

# A Methodological Test to Study the Concrete Workability with the Fractal Model

F. Achouri, K. Chouicha

**Abstract**—The main parameters affecting the workability are the water content, particle size, and the total surface of the grains, as long as the mixing water begins by wetting the surface of the grains and then fills the voids between the grains to form entrapped water, the quantity of water remaining is called free water.

The aim of this study is to undertake a fractal approach through the relationship between the concrete formulation parameters and workability. To develop this approach a series of concrete taken from the literature was investigated by varying formulation parameters such as G/S, the quantity of cement C and the quantity of water W.

We also call another model as the model of water layer thickness and model of paste layer thickness to judge their relevance, hence the following results: the relevance of the water layer thickness model is considered as a relevant when there is a variation in the water quantity. The model of the paste layer thickness is only applicable if we considered that the paste is made with the grain value  $D_{max} = 2.85$ : value from which we see a stability of the model.

**Keywords**—Concrete, fractal method, paste layer thickness, water layer thickness, workability.

## I. INTRODUCTION

IF the water content and the concrete proportions constituents were determined, the workability depends on the size range, particle size, shape and texture [1]; Based on these concepts we study the influence of parameters mentioned above on the workability. However, we have used models such as:

- Model of the water layer thickness [2]: This model is based on the hypothesis that the concrete workability is determined by the water layer thickness surrounding the grains of all granular mixture.
- Model of the paste layer thickness [2]: The hypothesis is that the concrete workability depends on the paste layer thickness (consisting of water and fine aggregate) which surrounds the coarse aggregate that remain.

Precisely, the fractal model allows determining in advance the thicknesses of water and paste layers.

## II. ADOPTION OF FRACTAL MODEL FOR THE CALCULATION OF WATER AND PASTE LAYERS THICKNESSES

To be able to use fractal model, it is required to prove that the studied granular mixture followed a fractal distribution by tracing fractals lines and deduction of fractal dimensions FD. From this moment, we can appeal to the models of water and

Fatima Achouri is with the Department of Civil Engineering, University of USTOMB, Oran 31000, Algeria (e-mail: achourifati@yahoo.fr).

Kaddour Chouicha is Phd with the Department of Civil Engineering, University of USTOMB, Oran 31000, Algeria.

paste layers thickness to develop an approach for workability studying.

### A. Hypothesis of Water Layer Thickness

Mixing water starts by wetting the surface of the grains, then fill the voids between the grains to form the trapped water. In this model, the quantity of water that remains called free water will give the workability of the concrete. Hence, the utility of adopting the fractal model to calculate the porosity and the determination of different volumes.

For determining the water layer thickness is essential to know the quantity of free water in the whole granular mixture, defined as the excess water after filling all the pores where the need to calculate the porosity (Por) of the granular mixture. Here, the fractal model can occur for calculating the porosity by an empirical formula shown by [3]:

$$Por(d/D) = por(d) - A_1 \cdot e^{-\frac{(X-X_{opt})^2}{2W^2}} \quad (1)$$

with: Por (d): porosity of the mixture of grains d, X represents FD.log (d / D), FD is the fractal dimension of the mixture.  $X_{opt}$ : represents the value of this parameter to the optimum (FDopt.log (d / D)), W: calculate from w.log (d / D). With w: coefficient given according to (d / D), A1: klemmung.

It will be possible to determine the total volume  $V_T$  and the void volume  $V_V$  by (4) and (5) in which the solid volume  $V_S$  is known from the dosage and the porosity Por being calculated using fractal model.

$$P = \frac{V_V}{V_T} \quad (2)$$

$$V_V = V_T - V_S \rightarrow P = \frac{V_T - V_S}{V_T} \quad (3)$$

$$V_T = \frac{V_S}{(1-P)} \quad (4)$$

$$V_V = V_T - V_S \quad (5)$$

The void volume  $V_V$  is the filling water volume  $V_{WF}$ .

$$V_V = V_{WF} \quad (6)$$

The volume of free water  $V_{WF}$  is the difference between the total volume water  $V_W$  and the filling water volume  $V_{WF}$ .

$$V_{WF} = V_W - V_{WF} \quad (7)$$

Knowing the total grain surface, the volume of free water can be reduced in thickness. For the calculation of the total

grain surface we use the fractal model. Based on the hypothesis of the grains sphericity mixture, the surface  $S_i$  of one grain with a diameter  $D_i$  is:

$$S_i = 4 \cdot \pi \cdot \left(\frac{D_i}{2}\right)^2 \quad (8)$$

Knowing the number of each size range  $N_i$ , taken from the fractal model, we can calculate the area of each particle size range  $S_{Ti}$ , as in (9).

$$S_{Ti} = N_i \cdot S_i \quad (9)$$

Thus, the total surface of the granular mixture  $S_{Tm}$  of "n" class is given by the following relationship:

$$S_{Tm} = \sum_{i=0}^{i=n} S_i \quad (10)$$

Hence, the water layer thickness is equal to:

$$T_{WL} = \frac{V_{WF}}{S_{Tm}} \quad (11)$$

#### B. Hypothesis of Paste Layer Thickness

The hypothesis is that the workability of concrete depends on the paste layer thickness (consisting of water and fine aggregate) which surrounds the coarse aggregate. Therefore, it is necessary in this case to define the porosity of the mixture consisting of coarse grains using (1) in order to define the filling paste volume  $V_{Pf}$  which occupies the void between the coarse grains ( $V_{Pf} = V_V$ ). The volume of excess paste  $V_{Pexc}$  which acts as a lubricant for this model will be:

$$V_{Pexc} = V_{p,t} - V_{p,f} \quad (12)$$

$V_{PT}$  is the total volume of the paste which is the sum of the volume of water  $V_W$  and the solid of grain fine  $V_{SF}$  (determined from the volume proportions dosage and partial refusal).

$$V_{PT} = V_{SF} + V_W \quad (13)$$

The problem for this model is to define the paste by its maximum grain diameter  $D_{paste}^{max}$ . For this, we calculated the thickness of several pastes with different particle size, and for the  $D_{paste}^{max} = (0.01\text{mm}, 0.1\text{mm}, 1\text{mm}, 2\text{mm}, 2.5\text{mm}, 2.8\text{mm}, 3.15\text{mm}, 5\text{mm}, 6.3\text{mm})$ . Beyond the diameter 6.3mm, we suppose that the surface force acting on the grain is reduced relative to the mass force.

### III. COMPOSITION OF THE STUDIED CONCRETE

The test campaign which was conducted at L CPC, has served as a platform to address the relationship between dosing parameters and workability. The experimental program, formulation, granulometry of the components and results are taken from [4]. The test was done on ordinary concrete; three sub-programs have been established with respect to a control concrete simply called OC (ordinary

concrete)

- Sub-program 1: G/S gravel-sand ratio is variable for OC (G/S = 1.4). Other concretes were formulated with a ratio of 0.5 - 1 - 2, abbreviated as follows: OC0.5, OC1 - OC2.
- Sub-program 2: the quantity of cement is variable (-200kg), (-100kg), (+100kg) and (+200kg) compared to the control concrete OC.
- Sub-program 3: the quantity of water varies with (+5 liter), (+10 liter) and (+15 liter) compared to OC.

TABLE I  
MASS COMPOSITION AND SLUMP VALUES OF THE STUDIED CONCRETE

| Concrete | Gravel<br>12.5-20<br>Kg/m <sup>3</sup> | Gravel<br>5-12.5<br>Kg/m <sup>3</sup> | Sand<br>0-5*<br>Kg/m <sup>3</sup> | Cement<br>Kg/m <sup>3</sup> | water<br>Kg/m <sup>3</sup> | Slump<br>(cm) |
|----------|--|---------------------------------------|-----------------------------------|-----------------------------|----------------------------|---------------|
| OC       | 709                                    | 382                                   | 779                               | 356                         | 182                        | 11.7          |
| OC 0.5   | 387                                    | 208                                   | 918                               | 349                         | 212                        | 9.7           |
| OC1      | 596                                    | 321                                   | 918                               | 349                         | 194                        | 16.2          |
| OC 2     | 816                                    | 349                                   | 658                               | 359                         | 177                        | 12.7          |
| OC-200   | 777                                    | 419                                   | 854                               | 153                         | 172                        | 12.8          |
| OC-100   | 744                                    | 401                                   | 818                               | 255                         | 174                        | 11.5          |
| OC+100   | 654                                    | 352                                   | 719                               | 443                         | 207                        | 19.7          |
| OC+200   | 617                                    | 332                                   | 678                               | 537                         | 211                        | 16.0          |
| OC+5     | 704                                    | 379                                   | 773                               | 353                         | 186                        | 16.7          |
| OC+10    | 701                                    | 377                                   | 770                               | 352                         | 190                        | 17.3          |
| OC+15    | 697                                    | 375                                   | 766                               | 350                         | 194                        | 19.8          |

\* The author states that the crushed sand 0-5 contains 8% of the total mass of fine crushing.

TABLE II  
VOLUME COMPOSITION OF THE STUDIED CONCRETE

| Concrete | Gravel<br>12.5-20<br>liter | Gravel<br>5-12.5<br>liter | Sand<br>0-5*<br>liter | Cement<br>liter | Total<br>liter |
|----------|----------------------------|---------------------------|-----------------------|-----------------|----------------|
| OC       | 265,05                     | 142,86                    | 292,20                | 112,37          | 812,48         |
| OC 0,5   | 144,67                     | 77,79                     | 446,36                | 107,32          | 776,14         |
| OC 1     | 222,80                     | 120,04                    | 344,34                | 110,16          | 797,35         |
| OC 2     | 305,05                     | 164,17                    | 235,56                | 113,32          | 818,10         |
| OC-200   | 290,47                     | 156,69                    | 320,33                | 48,30           | 815,79         |
| OC-100   | 278,13                     | 149,96                    | 306,83                | 80,49           | 815,41         |
| OC+100   | 244,49                     | 131,64                    | 269,69                | 139,84          | 785,65         |
| OC+200   | 230,65                     | 124,16                    | 254,31                | 169,51          | 778,63         |
| OC+5     | 263,18                     | 141,74                    | 289,95                | 111,43          | 806,29         |
| OC+10    | 262,06                     | 140,99                    | 288,82                | 111,11          | 802,98         |
| OC+15    | 260,56                     | 140,24                    | 287,32                | 110,48          | 798,60         |

### IV. METHODOLOGY

For all mixtures of concrete (cement with aggregate):

- We calculate the cumulative number  $Ncum$ ;
- We draw the fractal lines  $Ncum=f(diam)$  to define the fractal dimension FD of the granular mixture and prove the fractal distribution of the mixtures grains.

Then, to find relationship between formulations parameters and slump (workability indicator), we adopt two hypotheses following the methodology of calculation.

Hypotheses of the water layer thickness:

- Calculation of the total area of granular mixtures.
- Calculation of porosity Por.
- Calculation of volumes:  $V_V$  and  $V_T$
- Calculating the water layer thickness:  $T_{WL}$ .
- Tracing slump curves according to water layer thickness for each sub-program:  $A = f(T_{WL})$ ,

#### Hypotheses of paste layer thickness:

- Choice of diameter considered  $D_{paste}^{max} = (0.01\text{mm}, 0.1\text{mm}, 1\text{mm}, 2\text{mm}, 2.5\text{mm}, 2.8\text{mm}, 3.15\text{mm}, 5\text{mm}, 6.3\text{mm})$
- Determination of the number of coarse grain mixture  $N_{cum}$ , coarse grain ( $c,g$ ); and plotting the lines fractals to define the fractal dimension FD of the mixture of coarse grain considered.
- Calculation of total areas mixtures composed of coarse grains considered  $S_{Tm,c,g}$ .
- Calculation of porosity Por mixtures of coarse grains  $\text{Por}_{c,g}$ .
- Calculation of volumes:  $V_{V,c,g}$  and  $V_{T,c,g}$  of coarse grains.
- Calculating the volume of the excess paste:  $V_{p,exe}$ .
- Calculating the paste layer thickness  $T_{PL}$ .
- Tracing slump curves according to the paste layer thickness for each diameter  $D_i$ :  $A=f(T_{PL})$ .

#### V. COMPUTING THE NUMBER OF GRAIN MIXTURES

We calculate the total number of the granular mixture using the proceeding of calculation shown in [5]. This step will allow us to trace the lines fractals granular mixtures for each concrete, to test the hypothesis of fractal distribution of grain concretes studied and to set their fractal dimensions FD as shown in Figs. 1-12.

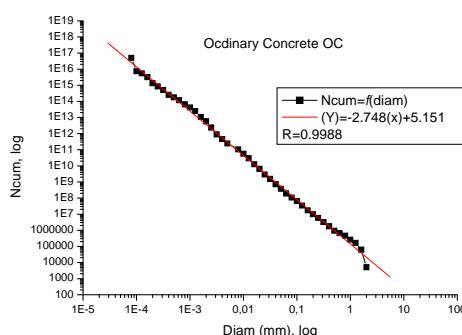


Fig. 1 Fractal line of control concrete OC, FD=2,748

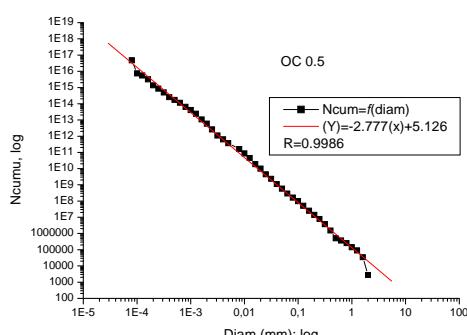


Fig. 2 Fractal line of OC 0,5, FD=2,777

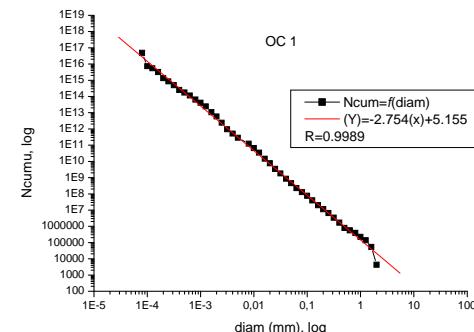


Fig. 3 Fractal line of OC 1, FD=2,754

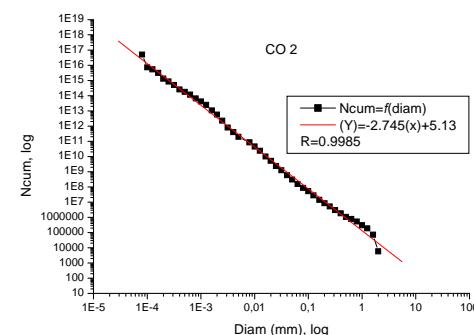


Fig. 4 Fractal line of OC 2, FD=2,754

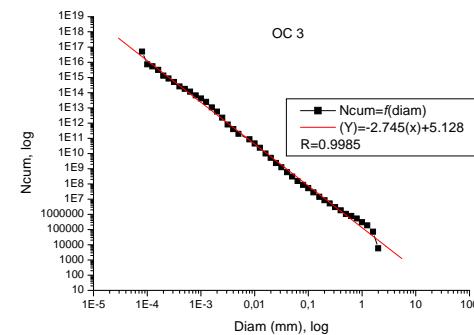


Fig. 5 Fractal line of OC 3, FD=2,754

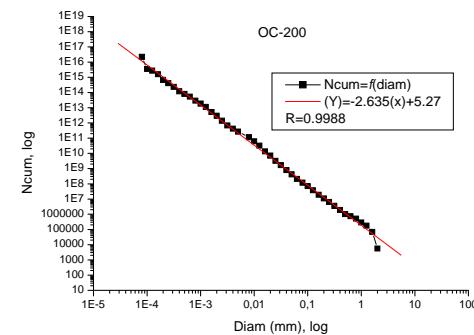


Fig. 6 Fractal line of OC-200, FD=2,635

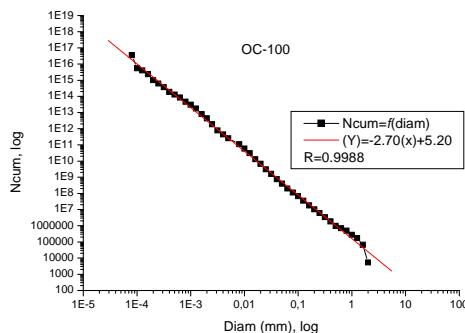


Fig. 7 Fractal line of OC-100, FD=2,70

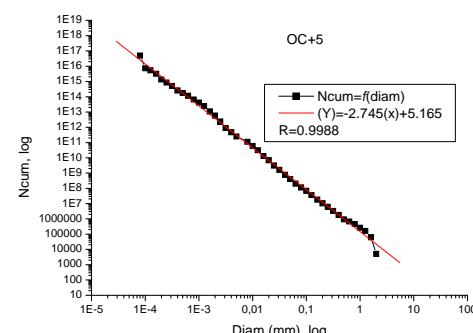


Fig. 10 Fractal line of OC+5, FD=2,745

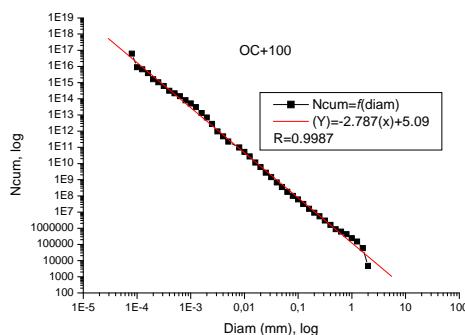


Fig. 8 Fractal line of OC+100, FD=2,787

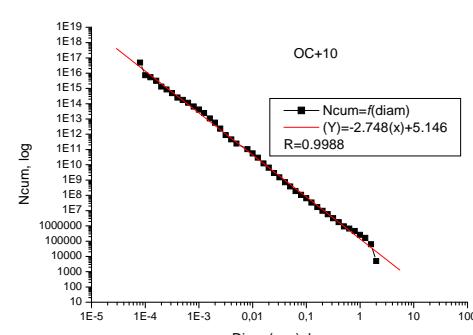


Fig. 11 Fractal line of OC+10, FD=2,748

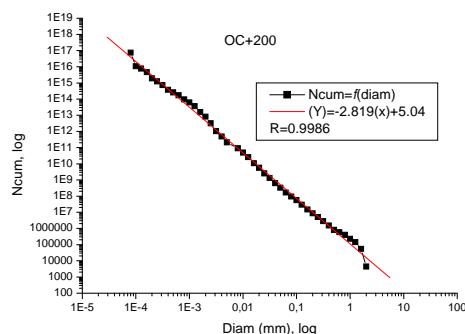


Fig. 9 Fractal line of OC+200, FD=2,819

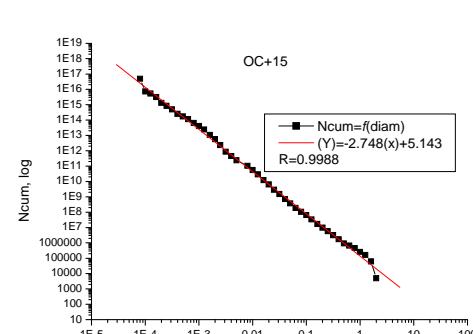


Fig. 12 Fractal line of OC+15, FD=2,748

TABLE III  
 THE WATER LAYER THICKNESS AND SLUMP VALUES

| Concrete | d [mm] | D [mm] | FD    | Por (d/D) | Vst [l] | V <sub>T</sub> [l] | V <sub>V</sub> [l] | V <sub>w</sub> [l] | V <sub>WF</sub> [l] | S <sub>Tm</sub> [cm <sup>2</sup> ] | T <sub>WL</sub> [cm] | Slump (cm) |
|----------|--------|--------|-------|-----------|---------|--------------------|--------------------|--------------------|---------------------|------------------------------------|----------------------|------------|
| OC       | 0,0008 | 25     | 2,748 | 0,080     | 812,48  | 883,52             | 71,04              | 182                | 110,96              | 1,90E+09                           | 0,000058             | 11.7       |
| OC 0,5   | 0,0008 | 25     | 2,77  | 0,079     | 776,14  | 842,95             | 66,80              | 212                | 145,20              | 1,89E+09                           | 0,000077             | 9.7        |
| OC 1     | 0,0008 | 25     | 2,75  | 0,080     | 797,35  | 866,97             | 69,62              | 194                | 124,38              | 1,89E+09                           | 0,000066             | 16.2       |
| OC 2     | 0,0008 | 25     | 2,74  | 0,081     | 818,10  | 890,07             | 71,97              | 177                | 105,03              | 1,89E+09                           | 0,000056             | 12.7       |
| OC-200   | 0,0008 | 25     | 2,63  | 0,088     | 815,79  | 894,85             | 79,07              | 172                | 92,93               | 9,06E+08                           | 0,000103             | 12.8       |
| OC-100   | 0,0008 | 25     | 2,7   | 0,083     | 815,41  | 889,51             | 74,09              | 174                | 99,91               | 1,40E+09                           | 0,000071             | 11.5       |
| OC+100   | 0,0008 | 25     | 2,75  | 0,080     | 785,65  | 854,25             | 68,60              | 207                | 138,40              | 2,32E+09                           | 0,000060             | 19.7       |
| OC+200   | 0,0008 | 25     | 2,82  | 0,077     | 778,63  | 843,59             | 64,95              | 211                | 146,05              | 2,78E+09                           | 0,000053             | 16.0       |
| OC+5     | 0,0008 | 25     | 2,74  | 0,081     | 806,29  | 877,22             | 70,93              | 186                | 115,07              | 1,89E+09                           | 0,000061             | 16.7       |
| OC+10    | 0,0008 | 25     | 2,748 | 0,080     | 802,98  | 873,19             | 70,21              | 190                | 119,79              | 1,88E+09                           | 0,000064             | 17.3       |
| OC+15    | 0,0008 | 25     | 2,748 | 0,080     | 798,60  | 868,43             | 69,83              | 194                | 124,17              | 1,87E+09                           | 0,000067             | 19.8       |

## VI. RELATIONSHIP BETWEEN THE CONCRETE FORMULATION PARAMETERS AND SLUMP

### A. Hypothesis of the Water Layer Thickness

Following the methodology previously described, the results found are recapitulated in Table III.

We have studied the evolution of slump for each sub - program: (OC+G/S, OC + cement, OC+ water). The Fig. 13 reflect this evolution.

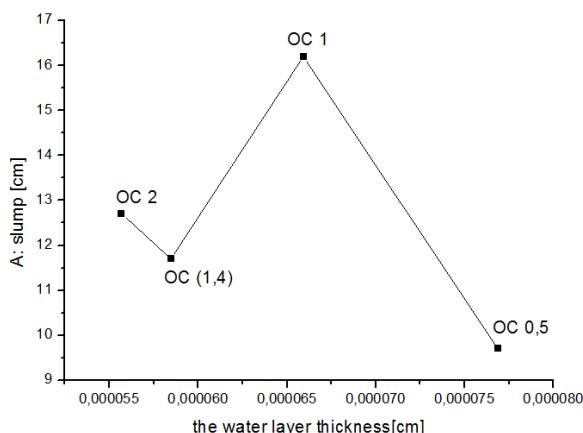


Fig. 13 Sub-program 1: OC+G/S,  $A=f(T_{WL})$

### B. Hypothesis of the Paste Layer Thickness:

After choosing  $D_{\text{paste}}^{\max}$ , we followed the methodology described before. For example for  $D_{\text{paste}}^{\max} = 0.01$ , the results are recapitulated in the Table IV.

We do the same for  $D_{\text{paste}}^{\max} = 0.1\text{mm}, 1\text{mm}, 2\text{mm}, 2.5\text{mm}, 2.8\text{mm}, 3.15\text{mm}, 5\text{mm}, 6.3\text{mm}$ , the results are shown on the Figs. 16-23.

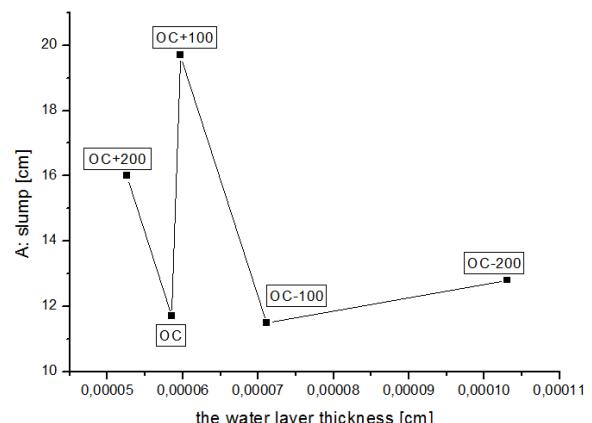


Fig. 14 Sub-program 2: OC+ cement,  $A=f(T_{WL})$

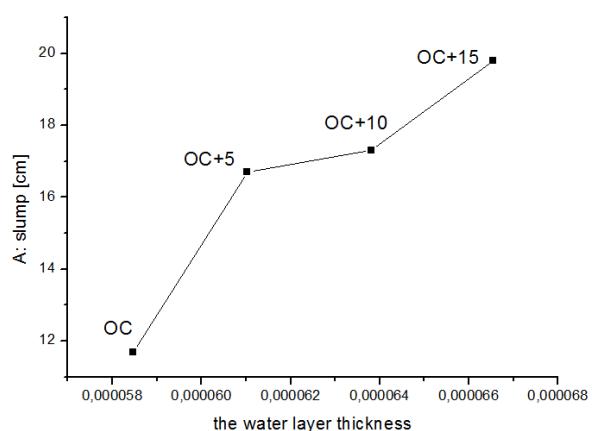


Fig. 15 Sub-program 3: OC+ water,  $A=f(T_{WL})$

TABLE IV  
 THE PASTE LAYER THICKNESS AND SLUMP VALUES FOR  $D_{\text{paste}}^{\max} = 0.01$

| Concrete | d [mm] | $D_{\text{paste}}^{\max}$ [mm] | $D_i + 1$ [mm] | D [mm] | Por (D <sub>i</sub> + 1 / D) | $V_{ST} > 0,01$ [l] | $V_T > 0,01$ [l] | $V_V > 0,01$ [l] | $V_{ST} < 0,01$ [l] | $V_W$ [l] | $V_P < 0,01$ [l] | $V_{p,exe}$ [l] | $S_{Tm} > 0,01$ | T <sub>PL</sub> [cm] | Slump (cm) |
|----------|--------|--------------------------------|----------------|--------|------------------------------|---------------------|------------------|------------------|---------------------|-----------|------------------|-----------------|-----------------|----------------------|------------|
| OC       | 0,0008 | 0,01                           | 0,0125         | 25     | 0,183                        | 756,42              | 925,73           | 169,31           | 56,06               | 182       | 238,06           | 68,75           | 2,68E+08        | 0,00026              | 11.7       |
| OC 0,5   | 0,0008 | 0,01                           | 0,0125         | 25     | 0,180                        | 721,13              | 879,65           | 158,53           | 55,01               | 212       | 267,01           | 108,49          | 2,98E+08        | 0,00036              | 9.7        |
| OC 1     | 0,0008 | 0,01                           | 0,0125         | 25     | 0,182                        | 741,87              | 907,06           | 165,19           | 55,47               | 194       | 249,47           | 84,28           | 2,78E+08        | 0,00030              | 16.2       |
| OC 2     | 0,0008 | 0,01                           | 0,0125         | 25     | 0,185                        | 762,08              | 934,52           | 172,44           | 56,01               | 177       | 233,01           | 60,57           | 2,56E+08        | 0,00024              | 12.7       |
| OC-200   | 0,0008 | 0,01                           | 0,0125         | 25     | 0,186                        | 789,98              | 971,07           | 181,09           | 25,81               | 172       | 197,81           | 16,72           | 1,67E+08        | 0,00010              | 12.8       |
| OC-100   | 0,0008 | 0,01                           | 0,0125         | 25     | 0,185                        | 774,40              | 949,63           | 175,23           | 41,01               | 174       | 215,01           | 39,78           | 2,18E+08        | 0,00018              | 11.5       |
| OC+100   | 0,0008 | 0,01                           | 0,0125         | 25     | 0,182                        | 716,73              | 876,50           | 159,76           | 68,94               | 207       | 275,94           | 116,17          | 3,10E+08        | 0,00038              | 19.7       |
| OC+200   | 0,0008 | 0,01                           | 0,0125         | 25     | 0,181                        | 696,01              | 850,22           | 154,20           | 82,93               | 211       | 293,93           | 139,72          | 3,56E+08        | 0,00039              | 16.0       |
| OC+5     | 0,0008 | 0,01                           | 0,0125         | 25     | 0,183                        | 750,71              | 919,23           | 168,52           | 55,59               | 186       | 241,59           | 73,07           | 2,70E+08        | 0,00027              | 16.7       |
| OC+10    | 0,0008 | 0,01                           | 0,0125         | 25     | 0,183                        | 747,56              | 915,38           | 167,82           | 55,43               | 190       | 245,43           | 77,61           | 2,66E+08        | 0,00029              | 17.3       |
| OC+15    | 0,0008 | 0,01                           | 0,0125         | 25     | 0,183                        | 743,58              | 910,51           | 166,92           | 55,12               | 194       | 249,12           | 82,19           | 2,64E+08        | 0,00031              | 19.8       |

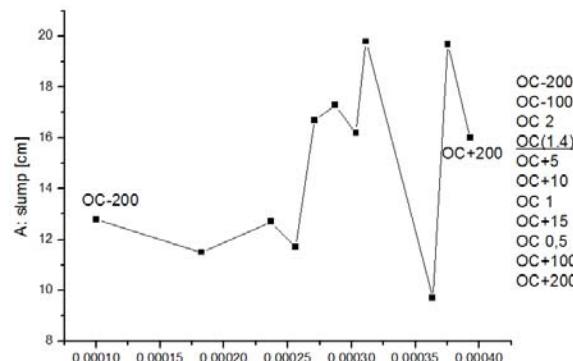


Fig. 16 Paste layer thickness [cm] for  $Di_{paste}^{max} = 0.001\text{mm}$

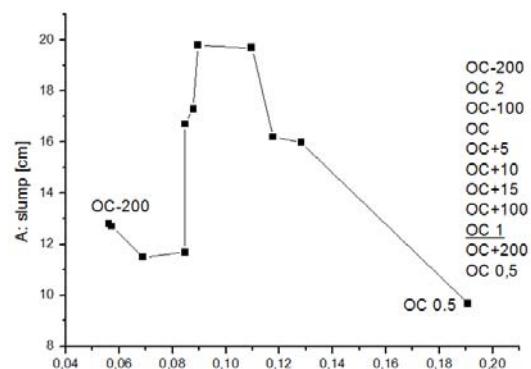


Fig. 20 Paste layer thickness [cm] for  $Di_{paste}^{max} = 2.5\text{mm}$

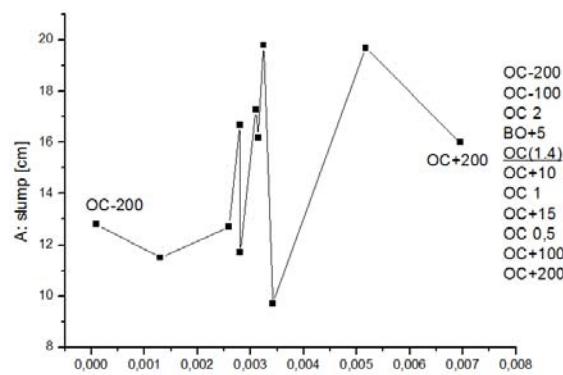


Fig. 17 Paste layer thickness [cm] for  $Di_{paste}^{max} = 0.01$

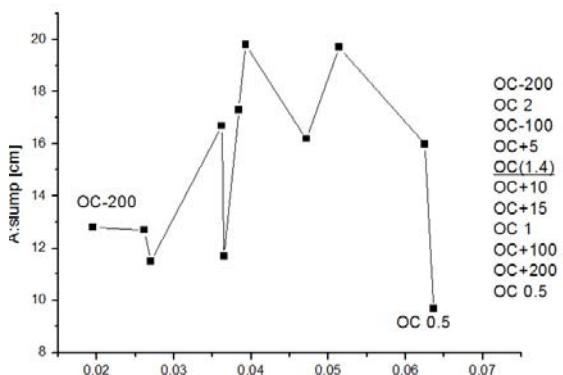


Fig. 18 Paste layer thickness [cm] for  $Di_{paste}^{max} = 1\text{mm}$

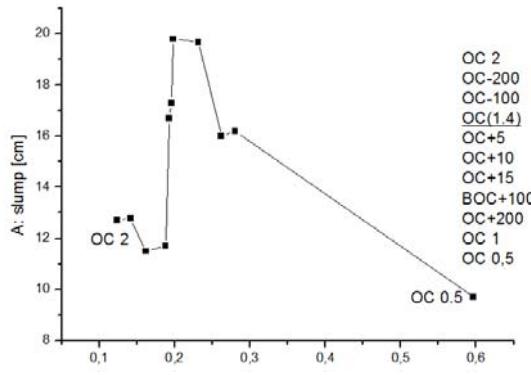


Fig. 22 paste layer thickness [cm] for  $Di_{paste}^{max} = 5\text{mm}$

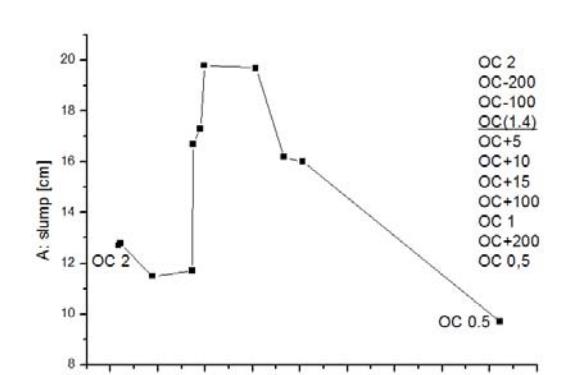


Fig. 19 Paste layer thickness [cm] for  $Di_{paste}^{max} = 2\text{mm}$

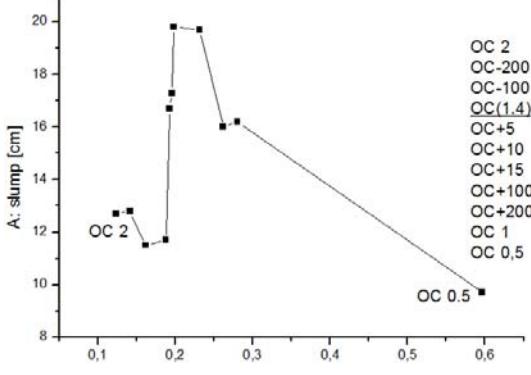


Fig. 23 Paste layer thickness [cm] for  $Di_{paste}^{max} = 6.3\text{mm}$

</div

## VII. RESULTS AND INTERPRETATIONS

### *A. Hypothesis of the Water Layer Thickness*

If we see the evolution of the slump in Fig. 12, we see an evolution and a logical succession of concrete in order: OC 2; OC 1.4; OC 1, OC 0.5 in terms of water layer thickness.

Similarly for Fig. 14 with the quantity of water for variant, the evolution is also logical starting with OC, OC + 5, OC+ 10 and OC + 15.

While the evolution of concrete for the sub-program 2, with the quantity of cement as a variable, does not respect the logic evolution: the classification of concretes is disturbed by a permutation on position between OC and OC-100. Regarding the role of the quantity of cement, the influence of the parameter cement does not appear.

### *B. Hypothesis of the Paste Layer Thickness:*

The appearance of the first three graphs: Figs. 15-17 for  $D_{paste}^{max} = (0.01, 0.1, 1)$  is not similar, and classification of different concretes is not stable.

From Figs. 18-22 for  $D_{paste}^{max} = (2 \text{ to } 6.3\text{mm})$ , the appearance of the graphs is more or less similar and the stability is noticed in different concretes.

For the pastes from  $D_{paste}^{max} > 2$ , concretes permute position and ranking until reaching a stability from  $D = 2.85\text{mm}$  value. From this value con cretes remain in their positions and the phenomenon remains same.

## VIII. CONCLUSION

### *A. Hypothesis of the Water Layer Thickness*

The model of the water layer thickness seems to be pertinent when it is applied to t he sub-program 3 (different concretes by the quantity of water) where the curve indicates a non-linear proportionality between slump and the water layer thickness.

This model is less pertinent for the case of sub-program 1 (concrete which differ in the G/S ratio) even if it is noted that the water layer thickness curve increases with the decrease in G/S ratio but slump varies without respect for the increase in G/S ratio.

The model is even less pertinent to the subprogram 3 (concrete which differ in the cement content) because the curve does not indicate any logic.

### *B. Hypothesis of the Paste Layer Thickness*

It seems that the paste in this model is composed of grains whose value  $D_{paste}^{max} = 2.85\text{mm}$  because from this v alue a stable classification is obtained.

This result derived from this series of concrete must be confirmed or denied using other series of concrete for we can adopt a paste layer thickness model applicable to all concretes.

More research is needed to find a relationship between workability and formulation parameters, using the f ractal model.

- [2] Hans W. Reinhardt, Timo Wüstholtz, "about the influence of the content and composition of aggregates on the rheological behavior of self-compacting concrete", Materials and Structures, 39, 683-693, 2006.
- [3] K. Chouicha, " La dimension fractale et l'étendue granulaire comme paramètres d'identification des mélanges granulaires ", Materials and Structures, 2006, 39, pp.665-681
- [4] T. Sedran: Rhéologie et rhéométrie des bétons. Application aux bétons autonivelants, thèse de doctorat, LCPC, 1999.
- [5] A. Lecomte, A. Thoomas," Caractère fractal des mélanges granulaires pour bétons de haute compacité ", Materials and Structures, 1992, 25, pp. 255-264.

**The Fatima Achouri** was born in Oran, Algeria, in 1977. She is a Ph D student at USTOMB University at the Civil Engineering Department.

The Kaddour Chouicha is PhD at USTOMB University at the Civil Engineering Department.

## REFERENCES

- [1] Adam M. Neville, « Propriétés des bétons », Eyrolles, 2000, 824 pages.