MODELLING OF FLUID CONCRETES BY EXPERIMENTAL DESIGNS

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ABSTRACT

The classical approach to concrete formulations often consists of varying the parameters of the mixture and measuring its effects on the behavior of the concrete in both fresh and hardened states.

This is a very time-consuming process and is the result of somewhat more limited information on concrete. For this purpose, an experimental model has been envisaged to give very precise information on fluid concretes. This model is based on experimental designs whose aim is to model them mathematically in order to evaluate the influence of its parameters and interactions.

The study ranges of the different parameters such as G/S ratio, W/C ratio and superplasticizer dosing have already been determined from our engineering thesis and DEA (Diploma of Advanced Studies) work. Formulations from an experiment matrix or HARDMAN matrix have been carried out in order to estimate the slump and the mechanical compressive strength of concrete.

Water dosage (E), cement dosage (C), superplasticizer dosages (Sika Viscocrete Tempo 12 and Rheobuild 561) and filler dosages (Filler Cipolin and Filler Dolomite), all per unit volume of the mixture in the fresh state are the factors considered.

Statistical tools are used in order to verify or make a decision on the formulations and on our assumptions of the mathematical models.

Keyword: *Fluid concretes, Experimental designs, Factor designs, Factors, Interactions, Modelling Mathematics*

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1. INTRODUCTION

Fluid concretes have been and still are the subject of numerous studies and research works. Even if the progress is considered considerable, adaptation and formulation studies are necessary in every region of the world.

The use of an experimental design for the formulation of fluid concretes is interesting in the sense that it will make it possible to strongly reduce the number of experiments to be carried out while increasing the number of parameters of the concretes studied, by detecting the interactions between its parameters and the optimal in relation to the expected results. The design of experiment is a quantity used as a criterion to evaluate the influence of constituents in concrete and allowing to easily modeling slump, compaction, porosities, shrinkage and compressive strengths of concrete.

The main objective of this work is to formulate fluid concretes using the experimental design method. In this case, we have tried to adopt formulas and mathematical models for compressive strengths, slump, compaction and shrinkage of concrete with raw materials that will specify these fluid concretes.

2. MATERIALS FOR CONCRETE [1][2].

After having determined the qualities of our materials in a laboratory, the following materials are recommended to continue the study on the formulation of fluid concretes:
- The cement Manda CEM II/A 42.5 of Holcim Madagascar;
- Two types of aggregates of class 5/15 (g2) and class 5/25 (G) coming from the quarry PK18 of the company SCB;
- Two types of sand: Sc quarry sand, also from the SCB company's PK18 quarry, and Sr2 river sand (Ikopa deposit);
- Two types of fillers: cipolin filler (FCP) and dolomite filler (FD);
- JIRAMA water;

- Two superplasticizers: SIKA Viscocrete Tempo 12 (Sp1) and Rheobuild 561(Sp2).

3. PERSPECTIVE DE L'ETUDES [2]

Based on the formulas of our Engineering and DEA dissertation studies, the conditions are thus

- Let's mix the two fillers (FCP + FD) considering the FCP/FD ratio...
- Let's also mix the two superplasticizers (Sp1 + Sp2) considering also the ratio Sp1 / Sp2;
- The cement dosage is adjusted at the same time 350 Kg/m3 or 400 Kg/m3 following the experimental designs;
- The water dosage changes as much as the cement dosage changes (E / C = 0.55);
- The sand and gravel dosage (no level) will all be equally maintained at 368 Kg/m3 (G/S = 1).

4. CONCRETE FORMULATIONS BY EXPERIMENTAL DESIGN [3]

4.1 Level parameters

The use of reduced or coded centered variables has the advantage of being able to generalize the design of experiments theory regardless of the factors or fields of study selected. Replacing the natural variables by coded variables will make it possible to have for each factor the same range of variation (between -1 and +1) and thus to be able to compare the effect of the factors between them. The low level is thus coded (- 1) while the high level is coded (+ 1). A new series of formulations was therefore carried out. These level parameters are presented as follows (Table 1).

Table - 1: Level parameters

Cement C [Kg]		Water E [L]		Sand [Kg]		Gravel [Kg]		Fillers F = F_{CP}/F_D		Superplastisizers Sp = Sp_1/Sp_2	
				Sr2	Sc	g2	G				
350	400	192,5	220	368	368	368	368	1	1,5	1	1,5
-1	+1	-1	+1	Pas de niveau				-1	+1	-1	+1

The water dosage varies according to the cement dosage: a dosage of 350 kg of cement corresponds to 192.5 L of water in a cubic meter of concrete (W/C = 0.55), and if the cement dosage is 400 kg, then the water is dosed at 220 L.

The superplasticizer dosage is 7 L, so if we combine the two superplasticizers, we have Sp=Sp1 + Sp2 = 7 L. If the ratio Sp1 / Sp2 = 1, it indicates that we use 3.5L of Sp1 and 3.5L of Sp2. And if Sp1 / Sp2 = 1.5; we make a mixture of 4.2L of Sp1 and 2.8L of Sp2.

The superplasticizer Sp1 has been widely used because the realization of fluid concretes from Sp1 has been satisfactory compared to Sp2 (Sp1 allows to have a good resistance in compression of the concretes).

The dosage of the fillers is still 193 kg, the mixture of filler cipolin and of filler dolomite is then F=FCP + FD = 193 Kg. The ratio Fcp / FD = 1 gives a dosage of Fcp = 96.5 kg and a dosage of FD = 96.5 kg. And if Fcp / FD = 1.5, we have Fcp = 115.8 kg and FD = 77.2 kg.

Similar to superplasticizers, the dosing of cipolin filler FCP is used considerably because its use in excess compared to dolomite filler allows to obtain a good result, as we have seen in our engineering and DEA thesis work.

4.1 Matrix of Effects [4]

With a four factor design (Cement, Water, Fillers, Superplasticizers) at two levels, we have a number of tests equal to 24 = 16, and since this number is acceptable for laboratory work a complete factor design is the most suitable for this study, as it is more accurate. With its 16 formulation tests, we have 16 new formulations of fluid concretes.

Complete factorial design 24 (four two-level factors)

The effects matrix is a 16 row and 4 column matrixes according to (Fig-1)

$$\begin{pmatrix}
-1 & -1 & -1 & -1 \\
+1 & -1 & -1 & -1 \\
-1 & +1 & -1 & -1 \\
+1 & +1 & -1 & -1 \\
-1 & -1 & +1 & -1 \\
+1 & -1 & +1 & -1 \\
-1 & +1 & +1 & -1 \\
+1 & +1 & +1 & -1 \\
-1 & -1 & -1 & +1 \\
+1 & -1 & -1 & +1 \\
-1 & +1 & -1 & +1 \\
+1 & +1 & -1 & +1 \\
-1 & -1 & +1 & +1 \\
+1 & -1 & +1 & +1 \\
-1 & +1 & +1 & +1 \\
+1 & +1 & +1 & +1
\end{pmatrix}$$

Fig-1: Matrix of effects

4.2 Matrix of effects with interaction [4]

For the four-factor factorial design (C, E, F, Sp), the interactions are as follows: C*E, C*F, C*Sp, E*F, E*Sp, F*Sp, C*E*F, C*E*Sp,E*F*Sp.

We have 9 interactions, 4 factors and 16 formulation trials; hence the matrix is a 16 row, 13 column matrixes (9 interactions + 4 factors). The effects matrix with interactions is shown in Figure 2 below:

$$\begin{pmatrix}
-1 & -1 & -1 & -1 & +1 & +1 & +1 & +1 & +1 & +1 & -1 & -1 & -1 \\
+1 & -1 & -1 & -1 & -1 & -1 & -1 & +1 & +1 & +1 & +1 & +1 & -1 \\
-1 & +1 & -1 & -1 & -1 & +1 & +1 & -1 & -1 & +1 & +1 & +1 & +1 \\
+1 & +1 & -1 & -1 & +1 & -1 & -1 & -1 & -1 & +1 & -1 & -1 & +1 \\
-1 & -1 & +1 & -1 & +1 & -1 & +1 & -1 & +1 & -1 & +1 & -1 & +1 \\
+1 & -1 & +1 & -1 & -1 & +1 & -1 & -1 & +1 & -1 & -1 & +1 & +1 \\
-1 & +1 & +1 & -1 & -1 & -1 & +1 & +1 & -1 & -1 & -1 & +1 & -1 \\
+1 & +1 & +1 & -1 & +1 & +1 & -1 & +1 & -1 & -1 & +1 & -1 & -1 \\
-1 & -1 & -1 & +1 & +1 & +1 & -1 & +1 & -1 & -1 & -1 & +1 & +1 \\
+1 & -1 & -1 & +1 & -1 & -1 & +1 & +1 & -1 & -1 & +1 & -1 & +1 \\
-1 & +1 & -1 & +1 & -1 & +1 & -1 & -1 & +1 & -1 & +1 & -1 & -1 \\
+1 & +1 & -1 & +1 & +1 & -1 & +1 & -1 & +1 & -1 & -1 & +1 & -1 \\
-1 & -1 & +1 & +1 & +1 & -1 & -1 & -1 & -1 & +1 & +1 & +1 & -1 \\
+1 & -1 & +1 & +1 & -1 & +1 & +1 & -1 & -1 & +1 & -1 & -1 & -1 \\
-1 & +1 & +1 & +1 & -1 & -1 & -1 & +1 & +1 & +1 & -1 & -1 & +1 \\
+1 & +1 & +1 & +1 & +1 & +1 & +1 & +1 & +1 & +1 & +1 & +1 & +1
\end{pmatrix}$$

Fig-2: Effects matrix with its interactions

4.3 Formulations of fluid concretes by experimental designs

From this effects matrix, we have the following 16 formulas for fluid concretes (Table 2)

Table -2: From this effects matrix, we have the following 16 formulas for fluid concretes (Table 2)

FLUID CONCRETE N°	C [Kg]	E[L]	g2[Kg]	G [Kg]	Sr2[Kg]	Sc[Kg]	F		Sp	
							Fcp[Kg]	Fd[Kg]	Sp1[L]	Sp2[L]
1	350	192 ,5	368	368	368	368	96,5	96,5	3,5	3,5
2	400	192 ,5	368	368	368	368	96,5	96,5	3,5	3,5
3	350	220	368	368	368	368	96,5	96,5	3,5	3,5
4	400	220	368	368	368	368	96,5	96,5	3,5	3,5
5	350	192 ,5	368	368	368	368	115,8	77,2	3,5	3,5
6	400	192 ,5	368	368	368	368	115,8	77,2	3,5	3,5
7	350	220	368	368	368	368	115,8	77,2	3,5	3,5
8	400	220	368	368	368	368	115,8	77,2	3,5	3,5
9	350	192 ,5	368	368	368	368	96,5	96,5	4,2	2,8
10	400	192 ,5	368	368	368	368	96,5	96,5	4,2	2,8
11	350	220	368	368	368	368	96,5	96,5	4,2	2,8
12	400	220	368	368	368	368	96,5	96,5	4,2	2,8
13	350	192 ,5	368	368	368	368	115,8	77,2	4,2	2,8
14	400	192 ,5	368	368	368	368	115,8	77,2	4,2	2,8
15	350	220	368	368	368	368	115,8	77,2	4,2	2,8
16	400	220	368	368	368	368	115,8	77,2	4,2	2,8

4.1 Concrete formula results

The slump, shrinkage, compaction and compressive strengths of concrete at 7 days and 28 days are shown in Table 3 below.

Table – 3: Characteristics of fluid concretes formulated from experimental designs

FLUID CONCRETE N°	ST [Cm]	R [%]	C [%]	Rc07 [MPa]	Rc28 [MPa]
1	22	0,13	91,4	17,14	27,15
2	16	0,12	95,12	23,16	29,12
3	22,5	0,11	95,12	14,29	26,11
4	21,5	0,12	96,13	17,71	28,28
5	22	0,06	96,83	16,12	29,72
6	15,5	0,08	97,73	24,89	42,18
7	21	0,13	98,13	15,23	27,24
8	19	0,12	97,56	16,25	30,73
9	19,5	0,16	94,19	18,66	26,08
10	17	0,11	96,85	21,83	28,34
11	18	0,12	92,52	18,82	27,14
12	18	0,13	95,29	21,71	27,89
13	18	0,09	96,12	16,85	30,73
14	15	0,08	96,25	26,13	40,88
15	17,5	0,09	95,24	23,21	36,11
16	17	0,08	95,67	24,08	39,87

The 28-day compressive strengths of the concretes are all high, above 25 MPa. The concretes can thus be used in the construction of a multi-story building with its good workability of ST over 16 cm. These fluid concretes have a good tightness with its very high compaction. They also have a low shrinkage.

5. CONCRETE MODELLING BY EXPERIMENTAL DESIGNS [4]

In order to allow the prediction of the response and the optimization of the system, the design of experiments method, due to its design and structure, allows a mathematical representation of the response "y" according to the subject factors of the study. We will limit ourselves to linear polynomial models using multiple linear regressions which are based mainly on the method of least squares. Two conditions must be met [Baron and Olivier, 1996]:

- The minimum number of tests performed must be equal to the number of unknowns Ai, and increases with the degree of the polynomial. So it is in our interest to look for the simplest models first.
- The model constituted must be validated in order to make reliable predictions.
- The so-called factorial designs of experiments all use the following mathematical model which links the answer Y to the factors X1, X2, Xi ...Xn. This theoretical model is postulated a priori. It is a polynomial model.
- The models sought are models expressing the answer "Y_j" as a function of the factors "Xi" and their interactions:

$$Y = A_0 + A_1X_1 + A_2X_2 + ... + A_nX_n + \sum_{i,j=1;i\neq j}^{n} A_{ij}X_iX_j + \sum_{i,j,k=1;i\neq j\neq k}^{n} A_{ijk}X_iX_jX_k + ...$$

$$\begin{bmatrix} y_1 \\ y_2 \\ \\ \cdots \\ y_j \\ y_l \end{bmatrix} = \begin{bmatrix} & & & & \\ & & & & \\ & & & & \\ & & & & \\ & & & & \\ \cdots X_i & \cdots X_iX_j & \cdots & X_iX_jX_l \end{bmatrix} . \begin{bmatrix} A_1 \\ A_2 \\ \\ \cdots \\ A_{ij} \\ A_{ijl} \end{bmatrix}$$

In a nutshell: [y] = [x]. [A]

Where A0, A1, An: are the coefficients of the polynomial.

Xi: represents a level of the factor i

Xj: represents a level of the factor j

Y: rethinking or greatness of interest

Product terms such as Aij.Xi.Xj correspond to order 2 interactions.

Product terms of type e.g. Aijk.Xi.Xj.Xk correspond to order 3 interactions.

5.1 Mathematical models of the compressive strengths of fluid concretes

The linear model of the 7-day Rc07 and 28-day Rc28 compression strength is written as follows:

$$Rc_j[MPa] = A_0 + A_1*C + A_2*E + A_3*F + A_4*Sp + A_{12}*CE + A_{13}*CF + A_{14}*CSp + A_{23}*EF + A_{24}*ESp + A_{34}*FSp + A_{123}*CEF + A_{124}*CESp + A_{234}*EFSp \quad (1)$$

5.1.1 Mathematical models of 7-day compressive strength Rc07

From the effects matrix and its interactions, we have the values of the coefficients of Ai, Aij and Aijk of Rc07 of the coded values -1 and +1

Table -4: Values of the coefficients Ai, Aij, and Aijk of Rc07 of the coded values -1 and +1

POLYNOMIAL COEFFICIENTS	A0	A1	A2	A3	A4	A12	A13	A14	A23	A24	A34	A123	A124	A234
	19,755	2,215	-0,843	0,590	1,656	-1,190	0,278	-0,189	0,190	1,386	0,566	-0,830	0,104	0,344

The Relationship (1) then becomes

$$Rc_{07}[MPa]=19{,}755+2{,}215*C-0{,}843*E+0{,}590*\frac{F_{CP}}{F_D}+1{,}656*\frac{Sp_1}{Sp_2}-1{,}190*C*E+0{,}278*C*\frac{F_{CP}}{F_D}-0{,}189*C*\frac{Sp_1}{Sp_2}$$
$$+0{,}190*E*\frac{F_{CP}}{F_D}+1{,}386*E*\frac{Sp_1}{Sp_2}+0{,}566*F*\frac{Sp_1}{Sp_2}-0{,}830*C*E*\frac{F_{CP}}{F_D}+0{,}104*C*E*\frac{Sp_1}{Sp_2}+0{,}344*E*\frac{F_{CP}}{F_D}*\frac{Sp_1}{Sp_2}$$

A correlation to this model was made with the aim of reducing interactions using STUDENT's significance test. The variables Cement C, Superplasticizers Sp =Sp1/Sp2 and the interaction Esp = E*(Sp1/Sp2) are significant for Rc07. A new model of the form :

$$Rc_{07}[MPa]=19{,}755+2{,}215*C+1{,}656*\frac{Sp_1}{Sp_2}+1{,}386*E*\frac{Sp_1}{Sp_2}$$

The Fischer-Snédecor test gives for v1 = 3 and v2 = 12, F (crit) = 3.49, for a risk of 5%. We have: (Fobs = 7.975) > (Fcrit = 3.49) so we accept the hypothesis HRc07 of the new linearity of the model of the compressive strength of fluid concretes at 7 days. This is well in agreement with the fact that all coefficients A1, A4 and A24 are significant. The PARETO diagram of fluid concrete N° 16 or the ABC Analysis, shown in figure 3, allows us to say that cement and superplasticizers have a major influence on the compressive strength of concrete at 7 days: we observe that 74% of the increase in compressive strength of fluid concrete at 7 days comes from the use of cement and superplasticizers. It is obvious that the use of superplasticizers allows reducing the water dosage. The water dosage has no influence on the compressive strength of the concrete because the latter is already calculated according to the dosage of cement used (W/C = 0.58).

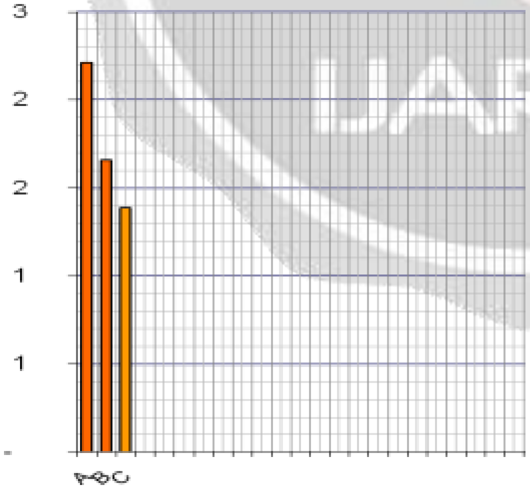

Fig -3: PARETO diagram of fluid concrete N° 21 of model Rc07 for a risk of 5%

A = Cement; B = Superplasttisizers ; C = Water + Superplastifiants

5.1.2 Mathematical models of 28-day compressive strength Rc28

The Values of the coefficients Ai, Aj and Aijk of the Rc28 of the coded values -1 and +1 are:

Table – 5: Values of the coefficients Ai, Aj and Aijk of the Rc28 of the coded values -1 and +1

POLYNOMIAL COEFFICIENTS	A0	A1	A2	A3	A4	A12	A13	A14	A23	A24	A34	A123	A124	A234
	31,098	2,313	-0,677	3,584	1,032	-1,042	1,419	-0,198	-0,518	1,299	1,183	-0,878	0,054	0,988

For a 5% risk, the variables Water E, and the interactions CSp, EF and CESp are not significant for Rc28. The mathematical model of the compressive strength of fluid concretes of the coded values -1 and +1 is then expressed by:

$$Rc_{28}[MPa] = 31{,}098 + 2{,}313 * C + 3{,}584 * \frac{F_C}{F_d} + 1{,}032 * \frac{Sp_1}{Sp_2} - 1{,}042 * CE + 1{,}419 * C * \frac{F_C}{F_d} + 1{,}299 * E * \frac{Sp_1}{Sp_2}$$
$$+ 1{,}183 * \frac{F_C}{F_d} * \frac{Sp_1}{Sp_2} - 0{,}878 * C * E * \frac{F_C}{F_d} + 0{,}988 * E * \frac{F_C}{F_d} * \frac{Sp_1}{Sp_2}$$

The Fischer Snédecor Test also allows us to say that this model of Rc28 is validated, after having carried out various statistical tests.

We interpret from the PARETO diagram of fluid concrete N°21 (Fig -4) that Cement C and Fillers F play a very important role in the compressive strength of concrete at 28 days: Cement C and Filler F have a high histogram and 74% of the increase in the 28-day strength of fluid concretes comes from the use of cement, Fillers and CF interaction.

The various elements coupled by the two parameters (EF, ESp, FSp) have very little influence on the 28-day compressive strengths of concrete.

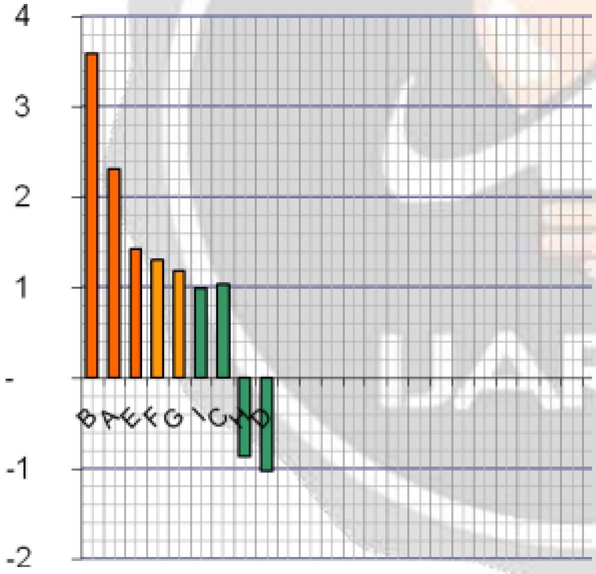

Fig -4: PARETO diagram of fluid concrete N° 21 of model Rc28 for a risk of 5%

A = Cement ; B = Fillers ; C = Superplastisizers ; D = Cement + Water ; E = Cement + Fillers ; F = Water + Superplastisizers ;

G = Fillers + Superplastisizers ; H = Cement + Water + Fillers ; I = Water + Fillers + Superplastisizers

5.1 Mathematical models of Slump Test of fluid concretes

The linear model of ST slumps of fluid concretes is written as follows:

$$ST[cm] = A_0 + A_1 * C + A_2 * E + A_3 * F + A_4 * Sp + A_{12} * CE + A_{13} * CF + A_{14} * CSp + A_{23} * EF + A_{24} * ESp + A_{34} * FSp + A_{123} * CEF + A_{124} * CESp + A_{234} * EFSp.$$

The calculations of the coefficients Ai, Aij and Aijk of the coded values -1 and +1 of the slump of fluid concretes are made by the Excel software and we have the results shown in the following table 5:

Table - 5: Values of the coefficients Ai, Aj and Aijk of the Aff of the ST of the coded values -1 and +1

POLYNOMIAL COEFFICIENTS	A0	A1	A2	A3	A4	A12	A13	A14	A23	A24	A34	A123	A124	A234
	18,719	-1,344	0,594	-0,594	-1,219	0,906	-0,156	0,594	-0,094	-0,469	-0,031	-0,031	-0,281	0,344

The Interactions CF, EF, FSp, CEF, CESp, EFSp are not significant for ST. It should therefore keep a model of the form:

$$ST[cm] = 18{,}719 - 1{,}344 * C + 0{,}594 * E - 0{,}594 * F - 1{,}219 * Sp + 0{,}906 * CE + 0{,}594 * CSp - 0{,}469 * ESp$$

The Fischer-Snédecor table gives for v1 = 7 and v2 = 8, F (crit) = 3.50, for a risk of 5%. We have : (Fobs = 22.680) > (Fcrit = 3.50) so we accept the HST hypothesis of the new linearity of the model of slump of fluid concretes.

According to the PARETO diagram (Figure 5), Cement C and superplasticizers Sp and the coupled derivative of cement and water CE act on the slumps of fluid concretes. It is quite normal that the use of superplasticizers gives fluid concretes.

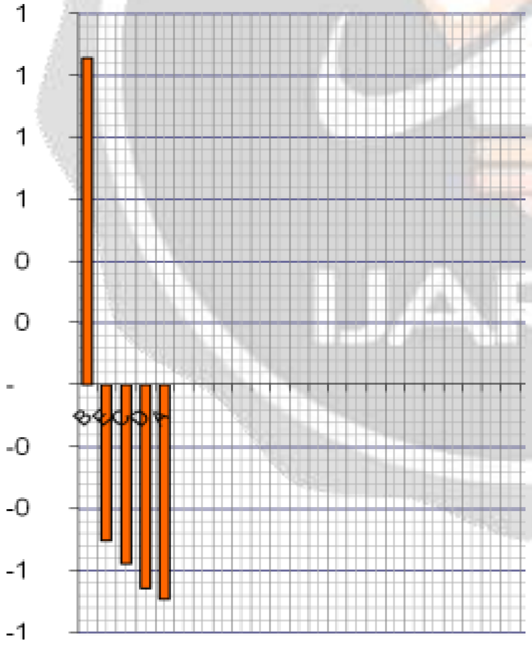

Fig -5: PARETO diagram of fluid concrete N° 21 of model ST for a risk of 5%

A = Cement; B = Water; C = Filler; D = Superplasticizers ; E = Cement + Water ; F = Cement + Superplasticizers ; G = Water+ Superplasticizers.

5.2 Mathematical models of fluid concrete shrinkages

The linear slump model R of fluid concretes is written as follows

$$R[\%] = A_0 + A_1 * C + A_2 * E + A_3 * F + A_4 * Sp + A_{12} * CE + A_{13} * CF + A_{14} * CSp + A_{23} * EF + A_{24} * ESp + A_{34} * FSp + A_{123} * CEF + A_{124} * CESp + A_{234} * EFSp$$

The coefficientsAi, Aij and Aijk of the coded values -1 and +1 of the shrinkage of fluid concretes are given in Table 6.

Table - 6: Values of the coefficients Ai, Aj ,Aijk of the R [%] of the fluid concretes of the coded values -1 and +1

POLYNOMIAL COEFFICIENTS	A0	A1	A2	A3	A4	A12	A13	A14	A23	A24	A34	A123	A124	A234
	0,108	-0,003	0,004	-0,017	-0,001	0,003	0,002	-0,004	0,009	-0,007	-0,006	-0,007	0,004	-0,007

The Interactions CF, EF, FSp, CEF, CESp, EFSp are not significant for R [%]. Therefore, we have

$$R[\%] = 0{,}108 - 0{,}017F + 0{,}009EF - 0{,}007ESp - 0{,}007CEF - 0{,}007EFSp$$

The Fischer-Snédecor table gives for v1 = 5 and v2 = 10, F(crit) = 3.33, for a risk of 5%. We have: (Fobs = 9.145) > (Fcrit = 3.33) so we accept the hypothesis HR of the new linearity of the model of shrinkage of fluid concretes.

The PARETO diagram (Fig - 6) shows that only Fillers F and interactions with water EF act on the shrinkage of fluid concretes.

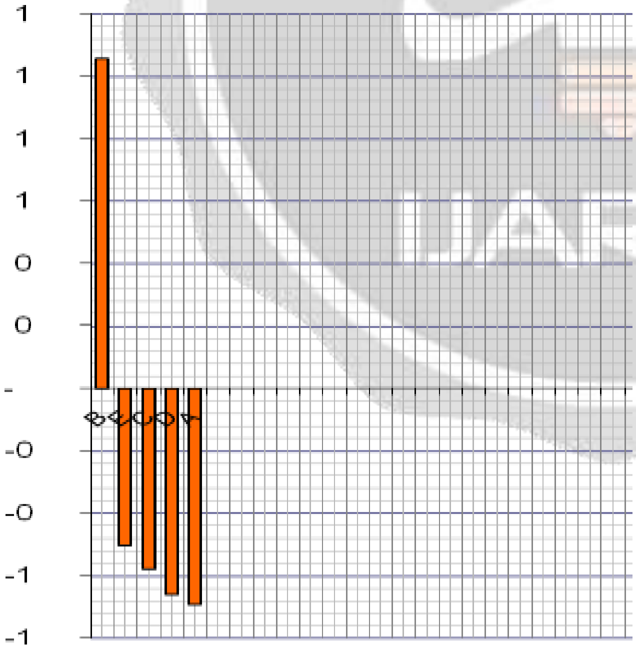

Fig - 6: PARETO diagram of fluid concrete N° 21 of model shrinkage for a risk of 5%

A = Fillers; B = Water + Fillers; C = Water + Superplasticizers; D = Cement + Water+ Fillers; E = Water+ Fillers + Superplasticizers.

5.1 Mathematical models of the compactness of fluid concretes

The linear model of the compacteness C of fluid concretes is written as follows

$$C[\%] = A_0 + A_1 * C + A_2 * E + A_3 * F + A_4 * Sp + A_{12} * CE + A_{13} * CF + A_{14} * CSp + A_{23} * EF + A_{24} * ESp + A_{34} * FSp + A_{123} * CEF + A_{124} * CESp + A_{234} * EFSp$$

Calculations of the coefficients Ai, Aij and Aijk of the coded values -1 and +1 of the compactness of fluid concretes are presented as follows

Table - 7: Values of the coefficients Ai, Aj, Aijk of the C [%] of the fluid concretes of the coded values -1 and +1

POLYNOMIAL COEFFICIENTS	A0	A1	A2	A3	A4	A12	A13	A14	A23	A24	A34	A123	A124	A234
	95,634	0,691	0,073	1,057	-0,368	-0,236	-0,579	0,058	-0,114	-0,659	-0,503	0,089	0,287	0,336

The interactions CF, EF, FSp, CEF, CESp, EFSp are significant for the C compactness of BFLs. It would therefore be necessary to keep a model of the form:

$$C[\%] = 95{,}634 - 0{,}691C + 1.057F - 0{,}579CF - 0{,}659ESp - 0{,}503FSp$$

The Fischer-Snédecor table gives for v1 = 5 and v2 = 10, F(crit) = 3.33, for a risk of 5%. We have: (Fobs = 18,294) > (Fcrit = 3.33) so we accept the HC hypothesis of the new linearity of the model of the compactness of fluid concretes.

According to this PARETO diagram (Fig - 7), Cement C and the coupled derivative of water and ESp superplasticizers act on the compacteness of fluid concretes.

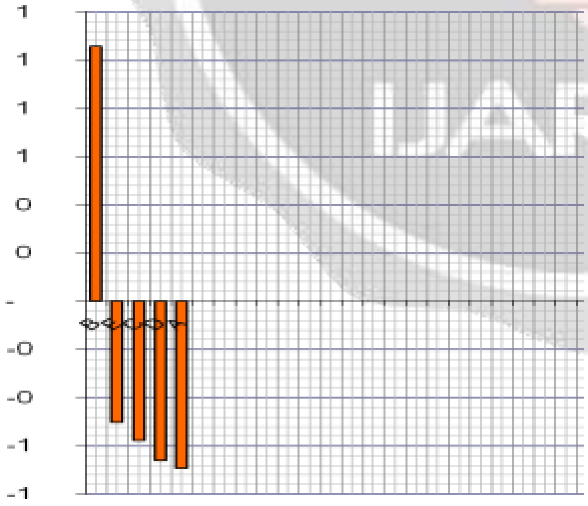

Figure 1 : Diagram of PARETO of fluid concrete N°21 of the model of compactness of the coded values -1 and +1 (Risk of 5%)

A = Cement ; B = Fillers ; C = Cement + Fillers; D = Water + Superplasticizers ; E = Fillers + Superplasticizers.

5. CONCLUSION

Experimental designs offer a simple and effective way to reduce the cost and increase the robustness of experimental studies carried out when designing or varying a product.

They provide a rigorous modeling framework, and their implementation requires only basic mathematical knowledge.

The ABC analysis allows us to say that cement, superplasticizers and fillers have a major influence on the compressive strength of concrete at 7 days and 28 days ;

Cement C, superplasticizers Sp = Sp1+Sp2 and the coupled derivative of cement and water CE act on the slump of fluid concretes. It is quite normal that the use of superplasticizers gives fluidity to the concretes.

Only the Fillers F and the water-coupled derivative EF have an influence on the shrinkage of fluid concretes; whereas the Cement C and the water-coupled derivative ESp act on their compactivities.

The use of experimental designs with coded values allowed us to obtain five models,

- A 7-day compressive strength model

$$Rc_{07}[MPa] = 19{,}755 + 2{,}215C + 1{,}656 \cdot \frac{Sp_1}{Sp_2} + 1{,}386E \cdot \frac{Sp_1}{Sp_2}$$

- A 28-day compression strength model

$$Rc_{28}[MPa] = 31{,}098 + 2{,}313 \cdot C + 3{,}584\frac{F_C}{F_d} + 1{,}032\frac{Sp_1}{Sp_2} - 1{,}042CE + 1{,}419C \cdot \frac{F_C}{F_d} + 1{,}299E \cdot \frac{Sp_1}{Sp_2}$$

$$+1{,}183 \cdot \frac{F_C}{F_d} \cdot \frac{Sp_1}{Sp_2} - 0{,}87 * CE \cdot \frac{F_C}{F_d} + 0{,}988E \cdot \frac{F_C}{F_d} \cdot \frac{Sp_1}{Sp_2}$$

- A Slump model

$$ST[cm] = 18{,}719 - 1{,}344C + 0{,}594E - 0{,}594\frac{F_{CP}}{F_D} - 1{,}219\frac{Sp_1}{Sp_2} + 0{,}906 * CE + 0{,}594 * C\,\frac{Sp_1}{Sp_2} - 0{,}469 * E\,\frac{Sp_1}{Sp_2}$$

- A shrinkage model

$$R[\%] = 0{,}108 - 0{,}017 \cdot \frac{F_{CP}}{F_D} + 0{,}009E \cdot \frac{F_{CP}}{F_D} - 0{,}007E \cdot \frac{Sp_1}{Sp_2} - 0{,}007CEF - 0{,}007E \cdot \frac{F_{CP}}{F_D} \cdot \frac{Sp_1}{Sp_2}$$

- And a model of compactness

$$C[\%] = 95{,}634 - 0{,}691C + 1.057F - 0{,}579CF - 0{,}659ESp - 0{,}503FSp$$

The models developed can be used to select the most economical mixes, while avoiding the need to carry out a large number of tests for an optimal mix that meets the specifications.

These models can be developed and improved by taking into consideration other parameters such as the influence of temperature and others.

6. REFERENCES

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