Mechanical Strengths of Self-Compacting Mortars Prepared with the Pozzolanic Cement in Aggressive Environments

M. Saidi, I. Djefour, F. Ait Medjber, A. Melouane, A. Gacem

***Abstract*— The objective of this research is to study the physical and mechanical properties and durability of self-compacting mortars prepared by substituting a part of cement up to a percentage of 30% pozzolan according to different Blaine specific surface area (SSB1=7000 cm^2/g and SSB=9000 cm^2/g)). Order to evaluate durability, mortars were subjected to chemical attacks in various aggressive environments, a solution of a mixture of nitric acid and ammonium nitrate (HNO_3 + NH_4NO_3) and a magnesium sulfate salt solution ($MgSO_4$)) with a concentration of 10%, for a period of one month. This study is complemented by a comparative study of the durability of mortars elaborated with sulphate resistant cement (SRC). The results show that these mortars develop long-term, mechanical and chemical resistance better than mortars based Portland cement with 5% gypsum (CEM 1) and SRC. We found that the mass losses are lowest in mortars elaborated with pozzolanic cement (30% substitution with SSB_2) in both of chemical attack solutions (3.28% in the solution acid and 1.16% in the salt solution) and the compressive strength gains of 14.68% and 8.5% respectively in the two media. This is due to the action of pozzolan which fixes portlandite to form hydrated calcium silicate (CSH) from the hydration of tricalcic silicate (C_3S).

***Keywords*—**Aggressive environments, durability, mechanical strengths, pozzolanic cement, self-compacting mortar**.**

I. Introduction

THE cement is the basic constituent of concretes and mortars. This hydraulic binder makes it possible to glue together the grains of sand and aggregates [1]-[7]. Developed in the early nineteenth century, cement is now the second largest consumer product in the world after water, and continues to rise. In Algeria, the addition is used as blast furnace slag, natural pozzolan or tuff ... etc. and varying the percentages additions could be obtained depending on field of application, different types of cement with physical-mechanical properties required [8]-[10].

The physicomechanical properties are improved by optimizing the amount of pozzolan addition; this increased resistance is due to the refining of the pores and grains. And we must not forget that the pozzolan cement additions have better resistance to acids and sulfates, compared to Portland cement, which tends to increase the durability of concrete and mortar [11], [12].

Pozzolans are natural products of volcanic origin composed essentially of silica, alumina and ferric oxide; they are used in the cement industry for their properties "pozzolanic" is an ability to fix the portlandite at an ambient temperature and to form compounds with hydraulic properties, which can harden by hydration [13], [14].

The valuation of natural pozzolan used as raw materials for the production of clinker, has protected non-renewable natural resources. With this enhancement, the cement industry contributes to solving problems of waste (not counting the resulting benefits in terms of CO_2 emissions) [15]. In this context, we must study the degradation mechanisms involved in severe chemical environments in order to link the durability and strength of the material with the compositional parameters imposed [16].

The objective of this research is to study the physical and mechanical properties and durability of self-compacting mortars produced by substitution of one part cement up to a percentage of 30% pozzolan according to different Blaine specific surface area (SSB1 and SSB2) and the superplasticizer action [17]. These specimens are subjected to chemical attack in two aggressive environments, a solution of a mixture of nitric acid and ammonium nitrate (HNO_3 + NH_4NO_3) and a magnesium sulfate salt solution ($MgSO_4$)) with a concentration of 10%, for one month. This study aims to investigate the effect of the substitution of cement with different fineness of the pozzolan on the mechanical properties and durability of self-compacting mortars [18], [19].

This work is complemented by a comparative study of the durability of mortars elaborated with SRC. The results show that these mortars develop long-term, mechanical and chemical resistance better than mortars based CEMI and SRC [20], [21].

II. Experimental Study

A. Materials for Mortars

The cements used are prepared in the laboratory CEMI 42.5 with composition (0% pozzolan, 5% gypsum and 95% clinker), CEMII with composition (30% pozzolan, 5% gypsum and 65% clinker) and SRC 42.5 manufactured industrially). Sand is the normal sand (0/2). The Pozzolana used has two specific surfaces of Blaine: SSB1 = 7000 cm^2 g and SSB2 =

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9000 cm^2/g. Adjuvant is a Superplasticizer for concrete (Tempo12 from SIKA).

B. Mortar Mixtures

The first part of this work consists to evaluate the mechanical strengths of self-compacting mortars elaborated with cement composed of 30% pozzolan with various SSB. These resistances are compared with the normal compacting mortar and mortar based on SRC and Portland cement. The specimens are prepared according to the European norm EN 197-1 [22], [23].

TABLE I
DETAILS OF MORTAR MIXTURES

Constituent Mortar	Pz 30%		Cement	CRS	Sand	Adjv%	W/C
	%	(g)	(g)	(g)	(g)	TP_{12}	%
MP1	/		450	/	1350	/	0.5
MP1+ TP_{12}	/	/	450	/	1350	1.5	0.4
MPZSSB1	30	135	315	/	1350	1.5	0,4
MPZ SSB2	30	135	315	/	1350	2	0,4
MSRC	/	/	/	450	1350	/	0.5
MSRC+T_{12}	/	/	/	450	1350	1.5	0.4

with MP1 (M1): Normal mortar with Portland cement. MC + TP12 (M2): Mortar with Portland cement adjuvanted TEMPO12. MPZ30 SSB1 (M3) and SSB2 (M4): The mortars with cement substituted by 30% pozzolan (PZ) adjuvanted Tempo12. MCRS (M5): SRC mortar. MCRS+ TP12 (M6): SRC mortar adjuvanted TEMPO12.

III. Results and Discussions

A. Physical Characteristics of the Studied Cement

Absolute Density and Normal Consistence: The consistence test is used to determine the percentage of water required for the production of a normal cement paste. The paste is called normal when the probe of 10 mm diameter Vicat apparatus is inserted to a depth of 6 ± 1 mm in 30 seconds according to the standard (EN 196-3); the water content is expressed as cement mass percentage.

The Setting Time of Studied Cements: The beginning and end of setting times are determined with the Vicat needle on a normal consistency of paste placed in a tapered mold according to standard NF P15-473. Fig. 1 shows the pozzolan SSB effect on the start and end of setting, it is noted when the SSB pozzolan increases the setting time to decrease.

B. Physical Properties of the Studied Mortars

Fluidity: This property is verified by a spreading test of the mortar which must be of the order of 20 ± 2 mm. Fig. 2 represents the spreading of different mortars. It is observed that the spread increases with adding and adjuvant [21].

Bulk Density: This measurement determines the volumetric efficiency (the mass ratio of the volume) of the composition of fresh and hardened mortar and verifies the validity of the theoretical formulation. In Fig. 3, we observe that the density of the mortar in the hardened state decreases by contribution to those fresh to except mortars with addition whose density increases in the hardened state.

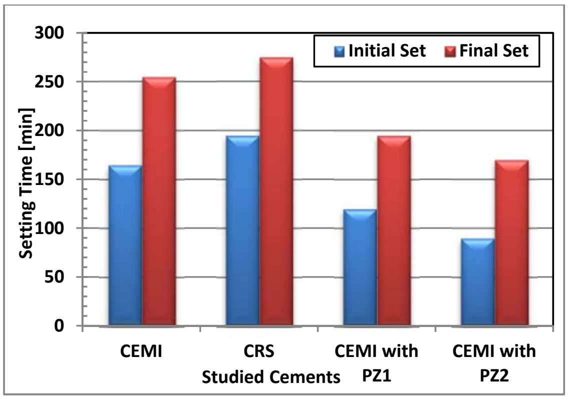

Fig. 1 Setting time a function of nature of cement

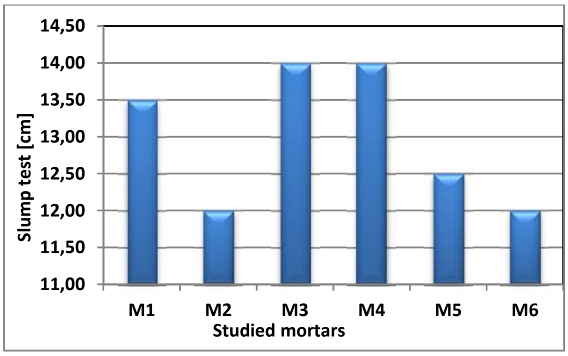

Fig. 2 Slump a function of nature of cement

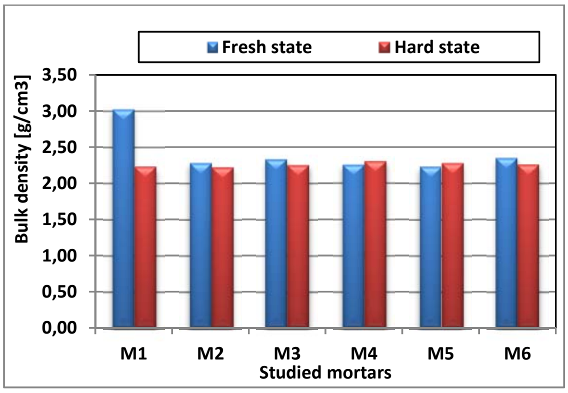

Fig. 3 Bulk density a function of nature of cement

The water absorption and porosity: To know the percentage of water absorbed and the percentage vacuum for each type of test, we did the tests of water absorption and porosity, by following the steps below:

1- Weighed respectful specimens (P1);
2- Samples then immersed in a tank filled with water at 20 ± 1C0 for 48 H;
3- Finally the test specimens are removed and wiped with a towel and weighed (P2);

C. Mechanical Properties of Various Mortars

Flexural and compressive strength: The bending tests are performed on the bending apparatus by placing the specimen symmetrical and centered on the plate of the hydraulic press provided with a three-point bending device and a continuous load is applied to the specimen until the rupture. The load P KN and the resistance Rf flexural MPa are displayed on the screen of the device where playback is performed. Figs. 5 and 6 show results for mechanical resistance (at 28 days) to bending made up of different combinations of test samples.

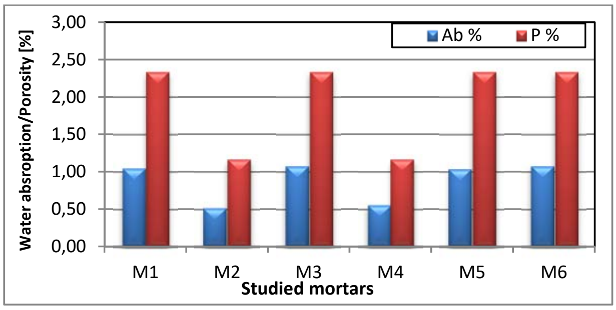

Fig. 4 Porosity a function of nature of cement

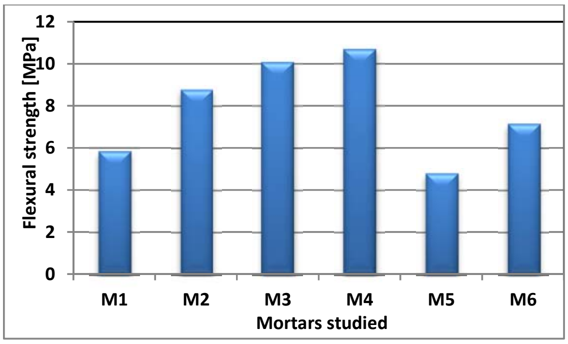

Fig. 5 Flexural strengths of different mortars

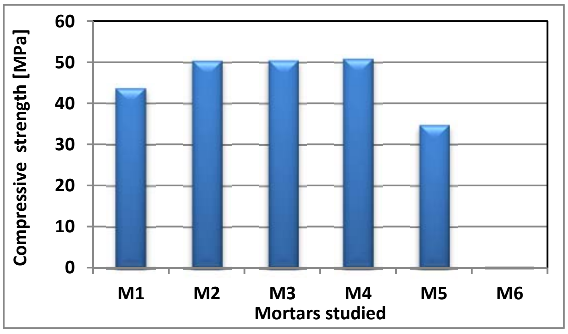

Fig. 6 Compressive strengths of different mortars

The compressive strength of the concrete was evaluated on the half-prisms from the three-point bending. The half prism is centered between the two plates of the apparatus and a load is performed at a constant speed of 0.5 kN/s until failure. It reads out the crushing load P KN and the resistance RC compression in MPa on the screen of the device. The compressive strengths of concretes made of different combinations are shown in Figs. 5 and 6. These figures illustrate the effect of the natural pozzolan on the strength of mortars. We observe that the best strengths are obtained with the addition of pozzolanic SSB2 and adjuvant (M4) compared to the other variants (Figs. 5 and 6).

D. Durability of Mortars

In the first three parts, we presented the materials used in this study and experimental techniques to characterize these materials and the formulation of test specimens and their mechanical properties. Knowledge of their characteristics is very important in our research, since each could significantly affect the study results. For this reason, we carried out the characterization of each constituent mortar. To characterize chemical resistance, samples are stored in laboratory water at a temperature of 20 ± 2 °C for up to 28 days. Various samples were dried at 100 °C to constant mass (elimination of free water) to measure the mass loss of each sample. To evaluate the durability of each mortar composition, these specimens are then immersed in different solutions (mixture of nitric acid and ammonium nitrate and $MgSO_4$ solution) with an identical concentration of 10%.

Successful combinations that we have selected for durability tests are:

- M1 witness;
- M2 with an adjuvant (TEMPO12);
- M3 and M4 with PZ30 (SSB1 and SSB2) with TP12 builder;
- M5 SRC with two types of TP12 builder;
- M6 SRC witness.

Chemical attack of the specimens immersed in these solutions is evaluated according to ASTM C 267-96. The pH of the solutions is measured using the pH meter prior to immersion of the specimens and each week after immersion of the test pieces (7, 14, 21, and 28 days). To assess the degree of degradation by calculating the weight loss of the test pieces immersed in various aggressive media according to time, we adopted the procedure below: Every seven days of attack and for a period of 28 days, the samples are removed, cleaned with distilled water to remove the mortar altered, dried and stewed until the total elimination of moisture absorbed (the mass was be constant) at a temperature of 100 °C. The degree of degradation is evaluated by the following weight loss formula:

$$\Delta M\,(\%) = (M1-M2)100/M1$$

with: ΔM: Weight loss in percentage; M1: dry mass of test specimens before immersion; M2: dry mass of test specimens after immersion.

E. Chemical Attack of Mortars by the Ammonium Nitrate and Nitric Acid

Figs. 7 and 8 show the mass loss percentages of the different mortars that have undergone a mixture of nitric acid and ammonium nitrate ($HNO_3 + NH_4NO_3$) concentrated to 10% with pH defeated.

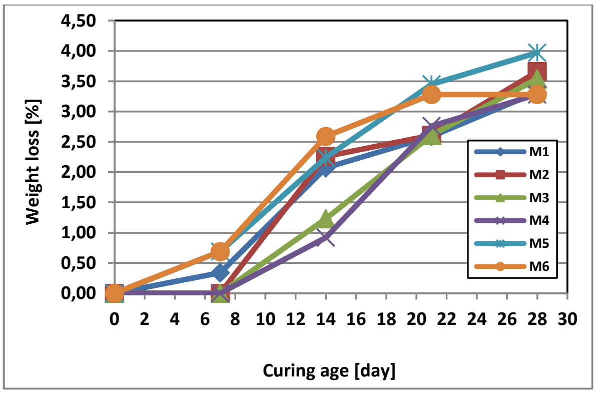

Fig. 7 Mass loss of the different mortars for a period of 28 days

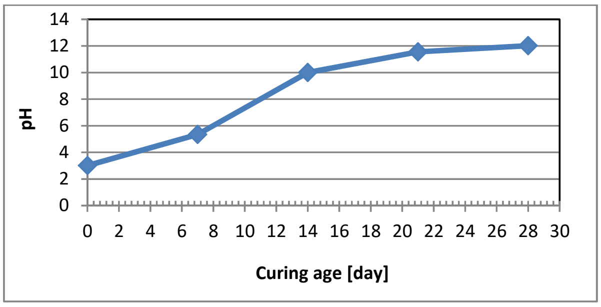

Fig. 8 The variation of pH of the mixture of nitric acid and ammonium nitrate (NH4NO3 + HNO3) versus time after immersion of the specimens

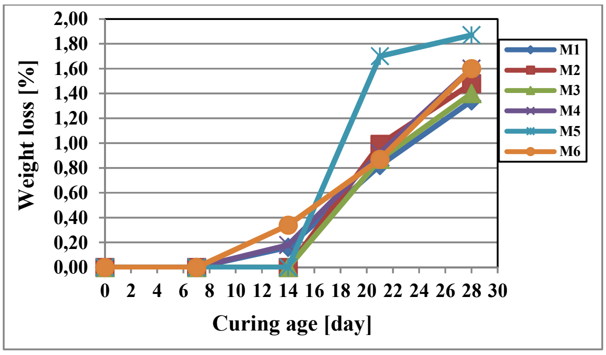

Fig. 9 Mass loss of the different mortars for a period of 28 days

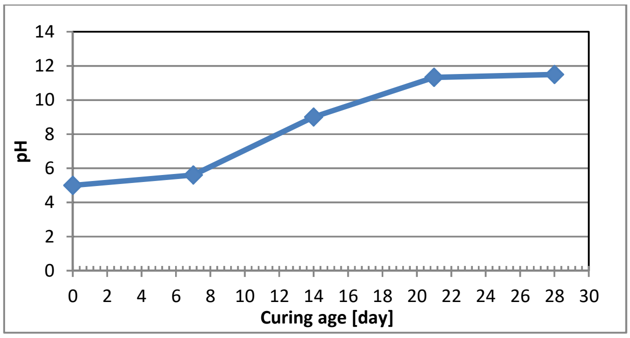

Fig. 10 PH variation of MgSO4 salt solution versus time after immersion of the specimens

F. The Mortar Attack by Salt $MgSO_4$

We used $MgSO_4$ with pH = 5.66. Fig. 10 shows pH variation of the solution ($MgSO_4$) versus time.

Specimens prepared with pozzolanic cement have better chemical resistance in both aggressive environments (when the SSB pozzolan increases the mass loss decreases), we can also note that the mortars CRS (control samples) have the lowest strength chemical with respect to salt solution attacks ($MgSO_4$) and nitric acid (HNO_3) and ammonium nitrate (NH_4NO_3).

When comparing specimens in different solutions, we find that the solution of nitric acid and nitrate ammonium is the most aggressive by contributing to the salt solution ($MgSO_4$):

- For its acidity;
- For training of expansive salts (gypsum and ettringite):

1. Secondary Gypsum by the reaction:

$$MgSO_4 + Ca(OH)_2 \longrightarrow CaSO_4 + Mg(OH)_2$$

2. Secondary ettringite by the reaction:

$$C3A + 26H_2O + 3CaSO_3.2H_2O \longrightarrow C3A.3CaSO_4.32H_2$$

We also notice an increase in the pH of the two aggressive solutions as a function of time due to the pH of the alkaline cement (pH = 13). This increase is inversely proportional to the loss of mass (when the pH increases, the loss of mass decreases).

The Mechanical Strength after Degradation

As we know, the deterioration of the concrete results in low mechanical strength, this was confirmed by compression testing after chemical attack.

Comparison of these results is performed according to the type of mortars. From the results of chemical attack after immersion of the specimens in various aggressive environments, we find that:

- All variants are subjected to degradation and decrease in mass as a result of attack by the solution (ammonium nitrate + nitric acid).
- All variants exhibit an increase in the mechanical strength against attack by solutions (MgSO4 and HN4NO3) except the specimens CEM1 witnesses. This increase in mechanical strength is directly proportional to the rate of substitution of pozzolan. This can be explained by the long-term pozzolan activity. Pozzolan in a form of reactive vitreous silica that the presence of water, can combine with the lime to form a calcium silicate hydrate of the same type as that formed during the hydration of Portland cement.

We can describe a pozzolanic reaction in the following simple manner:

$$CaO+SiO_2+H_2O \longrightarrow CaH_2SiO_4{\cdot}2\,H_2O$$ calcium silicate hydrate (CSH)

- The ammonium nitrate easily dissolves $Ca(OH)_2$ portlandite.
- Over time, the aggressiveness of ammonium nitrate is becoming increasingly important because they crystallize in the pores and concentration will be greater.

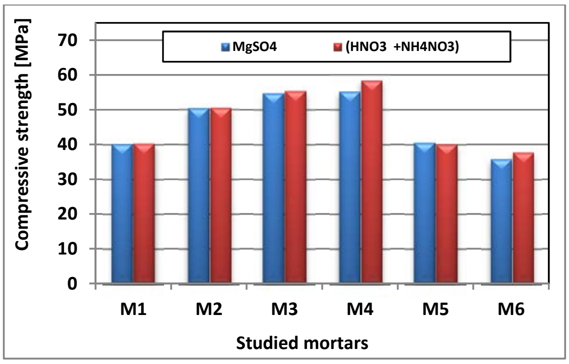

Fig. 11 Compressive strength of various specimens after chemical attacks

- The presence of pozzolan during hydration absorbs the portlandite emitted by the clinker to form mineral binding properties.
- The fine particles of pozzolana contribute to the compaction of the concretes, this increases its resistance to penetration by aggressive salts.
- In humid atmosphere, metallurgical cement has better resistance than in the dry atmosphere through reactions with water and portlandite.
- The resistance of the adjuvanted specimens is better due to the action of the superplasticizer and to the reduction of the quantity of water. However, they control the rate of hydration and influence the morphology of the hydrates formed and the steric effects are predominant. The species of greatest molecular weight also have a greater influence on the rheology of cement pastes.

IV. Conclusion

The mechanisms of chemical alteration of cementitious matrices in an aggressive environment are the phenomena of dissolution hydrates or progressive decalcification of the cement paste according to the local equilibrium diagram. The degradation of the mortar by aggressive solutions results from dissolution of the CH portlandite.

This study provides information on the possible chemical resistance of mortar based Baghlia washed sand and cement substituted by pozzolan. The latter has very important interests of technical, economic, environmental, mechanical strength and durability standpoint; experimental results conducted through this study allow the following conclusions:

- The results of the mechanical strength are better for cementitious mortars prepared by substitution of 30% pozzolan with SSB2.
- The results of the weight loss show that nitric acid is more aggressive than salt $MgSO_4$; however, the best chemical resistance is given by the specimens prepared with 30% pozzolan SSB2.
- The results of mechanical strength after etching shows that there is a decrease in resistance of mortars CEM1 in the acid mixture (HNO_3 + NH_4NO_3) and the salt solution ($MgSO_4$). However, we note an increase in other variants namely the mortar with the SSB2 in the acid mixture (HNO_3 + NH_4NO_3) and the salt solution ($MgSO_4$), this finding is due to formation of HSC and high compactness of these specimens.
- The chemical resistance of mortars made with 30% pozzolana is significantly better than those of CRS in the two environments studied.
- The effect of the superplasticizer is very beneficial because it improves the mechanical and chemical properties of these mortars.

Finally, and from these results, we can say that mortars elaborated with sand and substituted by pozzolan cement can be used in constructions in aggressive environments including underground constructions, baths storage, marine areas, chemical laboratories, wastewater etc...

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