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Steel fibre reinforced concrete as a structural material

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Abstract

Fibre-reinforced concrete is the concrete with addition of short fibres targeting the improvement of the propriety of this material. Its durability is basely connected with the long-term dynamic loading. The main characteristic in that case are the critical stresses. The object of this article is steel fibre reinforced concrete (SFRC). For both materials (concrete and SFRC) are also different levels of critical stresses: initiation σ_i and critical σ_{cr}. Test findings during compression of concrete samples with and without fibre addition by means of acoustic and classical methods is presented. Three kinds of samples are assumed: BZ1 (1% fibres), BZ3 (3% fibres) and BZS (without fibre). In the case of concretes from groups BZ1 and BZ3, the level of initiation stresses was not found. The process of fibre-reinforced concrete compression has a two-stage character, instead of the process for witness concrete destroying is three-stages. It can be stated that the addition of steel fibres has the influence on σ-ε relationship for concretes in compression, and the level of critical stresses σ_{cr} increases together with the height of the quantity of steel-fibres added to the concrete-mixture. During compression the presence of dispersed reinforcement in concrete influences the propagation of cracks.

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Keywords: Concrete; SFRC; acoustic emission method; deformation measurement method

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1. Introduction

Fibre-reinforced concrete, with the supplement of steel fibres is commonly applied to make industrial floors as well as road and airport runways. Fibre-reinforced concrete is also used to make machine foundations and other elements exposed to dynamic loads. In addition, concrete with the supplement of fibres is used as the shotcrete technology, for example as casing of the underground structures or at renovation-repair activities. At the same time, it should be noted that fibre-reinforced concrete is used more and more often as the material for structural elements. An example may be the latest structural solution, the steel-fiber composite floor (Fig. 1) or RC elements absorbing energy of destruction in the case of structures exposed to seismic action [1]. An interesting example of fibre-reinforced concrete application in water construction is the surface slab of the dam in Longshua (China), located in the area of seismic impacts [2]. This structure is located in alternately wet and dry environment, and it is periodically influenced by large difference in temperatures (during the day and at night). Some of the dam panels were made of traditionally reinforced concrete, and some of the same concrete with the supplement of steel fibres. The longest panel with fibres has 75 meters and it does not show clear cracks even after the recent earthquake.

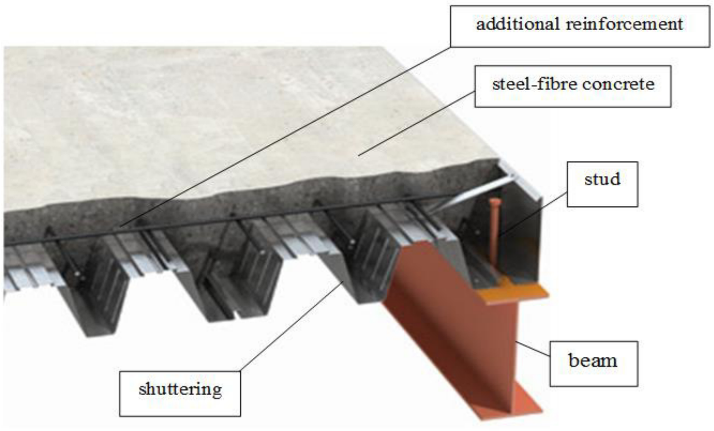

Fig. 1. Steel-fibre composite floor

Another example of steel fibres application in the structural elements is a thin shell structure covered buildings located in the European Oceanographic Park in Valencia. Structures are a combination of traditionally reinforced concrete and fibre-reinforced concrete (Fig. 2, 3).

Fig. 2: SFRC shells made in the European Oceanographic Park in Valencia [2]

Fig. 3: SFRC shells made in the European Oceanographic Park in Valencia [2]

Other structures constructed using concrete with supplement of fibre are railway stations made in the Ductal technology e.g. Shawnessy Light Rail Transit Station Calgary in Canada [3, 4] or Papatoetoe Railway Station in New Zealand [3], tunnels, reservoirs, pools, structures resistant to explosions and other impact loads, elements for reinforcement of hills and slopes, pipes and walls (Fig. 4) [5, 6], as well as a number of footbridges for pedestrians and bridges (Ductal), among others in Sherbrooke (Canada), in Seoul (Korea), Sakata-Mirai footbridge in Japan [3, 7], “Point du Diable” Ductal® footbridge in France [8] or the bridge over Shepherds Creek, 150km north of Sydney in Australia.

The essence of adding steel fibres to the concrete matrix is their anchorage force, therefore fibres with deformed tips are used. The geometric parameters of the applied fibres are also important. When comparing the graph of σ-ε relation for concrete with and without fibres, it can be noticed that the area under the curve, that is the energy needed to destroy the element, is greater for a material with the supplement of dispersed reinforcement. At the same time, limit deformation accompanying the total destruction of an element is greater for the one made of fibre-reinforced concrete [9-14].

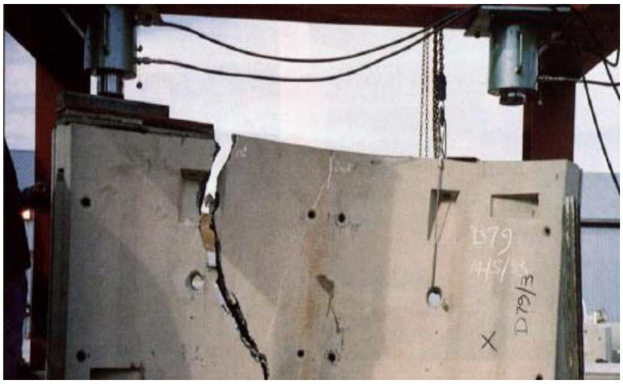

Fig. 4: Example of fibre-reinforced concrete tubing element examined in the natural scale [6]

It has been confirmed that the process of failure normal and high-strength concretes, as well as some special concretes under compression load proceeds in three stages [9, 14, 15]. Particular stages of failure demarcate the critical initiating stress σ_i and the critical stress σ_{cr}. The boundary between the stable initiation stage of cracks and the stable cracks propagation are σ_i, while stresses σ_{cr} demarcate stages of stable and unstable cracks propagation [9]. In the light of the presented information, an interesting thing is the fibre-reinforced concrete destruction process under compression loading. The purpose of the study is to examine, by means of two methods: the acoustic emission method, as well as the measurement deformation method, the process of the fibre-reinforced concrete destruction, differing in the content of steel fibres, along with specification of σ_i and σ_{cr} stress levels, in the function of increase in compressive stress levels. Knowledge in this respect seems to be necessary, because, as we can see, fibre-reinforced concrete has now more and more widespread application in the construction practice, and the knowledge on the values of these stress levels is directly connected with the problems of durability and operation of structural elements made of these concretes [9].

2. Tests

2.1. Materials

The tests covered 3 series of concretes marked accordingly: BZS, BZ1 and BZ3. These concretes were made of Portland cement CEM II/B S-32.5R, aggregate gravel, sand, super plasticizer, and tap water. The size of a maximum aggregate grain in these concretes amounted to 16 mm. Compositions of the examined concretes were identical, and they differed only in the quantities of used dispersed reinforcement. The composition of concrete mix is specified in Tables 1. For concretes of series BZ1 and BZ3, steel fibres were added with the dimensions of 1mm/50mm, in the quantity of, accordingly, 1% and 3% as compared to the concrete mass. On the other hand, concrete of BZS series was treated as the "witness" concrete and consequently, dispersed reinforcement was not used in it. Steel fibres were dosed to the mix in the last stage of mixing. Concrete samples were stored for 28 days in the climate chamber at the air temperature of 18˚C (±1˚C) and the relative air humidity of 95% (±5%), and then they were stored in dry-air conditions until the test.

Table 1. Composition specification for the designed concrete mix of the tested concretes BZS, BZ1 and BZ3

No.	Composition	Quantity [kg/m^3]
1	Sand 0-2 mm	630
2	Multi-fraction gravel 2-8	527
3	Single-fraction gravel 8-16	724
4	Cement CEM II/B S-32.5R	325
5	Water	162
6	Super plasticizer CHRYSO® Fluid CE 30	3,25
7	Steel dispersed fibre	according to assumptions

2.2. Materials

2.2.1. Acoustic emission method

For tests by means of the acoustic emission method, rectangular samples have been prepared, with the dimensions of 50×50×100 mm, cut out from larger test elements. As they were being compressed, AE descriptors versus time were registered. Compression was performed without friction at the specimen/strength tester plates interface. For this purpose the surfaces involved were polished to make them mutually parallel with an accuracy to 0,05 mm and then lubricated with grease. The investigations were carried out using a Vallen-Systeme AMS3 acoustic emission measuring set and two VS 150-M sensors with a 100-450 kHz transmission band (Fig. 5). During immediate compression of samples, the recorded descriptors of acoustic emission in the function of time were the events rate N_{zd} and the signal effective value RMS [16].

Fig. 5:Hydraulic testing machine, type INSTRON 1126, during test

Fig. 6: Hydraulic testing machine, type INSTRON 8505, during test

2.2.2. Deformation measurement method

Destructive tests, with the use of the deformation measurement method of cylinder samples with the dimensions of 150x300mm. Measurement of deformations was accomplished by means of the MGCplus type measuring system by Hottinger Baldwin Messtechnik consisting of AB22A central control unit, ML801 half-bridge multiplex tensometric amplifiers and of

CATMAN 3.11. software for system management, visualization, archiving and data processing. Measurement and constraint of the force were done by means of the universal, hydraulic testing machine of INSTRON type, with a four-pole 8505 frame and 8505PLUS electronic control unit (tower, console) (Fig. 6).

Deformation measurements were performed by means of plastic tensometric transducers, type 150/120LY41, by Hottinger Baldwin. Tensometers were stuck on two opposite walls parallel to the axis of the compressing force impact. The testing procedure consisted of loading the sample in a static manner by controlling machine piston displacement. Movement was provided with the speed of 0,5 μm/s. As a result of the tests, measurements were obtained from both opposite walls of the sample and then they were averaged.

2.3. Results

2.3.1. Results of acoustic emission testing

Figures 7–9 present the registered AE events rate N_{zd} recorded in the function of compression time of concretes BZS, BZ1 and BZ3. On the other hand, figures 10–12 present, for these concretes, results of registered signal

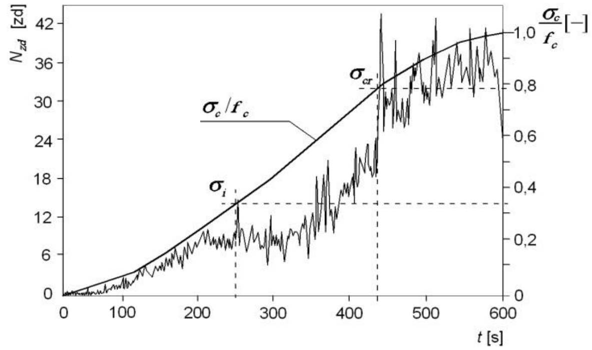

Fig. 7. Registered AE events rate N_{zd} along with the graph showing increase in relative compressive stress σ_c/f_c in the function of failure time in concrete BZS

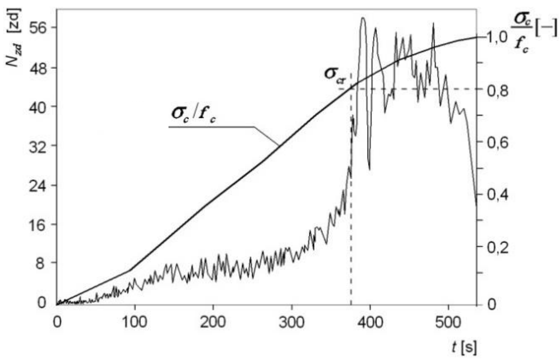

Fig. 8. Registered AE events rate N_{zd} along with the graph showing increase in relative compressive stress σ_c/f_c in the function of failure time in concrete BZ1

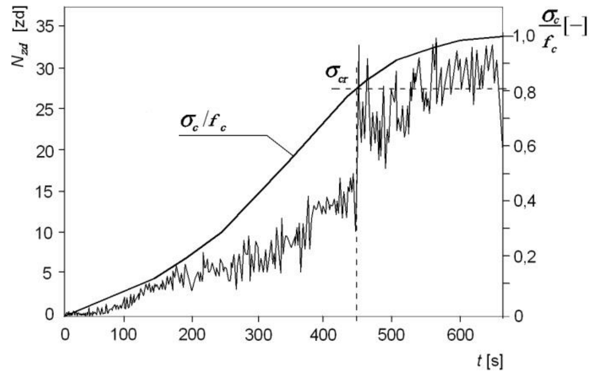

Fig. 9. Registered AE events rate N_{zd} along with the graph showing increase in relative compressive stress σ_c/f_c in the function of failure time in concrete BZ3

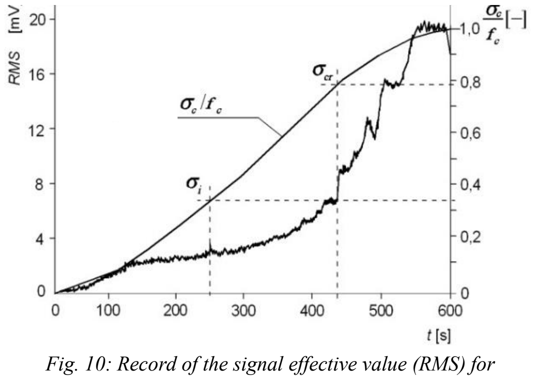

Fig. 10: Record of the signal effective value (RMS) for acoustic emission along with the plotted graph showing the increase in relative compressive stress value σ_c/f_c in the function of failure time in concrete BZS

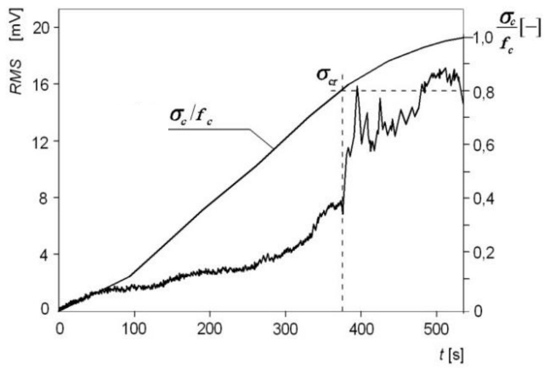

Fig. 11: Record of the signal effective value (RMS) for acoustic emission along with the plotted graph showing the increase in relative compressive stress value σ_c/f_c in the function of failure time in concrete BZ1

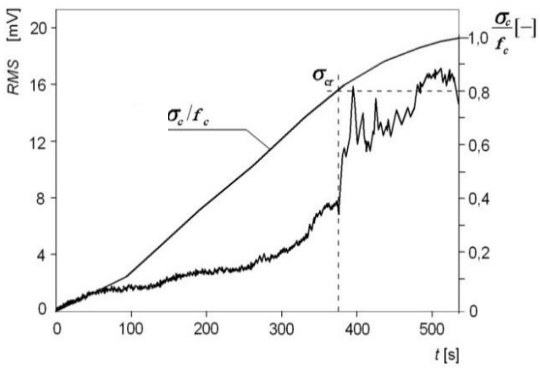

Fig. 12: Record of the signal effective value (RMS) for acoustic emission along with the plotted graph showing the increase in relative compressive stress value σ_c/f_c in the function of failure time in concrete BZ3

effective value for acoustic emission (RMS) registered in the function of compression time. Figures 7 to 12 also include graphs showing the increase in relative compressive stress σ_c/f_c versus failure time t and the levels of cracking initiating stress σ_i and critical stress σ_{cr}. In addition, levels of cracking initiating stresses σ_i and critical stresses σ_{cr} were determined, according to the criteria as specified in [9, 14]. Table 2 gathers the values of levels of these stresses specified for all tested concrete series.

Table 2. Composition specification for the designed concrete mix of the tested concretes BZS, BZ1 and BZ3

Concrete	Stress level values			
	σ_i [-]	variation factor	σ_{cr} [-]	variation factor
BZS	0,33	1,92	0,78	1,15
BZI	not observed	-	0,80	1,32
BZ3	not observed	-	0,81	1,30

Like for the acoustic emission method, levels of cracking initiating stresses σ_i and critical stresses σ_{cr} for deformation measurement method were determined, according to the criteria as specified in [9, 14]. Values of levels of these stresses are gathered in Table 3.

The graphs (Fig. 13) imply that along with growth in the quantity of steel fibres in concrete, the maximum stress achieved by concrete also grows, and a along with it - the limit deformation accompanying total destruction. For mix BZS (0% of fibre) the maximum stress was 35,58MPa, for mix BZ1 (0.5% of fibre) – 37,52 MPa and for mix BZ3 (3% of fibre) – 41,99MPa.

The more fibre was added to the concrete matrix, the larger the area under the curve, which means that more energy is needed to destroy such an element.

Tests conducted using methods indicated that the process of destruction process for concretes BZ1 and BZ3 containing dispersed reinforcement, loses its three-stage character. It is not possible to determine, in these concretes, the levels of cracking initiating stresses σ_i. In the case of these concretes, we can rather speak of "temporary" stable propagation of micro-cracks, passing next into "temporary" sudden propagation of micro-cracks. It should be assumed that during failure, the presence of dispersed reinforcement in concrete reduces propagation of cracks and contributes to reduction in stresses concentration at the places of defects and structure discontinuity.

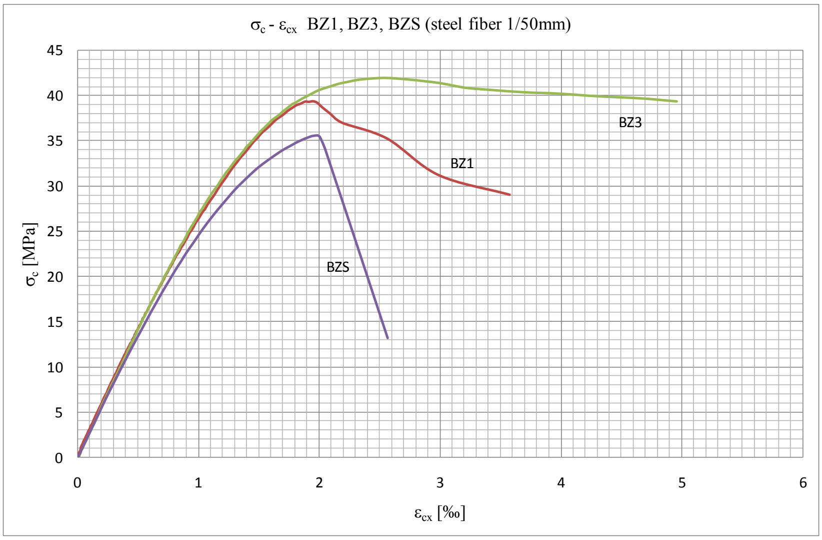

Fig. 13: Comparative graph of sigma – epsilon dependences for compressed concretes of mix BZ1, BZ3 and BZS

Table 3. Levels of cracking initiating stresses σ_i and critical stresses σ_{cr} specified by means of Deformation measurement method, in the examined concretes BZS, BZ1 and BZ3

Concrete	Stress level values			
	σ_i [-]	variation factor	σ_{cr} [-]	variation factor
BZS	0,33	2,45	0,78	1,78
BZI	not observed	-	0,80	1,84
BZ3	not observed	-	0,81	1,50

On the other hand, when it comes to stresses σ_{cr}, tests indicated that in concretes of BZ1 and BZ3 series, the level of these stresses is slightly higher as compared to the "witness" BZS concrete, not containing dispersed reinforcement and is, accordingly, 0,80 and 0,81 σ_c/f_c in concretes of BZ1 and BZ3 series and 0,78 σ_c/f_c in "witness" BZS concrete. At this point it is worth noting some analogy between the fibre-reinforced concrete failure process and the failure process of concrete saturated with methyl methacrylate [9, 17]

3. Conclusion

The conducted tests indicated that the course of destruction process of concretes containing dispersed reinforcement in the quantity of 1 and 3% loses its three-stage character. It is not possible to determine in these concretes the levels of stresses initiating cracking σ_i. For these concretes we may rather refer to "temporary" stable propagation of micro-cracks, developing, in turn, into "temporary" sudden propagation of micro-cracks. It should be assumed that during destruction, the presence of dispersed reinforcement in concrete hinders propagation of cracks and contributes to a reduced concentration of stresses at the places of defects and discontinuities in the structure [16, 18].

Added fibers make cement matrix somehow "sown together". Under the impact of load, energy cumulates to be finally released at a level of critical stresses that is higher than for "witness" concrete. So that an element with the addition of steel fibers would be destroyed, adhesion between cement matrix and aggregate must be lost, fibers must detach from the matrix, the matrix must be cut along fibers or fibers should rupture. The addition of fibers gives concrete elements greater ductility.

At this point, it is worth noting some analogy between the fiber-reinforced concrete destruction process and the process of destruction of concrete saturated with polymer: methyl-methacrylate [9, 16, 17]. The test proved that in polymer-impregnated concrete being compressed it is not possible to determine unambiguously the level of stresses initiating cracking σ_i. As a result of reinforcement of the concrete structure with polymer inclusions, three-stage character of destruction is lost. In addition, the level of critical stresses for concrete saturated with methyl-methacrylate is higher than for witness concrete.

References

[1] J.P. Curtis, D.A. Hills, M.D. Cook, P.J. Haskins, A D. Wood, A. Fenwick, J. House, The effect of fibre cross-sectional shape upon shock dissipation by fibrous composites, with potential application to insensitive munitions, Computational Methods in Structural Dynamics and Earthquake Engineering – COMPDYN, Crete, Greece, 2007.
[2] G. Vitt, Crack control with combined reinforcement: From theory into practice, Concrete Engineering International, issue 4, 2005, pp. 39-41.
[3] S. Montens, Ultra High Performance Fibre-Reinforced Concretes, Bouygues-VSL, Eiffage and Vinci companies, Microsoft Office Power Point presentation, Internet source.
[4] V.H. Perry, D. Zakariasen, First Use of Ultra-High Performance Concrete for an Innovative Train Station Canopy, Concrete Technology Today, Vol. 25, No. 2, 2004.
[5] E. Bychkov, Concrete reinforcement: Modern reinforced concrete products in Russia, Concrete Engineering International, issue 1, 2007, pp. 20.
[6] S. Walis, Steel fibre developments in South Africa, Tunels & Tunelling, issue 3, 1995, pp. 22-24.
[7] M. Behloul, J.F. Batoz, UHPFRC development on the last two decades: an overview, UHPFRC, No 11, Marseille, France, 2009.
[8] M. Behloul, R. Ricciotti, R.F. Ricciotti, P. Pallot, J. Leboeuf, Ductal® Pont du Diable footbridge, France, Tailor Made Concrete Structures – Walraven & Stoelhorst (eds), Taylor & Francis Group, London 2008.
[9] J. Hoła, Initiating and critical stresses and stress destruction in compressed concrete, Monograph 33, Scientific Studies of the Institute of Construction Engineering of Wroclaw University of Technology, No 76, WUT Publishing House, 2000.
[10] Z. Jamroży, Concrete with dispersed reinforcement (what a designer should know), Proceedings of 17th Polish Conference: Structural Designer Workshop, Ustroń, 20-23 February 2002.
[11] A. Łapko, Designing reinforced concrete structures, Arkady, Warsaw, 2000.
[12] M. Khaled, E. Ozgur, C. Tahir, Relationship between impact energy and compression toughness energy of high – strength fibre – reinforced concrete, Materials Letters, 47, 2001, pp. 297-304.
[13] J. Śliwiński, Ordinary concrete, designing and basic properties, Polski Cement Sp. z o.o, Kraków 1999.
[14] T. Gorzelańczyk, Moisture influence on the failure of self-compacting concrete under compression, Archives of Civil and Mechanical Engineering, vol. 11, No 1, 2011, pp. 45-60.
[15] K. Flaga, K. Furtak, Influance of the aggregate type on critical stresses levels in compressed concrete, Archive of Civil Engineering, No 4, 1981, pp. 653-666.
[16] T. Błaszczyński, M. Przybylska, J. Hoła, T. Gorzelańczyk, Fibre-reinforced concrete as structural and repair material, in: Modern repair methods in buildings and constructions, ed. M. Kamiński, J. Jasiczak, W. Buczkowski, T. Błaszczyński, DWE, Wroclaw, 2009, pp. 96-107.
[17] T. Broniewski, J. Hoła, I. Śliwiński, Application de la méthode d'émission acoustique aux essais du comportement du béton imprégné de polymère soumis á la compression, Materials and Structures, No 27, 1994, pp. 331-337.
[18] T. Błaszczyński, M. Przybylska, Fiber-reinforced concrete as structural material, Isolations, No 11-12, 2012, pp. 44-50.