

# Evaluating the Properties and Functionality of Steel Fiber Reinforced Concrete

by

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## **Abstract**

This report is contingent upon research and literature reviews, targeting steel fiber reinforced concrete (SFRC). It will explore all aspects involved, detailing both properties and functionality. Historical development of the modern application mix and design procedures will be discussed. A critical investigation based on laboratory testing is examined and a comparative discussion is provided. This report will also highlight the structural uses, benefits, applications and deficiencies acquired by SFRC.

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I perceive this opportunity as a big milestone in my career development. I will strive to use the gained knowledge in the best possible mean, and will continue to work on its improvement, in order to attain desired career objectives.

## **Study Method**

Research methods were conducted through various sources focusing primarily on Steel Fiber Reinforced Concrete. Informative articles were a basic yet strong foundation for comprehending the topic researched where a thorough perspective was obtained.

Published articles were used for dense analysis, experimental research, testing, and results. This gave an insight to how steel fiber reinforcement contributed to conventional concrete in various aspects.

Visual learning methods, such as animated videos and PowerPoint presentations, were of great aid. This made it easier to envision how the properties and mechanical characteristics of the researched topic functioned in real life applications.



# **1. Introduction**

## **1.1 History**

Fibers have been added to strengthen building materials, dating back to at least 3500 years ago, when ancient Egyptians were the leaders of innovative construction. During these times builders used various admixtures in their building materials. One of the most famous materials amongst the aforementioned admixtures was straw, which was used to reinforce mud bricks. It was also recorded that horse hair was used in mortar shortly after. Evidently, asbestos was discovered by Porter, as an effective admixing fiber and was used to reinforce concrete in the early 1900s. However, it was shortly discriminated by researchers during the 1950s due to the discovery of its health risks in residential building. This discovery led to intensified research within the field of reinforced concrete.

Engineers started focusing on other fibrous materials, which could also be successfully used as reinforcements. In the past 30 to 40 years, researchers discovered numerous fibrous materials that have been tested and proven to be effective, including steel, glass, natural, and synthetic fibers. These discoveries have been a major breakthrough in the world of structural engineering, and research in fiber reinforced concrete continues to this day.

## 1.2 Fiber Reinforced Concrete (FRC)

Concrete is naturally brittle and when comparing its tensile to compressive strength, it is observed that, compressive strength is usually ten times greater than its tensile strength. Due to this fact, concrete is therefore reinforced with steel bars, which comes in different applications, but all serve the same purpose, increasing the overall strength. However, construction material continues to evolve and with the demand for higher strength, crack, resistant and lighter concrete, many techniques and improvements have been developed to try to significantly meet these needs. A major outbreak to these demands was introducing fibers to reinforce concrete. Adding these fibers to concrete plays a significant role in its structural properties, causing it to gain higher strength, crack resistance and lighter concrete. The most effective contribution of fiber reinforcement in concrete is not its flexural strength, but to the flexural toughness of the material. It is not a substitute for conventional reinforcement when considering flexural strength, but contributes towards reducing bleeding in fresh concrete, and renders concrete more impermeable in the hardened stage.

Steel Fiber Reinforced Concrete (SFRC) is made using hydraulic cements that contain fine and coarse aggregates along with discontinuous discrete steel fibers. (ACI 544.4R). The cutting of drawn wires ends in the production of steel fibers. Fiber can be indented, crimped and shaped up in an irregular form in order to provide better mechanical bonding. The aspects that decide the distribution of steel fiber in an efficient matter include the steel fiber geometry, mixing technique, content, size and the collective shape. Steel fibers are considered to be short in length. Their length can vary, but has an aspect ratio (length/diameter) ranging between 20-100, as well as a diameter span of 0.15 mm to 1 mm. In the process of adding the steel fibers to a concrete mix, the fibers are spread out uniformly and randomly. This mixture is known as Steel Fiber Reinforced Concrete. In comparison to the properties of plain concrete, SFRC has shown to mark an increase in the following features: strength, toughness ductility, tensile toughness and flexural strength properties. Two properties that are not affected by the addition of steel fiber include creep and shrinkage. SFRC is very effective in controlling the progress of cracks into becoming visible ones. Also, it improves both impact and abrasion resistance. SFRC is commonly found in

refractory linings, blast resistance structures, tunnel linings, pavements and precast concrete units. However, an arising problem with the use of these fibers are balling or clumping when used in high percentages of concrete, as well as in dimensions with aspect ratios greater than 100. The properties and qualities SFRC offers will be further examined and discussed throughout the report.

### 1.3 Types of Steel Fibers

There are many different types of steel fibers in the market, as a result of the intensive research performed in this field. The ASTM A820 defines five general types used as a source of the steel fiber material. These types are:

Type 1: Cold drawn wire

Type 2: Cut sheet steel

Type 3: Melt extract

Type 4: Mill cut

Type 5: Modified Cold-drawn wire – (shaved into fibers)

The type that contains the highest tensile strength ranging from 145,000–445,000 psi, is Type 1. The reason for this is due to the fiber's shape and composition. The most effective shape from Type 1 steel fibers is the end hooked steel fiber, which is made by the use of high quality low carbon steel wire. The bent ends attribute to better anchorage improving the fiber-matrix bond characteristics. This specific type has high tensile strength, good toughness and is abundantly available at a low cost. As for the remaining steel fiber types, their tensile strength is much lower averaging 50,000-psi. Apart from their low tensile strength they are still widely used. This is because of the specific use of the concrete mix needed and five main parameters that usually define the choice of a specific steel fiber other than its tensile strength. The five parameters include the dosage, type, length of the fiber, effective diameter or aspect ratio, and deformation. They are all set depending on the structural use and the design mix of concrete. This will be further discussed in the composition and properties section.

## 1.4 Developments

Steel fiber reinforced concrete has been significantly focused on in the past 30 years due to its valuable properties. Research has been intensified in this field, due to its evident functionality and prosperous results. The idea of using such fibers to reinforce concrete has been widely accepted among construction companies. This is because of the continuous development of complex architectural designs and the endless demand for enhanced building material. An example of this application is witnessed in the shells constructed in the European Oceanographic Park in Valencia (Figure 1, 2). The thin shell structure covered building could not have been built without the aid of steel fiber concrete to keep the thin concrete application from cracking or chipping off (9).



Figure 1: European Oceanographic Park in Valencia



Figure 2: European Oceanographic Park in ValenciaValencia

Recent developments have also lead to the use of steel fiber reinforcement in columns as a result of its ductility improvements (14). This is highly effective in structures designed to work in seismic areas. During an earthquake, reinforced columns usually lose concrete covering the rebar, however the aid of steel fiber reinforcement has caused an increase in the concretes toughness allowing it to resist the seismic vibrations and adding more ductility and stiffness to columns (14).

Other research has shown the benefits of using steel fibers in other structural components like beams and roofs. However, verified advancements have been seen for its use in slab on grad (3). In rough environments, like industrial slabs or even bridges, steel fibers have been used as a substitute for conventional rebar, and had shown exceptional results.

## 2. Material

### 2.1 Composition/Properties

Steel Fibers come in different shapes and sizes depending on their physical properties and the required final render of concrete. The common geometric forms used are straight, hooked, paddled, deformed, crimped, irregular etc. Examples of these steel fibers are shown in Figure 1.

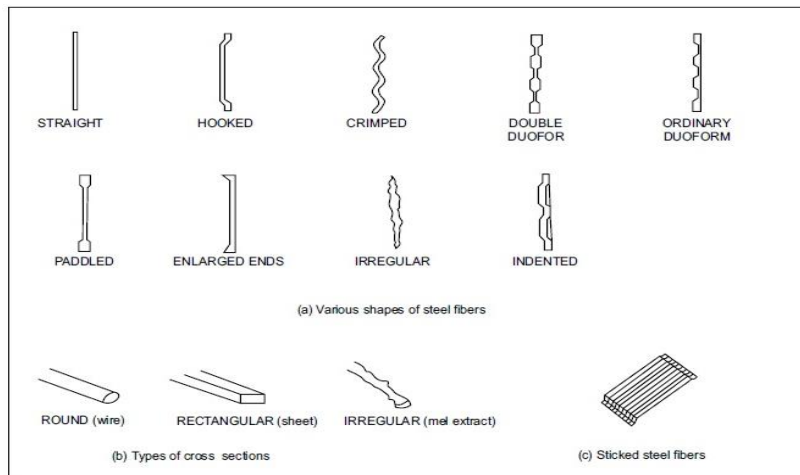


Figure 3: Different forms of steel fibers

They also come in different lengths and diameters (effective length and aspect ratio {length/diameter}, depending on requirement) according to the designed specimen and the concrete's structural use (7). Steel fibers are usually glued together when manufactured and separated during mixing to ensure uniform distribution and avoid steel fiber clumps or balls. Uniform distribution is critical to ensure the steel fibers' mechanical effect is evenly dispersed across all the concrete. Many techniques have been integrated to perfect the distribution of steel fibers, however there is no specific method that guarantees this process. The different techniques include, using a conveyor belt on-site, which slowly adds the steel fibers in the concrete mix to allow the fibers to distribute evenly throughout the mix (7). Another technique is through the use of a machine to evenly blow the steel fibers into the mix. On the other hand, if precast concrete is an option, having it done at a ready-mix plant off-site will surely be a better option than both due to the controlled environment aspect (7).

As an engineer is designing a concrete mix for any specified structural use, there are requirements for selecting the appropriate steel fiber. These include:

Fiber dosage, which is the quantity of steel fiber added to the concrete mix, is measured by mass of fibers per unit volume of concrete ( $\text{kg}/\text{m}^3$  or  $\text{lb}/\text{cy}$ ) (10). However, some engineers will provide the steel fiber volume as a percentage of the concrete's volume, making it easier to visualize, and stay constant across all the measurement systems. Table 1 shows an example of the equivalents between these measurements. The steel fiber dosages generally range from 12-to  $42\text{-kg}/\text{m}^3$  (20 to 70  $\text{lb}/\text{cy}$ ). Dosages above that range are extremely rare and any dosage below that range is usually used for replacing light-gauge wire mesh (10).

Pounds per cubic yard	Kilograms per cubic meter	Volume
20	12	0.15%
25	15	0.19%
30	18	0.23%
33	20	0.25%
35	21	0.26%
40	24	0.30%
50	30	0.38%
60	36	0.45%
66	39	0.50%
70	42	0.53%
132	78	1.00%

Table 1: Equivalent Steel Fiber Dosage Rate

The American Concrete Institute (ACI) sets guidelines for the steel fiber dosage that must be met. In accordance with the ACI's guide to design of slabs-on-ground for example, the guidelines specify that in ground support the fiber dosage for ground slabs should never be less than  $20\text{kg}/\text{m}^3$  (33  $\text{lb}/\text{cy}$ ) (10). Nonetheless, when steel fiber is needed to allow for wider joint spacing, the ACI recommends using a minimum of  $36\text{-kg}/\text{m}^3$  (60  $\text{lb}/\text{cy}$ ) (10). Due to the infinite shapes and material composition of the steel fibers, the designer can alter these guidelines to meet the requirements needed for the concrete mix.

The designer must also consider the type of steel fiber needed for a mix, based on how they are manufactured (7). The different types of steel fibers have been discussed earlier and their tensile strengths have been indicated, but all of them have specific characteristics that serve different needs. Manufacturers have been struggling to find which type of steel fiber works best and from a designers point-of-view, the main issue is certain properties may not be available in all the mentioned types. This makes it tougher for a designer to select the most efficient fiber type available in the market.

Another characteristic that must be considered is the steel fibers length (10). Although it is agreed upon that the length of the steel fiber is an important matter, nevertheless, there is no agreement as to which specified length is best. This is also a matter that is usually left for the designer to figure out, and is dependent on the structural use of the concrete mix. It has been proven through lab testing that in order to limit the widening of cracks in cured concrete and increase its flexural toughness, it is recommended that longer fibers be used (10). As for visible cracking on the surface of concrete, it is preferred that shorter steel fibers with a higher fiber count with less distance between fibers be used to remedy the issue (10).

The effective diameter or aspect ratio is also considered when designing steel fiber reinforced concrete (7). The effective diameter is measured for circular steel fiber cross-section and the aspect ratio is any fiber cross-sections that are not circular. The aspect ratio gives a better understanding of the bonding potentials. Steel fibers possessing aspect ratio greater than 2” usually have a higher potential of balling (10).

### 3. Testing

#### 3.1 Laboratory Experiment

Theoretical research, analytic model developments and testings have been conducted throughout history to check for quality and mechanical properties of SFRC. Each of those have been rendered to have unique techniques for measuring efficiency. The test discussed in this report is based on the laboratory testing's performed by Ege University (12). These testings will examine the compressive strength, split tensile strength, flexural strength and ultrasonic pulse velocity that steel fibers have on conventional concrete. This will be performed by the use of different aspect ratios and different steel fiber volumes- $V_f(\%)$  to check which specific steel fiber reinforced concrete design governs in efficiency (12).

The engineers performing the tests decided to use Type 1 steel fibers with hooked ends to maximize anchorage and better the fiber matrix bond. Three different aspect ratios were used for the hooked-end fibers including 45, 65 and 80 respectively. At each aspect ratio, three different fiber volumes were added to the concrete mixes at 0.5%, 1.0% and 1.5%  $V_f$ . A total of ten different concrete mixes were produced. Nine concrete mixes were produced with the different fiber volumes specified and one plain concrete mix for comparison. An average compressive strength of 40 MPa was designed for the concrete and a 28-day standard curing time was performed to perfect the tests and reduce margin of error as much as possible (12).

Concrete cube samples were used to test for compressive strength, split tensile strength and ultrasonic pulse velocity. As for the flexural strength test prismatic specimens were produced. A total of 120 concrete cubes were casted at a size of 150mm, and 60 prismatic specimens were casted at a size 100x100x600 mm. The concrete mix contained, CEM I 42.R type cement with specific gravity of 3.13 and specific surface of  $3670 \text{ cm}^2/\text{g}$ , super plasticizer at 2.5% by weight of cement, crushed limestone aggregate with a maximum size of 15mm and divided into three different size fractions AI, AII, AIII (Table 2). The water to cement ratio is 0.3-0.45 and the fineness modulus of the mixture is 3.64. The aggregates used in the concrete mix were in saturated-surface dry (SSD) conditions. The proportioning and description of the concrete mixture according to the ten different samples produced is summarized in Table 2 (12).



Mixture code	$l/d$ ratio	$V_f$ (%)	Batch weight (kg/m <sup>3</sup> )						
			PC	Water	AI	AII	AIII	Fiber	SP
CC	–	–	438	158.5	521	516	656	–	10.95
SFRC1	45	0.5	438	158.7	517	512	651	39	10.95
SFRC2	45	1.0	438	159	513	508	646	78	10.95
SFRC3	45	1.5	438	159	510	505	641	117	10.95
SFRC4	65	0.5	438	158.7	517	512	651	39	10.95
SFRC5	65	1.0	438	159	513	508	646	78	10.95
SFRC6	65	1.5	438	159	510	505	641	117	10.95
SFRC7	80	0.5	438	158.7	517	512	651	39	10.95
SFRC8	80	1.0	438	159	513	508	646	78	10.95
SFRC9	80	1.5	438	159	510	505	641	117	10.95

Table 2: Mix proportions and description of concrete mixtures

A slump test was also performed on the samples to verify whether the mix has been properly mixed, and to check the workability of the freshly made concrete. This test was also conducted to measure the effect steel fibers had on the efficiency and shape of the fresh concrete once it was mixed and ready. The results are shown in Table 3. A unit weight test was also performed to measure the effect steel fibers had on the sample produced. This is also indicated on Table 3 (12).

Mixture code	Slump (mm)	Unit weight (kg/m <sup>3</sup> )
CC	230	2200
SFRC1	220	2243
SFRC2	205	2308
SFRC3	200	2398
SFRC4	210	2333
SFRC5	195	2305
SFRC6	125	2367
SFRC7	200	2313
SFRC8	150	2367
SFRC9	145	2353

Table 3: Slump and Unit Weight of Concrete Mixture

### 3.2 Experimental methodology

The concrete specimens were mixed, placed into the molds, then vibrated by a table vibrator to release air bubbles and make sure the concrete take its cubical and prismatic shape. Once this was done the top surface of the specimen was leveled and finished. The concrete samples were then demolded and transferred to a curing tank, where they were cured for 28 days. The concrete specimens were cured and then tested. A digital compression-testing machine

(Figure 2) was used to bring each cube to its failure (3). The failure loads were noted and the compressive strength was calculated through the derived formula (12):

Compressive strength (MPa) = Failure load / cross sectional area



Figure 4: Testing of Compressive Strength Test Specimen

Prismatic specimens (Beams) were used for the flexural strength test. The cured specimens were tested under two point loads over an effective span. The flexural-testing machine (Figure 3) applied load up to failure and the corresponding deflection was noted. The flexural strength was then calculated through the derived formula (12):

Flexural strength (MPa) =  $(P \times L) / (b \times d^2)$

P=Failure load, L=Effective span (center-to-center), b=Width of specimen, d=Depth of specimen



Figure 5: Testing of Flexural Strength Test Specimen

The split tensile strength test was performed on the second half of the cured cubical specimens. The specimens were placed under a tensile-testing machine (Figure 4) and were loaded until splitting occurred. The loads were noted and the splitting tensile strength was calculated through the derived formula (12):

$$\text{Split Tensile strength (MPa)} = \text{Failure Load} / \text{cross sectional area}$$



Figure 6: Testing for Split Tensile Strength Test Specimen

An ultrasonic pulse velocity test (Figure 5) was conducted for all the cubic specimens after the 28-day curing time. The test was performed by transmitting an ultrasonic pulse through the specimen to check for any concrete cavities, cracks and defects. This will reveal any voids, honeycombing or discontinuities steel fiber might have caused. The digital receiver display will indicate the time ultrasonic pulse took, to travel between the specimens. This is then converted to velocity according to the diameter of the specimen (12). A final comparison is then made for the ultrasonic pulse velocity of the controlling concrete and the specimens tested.



Figure 7: Testing for Ultrasonic Pulse Velocity Test

### 3.3 Results

The tests were conducted after the 28-day curing time and listed in Table 4. The table illustrates the results of all specimens examined at a reported value of the average of six specimens. Graphs are also available to help better visualize the significant effect the different steel fiber used had when added to the concrete mix.

Mixture code	$l/d$ ratio	$V_f$ (%)	$f_c^a$ (MPa)	Relative $f_c$ (%)	$f_{st}^a$ (MPa)	Relative $f_{st}$ (%)	$f_t^a$ (MPa)	Relative $f_t$ (%)	UPV (m/s)	Relative UPV (%)
CC	—	—	49.1	100	4.06	100	5.94	100	4523	100
SFRC1	45	0.5	50.8	104	4.5	111	6.14	103	4466	99
SFRC2	45	1.0	53.7	109	4.69	116	6.32	106	4435	98
SFRC3	45	1.5	57.7	117	5.69	140	7.75	130	4336	96
SFRC4	65	0.5	53.5	109	4.51	111	6.24	105	4488	99
SFRC5	65	1.0	58.3	119	4.77	117	8.08	136	4356	96
SFRC6	65	1.5	56.4	115	6.26	154	9.33	157	4348	96
SFRC7	80	0.5	56.0	114	4.58	113	6.42	108	4320	96
SFRC8	80	1.0	58.3	119	5.18	128	9.74	164	4188	93
SFRC9	80	1.5	52.1	106	5.9	145	10.76	181	4112	91

Table 4: Mechanical Properties of Concrete Mixtures

The result for the compressive strengths ( $f_c$ ) computed for control concrete (CC) was 49.1 MPa. For the specimens with aspect ratio of 45 (including SFRC 1-3), the average compressive strength ranged from 50.8-57.7 MPa, indicating that the SFRC specimen with a  $V_f$ (%) of 1.5% showed the highest result. The average compressive strength for specimens with aspect ratios of 65 (including SFRC 4-6) ranged from 53.5- 58.3 MPa. At this aspect ratio the  $V_f$ (%) conducting the highest average compressive strength is 1.0%. Finally, the specimens with aspect ratios of 80 (including SFRC 7-9) present comparative results for the average compressive strength, ranging from 52.1-58.3 MPa. The highest result for compressive strength with an aspect ratio of 80 was achieved by the SFRC specimen with  $V_f$ (%) of 1.0%.

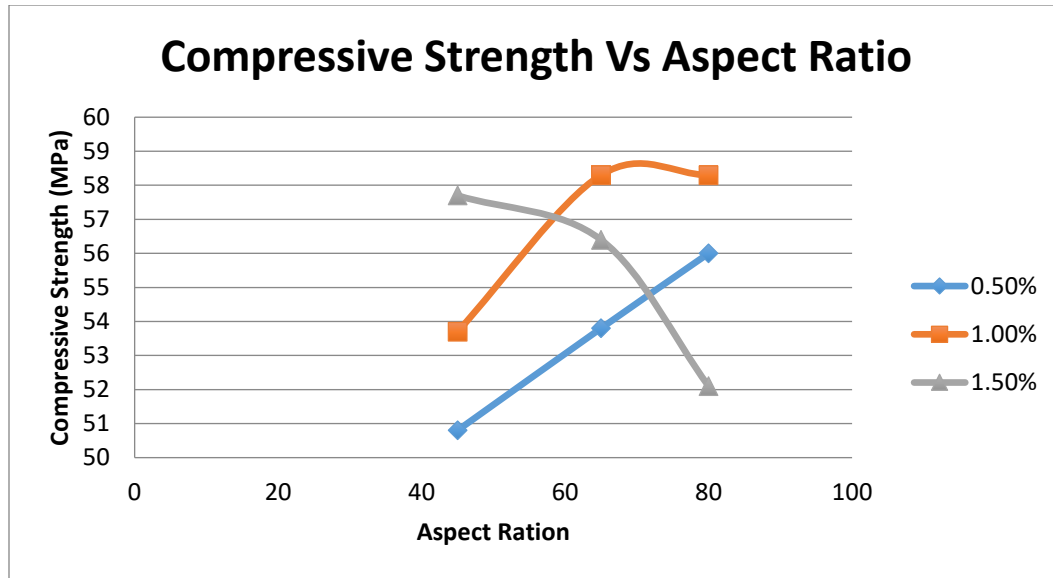


Figure 8: Compressive Strength Test Analysis

Split tensile strength ( $f_{st}$ ) for control concrete was computed as 4.06 MPa. The specimens with aspect ratio of 45 (including SFRC 1-3) obtained an average split tensile strength ranging from 4.5-5.69 MPa. The highest result was achieved by using a  $V_f(\%)$  of 1.5%. For specimens with aspect ratio of 65 (including SFRC 4-6), the average split tensile strength range obtained was 4.51-6.26 MPa. The  $V_f(\%)$  resulting in highest split tensile strength was achieved using 1.5% specimen. As for the specimens with aspect ratio of 80 (including SFRC 7-9), they produced a split tensile strength ranging 4.58-5.9 MPa. Indicating that the highest split tensile strength was achieved using SFRC specimen with  $V_f(\%)$  of 1.5%.

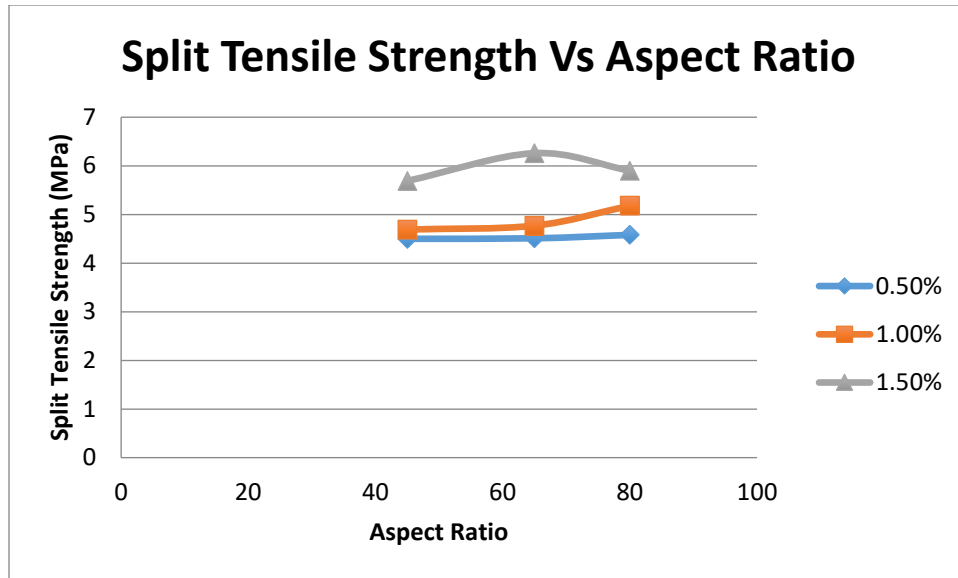


Figure 9: Split Tensile Strength Analysis

Flexural strength ( $f_f$ ) computed for control concrete was noted at 5.94 MPa. Specimens with aspect ratio of 45 (including SFRC 1-3) achieved an average flexural strength ranging from 6.14-7.75 MPa. The SFRC specimen responsible for the highest result had a  $V_f(\%)$  of 1.5%. For specimens with aspect ratio of 65 (including 4-6) their flexural strength results noted a range from 6.24-8.08 MPa. The  $V_f(\%)$  responsible for the highest flexural strength was 1.5%. Lastly, specimens with aspect ratio of 80 (including 7-9), their flexural results ranged from 6.42-10.76 MPa. Similarly, the results indicate that the highest flexural strength was also conceived by the specimen with  $V_f(\%)$  of 1.5%.

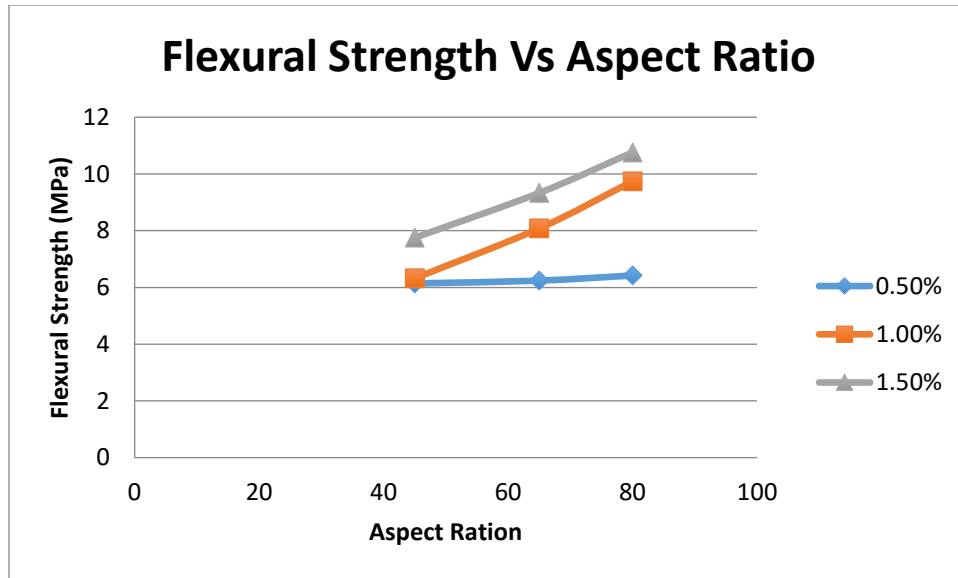


Figure 10: Flexural Strength Test Analysis

Ultrasonic pulse velocity (UPV) test was only performed on the cubical specimens and the noted test result for control concrete was 4523 m/s. Specimens with an aspect ratio of 45 (including 1-3) achieved a range 4336-4466 m/s, with the highest value conceived by the specimen with  $V_f(\%)$  of 0.5% and the lowest by 1.5%. Results for specimens with aspect ratio of 65 (including SFRC 4-6) ranged from 4348-4488 m/s and had the same effect of  $V_f(\%)$  as those of aspect ratio 45, leading with a maximum ultrasonic pulse velocity at 0.5%  $V_f(\%)$  and a minimum at 1.5%. As for the final results computed, specimens with an aspect ratio of 80 (including 7-9) had a ultrasonic pulse velocity range of 4112-4320 m/s with the same distribution of  $V_f(\%)$  producing the highest result at 0.5% and lowest at 1.5%, respectively.



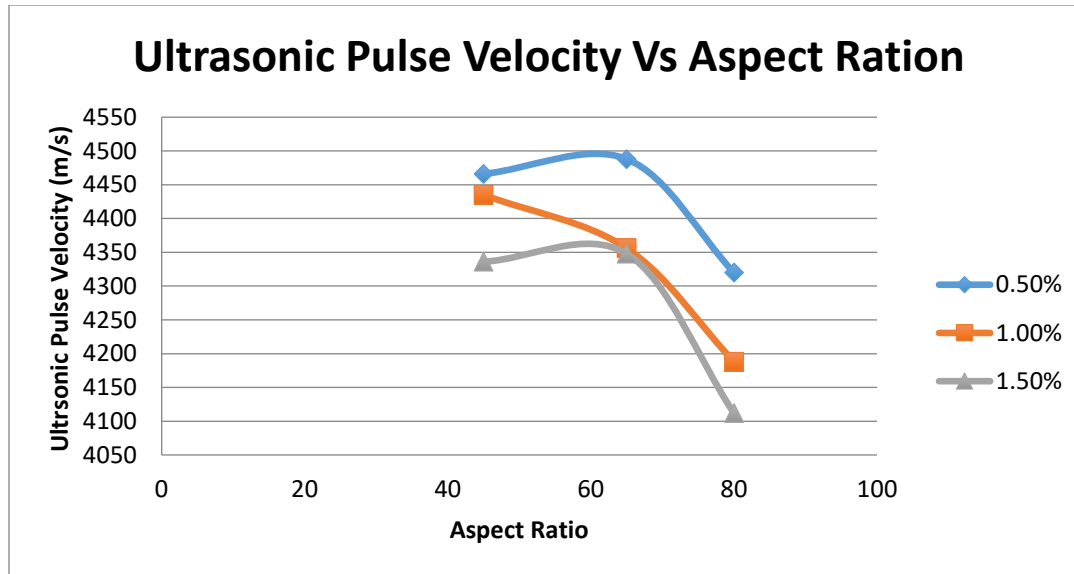


Figure 11: Ultrasonic Pulse Velocity Test Analysis

### 3.4 Comparison

Experimental research has proven that the SFRC specimens under going tension, compression and flexural tests showed more toughness and ductility behavior than that of plain concrete.

Compressive strength for the SFRC specimens with aspect ratio of 45 showed linear increase as the  $V_f(\%)$  increased. The increase in compressive strength was 19% when compared to the controlling concrete. Specimens with an aspect ratio of 65 showed unsystematic increases in strength, noting that SFRC with 1.0%  $V_f$  governed and produced the highest result. The compressive strength computed for this specimen showed an increase by 18.7% in compression to the control mix. The final test for specimens with aspect ratio 80 (including SFRC 7-9) showed the same unsystematic increase in compressive strength as that of specimens with aspect ratio 60. The highest result produced by these specimens was also at the same dosage of  $V_f$  1.0%. This indicates that a 1.0%  $V_f$  dosage at an aspect ratio of either 65 or 80 will provide the ultimate compressive strength. On the contrary, this is not a significant increase that suggests replacing rebar reinforcement, as conventional rebar will surely give healthier results.

On the other hand, tensile strength showed more prosperous results. For the first tested batch with aspect ratio of 45 (SFRC 1-3) a gradual increase was noted, and a significant increase of 40.2% was produced when comparing the highest result achieved with the control concrete specimen. This significant increase was observed at a dosage of 1.5%  $V_f$ . The second batch showed the highest results in comparison, an increase by 54.2% at a  $V_f$  of 1.5%. This substantial increase proves that SFRC is effective in resisting tensile strength.

Flexural strength tests had the highest results noted in all the experiments conducted. SFRC specimen with aspect ratio 45, showed a linear increase in strength as the  $V_f(\%)$  increased. A 30% increase was observed at 1.5%  $V_f$ . The second batch showed better results; at an aspect ratio of 65 and 1.5%  $V_f$ , the increase was 57.1% in comparison to the controlling mix. However, the final specimens tested showed the best results, at an aspect ratio of 80 and 1.5%  $V_f$  the flexural strength increased by 81.2%. This is significant evidence that steel fiber is highly effective and an excellent mechanism to resist flexural strength. In fact, further studies have shown that an increase in both aspect ratio and  $V_f(\%)$  could increase the flexural strength resistance by up to 150%.

Ultrasonic pulse velocity tests were not as successful as the strength test conducted. The results indicated a gradual decrease range of 1-9% in all specimens. As the  $V_f(\%)$ , aspect ratio and unit weight of concrete increased the ultrasonic pulse velocity decreased. In conventional concrete, there exists a relationship between unit weight and ultrasonic pulse velocity. The decreases in unit weight of concrete the higher the ultrasonic pulse velocity. Therefore, adding SFRC will surely increase the unit weight of the mix and cause higher porosity due to compacting difficulties, which evidently will decrease the ultrasonic pulse velocity.

## **4. Structural Integrity**

Steel fibers have been shown to increase the structural integrity of construction. In many applications the structural integrity of a structure depends on the steel fiber reinforcement. Test results in this report confirm the ability of steel fiber reinforcement to increase strength, resisting greater compressive, tensile and flexural loads in concrete. Applications of its use as substitute reinforcement have been witnessed in real life scenarios. An example of this can be seen in Toyota container stacking yard in India, where a reoccurring problem of slab cracking occurred due to the movement and stacking of heavy stock (4). The solution was to replace the existing floor  $17200m^2$  with a SFRC jointless floor. The new floor prevented heat cracking and resulted in higher resistance against impact and dynamic loads. The floor was monitored for 3 years after installation and showed great results indicating a prosperous life cycle. Other examples of SFRC constructions have observed to live a healthy life cycle with minor maintenance.

Research has shown how that SFRC structures hold together under loads, including the structures own weight, resisting breakage or bending. It has been proven to aid against collapsing structures constructed in seismic areas. It has also been noted that it performs its designed function efficiently for as long as the designed life of the structure (2). Therefore, concrete structures constructed with SFRC are considered having efficient structural integrity.

## **5. Structural Uses/Construction**

SFRC can generally be used in modern structural and non-structural applications. New advancements in steel fiber research allows for a broader opportunity for different uses. Steel fiber technology as an admixture, has proven its reliability and is found highly useful when considered as a reinforcement. SFRC can be found in hydraulic structures including stilling basins, dams, and sluiceways as new or replacement slabs. Its characteristics resist cavitation damage and can also be used to repair cracks through the use of steel fiber reinforced polymer sheets. Airport, aprons, highway paving and overlay are another place where SFRC is used. These applications require thinner than normal slab hence, the use of steel fibers to enhance their toughness and functionality. SFRC can be widely found in industrial floors, this is due to its resistances to high impact and thermal shock. SFRC used in bridge decks has shown high efficiency. However, it is only used as an overlay or topping to prevent concrete cracking from vibrations produced by passing cars and trucks. The primary structural support is conventional reinforced concrete. Shotcrete tunnel linings is another place where SFRC is frequently found. When excavation inside a tunnel takes place, the surrounding rock mass needs support to prevent collapsing. SFRC has been proven to be the optimum solution for stabilizing the deformation of the tunnels ground lining. Shotcrete covering also uses steel fibers as reinforcement in certain applications. It is used in highway and railway cuts to stabilize the rocks on the sides. Another similar application that uses shotcrete covering for the same reason is embankments. SFRC can also be found in modern thin architectural structures like foam domes. Future uses for SFRC will be developed for seismic resistant structures constructed in high seismic areas.

Further applications that use SFRC are precast panels, repairs and re-habitation of marine structures, highway construction and repair, railroad ties, machine bases and frames, thin sheets, shingles, roof tiles, pipes, prefabricated shapes, panels, curtain walls, precast elements, vaults, safes, impact resisting structures etc. The list of applications that use SFRC is extensive indicating its excellent properties and evident benefits.

## **6. Advancement**

The higher the demand for SFRC use as reinforcement, the more pertinacious scientists are to develop this technology to its furthest capability. The new advancements include using SFRC with other applications of reinforcement to enhance its strength and reinforcing capabilities. A leading company in fiber reinforcement technology (FiberMesh Co.) engineered a blend of steel and micro fibers for reinforcement of concrete. This blend proved to provide optimum combination of plastic shrinkage and long-term reinforcement within the concrete. The result of this blend increased crack resistance, ductility, and energy absorption. The blend also improved impact resistance, fatigue endurance, and shear strength of concrete. Further applications are currently under investigation and there are plenty of opportunities for further advancement.

## **7. Advantages/Disadvantages**

SFRC, like all materials contain advantages and disadvantage. However, its advantages tip the scale. These include faster installation in construction than conventional steel-rebar reinforcement. There's no need for intensified labor work, as steel fibers can be added to the concrete in the mixing phase (13, 15). SFRC does not require minimum cover. This can also be viewed as a disadvantage when the SFRC is exposed to rainfall. Rainfall damaging slabs allows aggregates and steel fibers to become exposed, giving it poor aesthetics. Steel fiber reinforcement can be made into thin sheets or irregular shapes making it useful in complex applications (15). It can be used to reduce section thickness throughout the concrete. SFRC can also be used for maintenance purposes (Steel Fiber Reinforced Polymer sheets). Moreover, the steel fibers can be manufactured from recycled steel making it more sustainable. SFRC contains high modulus of elasticity, making it effective for long-term reinforcement, even in hardened concrete. Ideal design and use of aspect ratio can makes it ideal for early age performance, like counter acting cracking in freshly casted concrete (15). The mechanical characteristics of SFRC are by far its main advantages as proven in earlier tests. Its increase in tensile strength has shown many uses in daily applications. The ability to retain greater toughness in conventional concrete

mixes is another useful benefit. SFRC capability of resisting higher flexural strength has made it considerably a better alternative than conventional concrete. SFRC also possesses enough plasticity to undergo large deformation once the peak load has been reached (7, 13, 15).

On the contrary, SFRC has a few disadvantages that must be considered before incorporating it into a design. Steel fibers are relatively expensive. Although market competition has lowered its cost, it is still relatively high (13). SFRC contains minor defects when used in onsite construction. The steel fibers tend to clump or ball when an unreliable distribution technique is used. The steel fibers will not float close to the surface or may not be properly oriented if not dispersed well. As for the final outcome efficiency, the SFRC has been noticed to reduce workability (7). It also cannot withstand high compressive strength making it useless in compressive strength reinforced structures. Although SFRC has a few disadvantages, its advantages have made it worth of using in construction.

## **8. Theoretical and Methodological Contribution**

Distribution determines the materials load bearing capacity. However, there is no definite way of telling whether the steel fibers have been uniformly distributed along the concrete. This has been one of the main elements of risk construction companies avoid using SFRC. Nevertheless, there are new developing software's that evaluate the fiber matrix by taking samples from finished concrete components and examining their steel fiber distribution (16, 17). Developers will take a specimen from the cured concrete and analyze it through an X-ray at the lab. The software's results reveal the finest micrometer sized structures within the material and generates a high-resolution 3D data set for the concrete sample. The software is based on probability calculations depending on the sample taken and does have limitations in terms of accuracy, but scientists are still working on developing this method and currently have reached prototypes which can analyze samples as big as beer crates which produce more accurate analysis for bigger scale developments (16, 17).

## **9. Conclusion and Recommendation**

The conducted tests exhibited the functionality of using steel fibers as reinforcement. When applied as a compressive strength resistance, their contributions were minimal, and in a corresponding research rebar reinforcement was proven to be a superior alternative. However, this was not the case for tensile and flexural strength. The steel fibers had a significant impact and were shown to increase both aspects of resistance. They increased tensile resistance by 54% and flexural resistance by 81%. Due to these test results, it can be conclude that steel fiber is a reliable source of reinforcement for both tensile and flexural strength. Unit weight must also be ominously considered; this factor alone can have a dramatic effect on the design of the concrete mix.

Steel fibers can be used in numerous applications, due to its beneficial characteristics. It is manufactured in different shapes, aspect ratio and mechanical properties. It can be used solely as reinforcement or embedded with steel rebar to enhance the necessary application required. Overall, I highly recommend the development and use of steel fibers in advance concrete construction as it facilitates in the design aesthetics, construction and finalized development phase.

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