Comparison of material properties of steel fiber reinforced concrete with two types of steel fiber

Z Marcalíková¹, L Procházka², M Pešata², J Boháčová² and R Čajka¹

¹ Department of Structures, Faculty of Civil Engineering, VSB-Technical University of Ostrava, Ludvíka Poděště 1875/17, 708 33 Ostrava-Poruba, Czech Republic
² Department of Building Materials and Diagnostics of Structures, Faculty of Civil Engineering, VSB Technical University of Ostrava, Ludvíka Poděště 1875/17, 708 33, Ostrava-Poruba, Czech Republic

E-mail: zuzana.marcalikova@vsb.cz

Abstract. The work is focused on the area of mechanical properties of two types of Steel Fibers for reinforced concrete. In both cases, the same concrete mixture is used. The Steel Fibers used differ in shape. The first one is short and straight fiber and the second one is 3D steel fiber. Steel Fiber Reinforced Concrete was prepared at a dosage of 40 and 75 kg steel fibers/m³. The experiment includes determination of strengths, concretely compressive strength, a three-point flexural test and Splitting Tensile Strength test. The results are summarized; fracture mechanics parameters necessary for structural modeling are also included.

1. Introduction
Steel fiber reinforced concrete is classified as a fiber reinforced composite [1]. Fiber concrete can vary by class of concrete, type of fibers, and its shape, length, diameter and surface finish [2, 3, 4, 5]. For building structures such as floors, foundations of buildings [6, 7, 8] or tunnel linings, it is often more favorable to use fiber reinforced concrete than conventional reinforced concrete or conventional concrete. Reinforcing the concrete by means of fibers increases the tensile strength [9, 10] of the concrete and the ductility. Other advantages of fiber reinforced concrete are reduced shrinkage cracking [11] and reduced concrete deformations, increased toughness and fatigue strength, improved cohesion. For the use of fiber reinforced concrete in construction, it is necessary to know in detail its properties [12, 13, 14], which are most commonly tested in laboratories on test specimens. The research results can be found in a number of recommendations [15] and technical conditions [16]. There are also a number of Steel Fiber Reinforced concrete associations such as RILEM [17], DaStB [18], BS [19] and Model Code 2010 [20]. Contemporary studied topics in the area of reinforced fiber concrete in the Czech Republic include, for example, durability determination and verification of mechanical properties. Also the possibilities of using secondary raw materials, such as cement kiln dust, are monitored.

2. Theory of experimental work
Tests of steel fiber reinforced concrete include determination of compressive strength on cubes a typical size of 150 x 150 x 150 mm. Testing compressive strength on cubes is always perpendicular to the filling direction.

Other tests included in the experimental program include splitting tensile strength tests. Two variants were chosen: perpendicular to the filling direction and parallel to the filling direction. The reason for this double test is checking homogeneity of fibers in test samples. The diagram of the test is shown in figure 1. The splitting tensile strength test is determined by the following formula:

\[ f_{ct,sp} = \frac{2 \cdot P_{\text{max}}}{\pi \cdot l \cdot d} \]  

where \( P_{\text{max}} \) is the maximum load, \( l \) is the length of the contact line of the body and \( d \) is the chosen cross-sectional dimension of the body.

![Figure 1. Tests of compressive strength and splitting tensile strength (parallel and perpendicular to the filling direction).](image1)

![Figure 2. Three-point bend test.](image2)

In order to verify the suitability of the test and to determine the fracture mechanics parameters, a three-point bend test in design is performed. The test scheme is shown in figure 2. The flexural strength of concrete in the case of a three-point bend configuration is determined:

\[ f_{ct,3B} = \frac{3 \cdot P_{\text{max}} \cdot L}{2 \cdot b \cdot (h - a_0)^2} \]

where \( P_{\text{max}} \) is the maximum load; \( L, b \) and \( h \) are dimensions: span, width and height of the cross-section, and the height of notch is \( a_0 \).

For wider classification of brittleness of concrete, it is also important to determine the fracture parameters of the concrete, which are also needed to investigate the creation and crack growth. The most critical fracture mechanics parameter is fracture work \( A \). It is the energy that the body takes until it is completely broken. The test bodies are provided with a notch in the middle of their span, so that cracks in the middle of the concrete beam could be expected. The cuts are most often performed at 1/3 of sample height. In order for us to correctly perform the three-point bend test, fibers with a maximum length of 60 mm are required for reinforced concrete samples and suitable concrete with a grain fraction of maximum 32 mm is also required. The size of the fraction of aggregate also has a large impact on the value of fracture energy \( W_f \), the larger the fraction of the aggregate used, the higher the value of fracture energy we can expect. From the load diagram, the fracture energy of \( W_f \) can be determined. Fracture energy is an integral that is equal to the area under the load diagram or so-called
work $A$ needed to create a crack, divided by the unit of surface of the test body without considering the notch depth. The fracture energy is defined as follows:

$$ W_f = \frac{A}{h \cdot (b - a_0)} $$

(3)

3. Steel fiber reinforced concrete

For the experiment, Dramix OL13/20 [21] and Dramix 3D 55 30BG [21] steel fibers in dosage of 40 and 75 kg/m$^3$ were selected. The basic characteristics of these steel fibers are listed in table 1. The concrete matrix has the recipe shown in table 2. Samples were prepared in the laboratory.

| Table 1. Basic properties of Dramix® steel fibers [21]. |
|----------------------------------------|-----------------|-----------------|
| Property                               | Dramix® OL 13/20 (Figure 3) | Dramix® 3D 55/30BG (Figure 4) |
| Length [mm]                            | 13              | 30              |
| Diameter [mm]                          | 0.21            | 0.55            |
| Flexural strength [N/mm$^2$]           | 2750            | 1345            |
| Dosage [kg/m$^3$]                      | 60              | 25              |
| Modulus of elasticity [GPa]            | 200             | 200             |

Figure 3. Dramix® OL13/20. Figure 4. Dramix® 3D 55/30BG.

The concrete mixture used for the tested samples can be classified as conventional concrete C25/30.

| Table 2. Basic characteristics of the concrete mix C 25/30. |
|----------------------------------------------------------|-----------------|
| Description                                              | Mixture [kg/m$^3$] |
| Cement                                                  | CEM WA-S 42.5   |
| Minimum amount of cement                                 | 320 kg          |
| Water-cement ratio w/c                                   | 0.625           |
| Aggregates 0/2 DTK Mankovice                            | 525 kg          |
| Aggregates 0/4 DTK Mankovice                            | 420 kg          |
| Aggregates 4/8 Tovačov                                  | 150 kg          |
| Aggregates 8/16 HDK                                      | 820 kg          |
| Water                                                    | 200 l           |
| Plasticizer STACHEPLAST                                 | 3.2 l           |
4. Compressive strength of concrete

Compressive strength testing included three samples for each variant. In total, 12 tests were performed. In the case of a 75 kg/m$^3$ wire dosing variant, the compressive strength was higher. The difference, however, was relatively small. Especially for Dramix OL13/20 steel fibers. The results are summarized in the graph in figure 5. Compressive strength for 40 kg/m$^3$ fibers was 36.4 MPa for Dramix OL13/20 and 38.5 MPa for Dramix 3D 55/30BG. In the 75 kg/m$^3$ version, the strengths were very similar to 40.1 for Dramix OL13/20 and 40.9 MPa for Dramix 3D 55/30BG. The aggregate compressive strengths and bulk weights are shown in tables 3 and 4.

![Figure 5. Compressive strength (cube).](image)

![Figure 6. Bulk density.](image)

Table 3. Compressive Strength - Cubic [MPa].

| Value | Amount of fibers [kg/m$^3$] | Type of fiber | Value |
|-------|-----------------------------|---------------|-------|
| MIN   | 40                          | 37.1          | 40    |
|       | 75                          | 37.3          | 2302  |
| MAX   | 40                          | 40.8          | 75    |
|       | 75                          | 42.0          | 2319  |
| Average | 40                          | 38.5          | 40.2  |
|       | 75                          | 42.1          | 2311  |

Table 4. Bulk weight [kg/m$^3$].

| Value | Amount of fibers [kg/m$^3$] | Type of fiber | Value |
|-------|-----------------------------|---------------|-------|
| MIN   | 40                          | 2302          | 40    |
|       | 75                          | 2311          | 2319  |
| MAX   | 40                          | 2315          | 75    |
|       | 75                          | 2339          | 2358  |
| Average | 40                          | 2310          | 40.2  |
|       | 75                          | 2330          | 2380  |

5. Splitting tensile strength

For the splitting tensile strength test was applied, i.e. 12 samples perpendicular to the filling direction and 8 samples parallel to the filling direction. The weight of these samples was about 8 kg. On the basis of the tests, the splitting tensile strengths computed for the direction perpendicular to the filling direction are shown in table 5 and parallel to the filling direction are shown in table 6. In the case of Dramix OL13/20 fibers, the difference in the dosage of 40 and 75 kg/m$^3$ was minimal. Flexural strengths were 3.1 MPa. A noticeable difference can be observed for Dramix 3D 55/30BG fibers. In this case, the strengths were 2.8 and 4 MPa. The difference, therefore, is more than 1 MPa. Also interesting are the results for strengths parallel to the filling direction. In all cases, the strength was lower. Smaller difference was detected in Dramix OL13/20 fibers. For Dramix 3D 55/30BG fibers, the
The difference was 75 kg/m$^3$ with a difference of more than 1 MPa. For samples with a fiber dosage of 40 kg/m$^3$, the difference in homogeneity depending on the direction of testing was small. The greater splitting tensile strength was in the direction perpendicular to the filling direction. Larger differences in the strength are for samples with a fiber dosage of 75 kg/m$^3$. The results are also marked in figure 7.

### Table 5. Splitting tensile strength - perpendicular to the filling direction [MPa].

| Value | Amount of fibers [kg/m$^3$] | Type of fiber | 
|-------|-----------------------------|---------------|
|       | Dramix OL13 | Dramix 3D | 
| MIN   | 40 | 2.8 | 2.6 |
|        | 75 | 2.6 | 3.6 |
| MAX   | 40 | 3.3 | 3.0 |
|        | 75 | 3.4 | 4.2 |
| Average | 40 | 3.1 | 2.8 |
|        | 75 | 3.1 | 4.0 |

### Table 6. Splitting tensile strength - parallel to the filling direction [MPa].

| Value | Amount of fibers [kg/m$^3$] | Type of fiber | 
|-------|-----------------------------|---------------|
|       | Dramix OL13 | Dramix 3D | 
| MIN   | 40 | 2.7 | 2.3 |
|        | 75 | 2.5 | 2.7 |
| MAX   | 40 | 2.7 | 2.6 |
|        | 75 | 2.6 | 2.8 |
| Average | 40 | 2.7 | 2.4 |
|        | 75 | 2.5 | 2.7 |

6. Three-point bend test

Another test of the concrete was a three-point bend test. A total of 12 beams of 150 x 150 x 600 mm were prepared in the laboratory with a notch in half-span. The depth of notch was 50 mm and the span at the loading test was 500 mm. The weight of the samples was approximately 31 kg. Six beams were reinforced by Dramix OL13/20 fibers, of which 3 beams had a fiber content of 40 kg/m$^3$ and 3 beams of 75 kg/m$^3$. Other six beams were reinforced with Dramix 3D 55/30BG fibers, of which 3 beams had a fiber content of 40 kg/m$^3$ and 3 beams of 75 kg/m$^3$. After 28 days, the three-point bend test was performed. Based on the results, the strength of all samples was subsequently determined (table 7). The test load was applied until the deflection was 8 mm. The flexural strength was very similar for both types of fiber dosing. The flexural strengths with Dramix OL13/20 fiber were 4.7 and 5 MPa. For Dramix 3D 55/30BG fibers, the flexural strengths were 4.3 and 5 MPa. The results are also marked in figure 8.
Table 7. Flexural strength in a three-point bend test.

| Value | Amount of fibers [kg/m³] | Type of fiber | \( \text{Type of fiber} \) |
|-------|-------------------------|--------------|-------------------------|
| MIN   | 40                      | 4.4          | 4.2                     |
|       | 75                      | 4.5          | 4.8                     |
| MAX   | 40                      | 4.9          | 4.6                     |
|       | 75                      | 5.8          | 5.2                     |
| Average | 40                    | 4.7          | 4.3                     |
|       | 75                      | 5.0          | 5.0                     |

Table 8. Fracture energy values corresponding to 8 mm deformation [N/m].

| Value | Amount of fibers [kg/m³] | Type of fiber | \( \text{Type of fiber} \) |
|-------|-------------------------|--------------|-------------------------|
| MIN   | 40                      | 1189         | 1699                    |
|       | 75                      | 1329         | 2973                    |
| MAX   | 40                      | 1518         | 2956                    |
|       | 75                      | 2043         | 3603                    |
| Average | 40                 | 1352         | 2272                    |
|       | 75                      | 1665         | 3354                    |

An evaluation of all load diagrams shown in Figures 9 and 10 was also carried out, as well as the determination of the work \( A \) respectively of fracture energy \( W_f \), for deformations of 8 mm.

Figure 9. Dramix OL13/20 load test process with fiber dosing of 40 kg/m³ and 75 kg/m³.

Figure 10. Dramix 3D 55/30BG load test process with fiber dosing of 40 kg/m³ and 75 kg/m³.

The curve of the diagram for both dosages is very similar. Slightly greater residual flexural strength occurs at higher dosages of fibers. For Dramix 3D 55/30BG, the differences are more pronounced. Also, in the case of the 75 kg/m³ dosage, the flexural strengths have two peaks. However, fracture energy needs to be determined for a more detailed description. The average fracture energy values are shown in table 8.

To illustrate the behavior of the fiber-reinforced concrete, a comparison of the working diagrams for the same dosing but different fibers in figures 11 and 12 is also made.

7. Results and discussion

The work dealt with the fracture mechanics parameters of selected two types of steel fiber reinforced concrete that differed in the dosage of fibers, which was 40 and 75 kg/m³. Specifically, Dramix OL13/20 straight fibers and curved fibers Dramix 3D 55/30BG were selected for the experiment. The
results have shown effect of fibers on the compressive strength and the flexural strength of the concrete.

Figure 11. Dramix OL13/30 and Dramix 3D 55/30BG stress tests (bending) with fiber dosing of 40 kg/m$^3$.

Figure 12. Dramix OL13/30 and Dramix 3D 55/30BG stress tests (bending) with fiber dosing of 75 kg/m$^3$.

However, the stronger effect of the fibers is in the case of flexural strength and fracture energy. It has also been shown that the flexural strength parallel to the filling direction is lower than in the direction perpendicular to the filling. Smaller differences were for Dramix OL13/20 fibers. The flexural strength difference was small for Dramix OL13/20 fibers for both dosings. However, the fracture energy was higher. Larger differences were for Dramix 3D 55/30BG fibers, both in flexural strength and fracture energy. Also, the curves of the diagrams were different. In the case of Dramix 3D 55/30BG and 75 kg/m$^3$, two peaks of flexural strength were even achieved in some cases. In the case of Dramix 3D 55/30BG fibers, higher residual flexural strength remains even after the test. Another possibility of expanding the knowledge about the mechanical properties of fiber concrete is to identify detailed fracture parameters [22], [23] suitable for advanced nonlinear analyzes of concrete structures [24], [25] where authors focus on this area in further research.

Acknowledgement
The work was supported by means of the project Utilization of secondary raw material in geopolymers production and by Conceptual development of science, research and innovation assigned to VŠB-TUO by the Ministry of Education, Youth and Sports of the Czech Republic.

References
[1] Brandt A M 2008 Fiber reinforced cement-based (FRC) composites after over 40 years of development in building and civil engineering Composite Structures vol 86 (1-3) pp 3–9
[2] Katzer J and Domski J 2012 Quality and Mechanical Properties of Engineered Steel Fibres Used as Reinforcement for Concrete Construction and Building Materials vol 34 pp 243–48
[3] Holschemachera K, Muellera T and Ribakov Y 2010 Effect of steel fibres on mechanical properties of high-strength concrete Materials& Design vol 31 iss 5 pp 2604-2615
[4] Koniki S and Ravi P D 2018 A study on mechanical properties and stress-strain response of high strength concrete reinforced with polypropylene–polyester hybrid fibres Cement, Wapno, Beton iss 1 pp 67-77
[5] Kasagani H and Rao C B K 2016 The influence of hybrid glass fibres addition on stress – Strain behaviour of concrete Cement, Wapno, Beton iss 5 pp 361-372
[6] Vaskova J and Cajka R 2018 Interaction of nonlinear numerical model of SFRC slab and nonlinear numerical subsoil model International Journal of GEOMATE vol 15 iss 47 pp 103-110 DOI: 10.21660/2018.47.3576

[7] Labudkova J and Cajka R 2017 3D numerical model in nonlinear analysis of the interaction between subsoil and sfcr slab International Journal of GEOMATE vol 13 iss 35 pp 120-127.

[8] Sucharda O, Bilek V, Smirakova M, Kubosek J and Cajka R 2017 Comparative Evaluation Of Mechanical Properties Of Fibre-ReinforcedConcrete And Approach To Modelling Of Bearing Capacity Ground Slab Periodica Polytechnica: Civil Engineering vol 61 iss 4 pp 972-986 DOI:10.3311/PPci.10688

[9] Kurihara N, Kunieda M, Kamada T, Uchida Y and Rokugo K 2000 Tension softening diagrams and evaluation of properties of steel fibre reinforced concrete Eng Fract Mech vol 65 pp 235-245 https://doi.org/10.1016/S0013-7944(99)00116-2

[10] Tipka M and Vasková J 2017 Tensile properties of structural fibre reinforced concrete of Fiber Concrete 2017 IOP Conf. Ser.: Mater. Sci. Eng. vol 246 DOI: 10.1088/1757-899X/246/1/012052

[11] Sucharda O and Bilek V Aspects of Testing and Material Properties of Fiber Concrete 25th Concrete Days 2018 pp 1-6

[12] Zaborski A 2016 Constitutive model for restricted compression of fiber concrete Cement, Wapno, Beton iss 1 pp 46-52

[13] Kormanikova E and Kotrasova K 2011 Elastic mechanical properties of fiber reinforced composite materials Chemieke Listy vol 105 iss 17

[14] RILEM TC 162-TDF 2002 Test and Design Methods for Steel Fiber Reinforced Concrete – Design of Steel Fiber Reinforced Concrete Using the σ-w Method: Principles and Application. Materials and Structures/Matériaux et Constructions vol 35 iss 249 pp 262–267

[15] di Prisco M, Colombo M and Dozio D 2013 Fibre- reinforced concrete in fib Model Code 2010: principles, models and test validation Structural Concrete vol 14 iss 4 pp 342-361

[16] RILEM 2011 About Rilem [Online] [Accessed on 4 May 2011]

[17] DAfStb guidelinel 2011 DAfStb-Richtlinie Stahlfaserbeton. Deutscher Ausschuss für Stahlbeton – DAfStb, Berlin, German. (In German)

[18] BS EN 14721: Test method for metallic fibre concrete – Measuring the fibre content in fresh and hardened concrete. BSI, 2005, 2007.

[19] Model Code 2010 – Final Draft, fib, Bulletin No 65 and 66. 1-2. 2012 http://www.bekaert.com/en/products/construction/concrete-reinforcement.

[20] Sucharda O, Pajak M, Ponikiewski T and Konecný P 2017 Identification of mechanical and fracture properties of self-compacting concrete beams with different types of steel fibres using inverse analysis Construction and Building Materials vol 138, pp 263-275 DOI: 10.1016/j.conbuildmat.2017.01.077

[21] Sucharda O, Konecný P, Kubosek. Done P. J. Finite element modelling and identification of the material properties of fibre concrete In Conference: 23rd Conference of Italian Group of Fracture Location: Sicily, Procedia Engineering, vol. 109, pp. 234-239, 2015.

[22] Sucharda O, Lehner P, Konecný P and Ponikiewski T 2018 Investigation of Fracture Properties by Inverse Analysis on Selected SCC Concrete Beams with Different Amount of Fibres Ec22 - Loading And Environmental Effects On Structural Integrity Procedia Structural Integrity vol 13 pp 1533-1538 DOI: 10.1016/j.prostr.2018.12.313

[23] Sucharda O and Konecný P 2018 Recommendation for the modelling of 3D non-linear analysis of RC beam tests Computers and Concrete, vol 21 iss 1 pp 11-20 DOI: 10.12989/cac.2018.21.1.011

[24] Sucharda O, Smirakova M, Vaskova, J., Mateckova P, Kubosek J and Cajka, R Punching Shear Failure of Concrete Ground Supported Slab International Journal of Concrete Structures and Materials vol 12 iss 1 Article number 36 DOI: 10.1186/s40069-018-0263-6