CONCRETE MATRIX PROPERTIES INFLUENCE ON FIBRE REINFORCED CONCRETE MECHANICAL BEHAVIOUR

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Abstract

At present, Steel Fiber Reinforced Concrete (SFRC) has been widely applied in civil engineering as construction material. The task of SFRC successful application in construction design needs the material behavior durable prediction depending on fibre type, its content and concrete mix composition. Within the framework of these research tree types of concrete mix with constant fiber content 140 kg/m^3 were investigated: conventional strength concrete, high strength concrete and ultra high strength concrete. Using special method of mix design quite workable and flowable mixes was obtained. Produced samples were tested under 4-point bending test, as a result deflection – applied force diagrams were obtained. Elasticity modulus and concrete compressive strength also were determined. Obtained results analysis was done. Performed investigations allow to conclude how to reach higher SFRC mechanical characteristics on the basement of more optimal concrete matrix mix composition.

Keywords: Steel fibre, concrete, bending test, compressive strength

1 Introduction

Initially fibres were added in concrete to improve mechanical properties of plain concrete having compressive strength 20 – 50 MPa. Fibre dosage in this case is 1…2 % from concrete volume (80…160 kg in 1m^3). Stress – strain behaviour of SFRC concrete using plain concrete matrix was investigated sufficiently. Although SFRC has been known already since the beginning of previous century, only recent achievements in concrete chemistry (i.e. superplasticizers, ultra-fine fillers and the invention of self compacting concrete) have opened new possibilities for fibre reinforced concrete with advanced physical and mechanical characteristics. In order to obtain high bending strength usually increases concentration of steel fibres up. Material with very high fibre content (volume fraction up to 20%) was elaborated at the end of 1980th, and is known as *Sifcon* [1]. The way of fibre content increasing is expensive economically because the fibre price is rising up the whole of SFRC construction member price. Nowadays Steel Fibre Reinforced Concrete have been applied more and more widely in building construction as load-bearing material for floor slab, tunnel walls etc. SFRC construction design methods consider

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mainly amount and type of fibre, but influence of concrete matrix mechanical properties on final product is not investigated sufficiently. Quit modern direction in concrete technology is to use the dispersed fibre reinforcement in combination with concrete matrix having very high compressive strength. Such material is designated as High Performance Fibre Reinforced Concrete (HPFRC) [7]. Modern SFRC construction design methods provides predicting bending behaviour of SFRC on the base of fibre pull-out mechanism, or bond between steel fibre and concrete matrix [2, 3]. One of the ways to improve this bond is to use high strength matrix. The aim of this work is to investigate mechanical behaviour of SFRC using concrete matrix with different compressive strength properties.

2 Materials and mix proportions

Modern Steel Fibre Reinforced Concrete is multi-component mix, containing more than 10 components. Course, fine and ultra-fine aggregates, different admixtures and fibres are necessary to provide mix workability as well as required mechanical characteristics of the material. Adding steel fibres to conventional concrete mix significantly decrease mix workability. A new approach to SFRC mix design provides necessity for higher paste content (up to 36-50 % by volume) in SFRC concrete mix, (what is close to self-compacting concrete mix composition). Our first mix (MIX 1) was designed as traditional strength concrete, having compressive strength class C16/20. Used cement content was 339 kg per 1m^3, local available aggregates were: natural gravel 2/10 mm, sand combination 0.3/2.5 and 0/1 mm as well as dolomite micro filler. Mix proportion is shown in Table1.

Table 1

SFRC mix compositions

Description:	**MIX 1**	**MIX 2**	**MIX 3**
Portland cement CEM I 42.5 N	339	309	500
Portland cement CEM I 52.5 N		188	250
Chrushed diabaz 0-5 mm			246
Chrushed diabaz 2-5 mm		157	483
Natural gravel 2-10 mm	697	256	
Natural sand 0.3-2.5 mm	697	880	260
Quartz sand 0-1 mm	199	166	208
Filler (Dolomite powder)	159	103	
Filler (Quartz powder)			104
Silicafume SF (microsilica)		50	83
Water	206	204	227
Superplasticizer	1.0	9.9	14.7
Fiber 60 mm Dramix	139	139	146
Water/(Cement+SF)	0.61	0.37	0.27

Water/Cement	0.61	0.41	0.30

The second (MIX 2) is high strength concrete mix, having strength class C80/95. Microsilica and high amount of super plasticizer was used in order to decrease water cement ratio and obtain dense cement matrix with close to self-compacting concrete properties. The third mix (MIX 3) was designed as High Performance Concrete (compressive strength higher than C100/115). The main peculiarity of this mix is high cement content (750 kg in 1 m^3), dense aggregates and use the advanced micro filler (microsilica in combination with quartz powder) to obtain optimal particle packing at material micro-level. The same straight steel fibres having hooked ends was applied in all tree SFRC mixes. The length of fibres was 60 mm, diameter 0.8 mm, (what corresponds to aspect ratio equal to 75). Steel fibre content 140 kg/m^3 was the same for all three SFRC mixes.

3 Experimental methods

Experimental program had included samples manufacturing (cubes and beams), samples curing and testing under bending and compression with the goal to obtain material mechanical properties.

3.1. Sample manufacturing and curing

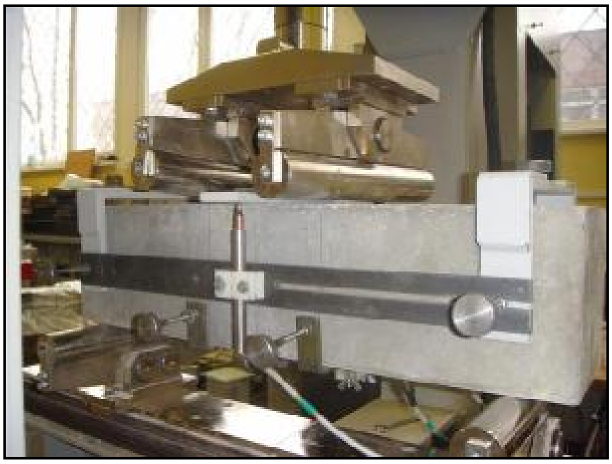
Concrete mixes were moulded according to method [4]. The samples were cured according to standard conditions (temperature 20$\pm$2^{o}C, humidity >95%). All tests were performed after the 56-day ageing period.

3.2. Compression and bending tests

Sample cubes 150x150x150 mm were tested for compression strength in conformity with Latvian building code [5], the rate of loading was 0.7 MPa/sec. The compressive strength has been checked on the compression testing machine with accuracy $\pm$1%. Samples were weighed preliminary to determine material density.

Beams 150x150x600 mm were used for bending tests. Prior to test, 10 mm deep notch was cut by diamond saw at the middle point of bottom part of each sample. Four-point bending loading scheme was realized, providing the distance between base 500 mm and 150 mm the distance between upper rolls (see Fig 1). Two special displacement transducers were used to measure beam deflection in the span middle point and one additional for measurement crack mouth opening dimension (CMOD).

Samples 150x150x300 mm were used for E-modulus testing under compression. The samples were loaded uniformly in compression testing machine with the rate 0.7 MPa/sec. Special indicators were used for micro-strain measurement. The distance between measuring points was130 mm.



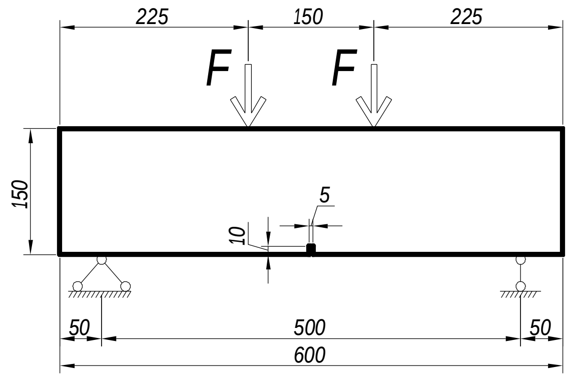


Fig. 1 Fiber concrete prism 4-point bending test.

4 Results and discussions

Strain – stress curves were obtained during the bending test, were summarized in Fig. 2. Minimum deviations between one mix samples correspond to good material homogeneity. Obtained in compression tests stress – strain diagrams are shown in Fig. 3. Cube compression testing results as well as characteristics obtained from strain – stress diagrams, are summarized in Fig 4.

Analysing obtained experimental results it may be concluded that high strength concrete matrix provides higher value for bending and compression E-modulus. Bending strength of MIX 3 samples is almost 2 times higher then strengths of MIX 1 samples despite on the same fibre content. High strength concrete provides higher elastic properties of material as well as more effective material post-crack behaviour.

It must be mention that during bending tests no fibre rapture was observed for all 3 mixes; in all cases fibre pull-out mechanism took place. It means that higher flexural strength, in the case of high strength concrete matrix, can be explained by higher bond between fibre and concrete matrix.

Important question for SFRC practical application is the comparative cost evaluation for concrete mixes MIX1-MIX3 is shown in Table 2. Despite the higher price for the unit volume materials with matrix having higher compressive strength consequently have lower price for mechanical properties.

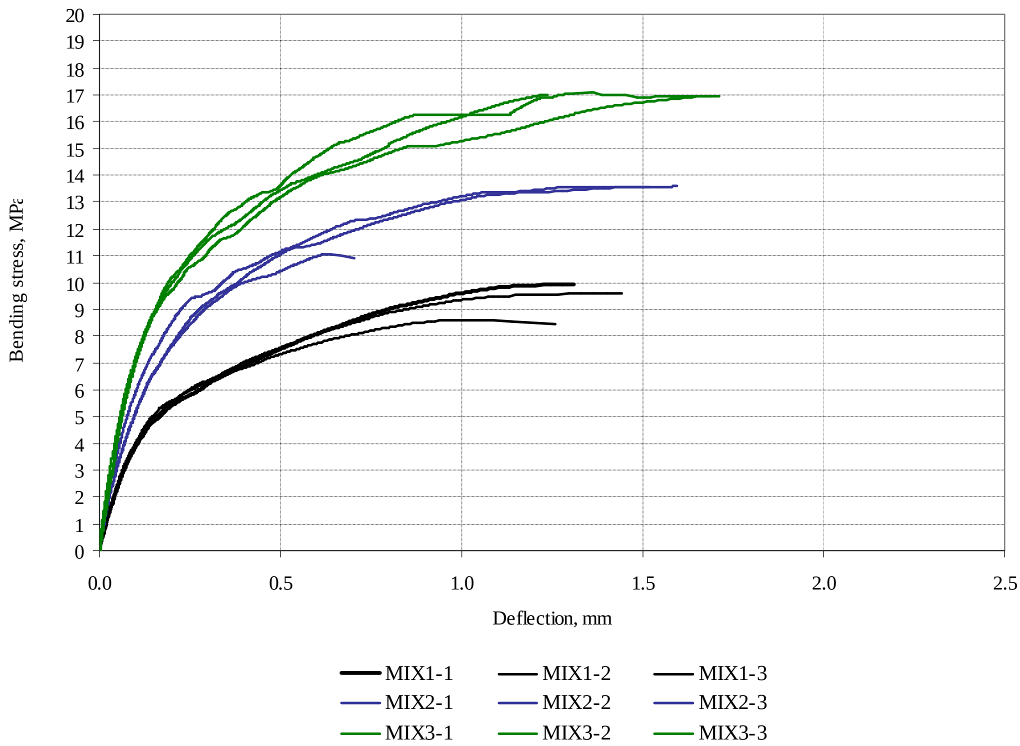


Fig. 2. Bending stress – deflection diagrams (sample 150x150x600 mm)

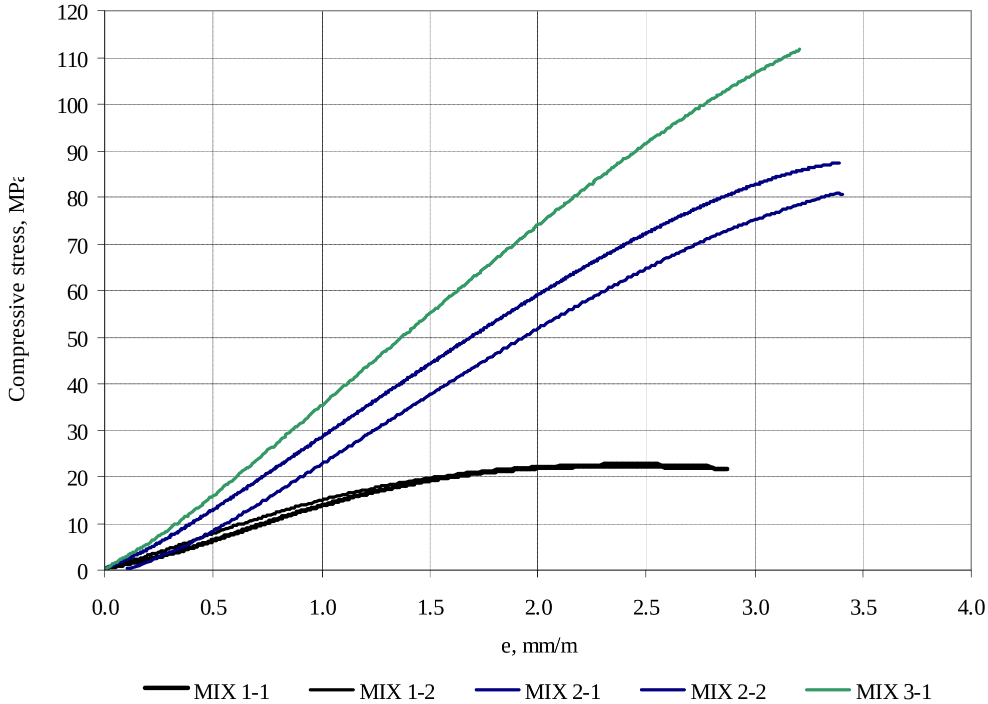


Fig. 3. Compression stress – deflection diagrams (sample 150x150x300 mm)

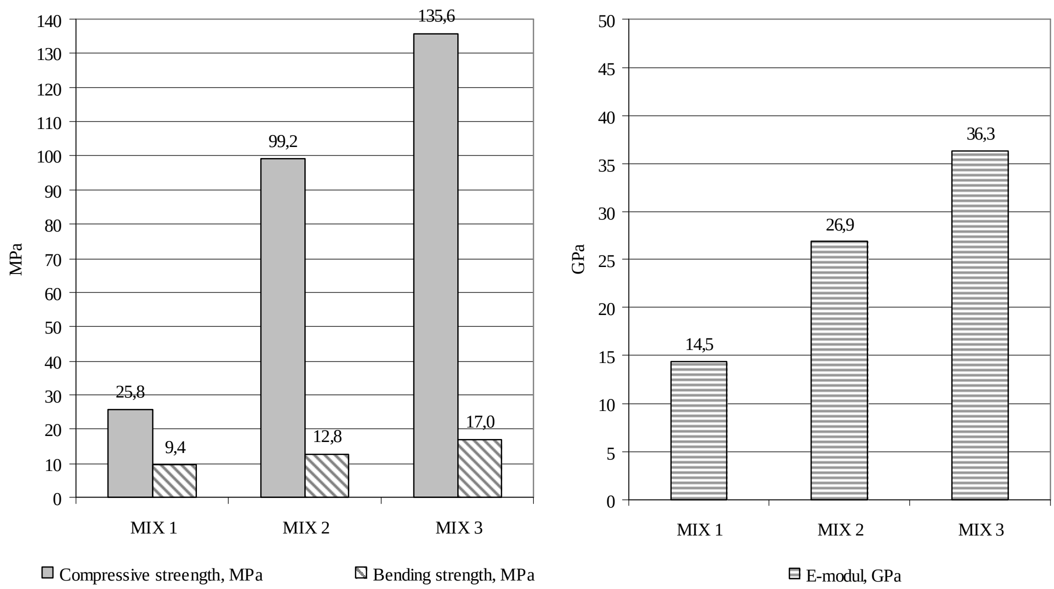


Fig. 4 Compressive strength, bending strength and E-modul test summarized results

Table 2

Economical considerations of SFRC mix

Cost (EUR) per 1 m^3:	**MIX 1**	**MIX 2**	**MIX 3**
concrete matrix	50	113	159
fibre	160	160	160
total SFRC	**210**	**273**	**319**
Cost of 1 MPa compr. strength	8.1	2.8	2.3
Cost of 1 MPa bending strength	22.4	21.3	18.7

5 Conclusions

Using SFRC concrete as construction material one of the important factors is not only steel fibre type and content, but mechanical properties of concrete matrix. For example, in performed experimental investigation, high strength concrete use leads to possibility significantly improve bending material behaviour (up to 80 %: from 9.4 to 17.0 MPa).

Analysing economical aspects of 3 different SFRC mix types can be concluded: SFRC concrete based on High Performance Concrete matrix has minor cost for 1 MPa bending and compressive strength comparing with materials based on mechanically weaker matrixes.

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