The Effect of Straight and Hooked-end Steel Fibers on the Ductility and Performance of Self-Compacting Concrete (SCC)

by

Fareez Akmal Bin Abu Bakar

Dissertation submitted in partial fulfillment of
The requirements for the
Bachelor of Engineering (Hons)
Civil Engineering

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CERTIFICATION OF APPROVAL

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Approved by,

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September 2012

CERTIFICATION OF ORIGINALITY

This is to certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

FAREEZ AKMAL BIN ABU BAKAR

ABSTRACT

Self-Compacting Concrete is a new technology involving concrete. It behaves similarly as the normal concrete meaning that it has strong compression strength but low in tension and flexural strength. Thus, SCC is a brittle material. In order to transform the SCC into a ductile material, the usage of short steel fibers are used. The effect of steel fibers on the ductility and performance of SCC is the main objective of this research. A straight steel fiber with dimension of 0.25mm in diameter and 25mm in length as well as a hooked-end steel fiber with dimension of 0.35mm in diameter and 30mm in length are used in this research. The result between the two types of the steel fiber will be compared. The volume fraction of the steel fiber to be inserted inside the SCC is 1.0%, 1.5%, 2.0% and 2.5%. Several cubes, beam and cylinder with similar mix proportion but different fraction of fibers were prepared. The sample were then tested with compression test after 3, 14 and 28 days of curing period while flexural and splitting tensile test were conducted after 28 days of curing period. The results between the two fibers were compared with each other as well as with the sample without any fiber. The addition of fibers inside SCC improved its ductility and performance. Both flexural and splitting tensile strength increase up to 82% depending on the percentage of the fibers inserted. The sample with hooked-end steel fibers showed a better result than the straight fiber in the flexural and splitting tensile test.

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CHAPTER 1

INTRODUCTION

1.1 Project Background

Concrete has been widely used for a construction material in all over the world. In fact, the first concrete has been used by The Greek and the Romans in the ancient time (Neville, 2006). This is due to the materials are easily available and it provide a relatively high compressive strength with the least cost.

Self-compacting concrete (SCC) can be considered as a new technology involving concrete. It has been introduced by Professor Okamura from Kochi University of Technology in 1986 in Japan. SCC has the ability to flow by its own weight and fill the formworks and go through all the reinforcement without the need of external or internal vibration or any means of compaction.

In a fresh state, SCC exhibit good flow ability, resistance to segregation and a good passing ability that ensure the concrete can fill in a dense reinforcement. In a harden state, the SCC has the same characteristics and strength of the normal concrete which is dense, homogeneous and has the same engineering properties. Hence the use of SCC can greatly increase the productivity since the concrete does not need to be compacted so less work is needed. In addition to that, human errors can also be reduced by the possibility of inventing a machine to place the concrete automatically and this will greatly improve the safety around the construction site. This will also indirectly reduce the cost by reducing the number of labors needed.

Since the introduction of the SCC in 1986, it has been widely used for the construction industry in the world especially in Japan and Europe (Ouchi, Nakamura, Osterson, Hallberg and Lwin, 2003). This is due to the self-compacting ability that makes it easy to fill the gaps in heavily reinforced structural members as well as the space which is hard to access in order to make necessary compaction. As an example, the SCC has been used in a very large batch for the construction of Ritto Bridge, Japan and The Sodra Lanken Project, Sweden (Ouchi, Nakamura, Osterson, Hallberg and Lwin, 2003).

Many researches have been done to improve the properties and characteristics of the SCC. The usage of fiber as the reinforcement in the SCC has also been introduced. The usage of steel fibers is well known to improve the mechanical properties of the concrete such as the compressive, tensile and flexural strength while the usage of plastic fiber such as polypropylene fiber is well known to improve the drying shrinkage behavior of the fresh concrete.

Normal concrete and SCC will generally have great compression strength but weak in tension and flexural strength which indicate that concrete is a brittle material. This will lead to a major failure due to tension and flexural stress even after the first crack. This will also represent the low ductility of the concrete. Steel bar reinforcement has been introduced to cater the brittle behavior of the concrete however, the usage of discontinues fibers has been introduced later.

There are many types of fiber available to be used but steel fiber has been widely used since 1990 due to a great tensile characteristic that it possesses (Labib and Eden, 2006). Steel fibers will provide a resistance to crack and able to give a good post-cracking behavior towards the concrete. Steel fibers will prevent a sudden loss in a load carrying capacity by providing a load transfer mechanism across the cracks formed.

1.2 Problem statement and research significance

Concrete is one of the world's most widely used construction materials. This is due to the concrete is well known to have a very good compression strength. SCC behaves similarly as the normal concrete. However, concrete is also known to have a very weak tensile and flexural strength. This is due to the brittle behavior of the concrete.

This is because concrete is made up of several materials such as aggregates and sand which are glued together with a cement paste. When the concrete is under tension, the aggregates are trying to pull away from each other and the cement paste is the only material left to hold the matrix together. Since the cement paste is weaker than the aggregate, so the concrete will fail under a minimum tensile stress which is about one tenth of the compression strength of the concrete. Concrete will fail right after the maximum load is achieved which indicates that concrete is not a ductile material. This will result in sudden tensile failure without warning. This is obviously not a desirable characteristic for a construction material.

Thus, concrete need some form of reinforcement to make up for the brittleness as well as to increase the tensile strength for it to be used in structural application. In order to transform the brittle behavior of the SCC to a ductile material, the usage of hooked end and straight steel fibers as the reinforcement are going to be investigated in this experiment. Even though, many researches has been done to study the effect of steel fibers on the performance of SCC, however less research has been conducted to identify the optimum volume fraction as well as the type of fiber that is better in helping to increase the ductility of the SCC. So there has been a gap to understand the performance of SCC with the addition of steel fibers.

This research is important as to transform a brittle SCC into a ductile material. The result will be beneficial as to provide information on the possibility to transform the SCC into ductile material. Even though many researches has been done to improve the ductility of the SCC by using steel fiber, less research has been done by utilizing two type of steel fibers. Thus this research is very beneficial and significance to provide information on the usage of two type of steel fibers to increase the ductility of the SCC.

1.3 Objective

The main objective of this research is to investigate the effect of straight steel fiber and hooked end steel fiber towards the ductility of the SCC. In order to achieve this objective, there are numerous sub-objectives which include the investigation on the compression and tensile strength of the SCC as well as the workability of the fresh SCC with fibers as the reinforcement which are summarized below:

a. To investigate the effect of the straight steel fiber and hooked end steel fiber towards the ductility and performance of the SCC
b. To identify the optimum volume fraction of the fibers to be included in SCC to increase the ductility of the SCC.
c. To identify the effect of workability of the SCC with the addition of both fibers.

1.4 Scope of study

There are many ways that can be done in order to improve the ductility of SCC. However, this research will be focusing on the usage of straight steel fiber and hooked end steel fiber to increase the ductility of the SCC by investigating the optimum type of steel fiber as well as the optimum volume fraction to be integrated in the SCC. The research will be completed with the extensive experimental works in the lab as well as detailed evaluation of test results.

CHAPTER 2

LITERATURE REVIEW

2.1 Ductility of Concrete

Ductility in general term refers to the ability of a material to deform or deflect due to the application of a tensile force. It is also referred to the ability of a material to withstand plastics deformation without rupture. Ductility may also be thought of in term of bendability and crushability. Ductile material will exhibit large deformation before fracture or failing. Brittleness is referred to the material which has a very low ductility where the material will be fractured upon the application of load. Chances of sudden failure are minimized by preventing progressive and disproportionate collapses.

According to Oliveira and Bernardo (2005), ductility is clearly stated if it is referred to the deformation state of the element that is being studied. Ductility in concrete refers to the ability of the concrete to withstand load that will cause deflection. Deflection in concrete is always associated with the flexural stress that is being subjected. Upon passing the maximum flexural load, a ductile concrete should be able to exhibit a deflection upon failure. Ductility is a desirable property in concrete because it allows stress redistribution which as mentioned before will ensure the concrete to withstand flexural load beyond the maximum load. It is also a desirable characteristics as it will provide a warning upon the failure which in this case is portrayed by the deflection of the concrete (Duthinh and Starnes, 2001).

In order to increase the ductility of the concrete, usage of fiber as the reinforcement has been introduced. There are many types of fibers existed to be used as the reinforcement in SCC, however, steel fiber has been known to be very effective in increasing the ductility of the SCC by means of improving the flexural toughness of the SCC.

2.2 Steel fiber reinforced concrete

Porter first suggested the use of steel fiber in concrete in 1910. However, the first scientific investigation of Fiber Reinforced Concrete (FRC) in the United State was done in 1963 (Behbahani, 2010)

Steel fibers can be defined as discrete, short lengths of steel having ratio of tis length to diemeter in the range of 20 to 100 with any of the several cross section, and that are sufficiently small to be easily and randomly dispersed in fresh concrete mix using normal mixing procedure (ACI 544.IR 1996). There are many types of steel fibers that are classified according to its shape, material, length, diameter and type of cross section as shown in the **Figure 1** below.

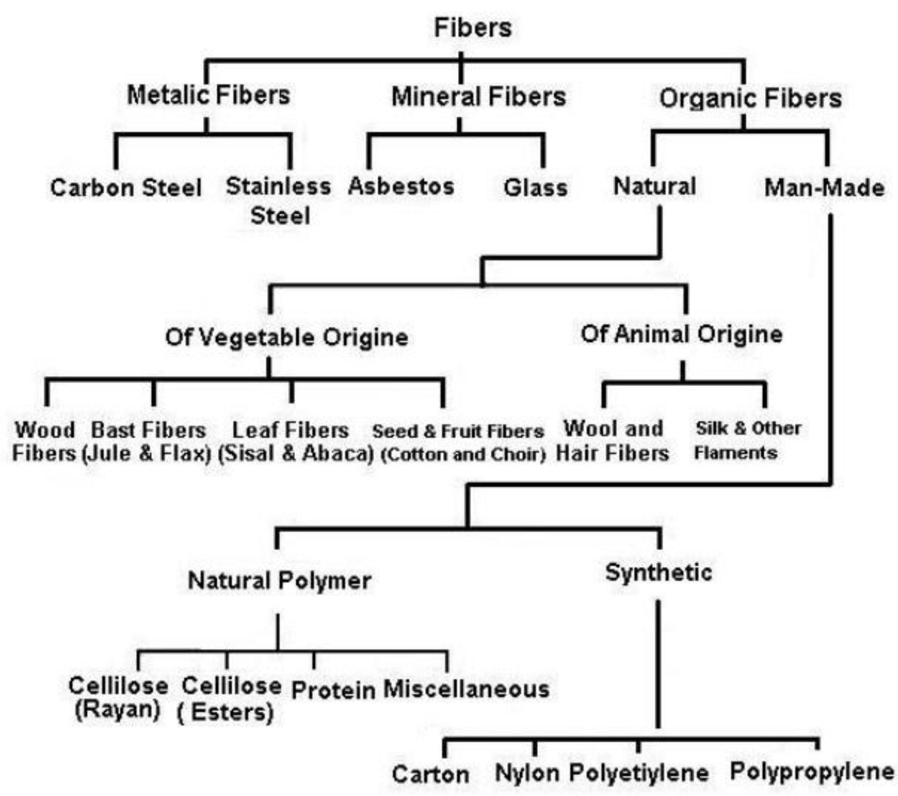

Figure 1: Different type of fibers based on materials (Behbahani, 2010)

The influence of the steel fiber towards the concrete depends on many factors such as fiber content, volume fraction, matrix strength, mix design and mixing of concrete. Fibers are primarily used for their ability to provide post-cracking resistance to the concrete. The addition of fibers to concrete in low-to-moderate dosages (1.5% by volume) does not greatly affect compression strain capacity and toughness. In tension, the ability of fibers to enhance concrete post-cracking behavior primarily depends on fiber strength, fiber stiffness, and bond with the surrounding concrete matrix.

Fibers are designed to pullout through the concrete matrix. Thus, the behavior of ductile concrete is highly dependent on the ability of the fibers to maintain good bond with the concrete as they are pulled out. Steel fibers of about 5% in volume, increase the cracking resistance, splitting tensile strength and direct tensile strength up to 2.5 times the strength of unreinforced concrete and 10 to 15 times increase in the ductility of the member.

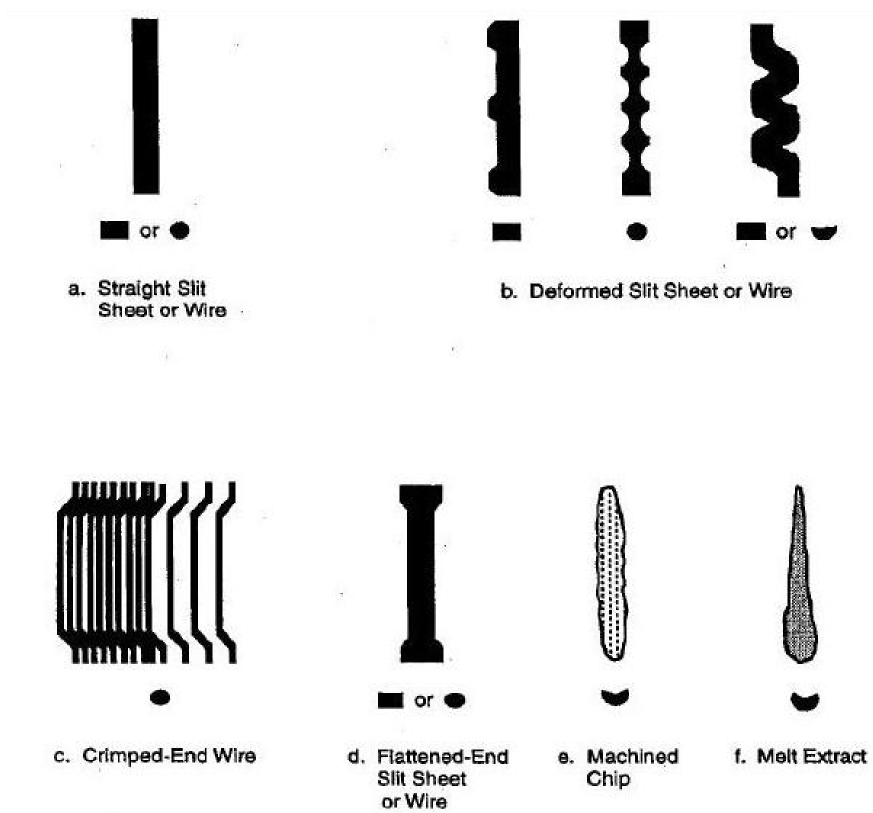

Figure 2: Different shape of fiber (Behbahani, 2010)

2.3 Stress-Strain (Stress-Displacement) relationship of typical fiber reinforced concrete

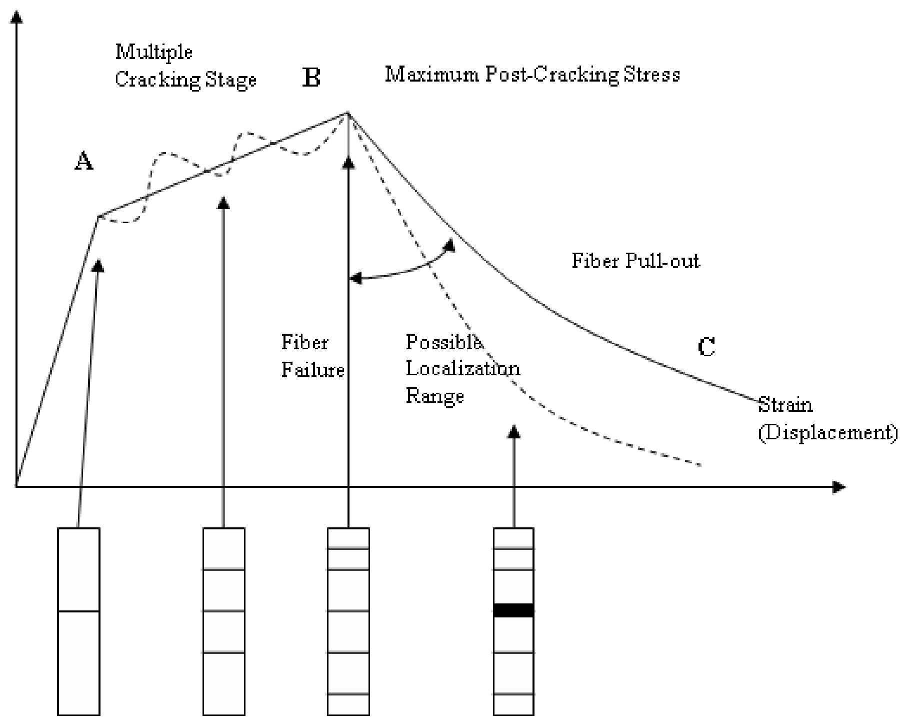

Figure 3: Stress-strain relationship (Suwannakarn, 2009)

Suwannakarn (2009) has been doing an extensive research on the stress-strain relationship of the typical fiber reinforced concrete. The **Figure 3** above shows the typical Stress-Strain (Stress-Diplacement) relationship of the fiber reinforced concrete. It can be divided into a few stages as below:

a. First cracking point (A)
b. Multiple cracking stage (A-B)
c. Maximum tensile strength (B)
d. Localization and softening stage (B-C)

2.3.1 First Cracking Point (A)

When the concrete is subjected to loading, it will eventually come across the time where the first crack started to appear. This is represented by this stage. This is due to the continuous loading that is being subjected to the concrete. The point A represents the stress subjected to the concrete when the first crack started to appear.

2.3.2 Multiple cracking stage (A-B)

After the concrete is subjected to further loading beyond the first crack, many cracks started to appear comprises of small and big cracks. This is represented in the A-B region and called as the multiple cracking stage. Multiple cracking stage is defined when more cracks appear in the direction parallel with the first crack. Normally, after the first crack, there are two possibilities that might happen which are strain softening and strain hardening (Suwannakarn, 2009).

Strain softening refers to the stage where the first and intial crack will continue to open due to fiber pull out. It will reduce the overall stiffness of the specimen due to the crack is continued to open. Other part of the specimen will remain to be non-cracked elements. When the load is increased, the cracks will be still opening or new cracks will start to form. Strain hardening refers to the stage where there are many new cracks formed. The number of cracks appeared will be increasing until the concrete achieve the ultimate strength.

2.3.3 Maximum tensile strength (B)

The specimen will eventually achieve the maximum tensile strength indicated by the maximum load that is subjected. The maximum load is represented by the point B in **Figure 3**. After that, the load that the concrete is able to withstand will be decreasing which represent the softening stage. At this stage, the formation of new cracks will be stopped and the localization failure will start to happen.

2.3.4 Localization and softening stage (B-C)

The localization stage will happen after the maximum tensile stress that the concrete can withstand. At this stage, the tensile resistance will be dropping with increasing displacement or crack opening. There will be no new crack that will be opening, but the major crack or the critical crack will start to open while other cracks will be closing. At this stage, if the concrete are not reinforced with fiber, it will fail right away which represent the brittle behavior of the concrete.

The concrete will still be able to withstand load due the fibers at the critical crack. The load will be transferred by the fibers towards the concrete. At this stage the load depends on the pull out behavior of the fiber. The pull out behavior of the fiber is determined by the shear strength at the interface of the fiber and the concrete. This strength is affected by the type of fiber and concrete used.

2.4 Advantages and disadvantages of using steel fiber as the reinforcement

The usage of steel fiber brings a lot of advantages. The advantages are listed as below (Clinton Pereira, 2009):

a. Fibers inhibit and controls the formation of intrinsic cracking in concrete caused both in the plastic and hardened stage of concrete, thus ensuring a more durable concrete construction.
b. Fibers reinforce concrete against impact forces, thereby improving the toughness characteristics of hardened concrete.
c. Fibers improve the resistance to shattering forces caused due to earthquake loads and vibrations induced in machine foundations, thus making concrete a more versatile material for such critical applications.
d. Fibers enhance the hardness of the surface of concrete against material loss due to abrading forces caused by frequent movement of wheel loads. This enhances the service life and safety of concrete pavements.

e. Fibers reduce the permeability and water migration in concrete, which ensures protection of concrete due to the ill effects of moisture.
f. Fibers reduce plastic shrinkage and settlement cracking when concrete is still green, thus enhancing the overall life of the structure and reducing the maintenance cost.
g. Fibers can replace the secondary reinforcement or crack control steel used in grade slabs, thereby reducing the overall cost of the structure.

However, there is still disadvantage of using the steel fiber as the reinforcement. The major disadvantage is it reduces the workability of the SCC. As a self consolidating concrete, the most important properties is the workability which represent the flow ability of the concrete as the SCC does not need to be compacted like the conventional concrete. Miao, Chern and Yang (2003) and Vairagade and Kene (2012) have been investigating the properties of fresh SCC with the addition of steel fiber. The result showed that the slump flow reduces significantly with the increase of steel fiber volume used. The result also revealed that the addition of steel fiber more than 1% will reduce the workability greatly.

However, the usage of superplasticizer has been proved to cater the problem. Oliveira and Bernardo (2006) in their research revealed that the usage of superplasticizer helps to increase the workability of the steel fiber reinforced SCC. The higher the volume of steel fiber added, the higher the volume of superplasticizer needed to reduce increase the flowability and the workability of the SCC.

2.5 Mechanical properties of Steel fiber reinforced concrete

2.5.1 Compressive strength of Steel Fiber Reinforced Concrete

Steel fiber only increases the compressive strength of concrete slightly. According to Nguyen Van Chanh (2004), steel fibers only helps the concrete to increase the compression strength of only up to 25% as shown in **Figure 4** below

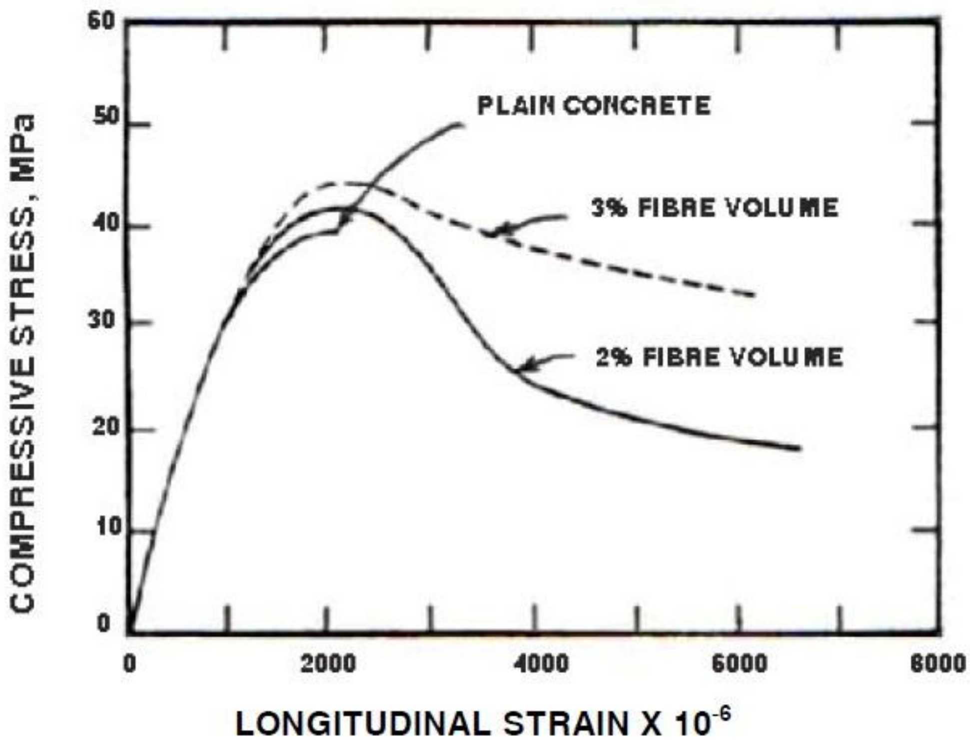

Figure 4: Compressive stress against Strain (Chanh, 2004)

However, from what can be seen above, the steel fiber helps the post cracking ductility or the energy absorption. The concrete can still with hold the load even after the peak load. It can be said that the fibers really help to hold the matrix together so that the concrete can still withstand load. The research done by Ramadevi and Venkatesh Babu (2012), also agrees with this where the test revealed that steel fiber only help to increase the compressive strength of the concrete slightly.

2.5.2 Splitting Tensile Strength of Steel Fiber Reinforced Concrete

Cai, Jiang, Zhu and Wang (2010) have been doing a research about the splitting tensile strength of steel fiber reinforced self compacting concrete. The results claimed that the addition of steel fiber as the reinforcement helps to increase the tensile strength of the SCC as shown in the **Figure 5** below.

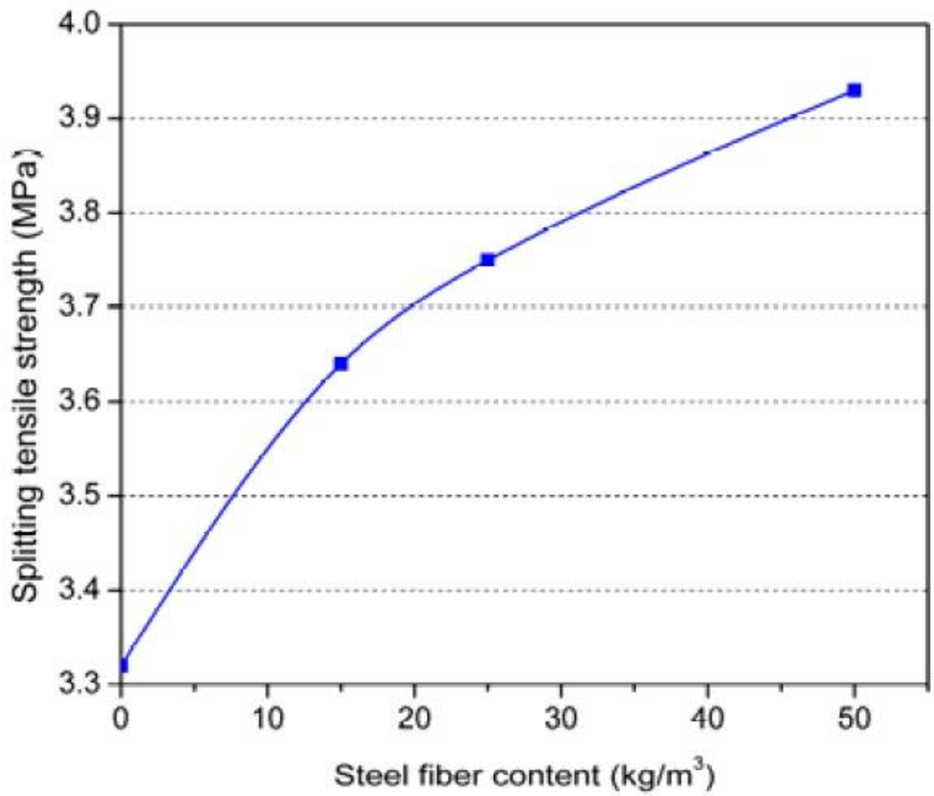

Figure 5: Splitting Tensile Strength against Fiber content (C,J, Z W, 2010)

Based on figure above, it show that the splitting tensile strength increase with the increase of steel fiber content. If it is compared with the SCC without the fiber, the splitting tensile strength increased up to 20% according to the amount of the fiber used. In addition to that, Nguyen Van Chanh (2004) also agree with this outcome as the result from his experiment revealed that the splitting tensile strength will increase of up to 60% based on the orientation of the fiber inside the concrete.

2.5.3 Flexural strength of Steel Fiber Reinforced Concrete

Flexural strength is one of the most important mechanical properties of concrete aside from compression strength. Flexural toughness is defined as stress capacity determined througha third-point loading test. Many researches has been done to study the flexural behavior of steel fiber reinforced concrete. Oucief, Habita and Redjel (2006) have been doing a research to study the flexural behavior of the self-compacting concrete with steel fiber reinforcement. He has been casting 6 (six) different sample with different amount of steel fiber used and the result is shown in the **Figure 6** below.

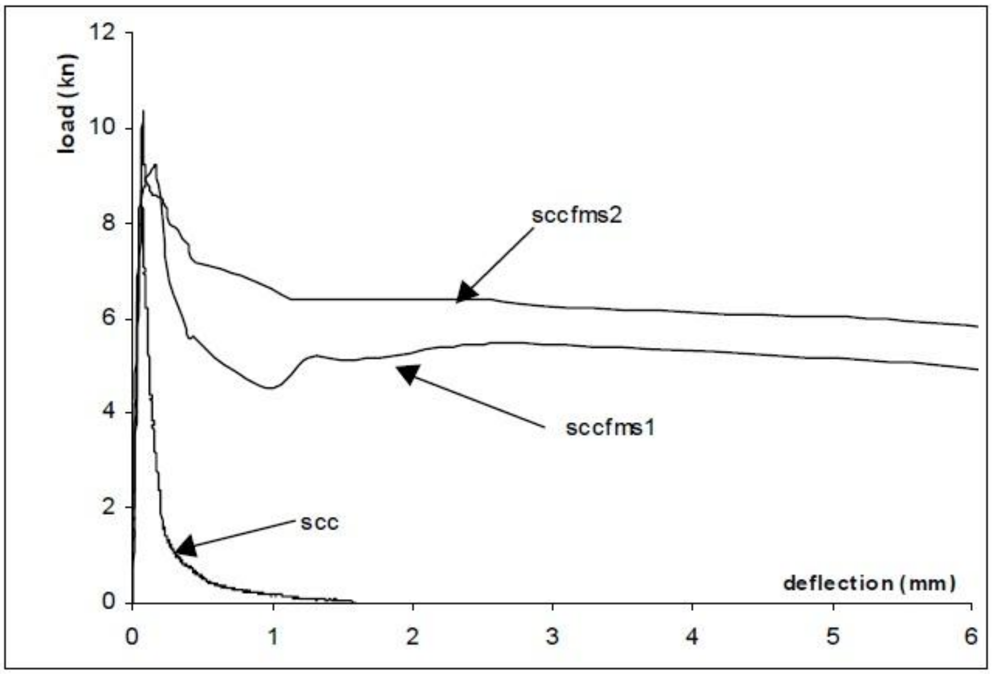

Figure 6: Load against Deflection (Oucief, Habita and Redjel, 2006)

From the figure above, it is seen that unreinforced self-compacting concrete exhibit a brittle behavior where the load decreases rapidly with increase of midspan deflection after peak load. The result of the fiber reinforced SCC however shows a significantly good flexural behavior where the it exhibit a good post cracking behavior that enable the SCC to withstand more load after the peak load. Ramadevi and Venkatesh Babu (2012) also agree on the result where in their experiments, it was found that the flexural strength increases significantly with the addition of the steel fibers as the reinforcement. In addition to that, Cai, Jiang, Zhu and Wang (2010) has also been investigating on this matter and revealed the same result as shown in the **Figure 7** below.

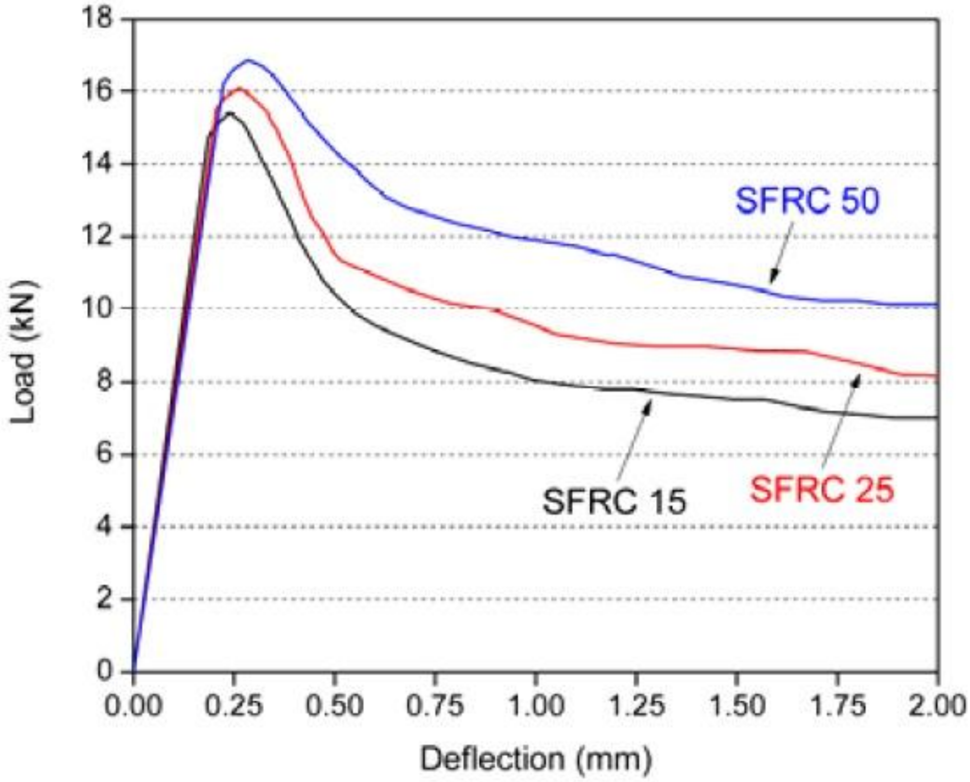

Figure 7: Load against deflection (C,J, Z W, 2010)

Ramadevi and Vankatesh Babu (2012) in their research also agrees in this matter where the test result revealed that the addition of steel fiber as the reinforcement in concrete has lead in the increase of the flexural strength of the concrete. The load carrying capacity is also increased significantly.

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter will be explaining about the research flow and the experimental program that will be conducted for this research. The observation and results will be carefully analyzed and be used to achieve the main objective.

The main objective of the research is to investigate the effect of straight steel fiber WSF 0220 and hooked end steel fiber GSF 0325 towards the ductility of the self-compacting concrete. The optimum volume fraction will be the main focus of this research in order to increase the ductility of the SCC.

The ductility of the self-compacting concrete is going to be determined by these three main tests which are; Compressive strength, splitting tensile strength and flexural bending test. The result from each test will be carefully analyzed. On top of that the workability and flow ability of the SCC will also be investigated by using these tests: Slump flow and V-funnel test. **Figure 8** represents the summary of the flow of the research program.

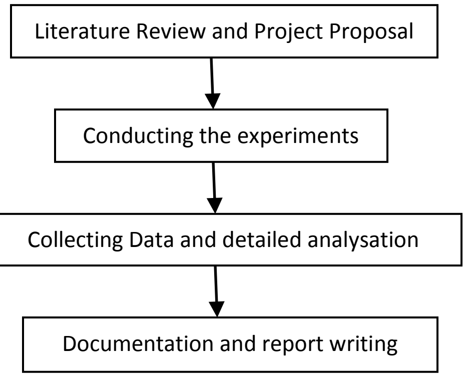

Figure 8: Process Flow

3.2 Timeline Review

The Gantt Charts below show the timeline review of the research program which is divided into 2 (two) which are Final Year Project 1 (FYP 1) and Final Year Project 2 (FYP 2).

No.	Detail / Week	1	2	3	4	5	6	7	8	9	10	11	12	13	14
1	selection of project topic														
2	Preliminary Research Work														
3	Submission of Extended Proposal														
4	Proposal Defence														
5	Project work 1 (Volume fraction)														
6	Submission of Interim Report														

Table 1: Gantt Chart of FYP 1 Starting on 21st May 2012

no.	Detail / week	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
1	Project Work 2 (Fiber ratio)															
2	Submission of Progress Report															
3	Data Analysation															
4	Pre EDX															
5	Submission of Draft Report															
6	Submission of Dissertation															
7	Submission of Technical Paper															
8	Oral Presentation															
9	Submission of dissertation															

Table 2: Gantt Chart of FYP 2 Starting on 18th September 2012

3.2 Materials

1. Steel Fibers

There are two types of steel fibers that are being used in the experiment which is summarized in the Table 3 below. Both of the steel fibers are coated by copper. The percentage of the steel fiber inserted is according to the volume of SCC meaning that, 2.0% steel fiber represent 2.0% out of total volume of SCC is steel fiber.

Fibre type	Code	L (mm)	D (mm)	L/D	Shape
Steel	WSF0220	20	0.2	100	 Straight
Steel	GSF0325	25	0.3	83	 Hook end

Table 3: Type of Steel Fiber

2. Ordinary Portland Cement (OPC)

3. Fine aggregates: Sand is used as the fine aggregate. The size used is less than 1.18mm which obtained from the sieve analysis

4. Superplasticizer: Superplasticizer is used to increase and maintain the workability and flowability of SCC.

5. Water: Water is needed for hydration of cement and to provide workability during mixing and placing

3.3 Mix Design

The water-cement ratio is kept constant at 0.18 and superplasticizer is at 2.75% for all the mixture. The mix design to cast 1 m^3 of SCC is shown in Table 4:

Materials	Amount
Ordinary Portland Cement	1000 kg
Fine aggregate	1000 kg
Water	180 L

Table 4: Mix Design

3.4 Preparation of specimen

The specimen will be casted as below

1. The materials needed for casting of SCC are measured and weight precisely.
2. The number of SCC test specimens that will be prepared is shown in **Table 2**.
3. The SCC is mixed by using the normal mixer.

Figure 9: Mixer

4. The test for the fresh state of SCC will be conducted which comprises of
    a. Slump Flow Test
    b. V-Funnel Test

5. The specimens will be put into respective mould which are as follow:
    a. Compressive strength test (100mm x 100mm x 100mm)
    b. Splitting tensile strength test (100mm in diameter and 200mm in length)
    c. Flexural strength test (100mm x 100mm x 500mm)

Figure 10: Sample inside mold

6. After 24 hours, the specimens will be removed from the mould and placed in the curing tank.

Figure 11: Sample after 1 day

7. After 28 days, the specimen will be tested with the three main mechanical tests which are:
    a. Compressive strength test
    b. Splitting tensile test
    c. Flexural strength test

8. The results obtained will be recorded accordingly and detailed analysis will be conducted.

Sample	F1 (%) Hooked-end	F2 (%) Straight	Volume fraction (%)	Test	Size of the specimen (mm)	No. of sample
F0	-	-	-	Compression Test	100 x 100 x 100	9
				Splitting Tensile Test	Diameter = 100, Length = 200	1
				Flexural Test	100 x 100 x 500	1
F1-1.0%	1.0	-	1	Compression Test	100 x 100 x 100	9
				Splitting Tensile Test	Diameter = 100, Length = 200	1
				Flexural Test	100 x 100 x 500	1
F1-1.5%	1.5	-	1.5	Compression Test	100 x 100 x 100	9
				Splitting Tensile Test	Diameter = 100, Length = 200	1
				Flexural Test	100 x 100 x 500	1
F1-2.0%	2.0	-	2.0	Compression Test	100 x 100 x 100	9
				Splitting Tensile Test	Diameter = 100, Length = 200	1
				Flexural Test	100 x 100 x 500	1
F1-2.5%	2.5	-	2.5	Compression Test	100 x 100 x 100	9
				Splitting Tensile Test	Diameter = 100, Length = 200	1
				Flexural Test	100 x 100 x 500	1
F2-1.0%	-	1.0	1.0	Compression Test	100 x 100 x 100	9
				Splitting Tensile Test	Diameter = 100, Length = 200	1
				Flexural Test	100 x 100 x 500	1
F2-1.5%	-	1.5	1.5	Compression Test	100 x 100 x 100	9
				Splitting Tensile Test	Diameter = 100, Length = 200	1
				Flexural Test	100 x 100 x 500	1
F2-2.0%	-	2.0	2.0	Compression Test	100 x 100 x 100	9
				Splitting Tensile Test	Diameter = 100, Length = 200	1
				Flexural Test	100 x 100 x 500	1
F2-2.5%	-	2.5	2.5	Compression Test	100 x 100 x 100	9
				Splitting Tensile Test	Diameter = 100, Length = 200	1
				Flexural Test	100 x 100 x 500	1

Table 5: Overview of specimen

3.5 Test on fresh SCC

Fresh state of SCC should be investigated in term of flow ability and the workability in order to ensure the SCC is able to keep the high flow ability characteristics. There are two tests that will be conducted which are

a. Slump Flow Test
b. V-Funnel Test

3.5.1 Slump Flow Test

This is the test to measure the flow and filling ability of the Self Compacting Concrete. Two parameters will be measures which are flow spread and flow time T50. The equipmen needed are as follow:

1. Base plate of size at least 900mm x 900mm with smooth plane test surface made up of rigid material such as steel
2. Abrams cone with internal upper/lower diameter of 100/200 mm and the height of 300 mm as shown in the **Figure 9**
3. Stopwatch
4. Ruler to measure the diameter of the flow
5. Moist sponge or towels

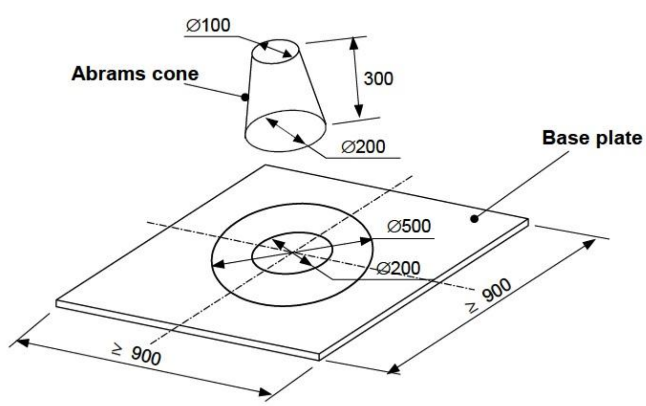

Figure 12: Base Plate and Abrams Cone

The procedure of the experiment is as follow:

1. Place the base plate in a stable position
2. Place the cone at the centre of the base plate
3. Fill in the SCC into the cone until perfectly full
4. Pre-wet the test surface of the base plate around the cone with the moist towel
5. Lift the cone perpendicular to the base plate in a single movement so that to ensure the concrete can flow freely without the obstruction of the cone.
6. Stop the stopwatch when the concrete first touch the 500mm circle diameter. The time will be recorded as the T50 value.
7. When the concrete has finished to flow, measure the largest diameter of the flow and the diameter that is perpendicular to it

The slump flow spread S is the average of diameter d_{max} and d_{perp} as shown in the equation below.

$$S = \frac{(d_{max} + d_{perp})}{2}$$

The slump flow time T50 is the period between the SCC leaves the cone onto base plate and SCC first touches the circle of diameter 500mm.

3.5.2 V-Funnel test

The V-Funnel flow time is the period which a defined volume of SCC needs to pass a narrow opening and gives an indication of the filling ability of SCC. The equipments needed are as follow:

1. V-Funnel as shown in **Figure 10**
2. Stopwatch
3. Straightedge for leveling the concrete
4. Moist sponge to wet the inner surface of the V-Funnel

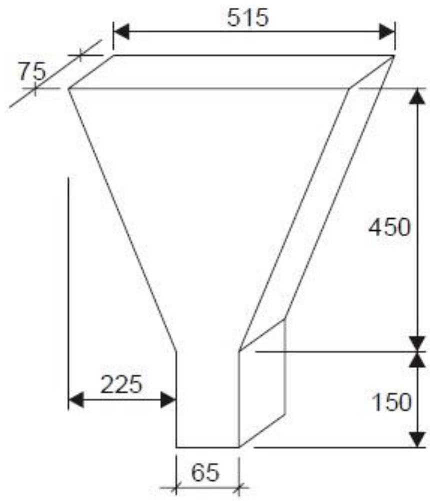

Figure 13: V-Funnel

The test procedure is as follow:

1. Place the cleaned V-funnel vertically on a stable and flat ground, with the top opening horizontally positioned.
2. Wet the interior of the funnel with the moist sponge
3. Close the gate and place a bucket under it to retain the concrete passed.
4. Fill in the SCC until completely full
5. Open the gate and at the same time start the stopwatch
6. The time is stopped when all the SCC has flow down and the time is recorded as t_V.

3.6 Mechanical test of SCC

3.6.1 Compressive strength test

The test is conducted by using BS 1881: Part 116: 1983 as the standard. According to the standard, the standard test cube should be 150mm x 150mm x 150mm but 100mm x 100mm x 100mm shall be used since the nominal maximum aggregate size does not exceed 25mm.

For this test, 3 (three) specimens will be casted in mould of size 100mm x 100mm x 100mm for each volume and ratio of fiber used. The compressive strength test for all specimens will be conducted after 3, 14 and 28 days of curing period.

The load will be applied at a constant rate until the specimen fail and crushed at the maximum load applied.

Figure 14: Compression test

3.6.2 Splitting Tensile Test

The test will be conducted according to the BS 1881: Part 3: 1970 standard where the size of the specimen for tensile splitting test is 100mm in diameter and 200mm in length.

For this test, 1 (one) specimen will be casted in mould of size 100mm in diameter and 200mm in length for each volume and ratio of fiber used. The splitting tensile test for all specimens will be conducted after 28 days of curing period.

The specimen will be placed in the testing machine with the axis is located horizontally between the plate of the testing machine. The load will be applied at a constant rate until the specimen fail and split into two parts.

Figure 15: Spliting tensile test

The ultimate load at failure will be recorded and the value of the tensile splitting strength is calculated as below:

$$F_{ct} = \frac{2 \times P}{\pi \times L \times D}$$

Where	F_{ct}	=	Tensile Splitting Strength (N/mm^2)
	F	=	Ultimate load at failure (N)
	L	=	Length of the specimen (mm)
	D	=	Diameter of the specimen (mm)
	Π	=	3.142

3.6.3 Flexural Strength Test

The specimen will be casted according to the BS 1881: Part 3: 1970 standard. The size of the test specimen should be 100mm x 100mm x 500mm.

For this test, 1 (one) specimens will be casted in mould of size 100mm x 100mm x 500mm for each volume and ratio of fiber used. The flexural strength test for all specimens will be conducted after 28 days of curing period.

The specimen will be subjected to 4-point bending test where it will be placed at 50mm from each end. The two point load will be subjected to the beam with the load rate of 1.6MN/m^2/min. The cracks formed will be observed for further analysis.

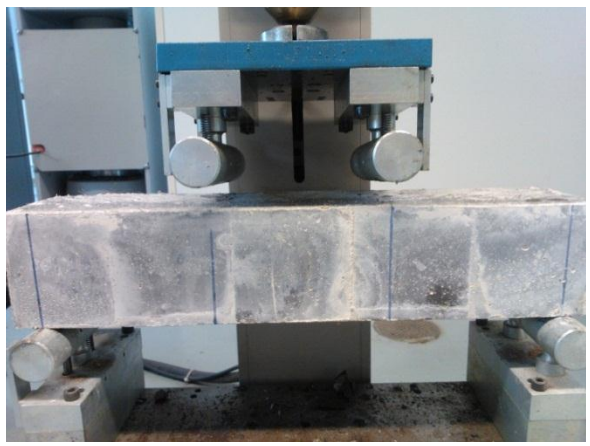

Figure 16: Flexural test

The modulus of rupture of flexural strength will be calculated as the formula below:

$$R = \frac{PL}{bd^2}$$

Where	R	=	Flexure strength, Mpa
	P	=	Maximum applied load, N
	L	=	span length, mm
	b	=	Average width of the specimen, mm
	d	=	Average depth of the specimen, mm

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 Fresh state test

4.1.1 Slump Flow Test

The SCC is tested with a slump flow test right after mixing it. Figure 17 below shows the result of the slump flow test conducted on fresh SCC.

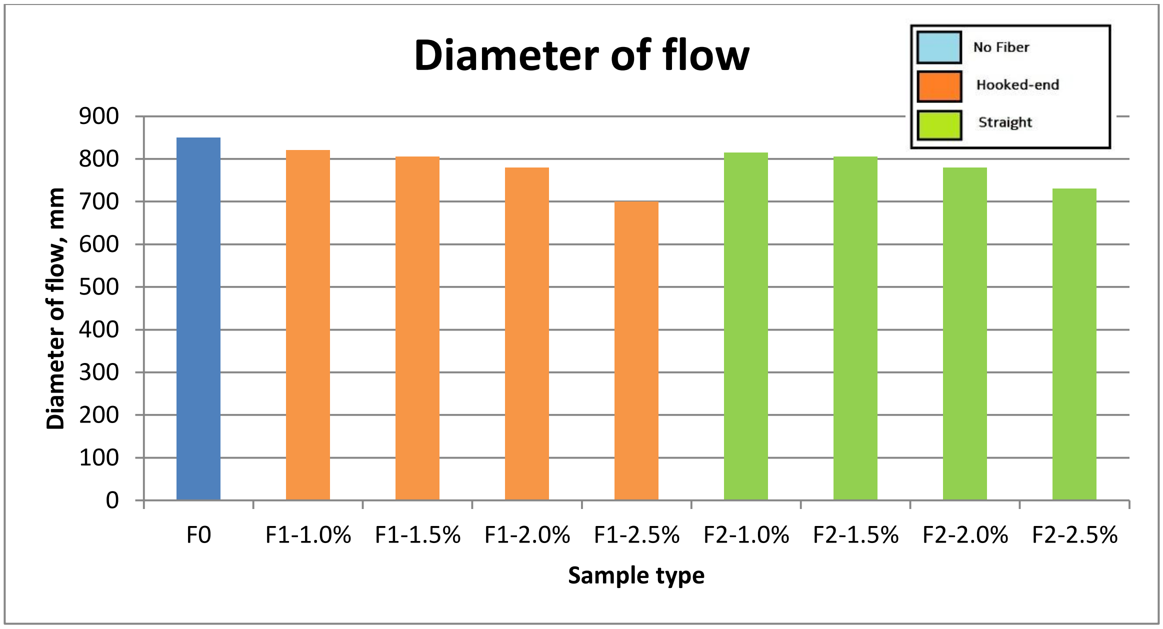

Figure 17: Flow Diameter

As what can be seen in the diagram above, the sample without any fiber will produce the highest slump flow which is about 850mm in diameter. This is expected since the sample does not have any fiber which can slow down the flow of the SCC.

This really proves that SCC has a really high flow ability which is needed as one of the properties of SCC.

The addition of fibers inside the SCC proves that it will reduce its flow ability. According to the diagram above, the higher the percentage of the fiber included inside the SCC, the greater the reduction of the flow. However, the results are still a good result considering that all of the flow diameters are more than 700mm. Different type of fiber does not bring much different to the flow ability since the flow ability of SCC by using the same percentage of fiber is almost the same.

4.1.2 V-Funnel Test

The SCC is tested with a V-funnel test right after mixing. The results are shown in the diagram below. V-funnel test indicates the passing ability of the SCC as well as the viscosity of the fresh SCC.

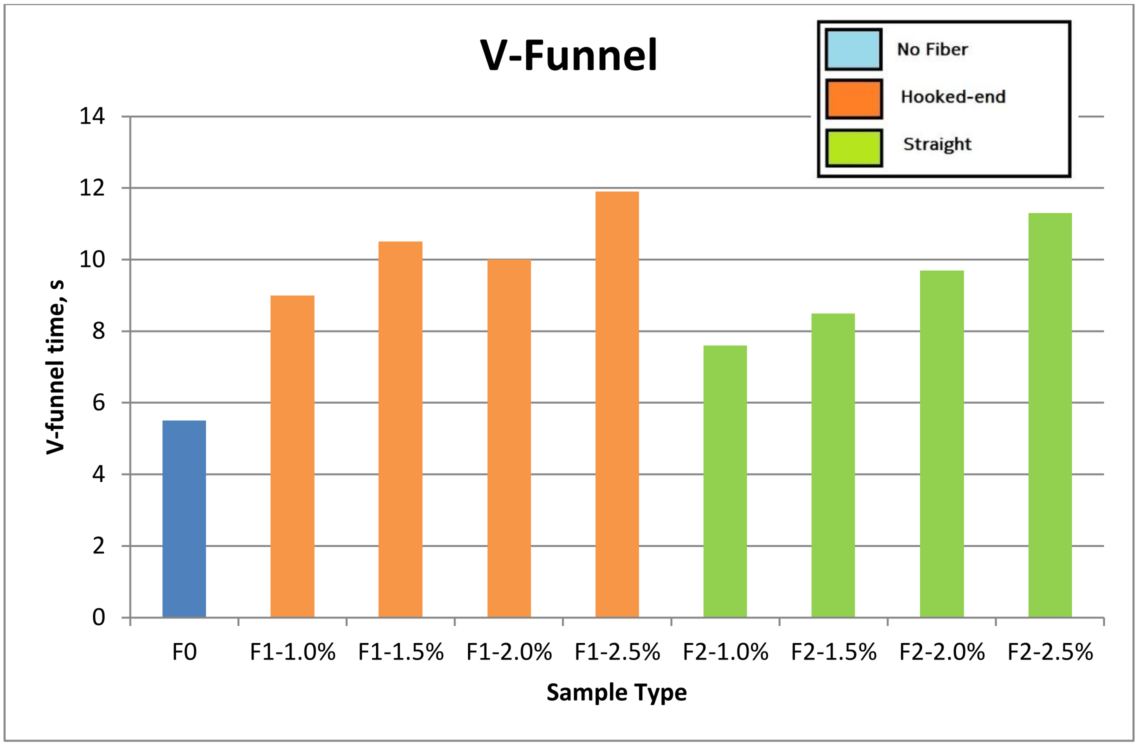

Figure 18: V-Funnel test

According to the diagram above, the sample without any fiber will result in the shortest time for V-funnel test which is about 5.8 seconds. This is as well expected since there are no fibers that can slow down the flow of the SCC that can obstruct the movement of the SCC to pass the narrow opening of the V-funnel. This indicates that the SCC has a great filling ability as well high viscosity.

The addition of fibers proves that the filling ability is reduced. This can be seen from the result above. The higher the percentage of the fibers inserted into the SCC, the greater the reduction of the filling ability of the SCC indicated by the increase in the time taken for the SCC to pass the narrow opening of the V-funnel. However, all of the results even with 2.5% of fibers inserted stay within 12 seconds marks which is required as one of the properties of SCC.

Different type of fiber does not bring much different to the result as shown in the diagram above. However, it can be seen that the sample with hooked-end fiber yields a little bit higher result compared to the sample with straight fibers. This is possibly due to the straight fiber is much longer in length than the hooked-end fiber. This may result in the flow is much more obstructed due to much more connection between the fibers due to its longer length.

As what can be seen from the result of the sample with hooked-end fiber, the addition of 1.5% of fiber will take much longer time than the sample with 2.0% of fiber. The result should be lower than the 2% of fiber. This is possibly due to the delay in conducting the test. Slight delay in conducting a fresh state test will affect the result since the SCC needs to be tested right after mixing. Hence it can be said that the result is higher due to the delay in doing the fresh state test.

4.2 Compression test

The diagrams below show the result for the compression test done after 3 days of curing period.

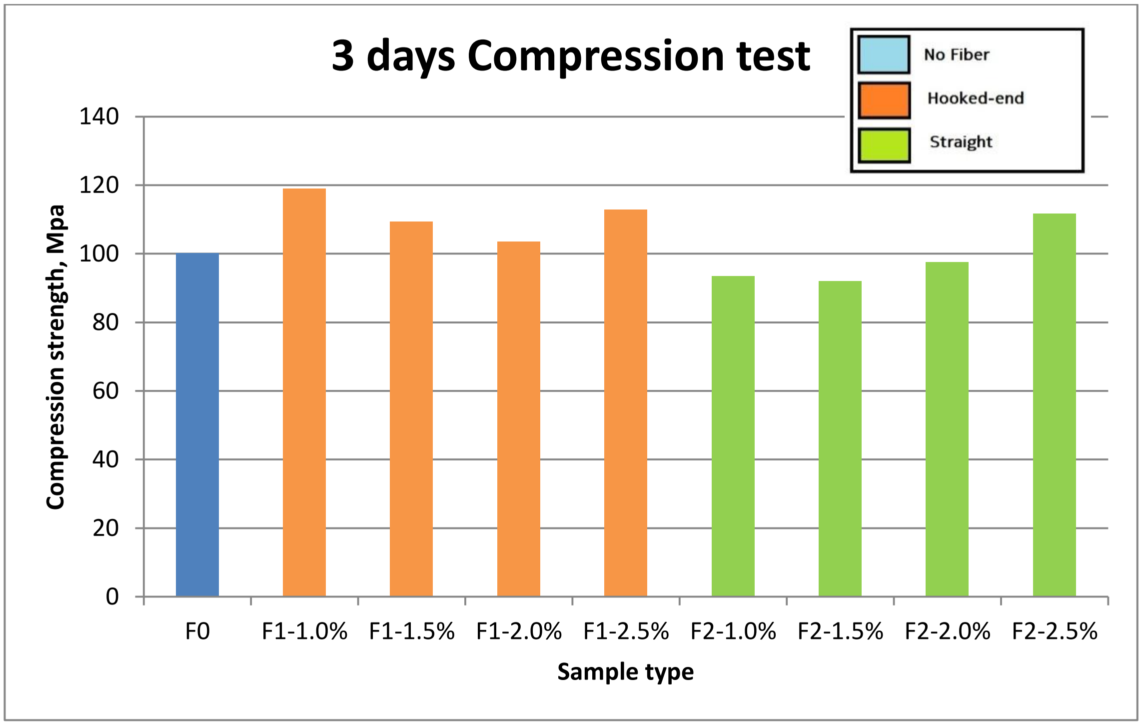

Figure 19: Compression test after 3 days

Based on the result in the diagram above, the compression strength shows a really good result. All of the samples managed to obtain more than 80MPa of compression strength only after 3 days of curing period.

The addition of fiber does not bring much difference to the sample without any fiber since there is only slight difference in the compression strength and the strength exceeded some of the sample with fibers. Different type of fiber also does not bring much different to the compression strength after 3 days of curing period.

However, this result does not indicate the final strength since the strength is still building up and this is just the early part of the strength development. The result might be changing after 28 days of curing period.

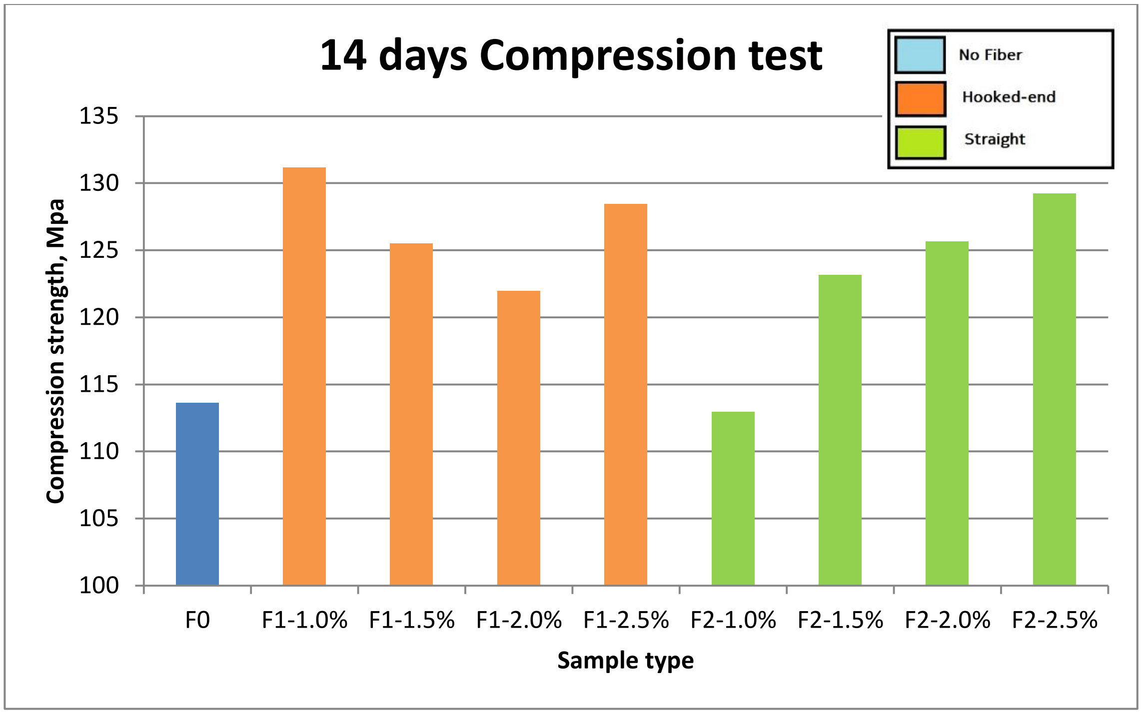

Figure 20: Compression test after 14 days

The diagram above shows the result of the compression strength of the SCC after 14 days of curing period. The result shows a good development in strength since all of the samples exceeded 110 MPa of compression strength.

The addition of fibers brings some noticeable difference in the compression strength. As what can be seen from the diagram above, most of the sample with a fibers yields higher compression strength compared to the sample without any fiber. The sample without fiber only achieve a compression strength of about 113MPa and most of the samples with fibers achieved more than 120MPa compression strength after 14 days of curing period. It can be said that fibers help to increase the compression strength.

However this result only represents the strength after 14 days of curing period. The strength is still developing and only achieved the ultimate strength after 28 days of curing period because after that it is expected only a slight increase in the strength.

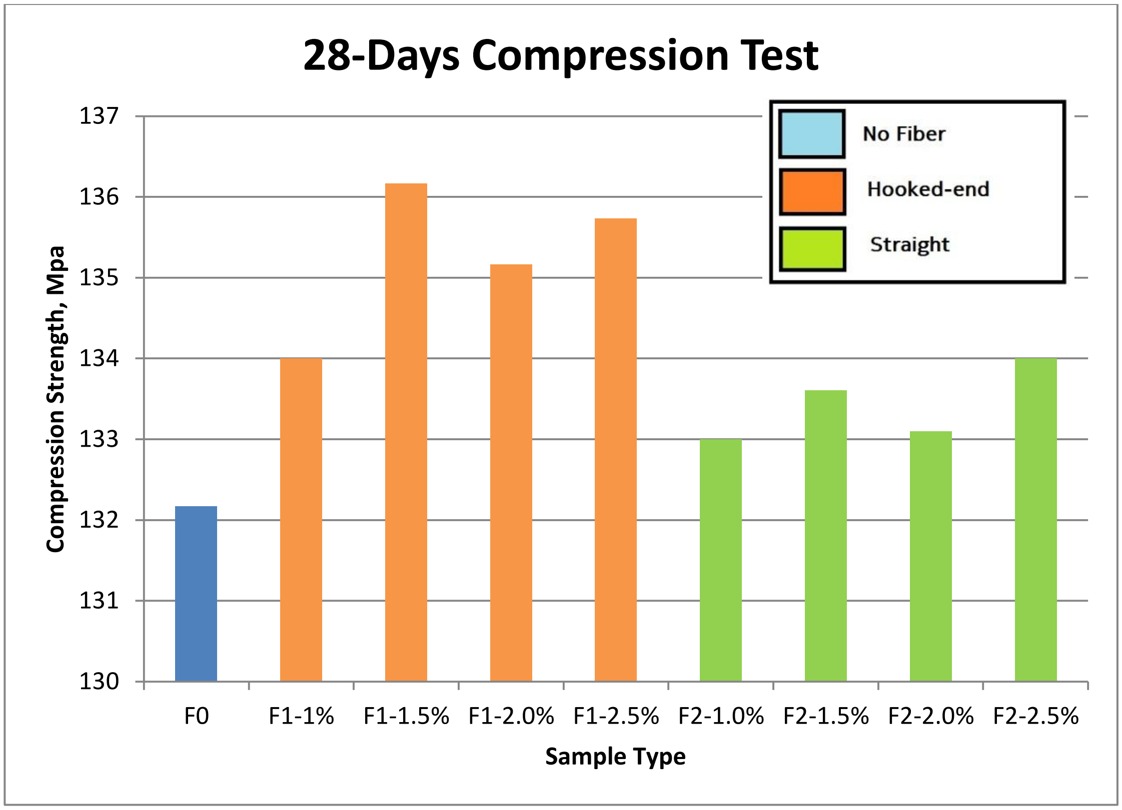

Figure 21: Compression test after 28 days

The diagram above shows the result of the compression strength of the SCC after 28 days of curing period. The result shows a good development in strength since all of the samples exceeded 130 MPa of compression strength.

Hence, it can be said that after 28 days, the compressive strength does not differ much between the sample with and without fibers. However, it can be noted that the sample with hooked-end fiber produced higher compressive strength than the straight fiber. Overall, only 3% of increase in the compressive strength of the sample with fibers compared to the sample without any fiber.

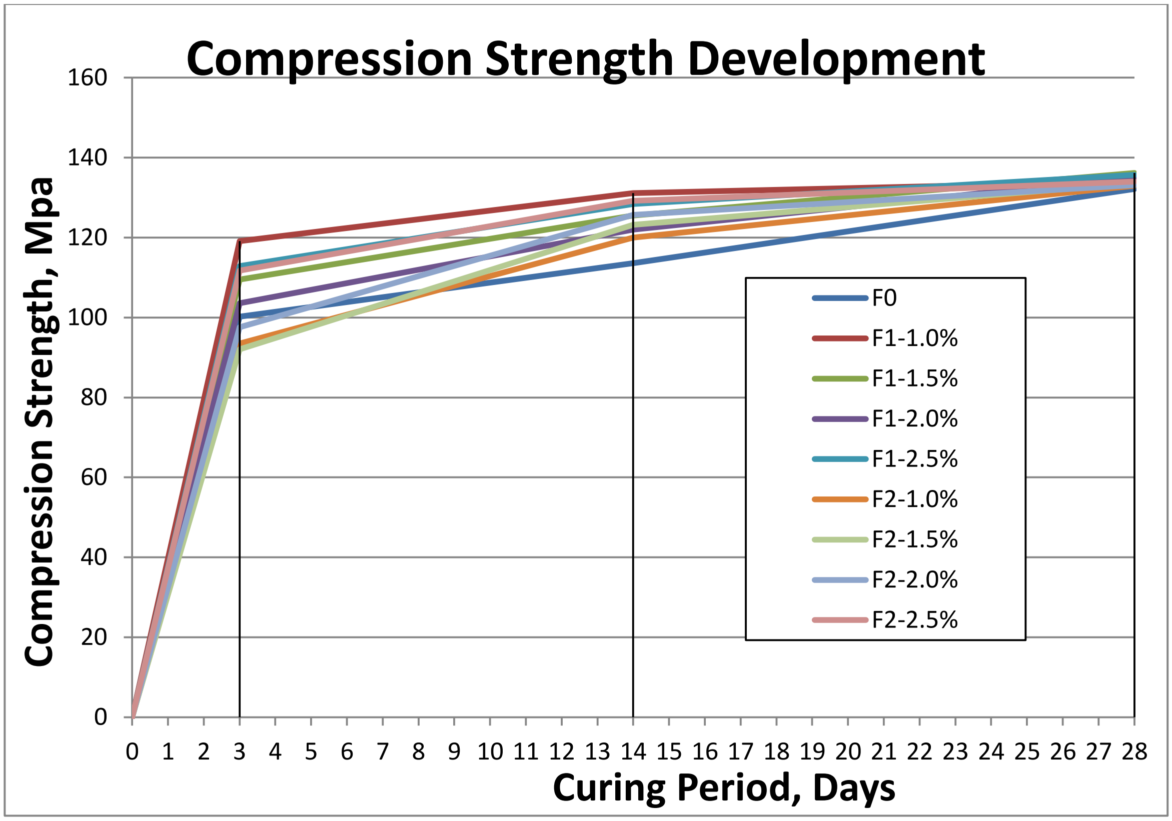

Figure 22: Compressive strength development

The Figure 22 above shows the compression strength development of the SCC over time up to 28 days of curing period. As what can be seen above, the compression strength developed highly in the early stage of curing period. After that, the strength is still developed but only a slight increment. This is expected since the early period is really important in the strength development.

The result shows almost homogenous strength after 28 days of curing period disregard of the fiber usage. Sample with and without fibers yields the compression strength of more than 130MPa after 28 days of curing period which is really high. Hence, it can be deduced that the addition of fiber does not bring much difference in the compression strength of SCC.

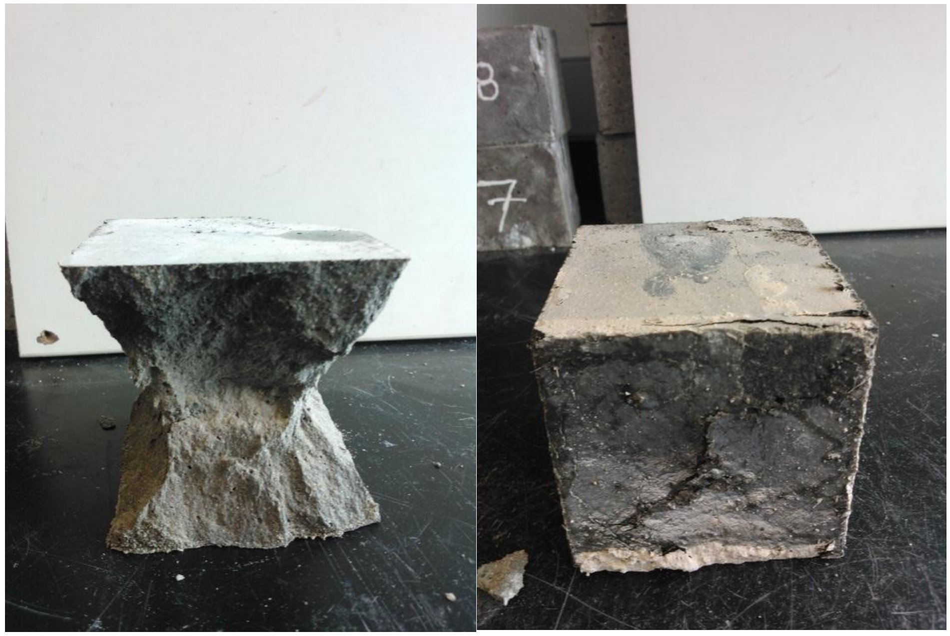

Figure 23: Cube sample after failing

Figure 23 above, shows the cube after failing the compression strength test. The picture on the left represents the sample without any fiber while the picture on the right represents the sample with fiber.

As what can be seen, the sample without any fiber broke apart. The shape cannot be seen and the sample broke into many pieces. However, the sample with fiber is still in one piece and the shape is still can be seen and recognized. It did not break into many pieces like the sample without any fiber. Although both of the samples had already failed, the sample with fiber only shows many cracks along the surface of the cube while the sample without any fiber broke into many pieces.

All of the samples with fiber are still in one piece after failing the compression strength test. Even only 1.0 % of fiber inserted, it yields the same result. This is expected since the fiber is holding the matrix together and bridging the cracks so that the cube does not break but only shows many cracks upon failure.

4.3 Splitting Tensile Test

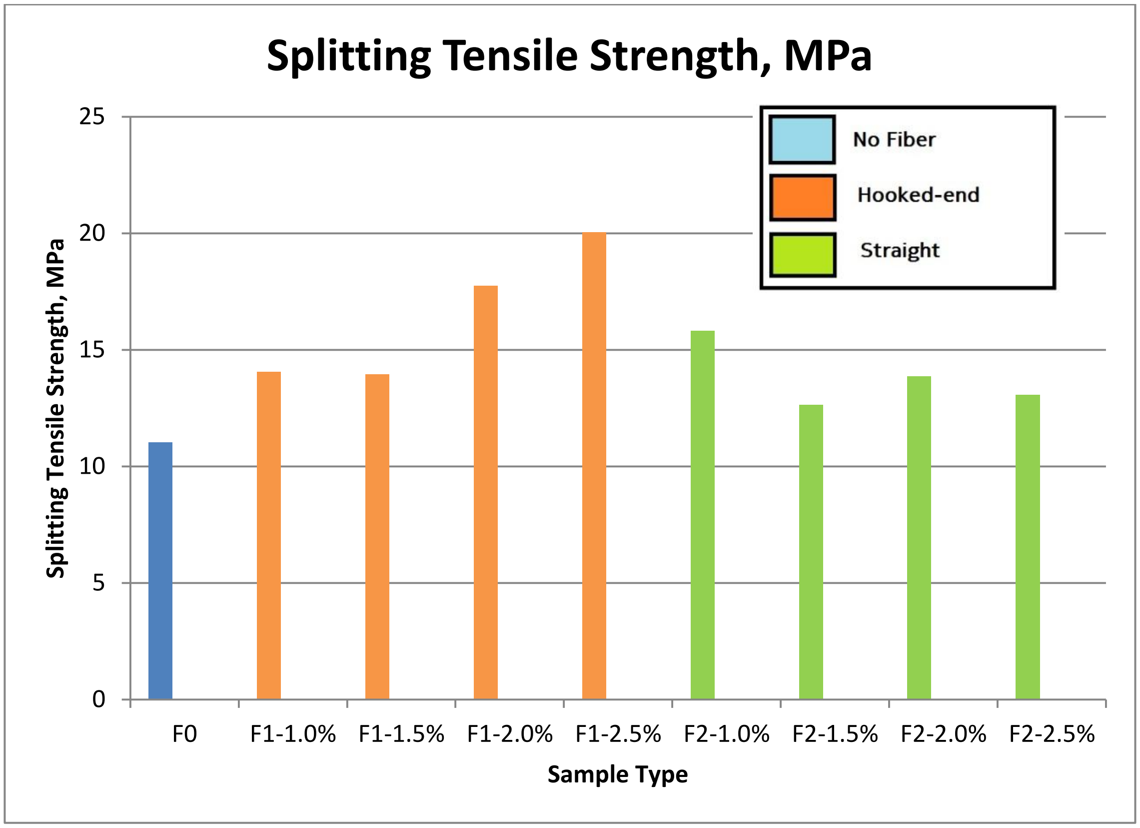

Figure 24: Splitting tensile strength after 28 days

Figure 24 above shows the result of the splitting tensile test of the SCC after 28 days of curing period. The sample with fiber yields a higher result than the sample without any fiber. This is expected since the fiber will be holding the matrix together hence the sample becoming harder to be split.

As what can be seen above, the sample with the hooked-end steel fiber yields a greater result than the sample with straight fiber. All the samples with hooked-end fibers exceed the sample with straight fiber in term of splitting tensile strength. In the sample with hooked-end fiber, as the amount of fiber increases, the splitting tensile strength will also increase while the sample with straight fiber shows variety of result as the percentage of fiber increases.

Figure 25: Cylinder sample after failing

The figure 25 above shows the sample after failing the splitting tensile test. The left picture represent the sample without any fiber while the sample on the right represents the sample with fiber.

As what can be seen from the picture above, the sample without any fiber breaks in many pieces and split into two major parts. The sample with fibers on the other hand does not break into many pieces but still in the original shape after failure. Many small cracks can be seen along the surface after failure happened.

All of the samples with fibers regardless of types did not break into many pieces. Even with the addition of only 1.0% of fiber the sample is still in one pieces and does not break into many pieces. The samples only show many cracks upon failure.

4.5 Flexural Strength

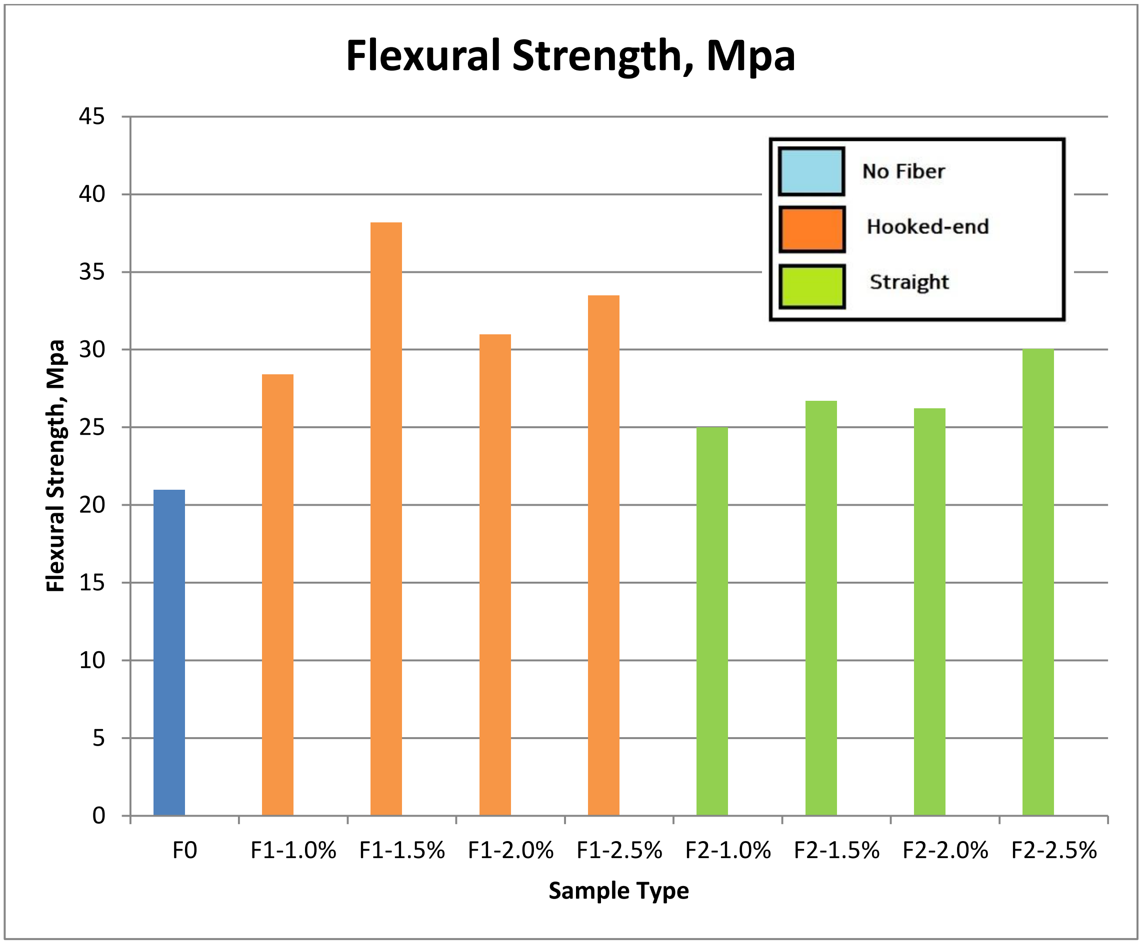

Figure 26: Flexural Strength after 28 days

Figure 26 above shows the result of a flexural strength test of the SCC after 28 days of curing period. The sample without any fiber produced the smallest flexural strength which is about 21MPa. This is expected since there are no fibers that can bridge the crack contributing to the increase in the flexural strength.

In comparison of the result between the two types of fibers, the hooked-end fiber yielded a better result than the straight fiber. The flexural strength of the sample using hooked-end exceeded the sample using the straight fiber in every percentage of the fiber used. As the percentage of the fiber used increased, the flexural strength also increased significantly. The highest result obtained was the sample with 1.5% of hooked-end steel fiber which produced about 37Mpa of flexural strength.

Figure 27: Flexural failure of the sample without fibers

Figure above shows the sample without any fiber after failing the flexural test. The sample broke into two parts at the major crack and it exhibit a sudden failure where there is no indication of the sample is failing until it broke. The sample did not show any sign of failure before breaking into two parts as shown in the figure above. This is not a desirable characteristic of a construction material because there is no indication of the failure.

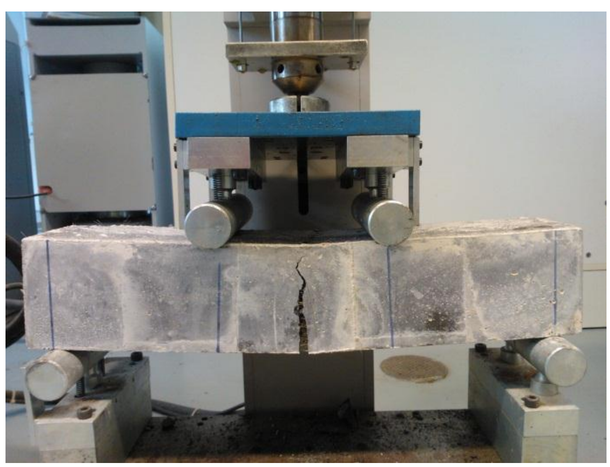

Figure 28: Flexural failure of the sample with fibers

Figure above shows the sample with fiber after failing the flexural test. As what can be seen, the sample did not break into parts but only showed a deflection upon failure. The sample also showed a lot of cracks before a major failure happen. This is a desirable characteristic for construction materials since it shows the sign of failure before major failure happen.

This is due to the fiber that is being inserted into the mix design. The fiber will be holding the matrix together stronger hence increase the flexural strength. The fiber will bridge the cracks formed making it harder for the crack to open more. After reaching the maximum loading, the major crack started to open. In this case, the strength is totally depending on the pull-out behavior of the fiber at the major crack. Hence the sample started to deflect upon failure which indicates a ductile behavior.

Figure 29: Steel fibers in between the cracks

The diagram above shows the fibers at the major cracks. It can be seen that the fibers are bridging in between the cracks and it help the sample not to break after the major failure. As the sample deflects upon failure, it indicates that the ductility has improved.

CHAPTER 5

CONCLUSION & RECOMMENDATION

5.1 Conclusion

This research has been successfully conducted and necessary result and discussion has been presented in the previous chapter. The main objective of this research is to identify the effect of the steel fibers towards the performance and ductility of SCC.

According to the discussion in the previous chapter, the higher the percentage of fiber included inside the SCC, the greater effect it will bring to the flow ability of the SCC. Different type of fiber does not differ much in term of affecting the workability of the SCC since same amount of fibers of different type yields almost the similar flow ability. The passing ability indicated by the V-funnel test also concludes that the addition of fiber will affect the passing ability of the SCC. The higher the percentage of fiber used the greater effect it will bring to the passing ability of the SCC.

Based on the result presented, it is safe to conclude that the usage of steel fiber enhance the ductility and performance of SCC regardless of types of the steel fibers used. The splitting tensile strength increases in the range of 14% to 82% and the flexural strength increases in the range of 19% to 82% depending on the percentage of the steel fiber used. The ductility is also enhanced by the deflection of the sample upon failure of the flexural test indicating the deformation upon the application of load. However, the addition of steel fiber does not bring much effect to the compression strength of the SCC as the result does not differ much between the samples.

In comparison between the two type of steel fiber used, the hooked-end steel fiber is much better. The highest flexural strength of the sample with hooked-end fiber is 82% greater than the sample without any fiber. While the sample with straight only achieve 43% increase in the flexural strength over the sample without any fiber. In splitting tensile strength, the hooked-end fibers able to increase the strength up to 82% while the straight fiber only 43%. This proves that hooked-end steel fiber is better than the straight steel fiber in enhancing the ductility and performance of the SCC.

As the better fiber is the hooked-end fiber, so the optimum volume fraction of the fiber is extracted from the result of the sample with hooked-end steel fiber. From the research and the analyzation made, the 2.5% of the steel fiber by volume is the optimum percentage to enhance the performance and ductility of the SCC. The addition of 2.5% of the hooked-end steel fiber will increase the splitting tensile strength up to 82% and the flexural strength up to 60% from the sample without any fiber.

Overall, the research has been successfully conducted and necessary conclusion has been drawn based on the analyzation made.

5.2 Recommendation

There are a few recommendations for further research on this topic:

1. **Increase the percentage of the steel fiber used**.

   In this research, the highest percentage of steel fiber used is only 2.5%. For further investigation, it is recommended to increase the percentage of the steel fiber up to 3.0% because the result shows a greater result with an increase in the percentage of steel fiber used.

2. **Increase the variety of the percentage of steel fiber used**.

   In this research, only 1.0, 1.5, 2.0 and 2.5 % of steel fibers are used. For further investigation, it is recommended to increase the number of the percentage of the steel fiber used for example use 1.0, 1.25, 1.5, 1.75 and 2.0 %.

3. **Investigate on the mixture of the two type of fiber**

   In this research only one type of fiber is used for a mix. For further investigation, the research could incorporate two types of fibers of the same materials or different for example is polypropylene fiber.

4. **Investigate on the possibility of increasing the compression strength of SCC**

   Since this research does not focus on the method to increase the compression strength of the SCC, it is recommended to for further research to investigate on the opportunity to increase the compression strength. It is important because most of the time, concrete will resist a compressive load.

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7.0 Appendices

	compression 3 day (Mpa)				compression 14 days (Mpa)				Compression 28 days (Mpa)			
	1	2	3	mean	1	2	3	mean	1	2	3	mean
F0	99.98	100.5	-	100.24	110.1	115.1	115.6	113.6	141.1	130.6	124.8	132.1667
F1-1.0%	121.3	119.5	116.5	119.1	129.6	132.6	131.3	131.1667	130.2	131.1	127.8	129.7
F1-1.5%	110.5	107.3	110.7	109.5	120.2	125.4	130.9	125.5	143	137.7	127.8	136.1667
F1-2.0%	106.4	110.5	93.92	103.6067	122.5	117	126.4	121.9667	135.9	133	136.6	135.1667
F2-1.0%	97.1	95.23	88.06	93.46333	111.6	107.1	120.2	112.9667	119.7	123.1	130.8	124.5333
F2-1.5%	99.14	102.7	74.25	92.03	125.1	123.4	121	123.1667	130.4	137.9	132.5	133.6
F2-2.0%	96.21	97.61	98.87	97.56333	126.3	125.7	125	125.6667	133.8	131.4	134.1	133.1
F2-2.5%	109.5	110.9	114.8	111.7333	130.1	132.8	124.8	129.2333	124.6	129.2	138.6	130.8
F1-2.5%	115.9	112.4	110.3	112.8667	129.1	127.4	128.8	128.4333	134.5	135.9	136.8	135.7333

Appendix 1: Compression Test Result

	Splitting tensile 28 days (Mpa)
	1
F0	11.02
F1-1.0%	14.05
F1-1.5%	13.95
F1-2.0%	17.75
F1-2.5%	20.05
F2-1.0%	15.81
F2-1.5%	12.63
F2-2.0%	13.87
F2-2.5%	13.06

Appendix 2: Splitting Tensile Test Result

	Flexural 28 days (Mpa)	
	1	
	Peak Load	Stress
F0	42	21
F1-1.0%	56.82	28.41
F1-1.5%	76.42	38.21
F1-2.0%	62	31
F1-2.5%	67	33.5
F2-1.0%	50	25
F2-1.5%	53.45	26.725
F2-2.0%	52.47	26.235
F2-2.5%	60.1	30.05

Appendix 3: Flexural Test Result

		Casting of SCC	Open Mould and cure	3 day test (Compression)	7 day test (compression)	14 day test (compression)	28 day		
							Compresion	Flexural	splitting tensile
Tuesday	25-Sep								
Wednesday	26-Sep								
Thursday	27-Sep								
Friday	28-Sep								
Saturday	29-Sep								
Sunday	30-Sep								
Monday	1-Oct	F0-W0.17-SP2.5							
Tuesday	2-Oct	F1-1.0-W0.17-SP2.5	F0-W0.17-SP2.5						
Wednesday	3-Oct	F1-1.5-W0.17-SP2.5	F1-1.0-W0.17-SP2.5						
Thursday	4-Oct		F1-1.5-W0.17-SP2.5	F0-W0.17-SP2.5					
Friday	5-Oct			F1-1.0-W0.17-SP2.5					
Saturday	6-Oct			F1-1.5-W0.17-SP2.5					
Sunday	7-Oct								
Monday	8-Oct								
Tuesday	9-Oct	F1-2.0-W0.18-SP2.5							
Wednesday	10-Oct		F1-2.0-W0.18-SP2.5						
Thursday	11-Oct	F2-1.0-W0.18-SP3.0							
Friday	12-Oct		F2-1.0-W0.18-SP3.0	F1-2.0-W0.18-SP2.5					
Saturday	13-Oct								
Sunday	14-Oct			F2-1.0-W0.18-SP3.0					
Monday	15-Oct	F2-1.5-W0.18-SP2.75				F0-W0.17-SP2.5			
Tuesday	16-Oct	F2-2.0-W0.18-SP2.75	F2-1.5-W0.18-SP2.75			F1-1.0-W0.17-SP2.5			
Wednesday	17-Oct	F2-2.5-W0.18-SP2.75	F2-2.0-W0.18-SP2.75			F1-1.5-W0.17-SP2.5			
Thursday	18-Oct	F1-2.5-W0.18-SP2.75	F2-2.5-W0.18-SP2.75	F2-1.5-W0.18-SP2.75					
Friday	19-Oct		F1-2.5-W0.18-SP2.75	F2-2.0-W0.18-SP2.75					
Saturday	20-Oct			F2-2.5-W0.18-SP2.75					
Sunday	21-Oct			F1-2.5-W0.18-SP2.75					
Monday	22-Oct								
Tuesday	23-Oct					F1-2.0-W0.18-SP2.5			
Wednesday	24-Oct								
Thursday	25-Oct					F2-1.0-W0.18-SP3.0			
Friday	26-Oct								
Saturday	27-Oct								
Sunday	28-Oct								
Monday	29-Oct					F2-1.5-W0.18-SP2.75	F0-W0.17-SP2.5		
Tuesday	30-Oct					F2-2.0-W0.18-SP2.75	F1-1.0-W0.17-SP2.5		
Wednesday	31-Oct					F2-2.5-W0.18-SP2.75	F1-1.5-W0.17-SP2.5		
Thursday	1-Nov					F1-2.5-W0.18-SP2.75			
Friday	2-Nov								
Saturday	3-Nov								
Sunday	4-Nov								
Monday	5-Nov								
Tuesday	6-Nov						F1-2.0-W0.18-SP2.5		
Wednesday	7-Nov								
Thursday	8-Nov						F2-1.0-W0.18-SP3.0		
Friday	9-Nov								
Saturday	10-Nov								
Sunday	11-Nov								
Monday	12-Nov						F2-1.5-W0.18-SP2.75		
Tuesday	13-Nov						F2-2.0-W0.18-SP2.75		
Wednesday	14-Nov						F2-2.5-W0.18-SP2.75		
Thursday	15-Nov						F1-2.5-W0.18-SP2.75		