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STUDY OF ADHESION OF CEMENT MIXTURE AND FIBRES AND CHANGES OF ITS TENSION PROPERTIES

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ABSTRACT
To obtain the starting point for theoretical numerical computations the fibre reinforced concrete construction properties, adhesion of cement mixture with steel and polypropylene fibres and changes in its tension properties commensurate with number and weight percentage in the tested specimen were tested under laboratory conditions.

KEYWORDS: fibre cement mixture, pullout test, tension properties, laboratory test

INTRODUCTION

Fibre reinforcement is an effective approach to improving mechanical and physical properties of concrete, especially brittleness during tensile and flexural stress. Therefore, the fibre reinforced concrete is increasingly used in a wide spectrum of structures. Fibre reinforced concrete is a concrete mixture with randomly, or, in some cases, regularly oriented fibres. Fibres accept tensile stress and, especially, restrain forces due to volume changes during the hardening of the concrete, and they also prevent creation of contraction cracks (Krátký et al., 1999). Use of fibres rapidly increases flexural tensile strength and resistance against dynamic loading of concrete. Adhesion of fibres with concrete is an important attribute that significantly influences characteristics of fibre-reinforced concrete. This adhesion is given by chemical response, friction and eventually by mechanical impacts of ends-arranged fibres, e.g. bending, extending etc. Fibre-reinforced concrete is used for both non-supporting and supporting structures, such as in the construction of concrete floors, ceiling construction and also for pre-stressed construction (Barták, 1994a, 1994b). Fibres of various lengths, materials and shapes are used for reinforced concrete matrices. Fibre material and design, as well as the quantity of fibres, have a dominant influence on physical and mechanic properties of fibre reinforced concrete. Fibres from steel, glass, synthetic or mineral materials are used most often.

With a wider utilization of the fibre-reinforced concrete, more attention is devoted to the detailed study of its properties (Mahasneh, 2005; Iskhakov and Ribakov, 2007). The extended experimental program described in this paper was carried out to obtain starting data for the assessment of theoretical models that can be used in computer programs. The main goal was to focus on determining the compressive force (interfacial traction), developed during the hardening of the fibre reinforced concrete and which grips the fibres embedded in the concrete mixture. Therefore, adhesion of the tested fibres with cement mixture (pull-out problem) and changes of its tensile properties in relation to the number of directed fibres or weight quantity of undirected fibres in cement mixture specimens was tested.

To study the physical and mechanical properties of fibre-reinforced concrete experimental methods, laboratory and in-situ experiments as well as numerical modelling methods have been used (Frantík and Keršner, 2005; Pešková and Procházka, 2008). Laboratory experiments described in this paper were focused on obtaining starting data for numerical analyses of the interrelationship of inserted fibres and concrete (Trčková and Procházka, 2009). That is why characteristics of individual tests differ slightly from procedures used for practical testing of fibre-reinforced concrete, given by standards.

USED MATERIALS

Considering the possibility of the laboratory, especially tested specimens' dimensions, cement mixtures with lower grain size distribution were selected:

1. Cement KNAUF BP 1
   - grain size up to 4 mm
   - compressive class C30 (according to the Czech standard ČSN EN 13813)

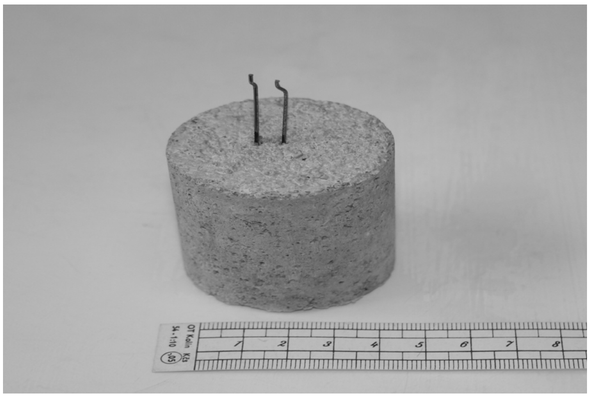

Fig. 1 Specimen with two metallic fibres before test.

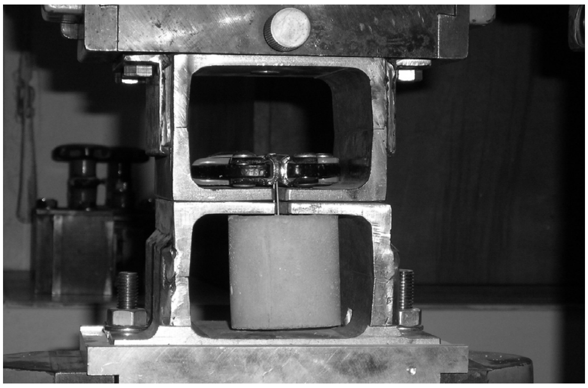

Fig. 2 Loading machine with adapted jaws.

- bulk density - original 1.498 g/cm^3
- shaken 1.795 g/cm^3
- particle density 2.761 g/cm^3
- flexural tensile strength 2.25 MPa

2. Backfilling cement mixture KNAUF BP 3
   - grain size up to 0.6 mm
   - compressive class C30 (according to ČSN EN 13813)
   - bulk density - original 1.180 g/cm^3
   - shaken 1.683 g/cm^3
   - particle density 2.758 g/cm^3
   - flexural tensile strength 4.42 MPa

3. Cement KNAUF BP 8
   - grain size up to 8 mm
   - compressive class C30 (according to ČSN EN 13813)
   - bulk density - original 1.497 g/cm^3
   - shaken 1.883 g/cm^3
   - particle density 2.769 g/cm^3
   - flexural tensile strength 2.58 MPa

The specimens were made in agreement with technical standard EN 12390-2. Cement mixture was placed into the form and vibratory compacted. Specimens were tested 28 days after preparation.

The steel fibres DRAMIX with a diameter of 0.90 mm, length of 50 mm and with bending on both ends, polypropylene fibres BeneSteel 80/55 – ribbons with a length of 55 mm, width of 1.5 mm and thickness of 0.4 mm, laterally shaped, and BeneSteel 55 with a length of 55 mm, diameter of 0.48 mm, and laterally shaped, were used for laboratory tests.

ADHESION OF STEEL FIBRES AND CEMENT MIXTURE

Tested specimens of cylindrical shape, with a diameter of 50 mm and height of 50 mm, were made for all three cement mixtures (Fig. 1). The force needed for the pullout of steel fibres from concrete specimens was measured on the mechanical loading machine, with a maximal loading force of 25 kN developed in purposely-adapted jaws for the fixation of the specimens for tensile tests (Fig. 2.).

During the preparation of specimens, one to three steel fibres were placed into a cement mixture cylinder, considered as a representative volume element, so as a 30 mm of the fibre lies in the cement mixture and the remaining part serves for fibre fixation in the grip installed on the measuring device. A specimen was placed in the lower jaw and fibre fixed in the grip was intromited into the upper jaw installed in the loading machine. When the jaws became more distant, then the fibre was pulled out from the specimen. When one fibre was used, it was placed in the centre of the specimen; two and three fibres were placed in the plane passing through the centre of the specimen, symmetrically to the centre. The distance between fibres was 5 mm.

The specimens were prepared and tested progressively for three cement mixtures and for one to three steel fibres. The extreme forces needed for pulling out fibres, dependent on the number of fibres, are given in Table 1 and Figure 3. The resulting forces are derived as an arithmetic average from 30 tests. Relative error is given respectively.

The extreme forces needed to pull the steel fibres out of the cement mixture increase quite linearly with the number of fibres. Due to small dimensions of specimen and technical abilities of testing device, it was impossible to increase the number of steel fibres placed in one specimen. Therefore, it was impossible to put more fibres into one specimen. It turned out that

Table 1 Extreme forces needed to pullout tests in Newton.

Number of steel fibres	Cement mixtures					
	BP1	R[%]	BP3	R[%]	BP8	R[%]
1	39	69	272	24	118	61
2	144	40	372	36	233	35
3	254	47	523	25	344	25

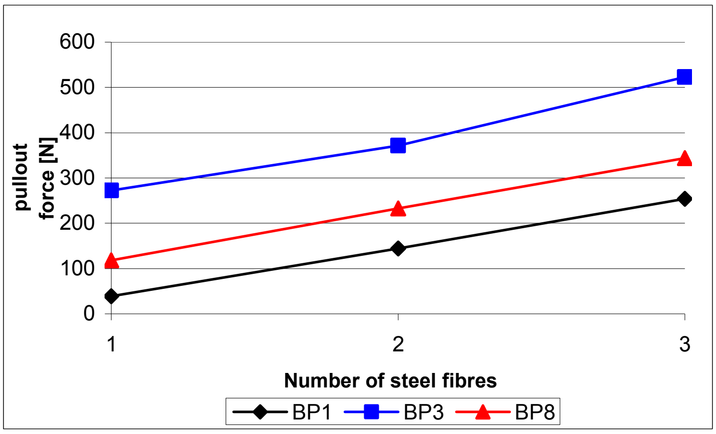

Fig. 3 Relation of the force, needed for pull out steel fibres, on the number of the steel fibres in cement mixture specimens.

the pullout force affected with the rate of the fine particles in the cement mixture.

FLEXURAL TENSILE STRENGTH AND RESIDUAL FORCES – REGULARLY PLACED FIBRES

a) DRAMIX steel fibres

With respect to laboratory equipment, specimens with a rectangular cross-section of 40 x 40 mm and a length of 160 mm were prepared. During the specimens' preparation, one, two or three steel fibres were placed in the košer third of the specimen, in a parallel way with specimens' length. 16 specimens were made and successively tested for each concrete mixture and with one, two and three steel fibres.

The testing device complied with Czech standard CSN EN 14651. A mechanical loading machine was used with a maximal loading force of 25kN, complete with a mechanism for transfer load from the testing device to the tested specimen. The mechanism consisted of two carry rollers and one load rollers. The rollers made free axial rotation possible, one carry roller and one load roller also made declination in the plane perpendicular to the longitudinal axis of the tested specimen possible (Figs. 4 and 5).

During test the force increases up to the specimen disturbance. After decrease of this force by that, second phase becomes, when increase of the force by adhesion of the fibres with cement mixture is recorded. The force needed to create crack in the

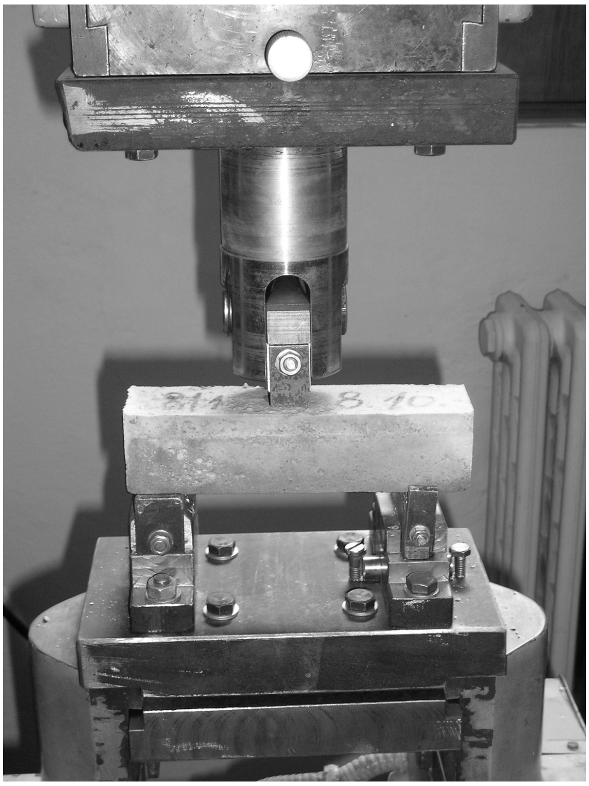

Fig. 4 Testing device with additional mechanism.

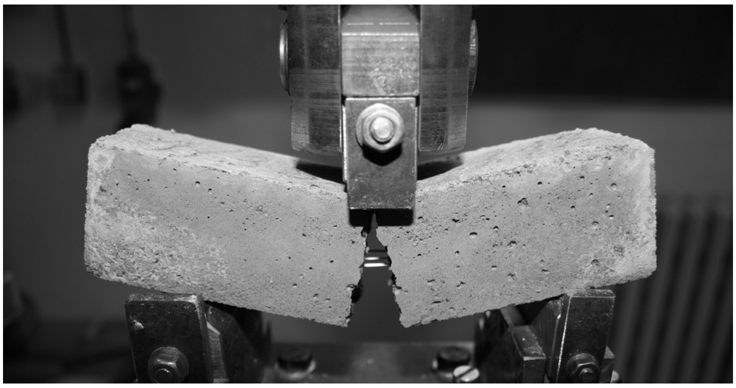

Fig. 5 Specimen after test.

Table 2 Flexural tensile strength in MPa.

Number of steel fibres	Cement mixtures					
	BP1	R[%]	BP3	R[%]	BP8	R[%]
0	2.25	22	4.42	8	2.58	11
1	2.77	4	4.93	6	2.88	7
2	2.72	8	5.16	7	2.79	5
3	2.80	12	5.11	8	2.92	11

Table 3 Residual force needed for release fibres in Newton.

Number of steel fibres	Cement mixtures					
	BP1	R[%]	BP3	R[%]	BP8	R[%]
1	59	16	201	4	110	66
2	188	18	290	12	225	10
3	258	19	347	11	296	28

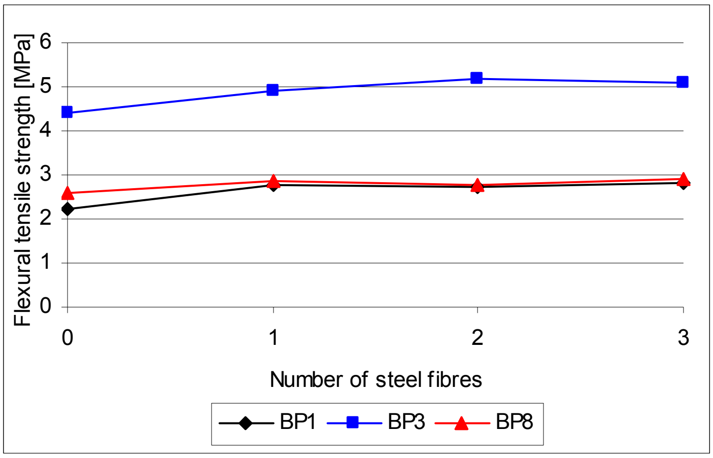

Fig. 6 Dependence of flexural tensile strength on the number of the steel fibres in cement mixture specimens.

specimen (Table 2, Fig. 6) was measured and also the extreme residual force needed for the fibres release (Table 3, Fig. 7) was determined.

Results of the tests show that the addition of steel fibres did not practically affect the flexural tensile strength; the effect was only a maximum of about 10 % to 20 % compared to unreinforced specimen, but with the number of fibres there is a significant increase of residual force needed for their release. This means that if the cement mixture

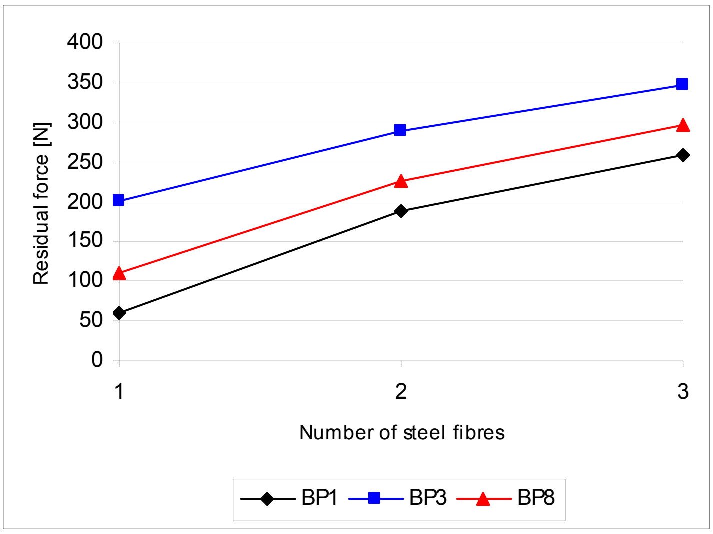

Fig. 7 Dependence of residual force on the number of the steel fibres in cement mixture specimens.

Table 4 Flexural tensile strength in MPa.

Number of fibres	Cement mixtures					
	BP1	R[%]	BP3	R[%]	BP8	R[%]
0	2.25	22	4.42	8	2.58	11
1	2.67	12	4.75	6	3.04	8
3	2.58	4	5.80	2	2.87	1
6	2.60	1	6.27	3	2.53	1

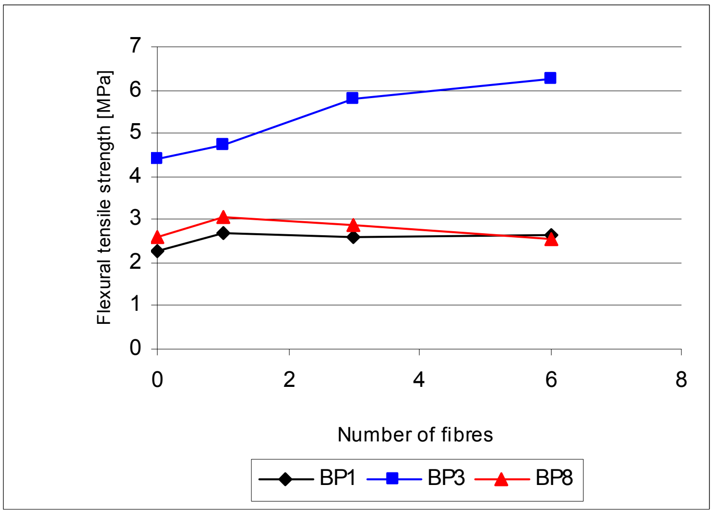

Fig. 8 Dependence of flexural tensile strength on the number of the polypropylene fibres in cement mixture specimens.

collapses by the flexural tensile strength, micro cracks arise in the specimen and the steel fibres are mobilized and take over the tensile stresses as late as their release out of the concrete. After that, the breakdown of the specimen follows.

b) BeneSteel 80/55 polypropylene fibres

BeneSteel 80/55 fibres were placed in the specimen in the same way as mentioned above. The dimensions of specimens were also the same. One, three or six fibres were placed in the specimens in successive steps.

Flexural tensile strength of fibre-reinforced cement mixture was determined greater than flexural tensile strength of unreinforced cement mixture in general. The dependence on the number of fibres was not explicit (Table 4, Fig. 8). Residual forces needed to release fibres increased with the number of fibres

Table 5 Residual force needed for release fibres in Newton.

Number of fibres	Cement mixtures					
	BP1	R[%]	BP3	R[%]	BP8	R[%]
1	29	20	25	19	15	22
3	40	13	37	15	22	13
6	107	4	130	21	103	9

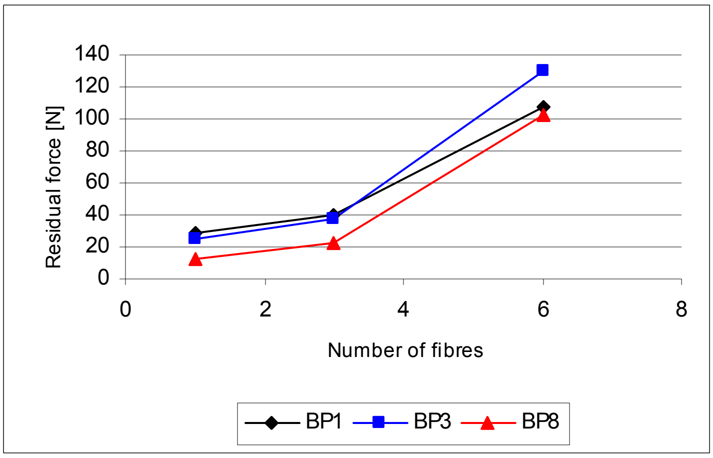

Fig. 9 Dependence of residual force on the number of the polypropylene fibres in cement mixture specimens.

for all specimens; the difference among used cement mixtures was not significant. (Table 5, Fig. 9). In comparison with the specimen with steel fibres, flexural tensile strength reached lower values. This was due to both higher adhesion of steel fibres with cement mixture and shape of steel fibres, i.e. camber on both ends of steel fibre.

FLEXURAL TENSILE STRENGTH AND RESIDUAL FORCES – RANDOMLY PLACED FIBRES

With respect to the fact that concrete mixtures reinforced with randomly placed fibres have been widely used, specimens with separate, mixed-in fibres, BeneSteel 55, were tested. Specimens with dimensions 40 x 40 x 160 mm were made from the cement mixture with 1, 3.5 and 5 grams of fibres in 1 dm^3 of the mixture, i.e. 0.04 %, 0.16 %, 0.23 % weight of undirected fibres in the specimen, respectively.

Cement mixture with a lower starting value of strength recorded increases in the flexural tensile strength depending on the weight percentage of undirected fibres in the specimen. The cement mixture, with a maximum grain size of 0.6 mm and approximately double starting value of the strength, a decrease of the flexural tensile strength with weight percentage of undirected fibres in the specimen was recorded after an initial increase of the flexural tensile strength about 21 % when the weight percentage of undirected fibres was 0.04 %. When the weight percentage of undirected fibres was 0.23 %, an increase in flexural tensile strength of only 3 % was recorded (Table 6., Fig. 10). With an increasing amount of fibres in the specimen, residual force needed for release fibres increased rapidly (Table 7, Fig. 11).

Table 6 Flexural tensile strength in MPa.

Weighted quantity of fibres (%)	Cement mixtures					
	BP1	R[%]	BP3	R[%]	BP8	R[%]
0	2.25	22	4.42	8	2.58	11
0.04	2.42	3	5.36	2	3.11	1
0.16	2.46	8	5.04	6	3.66	1
0.23	2.65	2	4.56	2	3.74	1

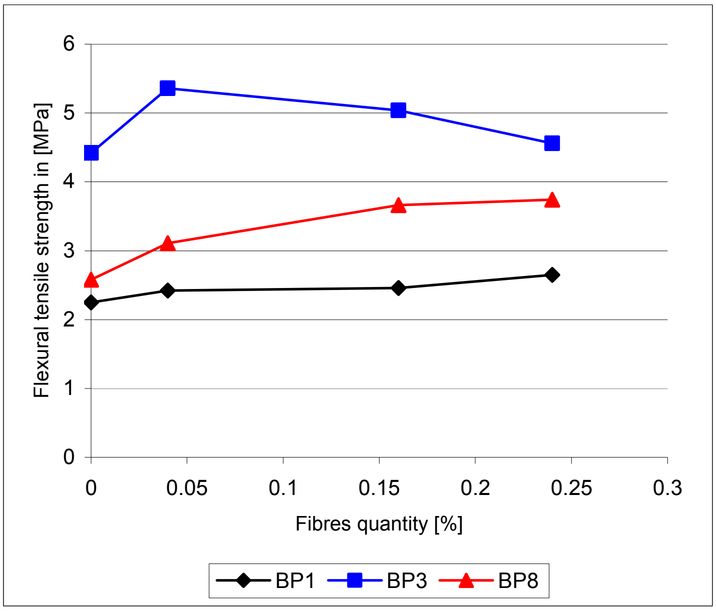

Fig. 10 Flexural tensile strength in dependence on the fibres weight quantity.

Table 7 Residual force needed for release fibres in Newton.

Weighted quantity of fibres (%)	Cement mixtures					
	BP1	R[%]	BP3	R[%]	BP8	R[%]
0.04	33	13	160	29	117	15
0.16	195	22	348	17	239	42
0.23	520	9	943	21	319	21

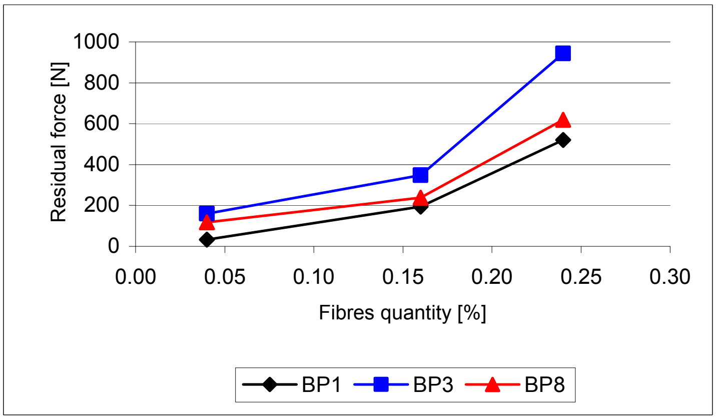

Fig. 11 Residual forces in dependence on the fibres weight quantity.

CONCLUSION

The result of pull out tests showed a linear increase of the force needed to pull steel fibre out of the cement mixture, approximately 115 N per one fibre, disregarding used cement mixture. This indicates that the mutual influence of fibre is not essentially significant; it means that in the real concrete mixture no mutual influence of fibres can be expected.

The presence of fibros in cement mixture had a very slight effect on the flexural tensile strength with number of regularly placed fibres in specimen, both steel and polypropylene fibres. Number of fibres had a significant influence on the residual forces which prevent collapse of the specimen. The residual forces increased with number of fibres, but not linearly.

Fibre-reinforced concrete has been used very often, not only for production of industrial concrete floors, but also in bridge construction, spread foundations, roof constructions, tunnel lining etc. In this way, more attention has been devoted to the study of the changes of physical and mechanical properties of concrete reinforced by various fibres.

The spread of fibre-reinforced concrete to different areas of the construction trade, where extreme conditions often occur, such as wide temperature changes, would need additional detailed research of the concrete's behaviour and knowledge of changes of its properties. Therefore, we have proposed a further research focus on this issue.

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