Compressive and Tensile Strength of Stainless Steel Cable Ties Fiber Reinforced Concrete

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Abstract. Due to high demand the use of concrete nowadays, many researchers have done studies and reforms to improve the strength and quality of concrete. Additional of fibers in the concrete mix is not novelty construction field. This study was carried out to investigate the compressive and tensile strength of stainless steel cable ties fiber reinforced concrete using concrete Grade 30 (C30/37). This paper also report on the relationship between the tensile and compressive strength concrete cylinder. This paper also identify the optimum percentage use of this fiber in concrete mix. This study will focus on determining the underlying strength of the cylinder regarding workability, tensile strength and compressive strength of concrete containing the fibers of stainless steel cable ties. Mould-casted to be used in this study are cylinder mould with diameter 100mm and height of 200mm. The percentage of the fiber stainless steel cable ties content used are 0%, 1%, 3% and 5%. 12 samples for compression cylinder test and 12 samples for split tensile strength test are prepared which each percentage has 3 samples and total samples for this study are 24 samples. Test that will be conducted are slump test for wet concrete mix, cylinder compressive test and split tensile strength test on sample age of 28 days. Results from the slump test was found that the workability decreases when the percentage of fiber are used increase. Compressive strength test found that the presence of the fiber in the concrete mix has created a more bonding between particles. Compressive strength of fibrous concrete increases as the percentage of fiber content is increased. The use of fiber percentage 5% produced the maximum compressive strength of 35.51 N/mm^2 which higher than the control concrete of 30.40 N/mm^2 with an increase of 16.8%. Split tensile strength tests found that the presence of the fiber in the concrete mix have improved the tensile strength and this concrete fiber has led to requires more power to break the bonds between the particles in the concrete. The percentage of the fiber content by 5% produced the highest tensile strength of 3.46 N/mm^2 higher than control concrete of 2.89 N/mm^2 with an increase of 19.7%. Relationship between tensile and compressive strength was found that the tensile strength is within 10% of the compressive strength. The data obtained do not indicate the optimum percentage of fiber content.

Introduction

Shear strength and bending forces capacity should be increased in a structure to bear a greater load. The main factor contributing to the increase in the strength of concrete is a mixture of concrete. Due to high demand the use of concrete nowadays, many researchers have done studies and reforms to improve the strength and quality of concrete to meet the demand of engineering design. Additional of fibers in the concrete mix is not novelty in the field of construction. But various type of fiber used and the manufacturing technology which is the cause study of fibers in the concrete mix is still done.

Fiber is divided into two categories: natural fibers and synthetic fibers. Natural fibers are available for the extraction of natural ingredients from natural plant fibers, animal fibers or mineral fibers such as coconut fiber, loofah, sugar cane, palm oil, animal fur, iron, and etc. Whereas artificial fibers or synthetic fibers can be obtained from synthetic materials such as polymers of natural or synthetic polymers. A variety of new building materials that have been studied to

improve the particular use of the fiber as an additive in the concrete mix some of which were hard to be found or extracted.
Materials in concrete mixtures affect the strength of concrete designed. In-depth research on the material thereof must be made to produce a stronger and quality concrete mix. Commercialization of fiber-based technology should be implemented more widely to optimize the use of fibers in concrete manufacturing technology.

Normally, when someone using cable ties and tie it tightly, it will be the resulting excess length that is not required. The surplus will be cut and removed and this will result in waste of potential materials. Apart from wasting that materials, which excess material are better being studied its potential as an additive fiber in the concrete mix.

In this study, stainless steel cable ties are used as ingredients in the concrete mix because it has special features of its own when compared to other fiber.

The objectives of the study are shown as below:

i. To determine the compressive strength and tensile strength of stainless steel cable ties fiber reinforced concrete.
ii. To study on relationship between tensile strength and compressive strength of concrete.
iii. To identify the optimum percentage use of stainless steel cable ties fiber in concrete mix.

This study will focus on determining the underlying strength of the cylinder regarding workability, tensile strength and compressive strength of concrete containing the fibers of stainless steel cable ties. Mould-casted to be used in this study are cylinder mould with diameter 100 mm and height of 200 mm. This study focused on a sample of experiments and tests to be carried out in the laboratory as well as studies in the literature on the fiber stainless steel cable ties.

This study is limited to the concrete grade or strength of **30 N/mm^2** in the cylinder compression test and the percentage of the fiber stainless steel cable ties content used are **0 %, 1 %, 3 % and 5 %**. The determination to achieve the objectives of this study involved two types of test which are compression of cylinder test and split tensile strength test.

Previous Studies

Fiber reinforced concrete (FRC) is concrete containing fibrous material which increase concrete properties. It contains short discrete filaments that are uniformly distributed and randomly oriented. Fibers include steel fibers, glass fibers, synthetic fibers and natural fibers each of which loan differing properties to the concrete. Moreover, the character of fiber reinforced concrete changes with varying concretes, fiber materials, geometries, distribution, orientation, and densities [1]. The compressive strength are improved with additions of steel fibers at different volume fraction. The splitting tensile test and modulus of rupture of high strength fiber reinforced concrete are continuously increase with the increasing fiber volume fraction [2].

Steel fibers in the matrix increase the ultimate compressive strength by the resultant arresting growth of cracks based on the bond of steel fiber and cement paste. The problem occur when fiber volume fraction increased to 2.5% or above because it cause the concrete not fully compacted. Additional of steel fiber in high strength, lightweight concrete only improve slightly of compressive strength but splitting tensile and flexural strength are largely improved [3]. The results from this study are steel fibers in reinforced high strength concrete beams can increase flexural rigidity before yield stage and can increase the displacement if beams at failure [4].

Methodology

The properties of the concrete strength is influenced by many factors among them are design of concrete mix, compaction of mixture, surrounding conditions, curing process and etc. These factors

are important in determining the strength of concrete. The provision of materials and tests that will be carried out must be in accordance with the standards set.

This study was conducted to determine the compressive strength of concrete cylinder and tensile strength of stainless steel cable ties fiber reinforced concrete. Methods testing for determining the strength of the fibrous concrete is a compression test of the cylinder for compressive strength and split tensile test for tensile strength.

Materials Preparation

Production of fibrous concrete consist of several main materials:

i. Portland cement,
ii. Fine aggregates and coarse aggregates,
iii. Free water,
iv. Fiber (Stainless steel cable ties).

Percentage of Fiber

Percentage of fiber or volume fraction (V_f) will affect the strength of concrete in compression, tensile, durability, resistance to cracking and workability of concrete. Excessive percentage of fiber will cause the fibers together in one place or clotted and not economic and it will reduce the workability of concrete.

This will cause bonding between concrete reduce and lower the strength of fibrous concrete produced. While little percentage used will cause the strength to be achieved will not succeed. In this study, the percentage to be used is 0 % as control samples, 1 %, 3 % and 5 % of stainless steel cable ties fiber to be mixed in the concrete mixture. Figure 1 and figure 2 shows the stainless steel cable ties fiber.

Figure 1: Stainless steel cable ties

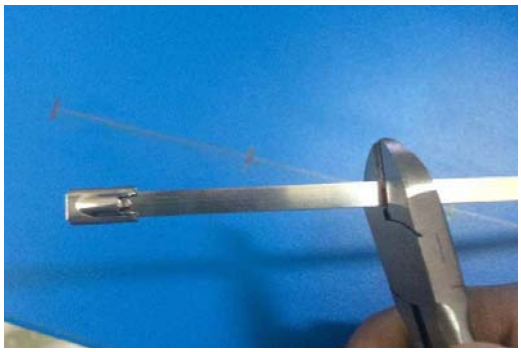

Figure 2: Extraction of fibers

Percentage of Fiber

In this study, concrete mix design for concrete grade **C30** was prepared for the casting of concrete specimens. Method to design the concrete mix are adopted from Experiment Handbook from Faculty of Civil Engineering, Universiti Teknologi Malaysia (UTM) [5].

Materials are mixed is intended to ensure that each particle aggregates in wet concrete are coated with cement paste. The first stage of mixing involves the weighing of materials to be used for each batch of concrete. Concrete mix is prepared using mixer provided at laboratory. Before the concrete mix was put into a cylindrical mold size 100 mm x 200 mm, the prepared mold need to be clean from dirt and inside of mould is smearing with oil on the sides and bottom of the mould so that the sample is easy to strip off the mould.

Concrete mixture was then placed into a mould and compacted by three layers of each layer so that it was no air in the mix that will result in honeycomb of concrete. Concrete is allowed to harden in the mould for 24 ± 8 hours and free vibration from concrete being mixed before the mould can be stripped off.

Next, samples are placed in a tank filled with water for the curing process with controlled temperature between 23 ± 1.7 °C until it was time for the sample tested at a predetermined age [6]. Table 1 shows the number of samples used in this study.

Table 1: Number of samples used in this study

Type of Test	Percentage of Fiber	Number of Samples	Total Sample
Compression Cylinder	0 %	3	**12**
	1 %	3	
	3 %	3	
	5 %	3	
Split Tensile Cylinder	0 %	3	**12**

Slump Test

Mould for slump test used frustum cone which has a height of 300 mm, bottom diameter 200 mm and top diameter of 100 mm. The mould is placed on a flat surface iron plate. Wet concrete mix fed into the mould of three layers where each layer is compacted using an iron rod with a diameter of 16 mm and a length of 600 mm for 25 times by releasing the rod vertically from the mold height. On the surface, the concrete is cut by screeding and rolling rod [6]. Figure 3 shows the slump test process.

After the process, the mold is lifted vertically slowly and concrete that no such support will begin to collapse. Reducing the height of the concrete is measured from the center of the slump in the nearest of 5 mm. Figure 4 show types of slump.

Figure 3: Slump test process

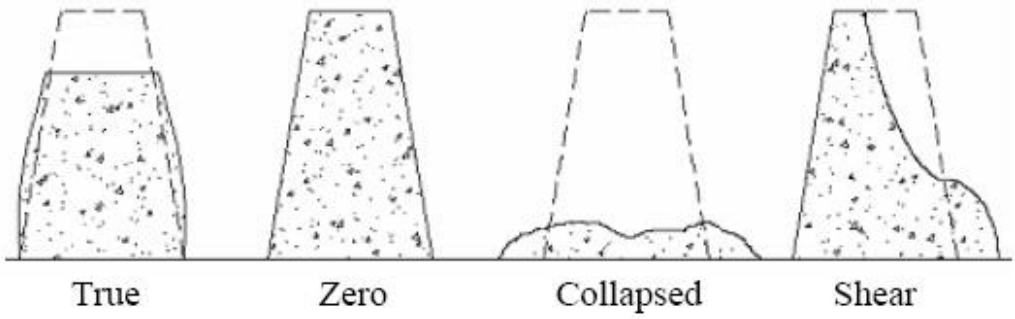

Figure 4: Types of slump

Cylindrical Compressive Test

Cylindrical compressive test was conducted according to the standards BSEN 12390. Samples that have been cured are tested at age of 28 days. The cylinder is placed vertically on the plate

compression machine like in Figure 5. For cylindrical sample size of 100 mm x 200 mm, the force to be imposed on an ongoing basis is 4.7 kN/s ± 1:57 kN/s until the cylinder fractured or broken and these samples have undergone maximum load. The compressive strength obtained through the following formula [6]:

$$\text{Compressive strength, f (MPa)} = \frac{\text{Maximum Load (P)}}{\text{Cylinder cross sectional area (A)}} \quad (1)$$

Figure 5: Compression test machine

Cylindrical Split Tensile Test

Split tensile strength test is performed in accordance with ASTM C496 which the sample is placed horizontally above the plate compression machine like in Figure 6. The load applied to the cylinder size 100 mm x 200 mm is 0.09 to 0.18 kN/s until the sample is cracked or broken along the vertical diameter. The maximum load borne by the sample is the failure load where the tensile strength can be obtained through the following formula [6]:

$$T = \frac{2P}{\pi LD} \quad (2)$$

Where;

T = Tensile strength, MPa,
P = Maximum load at failure, N,
L = Length of sample, mm,
D = Diameter of sample, mm.

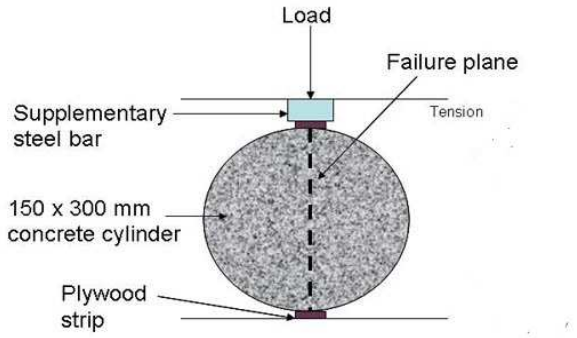

Figure 6: Split tensile test

Results and Discussion

Slump Test

In these study, the concrete slump ranges designed is between **10 mm to 30 mm**. The results of the slump test performed are shown in table 2.

Table 2: Results of concrete slump test

Type of Sample	Slump (mm)	Type of Slump
Control Concrete (0%)	20	True
Fibrous Concrete (1%)	20	True
Fibrous Concrete (3%)	18	True
Fibrous Concrete (5%)	10	True

Based on the results in table 2, all concrete mix produced is in the range of 10 mm to 30 mm. The workability of stainless steel cable ties decreased when increasing of fiber content. Figures of slump test are shown in figure 7 to Figure 10.

Figure 7: Concrete control

Figure 8: Fibrous Concrete 1%

Figure 9: Fibrous Concrete 3%

Figure 10: Fibrous Concrete 5%

Cylindrical Compressive Test

Compressive strength test was performed to compare the compressive strength of cylindrical concrete control with fibrous concrete. 12 samples of concrete cylinder with size of 100 mm x 200 mm are tested on age of 28 days to determine the compressive strength. Results of compression test of control concrete and stainless steel cable ties fibrous concrete are shown in table 3 and Figure 11.

Table 3: Results of compression test of control concrete and fibrous concrete on age of 28 days

Percentage of Fiber	Sample	Maximum Load (kN)	Compressive Strength (N/mm^2)	Average of Compressive Strength (N/mm^2)
0%	A	225.33	28.69	**30.40**
	B	234.99	29.92	
	C	255.88	32.58	
1%	A	258.63	32.93	**30.92**
	B	230.59	29.36	
	C	239.39	30.48	
3%	A	235.93	30.04	**32.13**
	B	264.60	33.69	
	C	256.43	32.65	
5%	A	247.95	31.57	**35.51**
	B	260.36	33.15	
	C	328.37	41.81	

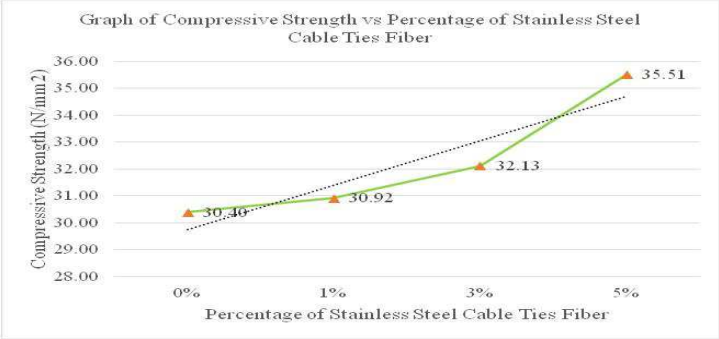

Figure 11: Graph of compressive strength vs percentage of stainless steel cable ties fiber at age of 28 days

Stainless steel cable ties fibrous concrete produces higher compressive strength than control concrete. The compressive strength is also increased when the percentage of fiber used increase. This is due to the bonding between the particles of the stainless steel cable ties fiber with concrete mix which has improved the durability of the concrete to crack or broke.

Cylindrical Split Tensile Test

The tensile strength test was conducted to measure the comparative performance of control concrete and fibrous concrete with varying percentage of stainless steel cable ties fiber in the concrete mix. Results of split tensile test of control concrete and stainless steel cable ties fibrous concrete are shown in table 4 and Figure 12.

Table 4: Results of split tensile test of control concrete and fibrous concrete on age of 28 days

Percentage of Fiber	Sample	Maximum Load (kN)	Tensile Strength (N/mm^2)	Average of Tensile Strength (N/mm^2)
0%	A	84.75	2.70	**2.89**
	B	95.21	3.03	
	C	92.04	2.93	
1%	A	99.42	3.16	**3.09**
	B	96.87	3.08	
	C	95.04	3.03	
3%	A	108.42	3.45	**3.37**
	B	108.73	3.46	
	C	100.47	3.20	
5%	A	112.01	3.57	**3.46**
	B	103.35	3.29	
	C	110.29	3.51	

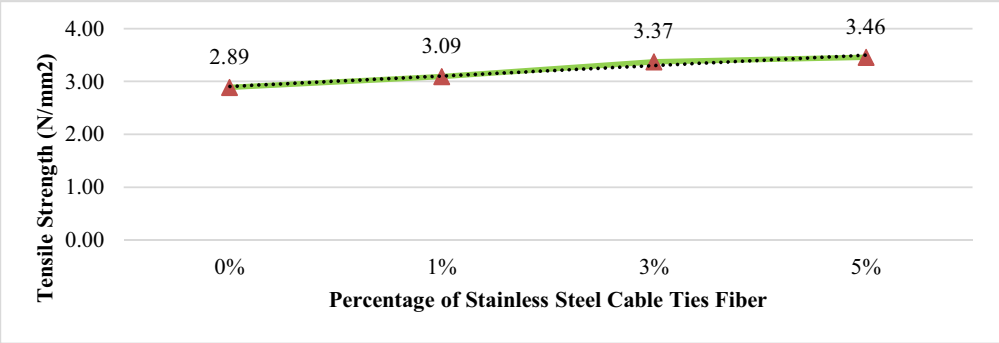

Figure 12: Graph of tensile strength vs percentage of stainless steel cable ties fiber at age of 28 days

Tensile strength of concrete fiber stainless steel cable ties is higher than control concrete. Tensile strength of fibrous concrete stainless steel cable ties increased when the percentage of fiber increases. This is due to the existence of particles increase the bonding strength between the fibers and the concrete mix. Particle bonding strength between the fibers and the concrete mix improve the strength of composite materials.

Relationship between Compressive Strength and Tensile Strength

Tensile strength will give a lower strength than the compressive strength of concrete for the same batch. Tensile strength usually gives a strength of about 10 % of the compressive strength [7]. Table 5 shows the relationship between compressive strength and tensile strength.

Table 5: Relationship between compressive strength and tensile strength at test age of 28 days

Percentage of Fiber	Compressive Strength (N/mm^2)	Tensile Strength (N/mm^2)	Ratio of Tensile Strength / Compressive Strength	Percentage Ratio of Tensile Strength / Compressive Strength
0%	30.40	2.89	0.095	**9.5%**
1%	30.92	3.09	0.100	**10.0%**
3%	32.13	3.37	0.105	**10.5%**
5%	35.51	3.46	0.097	**9.7%**

Based on result in table 5, tensile strength is lower than the compressive strength of concrete with same batch. The percentage ratio of tensile strength over compressive strength is about 10 %. This proves that the tensile strength is approximately 10 % of the compressive strength of the same concrete mix design and the same batch of concrete.

Failure Mode

The results of the compression tests and split tensile tests was found that there are two types of failure that is a failure on the side of a concrete structure for compression testing and the failure at the diameter of the concrete cylinder. Figure 13 and 14 shows failure mode.

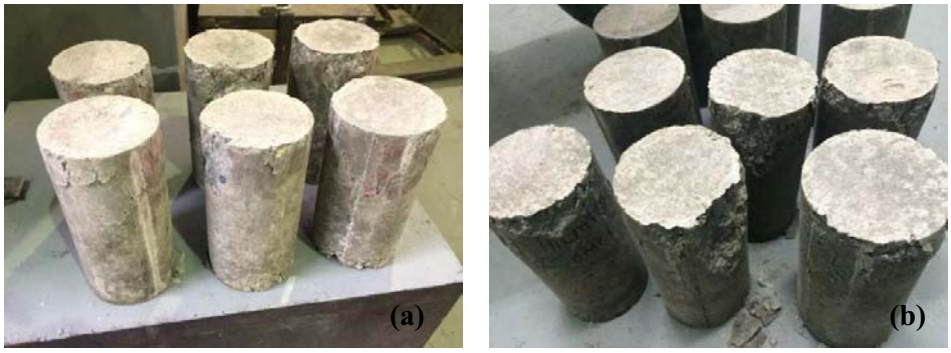

Figure 13: Compressive test failure mode. (a) sample 0% and 1%; and (b) sample 3% and 5%

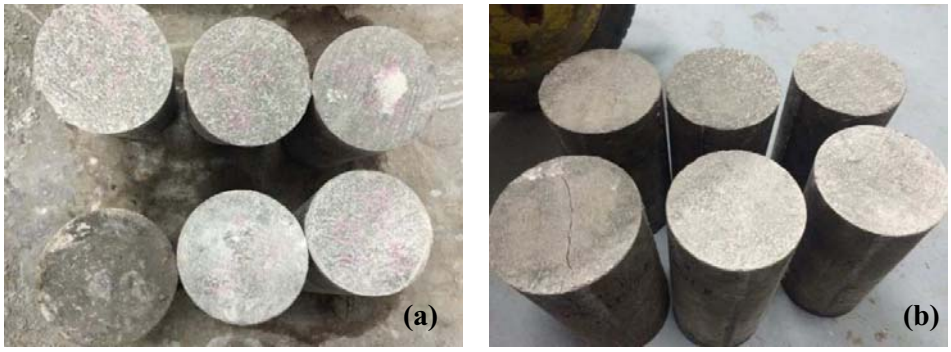

Figure 14: Split tensile test failure mode. (a) sample 0% and 1%; and (b) sample 3% and 5%

Conclusion

This paper shows the strength of stainless steel cable ties fibrous concrete when subjected to compressive and tensile loads. It also shows the workability of concrete with stainless steel cable ties fiber and the relationship between compressive strength and tensile strength of concrete.

Results from the slump test cone was found that the workability decreases when the percentage of stainless steel cable ties fiber are used increase. This is due to the presence of these fibers in the concrete mix has increased the mess in the mixture. It has increase work to compact the mixture in the mold. But in this study it was found that the fiber content of 5% can be used and can be compacted in the mould.

For compressive strength test found that the presence of the fiber stainless steel cable ties in the concrete mix has created a more perfect bonding between particles. Compressive strength of fibrous concrete increases as the percentage of fiber content is increased. Use of the percentage of fiber content of 1%, 3%, and 5% of the weight of cement, all showed increased compressive strength of the concrete than control concrete.

The use of fiber stainless steel cable ties percentage 5 % produced the maximum compressive strength of 35.51 N/mm2 which higher than the control concrete of 30.40 N/mm2 with an increase of 16.8 % of the compressive strength.

For split tensile strength tests found that the presence of the fiber stainless steel cable ties in the concrete mix have improved the tensile strength of concrete. This concrete fiber has led to requires

more power to break the bonds between the particles in the concrete. The use of the fiber content of 1 %, 3 % and 5 % of the weight of cement increased tensile strength when the fiber content is increased.

The percentage of the fiber stainless steel cable ties content by 5 % of the weight of the cement produced the highest tensile strength of 3.46 N/mm2 higher than control concrete of 2.89 N/mm2 with an increase of 19.7 %.

The relationship between tensile strength and compressive strength was found that the tensile strength is within 10 % of the compressive strength [7].

The data obtained in this study do not indicate the optimum percentage of fiber content for compression and tensile strength because it shows no decreasing in value as the percentage increase. The use of fiber stainless steel cable ties can be used in the concrete mix with a percentage content of 5% of the weight of the cement mixture. The addition of these fibers in the concrete mix can increase the compressive strength and tensile strength of the concrete.

Some modification can be made for further study in order to improve the compressive and tensile strength of fibrous concrete stainless steel cable ties. Using different length of stainless steel cable ties fiber in the concrete mix. Adding another type of test to fibrous concrete such as flexural beam test, the elastic modulus test and others to study the strength of fibrous concrete stainless steel cable ties with more detailed. Using other additives such as gypsum, POFA and etc. to examine differences strength and potential of the material.

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