org/10.1016/j.cemconcomp.2012.07.007
23. Sahmaran, M., Heru, A.C., Yaman, I.O., The effect of chemical admixtures and mineral additives on the properties of self-compacting mortars. Cem. & Con. Com. 2006. No. 28, Pp. 432–440. http://dx.doi.org/10.1016/j.cemconcomp.2005.12.003
24. Rizwan, S.A., Bier, A.T. Blends of limestone powder and fly-ash enhance the response of self-compacting mortars. Con. & Build. Mat. 2012. No. 27, Pp. 398–403, http://dx.doi.org/10.1016/j.conbuildmat.2011.07.030
25. Safi, B., Ghernouti, Y., Rabehi, B., Aboutaleb, D. Effect of Heat Curing on Strength Development of Self-compacting Mortars Containing Calcined Silt of Dams and Ground Brick Waste. Mat. Res. 2013. No. 16, Pp. 1058−1064. http://dx.doi.org/10.1590/S1516-14392013005000094
26. Famy, C., Scrivener, K.L., Atkinson, A., Brough, A.R. Influence of the storage conditions on the dimensional changes of heat-cored mortars. Cem. & Con. Res. 2001. No. 31, Pp. 795−803. https://doi.org/10.1016/S0008-8846(01)00480-X
27. Hashim, A.R., Sajedi, F. The effect of heat treatment on the compressive strength of cement-slag mortars. Mat. and Des. 2011. No. 32 Pp. 4618–4628. http://dx.doi.org/10.1016/j.matdes.2011.04.038
28. Derabla, R., Benmalek, M.L., Sajedi, F. Effect of Steam Curing on the Properties of Slag-Cement Concrete in Seawater Environment. 10th International Congress on Advances in Civil Engineering (ACE), METU, Ankara − Turkey, 17−19 October. 2012. 161 p.
29. Erdogdu, S., Kurbetci, S. Influence of cement composition on the early age flexural strength of heat-treated mortar prisms. Cem. & Con. Com. 2005. No. 27. Pp. 818–822. http://dx.doi.org/10.1016/j.cemconcomp.2005.03.006
30. Sajedi, F., Hashim, A.R. Effects of curing regimes and cement fineness on the compressive strength of ordinary Portland cement mortars. Con. and Buil. Mat. 2011. No. 25. Pp. 2036–2045. http://dx.doi.org/10.1016/j.conbuildmat.2010.11.043
31. Moinul, I.M., Saiful, I.M., Bipul, C. M., Amrita, D. Strength behavior of mortar using slag with cement in sea water environment. Journal of Civil Engineering (IEB). 2010. 38(2). Pp. 129−140.
32. Boufenara, K., Guetteche, M.N., Mezhoud, S. Durabilité des mortiers à base des laitiers de haut fourneau. Colloque CMEDIMAT, Oran – Algeria, 6−7 December. 2005.
33. Dreux, G., Festa, J. New guide of concrete and its constituents. Edition Eyrolles. 1998.
34. Common rules for precast concrete products, NF EN 13369. 2004.
35. Scrivener, K.L., Damidot, D., Famy, C. Possible Mechanisms of Expansion of Concrete Exposed to Elevated Temperatures During Curing (Also Known as DEF) and Implications for Avoidance of Field Problems. Cement, Concrete, and Aggregates. CCAGDP. 1999. 21(1). Pp. 93–101.
36. Concrete testing - Absorption of water by immersion. NBN B 15-215, Brussels: IBN. 1989.
37. NF P 15-433 Methods of testing cement. Determination of shrinkage and swelling. − Méthodes d'essais des ciments. Février 1994.
38. NF EN 196-1 Méthodes d'essais des ciments − Partie 1 : détermination des résistances − Méthodes d'essais des ciments – Partie 1: Détermination des résistances. Septembre 2016.
39. French Association of Civil Engineering AFGC. Recommendations for the use of self-compacting concrete. January, 2008. P. 63. http://www.afgc.asso.fr/images/stories/pub/Recommandations-SCC-AFGC-version-anglaise.pdf
40. Mezedjri, L. Modélisation de l'Impact de la Pollution Industrielle Hydrique dans le Golfe de Skikda (Littoral Est algérien). Thèse de doctorat, University Badji Mokhtar Annaba. 2008. http://dx.doi.org/10.13140/RG.2.2.11990.91204
41. Jau, W.C., Tsay, D.S. Study of the basic engineering properties of slag cement concrete and its resistance to seawater corrosion. Cement and Concrete Research. 1998. No. 28. Pp. 1363–1371. https://doi.org/10.1016/S0008-8846(98)00117-3
42. Pal, S.C., Mukherjee, A., Pathak, S.R. Corrosion Behavior of Reinforcement in Slag Concrete. ACI Material Journal. 2002. 99(6). Pp. 521−527.
43. Binici, H., Aksogan, O., Bahsude, E., Kaplan, H., Bodur, M.N. Performance of ground blast furnace slag and ground basaltic pumice concrete against seawater attack. Cons. and Buil. Mat. 2008. 22. Pp. 1515–1526. https://doi.org/10.1016/j.conbuildmat.2007.03.024
44. Battagin, A.F. Influence of degree of hydration of slag on slag cements. Proceeding GGBFS of the 9th ICCC, National Council for Cement and Building Materials, vol. III. New Delhi, India. 1992. Pp. 166–172.

Contacts:

Riad Derabla, rderabla@gmail.com

Fathollah Sajedi, sajedi@iauahvaz.ac.ir