Compressive Strengths of Concrete Formulated with Algerian Local Materials

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ABSTRACT

In the developed countries, concrete undergoes not only an improvement of its performance in both fresh and hardened states, but also a good control of the quality of its components. This is not the case in most of the building sites in our country. The factors affecting the quality of concrete during its production and implementation are numerous.

Due to this fact, we aim to study the influence of the nature of the components on the mechanical property of the mixture, in particular the compressive strength which remains, for the engineer, the most significant property of material, if one excludes the indicators of durability (Mounanga et al., 2006).

For this purpose, an extensive experimental program is conducted in our laboratory where more than 1500 cylindrical specimens 16x32 cm, using local materials, are tested. The mixtures are obtained using the Dreux-Gorisse's method and the cure of the specimens is done both out in the open and immersed in water.

We show on the one hand, that the intrinsic properties of the components of the studied concrete and particularly the broken up particles, offer to the concrete complete satisfactory resistances and on the other hand, the cement proportioning for the selected class does not offer notable differences as regards to compressive strengths. The whole experimental results obtained constituted a data bank. The latter enabled us to establish an abacus of formulation the use of which appears easy.

KEYWORDS: Broken up particles, Compressive strength, Concrete, Local materials, Statistical study.

INTRODUCTION

At the regional and national levels, concrete is the material used by excellence within all the building sites, in the sectors of the building and public works; it does not have an economic and powerful substitute. The compromise found between mechanical resistance, economy, aesthetics and simplicity of implementation, offers to this material the first place in the construction industry in the world. The quality of concrete constructions is very related to that of its components.

However, very few studies of research are devoted, in Algeria, to stress on the aspects related to the composition of concretes according to their use. The resistance is closely related to the intrinsic characteristics and to the proportioning of the various materials making the mixture which is the concrete.

Our work is part of a set of research themes with two main objectives: first, the study of the quality of the concretes resulting from local materials and second, the

constitution of a data bank of materials, components and concretes of Tlemcen's area in order to define certain phenomena that remained up to now unknown.

All the tests realised in this work were carried out according to national and international standards recognized in the field (AFNOR, ASTM and NA). Also, we measured the characteristics of the concrete in a fresh state (workability, entrained air, density) and in a hardened state (compressive strength) using destructive tests.

Characterisation of Used Materials

Cement

We have used for our study cement with low strength class, the CPJ CEM II/A 32.5 which meets the Algerian standard NA 44, of the Company of Cements of Beni-Saf in the wilaya of Ain-Temouchent, whose characteristics are given in Tables (1, 2 and 3). The analyses concerning the chemical composition and the mineralogical composition of Bogue were carried out at the laboratory of the manufacturing plant of cement, while those concerning the physico-mechanical characteristics and mechanics were carried out within our laboratory.

Table (1): Chemical composition of cement (%).

S_iO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	CaO libre
28.48	4.19	3.77	56.26	0.89	1.54	0.57

Table (2): Bogue mineralogical composition of cement (%).

C_3S	C_2S	C_3A	C_4AF
55.06	21.01	5.57	12.45

The test results show that cement is in conformity with the requirements of its class. This type of cement is not usually used for the manufacture of reinforced or prestressed concrete, because of its low strength class; on the other hand, it is well adapted to the most current uses of building.

Table (3): Physico-mechanical characteristics of cement.

M_v apparent (kg/m^3)		1088
M_v absolute (Densitometer Le Chatelier) (kg/m^3)		2980
M_v absolute (pycnometer) (kg/m^3)		2986
Consistency (%)		W=26.6 % then 133 g
Beginning of setting		2h52
Compressive strength (MPa)	2 days	17.80
	7 days	33.80
	28 days	48.70
Flexural strength (MPa)	2 days	3.49
	7 days	5.72
	28 days	6.80

Mixing water

For making the various concretes, we used the water distributed by the public network of Daira of Chetouene in the wilaya of Tlemcen (ALGERIA). The chemical analysis of this water was realized in the laboratory of Algerian Water Company; the values are recorded in Table (4) according the standard XP P 18-303.

Table (4): Composition of mixing water (mg/l).

Ca	Mg	Na	K	Cl	SO_4	CO_3	NO_3	PH	T(C)
74.4	49	40	5	95	170	300	42.3	7.5	17.1

Aggregates

The aggregates used come from two great quarries of the area of Tlemcen, the quarry of Djebel Abiod of Sidi Abdelli and the quarry of Dhar El Mendjel d' El Malah, which belong to the National Company of Aggregates (ENG). This choice is dictated by the fact that these are the two quarries which mainly supply the area due to their importance in production. These crushed limestone aggregates are commercialized as size ranges: sand 0/3 and gravels of classes 3/8, 8/16 and 16/25.

To be able to build reliable works according to standards and of high technico-economic effectiveness, it is necessary to determine the intrinsic characteristics of

the aggregates, since the latter constitute the skeleton of the concrete and more than 70% of its volume and thus

influence strongly its characteristics; namely the dimensional, physicochemical and mechanical properties.

Table (5): Identification of the properties of the aggregates of Djebel Abiod and Dhar El Mendjel (ENG).
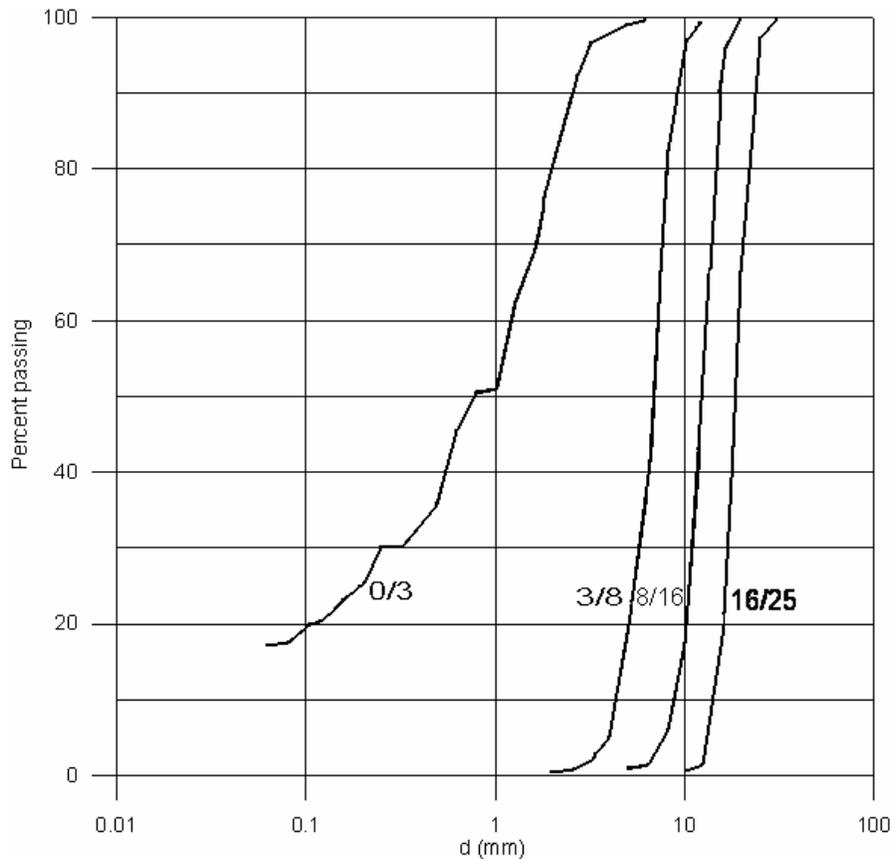
Characteristics of the aggregates:	Size ranges							
	0/3		3/8		8/16		16/25	
	DA	DM	DA	DM	DA	DM	DA	DM
Apparent bulk density (kg/m^3)	1426	1362	1355	1401	1423	1380	1374	1427
Absolute density (kg/m^3)	2500	2609	2587	2688	2587	2630	2565	2570
Sand equivalent (%)	63.2	84.6	-	-	-	-	-	-
Sand expansion (%)	DA : W_{opt} = 7 corresponds to it ρ_{app}= 1130kg/m^3 DM : W_{opt} = 7 corresponds to it ρ_{app}= 1190kg/m^3							
Silt content test (impurities) (%)	-	-	1.92	0.75	1.3	0.98	0.73	0.64
Coefficient of flatness (%)	-	-	19	19	8	16	8	4
Fineness Modulus	2.95	3.03	-	-	-	-	-	-
Content of fines (%)	17	15	-	-	-	-	-	-
Abrasion test Los Angeles (%)	-	-	4/6.3 27	4/6.3 26	6.3/10 31	6.3/10 26	10/14 31	10/14 28
Micro Deval test (%)	-	-	4/6.3 15	4/6.3 7	6.3/10 11	6.3/10 11	10/14 8	10/14 7
DA : quarry Djebel Abiod - DM : quarry Dhar El Mendjel								

Table (6): Composition of the concretes.

	Sand + Gravels (kg/m^3)	Cement (kg/m^3)	Water (kg/m^3)
Concrete DA	1731.1	350	210
Concrete DM	1772.6	350	210

Table (7): Characteristical resistances at 28 days.

	Djebel Abiod			Dhar El Mendjel		
	C=300kg/m^3	C=350kg/m^3	C=400kg/m^3	C=300kg/m^3	C=350kg/m^3	C=400kg/m^3
Average resistance f_c (MPa)	33.32	34.11	34.13	32.55	34.0	35.6
Standard deviation σ (MPa)	1.39	1.54	1.95	3.04	2.0	1.21
Characteristical resistance f_{ck} (MPa)	31.04	31.58	30.93	27.56	30.72	33.62

Figure (1): Grading curves of the aggregates of Djebel Abiod.

The characteristics of these aggregates are consigned in Table (5), and the results of the grain size analysis are represented in Figures (1 and 2).

The quarries of Djebel Abiod and Dhar El Mendjel produce clean sands which fulfil the requirements of the standard NA 455. Within the framework of our study, we used them just as they are, without any treatment (without washing) for the realization of the formulations of recommended concretes, in spite of their respective coarse fineness modulus as well as light discontinuities as shown in the grading curves (Fig.1 and Fig.2).

On the other hand, the gravels of the two quarries have a satisfactory cleanliness (< 3%), a favourable form (< 30%) and a good resistance to impact and to wear, with a coefficient LA<40% and MDE<35%.

EXPERIMENTAL PROGRAM

Knowing the importance of the proportions of cement and the ratio W/C for the characteristics of concrete in fresh and hardened states, we have chosen to vary these two parameters according to the flow chart presented in Figure (3), which led us to the realization of 36 formulations of concretes.

We have also used two modes of maturation of the concrete; the cylindrical specimens 16x32 cm were preserved after preparation and removal from the mould either out in the open or completely immersed in water (NA 426).

The reproducibility of the test of compression is very difficult to obtain, since the risks of errors concerning this test are multiple. It is often enough that one of the specifications is not followed during the test to obtain an
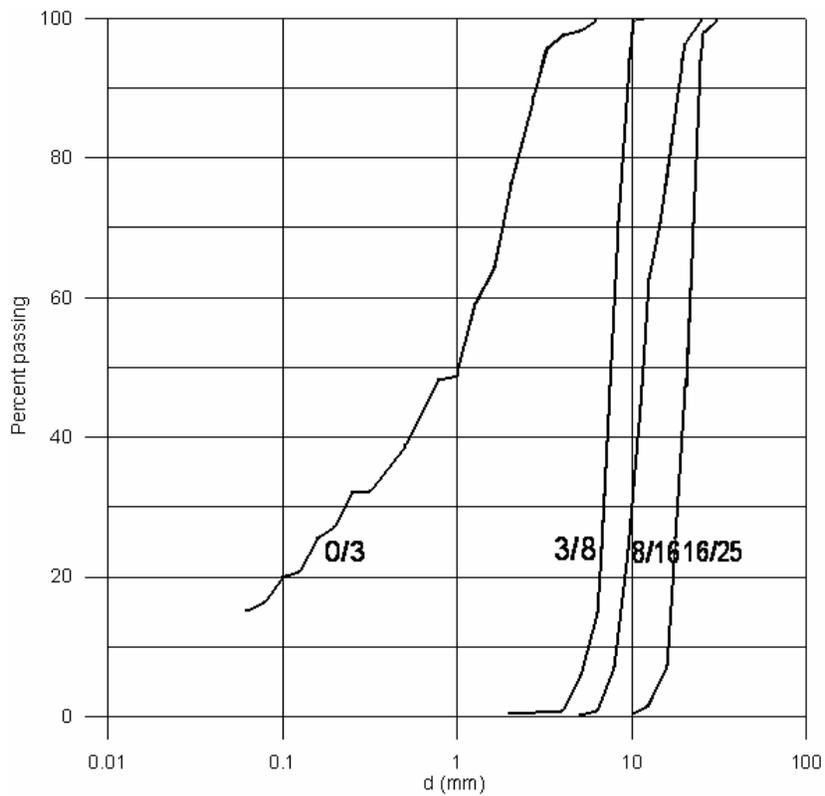
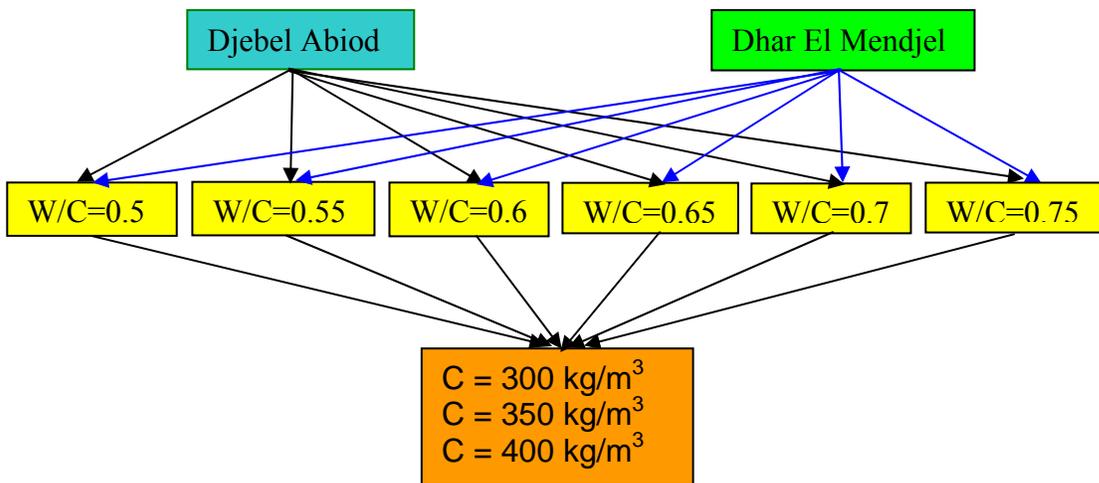**Figure (2): Grading curves of the aggregates of Dhar El Mendjel.**

Figure (3): Organigram of the experimental program.

aberrant result. We are trying to concentrate here on tests carried out with rigour and for which a statistical study can be led. This is why we studied in experiments, for each parameter, twenty cylindrical specimens instead of the three conventional ones. Each measurement of

resistance is the average value obtained for approximately twenty or so of specimens and this after having rejected the few aberrant values by using the test tabular of the normal law.
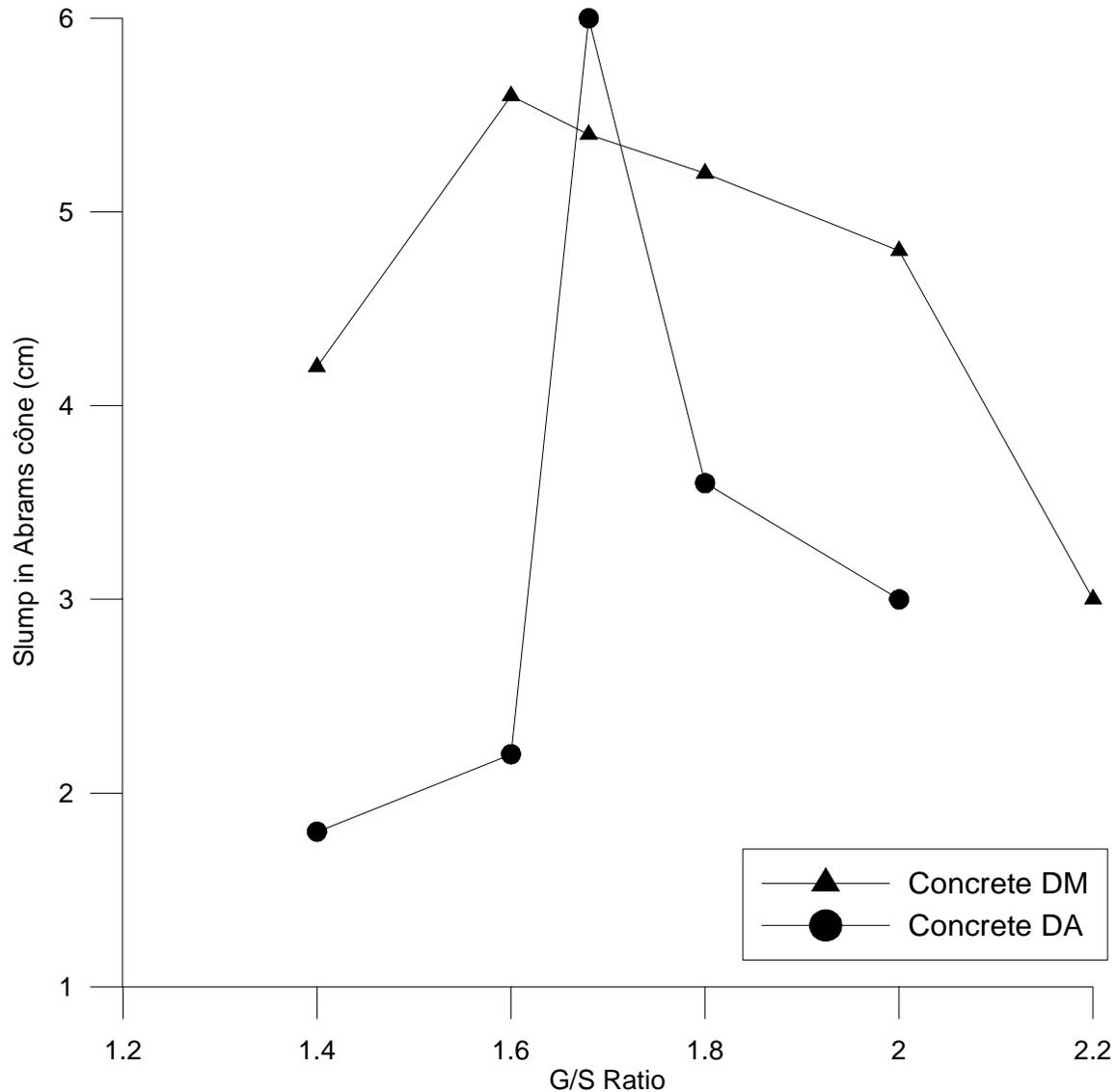
Figure (4): Optimization of ratio G/S according to slump.

The concretes were made in accordance with the standards in use. The materials dried beforehand in the drying oven at 110±5°C, are introduced into the concrete-

mixer in the following order: gravels (16/25, 8/16, 3/8), cement, sand and water. After a dry mixing about one minute, we add water mixing and we continue mixing

during two minutes. The installation in the cylindrical specimens took place, by vibration or, by pricking,

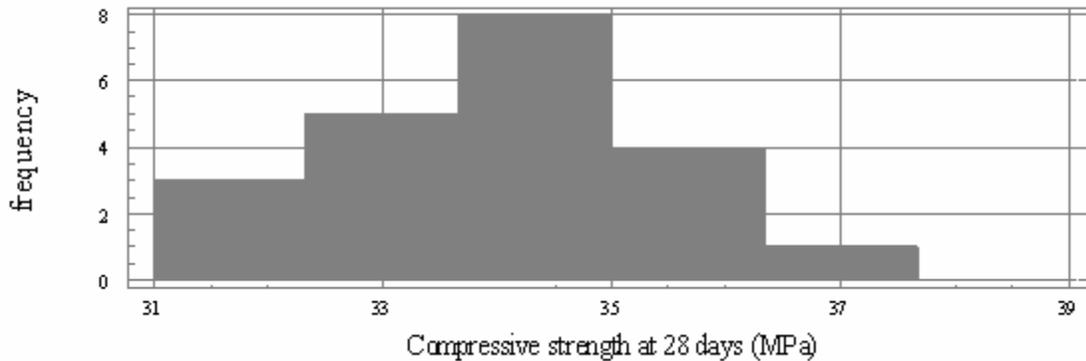according to the test results of slump and in accordance with the standards NF P 18-421, 422, 423.

Figure (5): Histogram of distribution of strengths at 28 days (Djebel Abiod).
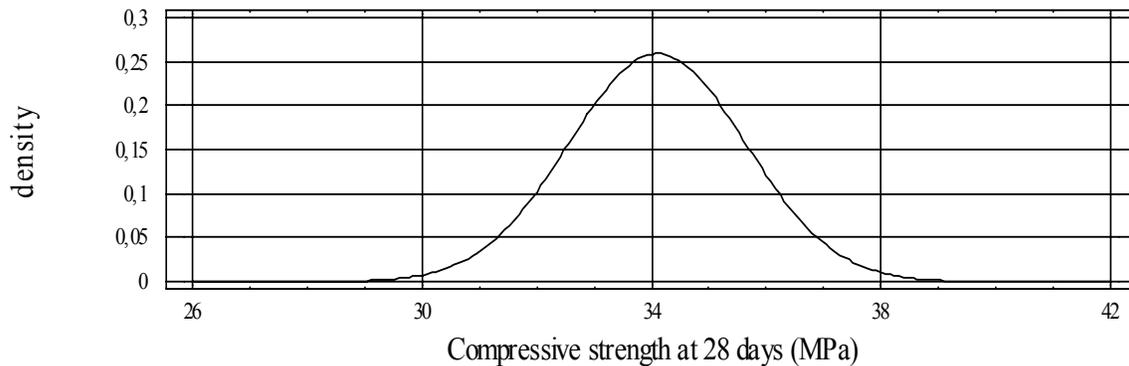

Figure (6): Distribution of strengths at 28 days according to the normal law (Djebel Abiod).

In this study, we choose to consider the ratio W/C constant and not the workability of the concrete.

The campaign of tests includes two parts: the first relates to the optimization of the granular skeleton of the concretes. The concretes are formulated initially by the method of Dreux-Gorisse (Dreux and Festa, 1995; Dreux and Gorisse, 1983; Gorisse, 1978), and then optimized by using the method of Baron-Lesage (Baron and Lesage, 1976, 1969; Lesage, 1974), leading to determining the optimum ratio gravels/sand (G/S). This latter gives, at constant paste, the highest slump. In the second part, the concretes are formulated on the basis of granular skeleton previously optimized, while varying the ratio W/C as well as the cement proportioning. Among the studied properties, we present only the results concerning the

compressive strengths at 28 days measured in the laboratory on standardized cylindrical specimens.

RESULTS AND DISCUSSION

The experimental program carried out has as an ambition; the study and the measurement of a significant number of properties. Within the framework of this article, we will stick to the most significant aspects which enable us to have a global vision on the concretes of the area.

Optimization of the proportions of the granular skeleton

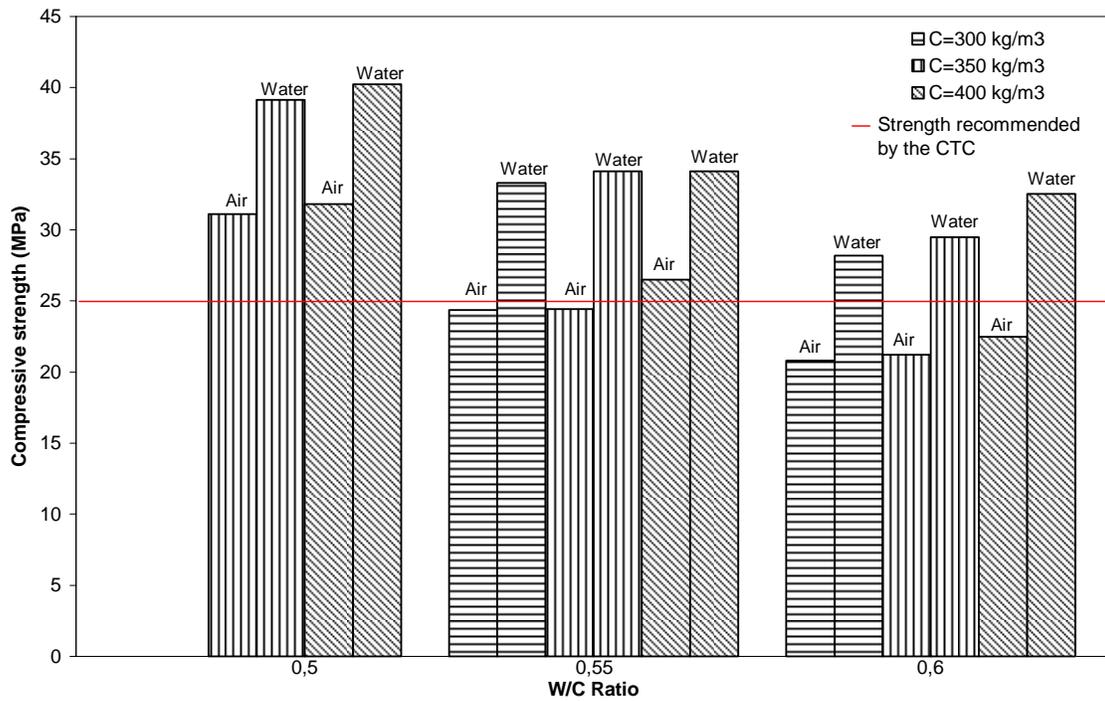The optimum ratio G/S for two concretes, whose compositions are specified in Table (6), is determined.

Figure (7): Concrete strengths at 28 days preserved in water and air for various water/cement ratios (Aggregates of Djebel Abiod).
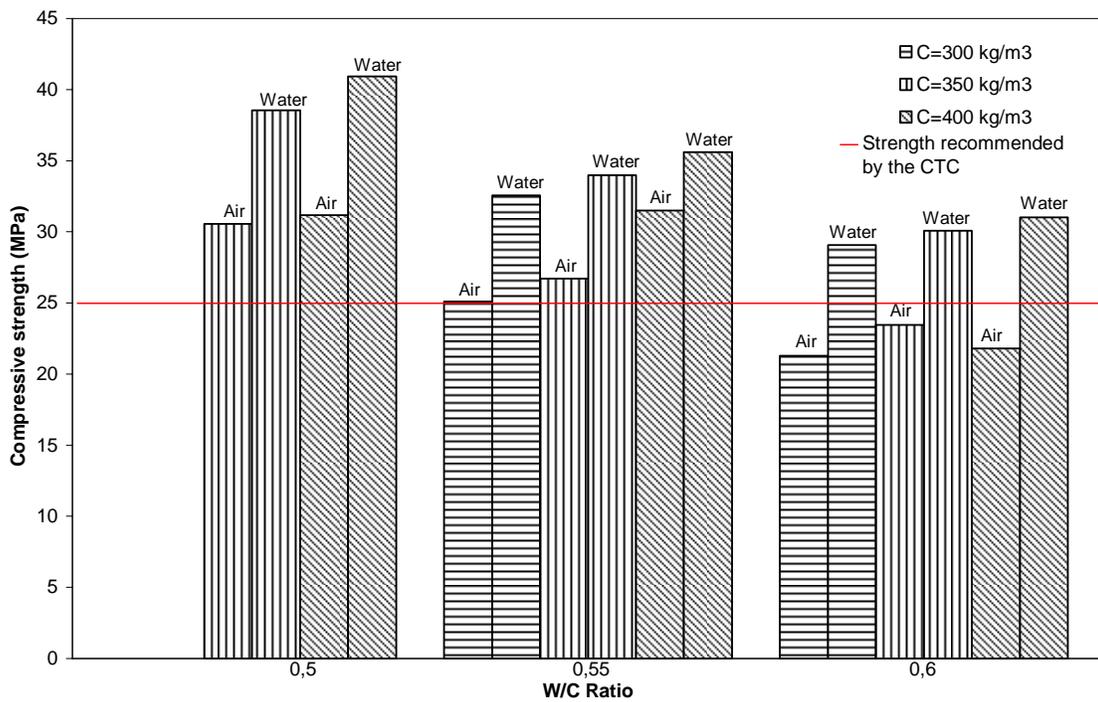

Figure (8): Concrete strengths at 28 days preserved in water and air for various water/cement ratios (Aggregates of Dhar El Mendjel).
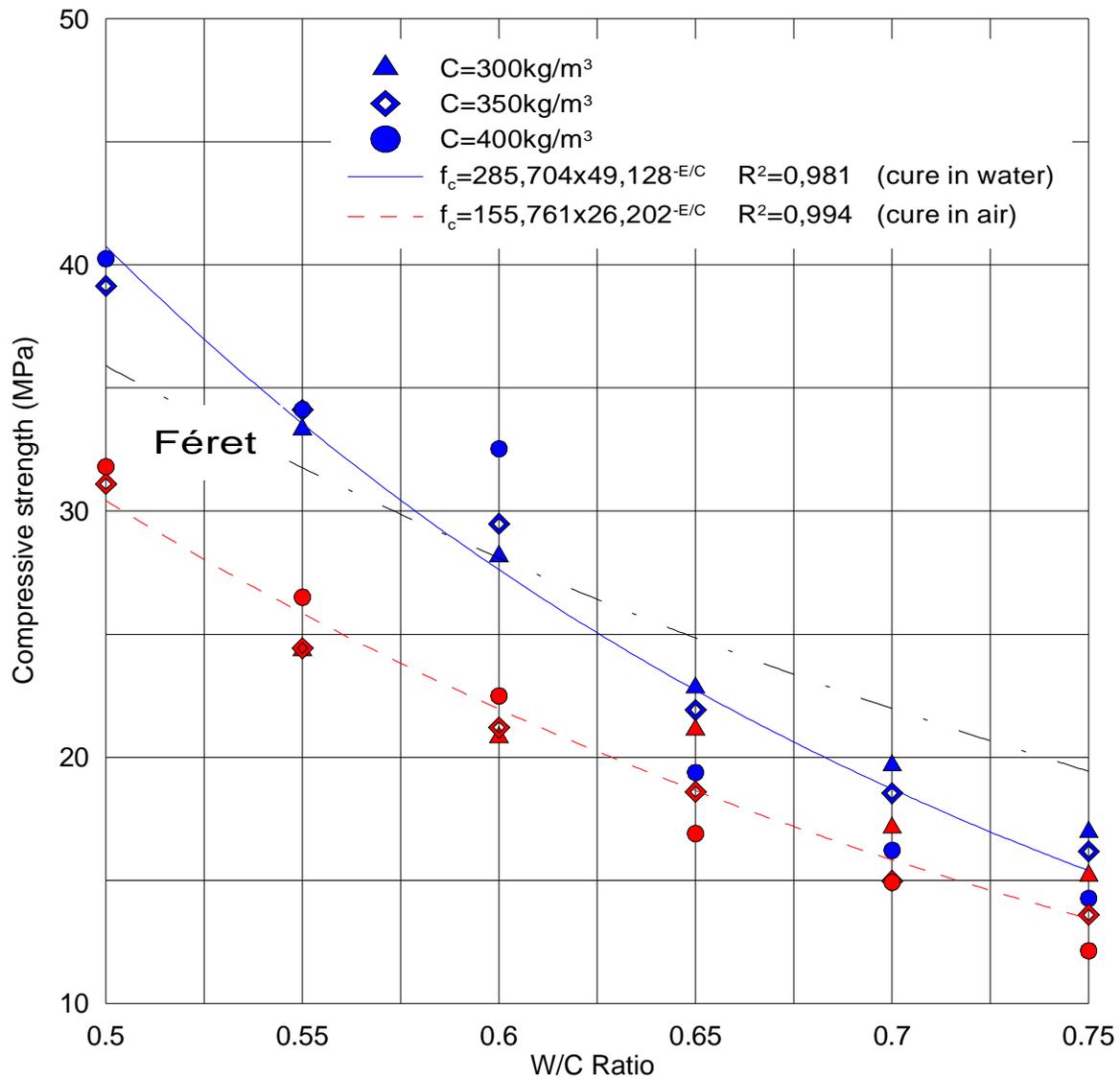
Figure (9): Relation between the compressive strength at 28 days and the water/cement ratio (Djebel Abiod).

According to the Baron-Lesage method, we manufactured several batches for each concrete, and the ratio G/S was modulated from 1.4 to 2.2. Figure (4) shows that the experimental optimum ratio (for which the slump is maximum) is 1.7 and 1.6 for concretes DA and DM, respectively.

Characteristical resistance, statistical size

From the results of strengths at 28 days, we noted that all the results obey the normal law and as an example, we present in Figures (5 and 6), the histogram of distribution of strengths, as well as the distribution of these strengths according to the normal law for W/C = 0.55, C=350 kg/m³, aggregates of Djebel Abiod and a cure in water.

The characteristical resistance f_{ck} of a population of values of resistance is the value of resistance such as the proportion of the results, giving a value which is lower to it, is equal to *p*. For a given normal population, the

proportion p is enough to define characteristical resistance as a statistical size (Barron and Ollivier, 1996). It is given by:

$$f_{ck} = f_c - k(p)\sigma \qquad (1)$$

where f_c is the average compressive strength of the concrete; σ is the standard deviation of the distribution; $k(p)$ is related to distribution of the reduced law:

$$\text{for } p = 5\% \qquad k = 1.64$$

Table (7) gives the 28 days characteristical resistances obtained with 5% of the risk for W/C=0.55, C=300 to 400 kg/m^3 and a cure in water.

Figure (5) shows the presence of a dispersion of the obtained strengths which is practically unavoidable but remains acceptable ($\sigma<5\%$). This is due mainly to the fact that a whole batch allowed the realization of only four specimens at the same time. Also, the preparation of the 40 specimens was not done completely under the same experimental conditions. The multiplication of the batches to have the totality of the studied cylindrical specimens did not allow, in our opinion, a repeatability of the bodies of tests.

Influence of the cure and the proportion of cement on the compressive strength of the concretes

According to Figures (7 and 8), we notice that strengths change between the two modes of cure; this is due to the conditions under which our specimens mature. Those immersed in water are more resistant because the hydration of cement in this case is complete, the drying at the youth of the concrete tends to decrease the compressive strength and to increase the cracking of the concretes (Khelidj et al., 1998).

For a given ratio W/C, the compressive strengths do not seem to be affected by cement proportioning (300 kg/m^3, 350 kg/m^3 and 400 kg/m^3), this remains valid for all examined ratios W/C. Under these conditions, a proportioning of 350 kg/m^3 remains sufficient and consequently economic.

The aggregates of the two quarries offer similar concretes in the evolution of their mechanical properties.

According to the standards on the application of the cure of the concrete and considering the class of cement used, it's the ratios W/C of 0.5, 0.55 and 0.6 which offer to the concretes the values of strengths higher than 25 MPa (value required by the Algerian National Organization of Structural Engineering Control (CTC)) for a cure in water. If the concrete dries out in the open, only ratios W/C of 0.5 and 0.55 respect this requirement.

It is thus very significant to use a cure either by protection of the concrete against drying or by vaporization of water at the early age of concrete when one uses low ratios W/C.
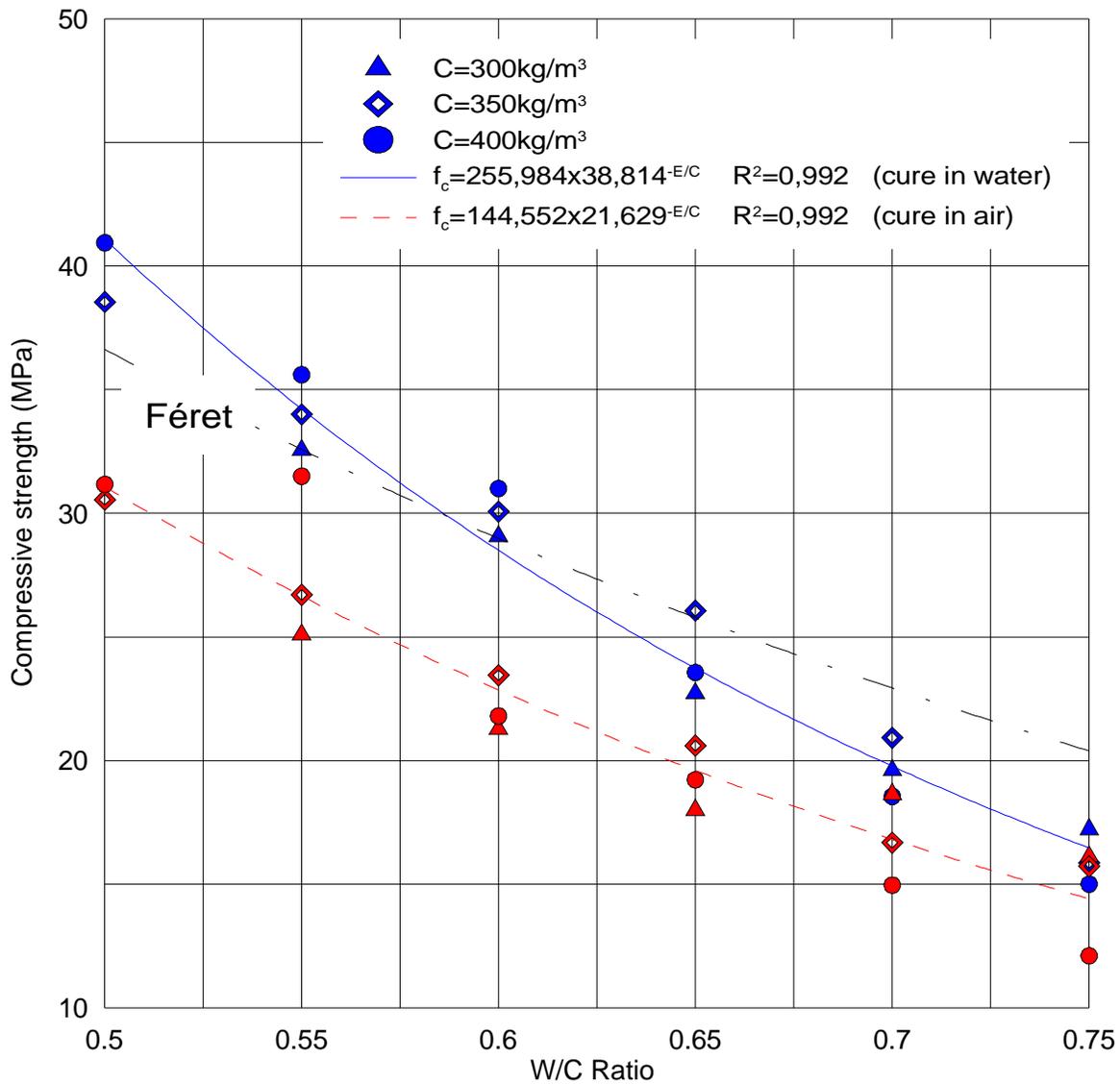
The relationship between strength at 28 days (cure in the air) and strength at 28 days (cure in water) is on average equal to 0.7.

Influence of ratio W/C on the compressive strength of the concretes

In practice, the ratio W/C is the most significant factor which conditions the compressive strength of a concrete (Neville, 1995). As one can see in Figures (9 and 10), cement proportioning for the selected class does not offer notable differences as regards to compressive strength. Under these conditions, a proportioning of 350 kg/m^3 remains sufficient and consequently economic. This justifies the use of a power model for the three proportionings tested. These Figures show also the existing practical relation between the strength and the ratio W/C, they are curves characteristical of concretes based on cement of the type CPJ CEM II/A 32.5. The experimental values are adjusted suitably according to a power law, in accordance with the general rule formulated by Rene Féret in 1896 like that established by Duff Abrams in 1919.

In its most complete form, the relation of Féret is written as follows:

$$f_c = k_f f_{mc} \left[\frac{v_c}{v_c + v_w + v_a} \right]^2 \qquad (2)$$

Figure (10): Relation between the compressive strength at 28 days and the water/cement ratio (Dhar El Mendjel).

where f_c is the resistance of the concrete to the considered expiry; f_{mc} the normal resistance of cement to the same expiry; v_c, v_w and v_a the respective volumes of cement, water and entrained air brought back to the volume of the concrete; k_f is a coefficient. This relation is presented in the form of a product of three terms:

- $\left[\dfrac{v_c}{v_c + v_w + v_a}\right]^2$, whose value depends on the

formulation of the concrete and, initially of the ratio W/C;

- f_{mc} whose value depends on cement;
- the coefficient k_f finally, whose value in the field of the current concretes, depends mainly on the aggregates (sand and gravels) used.

In our case f_{mc} = 48.7 MPa and k_f = 5.

We see that the relation of Féret depends directly on the ratio W/C, if the expected volume of air is neglected:
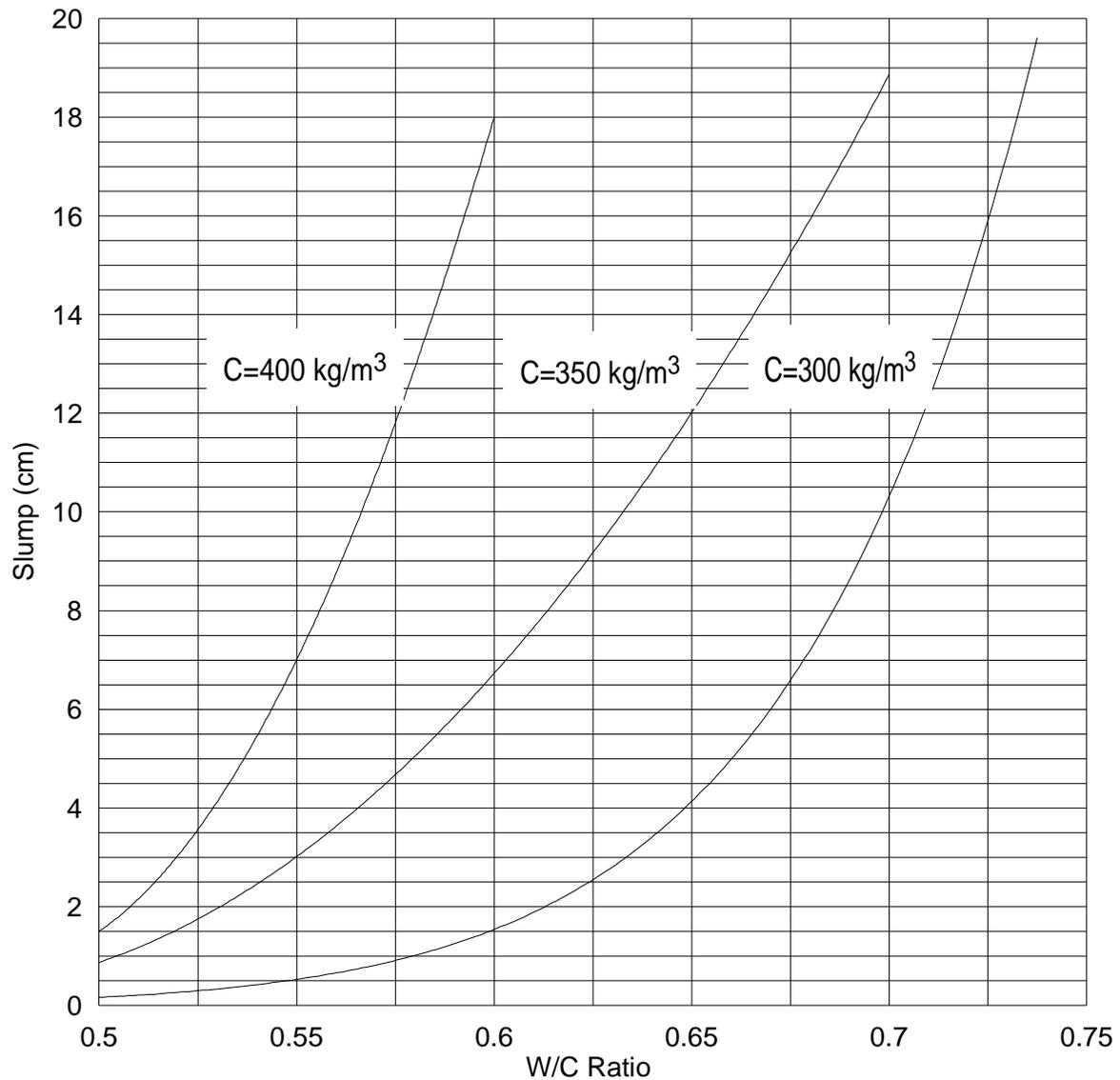
Figure (11): Abacus allowing to evaluate roughly the cement proportioning to be envisaged according to W/C ratio and of desired workability (slump in Abrams cone).

$$f_c = k_f f_{mc} \left[\frac{1}{1 + \rho_c \dfrac{W}{C}} \right]^2 = \frac{243.5}{\left(1 + 2.98 \dfrac{W}{C} \right)^2} \qquad (3)$$

where ρ_c, W and C are respectively the density of cement, the masses of water and cement, per unit of volume.

We can be satisfied to estimate the value of v_a while posing:

$$v_a = \alpha W \qquad (4)$$

The value of α depends on the consistency of the concrete as mentioned in (Baron and Ollivier, 1996), and in this case the relation of Féret becomes:

$$f_c = \frac{243.5}{\left(1 + 2.98(1+\alpha)\dfrac{W}{C}\right)^2} \qquad (5)$$

Within the framework of our study, the volumes of air were measured with an aerometer of concrete (standard NF P 18-353), and the equation used to represent the curve of Féret is as follows:

$$f_c = \frac{243.5}{\left(1 + 2.98\left(\dfrac{W+V_a}{C}\right)\right)^2} \qquad (6)$$

Figures (9 and 10) show that the values of the compressive strengths calculated by the relation of Féret are slightly different from those actually measured. This is due to the uncertainty of the aerometer of concrete which is about 0.5%. To that, another uncertainty is added, which is difficult to estimate. Indeed, the volume of air is that of the concrete in place in the aerometer and not that of the concrete in place in the test-tubes on which we measure resistance. However, the volume of air, sensitive to the conditions of mixing and installation, can differ from one case to another.

The results obtained show that the strength is high when the ratio W/C decreases.

Even though the rule of Féret was proposed a hundred and sixteen years ago, we have shown here, that it allows a very good forecast of the compressive strength of concretes prepared with various ratios W/C (Figs. 9 and 10). It however underestimates resistances for $f_c \geq$ 29 MPa and overestimates them for $f_c \leq$ 29 MPa. That makes it possible to be in safety for the average left of the concretes where $f_c \geq$ 25 MPa (value required by the Algerian National Organization (CTC)).

Abacus of formulation

The purpose of the method of Dreux Gorisse is to define, in a simple and rapid way, a formula of composition adapted to the studied concrete, but only a few batches of tests and making cylindrical specimens will allow to adjust the composition as well as possible to be adopted definitively according to desired qualities and materials actually used.

Knowing W/C is not enough to fix cement C proportioning arbitrarily and to deduce water W proportioning from it; because, while choosing, for example, a weak cement proportioning, one will find a weak water proportioning; one will then be likely to obtain a too much dry concrete (and *vice versa*). Cement proportioning is related thus to W/C but also to the necessary water proportioning for a satisfactory workability.

Considering the significant number of tests carried out, and while taking as a starting point the work of Dreux Gorisse (Dreux and Festa, 1995), we have elaborated an abacus being useful for the formulation of concretes (Fig.11) which allows determining cement C proportioning roughly according to W/C and of desired workability for various local materials. The curves of Figure (11) are close to those obtained by Dreux Gorisse (Dreux and Festa, 1995).

CONCLUSIONS

From the experiment tests done, which constituted a considerable experimental work (approximately 1500 cylindrical specimens 16x32 cm were made), one can draw up the following conclusions:

− The results of the tests show that the cement is in conformity with the requirements of its class. The densities are included in the interval imposed by the standard NA 231 and its consistency is in conformity with standard NF EN 196-3. In the same way, resistances against compression obtained at 2, 7 and 28 days are in conformity with the requirements of the standard EN 196-1, as indicated in Table (3).

− The present study shows that the aggregates of the two quarries chosen have presented good physical, physicochemical and mechanical properties, which meet in general the specifications required by the standard P 18-541. For our study, we used these

aggregates just as they are, we did not practise any treatment (washing) to formulate concretes recommended by the Algerian National Organization of Structural Engineering Control (CTC).

− Within the framework of the optimization of the proportions of the granular skeleton, the experimental optimum ratio G/S found (for which slump is maximum) is 1.7 and 1.6 for concretes DA and DM, respectively.

− The significant number of produced specimens (16x32 cm) showed the existence of dispersion in the results of crushing. These data will be the object of other works of a detailed statistical analysis to put forward the laws of distribution which govern them as well as the probability of the existing correlations between the properties of the concrete at the fresh and the hardened states.

− The specimens preserved in water presented higher strengths than those preserved in air following a better hydration of cement. The ratio between strengths at 28 days (cure in air) and conventional strengths at 28 days (cure in water) is on average equal to 0.7.

− According to the standards on the application of the cure of the concrete, and considering the class of cement used, it's the ratios W/C of 0.5, 0.55 and 0.6 which offer to the concretes the values of strengths higher than 25 MPa (value required by the Algerian National Organization of Structural Engineering Control (CTC)) for a cure in water. If the concrete dries out in the open, only ratios W/C of 0.5 and 0.55 respect this requirement. It is thus very significant to use a cure either by protection of the concrete against drying or by vaporization of water at the early age of concrete when one uses low ratios W/C.

− The concretes developed cover an extremely broad range of strengths from 12.1 MPa to 40.9 MPa intended for the reinforced concrete building structures or public works and this for a strength class of 32.5. These concretes have presented good rheological properties at the fresh state, and could be used under good conditions to manufacture various specimens.

− For a given ratio W/C, the compressive strengths do not seem to be affected by cement proportioning (300 kg/m^3, 350 kg/m^3 and 400 kg/m^3), this remains valid for all examined ratios W/C. Under these conditions, a proportioning of 350 kg/m^3 remains sufficient and consequently economic.

− The results obtained make it possible to observe that compressive strength at 28 days is high when the W/C ratio decreases.

− The experimental values of resistances are suitably adjusted according to a power law, in accordance with the general rule formulated by Rene Féret in 1896 like that established by Duff Abrams in 1919. We have shown here, that the relation of Féret allows a very good forecast of the compressive strength of concretes prepared with various ratios W/C. It underestimates however resistances for $f_c \geq 29$ MPa and overestimates them for $f_c \leq 29$ MPa. That makes it possible to be in safety for the average left for the concretes where $f_c \geq 25$ MPa (value required by the Algerian National Organization (CTC)).

− We have elaborated an abacus being useful for the formulation of concretes, allowing to evaluate approximately the cement C proportioning according to W/C and of desired workability, which extends from the firm state to the fluid state.

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