ISSN: 0975-8585

Research Journal of Pharmaceutical, Biological and Chemical Sciences

Study of the influence of a high water-reducing super plasticizer and accelerator of setting time on the physical properties and mechanical performance of mortars and concretes.

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ABSTRACT

In order to reduce the quantity of mixing water used and to improve the physical properties and mechanical performance of concrete, we have incorporated an additive of super plasticizer of a high water reducer and accelerator of setting 'HRWRASP103' in the formulation matrix of concrete at various percentages ranging from 0.5 to 4% by weight of cement with a step of 0.5%. The influence of the incorporation of HRWRASP103 in a cement matrix on the physical properties of fresh cement paste and on the mechanical performance of mortar and/or concrete in the hardened state has been studied on the other hand. The obtained results from various formulation elaborated shows that the dosage between 0.5% and 2.5% of HRWRASP103 by weight of cement in our formulations reduces the amount of mixing water used. We have distinguished that the setting time decreases. Similarly, the porosity, the capillary absorption and the absorption by immersion in water have been decreased on one hand. On the other hand, we observed that the compressive strengths at the young age (2 days), median age (7 days) and long-term (28 days) were improved. The addition of HRWRASP103 in the formulation of cement also allowed us to produce a durable concrete.
Keywords: Water reducer, setting accelerator, Porosity, Capillary absorption**,** Concrete of high performance, Compressive strengths.

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INTRODUCTION

The super plasticizers are necessary for producing the high-performance concrete [1, 2, 3]. They allow us to change the properties of the fresh concrete, such as the setting time, and the water content, the workability, the flow, the slumped and in the hardened state, namely the porosity, the capillary absorption, the absorption by immersion and also the mechanical performance [4, 5, 6, and 7].Several types of inorganic add or organic molecules can be used to obtain such results according to the action of its mechanisms which essentially consist in neutralizing the many electrical charges attached to the cement particles following its grinding operation [8, 9, 10]. Conferring to the norm EN 934-2, the super plasticizers are the polymers synthesized specifically for the concrete industry. They are based on the sodium or calcium salts of sulfonated poly-naphthalene (SPN), a polymer with the functions of polycarboxylate polyoxyethylene (PCP), sodium sulfonated poly-melamine (SMP) [11, 12].These super plasticizers are chemical structures incorporated during the mixing of concrete or mortar at a dose of less than or equal to 5% by weight of cement, in order to modify the properties of a mixture on fresh and/or hardened state. This will allow us to improve the fluidity of concrete by slightly dispersing the grains of cement from one another, either by reducing the demand for water or by keeping the dosage in the water constantly. The purpose of the high water reducer super plasticizer and setting accelerator (HRWRASP103) is to modify the time of the hydration reaction of cement by accelerating the setting, reducing the report W/C and improving the mechanical performance [13,14,15,16].The action of the mechanisms of HRWRASP103allows to increase the rate of hydration ,mortars and concretes, while modifying the ratio W/C and subsequently improving the mechanical performance, namely the porosity, the capillary absorption, the absorption by immersion and which finally influence on the compressive strength [17, 18, 19, 20].Indeed, the power of dispersion of super plasticizers which is explained by the adsorption at the interface of grains of cement, in consequence creating the repulsive forces between the particles, reducing or eliminating squarely the adhesion between the neighboring molecules, which will be fixed by absorption to the surface of cement and which causes a deflocculation of the grains of the last [21, 22, 23].When the organic molecules of the super plasticizers of HRWRASP103 are introduced into a suspension of a cementitious material, a large part of them is attached to the surface of the cement particles (adsorption) [24, 25].These parameters reduce the attractive forces of interactions between the particles, which exist between the atoms of the different particles and their physical effect modifying the inter-particles forces, which can intervene in the chemical processes of hydration and in particular of nucleation and crystal growth.

In this experimental work, different formulations of high-performance concrete have been developed at different percentages of HRWRASP103 ranging from 0.5 to 4% with a step of 0.5% by weight of cement, while partially substituting the mixing water by these super plasticizers. The effect of the addition of HRWRASP103 on physical properties of fresh cement paste and on the mechanical performance of concrete, namely, the porosity, the capillary absorption, the absorption by immersion in water and the compressive strength have been studied in this work.

MATERIALS AND METHODS

Cement

The type of cement used in this work is (CMI-42.5). This a Portland cement as a resultingfrom simultaneousat (95%) of clinker and (5%) of gypsum accordance to the standard EN 196-1. It is from of a cement factory of Amran - Yemen. The chemical compositions (clinker, gypsum, and cement), mineralogical (clinker) determined by X-rays fluorescence (XRF)and their physical properties are presented in tables (1, 2 and 3).

Table 1: Elementary chemical compositions of clinker, gypsum, and cement

Content (%)	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	SO_3	K_2O	Na_2O	Cl
Clinker	62.76	21.00	5.84	3.00	1.96	0.90	1.21	0.20	0.02
Gypsum	33.40	0.70	0.36	0.09	0.63	47.2	0.03	0.10	0.01
Cement	61.29	19.99	5.57	2.85	1.89	3.22	1.15	0.20	0.02

Table 2: Mineralogical composition of clinker

Chemical name	Mineral name	Chemical formula	Cement nomenclature	Content
Tricalcium silicate	Alite	Ca_3SiO_5	C_3S	47.70
Dicalcium silicate	Balite	Ca_2SiO_4	C_2S	25.10
Aluminate tricalcium	Aluminate	$Ca_3Al_2O_6$	C_3A	10.40
Tetracalcium Aluminoferrite	Ferrite	Ca_4AlFeO_5	C_4AF	9.10

Table 3: Physical properties of clinker and cement

Physical properties	Unity	Value	
Specific surface Blaine	$cm^2.g^{-1}$	Clinker	3360
		Cement	3240
Density	$g.cm^{-3}$	Clinker	3.17
		Cement	3.14

Super plasticizer

High Range Water Reducing and Accelerating Super plasticizer:(HRWRASP103), are polymers in the liquid form and synthesized especially for the concrete industry. They are a basis of salts of sodium or calcium of poly-naphthalene sulfonate, (figure. 1), salts of sodium of Polysulfone melamine (figure.2), acrylate-ester (polyacrylate) copolymer, or lignosulfonate of high purity, (figure. 3) [EN 934 - 2].

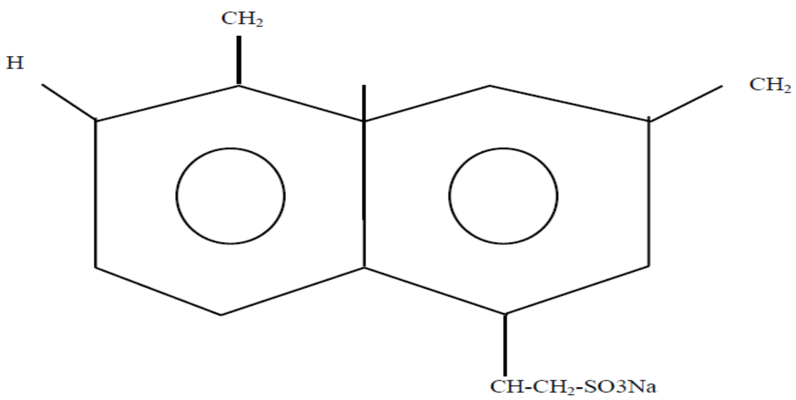

Figure 1: Scheme of poly-naphthalene sulfone

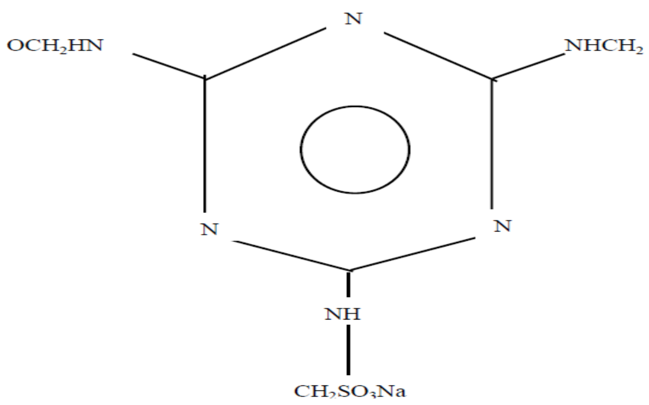

Figure 2: Scheme of poly melamine sulfone

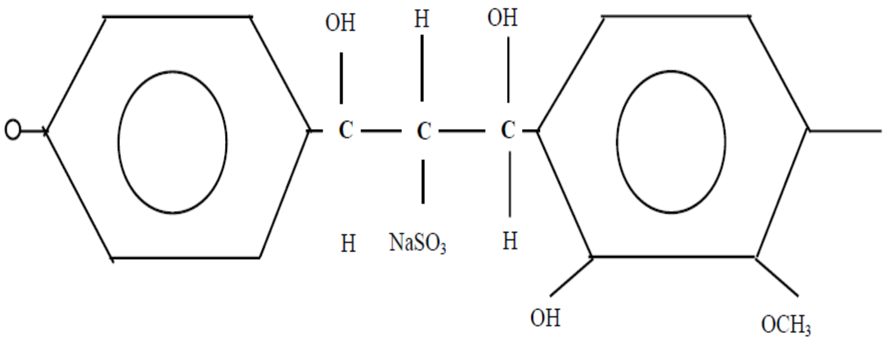

Figure 3: Scheme of lignosulphonate of high purity

The HRWRASP103 used in the formulations on our mortar and/or high-performance concrete was delivered by the company CONMIX Ltd in Sharjah, United Arab Emirates. It was incorporated during the mixing of concrete at doses from 0.5 to 4% by weight of cement with a step of 0.5%.
The physical properties of HRWRASP103 are assembled in Table 3.

Table 4: Physical properties of HRWRASP103

NOME	Nature	Color	Density	Training area	Chloride content
HRWRASP103	Liquid	Brown	1.22	0.5-1.0	Nile

The mixing water

To prepare our mixture, we used tap water (wells), its main features are gathered at the table (6).

Table 5: Main features of the mixing water

Components	pH	T, D, N	CO_3^{-2}	HCO_3^-	Ca	Mg^{+2}	Conductivity
Unit	-	(mg/L)	(mg/L)	(mg/L)	(mg/L)	(mg/L)	µS/cm
Value	7.00	450.00	216.00	0.00	56.40	52.40	692.00

Sand

To make our mortar, we used standard sand according to the norm EN 196-1, delivered by the new French company of Littoral. Its particle size analysis is illustrated in figure (1).

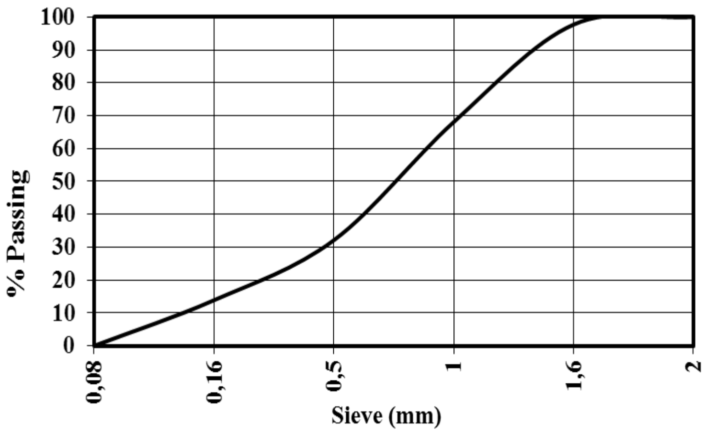

Figure 4: Curve granulometric of sand

The particle size analysis presented in figure (1) there is that used sand grains are distributed in a systematic way according to the specifications of the standard EN 196-1.

Methods

Method of preparation of fresh cement paste

The experimental protocols are used to determine the physical properties of fresh cement paste namely; the standard consistency and the initial/final time have been given by the standard EN 196-3. This is to make cement paste with 500 g of cement into the bowl of the mixer. The amount of water needed was chosen and taken into account the different percentages of HRWRASP103 that which have been used in our formulations, shown in Table 6. We immediately put the mixer with a slow speed for 90 Sec. Then we stopped the mixer for 15 Sec to bring the paste which is located beyond the mixing zone. Subsequently, we restarted the mixer at slow speed for 90 Sec. After we quickly introduced the paste into the frustoconical mold placed on a glass plate, without excessive compaction or vibration. Then the assembly is placed on the plate of the Vicat apparatus. Afterward, we measured the separation distance between the end of the probe and the base plate. This distance (d) is the consistency of the paste studied. And finally, the paste of the cement with a standardized consistency will be placed on the plate of the Vicat automatic device, to measure the initial and final time.

Table 6: Formulations matrix of fresh o cement paste with HRWRASP103

%HRWRASP103	Mass of cement (g)	Water (g)	%HRWRASP103	W/C
HRWRASP103-0	500.00	130.00	0.00	0.26
HRWRASP103-0.5	500.00	125.00	0.50	0.25
HRWRASP103-1	500.00	118.00	1.00	0.24
HRWRASP103-1.5	500.00	110.00	1.50	0.22
HRWRASP103-2	500.00	100.00	2.00	0.20
HRWRASP103-2.5	500.00	97.00	2.50	0.19
HRWRASP103-3	500.00	95.00	3.00	0.19
HRWRASP103-3.5	500.00	93.00	3.50	0.19
HRWRASP103-4	500.00	90.00	4.00	0.18

Methods of preparation of mortar and/or concrete base of HRWRASP103 in the hardened State

To achieve the objective of our study, we prepared the mortar of reference without and with HRWRASP103. The compositions have been inspired by the normal mortar defined by the standard EN 196-1, with a quantity of water adjusted and a paste with a consistency standard as shown in Table 7. The procedures followed for the preparation of our mortars begin with the mixer, and then we filled a mold (4 x 4 x 16) cm^3. The tightening of the mortar in this mold is obtained by introducing the mortar twice and by applying 60 shocks each time using the shock device. After the mold was leveled, covered with a plate of glass and was stored in the wet room. After 20 h or 24 h from the start of the mixing, the specimens were removed from the mold and were stored in water at 20 ° C ± 1 ° C until the time of the test of rupture. On the appointed day, the 3 specimens were broken in flexion(figure.5)and compression (figure.6), using the machine of compression test.

Table 7: Formulations matrix of mortar with HRWRASP103in the hardened State

%HRWRASP103	Cement (g)	Water (g)	Sand (g)	%HRWRASP103	W/C
HRWRASP103-0	450	225	1350.00	0.00	0.50
HRWRASP103-0.5	450	211.5	1350.00	0.50	0.47
HRWRASP103-1	450	195	1350.00	1.00	0.43
HRWRASP103-1.5	450	188	1350.00	1.50	0.42

HRWRASP103-2	450	170	1350.00	2.00	0.38
HRWRASP103-2.5	450	160	1350.00	2.50	0.36
HRWRASP103-3	450	155	1350.00	3.00	0.34
HRWRASP103-3.5	450	145	1350.00	3.50	0.32
HRWRASP103-4	450	142	1350.00	4.00	0.32

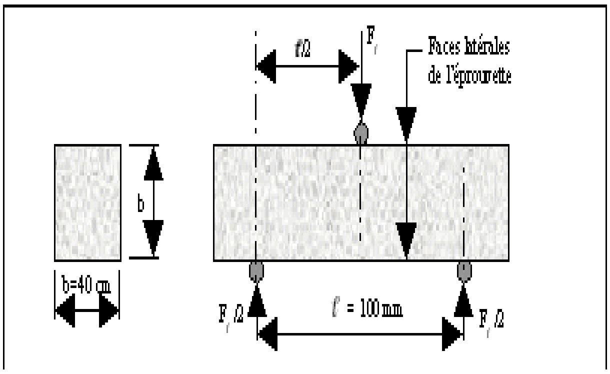

Figure 5: Device of bending load for the specimen's mortar

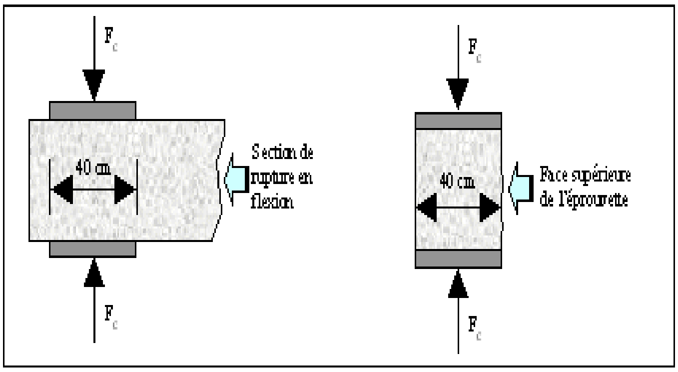

Figure 6: Device in compressive load for the specimens of mortars

RESULTS AND DISCUSSION

Influence of the HRWRASP103 on the physical properties of fresh cement paste

Influence of the HRWRASP103 on the amount of mixing water

To determine the optimal amount of water mix for each test, we have maintained in all our experiences the standard consistency fixed, it varied between 5-7 mm according to the specification of the standard (NF EN 196-3) + A1. And to keep the consistency stable, we have reduced the amount of mixing water based on the percentage of addition of HRWRASP103 in different matrices of a formulation. This experiment was executed using the Vicat, according to the standard (NF EN 197-1).

The figures (7, 8) offer the amount of water reduced and the report W/C always based on the mass fraction of HRWRASP103.

ISSN: 0975-8585

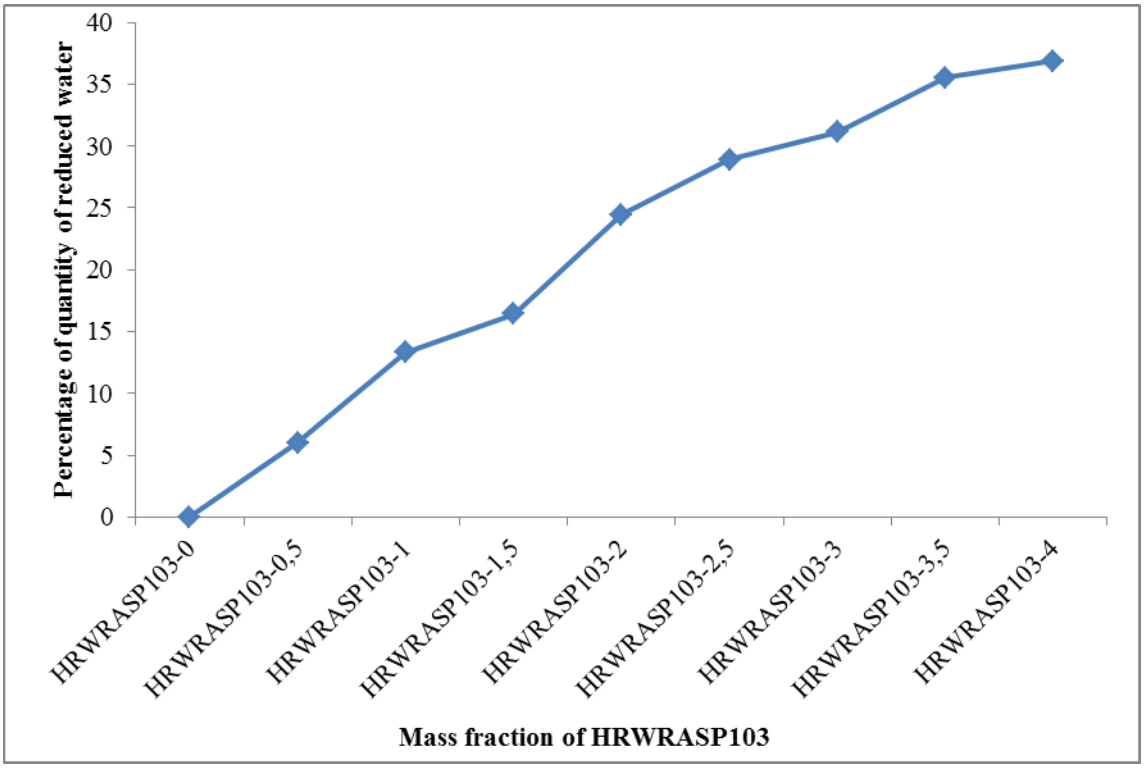

Figure 7: Variation of quantity of water reduced as a function of the mass fraction of HRWRASP103

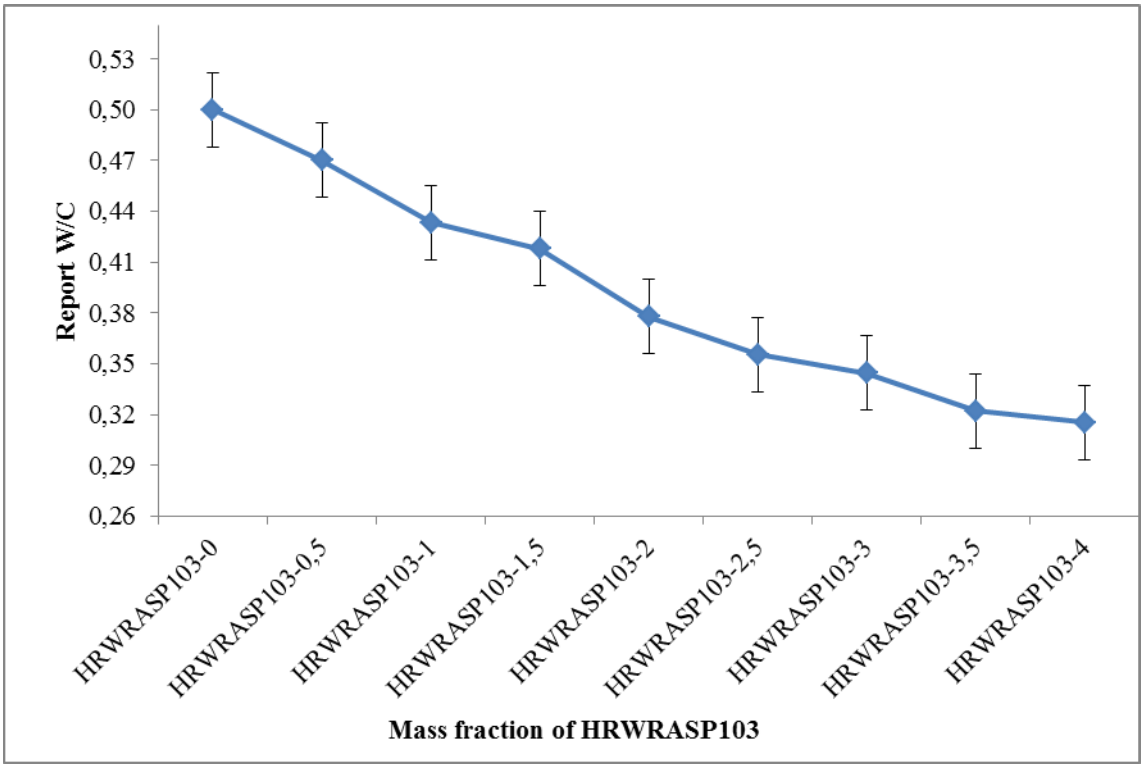

Figure 8: Report of W/C as a function of the mass fraction of HRWRASP103

According to the figures (7 and 8) that show the evolutions of the quantity of water used to make the mixture as well as the report W/C as a function of the various percentages of addition ofHRWRASP103, ranging from 0.5 % to 4% by weight of cement with a step of 0.5%. We have seen that the introduction of HRWRASP103 into the mortars reduces the amount of water used and therefore the report of W/C ratio has been decreased. This reduction in the amount of water is generally connected by dispersing action due to the adsorption of the HRWRASP103 on the solid surface of molecules. This will modify the zeta potential of the particles and promotes their dispersion due to a steric phenomenon hindrance. Our results corresponded with the other authors, as well[26, 27, 28, and 29]

Influence of the HRWRASP103 on the setting time

We measured the initial and the final time of fresh cement paste using the Vicat unit, according to the specification of the norm EN196-3.

The figure (9) registers the setting time as a function of the different percentages of HRWRASP103.

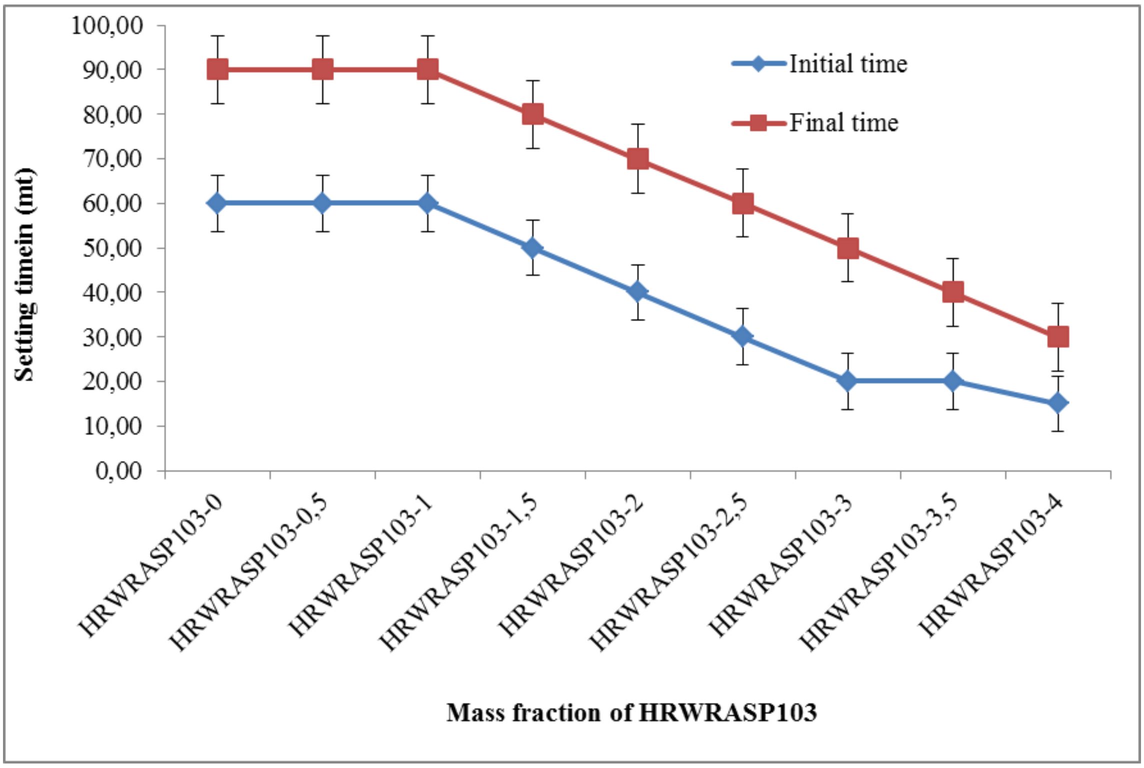

Figure 9: Variation of the setting time as a function of the mass fraction of HRWRASP103

From the figure (9), we found that the addition of HRWRASP103 in the formulation of concrete decreases the initial and the final time of fresh cement paste. This decrease is mainly due to the essential role of this addition that disperses the cement grains and which generates the interstitial space between the particles of cement and the aggregates. Indeed, it has been explained by the fact that the addition of HRWRASP103 increases the heat of hydration. The HRWRASP103 acts as a retarder in the hydration of the silicate phase and as an accelerator in the aluminate phase. The mechanism of this action may be due to the formation of a complex between the HRWRASP103 and the components of hydration of Portland cement. This gave us subsequently improved significantly to the development of the mechanical resistance of compression. Our results resembled with the other authors, as well [30, 31, and 32].

Influence of the HRWRASP103 on the physical properties in the hardened state

The concrete is a porous material. In other words, it contains pores or voids. These pores are critical to the strength and the durability of concrete. Indeed, a low porosity, a low capillary absorption and a low absorption by immersion in water are the best means of defense of concrete against and all aggressive agents.

Porosity

The porosity is an essential characteristic of mortar or concrete in the hardened State. It is part of the indicators, factors that determine the durability of the concrete. It is very important because grace of this characteristic that we can determine the strength of concrete, the carbonation and frost resistance of aggressive agents. Of course, it is calculated using the relation (1), dividing the volume of the report porous (empty) to the total volume of the concrete.

$$P = \frac{V_P}{V_T} \qquad (1)$$

With:

V_p: The volume pores of the specimens;
V_T: The total volume of the specimens, that is to say, the sum of the volume of solid and the volume of the pores.

The figure (10) illustrated the evolutions of the porosity of mortar based on the mass fraction of HRWRASP103.

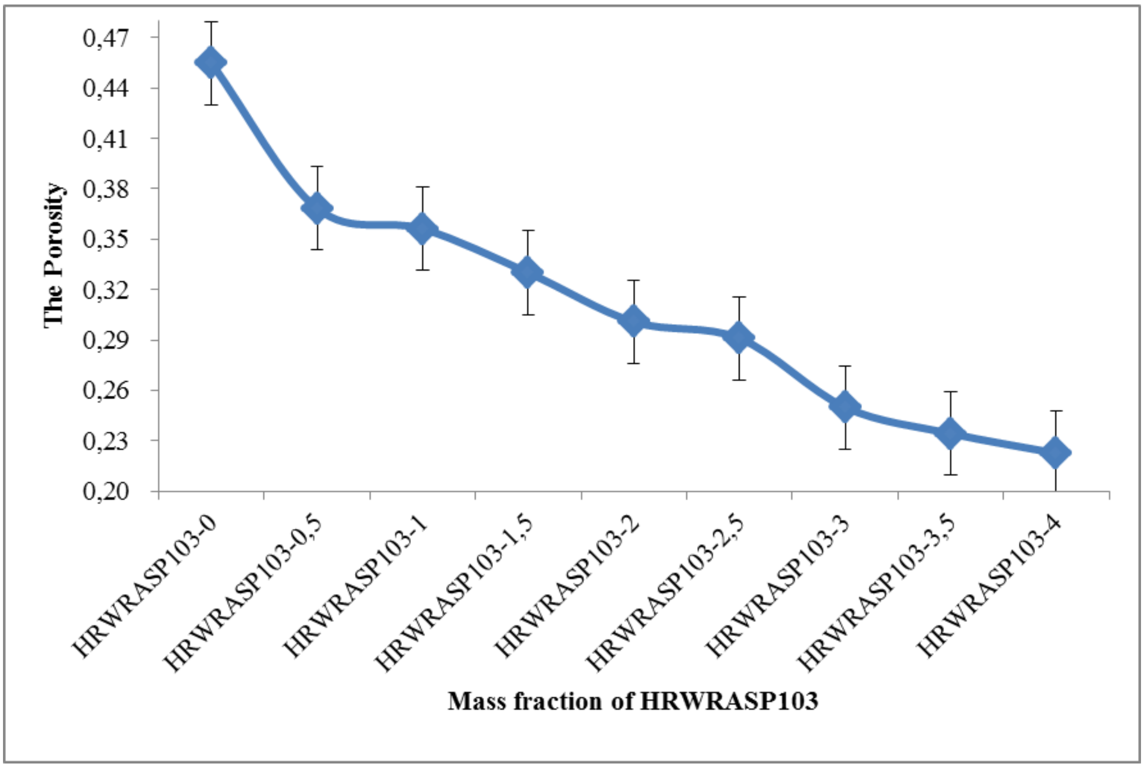

Figure 10: Variation of the porosity as a function of the mass fractions of HRWRASP103

At the figure (10), we observed that the porosity decreases with increasing the mass fraction of HRWRASP103 in the formulation matrix. This decrease is due to the fact that the molecule of HRWRASP103 was coming to disperse the cement grains, to fill the interstitial voids between cement and sand grains, and subsequently decreases the porous inside the material logically. These results resembled with the other authors, as well [32, 33, and 33]

Capillary absorption

A concrete in contact with an aggressive environment (pure water, salinity water, water containing organic acids) will suffer a much slower attack when the capillaries of the concrete are fewer and thinner. The capillary absorption (*CA*) of our formulations based on different percentages of HRWRASP103 has been calculated by using the formula (2) and expressed by gm.mm-².

$$CA = \frac{M_f - M_i}{S} \quad (2)$$

With:

CA: The capillary absorption (gm.mm-²)
M_f: The mass of the specimen after conservation for 2 days, 7 days and 28 days, in grams;
M_i: The mass of the specimen before conservation below the water in grams;
S: The area of the specimens in (mm).

The figure (11) legendary the developments in capillary absorption of mortar based on the mass fraction of HRWRASP103

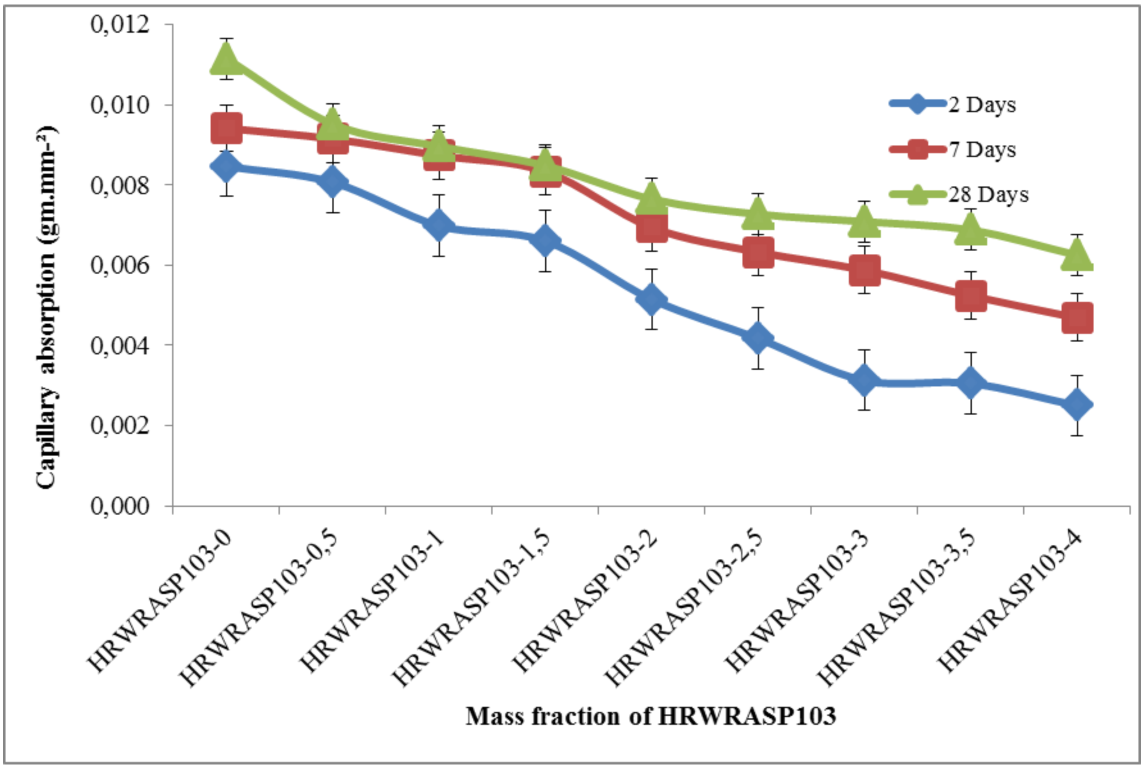

Figure 11: Variation of the capillary absorption as a function of the mass fractions of HRWRASP103

According to the figure (11) which illustrates the advancement of the capillary absorption of concrete at young age (2 days), median age (7 days) and long-term (28 days) as a function of different percentages of HRWRASP103, we noted that the capillary absorption of mortars was influenced by the porous structure and the percentage of super plasticizers. The last one can contribute in reducing the capillary absorption and pressure by a formation of a polymer film. Using of HRWRASP103, with a percentage from 0.5% to 4% compared to the mass of the cement significantly helps to slow down the process of water absorption. Indeed, we have seen through figures (7, 8 and 10) the W/C ratio decreases and also the capillary absorption coefficient was reduced. These effects are similar to the other authors, as well[35, 36].

Absorption by immersion in water

The absorption by immersion in water (Abs), is one of the indicators of concrete durability, calculated using the relation (3), and expressed as a percentage.

$$\text{Abs} = \frac{M_H - M_D}{M_D} \times 100 \qquad (3)$$

With:

M_H: The humid mass of the specimen after immersion;

M_D: The dry mass of the specimen after drying in an oven.

The figure (12) celebrates the evolution of the absorption by immersion in water based on the mass fraction of HRWRASP103

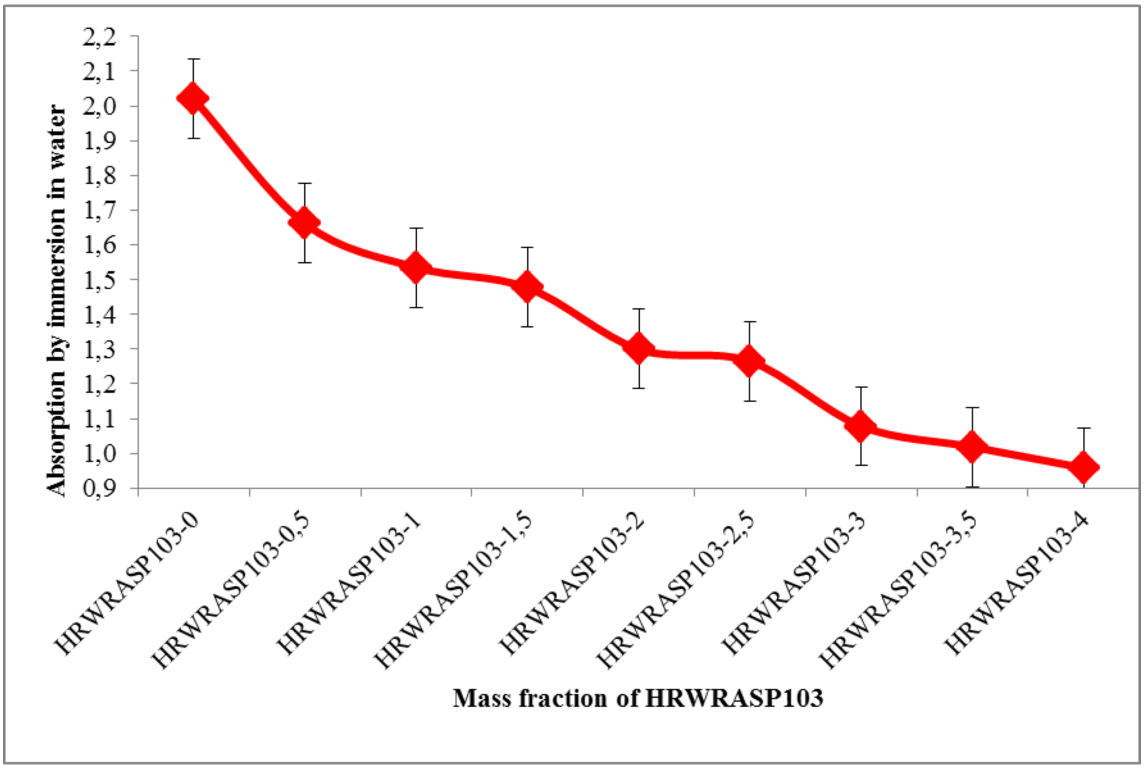

Figure 12: Variation of the absorption by immersion in water as a function of the mass fractions of HRWRASP103

The present experimental results in the figure (12) show that the absorption by immersion in water decreases conferring to the increase in HRWRASP103. This is due mainly to the fact that all mortars made by the HRWRASP103 have a porous structure when the pores can be filled by the HRWRASP103 or sealed with a continuous film of polymer. As a result, their absorption in water is lower than that of a mortar of reference. This depends on the nature of adjuvants and the ratio P/C. The durability indicators obtained through these tests allow us to conclude that the be-components mortars are the most efficient because they have a low porosity, a low capillary absorption and also a low absorption by immersion. These properties are similar to the other authors, as well [37, 38, and 39]

Influence of the HRWRASP103 on the mechanical performance of concrete

The influence of HRWRASP103 on the mechanical performance of mortar and/or concrete using the mechanical resistance of compression 'R_{mc}' has been tested. The measurements of 'R_{mc}' were made on standardized prismatic specimens (4x4x16) cm^3 according to the specification of the norm (NF EN 196-1). The 'R_{mc}' was measured at a young age 2 days / median term 7 days/long-term 28 days. To observe the progressive evolution of the mechanical performance of our formulation based of HRWRASP103 as a function of time. The 'R_{mc}' is calculated using the formula (4), and shown in the figure (13):

$$\text{Compressive strength} = \left(\text{Load}/\text{Area}\ (\frac{\text{N}}{\text{mm}^2})\right); \text{MPa} \qquad (4)$$

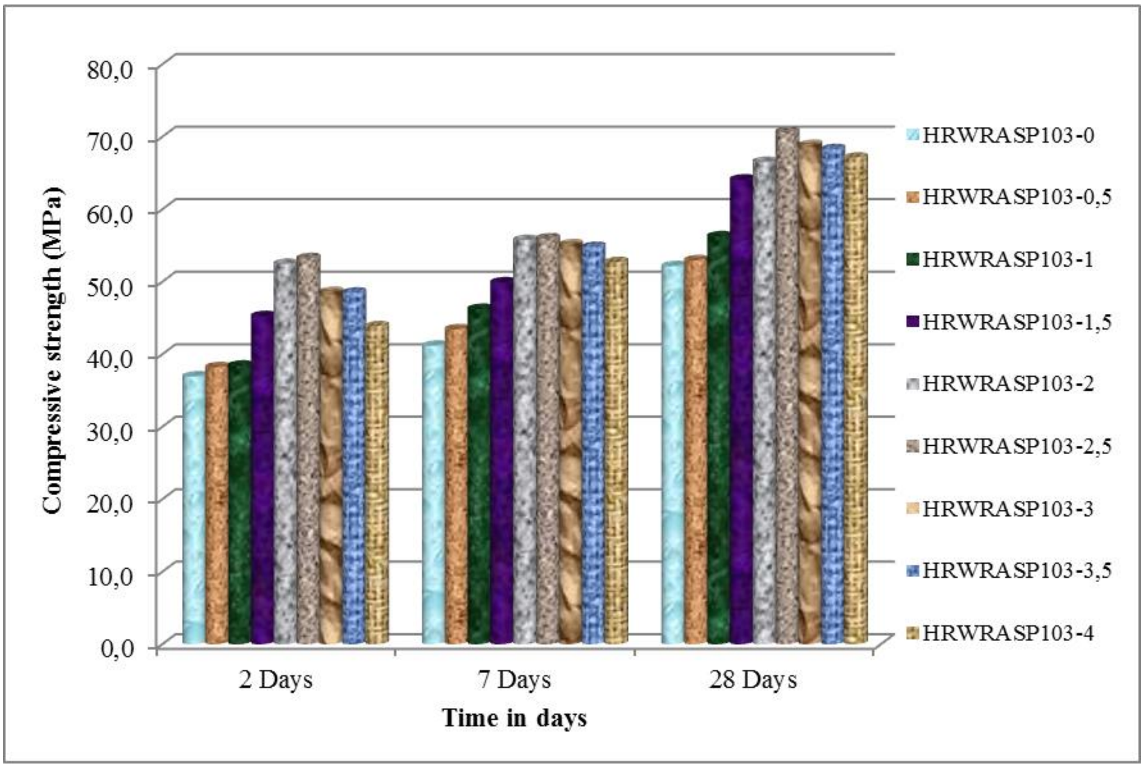

Figure 13: Variation of compressive strength as a function of time in days

From the results presented in figure (13), we found that the compressive strength at a young age, medium-term and long-term based on the mass fraction of HRWRASP103 increases with the percentages of 0.5 to 2.5%. We can see that the addition of HRWRASP103 which was reacted chemically with the lime present in cement during the hydration and promotes the formation of calcium silicate hydrated on one hand and on the other hand to disperse the cement grains. The HRWRASP103 fills the voids between the particles of cement and aggregate particles [40, and 41]. Beyond these percentages, the ' R_{mc}' decreases considerably. This shows that the 2.5% of HRWRASP103 is the saturation point.

Gain of mechanical compression resistance

At the end of this work, we have calculated the gain of' R_{mc}' using the formula (5):

$$\frac{R_{mcx}-R_{mct}}{R_{mct}} x100 \quad (5)$$

Where:

R_{mct} : Control compressive strength at 2/ 7 and 28 days of mortar;

R_{mcx}: Compressive strength of mortars with the different percentages of HRWRASP103, while X = 0.5%, 1, 1, 5... 4%.

The figure (14) displays the gain of 'R_{mc}' based on the different percentages of HRWRASP103.

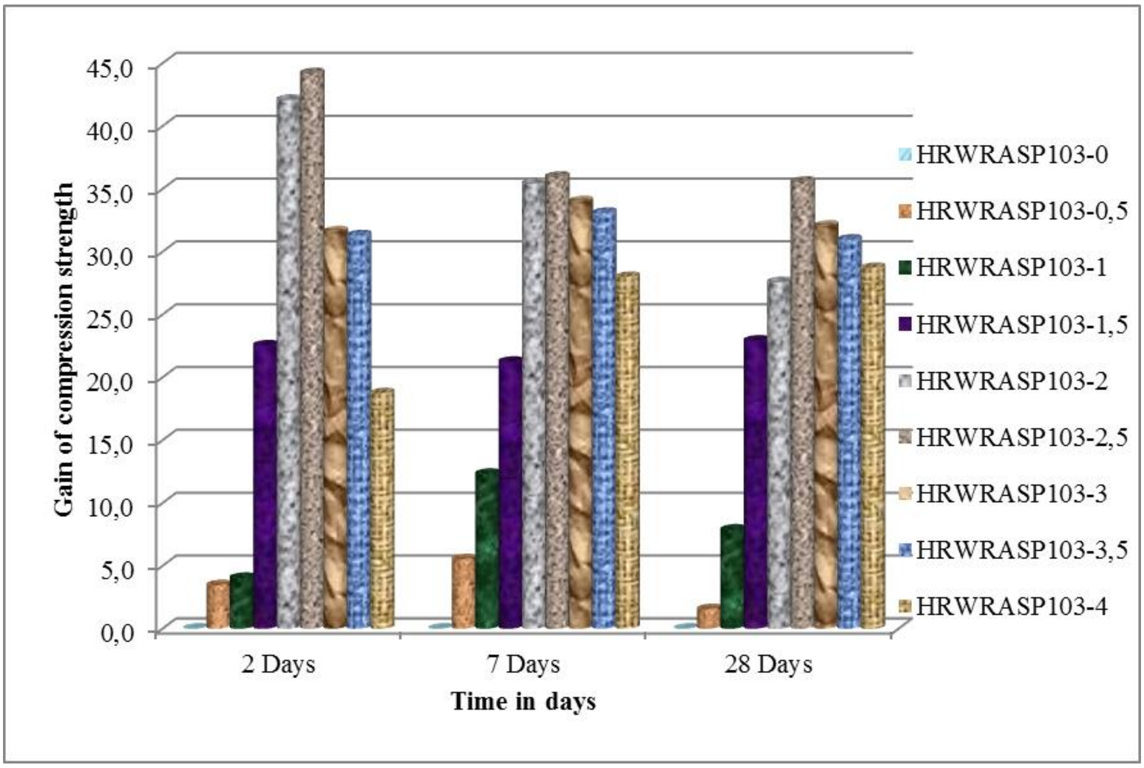

Figure 14: Variation of gain in R_{mc} as a function of time in days

According to the graph (14) that illustrates the gain of the R_{mc} as a function of time in days, we notice that the R_{mc} increases with the dosage of the 2.5% of HRWRASP103 by 44.2 / 35.96 / 35.56 for young age (2 days) /median age (7 days) / long-term (28 days) respectively.

Our study contributes to augment the compressive strength that allows us to produce a new concrete durable and also to reduce the quantity of water used.

CONCLUSION

This work, aims to study the influence of the addition of a super plasticizers of high water reducer and accelerator of sitting time on the physical characteristics of fresh cement paste and on the mechanical properties of mortars and/or concrete in the hardened state,namely,the porosity, the capillary absorption, the absorption by immersion in water and the mechanical strength at different percentages by weight of cement while partially substituting the water of mixing by theHRWRASP103.

The obtained results from the different formulations developed to show that the dosage between 0.5% and 2.5% of HRWRASP103 by weight of cement reduces the amount of water mixing by 37% compared with the control. In addition, the ratio W/C was decreased from 0.5 to 0.36. Otherwise, we have distinguished the initial time decreases from 60 to 15 minutes and the final time decreases from 90 to 30 minutes according to the percentage of HRWRASP103. Similarly, the addition of HRWRASP103 in the formulation matrix gives a favorable effect on the mechanical performance of concrete by decreasing of the values, namely, the porosity from 0.45 to 0.21, the capillary absorption at a young age (2days) from 0,0085 to 0,00025 $g.mm^{-2}$/ the median age (7 days)from 0,0095 to 0,00045 $g.mm^{-2}$ / long-term (28days) from 0.012 to 0.0006 $g.mm^{-2}$ and the absorption by immersion in water from 2.1% to 0.95%. On the other side, we observed that the compressive strength at a young age (2 days) / median age (7 days)/long-term (28 days) have been improved as a function of the increase of HRWRASP103 in the cement matrix. This improvement represents a gain in mechanical of compression strength by 44.20 / 35.96 and 35.56 at a young age (2 days) / (7 days) medium-term and long-term (28 days) respectively. So this work is important to contribute the augment in the compressive strength that allows us to produce a new concrete durable and also to reduce the quantity of water used.

ACKNOWLEDGMENTS

The authors are pleased to acknowledge all engineers and employees of the laboratory of cement and quality control of Amran cement plant of Yemen for providing the facilities for the research.

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