RHEOLOGICAL AND MECHANICAL PROPERTIES OF STEEL FIBRE REINFORCED SELF-COMPACTING CONCRETE IN PRECAST SLABS

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Abstract

In the paper the basic influence trends of different composition and properties of steel fibres on fresh mixture and mechanical properties (compressive and flexural strength researching in different length of precast beams) of Self-Compacting Concrete (SCC). Discussion about the results covers mechanism of fibres influence on effectiveness of admixtures. Presented relations can be used for selecting of optimal admixtures in presence of steel fibres as well as for control of properties of fresh SCC containing fibres. The research has shown the negative influence of fibres added to concrete mix on its rheological properties and workability. Optimal addition of superplasticizers improves its properties, and becomes positive as an additive to concrete mixes. The current state of knowledge is not sufficient to effectively control of mixtures with fibres according rheological and mechanical properties. Results of this study reveal that the usage of steel fibres with an addition of SP for SCC with the lowest yield point and viscosity. It compels to recognize the real nature of workability and to determine the impact of SP and fibres on phenomena taking place in fresh and hardened self-compacting concrete.

Keywords: steel fibre; self-compacting concrete; rheology; workability; Bingham model

1. Introduction

Little known research area is the influence of formation methods of self-compacting mixtures with the addition of steel fibres (SFRSCC) on the behavior of assumed technological and mechanical properties of concrete in the design process. There is no information on the actual dispersion and orientation of fibres in the mixture in the course of technological processes. The effect of steel fibres on the self-compactibility of concrete has been investigated already [1-3], including the examination of its mechanical properties at the same time [4-6]. However, studies on development of this technology, including the deployment of fibre in the mixture, are far less advanced. This is due to the complexity of

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such advanced research methods and limited methods for verifying such concrete structures. The addition of dispersed reinforcement enhances to varied degree various concrete properties, at the same time it creates difficulties in preparing a composition, which satisfies the conditions of a self-compacting, homogeneous matrix in the whole volume, and also significantly improves the physical-mechanical properties [7-8]. The most important issue is to determine the fibre distribution dispersed in various formed structural elements depending on the method of their self-compacting mixture's forming, taking into account the rheological properties of the mixture, as well as the volume ratio and geometrical parameters of steel fibres. The main objective of this study was to determine distribution and orientation of steel fibres in tested SFRSCC for a chosen structural model and its effect on mechanical properties. The aim of presented research was to determine the distribution of steel fibres in SFRSCC in specific case of the corner beam concreting of the structural element and the effect of the fibres on concrete's mechanical properties. Beam structural elements are specific but commonly performed concrete structures, hence the authors' proposal to analyze SFRSCC properties in suggested elements in terms of selected technological factors.

2. Research methodology

As a structural model, concrete beams with dimensions 1800×150×150 mm (Fig. 1A) and 1200×150×150 mm (Fig. 1B) were chosen, where concrete mixture was introduced to the form in one of the edge points (Fig.1). After hardening, elements were cut into two or three samples with dimensions 600×150×150 mm.

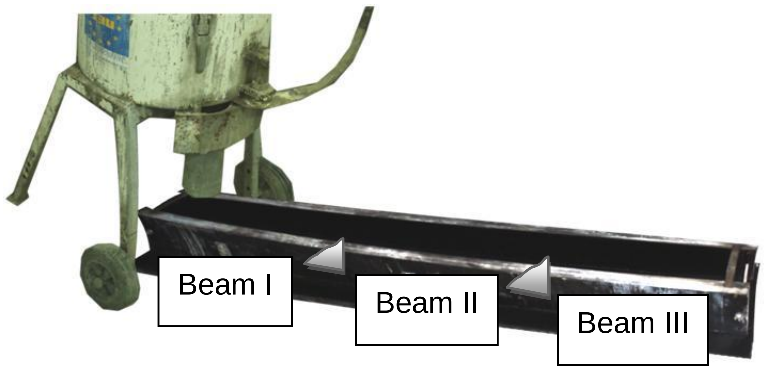

Fig. 1A. Methodology of forming concrete in case of concrete beam 1800x150x150 mm

Fig. 1B. Methodology of forming concrete in case of concrete beam 1200x150x150 mm

Obtained beams were analyzed by computed tomography, described earlier in the work [9] and measured their strength to tensile tests in bending, according to RILEM recommendations [10]. The composition of tested self-compacting mixtures is presented in Table 1. Two types of steel fibres were considered on three levels of volume ratio. The properties of used steel fibres are presented in Table 2. The self-compactibility of the mixture met the criterion throughout the interval of varying fibre content. The flow diameter of the reference mixture was SF=770 mm. The addition of SW35 and SW50 fibres did not effect significantly the value of SF, due to good plastic viscosity of the reference sample SCC mixture. The beams were deformed after 24 hours, and then cut into two or three parts of 600 mm in length. Indications I, II, III were assigned, depending on the increasing distance from the position of mixture's introduction. The influence of steel fibres type, fibres content and kind of forming beam on the flexural strength of SFRSCC are presented in Table 3.

Tab. 1: Composition of SFRSCC mix

Cement CEM I 42,5R	Sand (0-2 mm)	Aggregate (2-8 mm)	Steel fibres	Superpla -sticizer	Stabili-zer	W/C	Slump-flow
kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	kg/m^3	-	-
490	804	804	40-80-120	12,25	1,96	0,41	SF3

Tab. 2: The type of used steel fibres*

Symbol	Length (mm)	Width (mm)	The cross-section	Material	Tens.strength (N/mm^2)
SW 35/1.0	35±10%	2,30 - 2,95	Part of the circle	Low carbon steel	880±15%
SW 50/1.0	50±10%	2,30 - 2,95	Part of the circle	Low carbon steel	880±15%

* Remark: fibres with straight-shaped bars

Tab. 3: The influence of steel fibres type, fibres content and kind of forming beam on the flexural strength of SFRSCC f_{fl} [MPa]

Type of fibres		SW50		SW50			SW35		
Fibres content (kg/m^3)		80	120	40	80	120	40	80	120
Beam I	I specimen	9,17	7,95	4,96	6,56	6,35	3,54	4,55	7,12
	II specimen	9,10	8,59	4,63	5,97	5,52	3,81	3,75	6,11
Beam II	I specimen	8,41	10,80	4,62	7,92	8,85	3,73	4,52	6,99
	II specimen	8,64	11,97	4,15	7,52	9,98	3,37	4,65	6,82
Beam III	I specimen	8,80	12,19	-	-	-	-	-	-
	II specimen	8,26	13,52	-	-	-	-	-	-

The scope of the study included:

- Marking the consistency class after 10 minutes of the mixing process finish,
- forming (Figure 1),
- distribution of fibres with computed tomography (14 days after forming),
- marking tensile strength in bending f_{fl} (28 days after forming).

The computed tomography scanner used for testing was described in earlier authors' work [9].

3. The results and discussion

The results of tests for beams formed in various distances from the point of formation (Fig.1). Obtained results allowed to test the effect of the distance from the point of formation of SFRSCC on the distribution of fibres in matrix and mechanical parameters of beams. Beams of 600×150×150 mm cut from 1200×150×150 mm beams, were marked in such way that positioned closer to the point of formation is labeled as beam I, and the beam formed respectively further as beam II. Beams of 600×150×150 mm cut from 1800×150×150 mm beams, were labeled respectively as beam I, beam II and beam III, the last one was positioned the furthest from the place of mixture's introduction. In research, the 2D and 3D images of real distribution of steel fibres in tested self-compacting concrete beams were obtained due to the use of computed tomography method. Fig. 2A and 2B shows a selection of 2D and 3D images of steel fibres in tested SCC with the addition of variable content of SW50 fibres. It has been shown, that the increase in bending strength occurs with increasing content of SW35 fibres in SCC, what could have been expected. There were no significant differences in the bending force as a function of beam deflection noticed between beams I and II for SCC with steel fibres SW35. The SFRSCC mixtures and concrete with SW35 fibres are characterized by similar fibre orientation, their distribution and mechanical properties, regardless of the distance from the point of forming the SFRSCC. There is also similar, uneven distribution of fibres in the cross-sections of all beams. The amount of SW35 fibres increases towards the bottom section of beams. The orientation of beams parallel to the direction of flow of the mixture at formation of SFRSCC is observed. Additionally, the increase in amount of the air macro-pores with the increase of fibres content in the mixture is observed. On the basis of conducted observation, it could be concluded that the hypothesis of decreasing by fibres from deaeration of SFRSCC mixture is possible, especially in places with greater density of fibres in concrete matrix. In case of beams formed from the element of 1200×150×150 mm, the effect of SW50 fibres content on tensile strength in bending (Fig. 2) is analogous to the first series of samples with SW35 fibres. Also in these beams, there is the increase of bending force with the increase of SW50 fibres content. Additionally, there is an increase in bending force in case of beams II in relation to beams I with the increase in volume content of SW50 fibres. When the content of SW50 fibres is 120 kg/m^3, the increase in bending force in beam II, located at the further distance from the place of mixture's introduction to the form, is greater by 80% than in case of beam I. In case of the SW50 fibres content in SCC of 40 kg/m^3, there was no difference between the bending forces of beam I and beam II; whereas, in case of SW50 fibres content of 80 kg/m^3, there was the increase in bending force in beam II by 35% in relation to beam I. The second series of measurements confirmed these trends. Figure 2 presents the flexural strength f_{fl} - yield value g curves for SFRSCC with all detected steel fibres according Viskomat XL measuring as well. In general, increasing yield value g causes linear increase of flexural strength f_{fl} of SFRSCC with high coefficient of determination. For the formed elements, cut from beams of 1800×150×150 mm, the effect of SW50 fibres content on tensile strength in bending of tested SFRSCC, is illustrated on Fig. 4 (up – formation and the first measurement; down – formation and the second measurement). It has also been shown the increase in bending force with the increase of SW50 fibres content in SFRSCC.

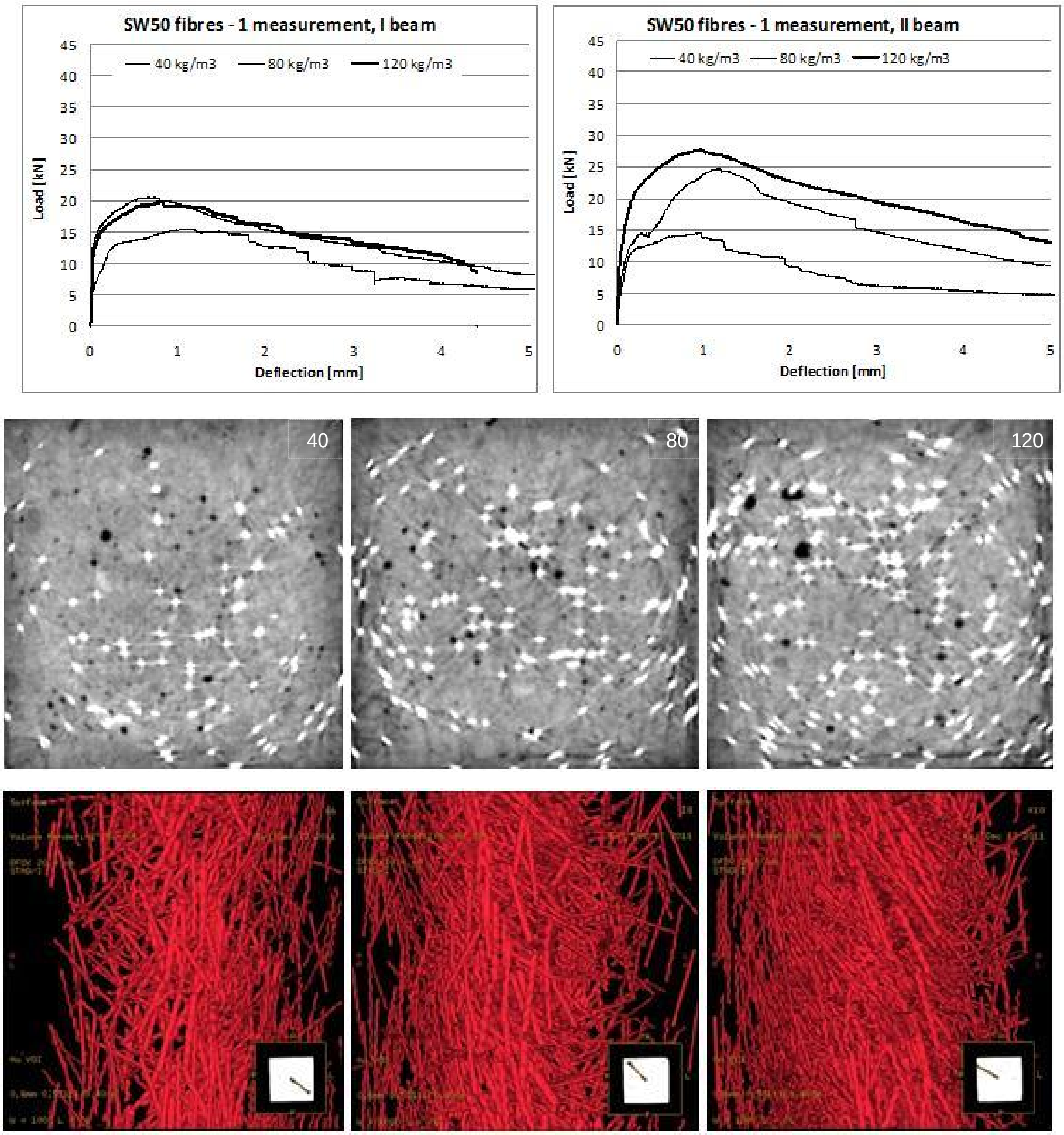

Fig. 2A: The effect of steel fibres SW50 on tensile strength in bending of beams I and II in the first measurement; X-ray 2D and 3D images of steel fibres in tested SFRSCC

Additionally, there was the increase in bending force for beams II and I with the increase of SW50 fibres content in tested SFRSCC. For SW50 fibres content of 120 kg/m^3 in SFRSCC, there was the increase of bending force in beam III (furthest one) by 65% in relation to bending force in beam I (closest one). For SW50 fibres content of 80 kg/m^3 in SFRSCC, there was no difference between bending forces in beams I, II and III.

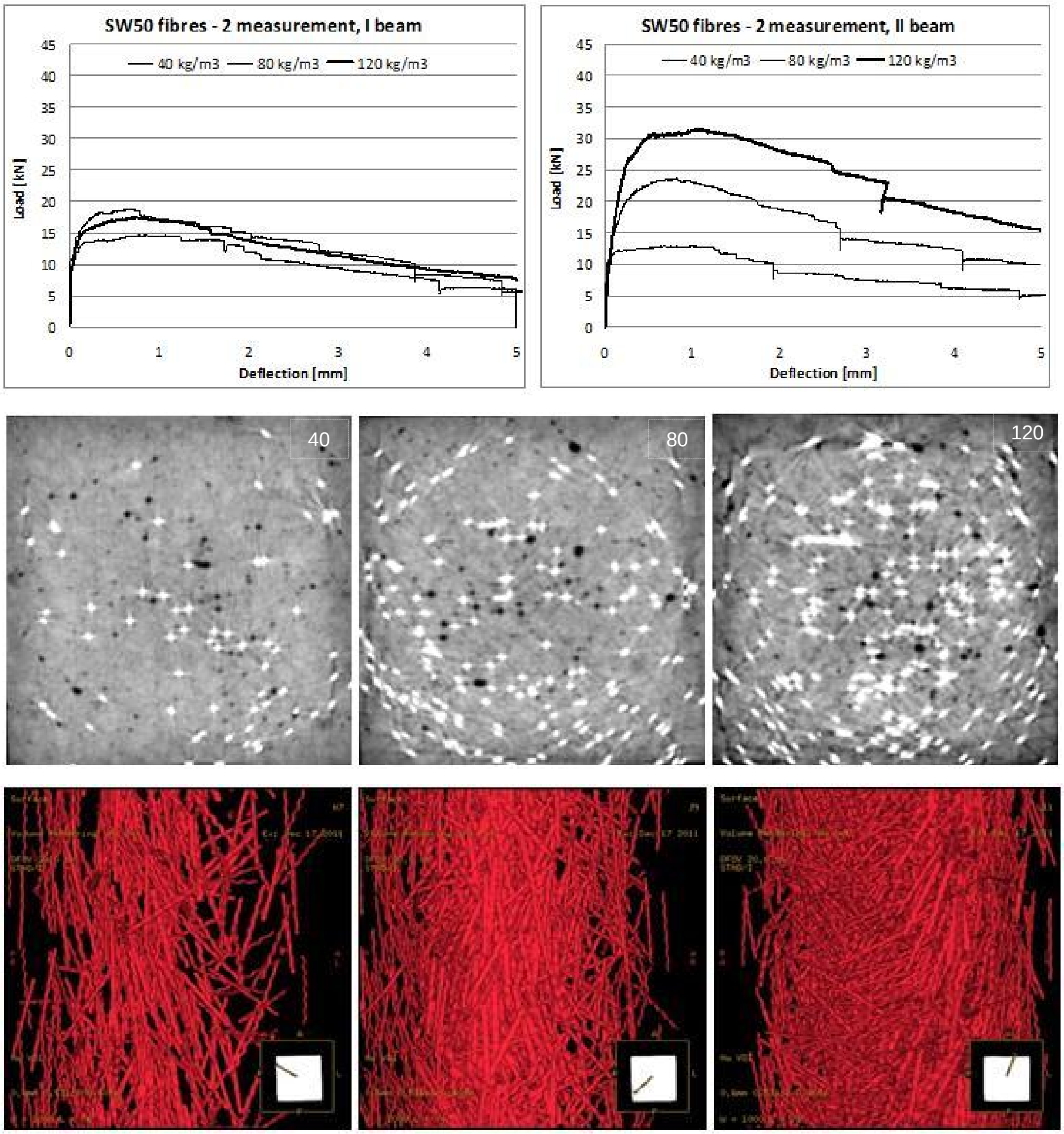

Fig. 2B: The effect of steel fibres SW50 on tensile strength in bending of beams I and II in the second measurement; X-ray 2D and 3D images of steel fibres in tested SFRSCC

The repeated tests on beams' formation and measurements confirmed these trends. Presented tests results show significant differences in strength parameters of SFRSCC beams in relation to the point of their formation. The increase in distance of SFRSCC mixture's formation significantly improves their strength parameters. Additionally, there was the increase in bending force for beams II and I with the increase of SW50 fibres content in tested SFRSCC. For SW50 fibres content of 120 kg/m^3 in SFRSCC, there was the increase of bending force in beam III (furthest one) by 65% in relation to bending force in beam I (closest one). For SW50 fibres content of 80 kg/m^3 in SFRSCC, there was no difference between bending forces in beams I, II and III. The repeated tests on beams' formation and measurements confirmed these trends. Figure 3 presents the flexural strength $f$fl - yield value g curves for SFRSCC with all detected steel fibres according Viskomat XL measuring. In general, increasing yield value g causes linear increase of flexural strength f_{fl} of SFRSCC with high coefficient of determination. We can used optimal fibre content and type according rheological and mechanical needs.

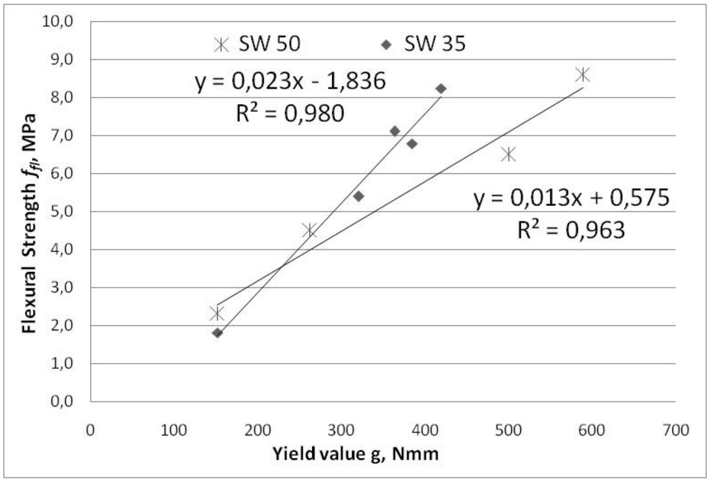

Fig. 3: Flexural strength $f$fl - yield value g curves for SW35 and SW50 steel fibres in SFRSCC

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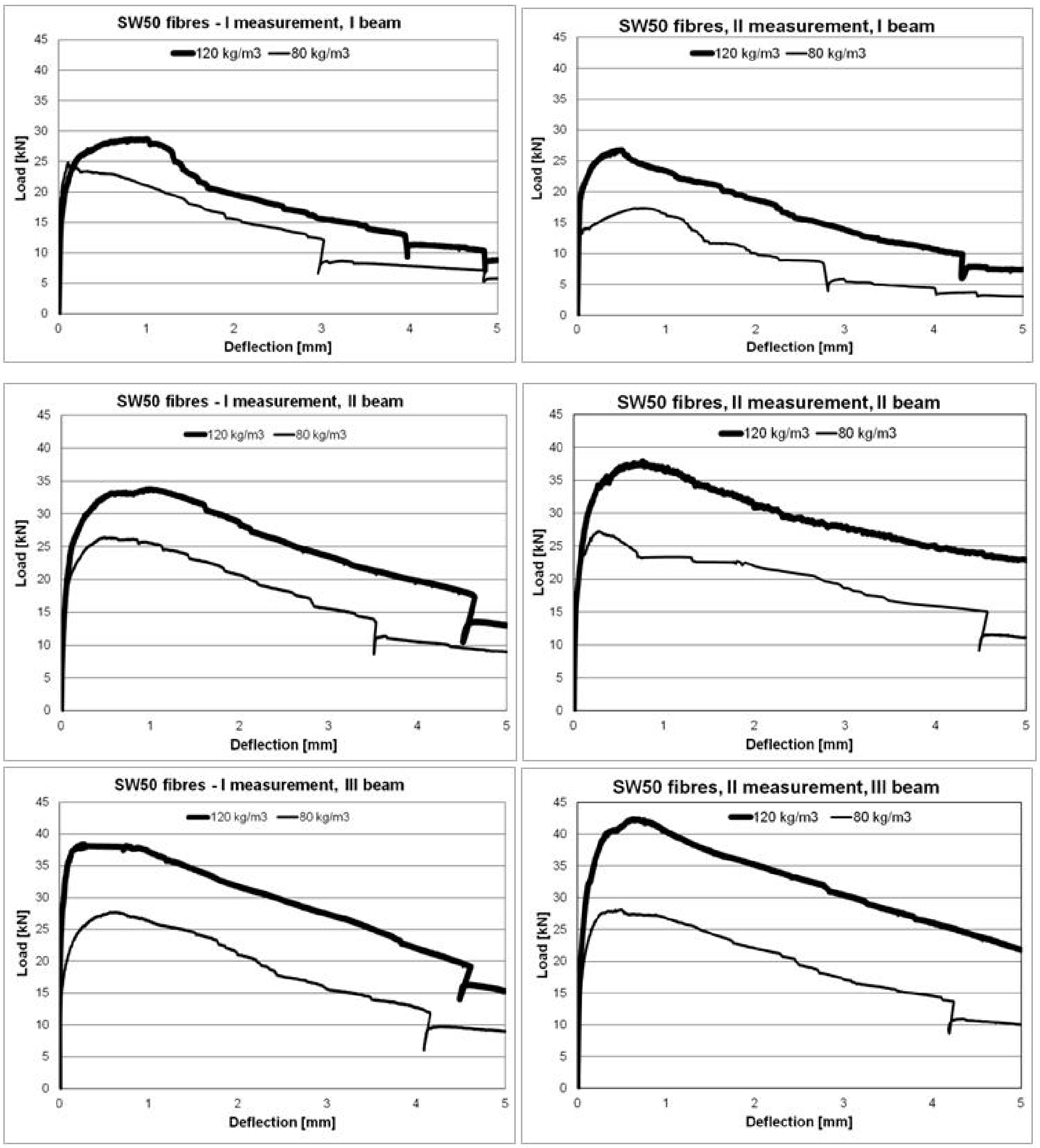

Fig. 4: The effect of steel fibres SW50 on tensile strength in bending of beams I, II and III, the first beams (left) and second beams (right).

4. Conclusions

The main scope of the paper was to examine the characterization of rheology and mechanical properties of SFRSCC and to establish the optimal relationships between rheology and mechanical properties. Rheological properties, slump-flow workability, compressive strength and flexural strength of SFRSCC were investigated. Basing on experimental research, with application of the new rheological equipment and computed tomography, some preliminary results were obtained in the undertaken realm of investigation. The study confirms technological problems connected with uneven distribution of steel fibres in SCC matrix. At the same time, fibres are generally parallel placed to the direction of concrete mixture's flow in the form. This phenomenon intensifies in elements with longer fibers (SW50) and with the increase of their volume ratio in the mixture. However, such orientation of fibres caused the improvement of strength in bending of beams with the addition of longer fibres (SW50). The increase in flexural strength was even up to 80% in beam II in case of SW50 fibres content of 120 kg/m^3, in relation to beam I, cut form the element of 1200×150×150 mm.

Similar, but somewhat smaller increase in resistance were found in beams III in relation to beams I cut from elements of 1800×150×150 mm. Obtained results may form a basis for the development of methods of designing self-compacting reinforced fibres, including the form of structural elements. The core of the problem is to determine changes in distribution of dispersed reinforcement in various structures depending on used technology of mixture's forming and its rheological properties, and also the volume and geometrical forms of steel fibres. Obtained results may also be used for modeling mechanical properties of selected structural elements.

The results of image analyses show that even when high volume of long fibres are used fibres in the self compacting concrete can be dispersed homogeneously without clumping, which results in enhancement in toughness of concretes. The long fibres are mostly oriented parallel to the flowability direction, vertically to the loading direction, and hence, they can operate efficiently under flexural loading. It was also observed that a low yield stress concrete leads to a good alignment of the fibres. The fibres are sufficiently oriented and connected together to ensure a longitudinal transfer loading. It was also shown that using the rheological properties of matrix with the content and geometry of fibre it is possible to predict the flexural strength of SFRSCCs. The orientation of fibers connected with the direction of the SFRSCCs mix flow during moulding was confirmed. Proved as well was the uniform distribution of fiber in the produced concrete element.

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