INFLUENȚA CONȚINUTULUI DE FIBRE ȘI A ORIENTĂRII ACESTORA ASUPRA REZISTENȚEI LA TRACȚIUNE A BETONULUI AUTOCOMPACTANT

INCREASING THE TENSILE STRENGTH OF FIBER REINFORCED SELF-COMPACTING-CONCRETE, AND EFFECTS OF FIBER TYPE AND ORIENTATION

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In this study, the effects of using fiber in self compacting concrete (SCC) on flow parameters, tensile and compressive strength of concrete were investigated. Unit weight, air content, slump flow, J-ring, V-funnel tests on fresh concrete and compressive, splitting tensile along with flexural strength tests on hardened concrete were performed, in addition fresh and hardened concrete properties were studied for to determine the relationship between them. A polypropylene fiber, an alkali-resistant glass fiber and two types steel fibers which have the different lengths and the different length/diameter ratio were used in the test specimens. It is observed that an increase in the amount, length and length/diameter ratio of steel fibers resulted in an increase of the tensile strength of concrete (more than 90% in flexural tensile strength according to non-fiber concrete series), while, properties of fresh concrete deteriorated and compressive strength of concrete decreased.

Keywords: *self compacting concrete, SCC, fibers, fiber concrete, tensile strength.*

1. Introduction

SCC is one of the important developments of concrete technology [1]. SCC, a high performance special concrete, was first developed in Japan, in 1986 [2, 3]. SCC is considered as a concrete that can be placed and compacted under its own weight without any vibration energy and can assure complete filling of concrete in formworks and narrow gaps between reinforcement bars [4]. SCC is better than the conventional concrete, because it can be increased speed of construction, reduction of labor costs, reduced noise and health hazards also increased mechanical properties and durability of concrete [5]. Despite the fact that SCC needs more cement and chemical additives than the conventional concretes, it has become very important because of the benefits that SCC has provided in recent years [6].

Fiber reinforced concrete is the other high-performance concrete. In general, concrete has brittle behavior, but using different fibers in concrete design can be improved energy absorption capacity, toughness, impact resistance and durability of concrete, also fibers usage reduces cracks of concrete [7]. The fibers added to the concrete usually obtained from metal, polymer, glass and other materials [8]. There are two types of polymeric fibers that macro-plastic fibers and micro-plastic fibers. The most common micro-polymeric fibers are polypropylene and nylon fibers and they are often used in concrete for the reduction of plastic and drying shrinkage cracks [9]. Some macro-plastic fibers are used in concrete to improve flexural strength, toughness and fatigue behavior [10]. The most common metal fibers are steel fibers and they are used to increase toughness, energy absorption capability of structural concrete member which used in different productions [11]. Besides the positive effect of fibers in concrete, reducing workability and flowability of fresh concrete and causing flocculated in concrete are also important issues to be worked on [12]. Hardened concrete properties are directly affected by fresh concrete structure [13]. The effects of various fibers adding in SCC in various amounts on changes in the properties of fresh concrete were investigated by many studies [14, 15]. In some studies, the adverse effects of polypropylene and glass fibers on the parameters of the concrete flowability were particularly addressed [14]. The amount, geometry, slenderness ratio (length/diameter) and size of fibers can affect concrete's workability, flowability and flocculate. For these reasons, fresh concrete tests of the fiber used in SCC should be considered [16].

Fiber usage in conventional concrete has negative effect on fresh concrete status, but it has positive effect on hardened process, however fiber usage in SCC can be more appropriately focused in this study, because fresh concrete performance

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with SCC is better than conventional concrete.

Using fiber in SCC and its results were subject areas of some recent studies [16, 17]. In this study, various fibers used in SCC and both fresh and hardened concrete properties of SCC have been studied, and especially weak tensile strength of concrete has been attempted to be increased.

2. Experimental study

In this study, Portland cement CEM I-42.5-R and F type fly ash from Zonguldak Catalagzi thermal power plant has been used. Chemical and physical components of the cement and fly ash are given in Table 1. In the experiments, natural sand (0-4), fine crushing gravel (4-8) and coarse crushing gravel (8-16) aggregates were used, including three groups. Saturated surface dry specific gravity of aggregates is 2.62, 2.72 and 2.70 g/cm^3, respectively. Aggregates maximum diameter was selected as 16 mm for the reason of high flowability and addition of fibers in the design of the concrete. In the experiments, Sika ViscoCrete Hi-Tech 30 which is a third generation concrete admixture was used. This high performance superplasticizer was deemed, because it can reduce water rate and can provide longer workability. The Ph of this high performance superplasticizer is 3-7 and its density 1.07-1.11 kg/l at 20 ^{o}C. Four different kinds of fibers were used in the experiments. Properties of the fibers used in the concrete mix are given in Table 2.

2.1. Experiment blends

For the experimental study, 13 different concrete series were produced. One of the series without fiber was produced for control and twelve series were produced with four types of fibers which have different length, geometry, usage rate and settlement. Fresh concrete unit weight, air content, slump flow, J-ring and V-funnel tests were performed on eleven series. These tests were not

Table 1

Some physical and chemical properties of cement and fly ash

	Components (%)									
	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	SO_3	Loss on Ignition	Cl^-	Na_2O	Blaine specific surface (cm^2/g)	Specific gravity (g/cm^3)
Cement	20.20	5.80	3.23	64.10	2.18	2.68	2.42	0.01>	-	3834	3.16
Fly ash	56.80	24.10	6.80	1.40	2.40	0.48	0.91	-	0.30	3812	2.20

Table 2

The fibers used in the concrete mixture and the properties

Fiber types / Properties of fiber	Steel Fibers		Polypropylene fibers	Alkali-resistant glass fiber
	Dramix RC 65/60 BN	Dramix ZP 308	Sika Fibre	Ar glass fiber
Specific gravity (kg/dm^3)	7.85	7.85	0.91	2.60
Length(mm)	60	30	12	24
Equivalent Diameter	0.90 mm	0.75 mm	18 μ	15.40 μ
Length/Diameter	67	40	-	-
Tensile Strength (MPa)	1160	1125	300-400	1808
Fiber geometry	Hooked	Hooked	Straight	Straight

Table 3

The type and amount of fiber in the concrete mixture

Serial No	The fibers used. *	The fibers used quantities (kg/m^3)
1	Fiberless (For control)	-
2	%100 SF60	40
3	%100 SF60	60
4	%100 SF60H	60 (Fibers placed by hand)
5	%100 SF30	40
6	%100 SF30	60
7	%100 SF30H	60 (Fibers placed by hand)
8	50%SF60+50%SF30	30+30
9	25%SF60+75%SF30	15+45
10	%100 PF12	7
11	%100 GF24	7
12	50%SF60+50%GF24	30+3.5
13	25%SF60+25%SF30+25%PF12+25%GF24	15+15+1.75 +1.75

* Designation of fibers used: 60 mm length steel fiber SF60; 30 mm length steel fiber SF30; 12 mm length polypropylene fiber PF12 and 24 mm length glass fiber GF24

Table 4

The materials used in the concrete mix ratios (%)

Serial No	1	2	3	4	5	6	7	8	9	10	11	12	13
Fine Aggregate	32.90	32.90	32.90	32.90	32.90	32.90	32.90	32.90	32.90	32.90	32.90	32.90	32.90
Coarse Aggregate	29.80	29.29	29.04	29.04	29.29	29.04	29.04	29.04	29.04	29.53	29.53	29.28	29.16
Fiber	-	0.509	0.764	0.764	0.509	0.764	0.764	0.764	0.764	0.769	0.269	0.516	0.641

Cement 11.3%, Water 20 %, Fly ash 6% and Superplasticizer was added by weight cement of 1.25% in volume of 100%.

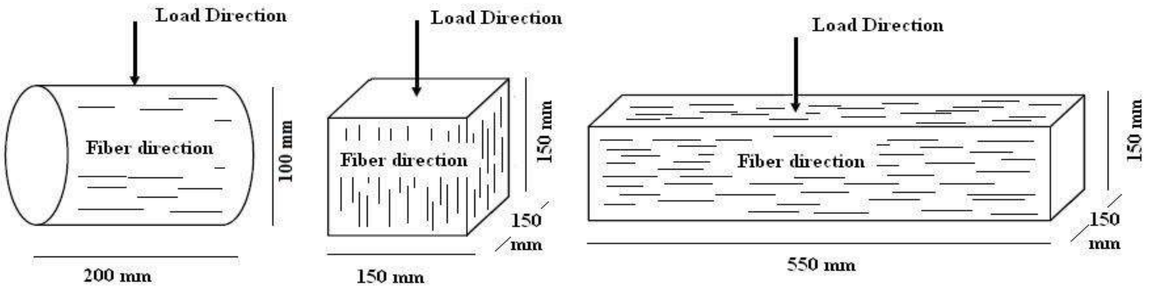

Fig. 1 - Dimensions of the test specimens and for two series; fiber orientation of the fibers in the sample is placed manually and upload forms.

done for two series which have hand placed fibers. (Their fresh concrete designs are same with predecessors' series. The only difference is that the fiber placing by hand.) Fiber bundles separated in water were placed in concrete and to fibers direction is given by hand. Dimensions of the test specimens: (Cylinder; diameter=100mm and height=200 mm), (Cube 150mmx150mmx150mm) and (Beam 150mmx150mmx550mm). Dimensions of the test specimens, and for two series; fiber orientation of the fibers in the sample is placed manually and upload forms are shown in Figure 1.

Fresh concrete tests of SCC were performed according to the EFNARC standards [18]. The splitting tensile strength on cylinders specimens according to the TS EN 12390-6 [19] standards, the compressive tests on cube specimens according to the TS EN 12390-3 [20] standards and the flexural tensile strength on prismatic beam according to the TS EN 12390-5 [21] standards were made at 7 and 28 days periods.

All samples were removed from the mold after 2 days from casting and cured in water content at 20 ^{o}C. Fiber type and quantity ratios of the test sample are presented in Table 3 and mixture ratios are given in Table 4.

The amount of cement, water and fly ash used in the concrete mixture is 350 kg/m^3, 200 kg/m^3 and 150 kg/m^3, respectively. These ratios were given by volume in the revised manuscript. Accordingly, the water / cement ratio is 0.57 and the water / binder ratio is 0.40.

3. Results

Fresh and hardened concrete tests as two main groups were done on prepared 13 different series. The test results are shown below.

3.1. Fresh concrete test results

The unit weight, air content, slump flow, J-ring and V-funnel tests were conducted to determine of fresh concrete physical workability and mechanical properties.

3.1.1. The unit weight and air content

Relation between unit weight and air content of concrete series are shown in Figure 2. In general, the unit weight reduced with the increasing amount of air content.

These measurements were performed on a total of 13 series concrete. 3rd series with 4th series and 6th series with 7th series have same components, but the fibers were placed properly in 4th series and 7th series. Only 2nd series has higher unit weight from the fiberless series and this result can be explained only with the fibers proper placing. Using fibers in the concrete components reduced the unit weight for all other series. As will be seen from Figure 2, in particular polypropylene and glass fibers reduced the unit weight of concrete too much. The 10th series which contains only polypropylene fibers has the worst unit weight value and these series have the highest air content.

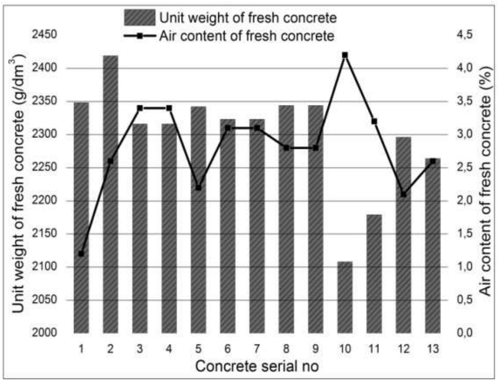

Fig. 2 - The concrete series' fresh unit weight and air content exchanges.

Concrete mixtures having more polypropylene and glass fibers due to the low density of these fibers and increased fiber surface area disrupted the concrete rheology and exhibits a hollow concrete structure. The use of fibers in the concrete mixture increases the amount of air in concrete. The 3th series and 4th series which contain 60 mm length and 60 kg/m^3 amount of steel fibers have more air content.

In general, increasing amount or length of steel fibers reduces unit weight and increases air contents of the concrete series.

3.1.2. Slump flow and T_{50} time

Adding fibers to SCC resulted in a reduction of diameter of slump flow and an increase in T_{50} time. Diameters of slump flow have been shown in Figure 3, and relationship between diameters of slump flow and T_{50} was demonstrated in Figure 4.

While fiberless self-compacting concrete is spread in 720 mm diameter, this value is dropped in 400 mm diameter for 10th series which contain 100% polypropylene fibers. In general, spread problem have occurred in polypropylene and glass fiber for all series (10th, 11th, 12th and 13th series), and these series could not reach 500 mm diameter, because these light fibers entered in the concrete mixes in large quantities. When the steel fiber is introduced into a series, the increase of the steel fiber length and quantity were reduced diameter of spread and increased the T_{50} time.

The highest T_{50} time have been seen for 3th and 4th series. Also, the increase of the steel fiber length and quantity quashed the circular appearance. The series with short steel fibers have more regular the circular appearance and short T_{50} time. These geometric circular distributions haven't been seen for the concrete mixtures which contain polypropylene and glass fibers.

3.1.3. J-ring results

As result of tests, 4 mm difference was occurred between the internal and external level of circle for concrete series which have no fibers.

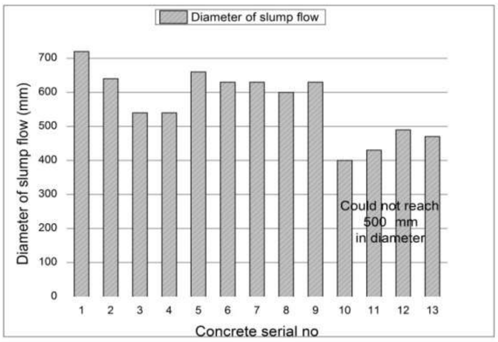

Fig. 3 - Diameters of slump flow for series.

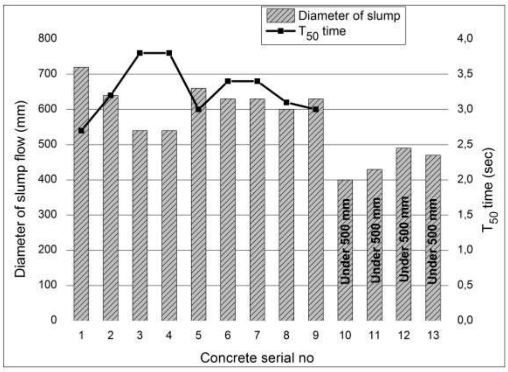

Fig. 4 - Diameters of slump flow and T_{50} time exchanges .

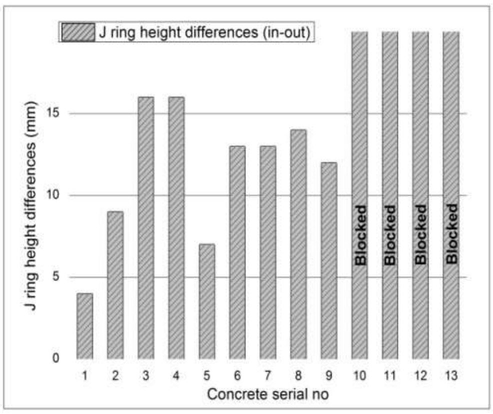

Fig. 5 - J-ring values of the concrete series.

Spread problem have occurred in polypropylene and glass fiber used all series (10th, 11th, 12th and 13th series), and blockages in the circle was observed. As mentioned in the previous sections, excess fiber and fibers' surface area are increased agglomeration for these concrete series. Differences between the internal and external J-ring was represented in Figure 5.

The amount of fibers and fibers' length increase the height difference for J-ring. J-ring of 3rd and 4th series with content of 60 kg/m^3 and length of 60 mm fiber reached as high as 16 mm and this result showed blockage. Reduction in amount or length of steel fibers' had a positive impact for J-ring.

3.1.4. V-funnel test results

The amount and length of fibers had negative effects for V-funnel. V-funnel time was shown in Figure 6. According to the Figure 6, some concrete series were blocked in V-funnel.

Fiberless concrete series completed the experiment in 8 second. V-funnel experiment wasn't suitable for 60 mm length steel fibers, because V-funnel outlet has only 65 mm length. Nevertheless these series completed experiment in 27 second. 6th and 7th series which content 60 kg/m^3 and 30 mm length steel fibers didn't complete the experiments, because fibers were blocked in the test tool output. The 8th, 9th, 10th and 13th concrete series didn't complete this experiment either. The series with polypropylene and glass fibers were blocked in the test tool output.

The amount and increased length of fibers have negative effects for the V-funnel experiment. The V-funnel experiment is not suitable for fibre concretes in general, because concrete series were clogged or emptying time was exceeded for V-funnel that has a 65 mm funnel opening width.

3.2. Experiment results of hardened concrete.

The compressive strength, splitting tensile strength and flexural tensile strength were performed on the hardened concrete samples.

3.2.1. Compressive strength results

In this study, it was observed that the increasing length and amount of fibers were adversely affected to compressive strength. There are some studies in the past which saying same or opposite results [6, 11]. Cube compressive strength of the concrete series was shown in Figure 7 at 7 and 28 day periods and relationship between 28 day compressive strength and air content is shown in Figure 8. In general, increasing air content resulted in a decrease compressive strength, and this can be seen easily from Figure 8.

Fibers placed in the pressure line, which have 60 mm length and 60 kg/m^3 in amount used in series named SF60H has the worst pressure resistance. This result shows that selected fiber direction was wrong. Compressive strength results of 5th, 6th, and 7th series which contain 30 mm fibers were better than the series with 60 mm steel fibers. In generally, same amount of short steel fibers are better than long ones for concrete compressive strength.

The compressive strength test results of 10th series which contains %100 polypropylene fibers were less than the fiberless series. Because, polypropylene fibers caused the loss of flow properties, they formed hollowed structure in concrete.

Compressive strength results of the 11th, 12th, and 13th series with glass fibers content were the highest ones in all of the series. In fact, glass fibers were adversely affected the flow parameters like polypropylene ones, but they had good compressive strength results. High tensile values of glass fibers may produce this result. The highest compressive strength was obtained for 7 days and 28 days from the 12.series which contain 50% of 60 mm long steel fibers and 50% glass fibers.

Another important result of pressure tests was that although both non-fibrous samples and fibrous samples fractured suddenly, fibrous samples test continued and the load on the samples discharged after a long time. It is a sign of ductile behavior of fibre series.

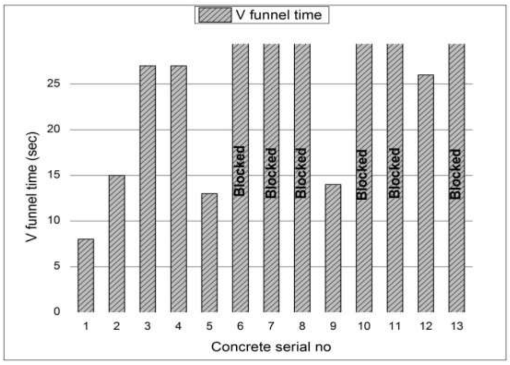

Fig. 6 - V-funnel time of the concrete series.

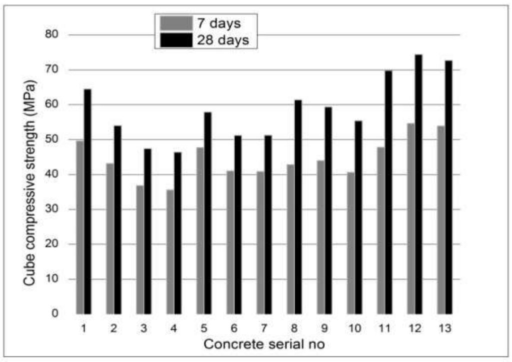

Fig. 7 - 7 and 28 days cube compressive strength strength and air content of fresh concrete.

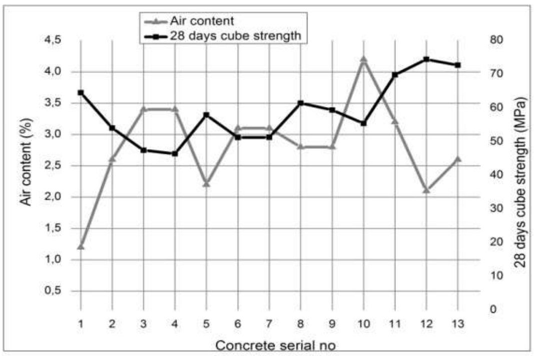

Fig. 8 - Linear representation of relationship between 28 days compressive strength and air content of fresh concrete for concrete series.

3.2.2. Splitting tensile strength test results

Steel fibers directly increased the splitting tensile strength proportional with length and increased amount of fibers. The 7 and 28 day splitting tensile strength values of concrete series in Figure 9. The 28 day splitting tensile and 28 day compressive strength is shown in Figure 10. The relationship of 28 day splitting tensile strength and air content of fresh concrete is shown in Figure 11. When all conditions are considered together, adding fibers especially steel fibers to SCC increases the splitting tensile strength.

After splitting tensile strength test on fiberless 1st series, cylindrical samples were divided into two pieces. In particular, there has been no complete separation of steel fiber samples. Experiments were continued on these samples with lower loading from breakage loading. Splitting tensile strength test results of all series were better than 1st series which has no fiber except 10th series with 100% polypropylene fibers for 28 days. Although, glass fibers series have some concrete cavity, results of these series were good because of high tensile strength of glass fibers. Better results can be expected from glass fibers concrete which has no settlement problems and a more accurate design mix proportion.

The highest splitting tensile strength was obtained from the 3rd series in which content of 60 kg/m^3 60 mm length steel fibers. The 4th series with the same content but fibers placed by hand (the same as the tensile strength direction of the fiber direction) were little lower in splitting tensile strength than the 3rd series. Splitting tensile strength of 4th series expectation was a bit higher than expected of the 3rd series, but hand inhomogeneous distribution and agglomeration are thought to be the cause of this result. In general, increasing the amount and length of steel fibers along with providing uniform distribution of these fibers has increased the splitting tensile strength of this concrete series.

Polypropylene fibers which were entered in the concrete mixes in large quantities, cause gaps in the concrete because of increased fiber surface are increasing adherence and clusters.

In Figure 10, the 28 day splitting tensile strengths were compared with 28 day compressive strengths of the concretes. Looking at the graph, it is seen that fiberless 1st series has high compressive strength, but low splitting tensile strength. Whereas 2nd, 3rd and 4th series which contain 60 mm length steel fibers have high splitting tensile strength, but low compressive strength. In general, especially long steel fibers in concrete series reduce the compressive strength and increase the splitting tensile strength. The 13th series which have all type of fibers, the result is an optimal result for the two strengths.

In Figure 11, 28 day splitting tensile strength were compared with air content of fresh concretes and was found that adding the fibers increases air quantity. Although the amount of air increases with the addition of fiber has increased splitting tensile strength at 28 day. The 10th series with 100% polypropylene fibers contain the most of air and has the lowest the splitting tensile strength.

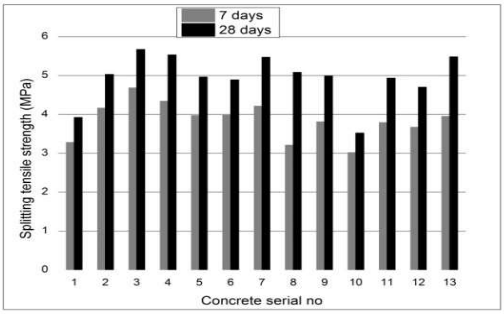

Fig. 9 - 7 and 28 days splitting tensile strength values change of concrete series.

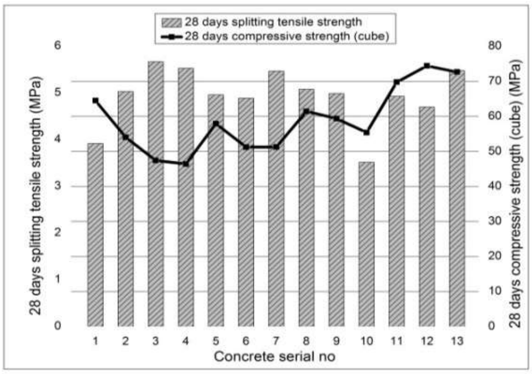

Fig. 10 - 28 days splitting tensile and 28 days compressive strength change.

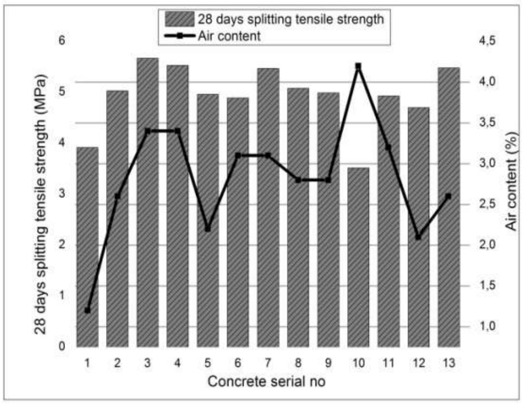

Fig 11 - Relationship of 28 days splitting tensile strength for 28-day period.

3.2.3. Flexural strength test results

Flexural strength results are given in Figure 12 at 7 and 28-day period. It was especially observed that steel fibers have limited the cracks.

When Figure 12 was analyzed, it was seen that flexural tensile strength of the 10th, 11th, and 13th series were lower than fiberless series for 7 days period, but these series have higher results than fiberless series for 28-day period. This demonstrated that the adherence of

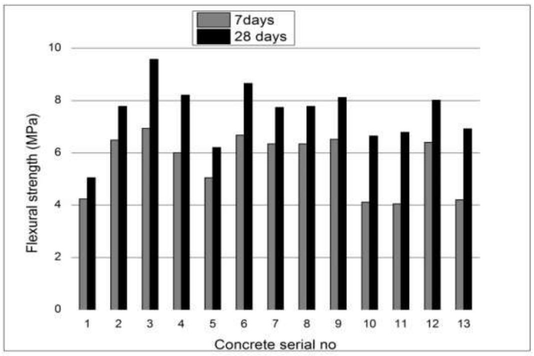

Fig. 12 - 7 and 28 days flexural strength of concrete series.

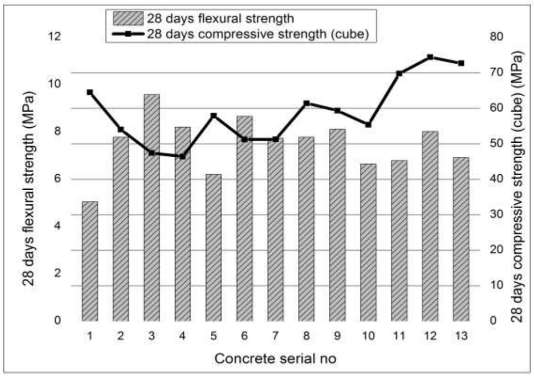

Fig. 13 - Relationship between flexural and compressive strength for 28-day period.

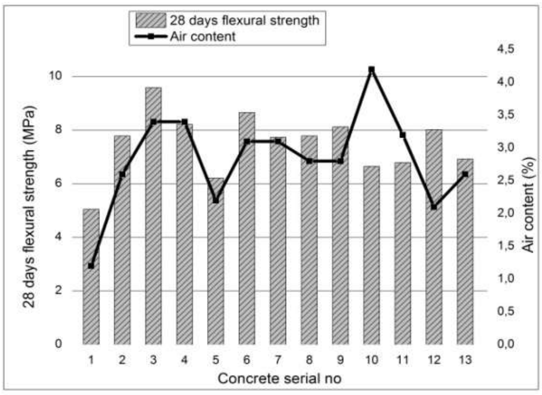

Fig. 14 - Relationship between 28 days flexural strength and air content (fresh concrete) .

polypropylene and glass fibers increases with time in flexural tensile strength.

The greatest flexural strength was obtained from SF60 (the third series) which fibers were used 60 kg/m^3. The 4th series, which has fiber orientation by hand, test results weren't as high as the 3rd series.

Flexural strength test results of 5th, 6th and 7th series with 30 mm length steel fibers were better than fiberless series but they weren't high like the series with 60 mm steel fibers.

In general, increasing the amount and length of steel fibers and providing uniform distribution of these fibers has increased the flexural strength of concretes too, like the splitting tensile strength.

Like splitting tensile strength tests, the samples of fiberless, polypropylene fibers and glass fibers series were divided into two pieces generally, but some of series with steel fiber have not been completely separated for samples, and these samples continued to be tested with lower loading from breakage loading. This shows that, steel fibers provide concrete ductile behavior. The 10th series, with 100% polypropylene, results were better than fiberless series, but it was thought that the effect of these fibers to the flexural tensile wouldn't be so good. It was not expected that the 11th series, which contain 100% glass fiber, test results would be so high as the results found, but these small glass fibers need to have more homogeneous distribution in concrete.

Relationship between flexural strength and compressive strength changes at 28 day period are shown graphically in Figure 13. The most remarkable observation for relationship between flexural and compressive strength is that compressive strength loss against concrete series with short steel fibers less than concrete series with long steel fibers and long steel fibers increased concretes' flexural strength highly. All series with glass fibers have high compressive strength, but their flexural strength results were not high.

Flexural strength and air content of fresh concrete is associated in Figure 14. Steel fibers increased the amount of air in fresh concrete nevertheless they increased flexural strength of concretes (Figure 14). This result proved the assumption which says that fibers usage increases the air content of concrete. Especially, because small and light polypropylene fibers amount is very high in concrete and these fibers' surface adherence create voids in the concrete structure. The 10th series, which contain 100% polypropylene fibers, have the highest air content. The 11th series with 100% glass fibers have high air content too.

The relationship between splitting and flexural strength was given in Figure 15 for 28 day period. Generally, flexural strength and splitting strength ratio was between 1 and 2. This value is proper because, flexural strength/2 or splitting strength/1.5 has given the concrete direct tensile strength. So, the accepted ratio bending/splitting is around 1.34 in the literature.

Especially, flexural strength/splitting strength ratio of the 10th series with 100% polypropylene fibers which have settlement problem were the highest as 1.89 and the series which contain long steel fibers strength/splitting ratio are high too.

The most important result of flexural strength/splitting strength ratio is the effect of the specimens' dimensions, because the settlement problem of concrete was reduced by increasing the test specimens' dimensions. Splitting strength test specimens were small cylinders, but flexural strength was used with bigger beam specimens. When the concrete dimensions are getting bigger then fibers propagation can be more homogeneous in the concrete. The homogeneous propagation of fibers is very important for self compacting concrete.

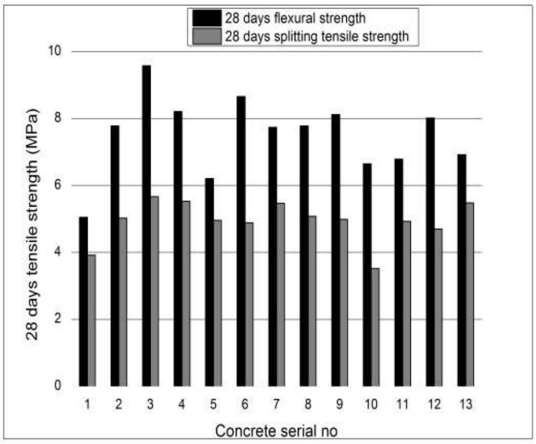

Fig. 15 - Comparison between splitting and flexural strength for 28-day period.

In Figure 15 it can be seen that the highest strength for flexural and splitting test were obtained from 3rd series which contain 60 kg/m^3 and 60 mm steel fibers, but compressive strength of these series were very low.

The general consensus for this study is that, the length and amount of increase of the fibers increase the flexural and splitting strength but reduce the compressive strength. Another factor that should not be forgotten, for high-strength concrete, the concrete is required to have good workability and flow parameters.

When the flow parameters and workability of self-compacting concrete is lost, concrete homogeneous distribution and the test results can not be estimated.

The results of this study generally coincide with the results of other studies that had been researched, but some studies about polypropylene fibers showed more positive results than this study [3, 8, 12, 14].

4. Conclusions

1. The results demonstrated that the air content increase of concrete caused a reduction in unit weight of self compacting fiber reinforced concrete. The properties of fresh concrete are deteriorated depending on the type, amount and aspect of fiber, and also settlement problems occurred due to increasing void ratio of concrete. In the series with polypropylene and glass fiber, increased number of fibers and fibers' surface (more fibers enter the total amount, because they are light) has an adverse effect on properties of self-compacting concrete.

2. Long steel fibers reduced slump flow spread diameter and the rate of spread, but when compared with short steel fibers these shorter fibers had better performance than the longer fibers. J-ring test usage which measures the concrete ability to pass around reinforcement of concrete should be questioned for fibre reinforced concrete series. V-funnel test is not very suitable for fiber reinforced self-compacting concretes, because concrete series were clogged or emptying time was exceeded for V-funnel that has a 65 mm funnel opening width.

3. Increasing length and amount of steel fibers resulted in a decrease in compressive strength of concrete. Generated internal stresses of steel fibers and increased amount of air in concrete can be the reason for this.

4. For the concrete series in which fibers are placed by hand, the strengths have been poor. Both selecting the wrong fiber direction and not well distributed fibers can be reason of this result. Distribution of fibers in a concrete mixture affects both fresh and hardened properties of the concrete. Irregular fibers distribution results disruption of flow characteristic, gaps in concrete, clogging between the rebars and reduction of hardened concrete strength.

5. In particular, the concrete series that contains a lot of long fibers has the best tensile strength (According to non-fiber series, splitting strength increased 45% and flexural strength increased 90%). Splitting strength of glass fiber series is better than polypropylene fiber series and four different kinds fiber used series (13.series) has a high splitting strength. Generally, this concrete series has low splitting and flexural strength while it did have high compressive strength. For all series, flexural strength/splitting strength proportion is between 1 and 2. Considering, both self compacting properties and tensile strength together, the best series is 9th series which has 25% long and 75% short steel fiber.

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