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Experimental Study of the Effect of Curing Mode on Concreting in Hot Weather

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ABSTRACT

Most developing countries have hot climate, ordinary jobsites characterized by reduced of human resources, equipment and infrastructures. The objective of this article is to make an experimental study of the influence of the hot climate such as that of Algeria, on the different properties of concrete in the fresh state, such as excessive water evaporation from the concrete surface, increased demand for water, increased slump loss corresponding to additional water on job-site, higher plastic shrinkage cracking and difficulty in controlling air content. At the hardened state, we could mention a reduction of strength at 28 days, decreased durability resulting from cracking at long-term period. To show the problems linked to concreting under these conditions and to present the appropriate solutions concrete or mortar can withstand the conditions in which it is implemented. Thus, negative effects caused principally by hot weather concreting motivated the choice of the such study. The research experimental work conditions in which the cementitious matrix was kept concerned two different environments, namely hot and dry climate conditions (t = 40°, h = 0%) alike the climate of the region of M'sila., and that of a medium with a hot and humid environment (t = 40°, h = 100%). The output of the investigation demonstrated the crucial role of the cure method in hot regions. The comparison of results for a reference concrete kept in air without any curing measures with two curing types simulating hot weather environment of the region M'sila was undertaken. These obtained outcome results were discussed based on the influence of climatic conditions to conclude procedures for hot weather concreting and suitable cure methods.

1. INTRODUCTION

Hot weather is defined as the association of high ambient temperatures, high concrete temperature, low relative humidity, high wind speed and exposure to solar radiation [1].

In arid and semi-arid regions, of which Algeria is a part, the unfavorable combination of these factors is often encountered and can lead to rapid evaporation of moisture at first from the surface layers which results in uneven shrinkage and hence the creation of severe thermal stresses in the mortar. The influence of the main climatic factors on the evaporation rate of the water from the surface of the mortar is well demonstrated in previous research work [2-4].

The ACI report associed the shrinkage cracking to the hot weather concreting, it reports that: "Plastic shrinkage cracking is frequently associated with hot weather concreting in arid climates. It occurs in exposed concrete, primarily in flatwork, but also in beams and footings and may develop in other climates whenever the evaporation rate is greater than the rate at which water rises to the surface of recently placed concrete by bleeding" [5].

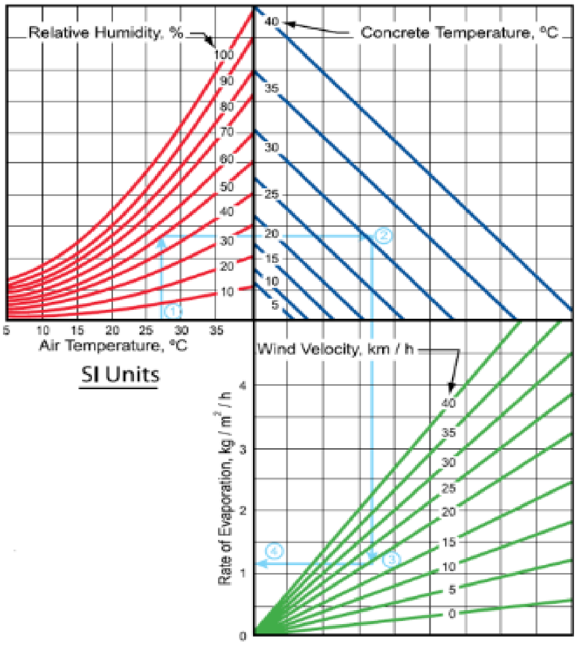
However, a precise conclusion on their effects can only be given by a detailed study specific to each factor.

Figure 1 shows that we can estimate the evaporation rate of surface water using the different meteorological information. [6] reports that nomographs are an attractive and easy-to-use graphical tool that allows the resolution of all the variables of a generally complex equation. The determination of the evaporation rate is a good indicator of the possibility of the appearance of plastic shrinkage [7]. However, Papadimitropoulos et al. [8] present a study in which they develop and evaluate analytical models which can effectively assess the appropriate values of the water evaporation rate over the entire range of independent parameters, as they consider that the Nomograph may be subject to the mistake.

Several researches note that the low relative humidity is an important factor, which can also affect the quality of the mortar. Indeed, it can cause the mixing water to evaporate very quickly, leading in hot weather to the rapid hardening of the mortar. It has been reported that when relative humidity drops from 90 to 50%, the water evaporation rate increases by 5 times which shows the influence of relative humidity on water loss. It could be pointed out that systematic studies of the properties of concrete cast and continuously exposed to either hot-humid or hot-dry climates remain to be done [9-13]. These effects can adversely affect the quality of the mortar and implicitly that of the concrete, especially during hardening where the hydration phenomenon is considerably affected and the mortar being relatively weak, cannot consequently withstand the generated stresses [4, 14-16].

A cure applied from an early age to the material can solve the problem of early cracking. It's affirmed in Ref. [17] that the cure provides sufficient protection to concrete in the plastic state.

The experimental program of this research work undertaken has the objective to study the effect of curing mode in hot climate conditions on the mechanical properties of the mortars based on local materials and preserved during its hardening in two different environments to simulate the hot climate region of M'sila (250 Km south of Algiers). In addition, it shows the importance of curing methods to overcome concrete problems in fresh and hard cases in this type of environment.



(Source: ACI 305R-10- Hot Weather Concreting) [1]

Figure 1. ACI Nomograph for estimating surface water evaporation rate of concrete

2. MATERIALS

The cement used is Portland class 325, its absolute density has been determined in the laboratory and it is 3.06 g / cm^3 and its chemical and mineralogical constituents are given in Tables 1 and 2. While the sand used is that of Boussaâda, it was dried in an oven at a temperature of 105° ± 5°C to constant weight. The purpose of this operation is to eliminate the influence of sand moisture on the W / C ratio of the mortar.

Table 1. Chemical composition of the cement used

Constituent	CaO	SiO_2	Al_2O_3	Fe_2O_3	MgO	$Na_2O + K_2O$
Content (%)	62-67	19-25	2-9	1-5	0-1	0-1.5

Table 2. Mineralogical composition of the cement used

Constituents	C_3S	C_2S	C_3A	C_4AF
Content (%)	50-75	7-30	0-18	4-20
Average	55	23	10	12

3. EQUIPMENT AND PROCEDURES

3.1 Equipment

The equipment used is: A mixer with a capacity of 5 kg which is equipped with an automatic speed regulator (Figure 2). A minimum speed is chosen which is considered sufficient to obtain a homogeneous mixture. Molds (4 × 4 × 16 cm^3) were used for making the test specimens of mortar after being vibrated by an impact table. An oven was used for the simulation of the hot and dry climate of hot and arid regions. It was set at 40° ± 2°C. The humidity in this oven is very low but uncontrollable. While for very high humidity levels (over 90%), similar specimens were stored in a climatic chamber.

Figure 2. Picture of the mixer with a capacity of 5 kg

3.2 Procedures

The composition chosen for our mortar is 1: 3 (one cement for three proportions of sand). Several mixtures were prepared beforehand to determine the amount of mixing water needed, finally the ratio E /C = 0.65 was maintained. The amount of water thus chosen allowed us, given the absorption of dry sand, to have a good workability of the mortar. The test pieces prepared for the selected tests were covered with plastic and then wet cloths and kept in the laboratory under standard conditions 20±2°C. After 24 hours the test pieces were uncoated, treated if necessary and then stored under the conditions set out in Table 3.

Table 3. Storage conditions of the test pieces

Mild climate	Hot and humid climate Conditions	Climate Hot and dry
Laboratory	Climatic chamber	Oven
Temperature θ = 22±2°C	Temperature θ = 40±2°C	Temperature θ = 40±2°C
Relative humidity RH=55%	Relative humidity RH= 90%	Relative humidity RH=0%

The treatment methods used are:

1. Curing by plastic (polyethylene): The test pieces are covered with several layers of plastic and then placed under different storage conditions,
2. Curing by wet burlap: the test pieces are covered with damp burlap and then wrapped in two layers of plastic to prevent the burlap from drying out. The canvas is maintained for 3 days during which it is watered once a day.
3. Air curing: the test pieces are simply left in the open

air without any protection against the evaporation of their mixing water, in order to be able to compare them with those which have been treated.

3.3 Tests carried out

3.3.1 Tensile strength test

This test was carried out on mortar specimens of dimensions 4 * 4 * 16 cm at 3.7 and 28 days. The bending apparatus having a maximum stress of 1148 N / cm^2. The value of the stress is directly read in N / cm^2 on a strip. The two pieces obtained after breaking are marked and tested in compression.

3.3.2 The compression test

The two pieces obtained after rupture of the specimens by bending are tested in compression by an automatic press having a maximum force of 300 kN. The increase in compressive load is automatic and the breaking force is indicated in kN by a needle. The compressive stress is calculated according to the classic RDM formula.

3.3.3 Absorption test

4 × 4 × 16 cm specimens were processed and stored under the climatic conditions described above until the age of 24 days. They were then placed in the oven at 105 ± 5 ° C for 72 ± 1/2 hour to remove all the evaporable water, then removed and wrapped in plastic to cool. After 24 hours, they were weighed (M1) and placed in water. The distance between the upper surface of the specimen and that of the water should be 25 ± 5 mm. After 30 min, the test pieces are removed from the water, wiped with a dry cloth and weighed (M2). The absorption is calculated using the formula:

$$Abs = (M2 - M1) * 100 \% / M1. \quad (1)$$

4. RESULTS AND DISCUSSION

4.1 Influence of curing methods on compressive and tensile strength

4.1.1 Test pieces stored at the laboratory (25 ± 2°C)

Compression case. The results are illustrated in Figure 3. At 3 and 7 days the best results are given by the treatment with the burlap, while the test pieces left in the air (without treatment) show the lowest resistance. Test pieces treated with polyethylene have intermediate results. At 28 days the difference between the strengths of the treated and untreated specimens increased considerably. The burlap / air and polyethylene / air resistance ratios become 2.53 and 3.17 respectively. Considering the results obtained after 28 days, it is necessary to mention the following remarks:

Contrary to what one would expect, the results obtained by the polyethylene method are the best. this confirms the results of the study [18] which concluded that the most effective method of curing against the early cracking of concrete remains the plastic film, explaining that the absence of evaporation on the surface not only reduces the amplitude deformations but also that the material remains saturated until setting, hence the absence of cracks.

The obtained results can also be explained by the difference in processing times, in fact, the polyethylene was held for 7 days while the burlap was only for 3 days. An approximate explanation is that since the test pieces have been left untreated for 28 days, it is likely that much of their mixing water has evaporated. As a result, the hydration of the cement and the development of resistance were stopped. In addition, the large temperature variations recorded at the laboratory level surely favored the development of microcracks inside the test pieces, which resulted in the decrease in strengths at 28 days.

Tensile strength. At the same figure, we can note the influence of curing methods on the tensile strength of specimens stored in the laboratory. It can be seen from this figure that until the age of 7 days the difference between the results obtained with the different treatment methods are practically insignificant. At 28 days the specimens treated with polyethylene and hessian showed the best results and their strength development between 7 and 28 days was of the order of 100%. On the other hand, the strength of the untreated specimens has remained substantially constant as its increase is only of the order of 37%. The non-treatment of the test pieces impedes the development of their resistance.

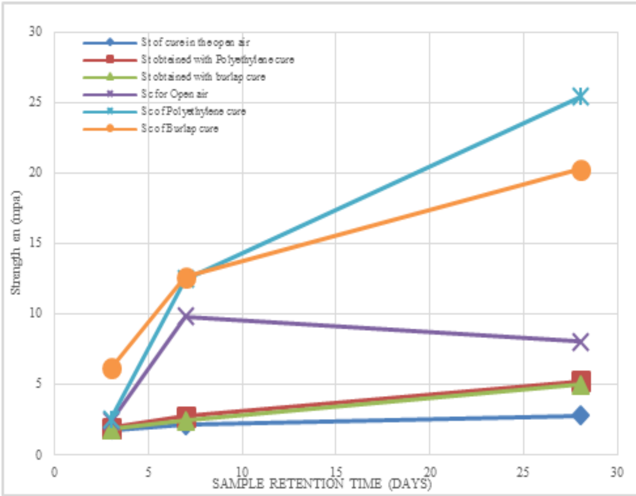


Figure 3. Influence of curing methods on compressive and tensile strength of specimen stored at the laboratory

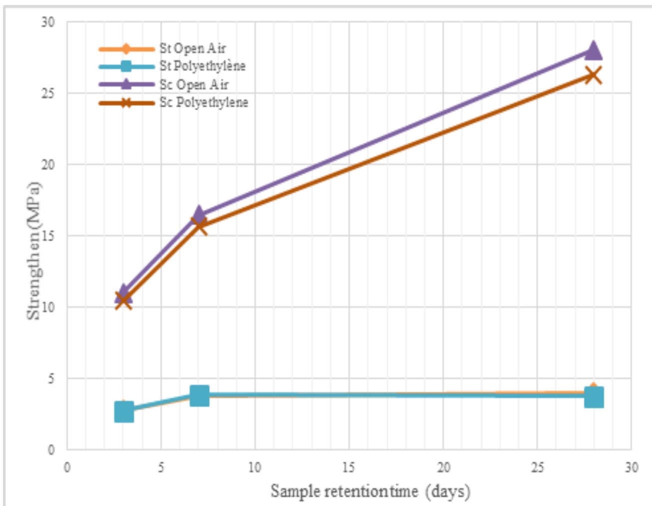


Figure 4. Influence of curing methods on compressive and tensile strength of specimen stored in the Climatic chamber

4.1.2 Test specimens stored in the climatic chamber

Case of compression and tensile test. This case is represented by Figure 4. Note that there is only a slight difference between the strengths of the two types of test specimens. At 7 days this difference remains insignificant, the ratio between the polyethylene / air resistances being of the order of 0.95. At 28 days this ratio remains more or less the same 0.94. The good results obtained by the untreated specimens are mainly due to the high humidity level within the enclosure. This humidity level and the condensation of water droplets inside the enclosure was a good method of wet curing specimens left untreated. This explains the development of resistance. This result seems to agree with that of the study [19] who considers that immersion in water is the best cure for improving the compressive strength of concrete.

For the tensile strength, it is clear that at any age (3, 7 and 28 days) the tensile strength values obtained are very close to each other. Indeed, the strength ratios of the test pieces treated with polyethylene to those untreated are respectively equal to 0.98, 1.03 and 0.93; at 3, 7 and 28 days respectively. It can therefore be concluded that the two types of curing had the same effect on the tensile strength of the tested specimen.

4.1.3 Test specimens stored in the oven

<u>Case of compression and tensile test</u>. The results are expressed graphically in Figure 5. At 3 days, all the test pieces have developed similar resistance. The high temperature having accelerated the hydration of the cement hence the rapid development of resistance. At 7 days the difference between the different curing methods becomes more pronounced and the burlap makes it possible to obtain the highest resistance. At 28 days the same order of magnitude is maintained and the supremacy of the wet method is confirmed.

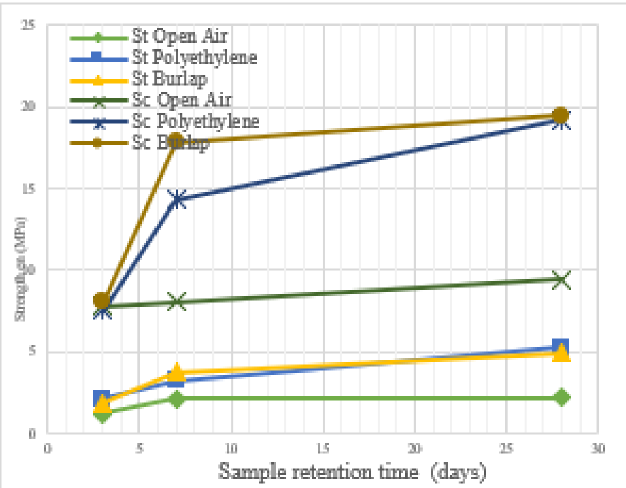


Figure 5. Influence of curing methods on compressive and tensile strength of specimen stored in the oven

From the curves in this figure, it can easily be seen that the compressive resistance of the untreated specimens is kept constant between 3 and 28 days.

Since the storage, conditions have been hot and the test pieces unprotected, evaporation of a large quantity of the mixing water is inevitable. As the development of resistance is linked to the hydration of the cement which in turn is linked to the presence of water. The consistent results we have obtained are therefore logical. On the other hand, the curve of the test pieces treated with jute cloth or with polyethylene, present an increasing development, this is mainly due to the fact that these test pieces have undergone an adequate treatment during their young age which allowed them to keep their water thus promoting the advancement of hydration.

For the tensile strength, we note that the curing by the burlap and by the polyethylene allowed to have the best results, while the untreated specimens had the lowest results. The burlap / air and polyethylene / air ratios are 185% and 153% respectively. This order of magnitude was maintained until the age of 28 days when the difference between treated and untreated specimens became very large.

4.2 Influence of storage conditions on compressive and tensile strength

4.2.1 Untreated specimens

The effect of climatic conditions on the compressive and tensile strengths of untreated specimens is illustrated in Figure 6. From this figure, it can be seen that the test pieces stored in the chamber and in the oven reached remarkable strengths at the age of 3 days, while those of the test pieces stored in the laboratory are relatively low. This is mainly due to the influence of the high temperature which accelerated the hydration of the cement. At 7 days, the resistances of the test pieces stored in the climatic chamber continued to develop normally, while those of the test pieces stored in the oven remained substantially constant. This can be explained by the fact that inside the enclosure the humidity is very high which allowed the mortar to retain its water and to benefit from the effect of temperature on the one hand and humidity on the other hand. While for the specimens left in the oven, evaporation of the mixing water is inevitable and the hydration is subsequently affected which results in a decrease in the development of resistance. At 28 days, the same findings can be made.

The same figure illustrates the results of the tensile strength. Note that the influence of storage conditions on tensile strength is similar, but less important than that obtained in compression. Indeed, the climatic chamber promotes the development of tensile strength at all tested ages. However, in the oven and in the laboratory the development of tensile strengths is insignificant. This is probably due to the same causes mentioned above for the case of compressive strength values.

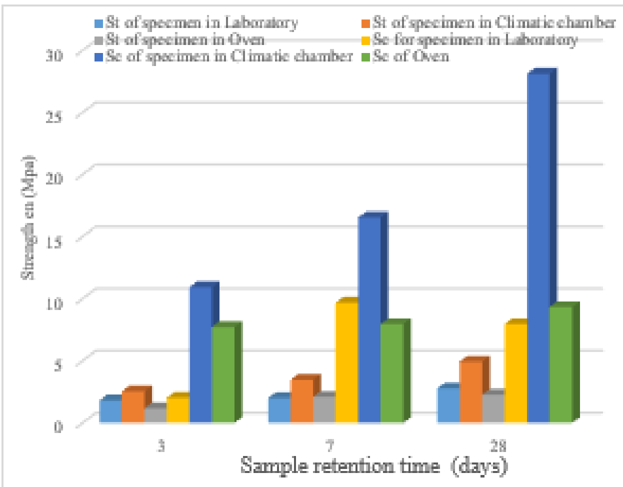


Figure 6. Influence of storage conditions on compressive and tensile strength of specimen left in Open Air

4.2.2 Test pieces treated with polyethylene and burlap

Figure 7 illustrates the case of compression. The test pieces that were protected by polyethylene and stored in hot conditions developed strong strengths at the age of 3 days, those stored in the enclosure gave the best strength. In the laboratory, on the other hand, the hydration took place less quickly, which gave relatively average resistance. At 7 days the same rate of resistance development is observed, up to the age of 28 days. The results obtained at 28 days are very close to those obtained in the climatic chamber and exceed those obtained in the oven.

The effect obtained on the test specimens in the case of traction is shown in the same figure. We note that up to the age of 7 days the resistance obtained in the chamber is slightly higher than that obtained in the oven and in the laboratory. However, and at 28 days, the latter showed a slight improvement and developed strengths greater than those of the specimens stored under hot conditions.

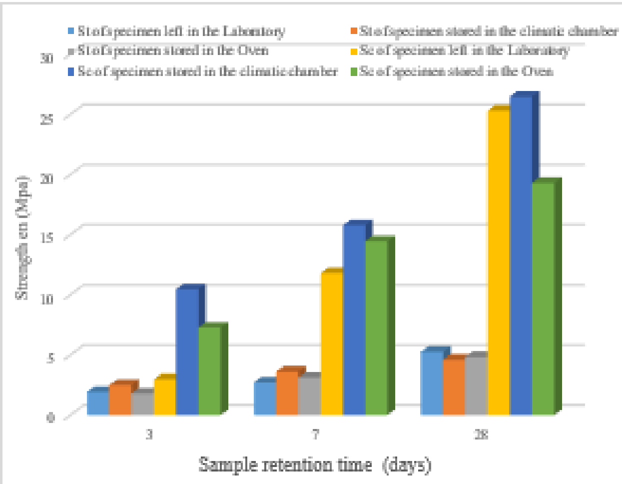


Figure 7. Influence of storage conditions on compressive and tensile strength of specimen covered with Polyethylene

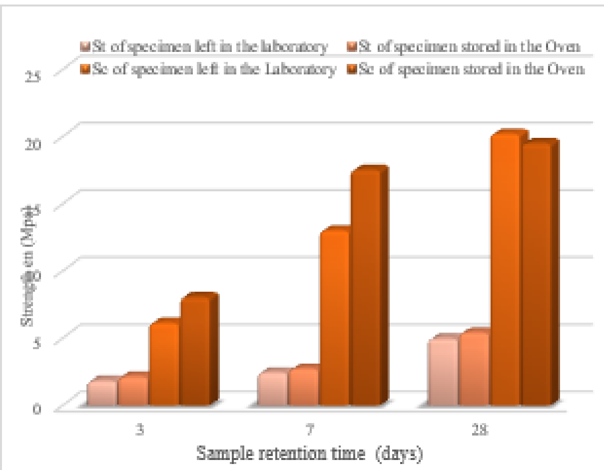


Figure 8. Influence of storage conditions on compressive and tensile strength of specimen covered with wet burlap

For the case of burlap cover, the results are expressed graphically in Figure 8. The results obtained at 3 and 7 days for the test pieces stored in the oven are superior to those obtained in the laboratory. The difference being accentuated at 7 days, this is mainly due to the wet treatment for a period of three days on the one side under storage conditions on the other, the increase in treatment temperature combined with wet curing favored this gain in strength. At 28 days, the development of resistance of the test pieces treated in the laboratory is very important. Consequently, the resistances obtained in this case are very close to those obtained in the oven. The results obtained in the oven treated specimens are slightly higher at all ages than those obtained in the laboratory. The influence of high level of temperature conditions is therefore almost negligible for this case.

4.3 Influence of curing and climatic storage conditions on the absorption of the mortar

The results of the absorption tests are shown in Figure 9. This clearly shows that the rate of water absorption is considerably reduced by the application of an effective method of curing. As water absorption is related to pore volume, proper hydration will go a long way in reducing pores and therefore reducing the rate of absorption. Thus, in the laboratory and in the oven, specimens that have been treated with damp cloth or polyethylene are relatively less absorbent than those left in the air. They must have lost a large part of water by evaporation which gave a negative result on the cement hydration process. Therefore, their structure becomes porous which results in high absorption. In the chamber, on the other hand, untreated specimens show relatively the lowest absorption rates. This is always linked to the humidity level existing in the climatic chamber and which made it possible to avoid any evaporation of the mixing water and therefore favored good hydration of the cement (i.e. a clear reduction of voids inside the mortar skeleton).

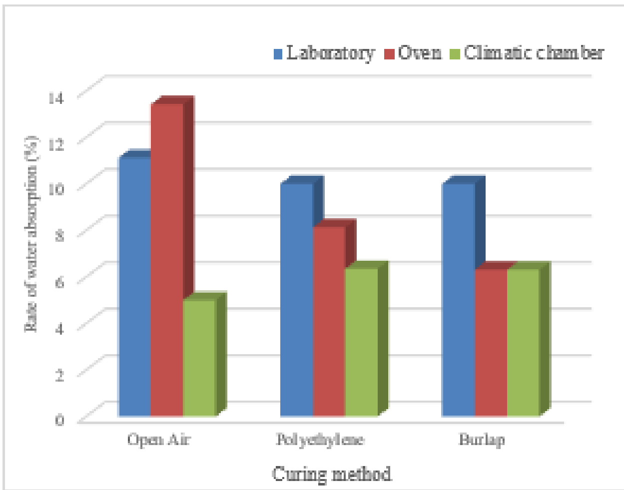


Figure 9. Influence of curing and climatic storage conditions on the absorption of the mortar

5. CONCLUSIONS

Based on the obtained results on fresh and hardened mortars related to hot climate procedures curing modes that is primordial for realizing a sustainable cement product, in regards to the present study analysis of obtained results, the following conclusions could be drawn:

The hot climate has a drastic effect on the resistance of the mortar to compression. Temperature and relative humidity have a positive or negative influence on the behavior of mortar exposed to different types of climate. As the most important problems of hot climate concreting for fresh mortars, are plastic shrinkage, excessive evaporation and early stiffing.

Further, hardened concrete, are subject to strength drop on long term and reduced durability.

Wet curing is the most effective compared to other mode of conservation. This is explained by the fact that the wet cure consists in limiting the evaporation of water, accelerating the hydration and minimizing the appearance of microcracks, which gives a good behavior of the mortar in compression.

The results obtained do not allow us to draw significant conclusions on the effects of the heat treatment conditions on tensile strength of the specimens as the small deviations recorded during the tensile tests is insignificant. Thus, it could be recommended; when evaporation rate is critical use hot climate concreting procedures.

The use of polyethylene as a curing method seems economically better and more efficiencies.

Absorption of mortar is much related to a good cure that promotes hydration and will result in a significant reduction in voids, which will allow the mortar to be less absorbent and therefore less permeable. Noting, hot conditions greatly enhance evaporation and adversely affect its porosity and permeability.

Finally it could be concluded that estimate and control of climatic conditions on jobsite is primordial for concreting in hot weather. Further, the use initial cure by using evaporation retarder or use curing product for a sufficient time, and utilization of adequate final cure method according to the characteristics of the element can be recommended.

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