# Research on Structural Characteristics of Self-Consolidating Concrete Reinforced with Steel Fibers and Utilizing Recycled Aggregate

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**Abstract -** Shear failure is characterized by a rapid and brittle breakdown that happens suddenly and without notice. Reinforcing concrete beams using stirrups at tighter spacing depending on design helps to prevent these sorts of failures. When working with Reinforced Concrete (RC) components like columns, beams, and slabs, it may be challenging to use mechanical vibrators to crush concrete into all corners of the formwork due to the crowded arrangements of rebars and stirrups. Inappropriate vibration and compaction may cause macropores and empty spaces within concrete, which can reduce the material's mechanical strength and longevity. Okamura had a brilliant idea when he created Self-Compacting Concrete (SCC) in 1986 to address all of these issues. The term "self compacting concrete" (SCC) says it all: this kind of concrete compacts itself under its own weight, without the need for any outside force. Traditional reinforced concrete beams often break at the shear span due to concrete tensile failure. This is why shear failure is often abrupt and brittle; to counteract this and boost the beams' shear strength, shear reinforcement in the shape of stirrups is commonly used. The post-cracking behavior and flexural-tensile strength of concrete are both improved by adding steel fibers to the mix. The use of short steel fibers in concrete has grown substantially in the last several years. The ability of the fibers to bridge the fracture faces, when present in enough quantity, gives composite materials like steel fiber reinforced concrete (SFRC) improved post cracking behavior. Sustainable building practices are essential to prevent the further depletion of natural resources, as the construction sector inherently isn't eco-friendly. The building industry's reliance on cement and natural aggregate has grown substantially in recent years. Limestone and other natural aggregates are becoming increasingly scarce, so there's a pressing need to find alternatives to cement and aggregates made from locally available waste, such as mineral admixtures (flyash, GGBS, silica fume) for cement and recycled concrete for coarse and fine aggregates instead of natural ones.

**Part - I**: Research on the effects of different amounts of steel fibers on the fresh and hardened properties of self-compacting concrete with different concrete grades (M30, M50, and M70) and different dosages (0%, 0.25%, 0.5%, 0.75 %, and 1% by volume of concrete) in order to establish the ideal dosage of steel fibers. Among the mechanical qualities are the strengths in compression, splitting tensile, and flexure.

**Part - II:** Finding out how various steel fiber contents affect the strength of SCC and reusing concrete waste as coarse aggregate are the goals of this project. There were three different volumes of steel fibers (SF) used to strengthen the SCC (0, 0.5, and 1% of the concrete volume), and there were five various levels of recycled coarse aggregate (RCA) utilized to replace the natural coarse aggregate (NCA): 0, 25, 50, 75, and 100%. We measured the hardened SCC specimens' compressive and tensile strengths. According to the study's experimental findings, adding steel fiber to SCC improves its mechanical qualities, especially its tensile strength. A twenty percent improvement in compressive strength was achieved by including fifty percent recycled particles into the concrete mixture. The combination of recycled aggregates and steel fibers resulted in concrete that met or exceeded all expectations, surpassing those of regular concrete. The disposal of concrete debris also has a beneficial impact, since it helps the economy and lessens environmental damage.

***Key Words***: Shear failure, Self-Compacting Concrete, steel fiber reinforced concrete, flyash, GGBS, silica fume.

## 1.INTRODUCTION

It is difficult to use any mechanical vibrator to effectively compress concrete when the rebars in reinforcement concrete (RC) parts, such beams, columns, and slabs, are arranged in an overcrowded manner. According to Broomfield (2003), improper compacting of concrete results in the formation of unoccupied spaces and micro pores, which in turn affect the concrete's strength and durability and may cause erosion. The term "self-compacting concrete" (SCC) says it all: SCC compacts itself under its own weight, without the need for outside compaction. Because of its aforementioned characteristics, it does not need vibration, which means it does not contribute to noise pollution. It also decreases labor costs and can condense to any corner of the form using its own weight without experiencing excessive segregation, which is especially useful in densely populated reinforcing applications. A shear failure occurs when the major tensile stress of concrete surpasses its tensile strength during the shear span, leading to diagonal fractures in Reinforced Concrete (RC) beams [Narayanan et al, 1987]. Since shear failure is characterized by a rapid and brittle onset, it must have occurred during warping. Stirrups are used to strengthen beams at certain design intervals in order to prevent these kinds of failures.

### 1.1 Self Compacting Concrete:

The problem of concrete constructions' longevity was first addressed in Japan with the development of Self-Compacting Concrete, a new generation of high performance concrete. As the name implies, the concrete is able to fill all of the formwork's corners and compress under its own weight, all while avoiding the need for external vibration, all while keeping the necessary consistency. Preparing SCC begins with the same fundamental components as regular vibrated concrete. Flyash, GGBS, and silica fumes are mineral admixtures, whereas high range water reduction admixtures (Super Plasticizers) are the only distinction. To achieve self-compatibility, the ratio of coarse particles to total volume of concrete is maintained constant at 50%, while the ratio of fine aggregates to total mortar volume is 40%. SCC also has a considerably greater binder content than regular vibrated concrete.

These attributes are satisfied while the concrete is still in its fresh state. As the principal method for determining whether SCC is consistent, slump flow values characterize the flowability of newly mixed SCC. Additional information on segregation resistance may be obtained by measuring the T50 cm time in addition to ocular observations. The V-funnel test can determine the viscosity of SCC, and the segregation resistance may be SCC has wide spread usage in precast industry, building, tunnel constructions, The V-funnel should be left at T5 minutes for 5 minutes to enable the concrete to settle. The duration between the V-funnel time and T5 minutes should not exceed 0 to 3 minutes.

Segregation of concrete occurs when the duration exceeds three minutes. The passing ability of SCC refers to the capacity of new mixtures to pass through densely packed reinforcement. The J ring and L-box tests may be used to determine SCC's passing capabilities. According to EFNARC in 2005,”

### 1.2 Fiber Reinforced Concrete:

Using pretensioning methods and traditional steel bars, concrete's tensile qualities have been the subject of several efforts over the years. These two approaches perform wonders for the tensile strength of concrete components, but they have no effect on the concrete's inherent tensile strength. The RC part fails prematurely because microcracks in the concrete expand and open up when subjected to loading. Recently, there has been a lot of talk about how using short, randomly disturbed fibers in concrete might assist improve the material's flexural and tensile strengths by resolving and arresting these microcracks. Fiber reinforced concrete is the result of adding fibers to regular concrete.

### 1.3 Shear Behaviour of Fiber Reinforced Concrete:

One of the key conditions in the limit state of collapse is shear. Reinforced concrete design shear analysis is notoriously difficult to pin down. Without stirrups, shear in reinforcing concrete (RC) beams is resisted by the aggregate interlocking force, longitudinal tensile reinforcement, and uncracked concrete in compression. Shear reinforcement (stirrups), concrete compressive strength (fck), longitudinal tensile reinforcement (st), shear span to depth ratio (a/d), and spacing of shear reinforcement (sv) were all factors that influenced the shear behavior of RC beams.

### 1.4 Recycled aggregate concrete:

In the field of civil and structural engineering, concrete has consistently ranked among the most popular and promising materials. Its superior performance, extended lifespan, and minimal maintenance requirements led to its selection. In order to achieve fast urbanization, all smaller buildings are torn down and replaced with larger ones. Landfills are a significant source of land and environmental contamination since they collect destroyed materials, the vast majority of which are concrete.

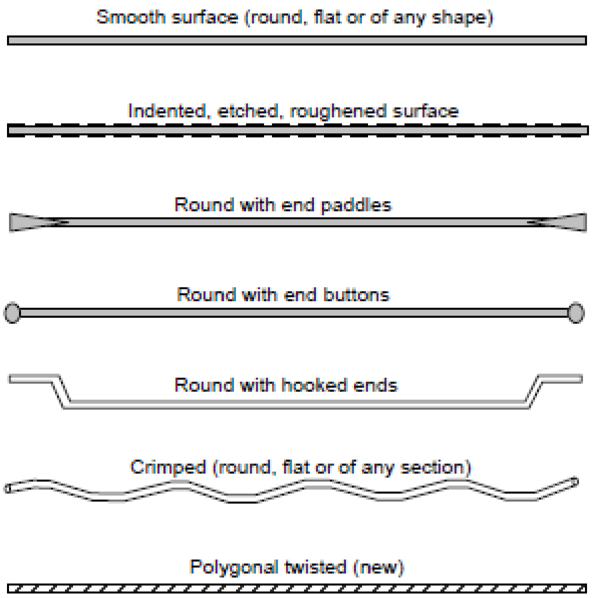


**Fig -1: Commonly available deformed steel fiber**

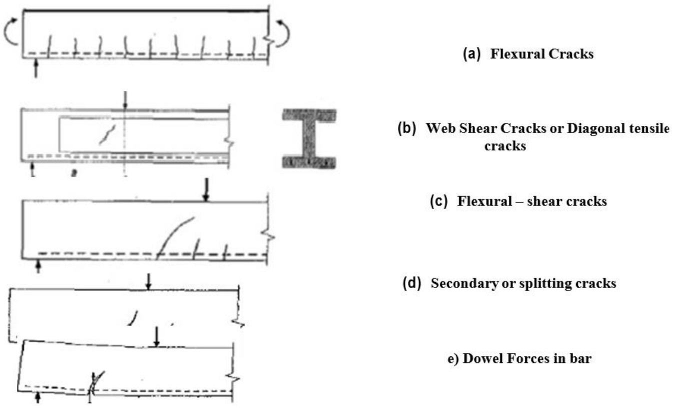


**Fig. 2 Modes of Failure of a RC beam**

### 1.1 Research Gap

1. Self-Compacting Concrete has numerous advantages including concreting in difficult environments and congested reinforcements. This type of special concrete has large scope in structural applications.
2. From the detailed literature review it is evident that the use of steel fibers in self- compacting concrete not only improves the load carrying capacity but also changes the failure pattern from brittle behaviour to ductile mode.
3. Effect of steel fibers on shear behaviour of Self-compacting concrete can be studied.
4. Recycled aggregates can be used as replacement of natural aggregates and can be used in self-compacting concrete for studying the shear behaviour.
5. Effect of stirrup diameter and spacing of stirrups on shear behaviour of SFRSCC can be studied.
6. Analytical modelling using finite element based software can be used in studying the shear behaviour of SFRSCC beams for both natural and recycled aggregates.
7. Studies on shear behaviour of steel fibers are limited to normal concretes.
8. Studies on Shear behaviour of SCC and SFRSCC is scant and the available models in the literature on vibrated concretes needs to be checked for SCC based on experimental work.

### 1.2 Scope of the Investigation

Evaluation of strength properties of steel fiber reinforced self-compacting concrete for various dosages of steel fibers (0%, 0.25%, 0.5%, 0.75% and 1% by volume of concrete) for three grades of SCC i.e. 30 MPa, 50 MPa and 70 MPa and thus maximize the dosage of steel fibers.

### 1.3 Objectives

1. To evaluate the fresh and hardened properties of steel fiber reinforced self- compacting concrete for various dosages of steel fibers for three grades i.e. 30 MPa, 50 MPa and 70 MPa and maximize the dosage of steel fibers based on fresh and hardened properties.
2. An important step toward a more sustainable construction industry and more environmentally friendly concrete is the substitution of recycled fine and coarse material for natural aggregate.
3. Using steel fiber, the researchers were able to increase the concrete's low tensile strength and prevent fractures from growing in reinforced concrete.

## 2. Structural Characteristics of Reinforced Steel Composites

The study is split into three stages based on the goals outlined in the preceding chapter. Improving the dosage of steel fiber in concrete from 0% to 1% by volume for three distinct concrete classes (SCC30, SCC50, and SCC70) and this chapter presents the mechanical behavior of self-compacting concrete that is reinforced with steel fibers.

First, we used the logical approach of mix design to create self-compacting concrete and tested its fresh and hardened qualities. To create SCC, the super plasticizer concentration was adjusted until the desired fresh qualities were reached. Testing for new characteristics, such as slump flow, V-funnel, and J-ring, was carried out on SCC in accordance with EFNARC standards. What follows is a presentation of the specifics of these test methods. This investigation took into account three different concrete grades: SCC30, SCC50, and SCC70. The mechanical properties, including compressive, split-tensile, and flexural strengths, were investigated using standard cube molds with dimensions 150x150 mm for compressive strength, cylinders with dimensions 150 mm in diameter and 300 mm in height for split tensile strength, and prism specimens 100x100x500 mm for modulus of rupture.

In the second phase, steel fiber reinforced SCC was created for three distinct concrete grades (M30, M50, and M70) using varying amounts of steel fibers (0%, 0.25 percent, 0.75 percent, and 1 percent by volume of concrete). Information on the cast specimens is included in Table 4.1. For every dose of steel fiber, new qualities were assessed. It was shown that fresh attributes diminished with increasing fiber dose. Compressive, split tensile, and flexural strengths are among of the toughened characteristics that are tested.

At the necessary levels, fresh SCC must have critical features such as filling capacity, passage ability, and resistance to segregation. Under its own weight, the filling ability of the SCC is defined as its capacity to flow into all areas inside the formwork. For SCC to function, the concrete must not only fill any empty space in the formwork, but also flow in both horizontal and vertical directions without trapping air either within or on top of the material. When tested, SCC must be able to pass its own weight through narrow spaces, such as the spaces between steel reinforcing bars. To ensure that the components of SCC are distributed uniformly near barriers, passing ability is necessary. The components of SCC exhibit consistent resistance to segregation, which is defined as their resistance to movement or separation, during transit and placement. Below, you can find information about the test processes that EFNARC [2005] has developed to meet these requirements.

### 2.1 Hardened properties of SCC:

After satisfying the fresh properties of SCC, the hardened properties of these three grades of concrete (M30, M50 and M70) were determined. A total of 60 specimens each for compressive, split tensile and flexural strength were cast and tested for different dosage of steel fibers for three grades of concrete.

### 2.2 Compressive strength

- After 28 days of curing the specimens were taken from curing tank and kept outside till the moisture content on surface of the cube is evaporated.
- The cube specimens were then tested in a standard compression testing machine of capacity 200 tones until failure.
- The specimen was placed in the machine in such a manner that the load was applied to opposite sides of the cubes as casted that is, not top and bottom.
- The load applied was increased continuously at a constant rate until the resistance of the specimen to the increasing load breaks down and no longer can be sustained.
- The maximum load applied on the specimen was recorded. The rate of loading and testing procedure was as per IS 516 [1956].

### 2.3 Split Tensile Strength

- The bearing surface of the casting was wiped clean, in case of cylindrical specimens the test was carried out by placing the specimen horizontally between the loading surfaces of the compression testing machine for split tensile strength and the axis of the specimen was carefully aligned with centre of the loading frames.
- The load was applied and increased continuously till the specimen breaks. The failure load was recorded.
- The test was performed as per IS: 516 [1956].

### 2.4 Flexural Strength

- The flexural strength of the specimen is also expressed as the modulus of the rupture.
- The method used in testing is third point loading.
- The test specimen should be turned its sides with respect to its portion moulded and centered on bearing blades. The load applying blades shall be brought in contact with the upper surface at the third points between the supports. The strength in the bearing is the extreme fibre stress on the tensile side at the point of the failure. The test was performed as per IS: 516 [1956].

### 3.Conclusions and Results from the part-1 study:

1. Due to addition of steel fiber, fresh properties of SCC30, SCC50 & SCC70 has decreased.
2. Addition of fibers has a marginal increase in compressive strength whereas split tensile and flexural strengths increased as dosage of fibers increased.
3. Based on fresh and hardened properties it can be confirmed that 0.5 % dosage of steel fibers by volume of concrete is maximum dosage for self-compacting concrete.
4. As the dosage of steel fibers has increased beyond 0.5 % by volume of concrete, balling effect was observed during mixing of concrete and it resulted in decrease in compressive strength for all grades of SCC.
5. Due to use of steel fibers, split and flexural strengths was increased gradually as the dosage of fibers increased, this increase can be due to the fibres bridging the crack propagation and resulted in increased ultimate load carrying capacity of the specimens and also delaying the failure of the specimens.
6. Shear Strength (Vuc) was slightly higher in case of SCC compared to Normal concrete.

| Mix | Cement (kg/m3) | Fly ash (kg/m3) | Silica fume (kg/m3) | CA (kg/m3) | FA (kg/m3) | Water (kg/m3) | w/b | SP (kg/m3) |
|---|---|---|---|---|---|---|---|---|
| M30 | 350 | 324 | - | 746 | 945 | 203 | 0.3 | 5.73 |
| M50 | 500 | 270 | - | 775 | 868 | 223 | 0.29 | 5.69 |
| M70 | 600 | 226 | 48 | 780 | 874 | 245 | 0.28 | 6.03 |

**Table 1: Mix proportions of SCC30, SCC50 & SCC70 grade SCC**

| Grade of concrete | Dosage of steel fibers (% by volume of concrete) | Specimens cast | | |
|---|---|---|---|---|
| | | Cubes | Cylinders | Prisms |
| M30 | 0% | 6 | 3 | 3 |
| | 0.25% | 6 | 3 | 3 |
| | 0.50% | 6 | 3 | 3 |
| | 0.75% | 6 | 3 | 3 |
| | 1% | 6 | 3 | 3 |
| | **Sub - Total** | **30** | **15** | **15** |
| M50 | 0% | 6 | 3 | 3 |
| | 0.25% | 6 | 3 | 3 |
| | 0.50% | 6 | 3 | 3 |
| | 0.75% | 6 | 3 | 3 |
| | 1% | 6 | 3 | 3 |
| | **Sub - Total** | **30** | **15** | **15** |
| M70 | 0% | 6 | 3 | 3 |
| | 0.25% | 6 | 3 | 3 |
| | 0.50% | 6 | 3 | 3 |
| | 0.75% | 6 | 3 | 3 |
| | 1% | 6 | 3 | 3 |
| | **Sub-Total** | **30** | **15** | **15** |

| Grade of Concrete | 50 MPa | | | | | EFNARC 2005 | |
|---|---|---|---|---|---|---|---|
| Dosage of Fibers | 0 % | 0.25 % | 0.50 % | 0.75 % | 1 % | Min. | Max. |
| Slump Test, (mm) | 750 | 660 | 620 | 600 | 570 | 550 | 800 |
| T50 Slump flow, (sec) | 2.3 | 3 | 6 | 8 | 11 | 2 | 5 |
| V funnel, (sec) | 6 | 6.9 | 7.5 | 21 | 22 | 6 | 12 |
| V funnel @ T5 min, (sec) | 7.5 | 8 | 10 | 23 | 25 | 6 | 15 |
| J-ring | 3 | 8 | 8 | 12 | 13 | 0 | 10 |

**Table 2: Details of SFRSCC specimens cast**

| Grade of Concrete | 30 MPa | | | | | EFNARC 2005 | |
|---|---|---|---|---|---|---|---|
| Dosage of Fibers | 0 % | 0.25 % | 0.50 % | 0.75 % | 1 % | Min. | Max. |
| Slump Test, (mm) | 750 | 700 | 680 | 600 | 570 | 550 | 800 |
| T50 Slump flow, (sec) | 3 | 5 | 5 | 7.5 | 8 | 2 | 5 |
| V funnel, sec | 6 | 7.5 | 8.5 | 16 | 19 | 6 | 12 |
| V funnel @ T5 min, (sec) | 6.5 | 7 | 9.3 | 20 | 23 | 6 | 15 |
| J-ring | 3 | 8 | 8 | 12 | 13 | 0 | 10 |

**Table 3: Fresh properties of SCC30 without and with steel fiber**

**Table 4: Fresh properties of SCC50 without and with steel fiber**

| Grade of Concrete | 70 MPa | | | | | EFNARC 2005 | |
|---|---|---|---|---|---|---|---|
| Dosage of Fibers | 0 % | 0.25 % | 0.50 % | 0.75 % | 1 % | Min. | Max. |
| Slump Test, (mm) | 720 | 710 | 680 | 640 | 450 | 550 | 800 |
| T50 Slump flow, (sec) | 2.5 | 3.25 | 4 | 5 | 24 | 2 | 5 |
| V funnel, (sec) | 10.5 | 10.5 | 11.8 | 12 | 15 | 6 | 12 |
| V funnel @ T5 min, (sec) | 12 | 12.6 | 14 | 15 | 20 | 6 | 15 |
| J-ring | 3 | 4 | 7 | 9 | 12 | 0 | 10 |

**Table 5: Fresh properties of SCC70 without and with steel fiber**

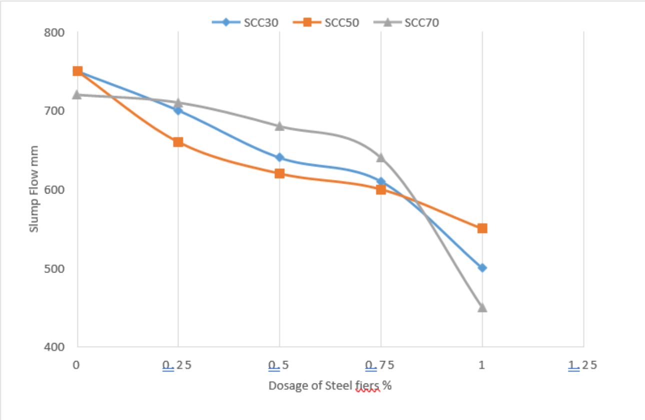


**Figure 3: Slump Flow vs Dosage of steel fibers**

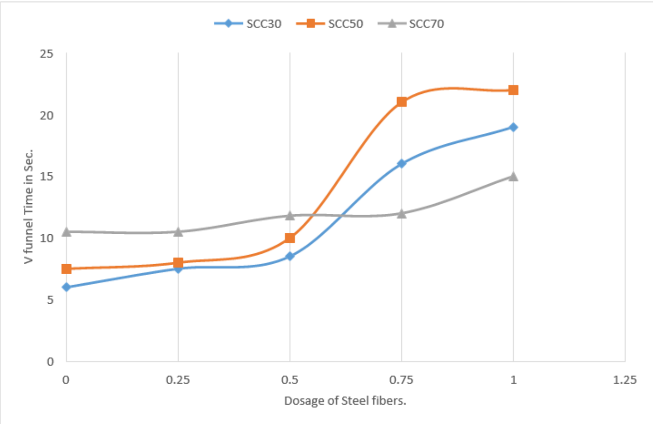


**Figure 4: V- Funnel (time) vs Dosage of Steel Fibers**

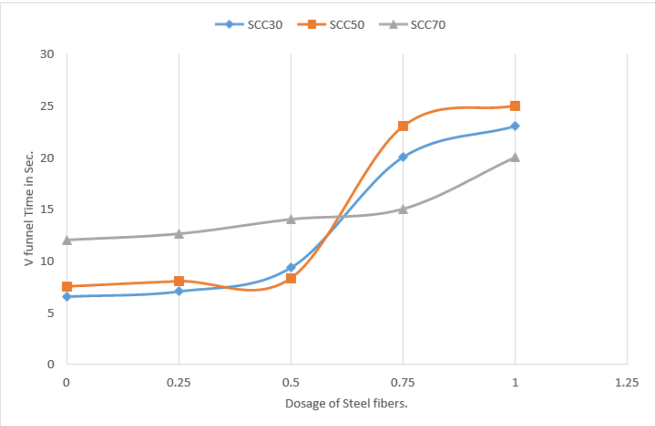


**Figure 5: V- Funnel at 5minutes (time) vs Dosage of Steel Fibers**

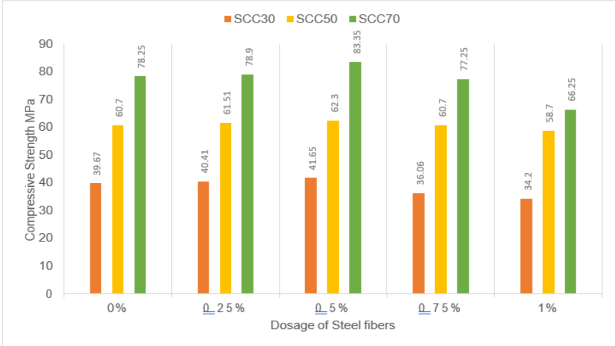


**Figure 6: Compressive strength vs dosage of steel fibers**

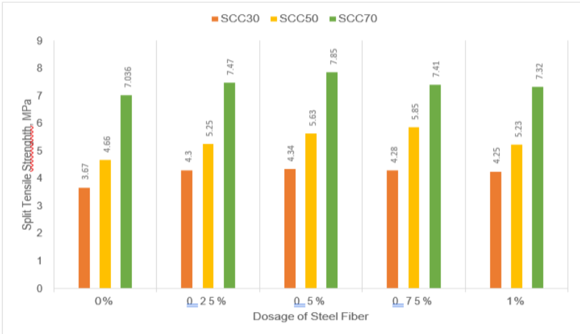


**Figure 7: Split Tensile strength vs dosage of steel fibers**

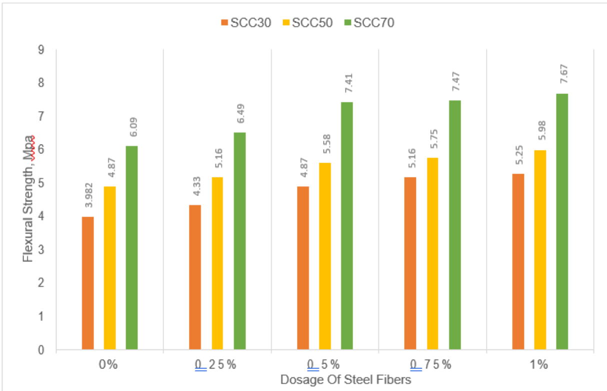


**Figure 8: Flexural strength vs dosage of steel fibers**

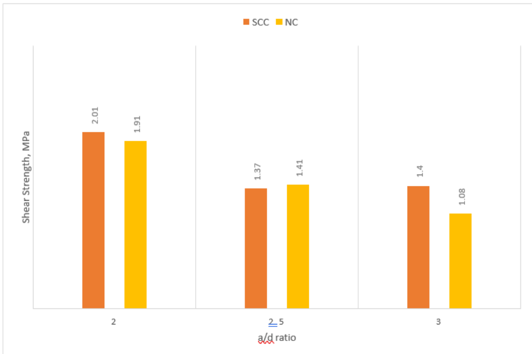


**Figure 9 Shear strength vs a/d ratio for M30 SCC and NC**

## 4. Conclusions and Results from the part-2 study: Recycled Aggregate Concrete and Steel Fibers

The concrete mixes were all made using Ordinary Portland Cement (OPC) (type I), which has a specific gravity of 3.15 and a fineness of 295 m2/kg. The SCC mixes included FA (class F fly ash) and SC (silica fumes) as binder ingredients. To meet the standards set by ASTM, Table 6 lists the chemical compositions of OPC, SC, and FA.

| Oxide (%) | OPC | FA | SC |
|---|---|---|---|
| SiO2 | 19.1 | 55.6 | 93 |
| Fe2O3 | 3.38 | 12.9 | 1.5 |
| CaO | 66.3 | 5.12 | 0.4 |
| Al2O3 | 6.43 | 20.7 | 0.8 |
| MgO | 1.46 | 2.66 | 0.2 |
| SO3 | 2.32 | 0.35 | 0.2 |
| Na2O+ K2O | 1.09 | 2.55 | 1.5 |
| Specific gravity | 3.16 | 2.3 | 2.4 |

**Table 6: Chemical analysis of cement and binder additives**

Natural fine aggregates (NFA) and natural coarse aggregates (NCA) were sourced from the same place and had specific gravities of 2.66 and 1.53 m/s², respectively, and water absorptions of 3.80% and 1.52 m/s², respectively, for all the concrete mixes. Tables 7 and 8 detailed the physical characteristics and results of the sieve analyses for coarse and fine aggregates, respectively. We gathered the recycled coarse aggregate (RCA) from the concrete block companies that made the remaining concrete blocks. Table 7 lists the physical characteristics and results of the sieve analysis of recycled coarse material.

| Sieve Size (mm) | Percentage passing (%) | ASTM C136-06 limits (%) |
|---|---|---|
| 4.75 | 100 | 95-100 |
| 2.36 | 92 | 80-100 |
| 1.18 | 79 | 50-85 |
| 0.6 | 45 | 25-60 |
| 0.3 | 23 | 30-Oct |
| 0.15 | 4 | 0-10 |

**Table 7: Sieve analysis of NFA.**

| Sieve Size (mm) | Percentage passing (%) | | ASTM C136-06 limits (%) |
|---|---|---|---|
| | NCA | RCA | |
| 12 | 100 | 100 | 90-100 |
| 9.5 | 61 | 46 | 40-70 |
| 4.75 | 12 | 7 | 0-15 |
| Pan | 2 | 4 | 0-5 |

**Table 8: Sieve analysis of NCA and RCA**

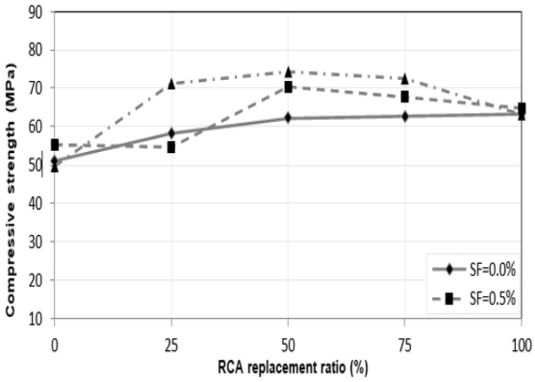


**Figure 10: Effect of RCA on compressive strength**

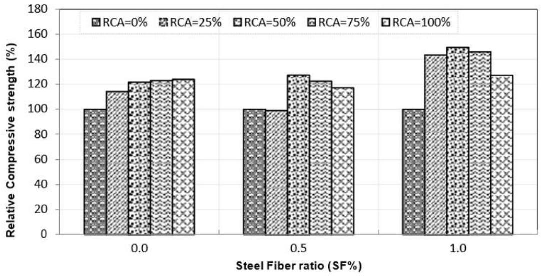


**Figure 11: Effect of SF% on relative compressive strength**

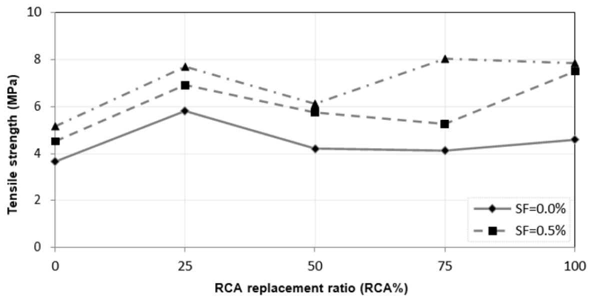


**Figure 12: Effect of RCA on tensile strength**

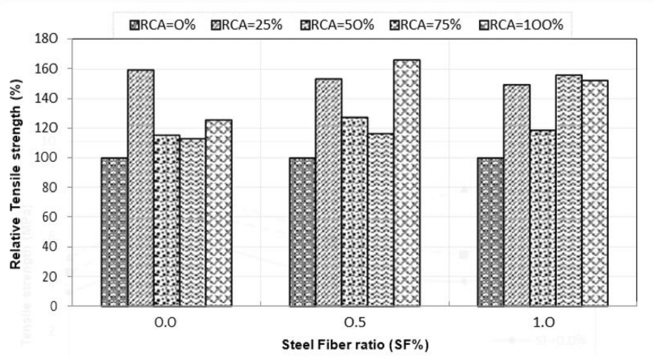


**Figure 13: Effect of SF% on relative tensile strength**

## 5.Conclusions:

1. The maximum dosage of steel fibers by volume of concrete for self-compacting concrete in all three classes (30MPa, 50MPa, and 70 MPa) is 0.5%, as validated by both fresh and hardened characteristics. Because the fibers stop the cracks from spreading, the specimens' split and flexural strengths go up, and their ultimate load bearing capacity goes up as well.
2. For normal strength concrete (30 MPa), using the maximum dose of steel fibers (i.e., 0.5% by volume of concrete) enhanced compressive strength by 4.9%, split tensile strength by 15.44%, and flexural strength by 22.3%.
3. Third, the compressive strength improved by 2.63%, the split tensile strength by 20.8%, and the flexural strength by 14.5% in the case of standard grade SCC (50 MPa) when the maximum dosage of steel fibers was added to the concrete (0.5% volume of concrete).
4. Similarly, when steel fibers were added to high strength SCC (70 MPa), the compressive strength improved by 6.51%, the split tensile strength by 12%, and the flexural strength by 21.67% with a dose of 0.5% of steel fibers.
5. 5. Table 5. Results from the pilot tests on SCC and Vibrated Concrete (VC) beams showed that the two materials had similar shear strengths. We looked at the 2, 2.5, and 3 shear span to depth ratios (a/d) in detail. Both the VC and SCC fracture patterns were quite comparable.
6. 6. For normal strength concrete (30 MPa), using the maximum dose of steel fibers (i.e., 0.5% by volume of concrete) enhanced compressive strength by 4.9%, split tensile strength by 15.44%, and flexural strength by 22.3%.
7. 7. Third, the compressive strength improved by 2.63%, the split tensile strength by 20.8%, and the flexural strength by 14.5% in the case of standard grade SCC (50 MPa) when the maximum dosage of steel fibers was added to the concrete (0.5% volume of concrete).
8. 8. Similarly, when steel fibers were added to high strength SCC (70 MPa), the compressive strength improved by 6.51%, the split tensile strength by 12%, and the flexural strength by 21.67% with a dose of 0.5% of steel fibers.

## 6.Recommendations for future work:

1. To investigate how the dowel effect affects the shear behavior of self-compacting concrete reinforced with steel fibers at various shear span to depth ratios (a/d).
2. This work aims to examine the shear behavior of NASCC and RASCC with and without steel fibers by examining the influence of gravel interlock mechanism.

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