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Effect of Steel Fibers on the Mechanical Strength of Concrete

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Abstract

The study is based on designing the mix design of the concrete for the class named MR_DK_E1: C30/37, one of the most widely used classes of normal concrete. To see the effect of the fibers on concrete, we will design three mixtures that in other components are similar to the first mixture "*Normal Concrete"*, but as an additive, we will add 0.75%, 1.5%, and 2.0% of steel fiber (Romfracht SRL Company Profile) to the mass of concrete. Although some researchers have already detailed the favourable qualities of steel fiber reinforced concrete (SFRC), there is very little data regarding the design and performance of this type of concrete. To get to know something more in terms of the properties of steel fiber reinforced concrete, during the realization of this work we will perform some experimental tests based on European standards to understand closely how fibers affect the growth and improvement of properties of concrete with lime aggregate and local cement CEM II/BM (WL) 42.5N, applying different percentages of fibers to the volume of the concrete. For all mixtures, the necessary tests on the properties of wet concrete and hardened concrete will be performed, while the obtained results will be compared between the same kinds, where conclusions and recommendations will be drawn that can serve for further studies and use in engineering practice in our country. Three different mixtures of fibre content were applied. Experiments show that for all selected mixtures of fibre content, a more ductile behaviour and higher load levels in the post-cracking range were obtained. The study forms the basis for the selection of suitable fibre types and content for their most efficient combination with regular steel bar reinforcement. Also, special attention will be given to the use of SFRC for constructive elements. This experimental research concerning SFRC has been performed in the building materials laboratory near UBT, the Proing laboratory-Pristina, and GIM-Skopje (Kosovo).

Keywords: Reinforced Concrete; Steel Fibers; Crack-Mouth-Opening Displacement (CMOD); Limit of Proportionality (LOP).

1. Introduction

Concrete is a general term for artificially obtained conglomerates made of cement, sand, and gravel. These ingredients, when mixed with water, form a dough in a plastic state that, after a while, binds and hardens, in which case the "strong" material called concrete is obtained. In the field of construction, it has been one of the most used materials since the early 1800s. However, it is known that concrete has poor traction. Low tensile strength combined with brittleness results in a failure condition without warning. This property is not desirable for any building materials. Thus, concrete requires some form of reinforcement to compensate for its brittle behavior and improve its tensile strength. Historically, steel rods have been used as the material of choice for reinforcing tensile concrete elements [1]. Advances based on cement technology, such as concrete technology, have led to the development of fiber-reinforced concrete materials (FRC) [2]. The concept of using fibers to improve the mixing properties of concrete dates back to ancient times. Then they used animal hair and straw to reinforce the bricks. In the early 1900s, asbestos fibers began to be used. In 1911, Porter discovered that fibers could also be used in concrete. In the 1950s, reinforced concrete with other fibers became a field of great interest after it was discovered that asbestos was dangerous to health [3]. Mixing concrete with

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fiber content can accept or retain a considerable amount of load even after the appearance of cracks. The main role of fibers is to create bridges between cracks and to resist their formation. The advantages of adding fibers to a matrix include increased compressive strength, tensile strength, increased flexibility, shear strength, durability, and resistance to external influences. The physical properties of the mixture depend on the type and dose of fibers added. Basically, four types of fibers can be used in concrete composition: steel fibers, glass fibers, natural fibers, and synthetic fibers [4-7]. Glass fibers provide a very good reinforcing effect, but they have poor resistance to alkalis. Natural fibers, such as palm wood, coconut, and vegetable fibers, have the advantage of being cheaply and easily renewable, but their durability is low [8].

There are many types of fibers, in different sizes and shapes, available for commercial and experimental use. The basic types of fibers are steel fibers, synthetic fibers such as polypropylene, glass, carbon, and polyolefins, as well as fibers from solid waste scraps. Using these fibers individually as well as on a hybrid basis has mechanical effects on fiber reinforced concrete (FRC) [9, 10].

Fiber-reinforced concrete as a building material in accordance with its properties in order to create a long-lasting building for the client at a low cost. The chapters on the properties, design, and processing of fiber-reinforced concrete. Fiber-reinforced concrete as an extension of concrete offers considerable advantages for building practice, which, based on the material properties, allows a very long service life [11-13]. First of all, we will explain how fibers are classified in some of the most important regulations. As it can be seen in Figure 1, in this paper we will consider two standards recommendations. First of all, we will deal with the classification of fibers according to European standards EN-14889-2. In this study, we will use only steel fibers. Concrete reinforcement fibers are short elements and have a length/diameter ratio of 20 to 100, with different cross-sections, and are so small that they can be easily distributed non-uniformly in the concrete mix using the procedures of mixing. Steel fibers can be categorized into five groups depending on the production process and their shape and cross-section: cold-drawn wires, thin-cut plates, factory scrap steel waste, modified wire in tow, and waste extracted from smelting [14]. Steel fibers have a modulus of elasticity (Young's modulus) of 205 MPa, tensile strength varies from 345 to 1700 MPa, and the length of the fibers varies from 19 to 60 mm [9]. To get the desired result from concrete, the fibers must have high tensile strength and elasticity modulus (Young's modulus). In addition to steel fibers, these properties also have synthetic fibers. A very large category of synthetic fibers is represented by plastic fibers, which can be found in two forms: micro-plastic fiber and macro-plastic fiber. Micro-plastic fibers are between 5 and 100 mm in diameter and 5 to 30 mm in length. These are effective in controlling cracks from plastic shrinkage of wet concrete, while in hardened concrete their effect is minimal [8]. Macro-plastic fibers have a tensile capacity of 300-600 MPa and Young's modulus of 4 to 4010 GPa. Macro-plastic fibers are widely used in concrete paths as well as in tunnels [15].

We have based this study on experimental results to understand the impact of steel fibers on the properties of concrete and to provide opportunities for further studies and the use of SFRC as a material in structural elements. To enable new areas of application, SFRC must be designed to withstand external forces, have sufficient ductility, high durability, and adequate workability. We know that reinforced concrete with steel fibers is not the same as conventional concrete, so we cannot use the same standards for design. The results obtained from this study are expected to contribute to the efforts made to characterize the mechanical properties of SFRC. This experimental research related to SFRC was conducted in the building materials laboratory at UBT-Higher Education Institution Prishtina based on experimental results performed according to European standards for SFRC testing to see the relationship between stress-strain in compression and traction by taking into account the number of fibers and the grade of concrete. The objectives of the paper are:

- Through experiments, we will notice the influence of fibers on the solidity of compressed concrete in class MR_DK_E1: C30/37, one of the most widely used classes of ordinary concrete;
- The study was carried out using the experimental method. We will also conclude on the influence of fibers on tensile strength in the aforementioned concrete class and how fibers affect the strain-deformation relationship;
- Also, during the experimental phase, we will control the impact of fibers on shear forces. Analytically, we will use general expressions for SFRC design based on the fib standard Model Code 2020;
- The data are analysed and experimental research concerning (SFRC) has been performed in the building materials laboratory near UBT, the PROING laboratory-Pristina, and GIM-Skopje (Kosovo).

2. Materials and Methods

The experimental work was carried out in two phases. Initially, slump tests were performed to determine the properties of fresh concrete, and the volume of concrete was measured for each SFRC mix. In the second stage, the properties of hardened concrete are defined.

2.1. Experimental Program

An experimental program was created to analyze the impact of the type of steel fibers used to reinforce the concrete matrix. This separated the behavior of ordinary concrete from that of fiber-reinforced concrete. Different mixtures were created to have the same matrix but different amounts of fiber content (starting from one fiber-free mixture and three mixtures with 0.75, 1.5, and 2.0% by mass of concrete).

2.2. Presentation and Analysis of Results

Table 1 shows the number of samples tested in compressive for different quantities of fiber content and the age of tested samples. We tested three samples after 7 days from each content of the volume quantity against the concrete mass, and the other remaining samples we tested after the age of 28 days.

Table 1. Samples tested in compressive

150×150×150 (mm)	Volumetric amount of fiber content (V_f)			
Age of samples	**BZ**	**0.75%**	**1.5%**	**2.0%**
7 days	3	3	3	3
28 days	3	3	3	3

The test results presented in Table 2, express the solidity of the cubic specimens subjected to compressive forces.

Table 2. Test results of cubic specimens by compressive forces

Solidity in compression f_c (C 30/37)									
150×150×150 (mm)		$V_f = 0$ %		$V_f = 0.75\%$		$V_f = 1.5\%$		$V_f = 2.0\%$	
		(kN)	(MPa)	(kN)	(MPa)	(kN)	(MPa)	(kN)	(MPa)
Age	**Name**	F_{th}	f_c	F_{th}	f_c	F_{th}	f_c	F_{th}	f_c
7 days	I	664	29.51	673.5	29.93	674	29.95	689	30.62
	II	686.2	30.49	651.3	28.94	655.8	29.14	669.65	29.76
	III	641.8	28.52	695.7	30.92	692.2	30.76	708.35	31.48
28 days	I	1036.3	46.06	1029	45.74	1025	45.55	1028	45.68
	II	1013.1	45.03	1060	47.10	1045	46.45	1045	46.45
	III	1024.7	45.54	1044.5	46.42	1035	46.00	1035.5	46.10

From which we understand that the fibers have a minimal impact on the compressive strength of concrete. In Figure 1, we have the comparison of test results suggesting that fiber-free mixtures are destroyed immediately after passing the peak load. In the mixture with a content of 0.75% of the fibers, the destruction comes shortly after the peak of the load. It is noticed that even after reaching the peak of the load, the sample continues to resist, which means that the volume of fibers has entered the work after cracks.

Figure 1. Procedures for preparing samples for testing: a) placing the sample in the cutting machine b) cutting to form the nozzle c) mounting the steel plates on both sides of the nozzle d) mounting the sensor for measuring CMOD

It is observed that increasing the number of fibers does not increase the compressive strength at visible values. It is clear that mixtures with fiber content to the concrete volume of 1.5% and 2.0% do not increase the solidity at high values compared to the mixture with a content of 0.75% of fibers. Some previous studies have concluded that increasing the fiber content also increases the air content in concrete. This affects not increasing the compressive strength of concrete by increasing the amount of fiber. We have approximately a 1% increase in compressive strength from fiber impact, which is negligible (Table 3). In Table 3, the average values of the results for the compressive strength from the cube sample tests are shown.

Table 3. Average compressive strength results from cubic sample tests

150×150×150 (mm)	Average compressive strength f_{cm} (C30/37)							
	Vf = 0 %		Vf = 0.75%		Vf = 1.5%		Vf = 2.0%	
	(kN)	(MPa)	(kN)	(MPa)	(kN)	(MPa)	(kN)	(MPa)
Age	F_{th}	f_{cm}	F_{th}	f_{cm}	F_{th}	f_{cm}	F_{th}	f_{cm}
7 days	664	29.51	673.5	29.93	674	29.95	689	30.62
28 days	1024.7	45.54	1044.5	46.42	1035	46.00	1036.5	46.10

We also tested samples of different ages and with the same fiber content, where it is seen that the concrete of class C30/37 for seven days has reached 65% of 28-day solidity, which conforms to the standard of increasing solidity in percentage to the age of concrete.

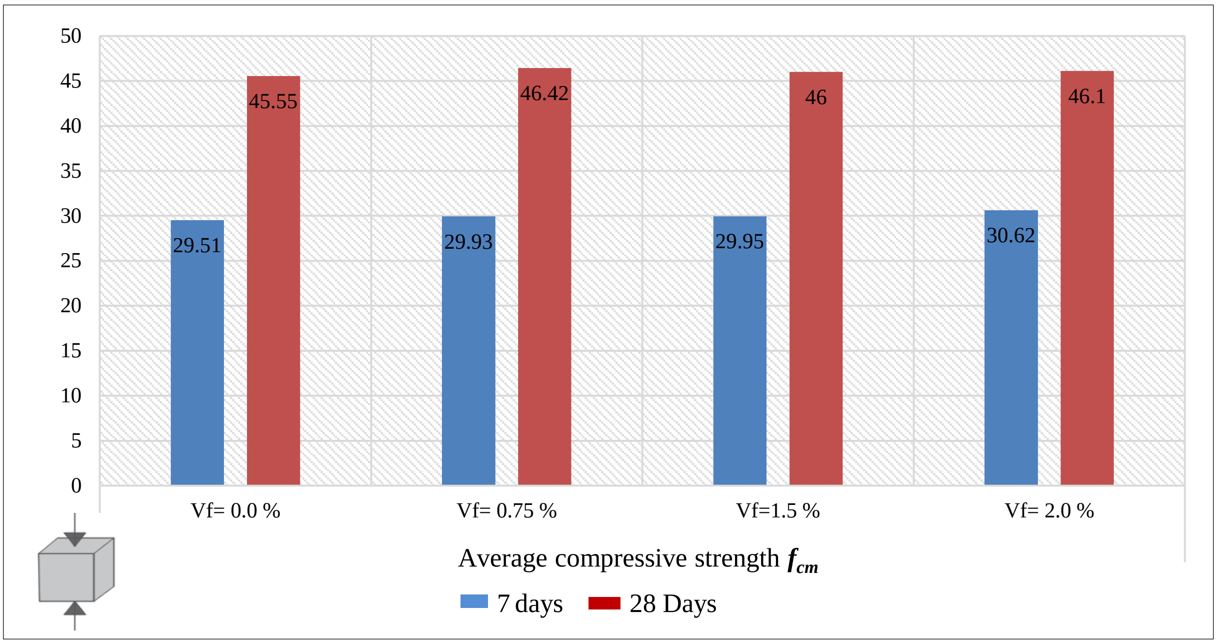


Figure 2. BZ and SFRC concrete results with fiber content were tested for 7 and 28 days

From Figure 3, we understand that the average results of compressive strength in cubic specimens for concrete grade C30/37 are excellent. From four different mixtures, we have obtained an average solidity that is close to the perfection proposed by the standard BS 8110-1 (1997) [16], which defines the properties of concrete for structural use.

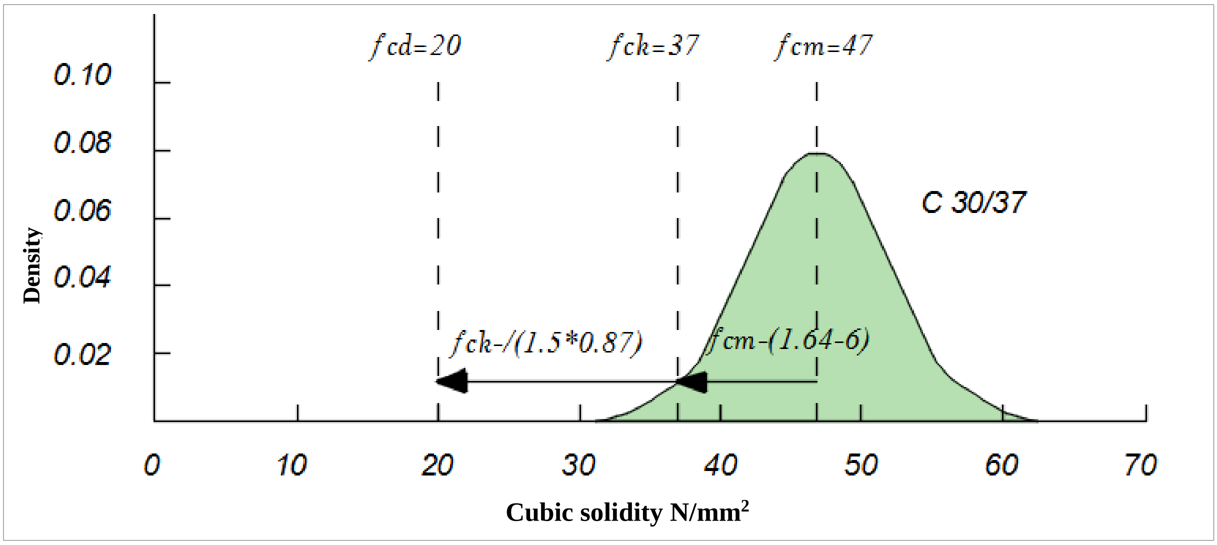


Figure 3. Definitions of compressive strength according to BS 8110-1 (1997) [16] adapted from Bamforth et al. (2008) [17]

As it was pointed out above in the literature review, the biggest problem with this type of concrete is the distribution of fibers. This problem we have also proved in the compression tests. In Figure 4 we can see that the fibers are concentrated around the edges of the samples.

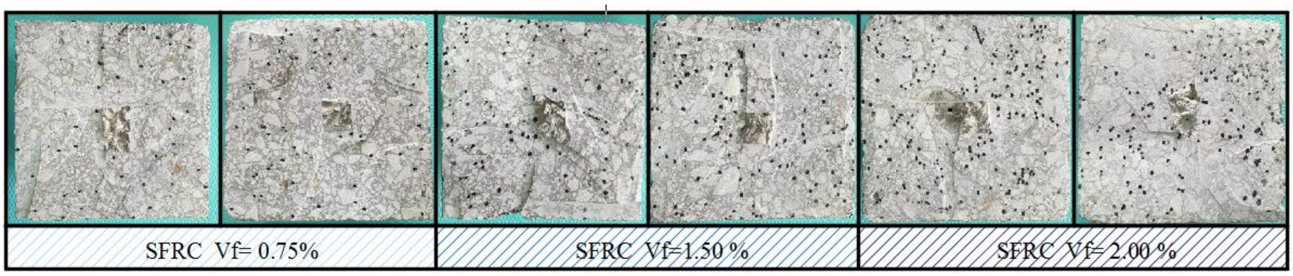


Figure 4. Distribution of fibers through the cross-section of samples

2.3. Results and Comparisons of Tensile Strength Tests - Solidity in Indirect Traction (Crack)

During this experimental program, we also tested the tensile strength of the crack. For this test, we used three cubes for each of the mixtures for each age, the results for each of the cubes are presented in Table 4 and Figures 5 to 8.

Table 4. Crack tensile test results for cubic specimens 150×150×150 (mm)

Tensile strength from cracking f_{ct} and f_{ctm} (C30/37)													
150×150×150 (mm)		B.Z Vf = 0 %			Vf = 0.75%			Vf = 1.5%			Vf = 2.0%		
		(kN)	(MPa)		(kN)	(MPa)		(kN)	(MPa)		(kN)	(MPa)	
Age	**Name**	F_{th}	f_{ct}	f_{ctm}	F_{th}	f_{ct}	f_{ctm}	F_{th}	f_{ct}	f_{ctm}	F_{th}	f_{ct}	f_{ctm}
	I	72.77	2.06		91.49	2.59		97.14	2.75		100.3	2.84	
7 days	II	68.47	1.93	2.06	94.32	2.67	2.59	95.33	2.69	2.75	97.3	2.75	2.83
	III	77.10	2.17		88.66	2.50		98.95	2.80		103.3	2.92	
	I	113.8	3.22		138.9	3.93		153.5	4.34		156	4.40	
28 days	II	108.9	3.08	3.15	141.35	4.00	4.00	154	4.33	4.34	159	4.5	4.45
	III	111.3	3.15		143.8	4.07		153	4.32		157.5	4.45	

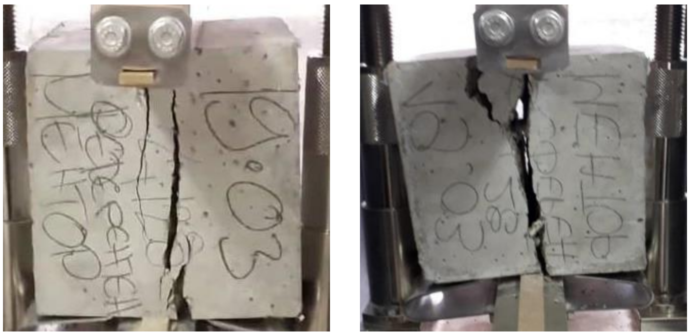


Figure 5. Results of cubic samples from indirect tension (crack) for ordinary concrete

Figure 6. Results of cubic samples from indirect attraction (crack) for SFRC with V_f = 0.75%

Figure 7. Results of cubic samples from indirect attraction (crack) for SFRC with V_f = 1.5

Figure 8. Results of cubic samples from indirect attraction (crack) for SFRC with V_f = 2.0%

As can be seen from the results, both the 7-day and the 28-day ones have an increase in the attractive force from the crack. In the 7-day-old samples, the increase is for 25.9% of the tensile strength from the crack to the mixture, with a content of 0.75% of fibers to ordinary concrete. In the mixture with a content of fibers of 1.5%, we see an increase of 33.5% compared to ordinary concrete without fiber content. We also have an increase of 38% in the mixture with fiber content in the amount of 2.0% (see Figure 9).

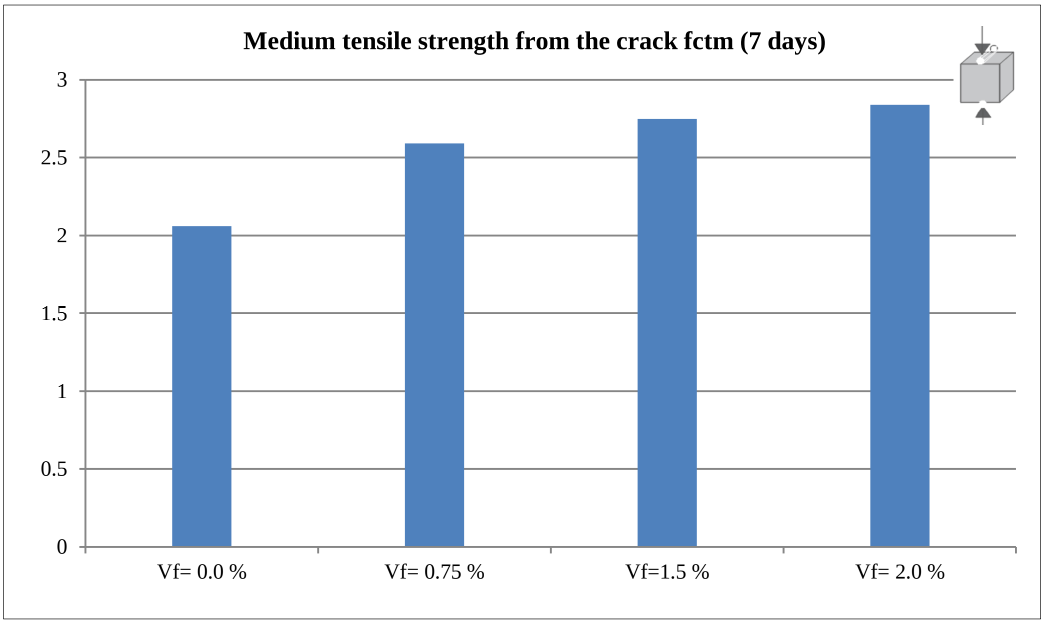


Figure 9. Results of average solidity in crack retraction for 7-day-old samples

However, even the test results of the 28-day-old samples show a nice, good increase in tensile strength from cracking into mixtures with additions of steel fibers (Figure 10). Solidity to crack has an increase of 28% in SFRC with content V_f = 0.75% of fibers, compared to ordinary concrete, increasing the number of fibers in the mixture also increases the attractive solidity by 38% for SFRC with content V_f = 1.5% versus ordinary concrete, and with 8.5% to the mixture with V_f = 0.75% of fibers to the volume of concrete, but with the addition of fibers in quantities of V_f = 2.0% we have an increase of 3% compared to SFRC with V_f = 1.5%, and to ordinary concrete, the increase in solidity in indirect tensile is by 42%.

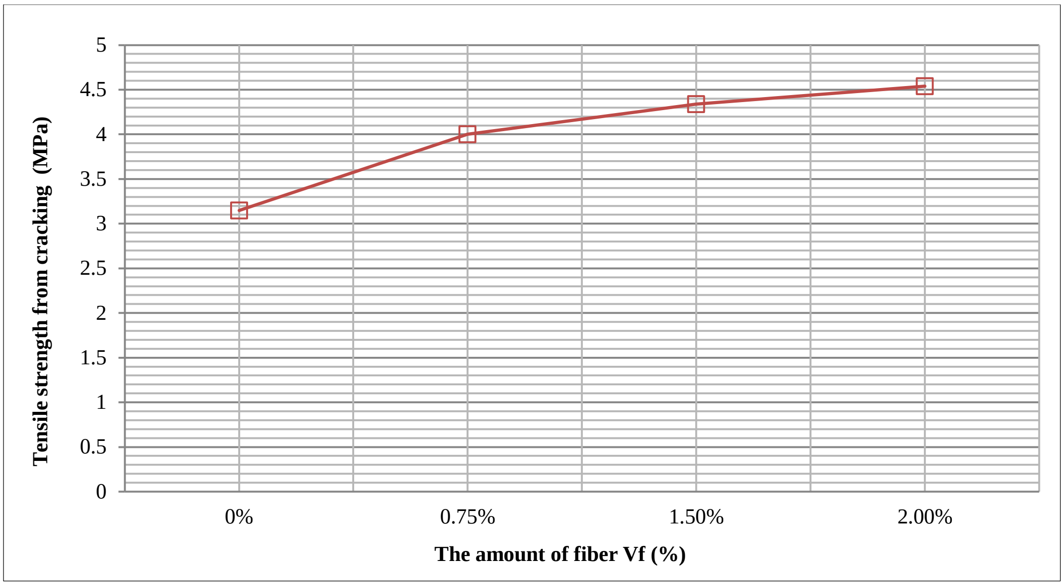


Figure 10. Presentation of retraction sample results from 28-day-old cracking

The ratio of compressive strength and tensile strength is shown in Figure 11. It is clear that the increase in compressive strength is in direct relation to the solidity in indirect tensile strength, with the addition of fibers in the mixture, we have increased solidity in both cases, but with increasing the amount of fiber, we have minimal increase in pre-mixing. We also compared the results of our tests with the analytical model proposed by Ashour et al. (1992) [18] for the relationship between compressive strength and crack retraction according to Equation 1.

$$f_{sp} = \frac{f_{cuf}}{(20-\sqrt{F})} + 0.7 + \sqrt{F} \quad (1)$$

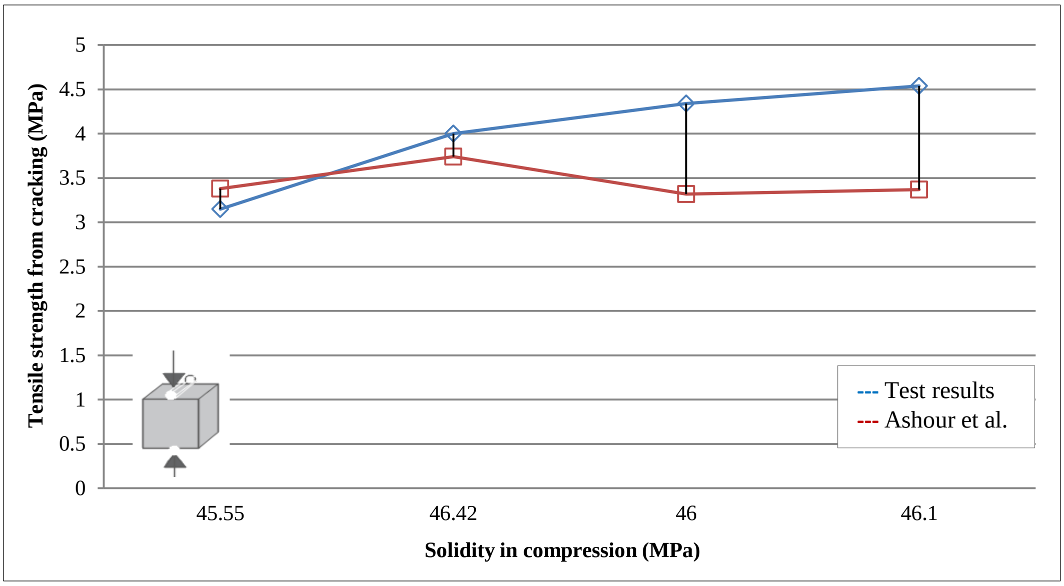


Figure 5. Relation of compressive strength to crack tensile strength for test results and comparison with the analytical model by Ashour et al. (1992) [18]

The test results and those derived from the analytical model are presented in Table 5.

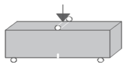
Table 5. Average results of compressive strength and crack tensile strength

Percentage of fibers V_f	Density (kg/m^3)	Solidity in Compression (MPa)	Tensile strength from cracking (MPa)	Ashour et al. f_{sp} (MPa)
0%	2412	45.54	3.15	3.4
0.75%	2448	46.42	4.00	3.74
1.50%	2450	46.00	4.34	3.32
2.00%	2451	46.10	4.45	3.37

2.4. Solidity in Indirect Tensile Bending

We also tested ordinary concrete prisms for resistance to indirect traction by bending, for this test we used another indirect method which is pure bending, we tested only three samples for the age of 28 days. The results of these tests are presented in Table 6.

Table 6. Results of bending tensile tests for ordinary concrete prisms

150×150×550 (mm) 	Ordinary concrete BZ C30/37					
	I		II		III	
	F (kN)	f_{ct} (MPa)	F (kN)	f_{ct} (MPa)	F (kN)	f_{ct} (MPa)
28 days	35.93	7.98	37.18	8.26	29.67	6.59
f_{ctm} (MPa)	7.61					

According to previous studies, it is assumed that the minimum tensile strength by bending for ordinary concrete should be approximately 10% of the compressive strength for the same mix. From our results, it is seen that we have passed this value $f_{(cm,\ BZ)} \geq 10\%\ f_{(cm,\ BZ)}$. These results tell us that we have completed the concrete recipe and can now proceed with other tests that are recommended for dimensioning structural elements with SFRC steel fiber reinforced concrete.

For the design of elements with SFRC according to *fib* Model Code (2010) [19], the characteristics of the material must be known first. One of the main properties according to this standard is the tensile strength after cracking. To derive these values of SFRC, following the instructions of BS EN 14651: (2005) + A1, (2007) [20], we performed the bending test to obtain the CMOD values. For each of the mixtures with different percentages of fibers we tested from three prisms, the calculator enabled us to take the numerical data obtained from the sensors and convert it into diagrams of the force/crack opening ratio. The method of calculating the required forces is shown in Figures 12 and 13. We have presented one of the three samples tested for CMOD, where the maximum cracking is also seen.

Figure 6. The samples tested for fiber content (Left), and the three samples tested for CMOD (Right)

Figure 7. Prism from SFRC V_f = 0.75% tested for CMOD

Figure 14 shows the diagrams of the force-crack width ratio (CMOD) obtained from the software of the testing machine for all three SFRC samples for mixing with fiber content V_f = 0.75%, it is clear that in all three cases the results are different, which shows that even here the distribution of fibers plays a special role.

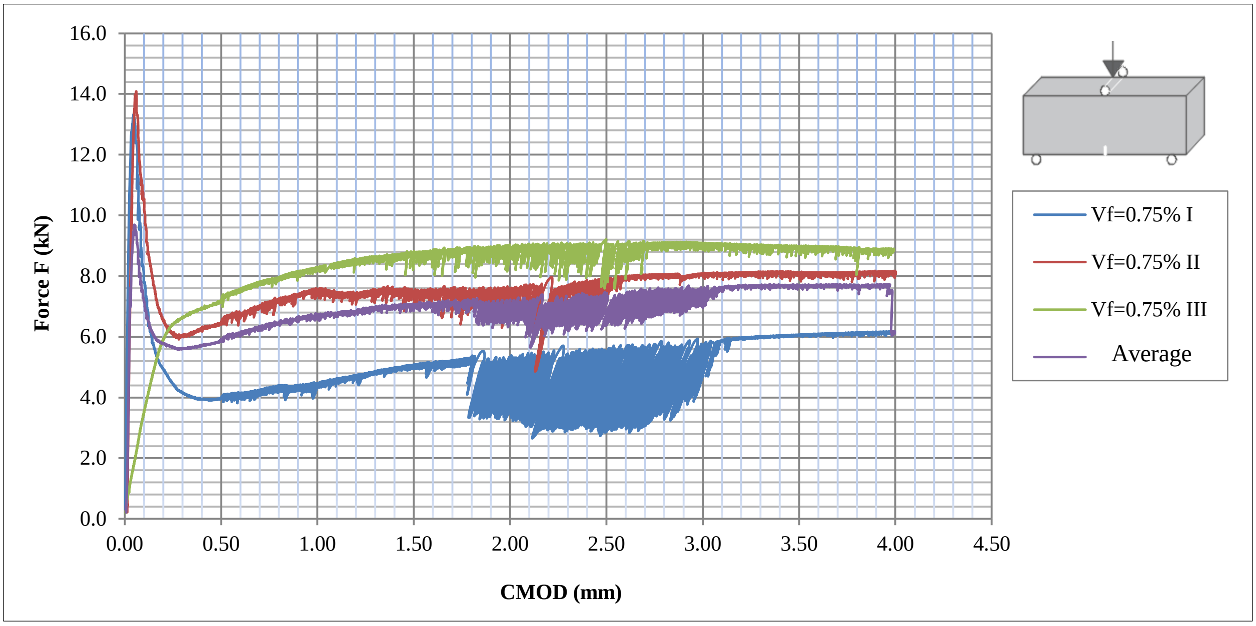


Figure 8. Load-width crack diagram (CMOD) diagram for all three SFRC prisms with fiber content V_f = 0.75%

Table 6 presents the results for the tensile strength remaining after cracking $f_{(R,\,j)}$ as well as the limit ratio $f\frac{f}{ct}L$ for each of the samples tested by mixing with a fiber content of V_f = 0.75%. The value of the results is obtained automatically from the data of the testing machine but, they have been checked according to the expression that the standard instructs us (BS EN 14651:2005+A1, 2007) [20].

Table 7. Test results for LOP and f $_{(R,\,j)}$ for prisms from mixture with V_f = 0.75%

V_f	Nr.	Sample	$F_{L,k}$ (N/mm²)	$f_{R1,k}$ (N/mm²)	$f_{R2,k}$ (N/mm²)	$f_{R3,k}$ (N/mm²)	$f_{R4,k}$ (N/mm²)
0.75%	I	150×150×550	5.04	1.50	1.90	1.29	2.30
	II		5.06	2.30	2.64	2.77	2.89
	III		3.20	2.48	3.06	2.88	3.04
	Average		**4.43**	**2.09**	**2.53**	**2.31**	**2.74**

Also, Figure 15 shows the average graph for testing the force-CMOD relation, from which the average results for this type of mixture are derived. The same procedures were followed for testing both groups of samples with V_f = 1.5% and V_f = 2.0%. Figure 8 shows the tested sample for the fiber content of 1.5%.

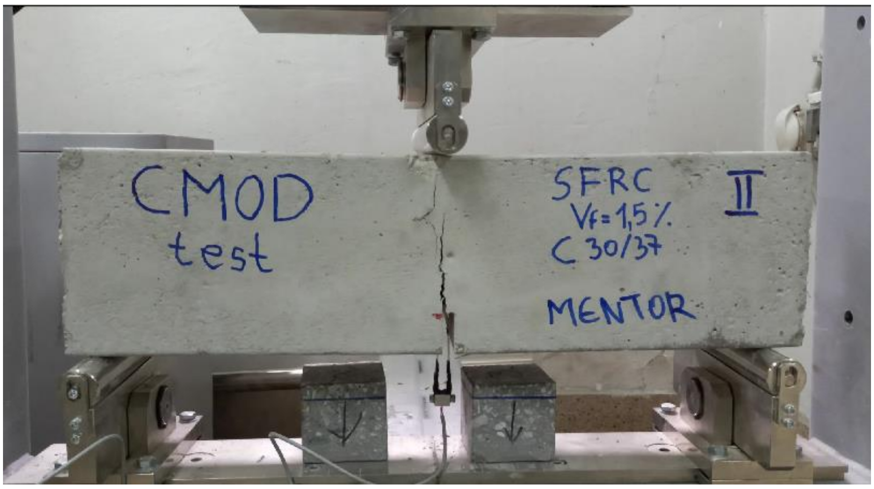


Figure 9. Prism from SFRC V_f = 0.75% tested for CMOD

The results are presented in tabular form in Tables 7 and 8, also in the graphical form presented in Figures 14 and 16, respectively.

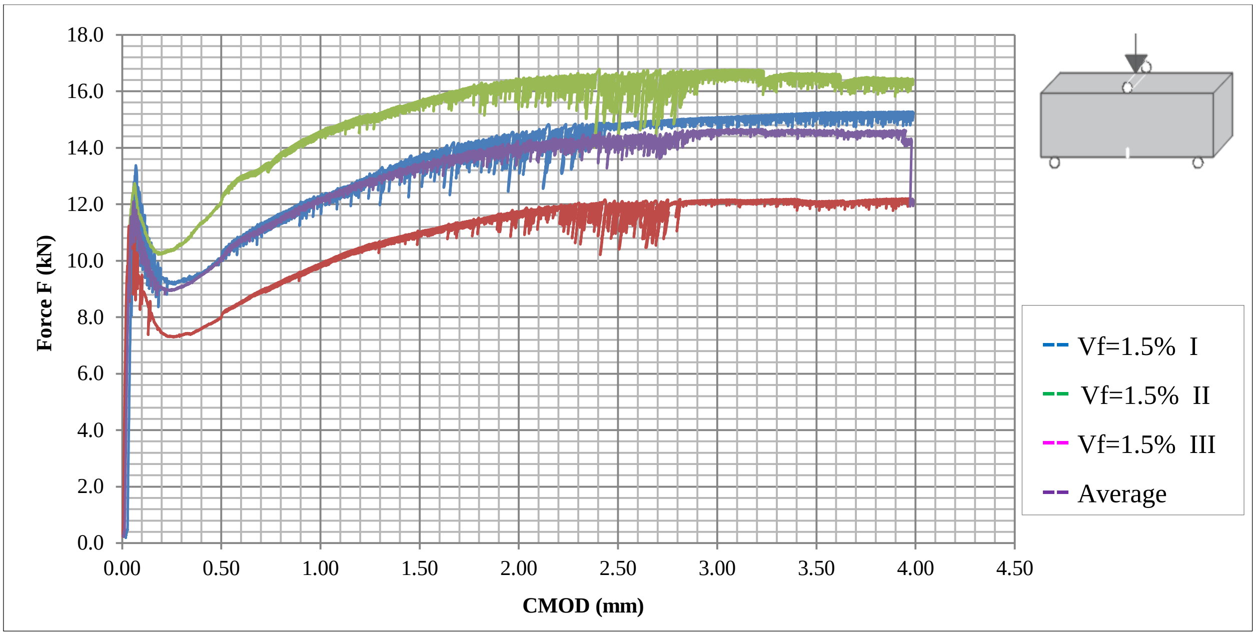


Figure 10. Load-width crack diagram (CMOD) diagram for all three SFRC prisms with fiber content V_f = 1.5%

Table 8. Test results for LOP and $f_{(R,j)}$ for prisms from mixture with V_f = 1.5%

V_f	Nr.	Sample	$F_{L,k}$ (N/mm^2)	$f_{R1,k}$ (N/mm^2)	$f_{R2,k}$ (N/mm^2)	$f_{R3,k}$ (N/mm^2)	$f_{R4,k}$ (N/mm^2)
1.5 %	I	150×150×550	4.97	3.28	4.34	4.78	4.94
	II		6.35	4.55	5.91	5.41	6.23
	III		4.24	2.77	3.81	4.10	4.18
	Average		**5.19**	**3.53**	**4.69**	**4.76**	**5.12**

In Figure 17, we have presented the prismatic sample for the content of the number of fibers of V_f = 2.0% tested according to (BS EN 14651:2005+A1, 2007) [20] to obtain the force-CMOD relation.

Figure 11. Prism from SFRC V_f = 2.0% tested for CMOD

In the Figure 18, diagram is shown Crack load-width ratio (CMOD) diagram for all three SFRC

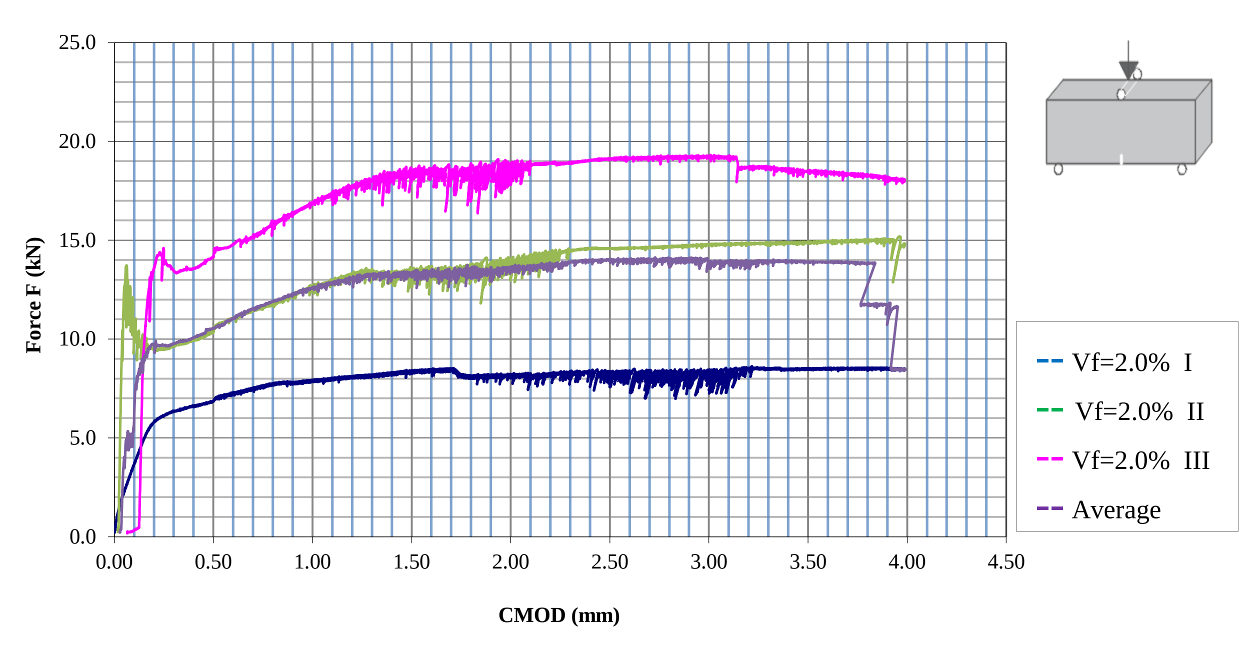


Figure 12. Crack load-width ratio (CMOD) diagram for all three SFRC prisms with V_f content = 2.0%

Table 9 shows all the results obtained from the testing of prismatic samples to find the resistance remaining after cracking. It is clear that with the increase in the number of fibers we have an increase in the resistance in question.

Table 9. Test results for LOP and $f_{(R,j)}$ for prisms from mixture with V_f = 2.0%

V_f	Nr.	Sample	$F_{L,k}$ (N/mm²)	$f_{R1,k}$ (N/mm²)	$f_{R2,k}$ (N/mm²)	$f_{R3,k}$ (N/mm²)	$f_{R4,k}$ (N/mm²)
2.0 %	I	150×150×550	3.26	2.58	3.17	3.0	3.20
	II		5.74	3.95	4.98	5.52	5.64
	III		7.30	5.35	7.00	7.22	6.99
	Average		**5.43**	**3.96**	**5.05**	**5.24**	**5.27**

Figures 19 and 20 show all the diagrams of the average force applied (F) to the crack opening (CMOD) where the increase in the applied force is seen, which means that we have an increase in the remaining resistance of the SFRC after the first cracks. This increase in strength is attributed to the steel fibers, i.e., the content of the volumetric amount of fibers to the volumetric mass of concrete.

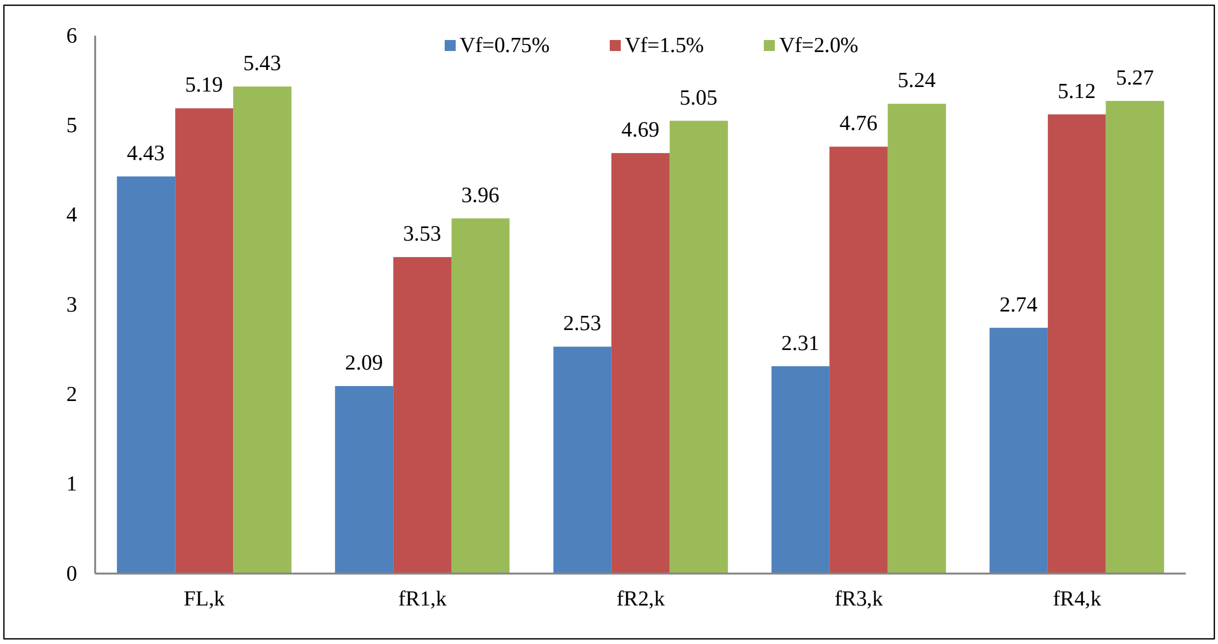


Figure 13. Comparison of results depending on fiber content

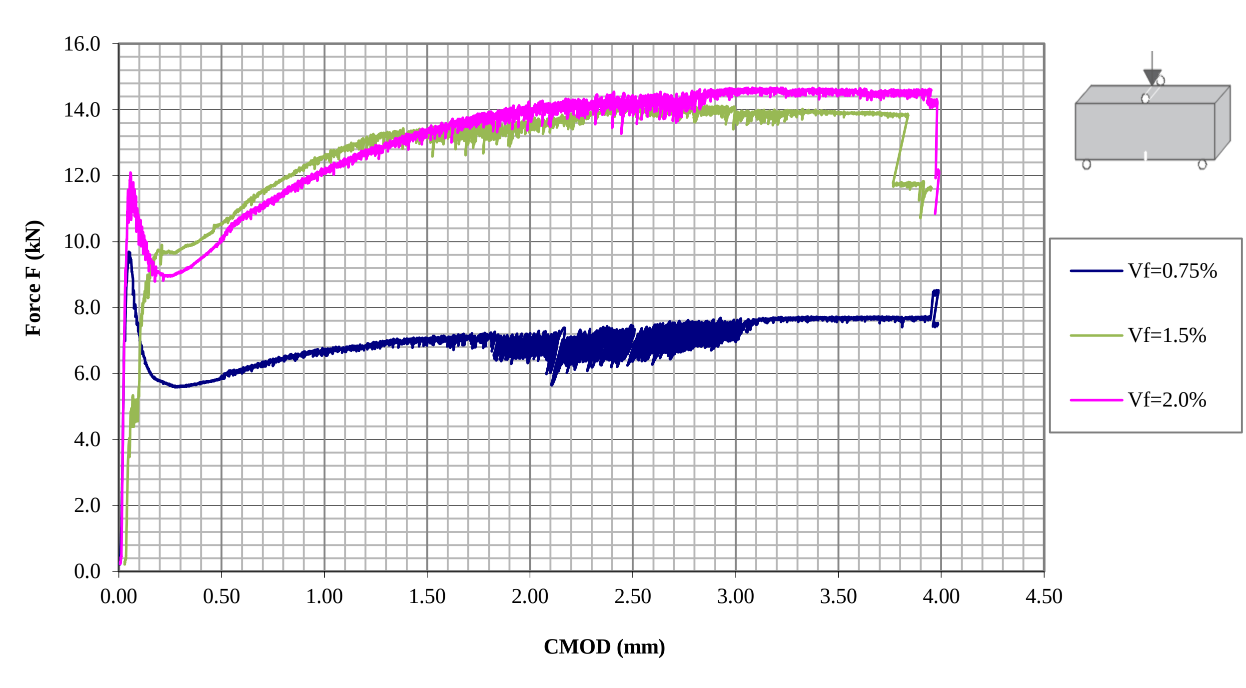


Figure 14. Crack load-width ratio (CMOD) diagram for all three SFRC prism tests averages with different fiber contents

To see the relation between F-displacement and F-CMOD in the testing of the III prismatic sample of the fiber content of $V_f = 0.75\%$, we simultaneously tested both relations. Figure 21 shows the graph for both relations.

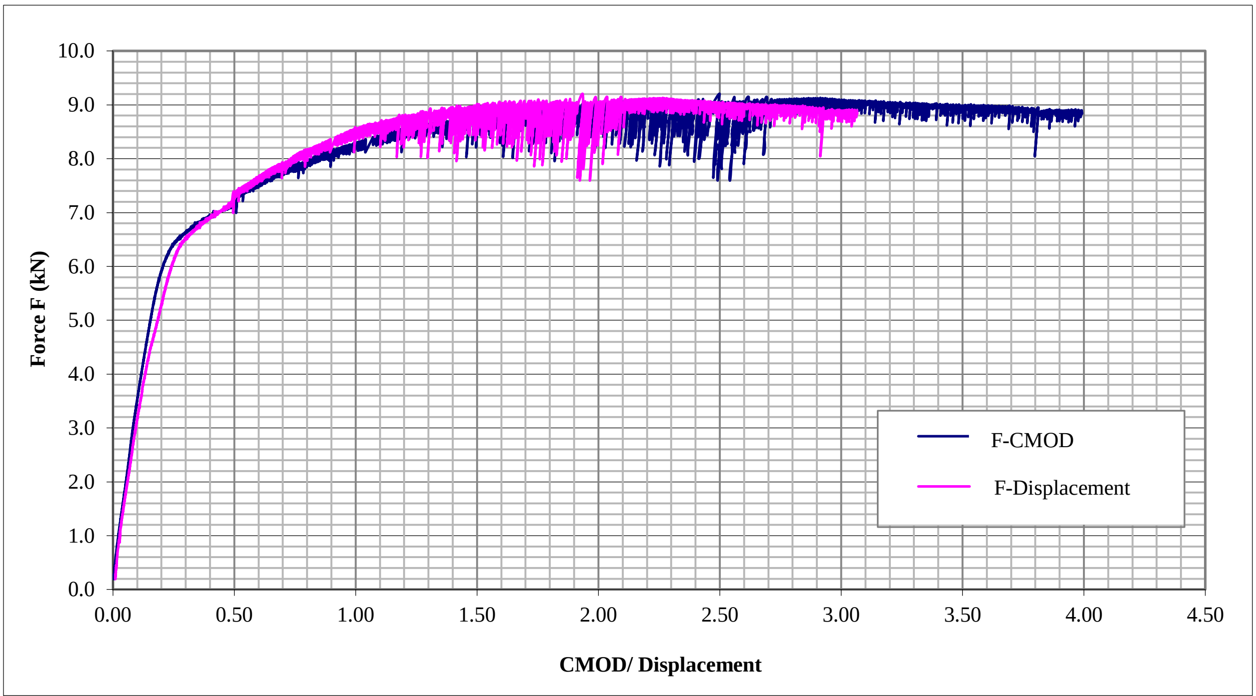


Figure 15. Comparison of the F-CMOD and F-Shift relation curve

From the diagram, it is clear that the displacements and CMOD have a close relationship. From both diagrams, we can derive the forces with approximate values that we need to calculate the residual resistance after cracks $f_{(R, j)}$ in the formwork of SFRC material. Figure 22 again shows the relationship diagram, but also adds the diagram obtained from *fib* Model Code 2010 [19] (equation 11.1 section 3.5.2.2) for approximate displacement calculations if we have CMOD data. From the presentation of the results, we see that the three diagrams are very similar, and it is proved that the relations are equivalent to F-displacement and F-CMOD. This increase in resistance is attributed to the steel fibers, i.e., the content of the volume amount of fibers to the volume mass of concrete.

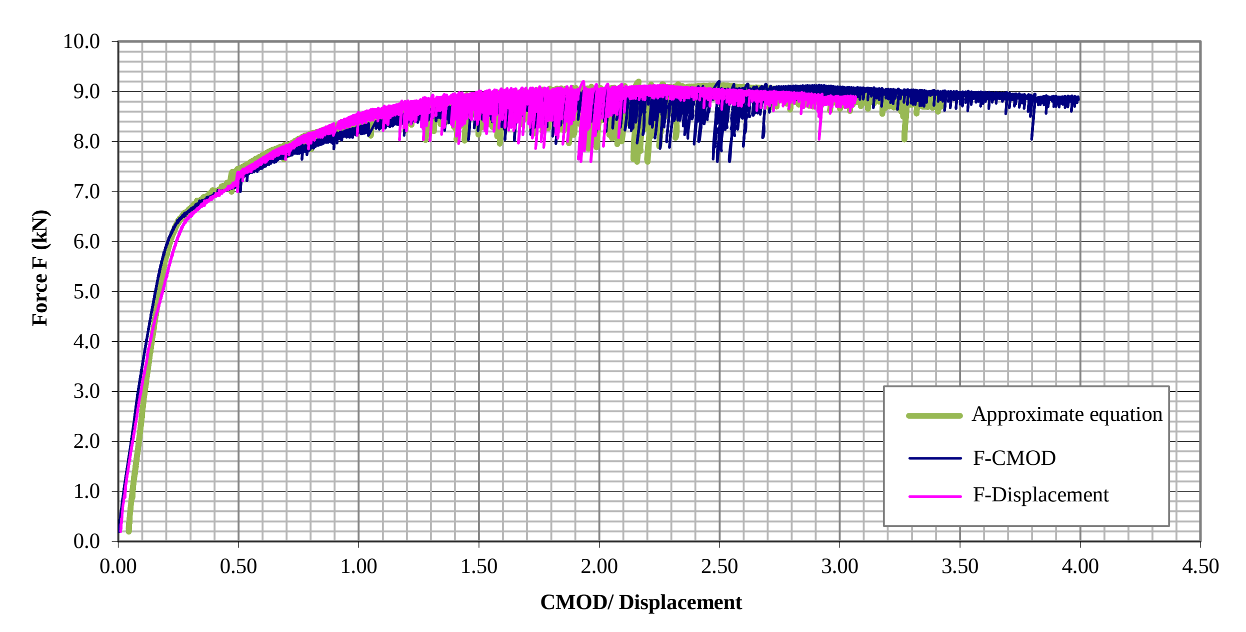


Figure 16. Comparison of the F-CMOD, F-Displacement, and Approximate Equation Relation Curve

Following the instructions of (*fib* Model Code 2010) [19] for the use of SFRC for structural elements after testing, which is one of the main conditions, the classification of the material should be done to understand whether it meets the above conditions and requirements. From Table 10, with the classification of the material, we see that the mixture with fiber content V_f = 0.75% belongs to the material named 2.0a, the mixture with content V_f = 1.5% and V_f = 2.0% is classified in the materials of class 3.0d and 3.0e. From the instructions of (*fib* Model Code 2010) [19] from the classification, we understand that mixing with the content of the number of steel fibers of V_f = 0.75% is not for constructive use, as it cannot reduce the amount of reinforcement required of the element where it should be used.

Table 10. SFRC material classification

SFRC characteristics obtained from EN14651 testing				**Unit**
The amount of content of steel fibers	$V_f = 0.75$	$V_f = 1.5$	$V_f = 2.0$	(%)
f_{Lk}	4.43	5.19	5.43	MPa
f_{R1k}	2.09	3.53	3.96	MPa
f_{R3k}	2.31	4.76	5.24	MPa
Classification	2.0 a	3.0 d	3.0 e	f_{R3k}/f_{R1k}
Secure coefficient. γ_F	1.3	1.3	1.3	Tip B
$f_{R3k}/f_{R1k} > 0.5, f_{R1k}/f_{Lk} > 0.4$	No	Yes	Yes	Constructive Use

3. Conclusion

To understand the mechanical behavior of SFRC as noted above, we have analyzed mixtures with different amounts of fiber content; 0.75%, 1.5%, and 2.0% by volume of concrete. All results are compared with ordinary concrete without fiber content but for the same grade as MR_DK_E1: C30/37. The greatest attention has been paid to CMOD testing as one of the conditions to obtain the values of solidity left after cracking, which is crucial for the design of structural elements with material from SFRC. The use of fibers showed satisfactory results on the mechanical properties but gave negative results on the properties of wet concrete. From these results, we understand that with the increase in the number of fibers, the workability of wet concrete becomes more difficult. If we think only of improving the mechanical properties of hardened concrete, it often happens to negatively affect the workability of the material. Increasing the number of fibers does not mean the same for compressive strength. The values obtained from the results of SFRC compression tests are negligible compared to characteristic concrete. Increasing the number of fibers increases the porosity of concrete. From our results, it is seen that the improvement in compressive strength, although minimal, comes from mixing with a fiber content of 0.75% to the volume of concrete. This analysis has shown good results. With the increase in the number of fibers, the increase in solidity is linear. For the fiber content of V_f = 2.0%, we have an increase in solidity in indirect traction from the crack of 29.21% to the characteristic concrete. With the increase in the number of fibers in V_f = 1.5%, additional solidity after cracking for f_{R1k} increased by 41% while for f_{R3k} we have an increase of 51% and MC 2010 classifies it in material 3.0d, which is a material used for structural elements, while in mixing with fiber content, V_f = 2.0% increase in additional solidity after cracking compared to mixing V_f = 1.5% is negligible and belongs to the same class as 3.0e. In conclusion for constructive and more economical use, it is worth using SFRC with a content V_f =1.5% of fibers, always referring to the test results.

4. Recommendation

From the comparisons of SFRC, the mixture with a content = 1.5% has good results and meets the economic conditions. It is recommended to be used for constructive elements. The research confirmed that the biggest problem with SFRC was addressed by all previous researchers during the literature review. The distribution of fibers plays a very important role in the mechanical properties of SFRC, while the amount of volume affects the reduction of concrete consistency. In other words, it will take more work and more vibration to put the concrete in place. As a recommendation to other researchers regarding SFRC, pay special attention to finding new methods for the possibility of distributing the fibers as uniformly as possible. Such a finding would be a further advance compared to our research. To investigate the fracture energy for concrete with fiber content. Use Finite Element Analysis (FEA) software to perform numerical simulation for the test with three points (BS EN 14651:2005+A1, 2007) [20].

4.1. Mention the Limitations of the Study and Prospects for Future Research

Limitations and future research: As with any other study, ours had some limitations. First, since all of our samples are made by us, there is the possibility of bias. Furthermore, although the best efforts were made to prepare and work the samples in a professional manner and according to standards, this may not have been sufficient to present and confirm the reliability of the examinations and results. Due to these limitations, further research should be conducted with larger samples to present more accurate results. Future studies may also be in the manufacturing industry of fibers from different materials. In addition, future studies can perform comparisons between steel fibers with shapes and dimensions as well as other materials. Second, this study focused on the influence of steel fibers on compressive strength. So, future studies can explore the opposite effect of the steel fibers' influence on other properties of concrete, such as during production, processing, and explanation. Finally, although our research findings suggest a good fit for all tested parameters, two important aspects should be kept in mind. First, in a reasonable number of well-crafted samples, a suitable recipe sometimes fails simply because of small differences between elements and other unforeseen factors. Therefore, more studies should be conducted in the future using steel fibers of different sizes and shapes in order to generalize the findings across industries. Second, since the reviews were conducted in the Kosovar and Macedonian contexts, this review can be further tested in other countries and the results can be compared.

4.2. Summarize How the Article Contributes to New Knowledge in the Domain

This research is of particular importance in the field of application of other elements in the concrete mix design and also in the changes that occur in the resistance of concrete as a result of using different percentages in concrete mixtures. As well as the changes that occur in the resistance of concrete as a result of the use of different percentages of fibers in concrete. The analysis is even more important since the data was obtained based on the laboratory experiments that were carried out in the laboratories of construction materials in UBT Pristina and in Skopje. This paper has special importance since the data and results were obtained based on the results obtained during the analysis and experiments. Therefore, they are also confirmation of different data based on the Euro codes.

4.3. Recommendations for Future Research

The effect of steel fibers has evolved from a new material to a successful and widely applied due to its mechanical properties and advantages over conventional concrete, but the higher production cost of steel fibers has limited its usage in the private and public works sector. The addition of steel fibers to the normal concrete batching plant raises the production cost of steel fibers. Thus, finding sustainable, environmentally friendly, and cost-reducing methods is one of the directions for further applications of steel fibres. Further investigations were highly recommended and should be carried out to understand more about the mechanical properties of fibre reinforced concrete. Several recommendations for further studies are mentioned below:

- The problem of the workability of the steel fibre reinforced concrete can be reduced by adding chemical admixture such as super-plasticizer, silica fume or blast furnace slag. Hence, with high workability, fresh concrete can mitigate the quick stiffening effects of the fibres.
- More investigations and laboratory tests should be done to study the mechanical properties of steel fibre reinforced concrete. Such application of fibres was recommended in testing on concrete slabs, beams and walls or conducting more tests such as abrasion, impact, blasting, shattering, shear or creeping of concrete.
- The combination of short steel fibres may tend to provide more efficient mechanical properties of the structure. Further investigation can be carried out by the combination of different types of short fibres into the concrete mix.

- To widen the use of steel fibre reinforced concrete, different or more complicated geometries of fibre can be used to investigate the effects of short fibres in the concrete through fresh and hardened properties.
- The mechanical properties of fibre-reinforced concrete may be different at various temperatures. Tests on freeze-thawing conditions were recommended.

5. Declarations

5.1. Author Contributions

Conceptualization, M.A., M.R. and D.K.; methodology, M.A.; software, M.R.; validation, M.A., M.R. and D.K.; investigation, M.A.; writing—original draft preparation, M.A.; writing—review and editing, M.A.; visualization, M.A. corresponding author, D.K. All authors have read and agreed to the published version of the manuscript.

5.2. Data Availability Statement

The data presented in this study are available in the article.

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5.4. Acknowledgements

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5.5. Conflicts of Interest

The authors declare no conflict of interest.

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