OPTIMIZING OF STEEL FIBER REINFORCED CONCRETE MIX DESIGN

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Abstract Cementitious matrices are the fragile materials that possess a low tensile strength. The addition of fibers randomly distributed in these matrices improves their resistance to cracking, substantially. However, the incorporation of fibers into a plain concrete disrupts the granular skeleton and quickly causes problems of mixing as a result of the loss of mixture workability that will be translated into a difficult concrete casting in site. This study was concerned on the one hand with optimizing the fibers reinforced concrete mixes in the fresh state, and on the other hand with assessing the mechanical behavior of this mixture in the hardened state, in order to establish a compromise between the two states. In the first part of this paper, an experimental study of an optimization method of fibers reinforced concrete while taking into account of some parameters related to the matrix e.g. volume of the admixture, volume of incorporated fibers and the volume of water and, cement (W, C) in function of workability time are presented. Finally, test specimens of mixture optimized by this method have been tested in compression and tension due to bending. The results have been compared with those of mixture test specimens optimized by Baron – Lesage method.

Key Words Concrete, Fibers, Optimization, Workability, Range

چکیده زمینه های سیمانی مواد شکننده ایی هستند که استحکام کششی پایینی دارند. افزودن فیبرهای توزیع شده به صورت تصادفی در این مواد باعث بهبود اساسی استحکام ترک خوردگی آنها می‌شود. پیوستگی این فیبرها در درون سیمان ساده، اسکلت دانه ای را بهم زیخته و بواسطه از دست رفتن کار پذیری مخلوط، مشکلاتی در اختلاط و ریخته گری بتن در محل ایجاد می‌کند. این تحقیق از یکسو با بهینه سازی فیبرهای مخلوط شده با بتن مسلح در حالت تازه ارتباط دارد و از طرف دیگر به ارزیابی رفتار مکانیکی این آمیزه در حالت سخت شده بطور مقایسه ای می‌پردازد. در ابتدا، یک مطالعه تجربی در باره روش بهینه سازی فیبرهای بتنی تقویت شده در ارتباط با تعدادی از عوامل تاثیر گذار بر مخلوط مانند حجم مواد مخلوط شده، حجم فیبرهای الحاق شده و حجم آب و سیمان به صورت تابعی از زمان کار پذیری ارائه می‌شود. در پایان، نمونه های آزمایشی مخلوط بهینه شده بوسیله روش این تحقیق تحت فشار و کشش کمانش، آزمایش شده و نتایج حاصل با نتایج روش Baron – Lesage مقایسه می‌شود.

1. INTRODUCTION

Recently, the application of composite materials has been growing rapidly. It is difficult to find a field of technical activity or objects produced for everyday life where composites are not used. Fiber reinforced cement matrices, which contain concretes and mortars reinforced with short fibers, are perhaps the most important group of modern materials applied since 1940's in various fields [1] from building constructions up to concrete layers on runways and highways.

The mechanism of reinforcement of concrete by fibers includes distributing short fibers regularly in the concrete matrix. This network of fibers opposes, depending on its density, to the widening of the crack and acts as crack arrestors by producing a pinching force which tends to make its propagation slower. It also causes transfer of stress across cracked sections allowing the affected parts of the composite to retain some post-crack strength to withstand deformations much greater than what can be sustained by the matrix alone.

Many studies [2-4] reported that the influence of fibers on the composite behavior of elements subjected to loading is complex. In the limit of elastic deformation, the fibers are not active and their role may be derived from the law of mixtures [5]. When the micro-cracks are open, the fibers act as crack-arrestors and control their propagation. The total strength is increased due to the fiber contribution. The load corresponding to the first crack is slightly increased, but the main effect is a considerable increase in the deformability as well as in the amount of energy of the external load.

However, these improvements require that factors including fiber volume, fiber geometry, fibers shape and fiber type be taken into account to give a good anchorage. These parameters also influence the main property of the fresh concrete as well as its workability. Indeed, the workability, which is the principle characteristic searched in the fibers concrete, poses a problem. The addition of fibers in the concrete matrix in a fresh state causes stiffening of the mixture and an accompanying loss of workability, which leads to difficulties in the mixing, placing and finishing procedure.

Concrete mix design can be defined as the process of selecting suitable constituent materials of concrete and determining their relative proportions so as to produce, as economically as possible, a concrete mix with certain properties in its fresh and hardened state. The most commonly specified features are workability, strength and durability. But, the incorporation of fibers in the concrete disorganizes the granular skeleton and leads to loss of mixture workability those results in a difficult concrete placement.

Gains brought by fibers are only obtained after an optimization of the mixture. In this regard, several methods of composition optimization of fibers concrete have been proposed [6-10]. These methods, mainly the one of Baron-Lesage, are very useful in the field performance of fibers reinforced concrete. However, methods of optimization have been developed that have permitted more economy security.

The aim of this experimental study is to verify the possibility of a new method of optimization of steel fibers reinforced concrete mix design while keeping constant the dosage of granular skeleton compounds proposed for the plain concrete.

2. TEST.PROCEDURES

The objective was of obtaining good fibers reinforced concrete workability with a good mechanical strength. For this reason, in this study it was attempted to establish a referential standard range that would give the percentage of fibers as well as the percentage of corresponding admixtures, which leads to an improvement in the mechanical properties of the composite.

The purposes of this research study are as follows:

- To record the time of outflow of the LCL workabilimeter of a fresh concrete according to the percentage of admixture and dosage in fibers.
- To establish a range giving the optimal quantities of admixtures and fibers which would permit obtaining an optimal mix design having the best workability.
- To compare the characteristics of the fiber reinforced concrete prepared from the range obtained and the one of fiber reinforced concrete formulated by Baron-Lesage method (the same dosage of fibers will be used).
- To verify the validity of the method for high dosages of fibers.

2. MATERIALS AND EQUIPMENT

2.1. Materials

2.1.1. Sand The sand gradation, as determined by using standard sieves [11], ranges from fine to medium (Figure 1). The calculated grading modulus was $M_f = 1.8$. It can be seen that the sand

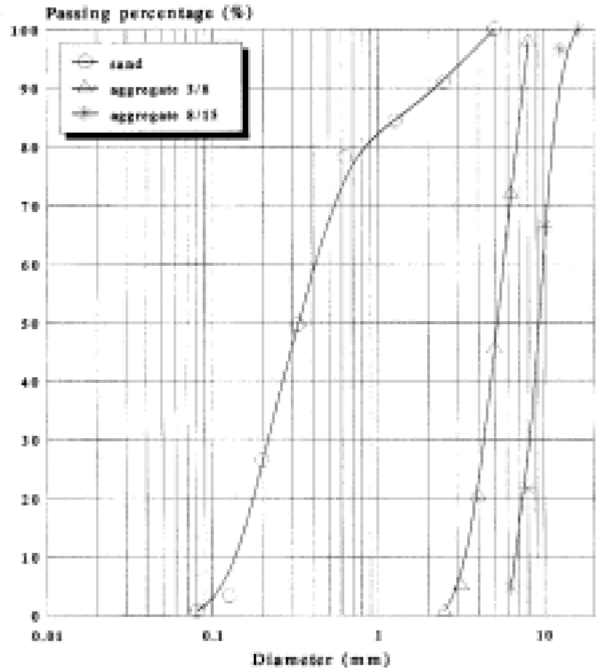

Figure 1. Grain size distribution of the sand and the aggregates used.

is uniformly graded. The sand's equivalent, as measured by NF P18 standard [11], shows that the dune sand used in this study was clean, siliceous and contained very few fine dust or clayey elements Its different characteristics are regrouped in Table 1. Its grading curve is shown in Figure 1. Its chemical composition is shown in Table 2.

2.1.2. Gravel Gravel is obtained by crushing the limestone rock from the quarry of COSIDER situated in EL-EUCH region (B.B.A). The gravel has two fractions 3/8 and 8/15. The sieve analysis results are shown in Figure 1. While some physical, morphological and mechanical properties are found in Table 1 and in Table 3.

2.1.3. Cement The cement used was of type CPJ 45 (Cement Portland with Additive). This cement was chosen because of its wide availability and extensive use in the concrete construction sector in Algeria. Its density is 3.1, and its Blaine's specific surface area is 3600 cm^2/g. The quantitative analysis carried out by x-ray fluorescence gave the results shown in Table 4 and the mineralogical composition according to Bogue's equations for the percentage of main compounds in cement [12] is given in Table 5. We should note, however, that the Bogue composition underestimates the C_3S content and overestimates C_2S because other oxides replace some of the CaO in C_3S.

2.1. 4 Admixture The admixture product used in our research is a super-plasticizer manufactured by the Algerian Granitex Company. This super-plasticizer, named "Medafluid SFA", has a density of 1.2, a content of dry matter of 36.16 % and a PH

TABLE 1. Some Characteristics of the Sand and Gravel Used in the Tests.

Materials	Density	Porous/ dense	Compactness	Porosity	Sand equivalent
Sand	2.56	1.64/1.83	36.42/70.76	36.58/29.24	75.4/77.2
Gravel 3/8	2.68	1.28	47.46	52.24	----
Gravel 8/15	2.68	1.32	49.25	50.75	----

TABLE 2. Chemical Composition (%, by weight) of the Sand of Dune Used.

Constituent, %	SiO_2	Al_2O_3	Fe_2O_3	Ca O	Mg O	Ca O free	SO	P.F	Insoluble
Sand of dune	86.04	1.35	0.86	6.63	0.08	----	---	5.00	---

TABLE 3. Some Physical and Mechanical and Morphological Properties of the Gravel Used.

Gravel Grading	Superficial tidiness (P)	$CaCO_3$ (%)	Flattening Coef..	Los Angles (LA)	MDE
3/8	1.5	85	18	20	16
8/15	1.28	83	13	23	17

TABLE 4. Chemical Composition (%, by weight) of CPJ Cement.

Constituent, %	SiO_2	Al_2O_3	Fe_2O_3	Ca O	Mg O	Ca O free	SO_3	P.F	Insoluble
CPJ 45	19.48	5.06	3.72	61.95	0.85	1.63	1.1	3.44	1.26

TABLE 5. Mineralogical Composition (%) for the Cement Used (according to BOGUE Potential).

Compounds,	C_4AF	CSH_2	C_3A	C_3S	BC_2S	C (Free)
CPJ 45	11.31	2.37	7.12	55.03	14.64	1.63

TABLE 6. Some Physical and Mechanical Properties of Fibers.

Density	Tensile strength MPa	Elasticity modulus MPa	Dilatation Coef (µ/m)	Fire resistance (°)
7.8	1000 to 3000	2.10^5	11	1500

of the order of 7.

2.1.5. Fibers The fibers used in this study were steel fibers having 1.2 mm diameter, 30÷50 mm length. Their physical and mechanical properties are shown in Table 6.

2 2. Equipment The workability of fresh mixes was determined on a special LCL workabilimeter shown in Figure 2, on which a result is expressed as flow time.

The workabilimeters is composed of a prismatic metal mould, which has smooth and indeformable surfaces, equipped with a vibrator and divided in two compartments by a removable metal partition, inclined to 38°C. This apparatus approved by LESAGE about 1958 to determine the value of the “stone/ wet sand” ratio, offering best workability, largely was described and studied by BARON and LESAGE. Then, it was constructed in the laboratory Central des Ponts et Chaussées (LCPC) in Paris. It has two advantages over slump measured on the Abrams cone or on the VeBe scale:

1. The amount of fresh mix is five times greater than that for the Abram’s cone, therefore, the results are more representative;
2. The flow of fresh mix in the box as shown in Figure 2 is more dynamic and simulates better

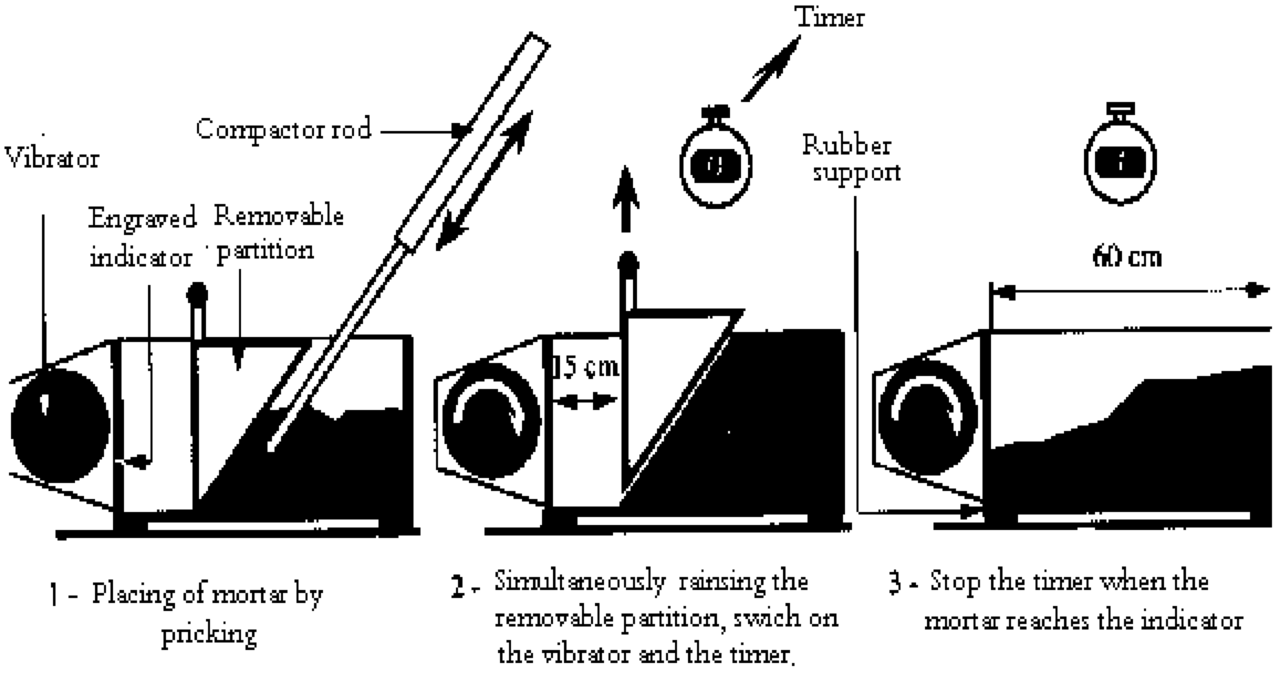

Figure 2. Apparatus for workability measurement (LCL workabilimètre) [13].

the behavior of the fresh mix in a mould.

The method of Baron-Lesage is based on two traditional approaches. One method, known after the names of Faury and Joisel, was derived from an assumption that the amount of water needed is related to the volume of the voids between solid grains. In the other method, proposed by Valletta, the amount of water is assumed to be proportional to the surface of the grains. The authors of Baron-Lesage method proposed to start with a selection of the ratios between fine and coarse aggregate to obtain best workability, which is the most important criterion of the mix quality [13]. Based on this concept, our method started by selecting the admixture content, the amount of cement and water, keeping $\frac{W}{C}$ constant.

3. CONCRETE MIX

The concrete mix proportion used (class 350 daN/ cm^2) was determined by absolute volume method " SCRAMTAIEV METHOD», [14].

Cement: 350 kg / m^3
Sand: 758 kg / m^3
Gravel: 1073 kg /m^3
Total Water: 215 l /m^3 (This quantity takes into account the degree of aggregates absorption).

4 PREPARATIONS AND CURING OF TEST SAMPLES

The complete amount of concrete necessary for the preparation of all test samples was prepared at once, in a 50 l concrete mixer. As a superplasticizer in liquid form was added, a special mixing procedure was used: dry mixing of aggregate (in mixer, 0.5 min), dry mixing of cement and aggregate (mixer, 0.5 min), addition of water, mixing by mixer for 3 min, addition of superplasticizer and then fibers, mixing by mixer for 2.5 to 3.5 min.

Fresh concrete was poured into standard

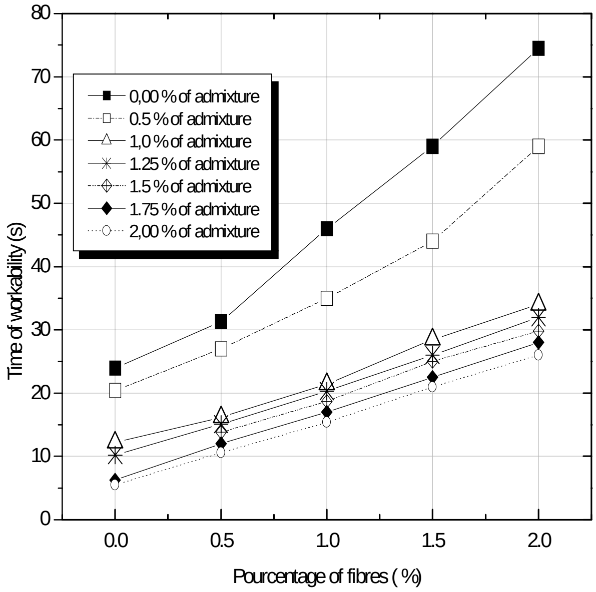

Figure 3. Variation of time of workability as a function of fiber percentage.

ironmoulds and compacted by a vibration table. After 24 hours, the specimens were demoulded and stored for 27 days under water (22°C) until the test are performed.

5. TESTING

5.1 Workability Measurement Methods used to assess the workability of plain concrete are not always adapted to fibers reinforced concretes. The method of measurement adopted in this case was the LCL WORKABILIMETRE. It consists of measuring the time of outflow of a fresh concrete between the stage of its setting up in the device and the stage of its out-flow under the action of stationary feature vibration. The workabilimeter, constructed by Lesage in the Laboratoire Central des Ponts et chaussées (LCPC) in Paris around 1958 (Figure 2), permits assessment of the ability of concrete to be casted. Two models of the LCL workabilimeter are available: one for the testing of concrete and the other for the mortars. The maniabilimeter measures the workability of designed concrete. Placed in a vibrating box, the concrete slumps to reach referential line and the time past is measured.

5.2 Compressive Strength Compression tests were carried out, at the age of 28 days, on cubic specimens (100 × 100 × 100mm). Tests were done using a hydraulic press model, type "STRASSENTEST (F.H.F)". The specimens were centered on the tray of the press then a continuous load was applied on the specimen. The ultimate compression load for each plain concrete and fiber reinforced concrete specimen were recorded.

5.3 Flexural Strength Flexural strength tests at the age of 28 days were performed on plain and steel fiber reinforced concrete prisms (70 × 70 × 280 mm[3]); with the same machine that used in the compressive tests. The loading was done in an automatic manner with a constant and continuous speed. The flexural strength of different mixes had been evaluated by the classic formula.

6. RESULTS

Initially, a concrete mix in one cubic meter was chosen (according the method of absolute volumes), and then its equivalent in 10 liters of concrete was prepared in order to facilitate reading on the workabilimeter.

The following fibers percentages: 0; 0.5; 1; 1.5 and 2 % were chosen for corresponding percentages of admixture values: 0; 0.5; 1; 1.25; 1.5; 1.75 and 2 %. Therefore, 5 values of fibers concentration for 7 different values of admixtures were considered. The test program contains, therefore, 35 mixes. For every mixture, flow time was assessed using the workabilimeter. Results obtained permit to draw 7 different curves (Figure 3).

Knowing that a good workability (using LCL) must have a flow time bounded within the limits of 10 and 15 seconds, then we have to take two straight parallel lines (Δ_1) correspondent to t_1=10 seconds and ($\Delta 2$) correspondent to t_2 = 15 seconds. These two straight lines cross the 7 curves presented in Figure 3 in five points in each line.

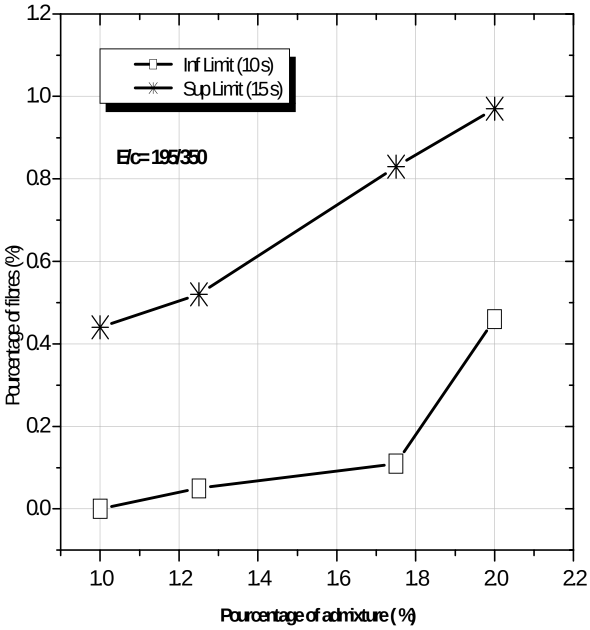

Figure 4. Optimization of mix-composition of fiber concrete.

The three points of (Δ_1) give the lower limits and the other five points (those of $\Delta 2$) give the upper limit, of our range (Figure 4). To verify the reliability of our range, we have proposed to prepare concrete test specimens with quantities of fibers and admixture, taken within the limits of this range. We have taken therefore some intermediate points to Δ_1 and $\Delta 2$ (Average values of the lower and upper limits). Percentages of fibers selected are noted f_1, f_2, f_3, f_4 and f_5.

Every percentage of fibers chosen had permitted to cast three cubic test specimens, (100 × 100 × 100 mm), which were tested for compression, and three other prismatic test specimens (7 × 7 × 28 cm) for the flexural tests where the age of concrete was twenty-eight days.

It was noted that the obtained range only covers the lower percentages of the fibers that are less than 1%. To resolve this problem, it was decided to repeat this second stage of the study, which consists of the investigation of volume increase influence (W and C), keeping the ratio $\left(\frac{w}{c}\right)$ constant in the translation range limits. It was found that the percentage of 7 % could be sufficient to displace and enlarge our range to cover the high fibers percentages (Figure 4). The aim of the third part of this research was to compare mechanical characteristics of fibers reinforced concretes prepared from the obtained range and those of fibers reinforced concretes formulated by Baron-Lesage method with the same dosage of fiber that has been used in the first stage (to know f_1, f_2, f_3, f_4 and f_5). It should be recalled that in the method of Baron-Lesage, first, we fixed a percentage of superplasticizer in compliance with the manufacture's recommendations (1.5 % of the cement weight). We fixed, at every time, the percentage of fibers (f_1, f_2, f_3, f_4 and f_5) and we studied the influence of the variation of the S/G ratio on the flow time of fresh concrete.

After several operations (for every quantity of fibers), we obtained the optimal ratio of S/G (S/G = 0.7, E/C = 0.557) that gives the biggest workability (the shortest flow time of workability).

For every optimal ratio (S/G), we prepared some cubic tests specimens (10× 10×10 cm) that were tested by the compression and prismatic tests. Specimens were tested to evaluate flexural strength at the age of 28 days.

7. DISCUSSION

7.1 Influence of Fibers Content and the Admixture Percentage on the Workability

Observing the curves shown in Figure 3, we notice that if the percentage of admixtures is less than 1 % then workability is poor (the flow time is long). It is recommended therefore not to use (with fibers) dosage of admixture less than 1 %.

An optimal workability range (function of the fibers concentration less than 1% and the dosage of admixture) was established. Curves of lower and higher limits tendency, forming the range, follow an increasing monotonous law of polynomial type of equation:

$$Y = a X^2 + b X + c$$

with Y: percentage of fibers, X: percentage of admixture, a, b, c: constants that depend on

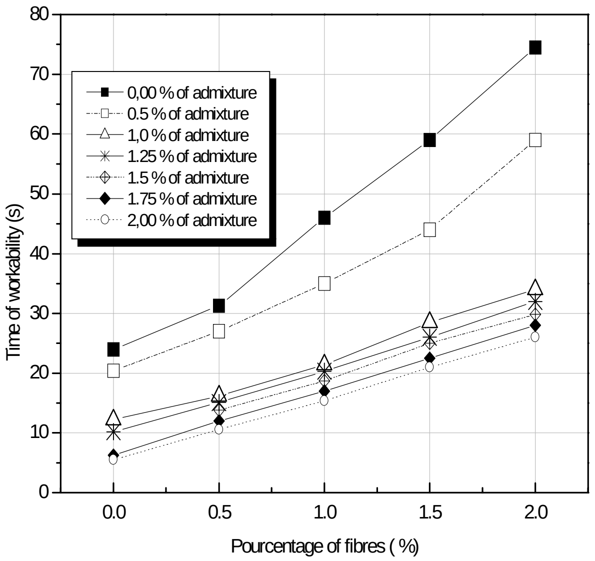

Figure 5. Variation of workability time in function of fiber percentages.

quantities of W and C and the type, shape and fibers dimensions. We also noted that for a fixed admixture dosage, the flow time is proportional to the percentage of fibers. However, if we fix the fibers percentages, the flow time will be in inverse proportionality to the admixture dosage.

The existence of such a relation allows us, for a fixed flow time, first to determine or to choose, for all fiber reinforced concretes, the percentage of admixtures and the corresponding fibers percentage. The range established in this investigation is a confirmation of what has just been cited above.

The improvement of the range to cover high fiber contents consists of giving greater values for the upper and lower limits. We estimate that the rate fibers must be accompanied with an increase of the $\left(\frac{w}{c}\right)$ ratio. In general, the higher the $\left(\frac{w}{c}\right)$, the higher the workability (with or without fibers) will be. Only, following the fibers nature, the best workable mixture is not always the most homogeneous one. The presence of an abundant quantity of water leads to the segregation phenomenon. In addition, the augmentation of water quantity increases the porosity of the mixture that has an effect of decreasing the mechanical performances and partially reducing the beneficial effect of fibers in the matrix.

For our study, we preferred to keep the ratio of w/c constant and undertake slight variation on W and C quantities (water, cement) in such manner not to affect the mechanical performance of the matrix. This consideration permits us to obtain a new range covering the slightly elevated fibers percentages (more than 2 %). Curves representing the lower and higher limits of the range (Figure 5) follow the same polynomial law governed by the previously mentioned equation.

7.2 Mechanical Strengths Study The efficiency and the reliability of our range appear in comparison between values of mechanical strength obtained while considering our optimization method and those determined by Baron-Lesage method.

7.3 Compressive Strength According to Figure 6, the compressive strengths determined by our method are, generally, superior compared to those obtained by Baron-Lesage method and all the percentages of fibers used. Two ranges were only noticed. In the interval (0.05 – 0.23 %), values of Baron-Lesage method are superior to those determined by our method. This can confirm that the method of Baron-Lesage is better for plain concrete, as it was developed for this type of concrete.

In the interval (0.23 – 0.73), it is clear that our method of optimization is the most efficient.

7.4 Flexural Strength Flexural strength in bending test showed nearly similar path to that of compressive strength. Except for the 28 days age, the values of R_t determined using our method from the range, are generally, superior to those determined by the Baron Lesage method (Figure 7).

The reason was that in Baron-Lesage method, the application of admixtures only varies with the flow time. When fibers are added, then the amount of coarse aggregate should be decreased to composite their influence on the flow time accordingly. While in our method, the optimization was based only on the percentage of fibers and

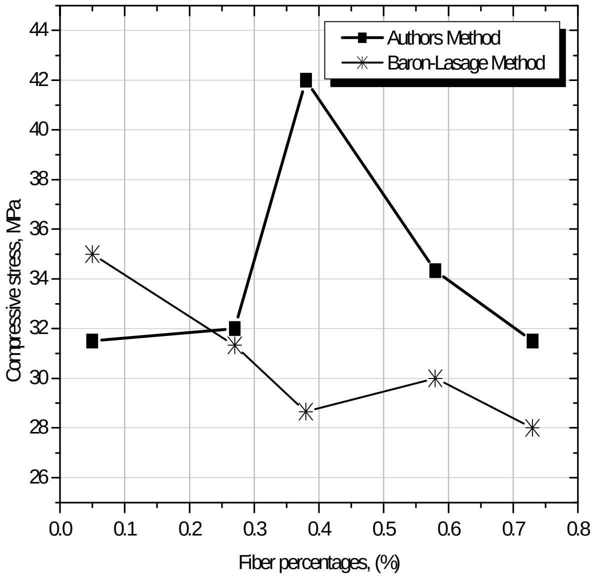

Figure 6. Variation of compressive stress, R_c in function of fiber percentages.

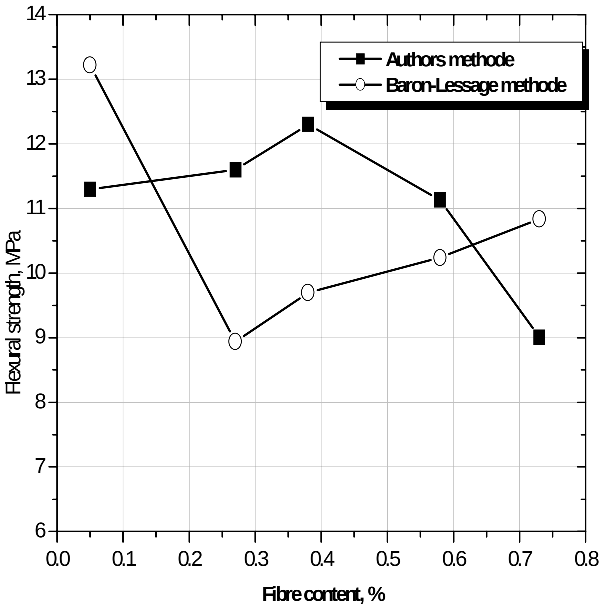

Figure 7. Variation of flexural stress as a function of fibre percentages.

admixtures without any reduction in the amount of coarse aggregates. This may be the only reason for the improvement of both flexural and compressive strengths.

8. CONCLUSION

Regarding the results obtained in this study, the following conclusions can be made:

1. The presented method differs from Barron-Lesage method in the experimental results of steel fiber reinforced concrete. Baron-Lesage method gives good results with plain concrete. With steel fiber reinforced the results are not significant while steel fiber reinforced concrete results are more significant even if the results of plain concrete are less than those of Baron-Lesage ones.
2. Admixture percentages less than 1% give the poor workability of fibers reinforced concretes.
3. An optimization method of fiber reinforced concrete mix design based only on the variation of the admixture contents and the quantities of W and C keeping, (W/C constant) was proposed.
4. The possibility to establish a prior, for a given fiber reinforced concrete, a range of optimization that depends only on the type of fibers used, their dimensions, the quantities of water (W) and cement (C) was confirmed. The lower and upper limits of the range follow a law governed by a polynomial equation of the second degree.
5. Mechanical properties of fiber reinforced concrete using this method showed an advantage compared to those of Barron-Lesage.

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