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RESEARCH ARTICLE

HYGROTHERMIC EFFECTS ON COMPRESSIVE STRENGTH OF CONCRETE IN THE SAHEL, CHAD

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ABSTRACT

Since its discovery, concrete has exhibited a varied behaviour in different environments and under different conditions of preservation. This variation was the major concern of many researchers. The majority of studies developed for this purpose are carried out in laboratories under well-controlled test conditions that do not reflect the actual conditions under which the concrete structure is put in place. In the Sahelian climate (arid and hot climate), the effect of ambient temperature and hygrometry greatly influences the mechanical resistance of concrete to compression. To illustrate this effect, we have tried in this study to make a comparison between the effect of the cure on concrete specimens prepared and subjected to the different real conditions of protective workings (burlap, polyane film, etc.) and test pieces kept in water within the laboratory. For this we carried out an experimental programme in which several test pieces were made and subjected to compression tests according to age. The results obtained show that in the environment where the ambient temperature is high and the relative humidity is low, fresh concrete increases in resistance at a young age and then loses in resistance at an older age and that the effect of the method of cure is very considerable and can control this result.

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INTRODUCTION

Concrete is the most widely used material in the world, with an average of 16,393,442 m^3 per day (Nonna Yermak, 2015), due to its economic appearance (low cost) compared to metal structures and its easy shaping. Its mechanical resistance can be influenced by several parameters such as the quality and proportion of materials used in its composition, the conditions of use and preservation (effect of temperature, relative humidity), etc. Numerous studies have been conducted to elucidate the influence of temperature on the various mechanisms involved in cement hydration (Klieger, 1958; Verbeck, 1968; Mamillan, 1970; Alexanderson, 1972; Byfors, 1980; Regourd, 1980; Neville, 2000). In the Sahel, concrete is exposed from an early age to a change in temperature causing rapid evaporation of water.

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This early evaporation leads to a disruption of the moisture reactions of the cement increasing porosity, causing cracking and in the long term, especially a decrease in the compressive strength of the concrete. Concrete tests are usually performed under laboratory storage conditions (in a water tank at 20°C, ±2°C). However, for a concrete structure element built in N'Djamena in hot periods, such as a pole, it undergoes a daily temperature between 35 and 40°C and a relative humidity of 10 to 40%. Under such conditions, it is assumed that considering the results of laboratory tests to justify the strength of concrete under actual construction conditions in the Sahel and specifically in N'Djamena may be flawed. To understand this margin of error, we took care to highlight certain phenomena and, if possible, to consider a corrective factor for tests under laboratory conditions. In this work, a set of objectives has been set. It consists of:

- Make a formulation of the test pieces using the Dreux-Gorisse method;
- Submit the specimens cast under different methods of cure;
- To make a comparison between the strengths of the specimens cast and preserved under laboratory conditions

and those of the specimens kept in the real climate in order to show the hygrothermal effect on the resistance to concrete compression;

- Establish the corrective factor.

The resources used are based on the study of concrete specimens; samples are subjected to five conditions of preservation and cure in two environments. The first environment corresponds to sun exposure with three types of conservation, some of which are covered with polyane film, jute cloth and others left in the open air. Then for the 2nd environment the samples are exposed in the shade in a laboratory room with two types of conservation, one of which in the shade in the open air in an ambient laboratory climate, and the other according to laboratory storage conditions (in water). All these samples are sprayed twice a day during their hardening period. An evaluation of the mechanical compressive strength by means of compressive tests with reference to the age of the test pieces was carried out.

MATERIALS AND METHODS

The sand used is of alluvial origin from Chari. The tests are standardized and performed as part of the AFNOR standards at the N'Djamena NHSPW Laboratory. The sand particle size analysis was performed according to NF P 18-560. The particle size curve is shown in Figure 5.

Fineness module according to NF P 18-304: The fineness module of sand is given by the relation:

$$M_f = \frac{\sum R_i}{100}$$

R_i : Cumulative refusals in (%).

$$M_f = \frac{[88.47+\left(\frac{63.93+47.60}{2}\right)+31.13+5.87+0.67+0.13]}{100} = 1.82$$

Absolute density according to NF P 18-554. The absolute density is the mass of a cubic meter of a material, regardless of the voids that may exist in or between grains.

$$M_{vabs} = 300/(470{,}5 - 350) = 2{,}49\ g/cm^3$$

Bulk density according to NF P 18-555. Bulk density is the mass of one cubic meter of a material, including both permeable and impermeable grain voids as well as voids between kernels.

$$M_{vapp} = (12106{,}2 - 3691)/5024 = 1{,}675\ g/cm^3$$

The gravel used is crushed DANDI gravel. Crushed aggregates require more water for their compactness and absorption, but have excellent adhesion to the cement matrix due to their chemical natures, porosity and roughness (Gallias, 2009; Koehler, 2007; De Larrard, 2000). Two classes of gravel were used: Class 10/20 (Gravel 1) and 3.15/10 (Gravel 2). The granulometric analysis of the gravel was performed according to NF P 18-560. The particle size curve is shown in Figure 5.

Absorption coefficient according to NF P18-555: The absorption coefficient Abs is the ratio of the mass of a sample that has absorbed water to the dry mass of that sample.

The cement used is P.C 32.5 cement manufactured by National Cement Company (SONACIM) (Figure 6).The quality mark NF (French Standard) on this cement is voluntary and complementary to the CE marking of common cements complying with the harmonized standard NF EN 197-1 since April 1, 2002. The NF brand not only attests that cements benefit from additional guarantees on their composition, performance and controls, but also, they comply with the level of quality required by the French market according to the climatic and environmental conditions as well as the implementation techniques used in France (Dupain et al., 2000). This is the tap water from the NHSPW laboratory intended for consumption and therefore frees from hazardous materials (Figure 7).

Concrete formulation according to the DREUX-GORISSE method: For the safety margin, the target strength is increased by 15% over the resistance we want to achieve.

- The desired strength for concrete at 28 days is: σ28 = 25 MPa
- The target resistance is then: σ'28j = 1.15 σ28 =1.15 x 25 = 28.75 MPa
- Desired subsidence A = 3 cm
- Cement C and water E dosage of one cubic meter of concrete:
- $\frac{C}{E} \backsimeq 2.27$ With C = 350 kg/m^3 $\Longrightarrow$ $E \backsimeq 154\frac{l}{m^3}$

It should be noted that the compressive strength of the concrete increases at the same time as the cement dosage C and decreases with the water dosage E (13, 14). Plot of the OAB granular reference curve (Figure 8): We thus obtain an optimal mix with an absolute volume of 31.25% sand and 68.75% gravel (Gravel 3.15/10 + Gravel 10/20). On the particle size curves, the points of intersection between the split lines and the OAB curve give the percentages of the following aggregates: Sand: 31.25%; Gravel 3.15/10: 10.71%; Gravel 10/20: 58.04%. For the cubic meter of concrete, the volumes and masses of the constituents are summarized in Table 4.

Manufacture and Preservation of Specimens

Stages of Concrete Production: After determining the quantities of the components for a cubic meter of concrete, the quantities of concrete for a cylindrical specimen volume should be evaluated by the rule of three (Figure 9). However, the concrete must have good workability. According to Dreux and Festa, the compactness; the actual strength of the concrete; the coating and adhesion of the reinforcements; the sealing; etc., depend on the workability (Dreux, 1998; Ghrici, 2007). Faury points out that openability is a set of practical qualities that fresh concrete must possess to be transported easily and without risk of defects (Faury, 1958; Baron, 1982). Lengthening the mixing time can increase the density of the concrete but cause a loss of handling of the concrete (Cazacliu et al., 2006). According to Vandanjon, this phenomenon can cause an increase in the specific surface area of the primary particles, that is, clusters that remain to be grouped when shear movements in fresh concrete tend to increase the threshold (Vandanjon et al., 2000). In addition, Zivkovic showed that the higher the temperature of the fresh concrete, the greater the demand for water and the decrease in slumping (Zivkovic, 1992; Baron, 1996).

Finally, Makhloufi and Bouhicha showed the evolution of the compressive strength of concrete as a function of subsidence (Makhloufi, 2008).

Placing Concrete in Moulds: After determining the subsidence at the Abrams cone, we proceeded to place the concrete in the cylindrical mould in two layers. With the vibrating needle, according to NF P 18-422, we vibrated the concrete manually with the number of costs obtained on the subsidence graph. Finally, we grind the top surface of the specimen with a grinding rule in accordance with NF P 18-404 (Figure 10).

Preservation of test pieces before release: After finishing the test pieces, they were all treated the same way. They were made at temperatures and humidity ranging from 17°C to 28°C and 40% to 42%, respectively, left in place for 24 hours and each is numbered (Figure 11).

Conservation after Release: The mould was then removed the day after manufacture and the samples were placed for 28 days under different storage conditions (methods of treatment). ACI 308-01 defines the cure of concrete as the procedure for maintaining sufficient moisture and a favourable temperature in the concrete during hydration until the desired properties of the concrete are developed (ACI 308R-01). The cure must be applied from the beginning of the setting of the concrete because a delay of a few hours can significantly reduce its effectiveness; and it must be continued for one week in normal cases and for two weeks in very dry and hot weather (Règles d'exécution des travaux de construction d'ouvrages en béton armé). Two environments are adopted with five different cure conditions:

Environment I: all test pieces are exposed to the sun and under actual climatic conditions T = 17 to 39°C and relative humidity RH = 40 to 42%. We have defined three conditions of conservation:

- sun-exposed samples covered with polyane films (Figure 12);
- sun-exposed samples covered with jute webs (Figure 13);
- Samples exposed to the sun, left in the open (Figure 14).

Environment II: All test pieces are placed in the laboratory enclosure, protected from the sun and in the ambient laboratory climate; T= 19 to 25°C and HR = 45 to 48%. We have defined two conditions of conservation:

- Samples in open-air shade (without cover) in an ambient lab climate (Figure 15);
- Samples stored in water at 100% RH in an ambient lab climate and T=25°c (Figure 16).

All these samples are followed by daily watering twice a day during their hardening, except for those kept in water that no longer need them.

Crush Test

Resistance to Compression: The compressive strength of concrete is generally considered its most important property. It generally projects an overall picture of the quality of a concrete since it is directly related to the structure of the hydrated cement paste.

The compression measurements were carried out at the ages of 3, 7 and 28 days by conditioning the walls (surface coating of the cylinder walls) of the test pieces using fine sand (NF P18-305).

Conduct of the test: The test for the determination of the compressive strength of the test pieces shall be carried out in accordance with the requirements of NF EN 12390-3. The breaking stress is given directly by the press machine with an accuracy of 0.5 MPa.

Placement and Centering of the test piece: Using a lower shelf and holds, we must ensure that it is centered in relation to the upper shelf. The loading faces of the trays or counter-trays and the loading faces of the test piece shall be cleaned so that they are clean. The test piece is positioned, crushing face up and centered. The centring error must be less than 1/100 of the diameter of the specimen (Figure 17).

Loading: The contact between the test piece and the top plate with the ball-joint shall be uniform. The press must be subjected to a continuous and uniform load without impact so that a uniform increase in stress of (0, 6 ± 0, 4 MPa) is caused until the specimen breaks.

RESULTS AND DISCUSSION

The results of the compression test for specimens subjected to different methods of treatment can be seen in Table 6. For the demonstration of the hygrothermal effect on the mechanical behaviour of concrete (compressive resistance), let us observe the following Figure 18 which gives the evolution of resistance curves as a function of age for the five conditions of preservation. Before 15 days of age, the temperature has a positive effect on the evolution of the resistance. But after 15 days of age, the rise in temperature has a negative effect on the development of the compressive strength of the test pieces. The resistance of the four conditions decreases compared with that of the test pieces in the water tank. This shows that the hygrothermal effect has a negative influence on the behaviour of the concrete if the temperature and humidity are not optimum.

We consider the observation of the results of three conservation conditions which are: test pieces exposed to the sun covered with jute cloth and test pieces exposed to the sun covered with polyane film and then test pieces in a water tank sheltered from the sun (Figure 19). The results of this figure show that for the first 18 days, the strength of test pieces exposed to the sun and covered in jute cloth and test pieces covered in polyane film have a strength which is greater than that of the test piece in the water tank sheltered from the sun. This proves that the increase in temperature is favourable for the evolution of the resistance of the concrete at its young age (less than 15 to 18 days). The opposite effect occurs over the long term (i.e., after 18 days). This confirms the work of BARNES (Barnes, 1977). We see that for the types of protection with jute cloth and polyane film, allow the concrete to minimize the loss of strength. The polyane film case better minimizes the loss of long-term resistance. Figure 20 shows the results of two storage conditions relating to test pieces in water sheltered from the sun and test pieces in the sun in the open air. It can be seen that the compressive strength of test pieces stored in water increases considerably with age, this can be explained by the fact that in water the hydration reaction has had all its time to complete itself.

Figure 1. Bulk density (sand) test

Figure 2. Bulk density (gravel) test

Figure 3. Absolute density test

Figure 4. Sand equivalent test according to NF P 18-597

While in the sun in the open air, the resistance increases considerably during the first 3 days and continues until the 17th day after, and it is above those obtained for test pieces immersed in water, this may be due to the high temperature which activates and accelerates the hydration of the cement. But after 17 days of exposure to the sun in the open air without protection, the effects of temperature lead to an excessive departure of the mixing water which reduces the processes of the hydration reaction giving thus the resistance to compression significantly lower. It is also remarkable that the watering water evaporates immediately, and that there is a large difference between the water temperature of the order of 20°c and the water temperature on the concrete surface, which can reach 39°c, which can cause significant heat shock. Figure 20 shows the results of the covered and uncovered test pieces observed under three conditions which are those exposed to the sun covered in jute cloth, in the shade and in a water tank sheltered from the sun.

The conservation effect on test pieces in the shade in the lab and in the sun with a jute blanket seems to be the same in terms of compressive strength beyond 24 days. Although watering is an intermittent operation, it seems to have a beneficial effect in our case with the relative humidity of 48% and the temperature varying from 19 to 25°C. The specimens in the shade within the lab are watered twice a day and the storage tank is permanently wet thanks to the watering water, which is favourable in terms of relative humidity.

Effect of age: According to the results found, it is observed that up to 28 days, resistance gradually evolves in both media (Figure 21), this evolution continues in the water until the long term, while in the sun in the open air the resistance to 28 days falls considerably.

In environment I (in laboratory enclosure protected from the elements), the age ratio of Rcj/Rc28 are:

- In water: Rc3/Rc28 = 30% ; Rc7/ Rc28 = 56,1%
- In the shade within the lab: Rc3/Rc28 = 35,33% ; Rc7/ Rc28 =6 5,37%

And in environment II (in the sun exposed to bad weather):

- Outdoors: Rc3/Rc28 = 41,57% ; Rc7/Rc28 = 74,91%
- With jute cloth cover: Rc3/Rc28 = 35,33% ; Rc7/Rc28 = 66.43%
- With polyane film cover: Rc3/Rc28 = 37,98% ; Rc7/Rc28 = 6 6.20%

Percentage Comparison of All Conditions Relative to Laboratory Condition (In Water): Table 7 shows the total strength values of the concretes for the five storage conditions. For the calculation of the percentage reduction in the compressive strength of the concrete, reference values were taken to be the relative strengths of the test pieces placed in a water tank in the laboratory away from the sun. This allows to calculate the percentages of decreases in the strength of the concrete of the other conditions compared to the reference concrete (in water). This allows us to introduce a corrective factor depending on the type of storage condition to adjust the actual long-term resistance of concrete at the worksite. This depends on the period during which the tests are performed. Compared to our tests, the period is November to January.

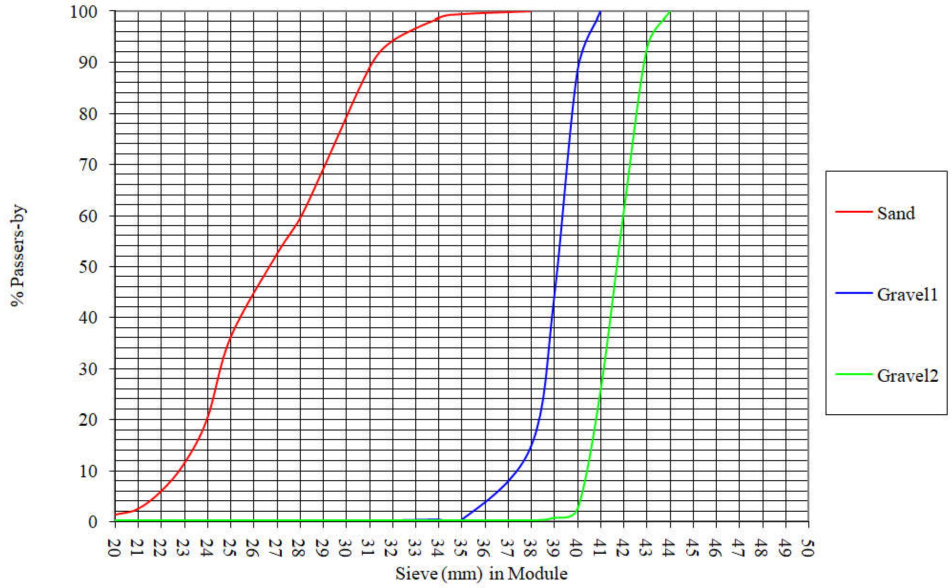

Figure 5. Sand granulometric curves, gravel 3.15/10 and 10/20

Figure 6. Cement used

Figure 7. Water used

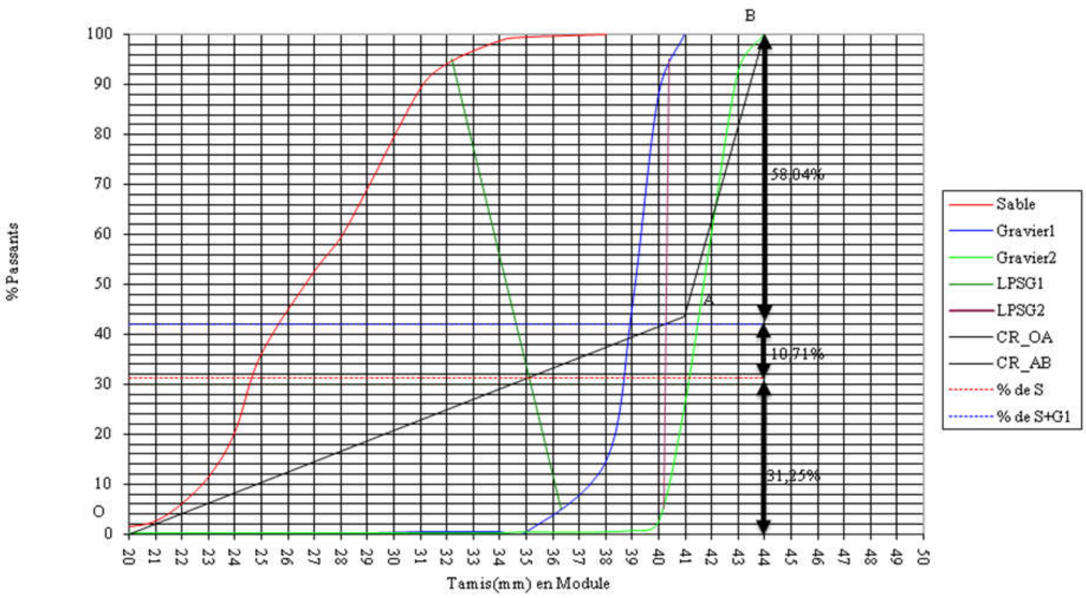

Figure 8. Granular Reference curve.

Figure 9. Cylindrical moulds 16 cm and 32 cm

Figure 10. Placement of concrete

Figure 11. Preservation of test pieces before release

Figure 12. Samples exposed to covered suns with polyane films.

Figure 13: Samples exposed to suns covered with jute webs

Figure 14. Samples exposed to the sun, left in the open air

Figure 15: Samples in the shade in the open air (without cover) in an ambient laboratory climate

Figure 16: Samples stored in water at 100% RH in an ambient laboratory climate

Figure 17: Placement of a test piece in the machine

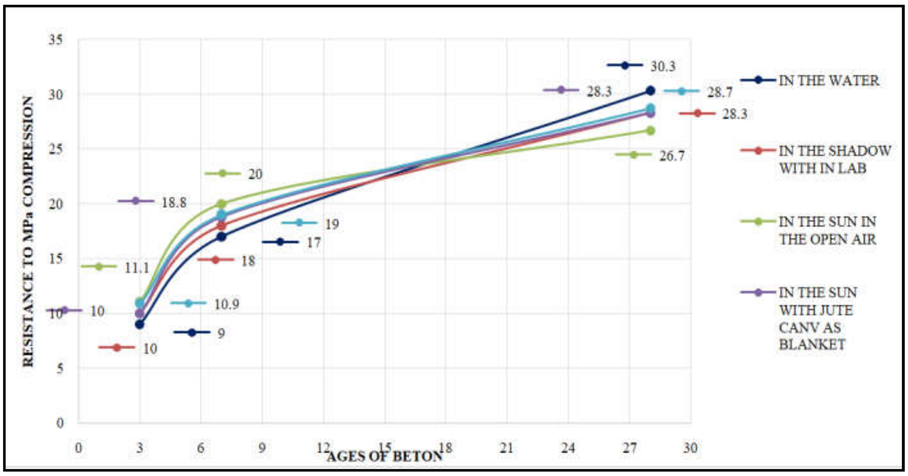

Figure 18. Influence of temperature and humidity on the compressive strength of concrete for the five conditions

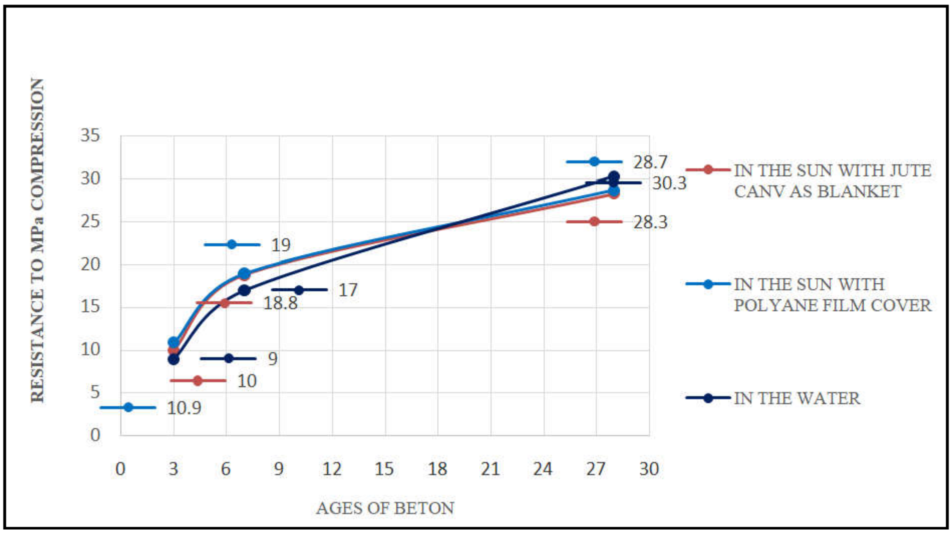

Figure 19. Hygrothermal influence on the compressive strength of the concrete for the three conditions (exposed and covered with jute cloth, polyane film and test tube in a water tank sheltered from the sun

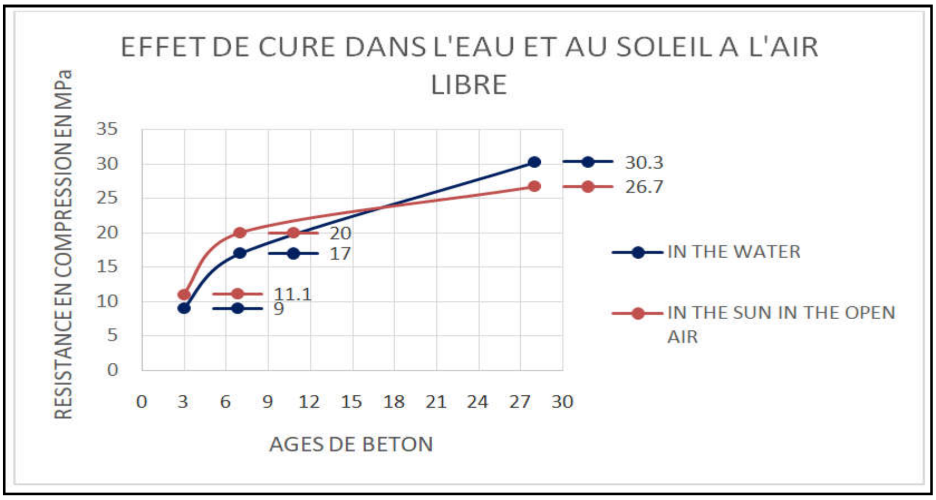

Figure 20. Influence of temperature and humidity on the compressive strength of the concrete for both conditions (blanketed test pieces exposed to the sun and test pieces in a water tank sheltered from the sun)

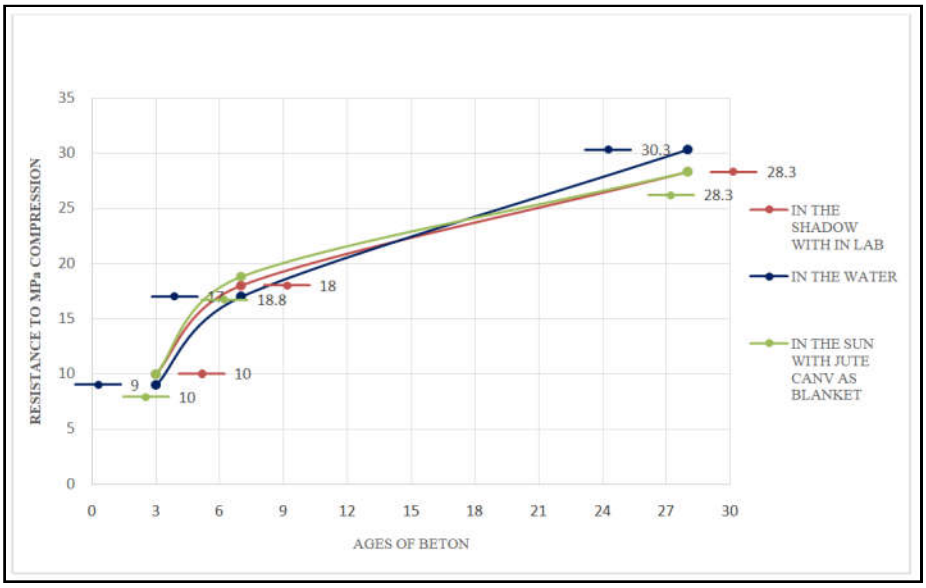

Figure 21: Hygrothermal influence on the compressive strength of the concrete for the three conditions (jute-covered test tubes exposed to the sun, test tubes in the shade and test tubes in a water tank sheltered from the sun)

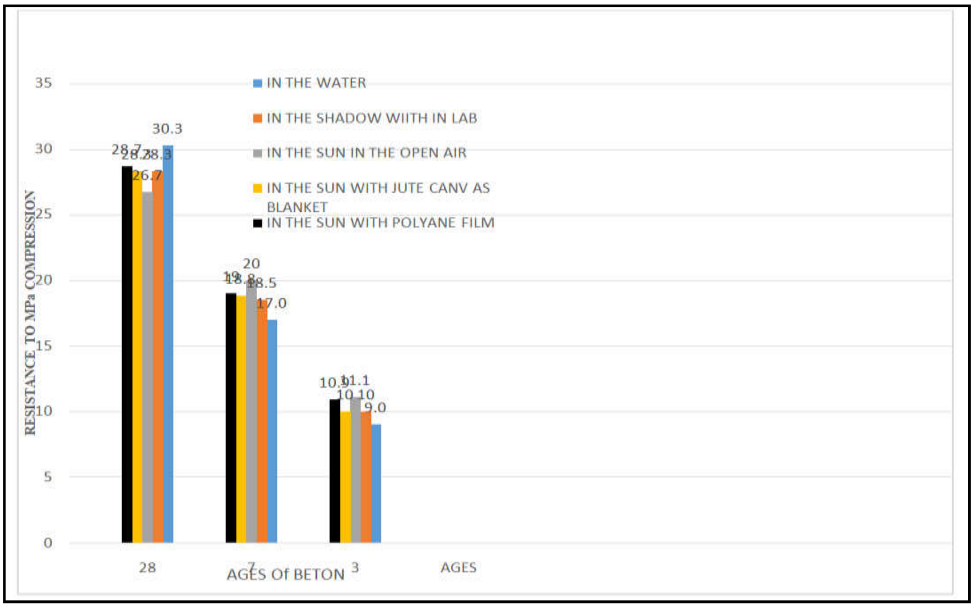

Figure 22. Histogram representative of different preservation methods

Figure 22 shows the mechanical compressive strengths of the 3, 7 and 28-day age specimens observed under five conditions. By making a comparison of the resistance values of the five conditions and for each type of age; it appears that at 28 days, the strength of the concrete obtained from the condition in water is the greatest.

Corrective factor: 28-day compressive resistance results show differences between the resistance obtained for conservation in water (laboratory condition) and those obtained for other conservation conditions (real climate conditions that reflect site conditions). These results show that resistance in the laboratory is rarely achieved on site and certain conditions differ more (Table 8). However, the strength of the concrete is the most important parameter for assessing the quality of the concrete. In calculating a structural element, the engineer must take this parameter into account. Generally, the resistance prescribed in the specifications is that obtained according to the laboratory conditions.

On the other hand, it seems exaggerated to adopt such a resistance without it being reached for a work exposed to the conditions of the real climate. For this reason, it is desirable that the implementation of a concrete must take into account all the parameters of the environment, especially those climate to give the short and long term, a resistance to the desired compression is precisely achieved. But in worksites in a Sahelian climate, it would be difficult to see the cost of reflecting laboratory conditions. In order to elucidate this problem, which considerably affects the durability of built works, we have put in place in this work a corrective factor allowing obtaining compressive resistances according to the methods of conservations compared to the reference condition (lab condition). This factor allows obtaining according to the cases the resistance that will be adopted in the calculation of ordinary projects in N'Djamena especially for the period from November to January.

The corrective factor (F_C is given by): $\mathrm{Fc} = 1 - \mathrm{r}$

$$\mathrm{r} = \frac{\mathrm{R''}_{\mathrm{C2\ 8}} - \mathrm{R'}_{\mathrm{C2\ 8}}}{\mathrm{R''}_{\mathrm{C2\ 8}}}$$

$\boldsymbol{F_C}$**:** Correction factor for compressive strength of samples held under real conditions.

$\boldsymbol{r}$ **:** Difference in the ratio of compressive strength at 28 days for samples retained under laboratory condition and samples retained under actual climate conditions compared to retained samples according to the laboratory condition.

$\boldsymbol{R'_{C28}}$**(In MPa):** The compressive strength of the preserved samples according to the actual climatic conditions.

$\boldsymbol{R''_{C28}}$**(In MPa):** Compressive strength of samples stored in water according to laboratory condition.

To obtain the approximate value of the resistance on the site, it is sufficient to apply the following formula:

$$R'_{C2\ 8} = R''_{C2\ 8} x Fc$$

For example: for samples exposed to the sun in the open air:

$$R'_{C2\ 8} = 30.3x0.881 = 26.7\ MPa$$

That is to say to obtain 26.7 MPa at the site, it is sufficient to formulate a concrete for a compressive resistance $R''_{C2\ 8} = 30.3\ MPa$ in lab.

Conclusion

This work of memory is devoted to the knowledge and understanding of the influence of hygrothermal effects on the mechanical behaviour of concrete under actual climatic conditions. In order to arrive at a conclusive result, we based ourselves on the bibliographic synthesis which enabled us to define a scientific and technical context for our work. We were able to know and understand the effects of temperature and hygrometry negatively affecting the compressive strength of concrete in the long term that is to say from the 18th day of age 28th. We also gave a general overview of the concrete material (aspects of the formulation principle and the mechanical behaviour), from which we found the influence of the surrounding environment on the hardening of fresh concrete, who encouraged us to take our study in this direction.

In our experimental study we formulated a concrete with rolled sand, crushed gravel and cement 32.5, all local materials. Using the same formulated concrete, we manufactured test pieces and placed those under five types of conditions. Based on the criterion of compressive strength, we were able to make the difference in the behaviour of the concrete according to the actual climatic conditions. The compression tests were carried out at three, seven and twenty-eight days to determine and understand the evolution of the resistance of the samples under these different conditions. The results of these tests led us to the following conclusions:

- The long-term compression resistance (greater than or equal to 18 days) of the test pieces for the five storage conditions is negatively influenced by temperature and relative humidity. It depends on one condition to another. The most accentuated case is that of the test tube exposed to the sun without cover. The most favourable is the test pieces with polyane film cover.
- In the short term (less than or equal to 18 days), the temperature has a positive effect on the evolution of the resistance. This is the case for test pieces exposed in full sun without being covered with the highest resistance. This is followed by the cases of specimens exposed to the sun and covered. This leads us to understand that in the short term, temperature has a positive influence on the evolution of resistance.
- The cure of concrete is important at the beginning of its setting and hardening in a warm climate. The application of polyane film is the most advisable to reduce the need for water supply and ensures adequate hydration by preventing water from evaporating. The jute cloth is more suitable if it is kept constantly wet.
- Compressive resistance decreases with exposure conditions. It is necessary to take account of a corrective factor to be applied to the 28-day compressive strength of test pieces made and placed in a water tank sheltered from the sun. It must be applied according to the conditions of exposure. If no, there is a margin of error related to the hygrothermal influence that distorts the actual compressive strength of a concrete on site.

Recommendation

- For our concrete works, it is important to carry out the daily cure and to protect all structural elements with polyane films;

- Knowing that the compression tests are carried out on test pieces placed in a water tank and sheltered from the sun. This does not reflect the actual strength of a concrete exposed to temperature and under the influence of a relative humidity of around 50%. This leads us to propose a correction to be applied to test pieces under laboratory conditions. The corrective factors identified range from [0.881 to 0.947] and correspond to the period from November to January.

REFERENCES

ACI 308R-01, “Guide to curing concrete“, 2001, 31p.

Alexanderson J. 1972. Strength losses in Heat Cured Concrete, Swedish Cement and Concrete Research Institute at the Royal Institute of Technology, Stockholm.

Barnes B. D., Orndoref R. L., Roten J. E. 1977. Low initial curing temperature improves the strength of concrete test cylinders, J. Amer. Concr. Inst., 74, N°12, pp. 612-15.

BARON J. 1982. La nécessité d’une démarche pragmatique : idée de maniabilité et sa mise en pratique, (dans « Le béton hydraulique, connaissance et pratique »), Presse de l’Ecole Nationale des Ponts et Chaussées, Paris.

Baron J., Ollivier J.P. 1996. Les bétons bases et données pour leur formulation, Edition Eyrolles, Paris, 522 p.

Byfors J. 1980. Plain concrete at early ages, Swedish Cement and Concrete Research Institute at the Institute of Technology, Ed., Stockholm, CBI, Reaserch3:8.

Cazacliu B., Guieysse B., Garcin O., Buisson F., Baudru Y., Chanut S., Lallemant-Gamboa I. 2006. Laboratory evaluation of 9 mixers, rapport LCPC pour le projet européen Innocrete, 71 p.

D.T.R. BE 2-1, “Règles d’exécution des travaux de construction d’ouvrages en béton armé “, C.G.S ,1991.

De Larrard F. 2000. Structures granulaires et formulation des bétons, traduit de l’anglais par LECOMTE A., Etudes et recherches des laboratoires des ponts et chaussées, Paris, 414 p.

Dreux G., Festa J. 1998. Nouveau guide du béton et ses constituants, éditions Eyrolles ; Paris, 409 p.

Dupain R., Lanchon R., Saint-Arroman J.C. 2000. Granulats, sols, ciments et bétons, Edition Casteilla, Paris, 236 p.

Faury J. 1958. Le béton : Influence de ses constituants inertes. Règles à adopter pour sa meilleure composition, sa confection et son transport sur les chantiers, 3e édition, Dunod, Paris.

Gallias J.L., Kara-Ali R., Bigas J.P. 2000. The effect of fine mineral ad mixtures on water requirement of cement pastes, Cement and Concrete Research 30, pp. 1543-1549.

Ghrici, M. 2007. “*Technologie avancée des bétons* “, Cours de Magister, Institut de Génie Civil, Université de Chlef.

Klieger P. 1958. Effect of mixing and curing temperature on concrete strength, J. Amer. Concr. Inst., 29, 12, 1063-1081.

Koehler E.P., Fowler D.W. 2007. Aggregates in self – consolidating concrete– International Center for aggregates Research (ICAR), The University of Texas at Austin, March.

Makhloufi Z., Bouhicha M. 2008. Formulation du béton calcaire du turonien de Laghouat, Algérie Equipement, N° 44, mai, pp. 14-21.

Mamillan M. 1970. Recherches expérimentales sur l’accélération du durcissement du béton par le chauffage, Annales de l’ITBTP, 267-268, 133-203.

Neville A.M. 2000. Propriétés des bétons, ed. CRIB., Paris, Eyrolles, 806 p

Nonna Yermak, 2015. Comportement à hautes températures des bétons additionnés de fibres. Thèse de Doctorat, Université de Cergy-Pontoise.

Regourd M., Gautier E. 1980. Comportement des ciments soumis au durcissement accéléré. Annales de l’ITBTP, N° 387, oct.

Vandanjon J.O., DE Larrard F., Dehousse B., Villaine G., Maillot R., Laplante P. 2000. Homogénéisation des bétons en centrale de fabrication discontinue. Influence du temps de malaxage et du mode d’introduction des additions minérales, Bulletin des Laboratoires des Ponts et Chaussées, Vol. 228.

Verbeck G.J., Helmuth R.A. 1968. Structures and physical properties of cement paste, Proc. 5th Int. Symp. On the Chemistry of cement, Tokyo, Vol. 3, pp. 1-32.

Zivkovic S.D. 1992. The effect of increased temperature on fresh and hardned concrete, in : Concrete in hot climates, Proceedings of the third international RILEM conference, Torquay, 21-25 september 1992, E. & F.N. Spon, Ed., London, 1992, 3-12.

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