# DISPERSE REINFORCED CONCRETE USED IN OBTAINING PREFABRICATED ELEMENTS FOR ROADS

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**ABSTRACT**

Concrete is the most used material in construction. By improving the performance of materials and of technologies, concretes with outstanding performances were also developed, in the past two decades. Concrete with dispersed reinforcement represents a new generation of reinforced concrete that combines a good behavior of concrete compressive strength with an increased tensile strength of steel fibers. Using this material, monolithic and prefabricated concrete elements with high mechanical strengths and high durability can be obtained. Technological processes for preparation of concrete with dispersed reinforcement are similar to the conventional methods and do not involve using additional equipment for dosing the dispersed reinforcement.

The study aimed the development of road plates made with optimized disperse- reinforced concrete. The first tests were done on plates from the gutter roadway, having a classic reinforcement, using different percentages of fibre reinforcement in the concrete composition, leading to the development of a new optimized economical solution. The results prove the enhanced characteristics of the disperse-reinforced concrete versus conventional concrete, and hence of the developed concrete plates.

*Keywords*: dispersed reinforcement, steel fibers, corrugated fibers, reduced costs

**REZUMAT**

Betonul este materialul cel mai folosit în construcții. Prin performanța materialelor şi a îmbunătățirii tehnologiilor s-au creat betoane cu performanțe deosebite în decursul ultimelor două decenii. Betonul armat dispers cu fibre, reprezintă o nouă generație a betonului armat, care combină buna comportare la compresiune a betonului cu rezistența sporită la întindere a fibrelor. Din acest material se pot realiza elemente din beton monolite şi prefabricate, cu rezistențe mecanice ridicate şi durabilitate mare. Procedeele tehnologice de preparare a betoanelor cu armatură dispersă nu diferă in mod substanțial de procedeele clasice, ele nepresupunând echipamente suplimentare pentru dozarea armăturii disperse.

Studiul de față a avut drept obiectiv realizarea plăcuțelor carosabile cu beton armat dispers în formula cea mai eficientă pentru armare, economia de material şi manoperă. S-a pornit de la ideea de eficientizare a plăcuțelor de rigolă carosabilă, clasic armate, folosindu-se în compoziția betonului procente diferite de armare cu fibre metalice, ajungându-se la o soluție nouă economică. Rezultatele obținute dovedesc caracteristicile îmbunătățite ale betonului armat dispers versus betonul armat convențional şi implicit al plăcuțelor realizate.

*Cuvinte cheie*: armare dispersă, fibre de oțel, fibre ondulate, preț redus

## 1. INTRODUCTION

Progress toward performance concrete has been understood in Romania only in terms of compressive strength and increased workability, for pumped concrete having a maximum class of C 80/95, for structures with dense reinforcement and even for prefabricated elements [1]

There is an ongoing research regarding performance concrete but implementation is still difficult. On a national level, concrete quality is governed by several regulations (NE 012-1: 2007)[2], (NE 013: 2002) [3] and (SR EN 206-1: 2002)[4]. Concrete for roads regulated by the norm (NE 014-2002)[4] for execution of cement concrete pavements. The mentioned regulations do not contain separate provisions for special concretes as is the concrete with dispersed reinforcement. These concretes can be made up to a point just based on the specification book and special technical specifications, complementary to existing regulations.

In the last decade, manufacturers of precast elements and constructions, designers and execution engineers, researchers and professional organizations of civil engineering and technologists have called for the elaboration of comprehensive norms in the field of high performance concrete. Thus, a technical code was developed, GP code 075/2002[6], regulation published by the Ministry of Public Works, Transport and Housing in the year 2003. In 2007 Eng. Ion Ionescu develops „The technical guide for the design of compositions for high strength concrete [7], that mentions the disperse reinforcement for concrete classes C50/60÷C100/115. In the same year the standard SR EN 14889-1)[8] is published, being the first harmonized standard for fibers for concrete.

In Romania the guidelines were first introduced in 1991 by Olariu, I., Ioani, A., et al) [9], by O.Corbu in her research studies for the PhD thesis (Corbu, 2011)[1] and through the researches made for the grant Program PN II -IDEI- ID_1053/2007-2010 [10]. The design of concrete admixtures for the Ultra High Performance Concrete (UHPC) with reactive powders and disperse reinforcement began for the first time in the PN II Grant activity (Grant director Prof. C. Măgureanu) in 2008 [11], [12], 2010 [13], 2011 [14], 2012 [15], 2013 [16] The UHPC was used in making prefabricated slender elements. The developed UHPC was patented in December 2013 [17]. The first patent obtained for a disperse reinforced concrete belongs to G. C. Martin, concrete patented in 1927 in California and used for making pipes of steel fiber reinforced concrete [18].

Another research on using UHPC with dispersed reinforcement at building columns with complex cross-section was made by M. Popa, C. Corbu and R. Zagon in 2013 [19].

Steel fiber reinforced concrete is mainly used for industrial floors and highways, but it can also be used for improving the behavior of the structural elements. There is an increasing trend on a national level of building new structures with slender elements.

## 2. MATERIALS AND METHODS

In order to obtain concrete with higher performances and a price economy for precast elements (in this case, the roadway plate), the study concerns the development of concretes with disperse reinforcement, respectively steel fibers (BFM in Romanian - *beton cu fibre metalice*). The research attempted to define the BFM concrete composition and the determination of compressive strength at 28 days in order to establish the concrete class and its applicability in roadway plate elements made in 3 variants. The proposed variants used for testing and for obtaining important characteristics than can define it applicability, are:

$\mathbf{P_{BC}}$: the plate with concrete and conventional reinforcement under the form of welded mesh;

$\mathbf{P_{BFM40}}$: the plate with BFM, containing 40 kg of corrugated steel fibers;

$\mathbf{P_{BFM50}}$: plate with disperse reinforcement, containing 50 kg of corrugated steel fibers;

$\mathbf{P_{BFM40\ OB}}$: the plate with BFM, containing 40 kg of corrugated steel fibers and conventional reinforcement, under the form of welded mesh.

Thus, the research program addressed the theoretical and experimental study of disperse reinforced concrete, with the above mentioned application. Several admixtures were carried out to obtain BFM concrete with the most favorable characteristics.

The materials used for the roadway plates are listed below, having usability established in terms of characteristics and performances.

**Cement:** The type of cement used in the composition of concrete is CEM II AS 32.5R, based on SR EN 197-1 2011 [20], cement having high initial resistance

**Aggregate:** The used aggregate 0/4 mm sort and 4/8 mm sort, are river aggregates, based on SR EN 12620 + A1 2008 [21], from the concrete station of TIRRENA SCAVI company.

**Water:** The water used for the concrete mix came from the public water supply pipe, as mentioned in SR EN 1008: 2003[22].

**Additive:** The additive used in the compositions belongs to the superplasticizer class based on polycarboxylates, one of the newest types of additives.

The used additive is REOBUILD in accordance with SR EN 934-2 2009 [23].

The properties of the product are: reduced mixing time, quick effect, minimal adhesion, water saving above average, economic dosage, high initial strength, high quality concrete surfaces without components that favor corrosion, reduced hardening time

**Fibers:** Steel fibers for the disperse reinforcement of concretes are manufactured from cold drawn steel wire, with low carbon content or of stainless steel. Steel fibers are manufactured in various forms: smooth (straight) with beaks or curled ends. This fibers are used in constructions for disperse reinforcement of concretes. For the studied concrete, steel fiber having the following characteristics were used: corrugated steel fibers, type SRO 1,1/30 with a length of L= 30 mm and a diameter of Ø = 1,1 mm; geometric ratio (l/d = 27.27). The steel used in obtaining the fibers has a higher quality ($R_a$ > 1.100 N/mm$^2$), given by SC Rom Fracht SRL company, in accordance with SR EN 14889-1/ 20078.

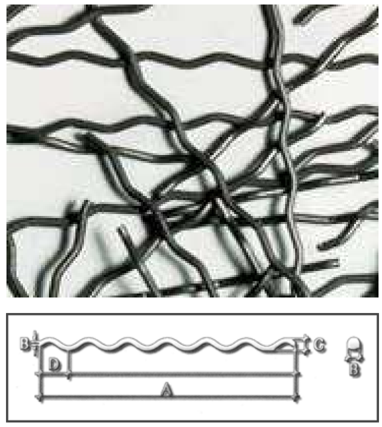


**Fig. 1.** Corrugated steel fibers [24]

The wavy shape of fibers implies a greater effort in order to be plucked “Fig. 1. a and b”.

Steel fibers are substantially improving the ductility characteristics. They improve the tensile strength, absorbing the tensile stress when crack appears, in the same time limiting also the crack opening. The dimension of the crack opening depends on the possible elongation of fibers. It means that the fibers must have a tensile strength and an increased elastic modulus, which leads to the need of using steel fibers [4].

**Conventional reinforcement:** consists of a welded mesh STNB type with mesh sizes of 100 x100 mm and Ø 6 mm of bars or mesh made with independent bars of OB 37 Ø 6 mm, placed at 5 cm from the concrete formwork, in accordance with ST 009 – 05 [25], used constructively in the precast element in the lower position of the element.

The **methodology determination** of the BFM concrete composition implies knowing the following elements:

• the concrete class – C16/20;

• the characteristics of the elements that will be executed (reduced cross section with a small distance between the reinforcement, which implies a granulosity of aggregate of 0/8 mm and a workability S1(T2);

• laying conditions - vibropressing;

• curing conditions - normal.

After preliminary tests, the following composition was obtained: cement type CEM II AS 32.5R – 375 kg/m$^3$; river aggregate 1.899 kg/m$^3$ (sort 0/4 = 733 kg/m$^3$, sort 4/8 = 733 kg/m$^3$; water + additive – 241 litres/m$^3$;

For the concrete preparation, steel fibers were used in the variant with 40 kg/m$^3$-BFM$_{40}$, respectively 50 kg/m$^3$-BFM$_{50}$.

For a uniform distribution of fibers throughout the mixture, they were mixed for a minute in the dry admixture, after which water and additive were added.

## 3. RESULTS AND DISCUSSION

### *3.1. Establishing fresh and hardened concrete characteristics*

To determine the characteristics of conventional concrete (BC) and of fiber disperse reinforced concrete (BFM) for the two variants of dispersed reinforcement, for the fresh and hardened state, the requirements (sampling, storage and testing) mentioned in the national standards were considered SR EN 12350[26] [27] – Tests on fresh concrete and SR EN 12390[28]27 [29] [30] – Tests on hardened concrete. Results are given in Table 1.

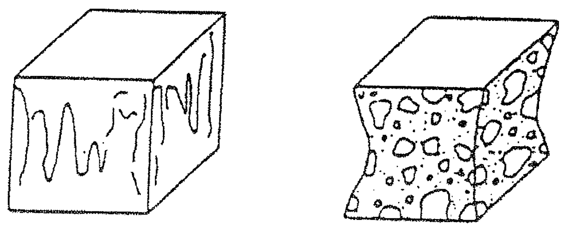
**Consistency** of the designed concrete, determined through compaction method, for all the 3 compositions of concrete (3B), falls within the limit of the proposed class S1, with values between 10 and 40 mm.

**Temperature** of concrete does not exceed the limits allowed by the Code of practice NE 012-1:20072, for (3B).

**Air-Entrained** for admixtures that contain an aggregate with a maximum diameter of 8 mm in accordance with SR EN 12350-7:2009[27] may exceed 6%, as in the case of (3B).

**The average compressive strength** $f_{cmcube}$ is a representative characteristic of concrete quality, because it allows obtaining sufficiently precise indications on the behavior of materials in various applications, on the deformation properties and durability of concrete.

It examines the rupture of plain concrete and steel fiber reinforced concrete under load demands, compression on specimens, determining in an experimental manner the compressive strength values.



a. b.

**Fig. 2.** Breaking mode of concrete cubes subjected to central compression, for the reinforced concrete with fibers (a) and without fibers (b) [31]

Based on the tests carried out and on the obtained values, the assessment of the concrete quality is established. The concrete (BC), (BFM$_{40}$), (BFM$_{50}$) will be placed in the corresponding class, based on the average resistance obtained for cubic samples having a size of 150 mm, at 28 days ($f_{cmcub28}$) from which is subtracted $\Delta f$ = 8 MPa (representing proposal „a" from Table 2, as mean value of the interval (6 ÷ 12) MPa from proposal "c" - values in accordance with NE 012-1:2007 [2] for initial testing.

Table 2 gives the inclusion in the appropriate classes of resistance of the tested concretes. Based on the obtained value, it is observed that the resistance increases with the increase of the fiber percent that is contained by the concrete.

**Flexural strength** for (3B) is between the ranges of 10÷20% of the compressive strength. For the mentioned testing the influence of the long fibers it can be remarked, which contribute to the improvement of the ductile behavior.

**Split tensile strength**. is supported by the fibers presence, respectively by the amount of reinforcement in the composite.

**Freeze-Thaw resistance** measured in accordance with SR 3518:2009[32] through „Resistance loss" which implies the number of freeze-thaw cycles that the concrete is subjected to and that must withstand without the decrease of the compressive strength by more than 25% compared to the strength of the concrete sample witness (not subjected to freeze-thaw cycle) .

The values for the strength loss for (2B) subjected to 150 cycles are well below the limit of 25% imposed by the standard.

**Depth of water penetration under pressure** This is determined by placing the cubic test pieces at a pressure of 5 bar, in accordance with the standard (SR EN 12390:8) [30]. Results are good, water penetration for (BC) of 27% from the standard permissible value of 100 mm, $BFM_{40}$ of 31% and $BFM_{50}$ shows a penetration of 47% due to high porosity of the composite caused by the great amount of fibers under which air bubbles often exist.

**Böhme Abrasion test** The purpose of the test is to determine the Böhme abrasion resistance expressed by a volume loss reported to 5000 $mm^2$. It is applied at concrete paving, concrete slabs and concrete borders in accordance to Annex H from SR EN 1338, 1339, 1340: 2004[35] [36] [37].

The standard gives at paragraph 5.3.4 a table with the abrasion resistance classes, performance classification based on the volume loss.

**Table 1.** Characteristics of fresh and hardened concrete

| Crt. No. | Characteristics | UM | Reference level | Testing methods | Mixes | | |
|---|---|---|---|---|---|---|---|
| | | | | | BC | $BFM_{40}$ | $BFM_{50}$ |
| 1. | Consistency (S) | mm | 10÷40 | SR EN 12350-2:2009 | 40 | 35 | 30 |
| 2. | Temperature (T) | $^0C$ | 5÷30 | NE 012-1:2007 | 25 | 20 | 22 |
| 3. | Air Entrained (for Aggregates Ø=8 mm) | % | ≥ 6,0 | SR EN 12350-7:2009 | 6.3 | 6.7 | 7.1 |
| 4. | Compressive strength ($fcm_{cub}$) | MPa | Min 28 | SR EN 12390-3:2002 | 31 | 45 | 48 |
| 5. | Flexural strength (fti) | MPa | Min 1.85 | SR EN 12390-5:2009 | 1.8 | 2.51 | 3.28 |
| 6. | Split tensile strength (ftd) | MPa | Min 3 | SR EN 12390-6:2002 | 2.08 | 3.03 | 3.95 |
| 7. | Freeze-Thaw resistance at 150 cycles - Loss in compressive strength (η) | % | Max 25 | SR 3518:2009 | 5.0 | 3.3 | 4.8 |
| 8. | Depth of water penetration under pressure | mm | Max 100 | SR EN 12390-8:2009 | 27 | 31 | 47 |
| 9. | Apparent density (ρ) | $Kg/m^3$ | 2400 | SR EN 12390-7:2002 | 2284 | 2307 | 2323 |
| 10. | Volume loss | $\Delta V$ / 5000 $mm^2$ | | SR EN 1339:2004 | 25400 | 14590 | 13888 |

**Table 2.** Relations for determining the characteristic strength $f_{ck}$ [1]

| Crt. No. | Source | Mathematical relation (cylinders with H/ Φ- 300/150 or cube with l= 150 mm) | Maximum class |
|---|---|---|---|
| 1. | fib Bulletin 42 [33] | **a.** $f_{cm} = f_{ck} + \Delta f$, $\Delta f = 8$ MPa | C120 / 140 |
| 2. | ACI 318 [34] | **b.** $f_{c'r} = 1{,}1 \cdot f'_c + 10$ MPa | Not applicable |
| 3. | NE 012-1:2007 2 | **c.** $f_{cm} = f_{ck} + (6 \div 12)$ MPa | C100 / 115 |

**Table 3.** Establishing concrete classes [1]

| Crt. No. | Admixture symbol | $f_{cmcube28}$ [MPa] | $f_{ckcube}$ [MPa] | Concrete class at initial testing |
|---|---|---|---|---|
| 1. | BC | 31 | 23 | C16/20 |
| 2. | BFM 40 | 45 | 37 | C30/37 |
| 3. | BFM 50 | 48 | 40 | C30/37 |

Abrasion (wear resistance) is expressed in volume loss of the sample after subjecting it to ageing. If the volume loss is small, the sample is more resistant to wear. (BC) based on the obtained results has a value $\leq$ 26000 mm$^3$ / 5000 mm$^2$, corresponding to class 2, G mark in accordance with SR EN 1339:2004[36]. ($BFM_{40}$) and ($BFM_{50}$) have values $\leq$ 18000 mm$^3$ / 5000 mm$^2$, corresponding to class 4, I mark in accordance with SR EN 1339:2004[36]36, being the best wear resistance class.

### *3.2. Determining the characteristics of roadway plates*

The roadway plates were tested using the vibropressing method, the testing being carried out for the following: ($P_{BC}$) $_{OB}$ plate from (BC) and welded mesh placed spatially, ($P_{BFM40}$) plate from ($BFM_{40}$), ($P_{BFM50}$) plate from ($BFM_{50}$) and ($P_{BFM40\ OB}$) plate from ($BFM_{40}$) and welded mesh positioned at 50 mm from the bottom of the base plate. Nominal dimension of plates is L = 490 mm, l = 300 mm, h = 150 mm.

The static scheme for plate testing in the testing device was established by considering the effective work of the plates, in accordance with STAS 10796/2:79[38] (paragraph 2.1.6, fig.8b).

Distance between supports was establish at a distance of L = 330 mm.

The test specimen is supported on two steel cylinders with a diameter of Ø = 50 mm.

The distance between the edge of the plate and the cylinder axis having the diameter of Ø = 50 mm (support) is of 80 mm as in Figure 2.

The force is applied through another metal cylinder having a diameter of Ø = 50 mm, placed on the upper surface of the specimen, along the central axis of the plate.

The force is applied perpendicular to the specimen, with a loading rate of between 0.04÷0,06 MPa/s.

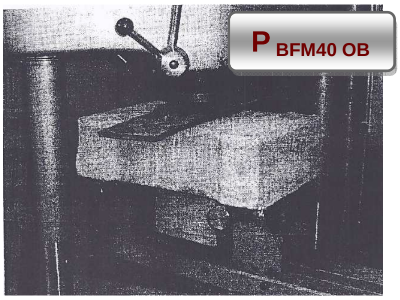



**Fig. 3.** Plate placing/ Plate breaking $P_{BC\ OB}$

**Table 4.** Plates characteristics

| Crt. No. | Characteristics | UM | Reference level | Mixes | | | |
|---|---|---|---|---|---|---|---|
| | | | | $P_{BC\ OB}$ | $P_{BFM40}$ | $P_{BFM50}$ | $P_{BFM40\ OB}$ |
| 1. | Flexural strength $f_{ti}$ | MPa | Min 1.85 | 8.28 | 5.83 | 6.66 | 7.60 |
| 2. | Apparent density | Kg/m$^3$ | 2400 | 2384 | 2310 | 2338 | 2265 |
| 3. | Mass | Kg | - | 49.80 | 48.43 | 48.32 | 45.70 |

Together with Figure 3, other suggestive images are presented (Fig. 4), corresponding to the values given in Table 4 in reference to the roadway plates bend testing. It can be seen that the plates containing welded mesh have the best flexural behavior (Figure 3 and Figure 4c). From the values given in Table 4 for the two plates, is noticed that the flexural strength values are almost equal.

This test is crucial for choosing the most efficient solution for the plate, in terms of mass production and labor involved.


**Figure 4.** (4a, 4b, 4c) Plates breaking $P_{BFM40}$, $P_{BFM50}$, $P_{BFM40\ OB}$

## 4. CONCLUSIONS

The aim of the study presented in the article was the investigation of the fibers influence by partial or total replacement of conventional reinforcement and selection of the most suitable solution in terms of acquired characteristics and economic aspects.

When designing the concrete composition, the concrete consistency and the plates placing were considered, respectively the vibropressing, represented by the consistency class S1.

The concrete class is defined by using the characteristic resistance $f_{ck}$ of the cube.

From the tests carried out on concrete quality and based on the values of the obtained characteristic compressive strengths, it shows that the steel fiber reinforced concrete, initially assessed as a concrete class of **C16/20** it may fall in a superior class **C30/37**(Table 3). The fibers advantage may be revealed in the compressive failure mode in the case of the cubic sample.

Plain concrete cubes have a classic failure, „two superposed truncated cones, in contact with the small bases". The disperse reinforced concrete cubes have a specific failure in which fibers have the tendency to keep cracks closed, creating the impression of unbroken specimen.

Steel fibers are limiting, from the smallest scale testing, the cracking process. When the cracks appear, the fibers crossing the crack will absorb some of the tension, thus preventing their propagation (Figure 4).

In Table 4 it is noted that based on the bending results, fibers give ductility to the conventional concrete, because of an almost homogenous spatial distribution of fibers, and that the disperse reinforced concrete has a high bending resistance, compressive resistance and wear resistance.

Volume loss values show good behavior at wearing (abrasion) of $BFM_{40}$ used in making the plates $\mathbf{P_{BFM40}}$ and $\mathbf{P_{BFM40\ OB}}$, the latter being considered the most advantageous solution.

**The advantages** in using disperse reinforced concretes refer to:

- obtaining concretes with high compressive strength classes
- reaction to climatic and thawing agents, superior to classic concretes
- high permeability to water pressure
- economic efficiency as a result of the reduction of reinforcement amount required for the same intensity of loading. The efficiency was also caused by the reduction of labor involved and therefore of labor costs. It also implies a reduction of execution time of elements and storage space.
- by adding metal fibers, the concrete gains elasticity and reliability. The usage of fibers allows reducing the concrete section which generates considerable costs reduction by 20%.

## 5. ACKNOWLEDGMENTS

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