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The Effect of Steel Fiber Content on The Splitting Tensile Strength of Steel Fiber Reinforced Concrete (SFRC)

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Abstract

Concrete is a composite material consisting of two main components namely aggregate and cement mortar as a binder. Concrete has high compressive strength but weak tensile strength. The addition of fiber in concrete can improve ductile behavior before collapse, inhibit the growth of crack expansion and increase durability. This study aims to examine the effect of fiber content on the mechanical properties of fiber concrete. The fibers used were ssteel fibers with hooked end, and l/d ratio = 67,7 mm with normal concrete quality f'c = 25 MPa. The percentage of fiber content used in this study was 0%, 0,1%, 0,2%, 0,3%, 0,5%, 0,75%, 1%, 1,5% and 2%. The results showed that the addition of fiber in concrete was able to increase the split tensile strength by 7 – 117%. Fiber concrete has higher ductility than normal concrete. This is indicated by the high deflection of fiber concrete compared to the deflection of normal concrete under load.

Keywords

Fiber concrete, fiber steek, splitting test, workability, aspect ratio, ductility

INTRODUCTION

Concrete is the most common building material in building construction that has unique advantages, including high compressive strength, the ability to be models as needed, and does not require continuous maintenance after hardening. However, concrete also has disadvantages, such as low tensile strength, making it brittle. The basic composition of concrete is cement, water, and aggregates.

Currently, most building in Indonesia still use reinforce concrete construction. This can be observed from the physical characteristics of buildings, which have large structural dimensions, affecting the overall weight of the structure. However, concrete has high compressive strength but low tensile strength and is often neglected in design. The low tensile strength shown in concrete causes the material to crack easily when subject to tension. Various methods have been made to overcome concrete weakness in tension. The methods include using steel bar to form reinforced concrete structures, applying prestressed forces, and the use of fibers in concrete.Therefore, many studies have been conducted to improve the tensile strength of concrete, one of which is by adding fibers to the concrete mixture.

Steel Fiber Reinforced Concrete (SFRC) exhibits enhanced mechanical properties compared to conventional concrete due to the presence of steel fibers, which improve its tensile strength, ductility, and toughness. The mechanical performance of SFRC is influenced by various factors, including fiber content, fiber geometry, fiber orientation, and the bonding between fibers and the cement matrix. Dramix steel fiber is a steel fiber produced through a cold drawn process with grooves at the ends that will provide optimal bonding. Concrete that has steel fiber reinforcement concrete will provide ductility and high load bearing capacity. The maximum strain of concrete with 4D Dramix steel fiber also increased where normal concrete usually only has a maximum strain of less than 0.004 (design strain for normal concrete = 0.003). However, concrete with 4D steel fibers proved to be able to reach a maximum strain greater than 0.005 at the time of peak load.

Fiber reinforced concrete is a modification of conventional concrete by adding fibers to the mixtures. The fibers are generally rod-shaped with a diameter between 5 to 500 μm and a length of about 25 mm to 100 mm. The addition of fibers in concrete will develop micro size reinforcements in concrete. However, it is challenging to spread the micro reinforcements from fiber evenly in the concrete mix. It is suggested to reduce the maximum size of aggregates to not greater than 19 mm to facilitate mixing and to provide space for the fibers [1]. The use of fibers in concrete should also consider fiber size and shape, fiber aspect ratio, and the amount of fiber. The amount of fiber is an important aspect in fiber reinforced concrete as the addition of fiber in concrete can also reduce the workability and setting time of fresh concrete [1], [2], [3], [4]

The addition of steel fibers is expected to enhance the tensile strength of concrete due to the high tensile resistance of steel. The addition of 0.75% steel fibers by volume has been proven to significantly improve the strength of self-compacting concrete in high-strength concrete [5]. Other studies have also shown that the addition of steel fibers, in the form of galvanized wire, can improve both the compressive strength and split tensile strength of concrete. Therefore, fiber-reinforced concrete can be considered a solution for enhancing concrete quality. Steel fiber concrete is considered the future of concrete technology, as it is expected to enhance the tensile strength of concrete itself. However, the production of steel fiber concrete requires specific technical steps related to the materials used and the manufacturing process. The materials used for steel fiber concrete include coarse and fine aggregates, portland cement, steel fiber cuttings, and water. The manufacturing process is similar to that of conventional concrete, with the key difference being that steel fibers are mixed together with other concrete components as a substitute for traditional reinforcement. In previous studies, the steel fibers added to concrete mixtures were typically in the form of elongated rods, the addition of steel fiber content can increase the split tensile strength of concrete. A fiber content of 1.5% results in a maximum tensile strength increase of up to 30% [6]. Fibers play an active role in resisting cracks, and the specimen will fail when the steel fibers are pulled out from the concrete matrix. The addition of steel fibers significantly influences the increase in the split tensile strength of concrete. Adding 1.5% steel fibers of the total concrete volume is the optimal content for enhancing split tensile strength compared to 1%. It can also be stated that the higher the steel fiber content used, the greater the split tensile strength that can be achieved [7]. The effect of steel fibers becomes significant and can be seen when the concrete receives 70% of the ultimate stress of the concrete. In this condition the tensile force on the fiber develops pull-out anchoring that prevents the enlargement and widening of hair cracks. Research has shown that using steel fibers in concrete can increase flexural strength, energy absorption capacity, and the ductility of structures. Steel fibers can also inhibit crack growth, and increase the durability of concrete. Moreover, the addition of fiber in concrete mixture is able to prevent early cracking due to heat of hydration or loading [8], [9], [10], [11]. Based on previous research, it has been explained how the effect of fiber addition in concrete, both types of carbon fiber, bendrat wire fiber, steel fiber and polypropylene fiber. The addition of fiber in concrete will increase the strength of the concrete itself. The more fiber dosage used in the concrete mixture, the more it will increase the compressive strength of the concrete itself. In previous studies, it was more likely to examine the dosage aspect of the fiber ratio in concrete, and also the effect of fiber geometry shape in concrete. Therefore, in this study, it will be sought what is the optimum fiber concentration used in concrete mixes and how the effect of fiber addition with Dramix 4d steel fiber type. In previous study, in addition to adding fiber in concere, additional additive were also added which would also affect the strength of concrete, such as silica fume, latex, fly ash, microsilica or other additives. For this reason, in this study no additive were added that could affect the strength of concrete.

Besides having advantages, the only disadvantage of using steel fiber is reduces the workabililty and setting time of fresh concrete[12]. Slump in concrete is affected by the type of fiber used, wavy fibers produce slightly higher slump values, and with the addition of wavy fiber content can reduce the power of UHPC [13], [14]. There are three types of fibers, namely straight fibers, wavy fibers and hooked end fibers. the addition of steel fibers with hooked ends is able to increase compressive strength, tensile strength and flexural strength higher than straight and wavy fibers [15] Steel fiber concrete is recommended to use superplasticizer in the process to improve the bond between steel fiber and concrete and to improve workability [16].

RESEARCH SIGNIFICANCE

This study aims to investigate the effect of steel fiber content to the splitting tensile strength of SFRC. By analyzing the relationship between steel fiber content and splitting tensile strength, this research provides valuable insights into optimizing fiber dosage for maximum performance. The findings of this study will contribute to the development of more durable and resilient concrete structures, particularly in applications requiring improved tensile strength, such as pavements, bridge decks, tunnel linings, and industrial floors. Moreover, the results of this study can serve as a reference for engineers and construction practitioners in selecting appropriate fiber reinforcement strategies for various structural applicationse.

METHODOLOGY

The effect of fiber content on the splitting tensile strength og concrete is investigated in the laboratory. Concrete specimens with 8 different fiber contents ranging from 0% to 2% are examined their compressive strength. The concrete is composed of type I Portland Cement, sands form muntilan, coarse aggregates form Batang, and steel fibers of Dramix 4D with l/d of 67,7. Figure 1 shows the shape of steel fibers used, and Table 1 shows the properties of the steel fibers.

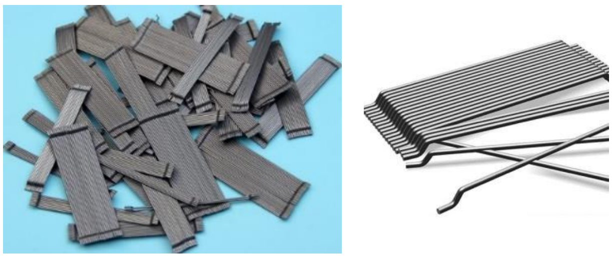

Figure 1 Dramix Steel Fibers

Table 1 Spesifikasi Serat Baja Dramix 4D

Performance	Dramix 4D
Material Properties	
Tensile Strength (MPa)	1500
Young's Modulus (MPa)	(b) 210000
Geometry	
Length (l) (mm)	60
Diameter (d) (mm)	0,9
Aspect ratio (l/d)	67,7

Table 3 Mix Design of Fiber Steel Concrete

No	Variasi Campuran Serat %	Semen (Kg)	Pasir (Kg)	Kerikil (Kg)	Air (Lt)	Serat (Kg)	Superplasticizer (Liter)
1	0,00%	470	892	922	173	0,00	2,82
2	0,10%	470	892	922	173	7,46	2,82
3	0,20%	470	892	922	173	14,92	2,82
4	0,30%	470	892	922	173	22,39	2,82
5	0,50%	470	892	922	173	37,31	2,82
6	0,75%	470	892	922	173	55,97	2,82
7	1,00%	470	892	922	173	74,62	2,82
8	1,50%	470	892	922	173	111,93	2,82

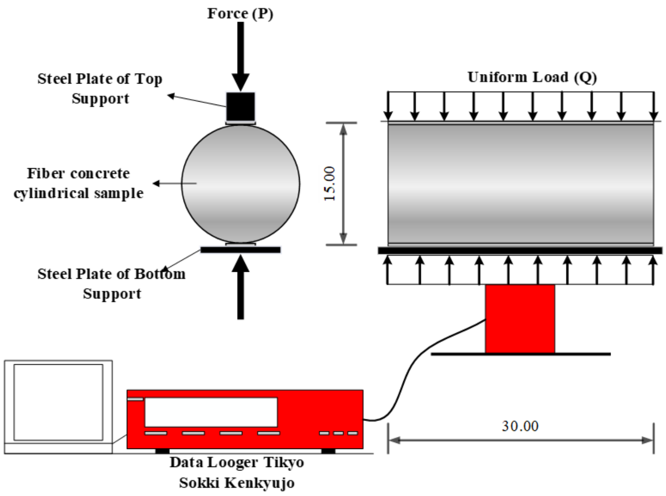

Figure 2. The Illustration of Splitting Tensile Test

The concrete materials are analyzed to determine its characteristics as the basis for determining the mixture ratio. The material tests include sieve analysis, original moisture content, saturated surface dry (SSD) moisture content, bulk density, and SSD density. The materials properties are presented in Table 2.

Table 2 The Characteristic of Concerte Properties

No.	Material Properties	Unit	Value
1	Coarse Aggregates 10-20mm		
	- Bulk Density	Kg/m³	2752
	- SSD Density	Kg/m³	1626
	- Water Absorption	%	1,68
	- Fineness Modulus	-	7,63
2	Fine Aggregates		
	- Bulk Density	Kg/m³	2660
	- SSD Density	Kg/m³	1514
	- Water Absorption	%	1,317
	- Fineness Modulus	-	3,18
3	Cement		
	- Spesific Gravity		3100,000
4	Steel Fiber		
	- Spesific Gravity		7462
5	Superplasticizer		
	- Spesific Gravity		1180

The concrete specimens for splitting tensile strength tests are cylinder with a size of 15 x 30 cm. The steel fiber contents studied consisted of 0%, 0.1%, 0.2%, 0.3%, 0.5%, 0.75%, 1%, 1.5% and 2% of the concrete volume. The SFRC specimens were made in a batching plant of a concrete ready-mix industry to ensure the quality of the specimens. Steel fibers were added to the mixture gradually during the mixing process. The concrete mix design and the number of specimens are presented in Table 3.

The testing method refers to ASTM C496/C496M – 04 "*Standard Test Method for Splitting Tensile Strenth of Cylindrical Concrete Specimens*" and SNI 03 – 2941 – 2002 "Testing methode of concrete splitting tensile strength". The test setup is as shown in Figure 2. The split tensile strength value was obtained through laboratory compressive strength testing by applying a compressive force along the diameter of the cylindrical concrete specimen until the limit of collapse. To spread the load along the length of the cylinder used plywood pads with a nominal thickness of 3.2 mm (1/8 in), and a width of approximately 25 mm (1 in) were used. This test measures the load on each specimen using a load cell which is connected to a data logger. The applied load is monotonic with a loading rate of 0.4 MPa per second. The compressive tests were carried out at the age of 28 days.

RESULTS AND DISCUSSIONS

The splitting tensile test were carried out until the specimens failed. The results of the splitting tensile test show a difference in crack patterns between fiber-reinforced concrete and normal concrete. When reaching the maximum tensile force, the presence of fibers in the concrete prevents it from splitting into two or breaking apart. Instead, the concrete remains intact, with almost all fiber-reinforced specimens exhibiting a similar failure pattern. The cracks that appear are typically horizontal or vertical. For a clearer illustration of the concrete crack pattern, refer to Figure 3. Another difference between fiber reinforced concrete and normal concrete is related to its ductility. Concrete with fibers has greater ductility compared to concrete without fibers, as observed in split tensile and flexural strength tests. The difference in ductility between fiber reinforced and non-fiber-reinforced concrete in the split tensile test can be seen in the significant difference in deflection. In fiber reinforced concrete, the deflection at maximum load ranges from 4 to 6 mm, with a maximum deflection between 6 and 9 mm, depending on the fiber percentage. In contrast, the deflection at maximum load for non-fiber concrete is only 3 mm. The addition of fibers in concrete enhances its ductility, as indicated by the increased elongation of the concrete under loading. By using the average value of the specimen for each variation, made into a tensile strength corellation diagrham with fiber content as shown in Figure 4. The relationship between deflection and load for fiber reinforced concrete and non fiber reinforced concrete is presented in figure 6 and 7.

Figure 3 Specimen of splitting tensile test

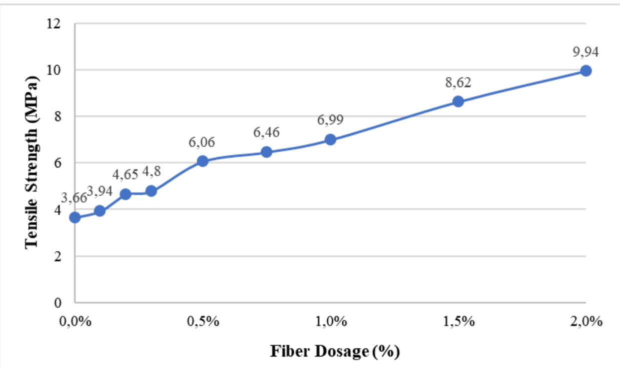

Figure 4 Corellation Diagram Between Fiber Dosage (%) and Tensile Strength (MPa)

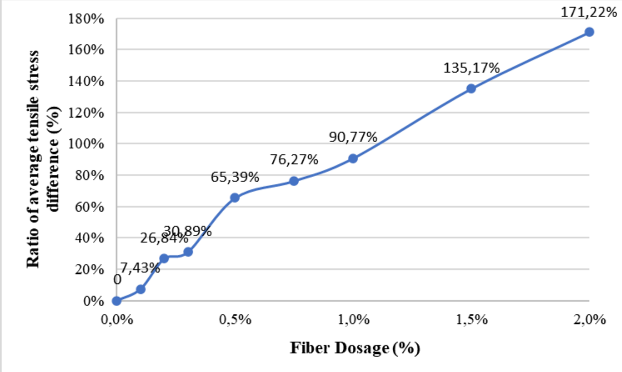

Figure 5 Ratio of average tensile stress difference

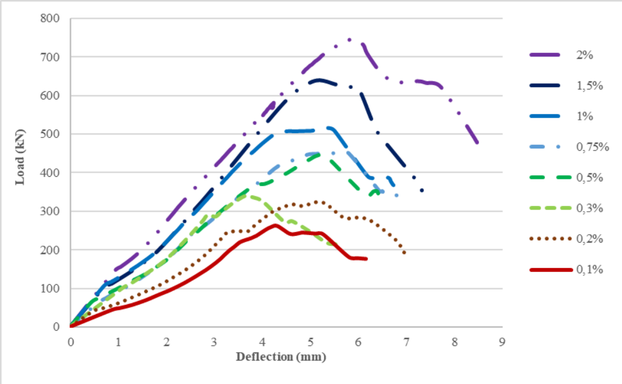

Figure 6 The Correlation of Load & Deflection on the splitting tensile strength test concrete with all fiber content used

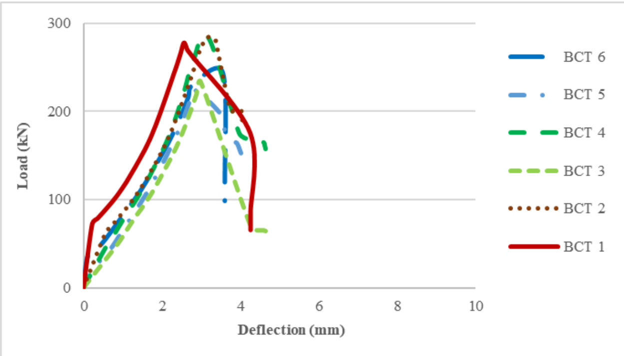

Figure 7 The Correlation of Load & Deflection on the splitting tensile strength test concrete without fibers

Based on the corellation of tensile strength with fiber content as shown in Figure 4, it is explained that there is an increase in tensile strength value of 7% to 171% with fiber content 0,1% to 2% as shown in Figure 5. There was an increase of about 37% in the splitting tensile test with the addition of fiber content up to 1,25%[17]. While in a previous study, it was also explained that adding 2% fiber content in concrete could increase about 17,1% of the splitting tensile test. The addition of steel fiber content can increase the split tensile strength of concrete. Fiber content of 1,5% produces maximum tensile strength up to 30% [6]. The addition of steel fibers greatly affects the increase in split tensile strength of concrete. The addition of steel fiber as much as 1.5% of the total volume of concrete is the optimal level to increase the split tensile strength of concrete when compared to 1%. It can also be said that the higher the level of steel used, the higher the split tensile strength that can be produced [7]. It can be concluded that the result of this study are different from the result of previous studies, due to differences in the shape and geometry of the fibers used. In this study, the optimum fiber content used in increasing the split tensile strength is 1.5%. Where with the addition of steel fiber >1.5%, the value of split tensile strength is relatively same or only increases slightly. But if considered with 1% and 1.5% fiber content, the difference in split tensile strength value is relatively far away.

CONCLUSIONS

This study shows that the addition of steel fibers can increase the tensile strength of concrete. The increase in tensile strength of fiber concrete with normal concrete is about 7 – 171%. The increase in tensile strength and compressive strength in the presence of fiber is relatively similar. However the increase due to the presence of fibers in the tensile test is more consistent than the increase in the compressive strength of fiber concrete. The cracking pattern of concrete with fiber an without fiber in te tensile strength test is very different, concrete with fibers does not immediately crumble or split in half. However, concrete without fibers, when it reaches the maximum tensile load, the concrete immediately disintegrates.

Fiber concrete has higher ductility than normal concrete. This is indicated bt the deflection with fiber concrete is higher than the deflection with normal concrete.

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