FLEXURAL STRENGTH BEHAVIOUR OF STEEL FIBER REINFORCED CONCRETE BEAM

By

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Dedication

To my amazing family

and

To my respected teachers.

Approval/Declaration by the Supervisor(s)

This is to certify that **Md. Iftakhar Ahmed** has carried out this research work under my supervision, and that he has fulfilled the relevant Academic Ordinance of the Chittagong University of Engineering and Technology, so that he is qualified to submit the following Thesis in the application for the degree of MASTER of ENGINEERING in CIVIL ENGINEERING. Furthermore, the Thesis complies with the PLAGIARISM and ACADEMIC INTEGRITY regulation of CUET.

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Abstract

Cement concrete is the most utilized construction material globally. Its extensive use can be attributed to its ability to take any shape. Cement-based concrete is prone to microcracking, exhibits minimal tensile strength, possesses low ductility, and exhibits limited crack resistance. These factors combine to cause brittle concrete failure. Modern civil engineering projects must meet certain durability and structural requirements. Every structure has a specific function and conventional cement concrete must be adapted to these requirements. According to research, adding different types of fibers to concrete in a certain amount can improve the mechanical properties, serviceability and longevity of structures. Currently, a significant characteristic of steel fiber concrete (SFRC) is its exceptional resistance to crack initiation and propagation. The main goal of the research is to predict how an SFRC beam will behave in terms of flexural strength. Steel fibers mixed into concrete were used to cast 180 prisms (100 x 100 x 500 mm) and 360 cubes (100 x 100 x 100 mm). This study modifies the fiber content of 1%, 1.5% and 2% with different aspect ratios (50, 60 and 70) in concrete to investigate the influence of steel fibers on the strength of M30 grade concrete. To examine the impact of steel fibers, tests for compressive strength, flexural strength, and splitting tensile strength were conducted. The overall results indicate that mechanical strength development can be effectively achieved with steel fiber concrete with 1 mm diameter, aspect ratio of 70 and 1.5% steel fibers.

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M‡elYv Bw½Z K‡i †h wbw`ó cwigv‡Y Kswµ‡U wewfb ai‡Yi dvBevi h³ K‡i KvVv‡gvi hwšK kw³, ¯wqZ Ges cwi‡levnvM¨Zv evov‡bv †h‡Z cv‡i| B¯úvZ dvBevi wiBb‡dvmW Kswµ U (GmGdAvi wm) Gi e¨wZµgx dvUj cwZ†ivax Ges dvUj cmvi cwZ‡ivax ¶gZv eZgv‡b Zvi gj ˆewkó¨¸wji g‡a¨ GKwU wnmv‡e ¯xKZ| GB M‡elYvi gj D‡Ïk¨ nj GmGdAvi wm weg Gi bgbxq kw³i cevfvl †`lqv| GB M‡elYwU †Z Kswµ‡U Dcw¯Z 1% 1.5% Ges 2% dvBevi‡K mvgÄm¨ K‡i Gg 30 †M‡Wi Rb¨ Kswµ‡Ui kw³‡Z B¯úvZ dvBev‡ii cfve cix¶v K‡i| B¯úvZ dvBev‡ii cfve cix¶v Kivi Rb¨ ms‡KvPKvix kw³ cix¶v, bgbxq kw³ cix¶v Ges wef³ cmvi Yxq kw³ cix¶v cwiPwjZ n‡qwQj| mvgwMK ch‡e¶Y †`Lvq †h GmGdAvi wm Kswµ U 1.5% B¯úvZ dvBevi Ges 70 w`K Abcvi kw³ weKv‡ki `wó‡KvY †_‡K KvhKi e‡j cgwYZ nq|

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Nomenclature

AASHTO	:	American Association Of State Highway And Transportation Officials
ACI	:	American Concrete Institute
AR	:	Aspect Ratio
ASTM	:	American Society For Testing And Materials
BS	:	British Standard
COD	:	Chemical Oxygen Demand
FRC	:	Fiber Reinforced Concrete
IS	:	Indian Standard
OPC	:	Ordinary Portland Cement
SF	:	Steel Fiber
SFRC	:	Steel Fiber Reinforced Concrete
SIFCON	:	Slurry Infiltrated Fiber Concrete
SIMCON	:	Slurry Infiltrate Mat Concrete

CHAPTER 1: INTRODUCTION

1.1 BACKGROUND

The versatility of concrete in taking any form of shapes renders it the most prevalent construction material globally. Furthermore, it substitutes antiquated construction materials like stone and brick.

Concrete can be more durable and the strength can be enhanced adding additional specialized ingredients and making necessary adjustments to its components, which include water, aggregates and cementitious materials. Concrete is consequently suited for an extensive variety of uses. Nevertheless, concrete has certain disadvantages including: (i) Low tensile strength (ii) Low post cracking capacity (iii) Brittleness and low ductility (iv) Limited fatigue life (v) Incapable of accommodating large deformations (vi) Low impact strength etc. [1] [2]

Concrete naturally contains internal microcracks, and these microcracks propagate throughout the material, causing brittle fractures. This leads to low tensile strength [3]. Previous researches have attempted to increase the tensile characteristics of concrete components by utilizing restraining techniques in addition to typical steel reinforcing bars. These two techniques are capable to enhance the tensile strength of concrete members.

Plain concrete can develop structural cracks or microcracks even before to loading, especially when drying shrinkage or other variables that alter volume are present. These early cracks are typically only a few micrometers wide, but they can be larger in the other two dimensions. As microcracks propagate and open under load, further cracks occur at the locations of smaller faults because of stress concentration. For a variety of reasons, such as directional changes when the more resilient matrix grains are avoided, can cause the structural cracks to spread slowly or in tiny jumps. The main reason for inelastic deformation in concrete is the formation of these microcracks.

The addition of tiny, evenly distributed fibers to concrete has long been known to improve both static and dynamic characteristics, while also serving as a crack stopper. Concrete with fibers that are discontinuously distributed and evenly spaced at predetermined intervals is known as fiber-reinforced concrete. [3]. Discrete fibers do not include long wires or rods, woven fabrics, or continuous nets. Fibers are tiny pieces of material that are used for reinforcement and have certain properties. They can have a flat or round shape. Aspect ratio is a useful parameter often used to describe fibers and is defined by the length to diameter ratio. The typical range for aspect ratios is between 30 and 150.

In the cement matrix of composite fiber-reinforced concrete, the fibers are arranged either neatly or randomly. Naturally, the effective transfer of stress between the fibers and the matrix determines its properties. This transfer is mainly influenced by the aggregate's size and shape, the type, geometry, content, distribution, and orientation of the fibers, the concrete mix, compaction methods, and mixture design. [4]

Not every fiber type can be used profitably and efficiently in cement and concrete, despite tests being done on all kinds of fibers. Every type of fiber has unique characteristics and restrictions. Fibers such as carbon, asbestos, steel, nylon, polypropylene, coconut, and glass could all be utilized.

Steel fibers typically have a circular shape and a diameter of 0 to 75 mm and are one of the most used types of fibers. Although research has shown that the fibers only rust on the surface, steel fibers tend to rust and lose some of their strength. The flexural, impact and fatigue strength of concrete are significantly increased through the use of steel fibers. It is used extensively in many different structures, particularly bridge decks, airfield pavements and road pavements. Moreover, thin plates and shells were built using steel fibers.. [5]

The interfacial connection between the matrix and the fibers also influences the efficiency with which stress is transferred from the matrix to the fiber. A strong bond is necessary to increase the composite's tensile strength. A larger contact area, improved friction qualities and grip, as well as treatment of the steel fibers with acetone-sodium hydroxide can improve interfacial bonding.

The benefits of enhanced static and dynamic tensile strength, improved fatigue strength, and energy-absorbing properties have led to a growing utilization of fiber reinforced concrete [6] [7]. Isotropic properties not found in traditional reinforced concrete are the result of the even distribution of fibers throughout the concrete. Coverings of airfields, road pavements, industrial floors, bridge decks, duct linings, explosion-proof structures, fireproof linings, etc. have all been tested with fiber-reinforced concrete. Fiber concrete can also be used to make prefabricated parts such as pipes, boats, beams, steps, wall panels and manhole covers. The trade name "Wirand Concrete" refers to fiber-reinforced concrete. Wirand concrete is widely used in the USA following a great deal of research. Furthermore, the feasibility of utilizing fiber-reinforced concrete in the production of prefabricated "U"-shaped formwork forms for the purpose of casting small beams and lintels is being investigated.

It's not a new idea to use fibers as reinforcement. In the past, straw, horsehair, etc. were used as fibers in mud bricks, mortar, etc. When the concept of composite materials first surfaced in the 1950s, fiber-reinforced concrete quickly gained popularity. Glass, synthetic fibers and steel (SFRC) were used in concrete as early as the 1960s, and research into new fiber-reinforced concrete is still ongoing today. [8]

Researchers have carried out a great deal of experimental research on the properties of SFRC, and their findings have been published in papers. [1], [3]. The addition of steel fibers to concrete is thought to enhance its mechanical and engineering qualities. The main factors include the different aspect ratios, concrete qualities and fiber content. In addition, strength parameters such as compressive, tensile, splitting cylinder, bending and shear strength as well as deformation properties including ductility, deflection, and crack initiation and propagation are also considered. When comparing SFRC samples with plain concrete, the percentage increase in compressive and tensile strength is reported to be between 5% and 20%. This is because the fiber content and aspect ratio of the SFRC samples vary between 1% and 8% and 50% and 100%, respectively. In addition, the flexural strength and elastic modulus are reported to have increased by 20% to 65% and 5% to 25%, respectively.

Although the technology has gained widespread acceptance and the benefits of SFRC are widely recognized, the actual practical use of this material in these regions is still in its infancy [8]. The study's primary objective is to perform a thorough investigation on the cost-effective use of fibers in concrete to enhance its mechanical and engineering properties for structural applications.

1.2 PROBLEM STATEMENT

Changes in cementitious material, aggregate, water and other ingredients, as well as adding certain ingredients, alter concrete's strength and durability. There are therefore many possible uses for concrete. Conversely, concrete has some disadvantages, including low impact strength, low tensile strength, low post-cracking capability, brittleness and low ductility, short fatigue life, and the inability to handle large deformations.

Microscopic cracks in the bond between mortar and aggregate are the cause of concrete's inherent vulnerability. The mixture's susceptibility can be decreased by incorporating steel fibers. The toughness or resistance to crack propagation of the concrete mix can be improved by adding different kinds of fibers, akin to those found in conventional composite materials. These fibers play a role in stress transfer at the internal microcracks. For this reason, this type of concrete is also called steel fiber concrete (SFRC).

Nevertheless, adding fibers to brittle cement and concrete materials can be a simple, inexpensive and practical way to improve their inherent weaknesses of low tensile and impact strength. It also improves many of the structural properties of the basic materials, including resistance to thermal shock, spalling, fatigue effects, and fracture toughness.

1.3 OBJECTIVES OF THE RESEARCH

The fundamental objective of this research is to predict how the steel fiber-reinforced concrete beam would perform in terms of flexural strength. The specific objectives are:

1. To evaluate the steel fiber reinforced concrete used in the SFRC beam for compressive, flexural, and tensile strength.
2. To estimate the optimum fiber content for fiber-reinforced concrete beam.

1.4 SCOPE OF THE RESEARCH

The study considers many properties of steel fiber concrete, such as concrete types, fiber content, aspect ratios, fiber size and strength qualities, depending on what is required to achieve the project objectives. The study report will provide the necessary information regarding the optimum value of fiber content, strength, properties from economic point of view. When producing concrete test specimens, different proportions of steel fibers (1%, 1.5% and 2%) and aspect ratios (50, 60 and 70) are used.

Following properties of concrete have been evaluated to fulfill the objectives of this study:

- Workability
- Compressive strength
- Split Tensile strength
- Flexural strength

The variables listed below were the only ones included in this study:

- The period for curing was 7, 14, and 28 days respectively.
- Compressive strength specimens were 100 mm cubes in size.
- Spit tensile strength specimens were 100 mm cubes in size.
- A beam measuring 500 mm x 100 mm x 100 mm served as the specimen size for flexural strength.
- Aspect ratio of fiber was 50,60 and 70.
- Fiber percentage 1%, 1.5% and 2% by weight
- Types of steel fiber: straight steel fiber.
- Grade of Concrete: 30 MPa
- Method of concrete mix: ACI 211.1-91 [9]

CHAPTER 2: LITERATURE REVIEW

2.1 INTRODUCTION

From prehistoric times fibers have typically been utilized to strengthen fragile materials. The plaster was reinforced with horsehair, and the sun-reinforced bricks were reinforced with straw. Asbestos fibers have most recently been utilized to strengthen Portland cement. Concrete fibers have been used since the early 1960s, although the concept of employing individual fibers to strengthen a brittle matrix is not unique. Initially, just linear steel fibers were utilized. Although flexural strength increased, the most significant increases were observed in ductility and fracture toughness. The fiber contributions were examined using the mixing law since it was acknowledged that the fiber concrete needed to be designed to attain a specific ductility or energy absorptionIn the late 1950s and early 1960s, Romualdi, Batson, and Mandel conducted research that paved the way for the progress of SFRC. Although reinforced concrete techniques have been patented since the turn of the century, it was not until the late 1950s that significant progress occurred in the field of SFRC. Since then, steel fibers have been somewhat optimized for concrete installation. Improved mixing, placement, consolidation and finishing methods were also used in SFRC.

2.2 HISTORY OF STEEL FIBRE REINFORCED CONCRETE

2.2.1 Steel Fibre Reinforced Concrete's History

It is not uncommon for fibrous elements to be accessible to improve the structural integrity of a brittle matrix. Throughout history, fibers have been utilized as reinforcement. Fiber-reinforced composite materials were first used in ancient Egypt around 2,500 years ago [10]. Examples of these materials include straw-reinforced mud bricks and horsehair-reinforced mortar.

Asbestos fibers were first used on a large scale in concrete construction industry at the beginning of the twentieth century. Porter's 1910 publication [11] documents the earliest known experiments with steel fibers. It was discovered that adding short steel pieces considerably improved the concrete's tensile and compressive strengths.

Up until the early 1950s, composite material technology made very little progress. At that time, it was discovered that asbestos fibers, which were becoming a highly widespread building material, carried health dangers. This led to extensive research into alternate building methods, including reinforced concrete with steel fibers.

2.2.2 Historical Development

The field of fiber strengthening mechanics saw its first notable advancement thanks to Romualdi in the early 1960s [12]. Romualdi proposed a fracture mechanics method to evaluate the breaking strength of masonry reinforced with closely spaced steel strands. Developing a framework to explain the constitutive behavior of a fiber-reinforced composite was an innovative approach [12].

The flexural strength of steel fiber reinforced concrete was estimated using a constitutive relationship [13]. It was stated in the context of this publication that there was a mostly linear interfacial binding tension between the fibrous components of the brittle matrix. It was possible to obtain a decent correspondence between the suggested relationship and the earlier experimental findings. Regretfully, the aforementioned framework was limited to composites that exhibited tension hardening behavior—that is, the capacity to withstand further stress after the initial fracture formed [14]. In response to this problem, Lim developed an analytical model that combines simulation of tension hardening and softening to explain the tensile characteristics of SFRC. [14].

SFRC has been developed in response to the construction industry's increasing demand for alternative construction methods. SFRC finds application in both commercial and industrial settings. These include floor slabs supported on piles or the ground, walkways, and tunnel linings. As a result, significant progress has recently been made in SFRC constitutive modeling. [15] [16] [17], and [18].

2.3 FIBER REINFORCED CONCRETE

Despite the material's natural brittleness, concrete often has a tensile strength ten times greater than its compressive strength. Steel bars are therefore used to reinforce the concrete; Despite their varied applications, these bars all add to the material's overall strength. But, building materials are constantly changing, and numerous methods and advances have been developed to meet the need for concrete that is stronger, more crack-resistant and lighter. The addition of fibers to reinforce concrete was an important response to these requirements. The structural properties of concrete are significantly improved by these fibers; they also make the material lighter, more crack-resistant and all-round stronger.

Concrete's flexural toughness, not flexural strength, is where fiber reinforcing contributes most effectively. When flexural strength is taken into account, it is not a replacement for traditional reinforcing; nevertheless, it does help to lessen bleeding in newly mixed concrete and increases the impermeability of mature concrete.

SFRC is created by addig fine and coarse aggregates with hydraulic cements containing discrete, discontinuous steel fibers (ACI 544.4R) [19]. It is possible to give the fiber irregular shapes, crimps and depressions to improve mechanical bonding. Geometry of SF, mixing method, collective shape, content and size, are the factors that influence how well the steel fibers are distributed. It is thought that steel fibers are rather short. Their length can be different, and their spreading diameter varies between 0.15 mm and 1 mm. Their length to diameter ratio, or aspect ratio, is between 20 and 100. The steel fibers are distributed evenly and randomly when added to a concrete mix. In terms of ductility, tensile and flexural strength, toughness, and other attributes, SFRC has demonstrated a sizable improvement over regular concrete. There is no difference in creep or shrinkage parameters when steel fibers are added. A particularly effective application of SFRC is to control the progression of cracks to visible cracks. It also increases abrasion and impact resistance. SFRC finds numerous applications in various areas such as fireproof linings, explosion-proof structures, tunnel linings, roadways and prefabricated concrete modules. However, agglomeration or clumping occurs when these fibers are used in large proportions of concrete and in dimensions where the aspect ratio is greater than 100. The report will take a closer look at and explain the attributes and features that SFRC offers.

Steel fiber incorporation into concrete was first suggested by Porter in 1910. (Naaman, 1985) [20]. According to Romauldi et al. (1963) [12], the United States conducted its first scientific study of fiber-reinforced concrete (FRC).To increase the workability and stability of SFRC systems, chemical additives called superplasticizers can also be added to the concrete mix.

Three varieties of SFRC can be identified by criteria such as application, fiber volume %, and fiber effectiveness. To illustrate, SFRC is split into the following groups according on the percentage of fiber volume: 1- A very low volume percentage of SF, which has long been used as a pavement reinforcing ingredient and to control plastic shrinkage. 2- A moderate volume fraction of SFs—between 1% and 2% of the concrete volume—can improve impact strength, flexural strength, modulus of rupture (MoR), and other desired mechanical qualities. 3- A large volume fraction of SF (more than 2% of concrete volume) is used for applications such as impact and explosion protection structures. This form of concrete includes SIFCON and SIMCON.

SFs are typically utilized as secondary reinforcement on prestressing strands in conjunction with normal steel bars. Due to processing and financial constraints, these composite materials are only suitable for specialized applications; however, they have mechanical properties and can be used in the high volume fraction class of SF without the need for additional continuous reinforcement.

2.4 TYPES OF STEEL FIBRE

Due to the extensive research conducted in this area, steel SF are available. Five general categories are defined by ASTM A820 [21] as sources of SF material. These categories 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)

Type 1 tensile strength is the highest, ranging from 145,000 to 445,000 psi. This is due to the content and form of the fiber. Of all Type 1 steel fiber forms, end hook steel fiber is the most practical. The curved ends improve the fiber-matrix connection properties, which is due to improved anchoring. With excellent toughness and high tensile strength, this particular grade is inexpensive and easily available. Tensile strength of the other types of SF is significantly lower, averaging just 50,000 psi. They are still extensively used in spite of their low tensile strength. In addition to the specific way the required concrete mix is applied, this can also be attributed to the five main factors that, in addition to tensile strength, in many cases decide which steel fiber is chosen. The five parameters are dosage, type, fiber length, aspect ratio or effective diameter and deformation. All of this is determined by the specific design mix and its structural application.

2.5 DEVELOPMENT: PRESENT WORKS

The past thirty years have seen a lot of interest in steel fiber reinforced concrete because of its advantageous qualities. The field has seen an increase in research because of its clear usefulness and successful outcomes. Construction businesses have generally adopted the idea of reinforcing concrete with such fibers. This is a result of both the never-ending need for better building materials and the ongoing creation of intricate architectural designs. The shells built in Valencia's European Oceanographic Park serve as an illustration of this use (**Figure 2.1**). Steel fiber concrete was required during the thin shell construction covered building's construction to keep the thin layer of concrete from chipping or breaking.

Figure 2.1: European Oceanographic Park in Valencia [22]

Due to its increased ductility, steel fiber reinforcement has also been used in columns because of recent advancements. When applied to structures intended to operate in seismic zones, this is quite successful. Even though steel fiber reinforcing has increased the toughness of concrete, strengthening its resistance to seismic shocks and improving column ductility and stiffness, reinforced columns sometimes lose the concrete covering the rebar during an earthquake. Additional study has proved the advantages of using steel fibers in various structural elements, such as roofs and beams. However, when used in slab on grad, verifiable improvements have been shown. Steel fibers have been employed in place of traditional rebar in abrasive conditions, such as industrial slabs or even bridges, with remarkable results.

2.6 COMPOSITIONS/ PROPERTIES OF STEEL FIBRES

Depending on the final concrete render required and their physical attributes, steel fibers come in a range of sizes and shapes. Various geometric shapes, such as straight, hooked, paddling, distorted, crimped, and irregular, are frequently utilized. **Figure 2.2** depicts a few of these steel fibers. To guarantee even distribution and prevent SF clumps or balls, steel fibers are often bonded together during manufacturing and separated after mixing. To distribute the mechanical action of steel fibers evenly throughout the entire concrete, uniform distribution is essential. There isn't a single methodology that guarantees the optimal distribution of steel fibers, despite the integration of numerous ways. One of the various methods involves utilizing an on-site conveyer belt to gradually introduce steel fibers into the concrete mixture, enabling the fibers to disperse uniformly throughout the mixture. Another method is to uniformly blow steel fibers into the mixture using a machine. However, because precast concrete can be completed in a controlled environment, it is unquestionably preferable to both when done at an off-site ready-mix facility. Engineers select the correct steel fiber based on the specifications of the mix design and the intended use..

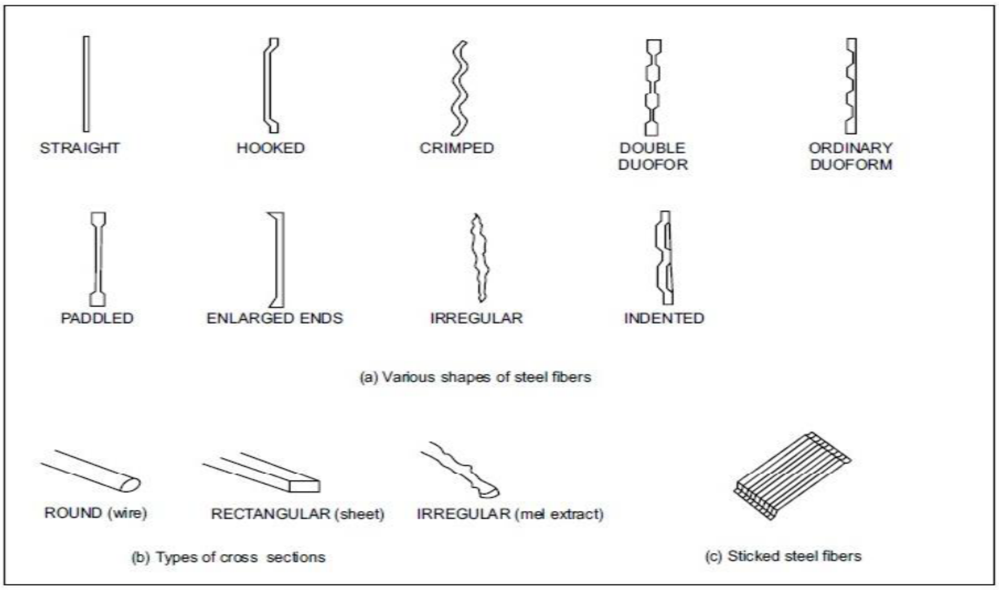

Figure 2.2: Various forms of SF [22]

The mass of fibers per unit volume of concrete, or kg/m3 or lb/cy, is used to calculate the fiber dosage—the amount of SF added to the concrete mix. (10).To make the steel fiber volume easier to see and consistent across different measuring techniques, some engineers will instead give it as a % of the volume of the concrete. An illustration of the equivalency between these metrics can be seen in **Table 2-1**. The dosages of steel fiber typically fall between 12 to 42 kg/m^3 (20 and 70 lb/cy). Any dosage below that range is typically utilized to replace light-gauge wire mesh, while dosages over that range are very uncommon.

Table 2-1: Rate of Equivalent Steel Fiber Dosage. [22]

Pounds per cubic yard	Kilograms per cubic meter	Volume (%)
132	78	1
70	42	0.53
66	39	0.50
60	36	0.45
50	30	0.38
40	24	0.30
35	21	0.26
33	20	0.25
30	18	0.23
25	15	0.19
20	12	0.15

The American Concrete Institute (ACI) outlines steel fiber specifications. According to the ACI manual on slabs-on-ground design, fiber quantity for ground slabs in ground support should always be at least 20 kg/m3 (33 lb/cy). In circumstances when steel fiber is required to provide increased joint spacing, the ACI suggests a minimum of 36 kg/m3 (60 lb/cy). The designer can adjust these criteria to meet concrete mix needs due to the limitless forms and material composition of SF. The engineer must also consider the sort of steel fiber necessary for a blend, which varies depending on how it is manufactured. While we've already covered the many types of steel fibers and their related tensile strengths, each has unique properties that serve a variety of purposes. The key problem from the perspective of designers is that certain features might not be present in all the described forms of steel fiber, which has caused manufacturers to struggle in their quest to determine which type works best. Selecting the best available type of fiber becomes increasingly challenging for a designer as a result.

Another aspect that must be considered is the length of the steel fibers. While there are differing views regarding the optimal length, it is generally accepted that the length of the steel fiber is a significant factor. This is another issue that is typically left up to the designer and is reliant on how the concrete mix will be used structurally. Longer fibers are recommended to stop cured concrete cracks from getting wider and to increase the material's flexural toughness, according to lab testing. Using steel fibers that are shorter, have a higher fiber count, and are spaced closer together is the best option if the surface of the concrete exhibits visible cracking. Effective diameter and aspect ratio measurements are performed on steel cross-sections, both circular and non-circular.

Analyzing the aspect ratio will help you grasp the bonding potentials better. In situations where the aspect ratio of steel fibers is larger than two, balling is more common.

2.7 COMPACTION AND FIBRE ORIENTATION

Theories of random fiber orientation in space and uniform fiber distribution have been developed to explain the behavior of fiber-reinforced concrete. While fibers align during compaction due to external vibration, Edgington and Hannant's (1972) research [23] indicates that this isn't always the case. Shape of the specimen, size of the aggregate, and direction of vibration can all affect the phenomena.

When it comes to the manufacturing of components, the anisotropic qualities can be effectively utilized by aligning the fibers in the most advantageous direction with respect to the stress field during the compaction process. Cook and Uher's (1974) [24] experimental study revealed that some fiber orientation had been induced by vibration. The effect of vibration was confirmed by Herring et al. (1974) [25] using data from cube testing. By eliminating the randomness of the fiber distribution, Potrzebowski (1983) [26] claims that vibration of fiber concrete creates anisotropy in terms of strength properties.

Poker vibrators, tables, and surface vibration can all be used to compact steel fiber concrete. On the other hand, the direction and kind of vibration can significantly affect the orientation of the fibers. It was discovered that the direction of applied stress was directly correlated with the fiber orientations in steel fiber reinforced concrete. This fiber alignment can be intentionally or inadvertently produced by a variety of techniques, such as surface vibration, which causes the fibers to align as seen in **Figure 2.3** at a right angle to the direction of vibration.

Bergstrom (1975) [27] employed vibration and magnetic fields to help guide fiber orientation in the intended direction. The classification of fiber configurations is displayed in **Figure 2.4**. Fiber alignment in specimen 1D is shown as being in a single plane parallel to one another, whereas specimen 2D shows fiber alignment in a random and mating pattern. The 3D specimen, which is one dimensional, provides guidance on the optimal alignment of steel fibers in the matrix, ideally in three dimensions and with random orientation.

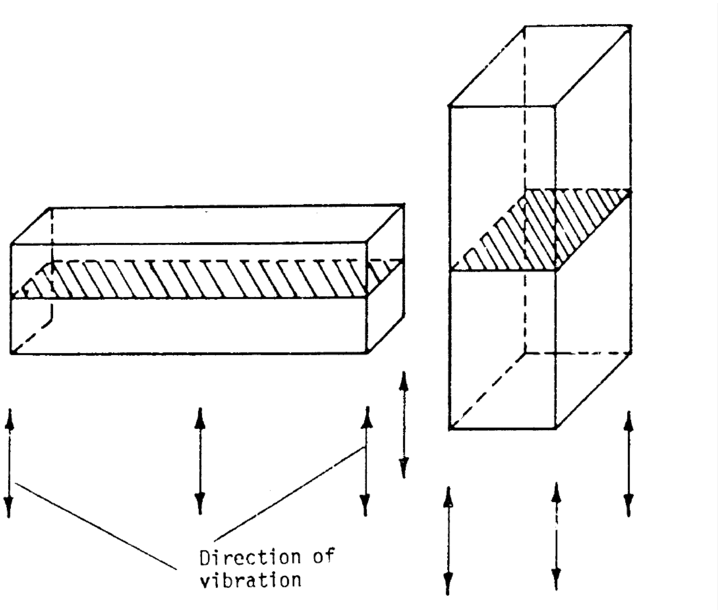

Figure 2.3: Vibration's Effect on Fibre Alignment. Arrangement [28]

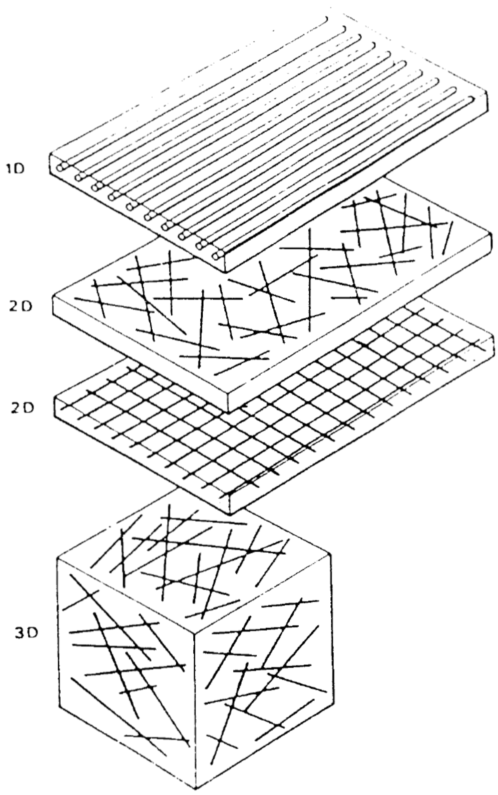

Figure 2.4: Classification of Fibre Arrangement [28]

2.8 CRACKING

Steel fiber reinforced concrete's ability to stop cracks is one of its main advantages. **Figure 2.5** depicts the steel fibers' ability to stop cracking. Axial shortening from shrinkage combined with the horizontal stresses that form between the slab, the pile head, and the ground are important causes of cracking. A pile-supported slab's serviceability performance may be negatively impacted by significant cracking. The floor's levelness may be impacted by severe cracking. Because of driving over the crack, severe cracking may cause damage to the concrete. Consequently, spalling may occur at cracks (Fricks, 1992) [29]. Aesthetic concerns are raised by the degree of cracking, but they are primarily restricted to scenarios in which pile-supported slabs are utilized for commercial projects, like big shopping centres (Fricks, 1992) [29]. But industrial flooring is also prone to cracking. This is because it is challenging to ascertain how the fibers impact crack widths.

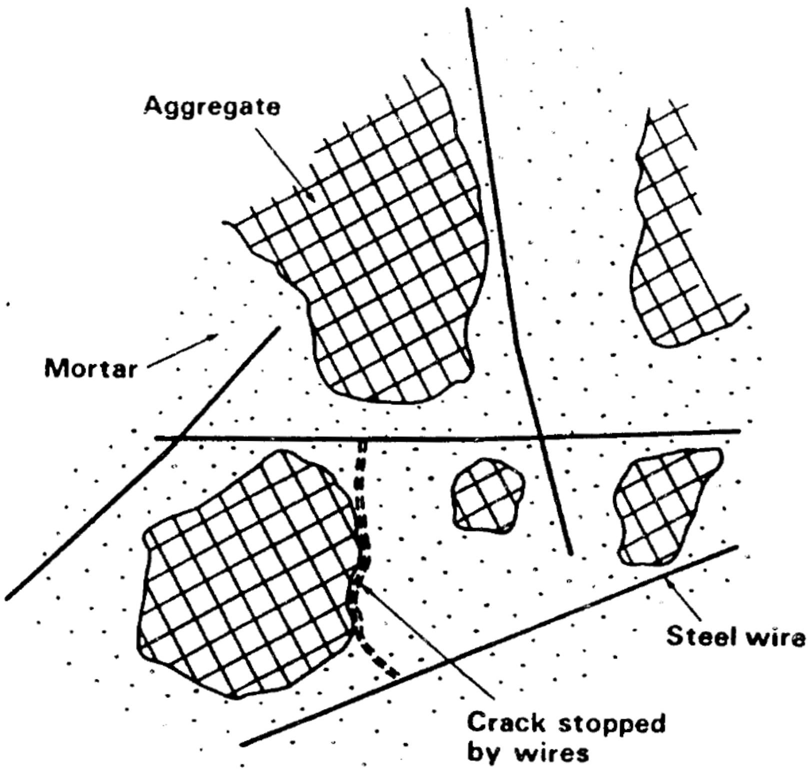

Figure 2.5: Crack noticeable of SF in concrete [28]

2.9 FIBER STRENGTH

It is widely acknowledged that composites with stronger steel fibers typically have stronger composites. This isn't the case with steel fiber reinforced materials, though, as fiber withdrawal will take place first. The strength of this type of composite is determined by the strength of the bond between the steel fiber and the matrix (Hannath, 1978) [23] .

2.10 EFFECT OF STEEL FIBER REINFORCEMENT

When it comes to preventing cracks, one of the best building materials is steel fiber reinforcement concrete (SFRC). Water, hydraulic cements, fine and coarse aggregate, and discontinuous tiny fibers (steel fiber) make up this composite material. Steel fiber's main purpose is to alter micro and macrocracking by stopping fractures at their start and preventing them from spreading. Fiber composites have higher extensibility and tensile strength because of their capacity to stop fractures, especially under flexural loading. Additionally, the fibers can maintain the matrix's cohesiveness even after significant breaking.

Concrete is brittle; steel fiber changes it into composite materials that are ductile, strong, resilient, and long-lasting. The fiber composite's energy absorption capabilities and resilience to shock or impact loadings would both be significantly enhanced by this change from brittle to ductile transition. Above all, using steel fibers can save a lot of money. This is mostly because they can replace conventional reinforcement entirely or in part, but they can also improve longevity and serviceability.

2.11 MECHANICAL PROPERTIES OF SFRC

2.11.1 Compressive Strength

Steel fibers have a major impact on the tensile response of steel fiber reinforced concrete; however, they have less of an impact on the compressive response. Studies have shown that the concrete matrix's elastic modulus is slightly decreased when steel fibers are added (Neves et al, 2005) [30]. The addition of the tiny voids produced by the steel fibers explains this fact. When there is a compressive failure, this may be advantageous (Barros & Figueiras, 1999 [16] ; Labib, 2017 [31]). In **Figure 2.6,** these two impacts are visually demonstrated:

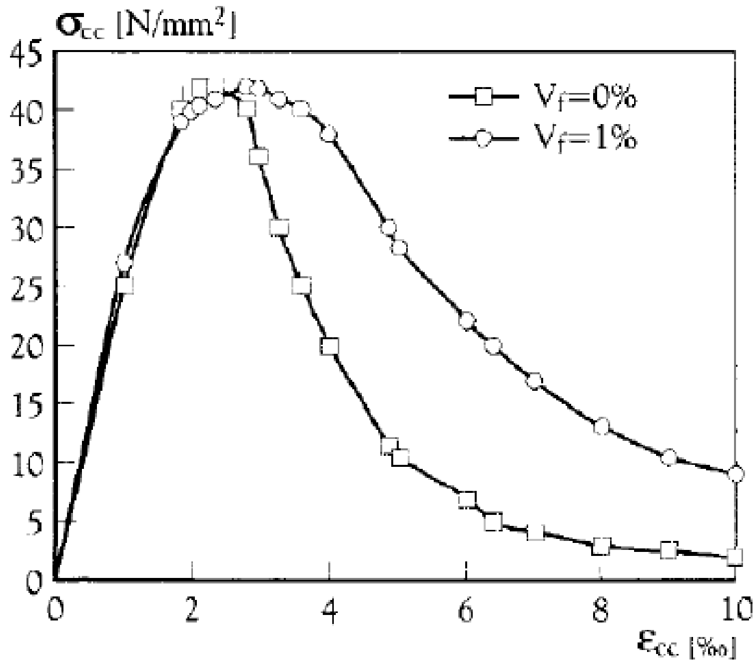

Figure 2.6: An illustration of a standard SFRC and normal concrete specimen under compression.

2.11.2 Flexural Strength

The intrusion of steel fibers has a considerable effect on the extensible response of plain concrete, in contrast to compression or tension. The fracture toughness behavior of various fiber materials is often inferred by three and four point bending tests (refer to Figure 2-7). A trustworthy results is produced by these experiments, enabling the comparison of various fiber kinds. The toughness behavior of steel fibers can be inferred from the region beneath the load deflection response, as shown in **Figure 2.7**. **Figure 2.8** displays the typical stress distributions of a segment that has been bent. According to the results of the fracture toughness test, the quantity of fibers added significantly affects how the concrete behaves after cracking. Stress greater than its ultimate tensile strength cannot be sustained by the fragile concrete matrix.

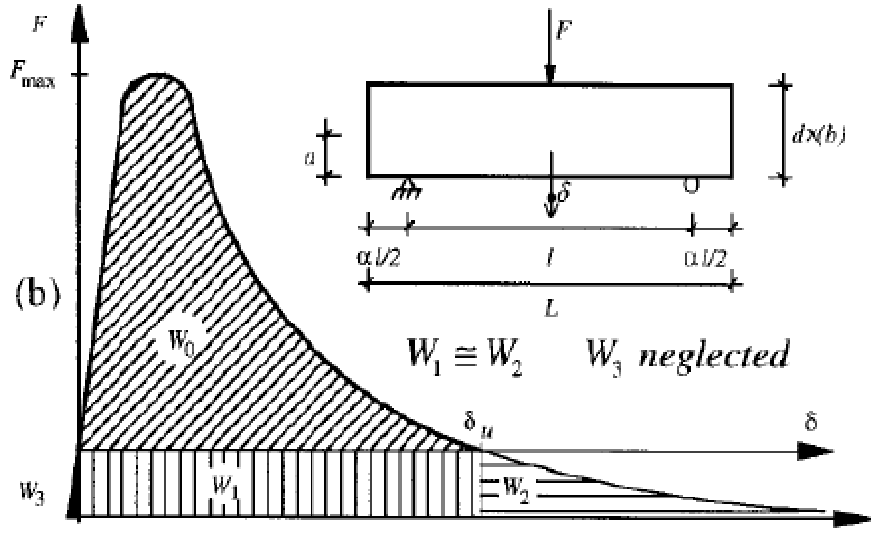

Figure 2.7: SFRC's Normal Response in Flexure (Barros and Figueiras, 1999) [16].

Phase 2 shows how, at the first microcrack initiation, the beam's neutral axis moves upward. Steel fibers and aggregate interlock are currently used to bridge the micro crack. Phase 3: As the fracture moves through the portion, it gets bigger. At the concrete matrix-fibre contact, considerable forces accumulate as the steel fibers bridge the fissure.

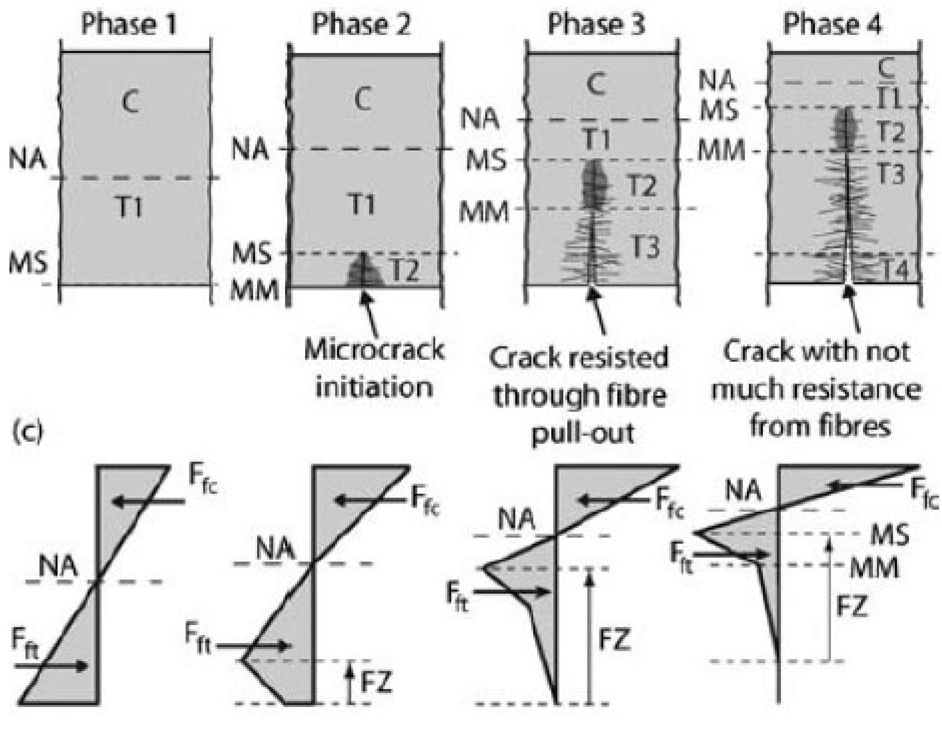

Figure 2.8: Stress distribution in a concrete section subjected to four-point bending (Tlemat, Pilakoutas, & Neocleous, 2006 [32])

2.11.3 Split Tensile Strength

The response of unreinforced concrete to tension is brittle by nature. The purpose of adding steel fiber to normal concrete is to increase its tensile strength. The improvement in tensile capacity is demonstrated clearly in **Figure 2.9.** Different post-cracking capacities are evident between normal concrete and SFRC. A sharp decline that occurs after cracking is the hallmark of the post-cracking response in plain concrete. The emergence of a single crack indicates failure. When concrete is reinforced with steel fibers, it exhibits behavior that is significantly better than unreinforced concrete in terms of "crack arrest" and "crack-bridging" mechanisms.

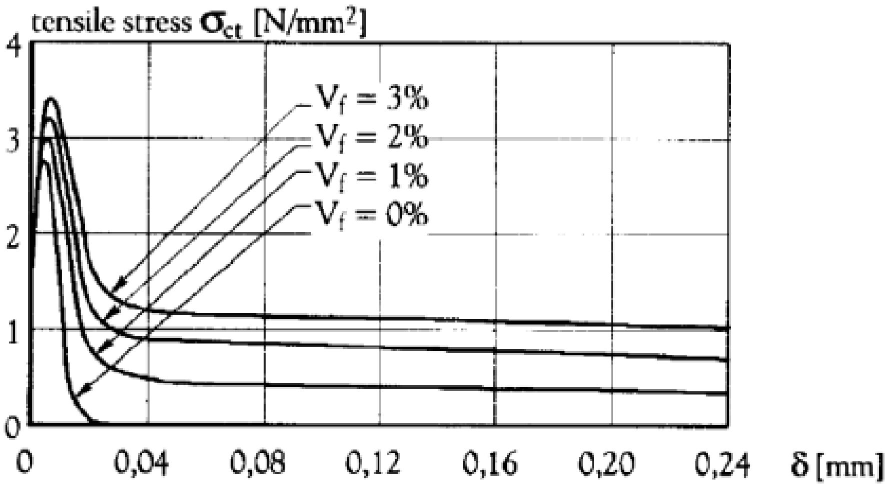

Figure 2.9: Diagram illustrating the tensile response for various steel fiber dosages (as cited in Kooiman, 2000 [33]).

A steel fiber reinforced composite's tensile response can be classified into three distinct phases: the elastic, the micro-cracking, and the fiber pull out and failure phase.

2.12 COMPONENT OF STEEL FIBER REINFORCED CONCRETE

Following are the components of SRFC:

- Cement
- Fine aggregate
- Coarse aggregate
- Concrete
- Water
- Steel fibers

2.12.1 Cement

A mixture of calcium, silicon, aluminum, iron, and oxygen compounds make up the phases of Portland cement, the most common cementitious ingredient in concrete today. An essential component of construction projects, cement is a widely recognized building material.

2.13 Hydration of Cement

Cement hydration is the process by which cement particles react with water through a combination of chemical and physical reactions. Fresh concrete's setting and hardening properties are directly caused by hydration. The characteristics of hardened concrete are also impacted by the hydration process. For this reason, knowledge of the chemistry of hydration is necessary in order to understand the properties and behavior of cement and concrete.

2.14 AGGREGATES

The majority of these are inert, naturally occurring granular materials like crushed stone, gravel, and sand. However, the use of synthetic and recycled materials is becoming more prevalent in technology.

2.15 WATER

One of the main ingredients of concrete is water. It hydrates—a chemical reaction with cement—to give concrete the desired qualities. A mixture's water to cementitious material ratio (w/cm) is calculated by measuring the amount of water known as mixing water, which also effects the slump of the concrete. The strength and longevity of concrete are mostly governed by its weight per cubic centimeter. Concrete mixing water is available in a variety of formats and volumes. It can be measured at the batch plant and incorporated into the mixer. It can also be applied on-site or during delivery after batching, provided that the aggregates are free of ice and moisture. The water used for mixing excludes water that has been absorbed by aggregates.

The type and quantity of mixing water used in concrete have a significant impact on the hardened concrete's strength and longevity. When building concrete, you can use practically any naturally occurring drinkable water with no odor or taste as the mixing fluid. Even if some water is unsafe to drink, it can be utilized to make concrete. In general, pipe-borne drinking water supplies are safe to use while building concrete.

Salt or brackish water can lead to a numerous problems for concrete, including efflorescence, dampness, rust, and damage to embedded reinforcement and paint systems. For durable concrete work, it is therefore advised not to use such water, and its use is typically avoided.

2.17 REINFORCEMENT AND FIBERS

For several reasons, including managing tensile stresses from direct tension, bending shear, etc., reinforcement is crucial in structural concrete.), confinement, ductility, crack bridging, and many more. Concrete can be reinforced with a variety of materials, such as bars, mesh, strands, and occasionally fiber.

2.18 PROPERTIES OF CONCRETE

Concrete's properties have an important impact on its strength. Concrete has the following advantageous qualities.

2.18.1 Strength

Although other qualities like durability and impermeability may actually be more significant in many real-world scenarios, strength is generally regarded as the most valuable attribute of concrete. Strength, however, typically provides a general indication of the concrete's quality. Concrete can have the following strengths: Concrete cube shear strength capacity, concrete beam flexural strength, concrete cube tensile strength, and compressive strength.

2.18.2 Elastic properties

Because they affect how concrete structures deform under load, concrete's elastic properties are significant not only for reinforced concrete design but also for other applications. Under identical distortion conditions, it is critical to evaluate concrete relative stresses. At all loading stages, concrete exhibits a noticeable permanent setting even at low loads, and its deformation is not directly proportional to stress. As a result, it is not completely elastic for all loading scenarios. The richness of the mixture and the degree of stress both affect how elastic concrete is. They also change depending on how old the concrete is.

2.18.3 Fatigue of the concrete

In the event of flexure, plain concrete fatigues. The ability of a concrete to withstand flexures is indicated by an endurance limit, which is determined by counting the repetitions of stresses. In the design of concrete pavements, the maximum permissible flexural working stress is restricted to 55% of the concrete's modulus of rupture strength.

2.18.4 Durability of concrete

Concrete must withstand the conditions for which it was designed without breaking down over time. Concrete of this type is reputedly long-lasting. The concrete itself may be the source of the lack of durability, or it may result from external factors outside of its immediate surroundings. Abrasion, severe temperature fluctuations, weathering, electrolysis, and attacks by natural or artificial liquids and gases are examples of external causes that can be mechanical, chemical, or physical. The alkali-aggregate reaction—a reaction between the silica components of the aggregates and the alkalies in the cement—and the permeability of the concrete, as well as variations in volume brought on by the different thermal properties of the aggregates and cement paste, are the internal causes.

Permeability is the final factor that determines how vulnerable concrete is to outside forces; therefore, concrete needs to be relatively impervious in order to be durable.

2.19 RELATED RESEARCH WORK ON CONCRETE.

Researchers and scientists are now more interested in assessing the performance of this type of concrete due to the advantageous use of steel fiber in it. Some of investigation reports in this regard are presented below:

Muhammad Nasir Amin et. al (2022) [34] discovered that the high cost, steel fiber deterioration, and even dispersion of fibers in the mixture are the main obstacles to the use of SFRC. Applying a zinc, brass, or copper coating to steel fiber—particularly that derived from used tires—may be a preferable solution to get around these problems [1].

Concrete that has steel fiber added to it becomes stronger and more resilient than untreated concrete, according to research by Rishav M. et al. (2023) [35]. Steel fiber reinforced concrete delivers enhanced durability against abrasion, fatigue, and impact in addition to having high flexural and fatigue strength. SFRC is a reasonably priced architectural option these days. Incorporating steel fibers into concrete increases its ductility.

According to Shashank Shubham et al. (2020) [36], steel fiber reinforced concrete has higher durability, impact and abrasion resistance, as well as high flexural and fatigue flexural strengths [10].

Patil Shwetal et. al (2014) [37] found that there was a significant increase in flexural strength from 29%to 119.69% at an AR of 70 and by raising the fiber proportion volume from 0% to 2%. [38].

A.M. Shende et. al (2012) [1] found that the prism flexural, split tensile, and compressive strengths produced by 3% fibers are higher than those from 0%, 1%, and 2% fibers. It was also discovered that when comparing aspect ratios of 50 to 60 and 67, all of the strength properties were found to be on the higher side.

S. A. Mahadik et. al (2014) [3] found that the flexural strength of concrete in beams having 0.25%, 0.50%, 0.75%, and 1% of steel fibers was greater than that of beams without steel fibers. This could be because the microcracks in the concrete mass are successfully held in place by the steel fibers. Moreover, it has been noted that the concrete's compressive strength is higher for cubes having steel fibers at 0.25%, 0.50%, 0.75%, and 1% than for cubes without steel fibers. This could be because the steel fibers in the concrete mass successfully contain the microcracks.

S. Gayathri et. Al (2018) [39] shown that among the six specimens tested, the specimens with fully welded mesh had a better performance with a grid configuration of 50.8 x 50.8 mm. Moreover, it is found that welded mesh can be used as an affordable alternative to conventional shear stirrups.

Ryabchikov et al. (2018) [40] studied the compressive strength, equivalent flexural ratio, and equivalent flexural strength of SFRC using Savex 1/50 steel fibers. While the dosage of 40 kg/m³ produced a 31% enhancement above their average values, the corresponding flexural strength and ratio of SFRC with dosages of 20, 25, 30, and 35 kg/m³ remained comparable. Because the derived stress values meet the code requirements, they are suitable for use in the design of SFRC elements in all circumstances [41]. Surprisingly, with the exception of S40, where the increase was a significant 30%, the compressive strength of steel-fiber-reinforced concrete was only marginally higher than that of ordinary concrete.

2.20 CONCLUDING REMARKS

The study emphasized the advantages and disadvantages of the beam to ascertain the flexural properties of SFRC, based on the research team's investigations, case studies, and survey of current structures. The following lists a few of the investigation reports related to this:

1. The main drawbacks to using SFRCs are their high cost, the steel fibers' tendency to corrode, and the uneven dispersion of the fibers in the mixture. But applying a zinc, brass, or copper coating to recycled steel fiber—particularly from used tires—might be a better way to address these issues.
2. When compared to untreated concrete, steel fiber is added to concrete to increase its strength and durability. Enhanced flexural strength, impact resistance, and resistance to abrasions.
3. At a constant AR of 70, flexural strength increases significantly from 29.2% to 119.69% when the percentage volume of fibers is increased from 0.5% to 2.5%.

Various destructive and non-destructive tests have been performed as required to assess the physical as well as mechanical aspects of concrete and its deterioration in aggressive environment. Also attempt has been made to find the optimum level of SRFC for improvement of flexural strength in concrete.

CHAPTER 3: MATERIALS AND METHODOLOGY

3.1 GENERAL

SFRC specimens were prepared using steel fiber, Sylhet sand, and 20 mm downgraded stone chips as coarse aggregate in order to investigate the impact of steel fiber on concrete. To ascertain the effects of steel fiber on concrete, this research program includes an examination of the literature and experimental analyses. In this chapter, the experimental program is briefly described, covering the various materials used, concrete mix details, the types of test specimens that are cast and cured, as well as the destructive and non-destructive test techniques. To appraise and compute the steel fiber-mixed concrete beam's performance.

3.2 MATERIALS

3.2.1 Binder

According to ASTM C150 [42] Type I specifications, Ordinary Portland cement (OPC) was employed in the investigation. These are its physical and chemical characteristics, listed in **Table 3-1** and **Table 3-2**, respectively.

Table 3-1: Physical properties of Portland cement used in this investigation

Characteristics	Results	ASTM C150 Specifications
Fineness:		
0.075 mm (#200 Sieve) passing (%)	94	>90
Blaine Specific surface (cm^2/gm)	3030	>2800
Normal Consistency (%)	26	22-30
Soundness (mm)	7	<10
Setting Time:		
Initial Setting Time (minutes)	155	>45
Final Setting Time (minutes)	225	<375
Specific Gravity	3.07	3.15
Compressive Strength:		
3-days (MPa)	15.3	>12.4
7-days (MPa)	23.8	>19.3
28-days (MPa)	31.1	>27.6

Table 3-2: Portland cement's chemical compositions used in this investigation

Oxide	Shorthand Notation	Common Name	Results (%)	Limiting value (%) (Neville, 2005; Gambhir, 2005)
CaO	C	lime	63.49	60-67
SiO_2	S	silica	21.01	17-25
Al_2O_3	A	alumina	5.80	3-8
Fe_2O_3	F	ferric oxide	3.60	0.5-6.0
MgO	M	magnesia	1.46	0.5-4.0
K_2O	K	alkalis	0.87	0.3-1.2 (as Na_2O)
Na_2O	N	alkalis		
SO_3	S	sulfur trioxide	2.56	2.0-3.5
CO_2	C	carbon dioxide	---	---
H_2O	H	water	0.07	---
Bogue's Potential Compound Composition:				
$3CaO.SiO_2$	C_3S	Tricalcium silicate	47.38	25-50
$2CaO.SiO_2$	C_2S	Dicalcium silicate	24.51	20-45
$3CaO.Al_2O_3$	C_3A	Tricalcium aluminate	9.28	5-12
$4CaO.Al_2O_3.Fe_2O_3$	C_4AF	Tetracalcium aluminoferrite	10.95	6-12

3.2.2 Coarse Aggregate

Basalt, granite, quartzite rock is generally used as raw materials for coarse aggregate in concrete construction. In this investigation, stone chips were collected from Ready Mix Concrete Company. In this study, coarse aggregate in the form of quartzite rock chips was utilized. The coarse aggregate's maximum nominal size was 20 mm. The sieve analysis and other properties of the coarse aggregate are presented in **Table 3-3** and **Table 3-4**, respectively.

Table 3-3: Analysis of coarse aggregate using a sieve

Sieve opening (mm)	Passing (%)
37.5	100.0
19	46.7
9.5	15.7
4.75	1.5

Table 3-4: Characteristics of the coarse aggregate

Properties	Result
Specific gravity :	2.75
Unit weight (kg/m^3) :	1560
Absorption capacity (%) :	0.70
Total moisture (%) :	0.28

3.2.3 Fine Aggregate

Concrete has been made with Sylhet sand as the fine aggregate. **Table 3-5** and **Table 3-6** provide the pertinent properties of fine aggregate as well as the outcome of the grain size analysis.

Table 3-5: Sieve analysis of fine aggregate

Sieve size (mm)	Cumulative %	
	Passing	Retained
4.75	100.0	0.0
2.36	96.0	4.0
1.18	78.5	21.5
0.60	53.5	46.5
0.30	12.0	88.0
0.15	2.0	98.0

Table 3-6: Properties of fine aggregate

Properties	Result
Fineness Modulus	2.58
Specific gravity	2.61
Unit weight	1495 kg/m^3
Absorption capacity	1.5%
Total moisture	0.9%
Chloride Content	0.004%
Sulfate Content	0.005%

3.2.4 Water

One of the strongest building materials is concrete, and one of the structural components of concrete that uses the most energy is cement. One of the most important aspects of mixing water quality is performance in both initial and final states. The quality of water has a considerable impact on concrete preparation. Water contaminants can reduce concrete strength and durability while also interfering with the cement's ability to set. Health concerns pertaining to the safe handling of such water also need to be considered. The quality records of test results provide information about the suitability of the water. Mixing of water with their constituents, including sulfate chloride and total alkalis. is restricted in some ways. Using regular tap water, the specimens were cast and pre-cured **Table 3-7** lists the relevant characteristics of the water that was used.

Table 3-7: Analysis of Mixing Water

Sl. No	Matter	Content (mg/liter)
1.	Total solids	**189.0**
2.	Dissolved solids	**181.0**
3.	Suspended solids	**10.0**
4.	pH value	**7.8**
5.	Chloride concentration	**8.5**
6.	Hardness (total)	**110.0**
7.	Hardness (temporary)	**10.0**
8.	Hardness (permanent)	**100.0**
9.	Dissolved oxygen	**7.9**
10.	Alkalinity	**80.0**
11.	COD	**0.03**
12.	Residual chlorine	**0.05**
13.	Organic ammonia	**-**
14.	Nitrite	**-**
15.	Nitrate	**-**
16.	CO_2	**-**
17.	Turbidity	**Clear**

3.2.5 Steel Fiber

Steel fiber is a low carbon, cold-drawn wire fiber manufactured in compliance with ASTM A820/A820M [21]. Steel fibers provide higher energy absorption and increases concrete ductibility. In a variety of applications, including flooring, tunneling, and housing, steel fibers can be utilized alone or in conjunction with more conventional reinforcements like rebar, wire mesh, or pre-stressing elements. Readily available steel fiber was collected from local market and then cut it into different length as per aspect ratio. The steel fiber utilized in this investigation is shown in **Figure 3.1**.

Figure 3.1: Steel fiber collected from local market

3.3 MIX DESIGN AND CASTING

3.3.1 Mix proportioning of SFRC

In this investigation, SF has been utilized. By weight of the total mix, steel fiber was added to the concrete. Three different percentages of steel fiber i.e., 1 %, 1.5% and 2% were used by weight. For comparison, a concrete mix of 100% OPC was included in this program. A particular mix ratio were used for making the test specimen. Specimens of ordinary Portland cement (OPC) concrete were created and subjected to an ordinary water environment. The concrete test specimens were made with varying percentages of steel fiber. The various test variables including different materials are listed below.

The strength of structural concrete generally varies from 20 to 40MPa in Bangladesh. So, concrete of 30 MPa was selected in this investigation. The design proportion of the concrete mixes are outlined in **Table 3-7**.

Table 3-7: Mix proportion of concrete ingredient

Mixture Constituent	Properties
Grade of Concrete	30 MPa
Cement (kg/m^3)	435
Water (kg/m^3)	218
Sand (kg/m^3)	545
Stone Chips (kg/m^3)	1150
Water Cement Ratio	0.45

Concrete for Test Specimens:

- Control
- SFRC (Steel fiber reinforced concrete)

Concrete Grade:

30 MPa

Steel fiber percentage used:

0%, 1%, 1.5% and 2%

Diameter of wire: 0.5 mm and 1 mm

Aspect Ratio: 50, 60 and 70

Specimen Size:

100x100x100 mm cube

100 x 100x 500 mm prism

Exposure period: 7, 14 and 28 Days.

The test specimens after casting were subjected to plain water curing for 7 days, 14 days and 28 days. The specimens underwent a series of destructive tests to determine their strength after a specific exposure period.

Destructive Tests:

(a) Concrete cube compressive strength

(b) Concrete cube splitting tensile strength

(c) Concrete beam flexural strength

After carrying out all the strength test, the test results are analyzed and presented for ease of analysis in graphical and tabular form. The test results are critically analyzed and rationally discussed in conjunction with their correlation with conventional principles in order to reach a useful conclusion. For each test case, the representative data was the mean of the three test specimens.

3.3.2 Preparing, Casting and Curing of Specimen

3.3.2.1 Preparation

The mix proportion was followed when thoroughly mixing the coarse aggregate, Portland cement, steel fiber, and fine aggregate. After one minute of dry mixing, water was progressively introduced. For an additional three minutes after adding the water, the mixer's contents were mixed. To create concrete specimens, the mixture was then poured.

3.3.2.2 Casting

Following thorough mixing, specimens were cast in two equal layers following compaction. A circular temping rod with a 16 mm diameter and length of 0:45 m was used to manually compact each layer with 25 blows. The specimens were cast for 24 hours before being demolded. There were 540 total specimens, of which 180 were prisms and 360 were cubes. The various stages of casting cube and prism specimens are depicted in **Figure 3.2.**

Figure 3.2: Casting of cube & prism specimen for different curing ages

3.3.2.3 Curing

The specimens were immediately demolded and soaked in a plain water environment for 7, 14, and 28 days to cure. Then the specimens were tested at different ages as per test program. **Figure 3.3** presents the curing process of specimens.

Figure 3.3: Curing of the specimen

3.3.3 Specifications of Test Specimen:

100 mm concrete cubes and a 100 mm x 100 mm x 500 mm beam were chosen in order to assess the performance of SFRC. A total number of 540 specimens were cast as per requirement of the test for various tests. After casting the specimens were placed in plain water environments. As required by the test program, three distinct percentages of steel fiber—1%, 1.5%, and 2%—were utilized to create different test specimens. For comparison, similar types of specimens without steel fiber were cured as control sample. A list of sample designation are given below in **Table 3-8**:

Table 3-8: List of Sample Designation

Sample Designation	First term represent steel fiber dia (mm), 2nd term "SFRC" represent Steel Fiber Reinforce Concrete, 3rd term "0.0" represent steel fiber % and last term "(0)" represent AR
0SFRC0.0(0)	Concrete without steel fiber
0.5SFRC1.0(50)	0.5 dia Fiber, SFRC, 1.0% fiber , AR= 50
0.5SFRC1.0(60)	0.5 dia Fiber, SFRC, 1.0% fiber , AR= 60
0.5SFRC1.0(70)	0.5 dia Fiber, SFRC, 1.0% fiber , AR= 70
0.5SFRC1.5(50)	0.5 dia Fiber, SFRC, 1.5% fiber , AR= 50
0.5SFRC1.5(60)	0.5 dia Fiber, SFRC, 1.5% fiber , AR= 60
0.5SFRC1.5(70)	0.5 dia Fiber, SFRC, 1.5% fiber , AR= 70
0.5SFRC2.0(50)	0.5 dia Fiber, SFRC, 2.0% fiber , AR= 50
0.5SFRC2.0(60)	0.5 dia Fiber, SFRC, 2.0% fiber , AR= 60
0.5SFRC2.0(70)	0.5 dia Fiber, SFRC, 2.0% fiber , AR= 70
0SFRC0.0(0)	Concrete without steel fiber
1SFRC1.0(50)	1.0 dia Fiber, SFRC, 1.0% fiber , AR= 50
1SFRC1.0(60)	1.0 dia Fiber, SFRC, 1.0% fiber , AR= 60
1SFRC1.0(70)	1.0 dia Fiber, SFRC, 1.0% fiber , AR= 70
1SFRC1.5(50)	1.0 dia Fiber, SFRC, 1.5% fiber , AR= 50
1SFRC1.5(60)	1.0 dia Fiber, SFRC, 1.5% fiber , AR= 60
1SFRC1.5(70)	1.0 dia Fiber, SFRC, 1.5% fiber , AR= 70
1SFRC2.0(50)	1.0 dia Fiber, SFRC, 2.0% fiber , AR= 50
1SFRC2.0(60)	1.0 dia Fiber, SFRC, 2.0% fiber , AR= 60
1SFRC2.0(70)	1.0 dia Fiber, SFRC, 2.0% fiber , AR= 70

A complete work plan for this investigation mentioning the variables studied with respect to materials used, curing state tests involved is shown with the help of a suitable flow diagram (Ref. **Figure 3.4**)

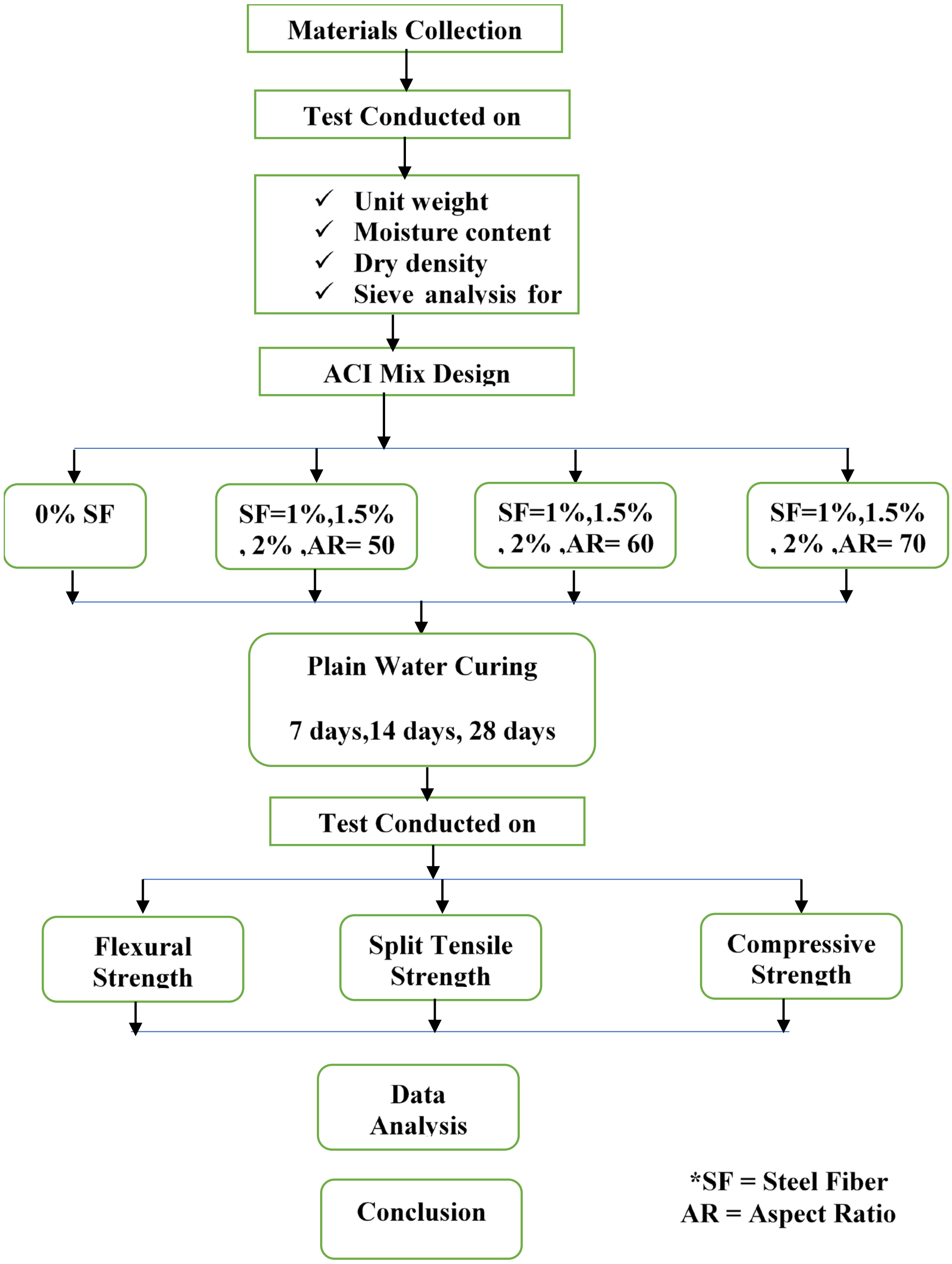

Figure 3.4: Flow diagram of the experimental program

3.3.4 Test Conducted

To evaluate and predict the strength progression of concrete specimens at different ages, the subsequent experiments were conducted.

a) Concrete cube compressive strength

b) Concrete cube splitting tensile strength

c) Concrete beam flexural strength

The above-mentioned tests are described below.

3.3.4.1 Compressive Strength

The most crucial factor in predicting how well concrete will work is its compressive strength. Utilizing a digital compression machine in accordance with BS 1881-116:1983 [43], the concrete cube compressive strength was assessed. Loads were applied with a uniform rate to other than casting faces. The dimensions were measured before applying loads. **Figure 3.8** displays the test configuration used to measure compressive strength. The machine recorded the maximum load withstand by the specimen up to failure. Then the concrete cube compressive strength was determined using the following expression:

Compressive strength, $\sigma = P/A$ .Where,

P = The specimen's maximum load at failure

A = The machine's plunger's mean surface area in contact

Figure 3.5: Test setup for determining concrete cube compressive strength.

3.3.4.2 Split Tensile strength

An additional crucial factor for predicting the tensile properties of concrete is cracking strength. It is also employed to assess concrete's shear resistance. The test yields more consistent results than other tests and is easy to administer. Compared to the modulus of rupture value, the determined strength is more accurate in representing the concrete cube tensile strength. After setting up the standard test configuration for this test, as shown in **Figure 3.6,** the concrete splitting tensile strength was estimated using the same compressive strength equipment. The specimen's ultimate load was noted, and the concrete splitting tensile strength was then estimated using the formula provided by IS 5816: 1999 [44].

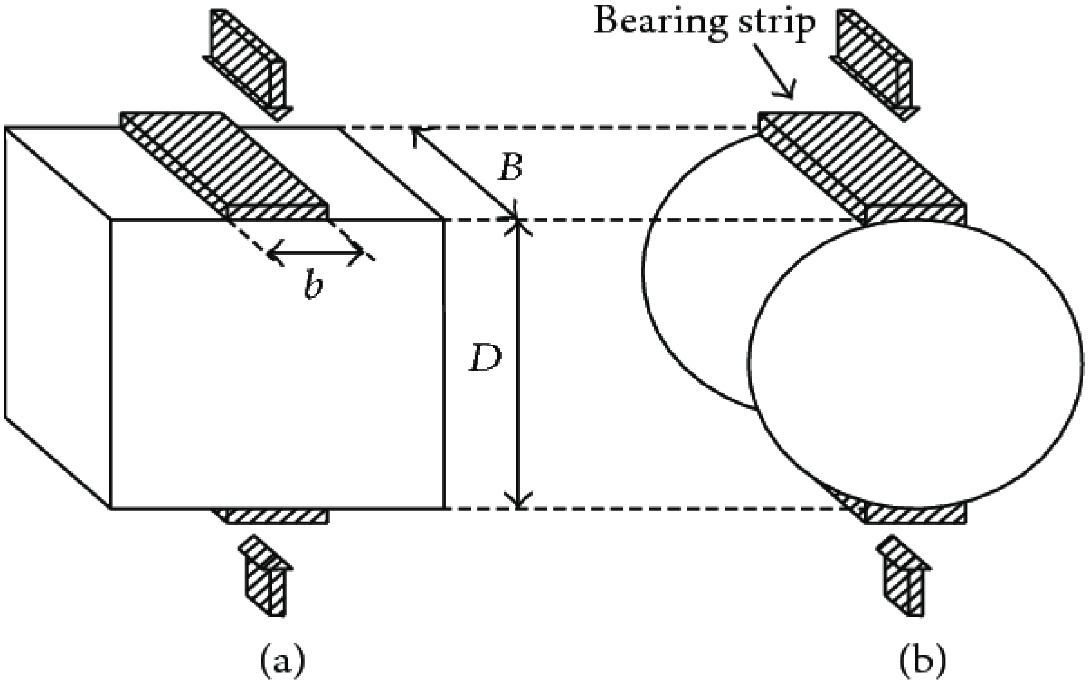

Figure 3.6: Schematic diagram for splitting tensile strength of cubical specimen

Splitting tensile strength, $f_{ct} = 2P/(\pi ld)$

Where,

P = The specimen's maximum load at failure

l = The specimen's length

d = The specimen's cross-sectional dimension or size

For Cubical specimen,

$f_{ct} = 2P/a^2$

Where, a= dimension of cube

Figure 3.7:Test apparatus for determining concrete split tensile strength

3.3.4.3 Concrete Beam Flexural strength

Beam flexural strength is one way to calculate the concrete tensile strength. It is a measurement of a concrete beam's capacity to withstand bending at failure. After 28 days, it is measured by loading a specimen with dimensions of 100 mm by 100 mm by 500 mm. The ASTM C293 (2018) [45] standard test methods (center-point-loading) were applied to ascertain the flexural strength of the concrete beam. Three specimens were used for each mix's flexural test, and each test case's average values are noted. **Figure 3.8** depicts the beam testing setup that was utilized to ascertain the flexural strength.

(a)Concrete Beam Flexural test (before loading)

(b) Concrete Beam Flexural test (after loading)

Figure 3.8: Test setup for determining concrete beam flexural strength

The specimen was continuously and shock-free loaded. Up to the breaking point, the rate of application of the load was constant. The flexural strength was calculated using the following formula.

$$F_r = \frac{PL}{BD^2}$$

Where,

F_r = Flexural stress (N/mm^2) , P= Maximum Load (N)

L = distance between supports, B= width of the specimen

D = Thickness of the specimen

CHAPTER 4: RESULTS AND DISCUSSION

4.1 INTRODUCTION

The test results those are obtained from various experiments conducted as per experimental program are presented and discussed in the following sections. Specimen made from OPC and SFRC are exposed to plain water. In this study, various types of destructive tests related to the concrete strength have been carried out, and the test findings are presented both in graphical and tabular forms. The test results are critically analyzed and discussed to arrive at some useful conclusion.

4.2 COMPRESSIVE STRENGTH

The Compressive strengths of SFRC and OPC concrete subjected to a plain water curing are shown graphically in **Figure 4.1** to **Figure 4.4** and are illustrated in Tables 4.1 to 4.2. In **Figure 4.5** to **Figure 4.6** and **Table A- 1** to **Table A- 2**, the relative compressive strengths are also displayed for convenience of comparison**.** SFRC compressive strength was obtained by adding 1%, 1.5% and 2% steel fibers at 7, 14 and 28 days of curing. From **Figure 4.1** it is seen that compressive strength of concrete at 14 days curing periods with 0 % (control sample), 1%, 1.5 % and 2 % steel fiber for aspect ratio 50%, 60% and 70% are 26.9 MPa, 28.7 MPa, 29.7 MPa, 30.4 MPa ,30 MPa ,31.9 MPa, 31.5 MPa, 30.7MPa, 32.3 MPa and 31.1 MPa respectively Similarly, concrete at 28-day curing periods with 1%, 1.5%, 2%, and 0% steel fiber for aspect ratios of 50%, 60%, and 70% has the following values: 30.7 MPa, 33.1 MPa, 33.4 MPa, 34 MPa, 34.6 MPa, 34.9 MPa, 35.3 MPa, 33.9 MPa, 34.2 MPa, and 34.5 MPa, in that order. **Figure 4.2** shows the compressive strength of concrete at 14-day curing times with 1%, 1.5%, 2%, and 0% steel fiber for aspect ratios of 50%, 60%, and 70%, respectively. The values are 26.9 MPa, 29.7 MPa, 30.3 MPa, 30.8 MPa, 31.7 MPa, 32.3 MPa, 33.3 MPa, 32.8 MPa, and 33.8 MPa.In the same way, concrete after 28 days of curing times with 1%, 1.5%, 2%, and 0% steel fiber for aspect ratios of 50%, 60%, and 70% is 30.7 MPa, 33.9 MPa, 34.4 MPa, 34.8 MPa, 35.3 MPa, 35.8 MPa, 36.3 MPa, 35.0 MPa, 35.3 MPa, and 35.6 MPa, in that order. It has been noticed that the compressive strength of concrete for the specimen with steel fibers 1.0%, 1.5% and 2.0% is more than that of specimen without steel fibers.

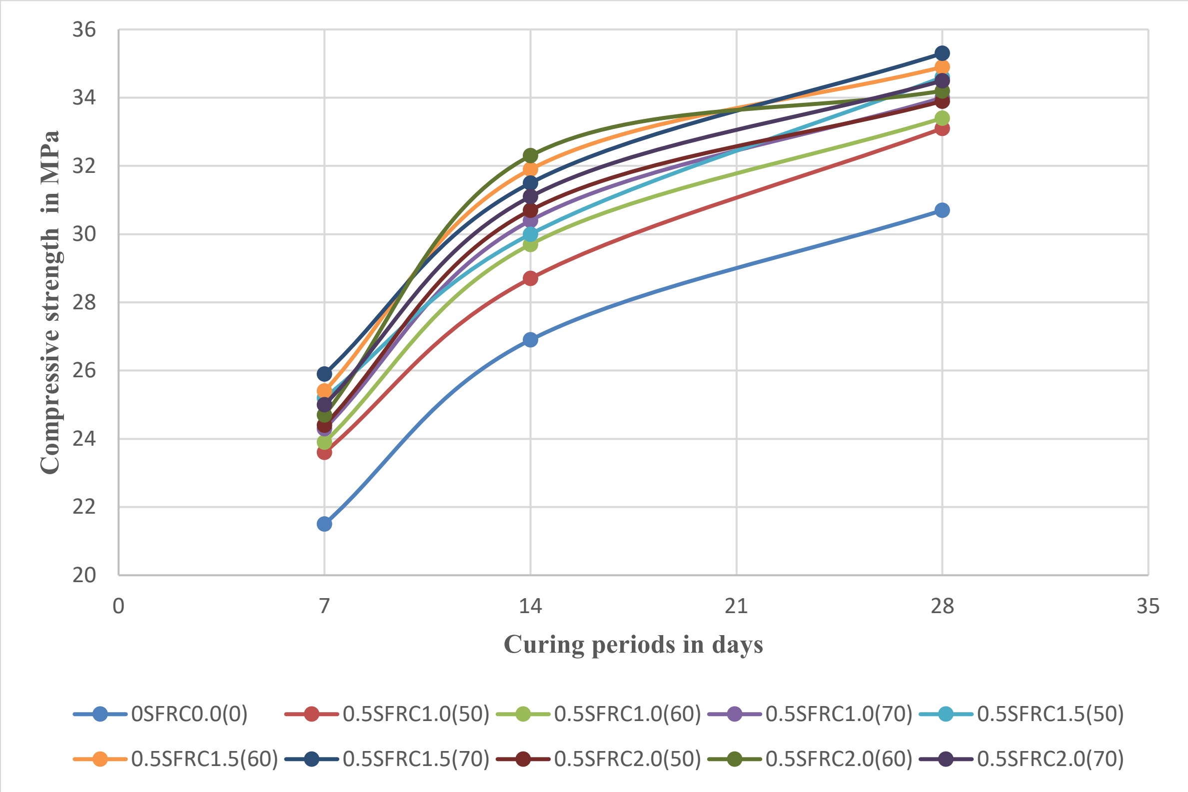

Figure 4.1: Compressive strength behaviour of SFRC at varying percentage of 0.5 mm steel fiber, aspect ratios and curing periods.

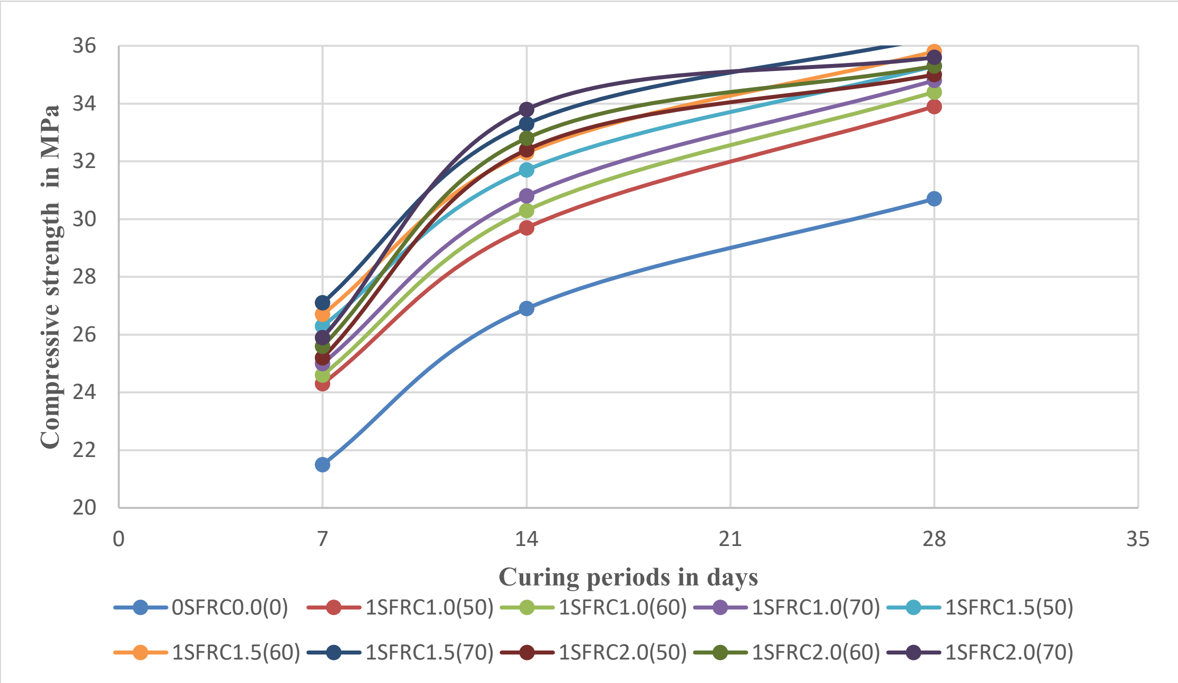

Figure 4.2: Compressive strength behaviour of SFRC at varying percentage of 1 mm steel fiber, aspect ratios and curing periods.

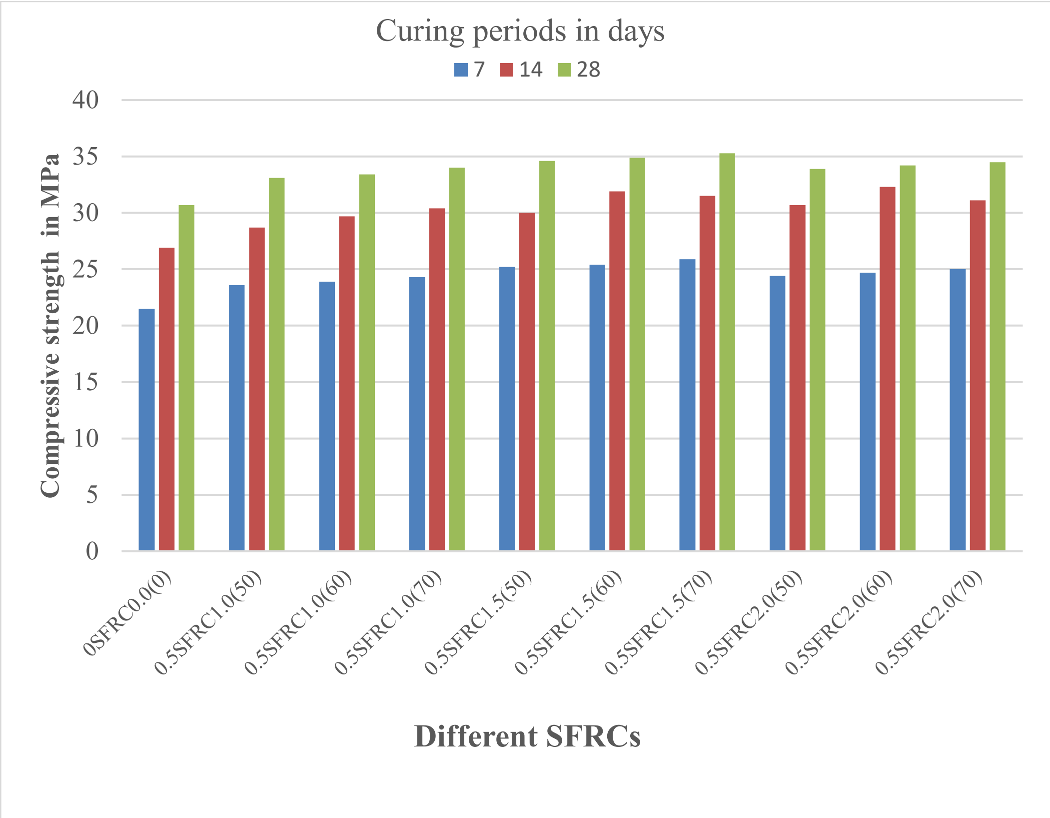

Figure 4.3: Compressive strength behaviour of SFRC at varying percentage of 0.5 mm steel fiber, aspect ratios and curing periods.

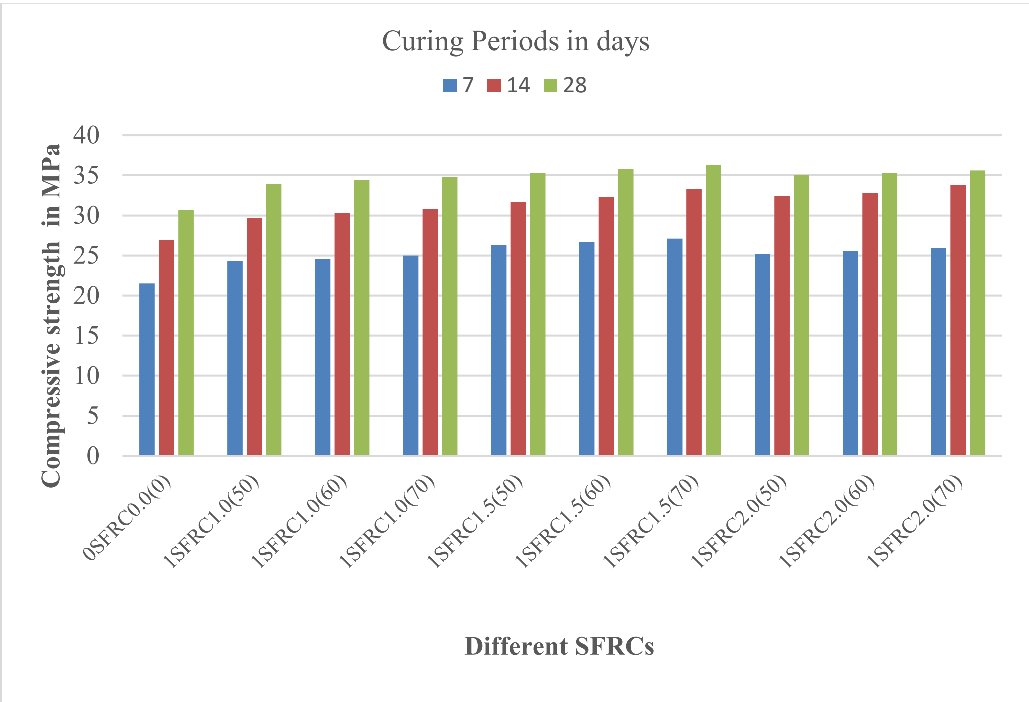

Figure 4.4: Compressive strength behaviour of SFRC at varying percentage of 1 mm steel fiber, aspect ratios and curing periods.

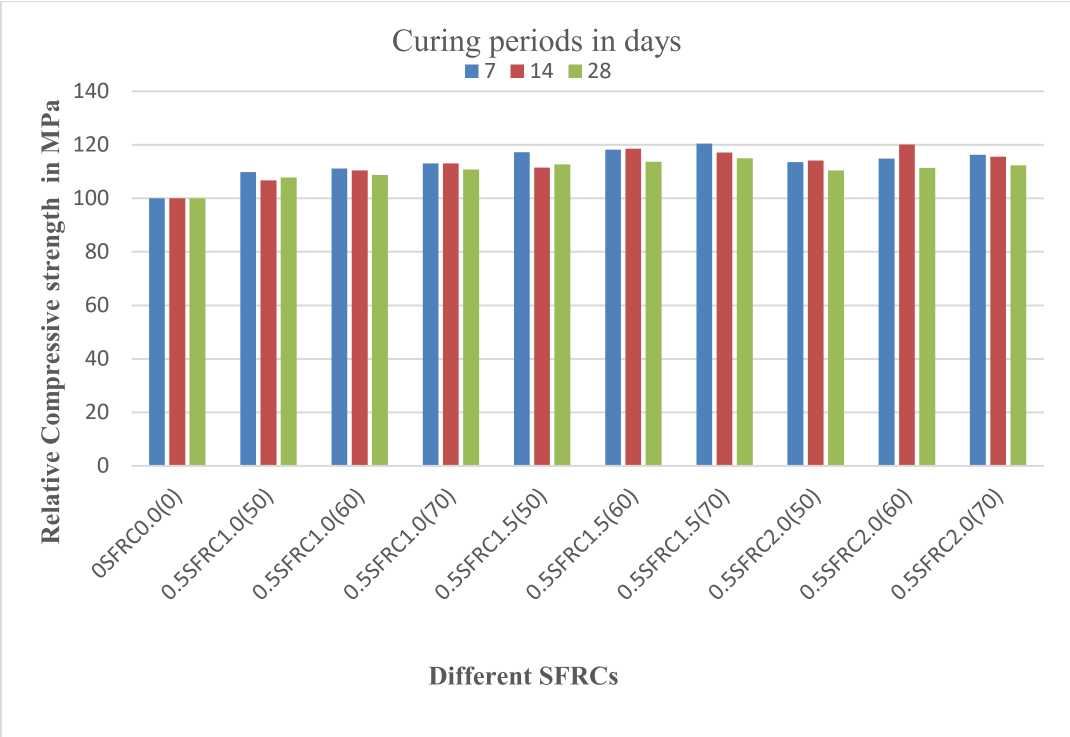

Figure 4.5: Relative Compressive Strength of SFRCs for 0.5 mm diameter steel fiber with different aspect ratios.

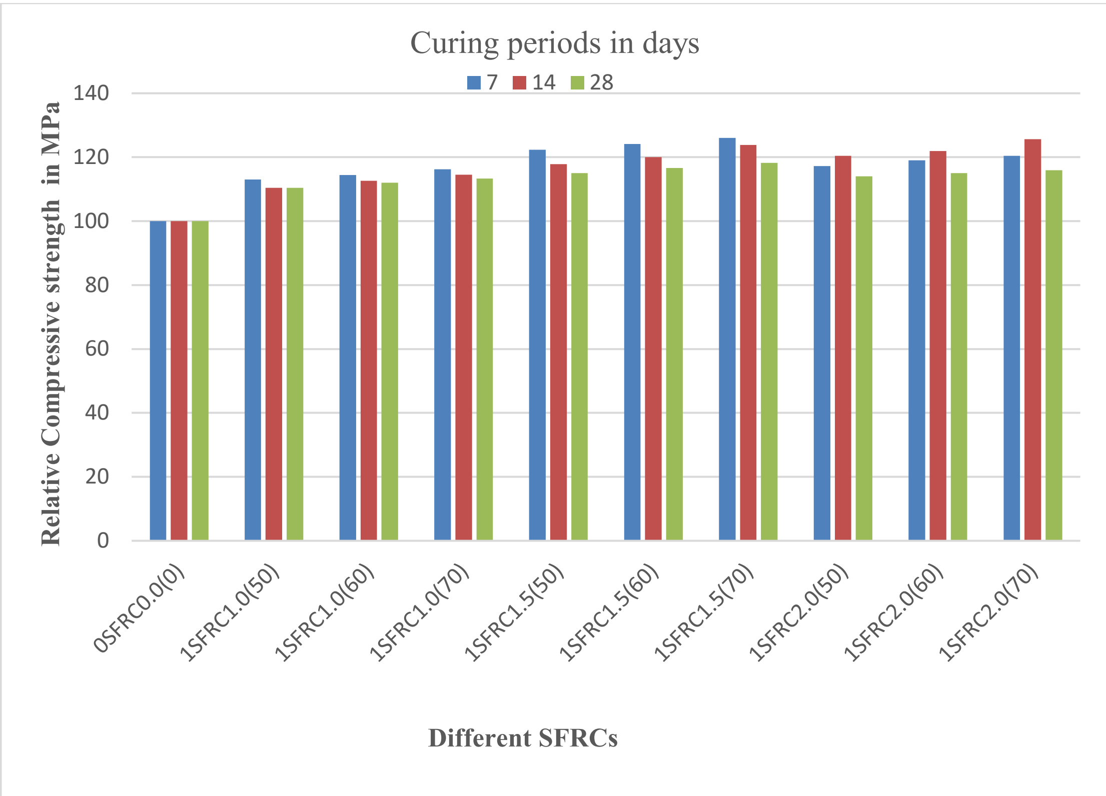

Figure 4.6: Relative Compressive Strength of SFRCs for 1 mm diameter steel fiber with different aspect ratios

The data show that the specimen with 1 mm steel fibers 1.5% by weight of concrete and aspect ratios of 70 can achieve the largest percentage improvement in compressive strength (+18%). It is therefore advised to add 1.5% of steel fibers by weight to concrete in order to maximize the improvement in compressive strength. It has been noted that compressive strength increases along with an increase in aspect ratio. Similar outcomes were mentioned by A.M. Shende et al. (2012) [1] who found that the flexural strength increased up to 24%. Also, test results reported by S. A. MAHADIK, et al. (2014) [3] indicated that there was a 19.50% improvement in compressive strength.

4.3 SPLIT TENSILE STRENGTH

The Split Tensile strengths of SFRC and OPC concrete subjected to a plain water curing are shown graphically in **Figure 4.7** to **Figure 4.10** and are illustrated in **Table A-3** to **Table A- 4**. In **Figure 4.11** to **Figure 4.12** and **Table A- 3** to **Table A- 4**, the relative split tensile strengths are also displayed for convenience of comparison**.** SFRC split tensile strength was obtained by adding 1%, 1.5% and 2% steel fibers at 7,14 and 28 days of curing. SFRC split tensile strength was obtained by adding 1%, 1.5% and 2% steel fibers at 7,14 and 28 days of curing. **Figure 4.7** shows that the split tensile strengths that were developed after seven days of curing were 2.36 MPa, 2.8 MPa, 2.88 MPa, 2.97 MPa, 3.06 MPa, 3.15 MPa, 3.24 MPa, 3.3 MPa, 3.17 MPa, and 3.21 MPa, in that order. Developed strengths are 3.11 MPa, 3.57 MPa, 3.69 MPa, 3.77 MPa, 3.91 MPa, 4.03 MPa, 4.09 MPa, 4.11 MPa, 4.15 MPa, and 4.21 MPa, respectively, at 14 days of curing periods. The obtained strengths at 28 days of curing periods are 3.63 MPa, 4.12 MPa, 4.19 MPa, 4.28 MPa, 4.42 MPa, 4.52 MPa, 4.61 MPa, 4.37 MPa, 4.46 MPa, and 4.54 MPa, in equivalent measure. The obtained strengths at 28 days of curing periods are 3.63 MPa, 4.12 MPa, 4.19 MPa, 4.28 MPa, 4.42 MPa, 4.52 MPa, 4.61 MPa, 4.37 MPa, 4.46 MPa, and 4.54 MPa, in equivalent measure. It has been observed that the split tensile strength of concrete for the specimen with steel fibers 1.0%, 1.5% and 2.0% is more than that of specimen without steel fibers.

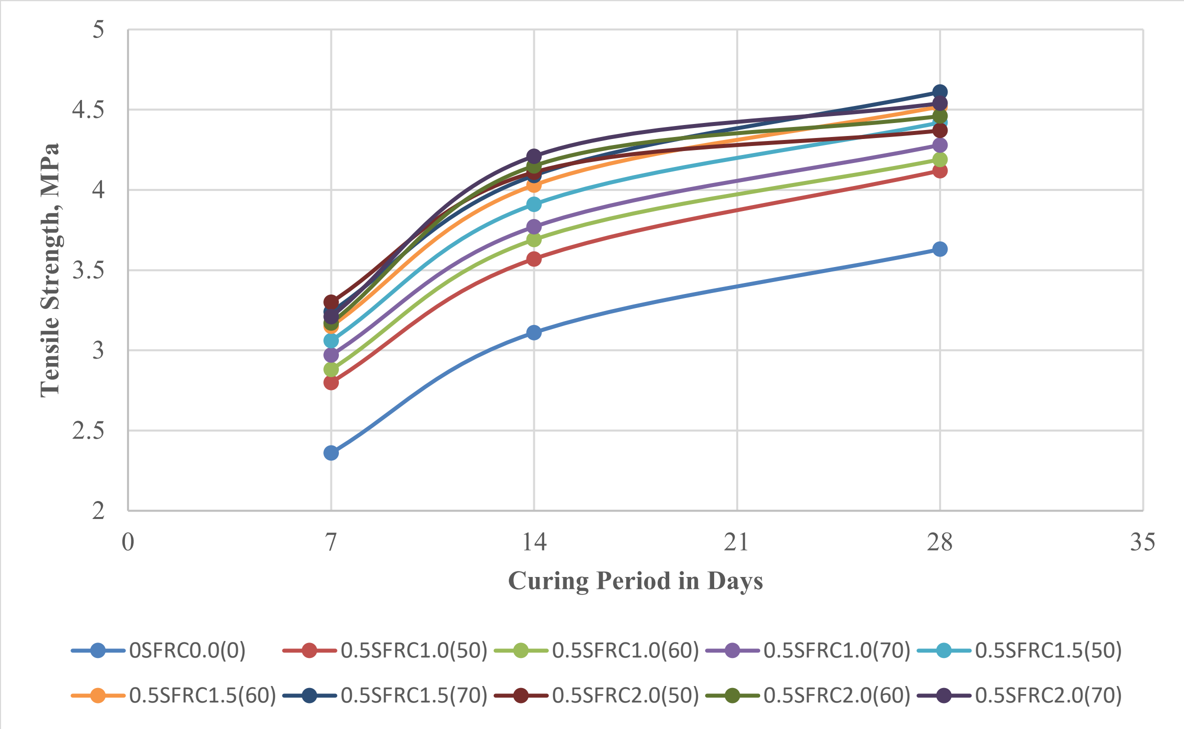

Figure 4.7: Split tensile strength behaviour of SFRCs at varying percentage of 0.5 mm steel fiber, aspect ratios and curing periods.

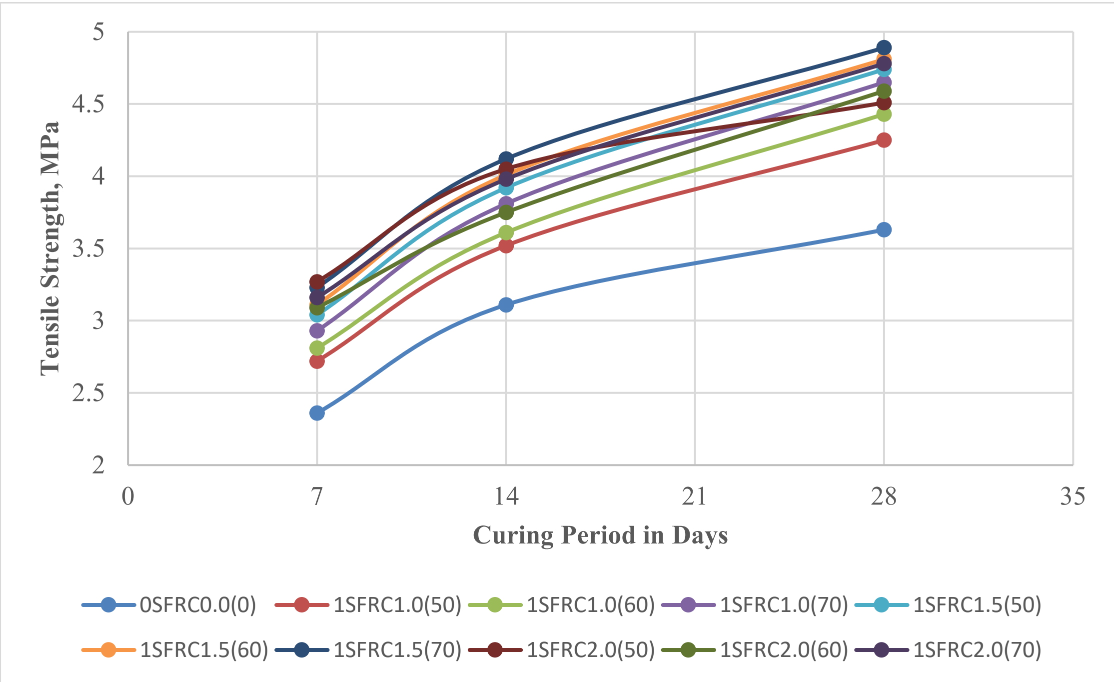

Figure 4.8: Split tensile behaviour of SFRCs at varying percentages of 1 mm steel fiber ratios, aspect ratios and curing periods.

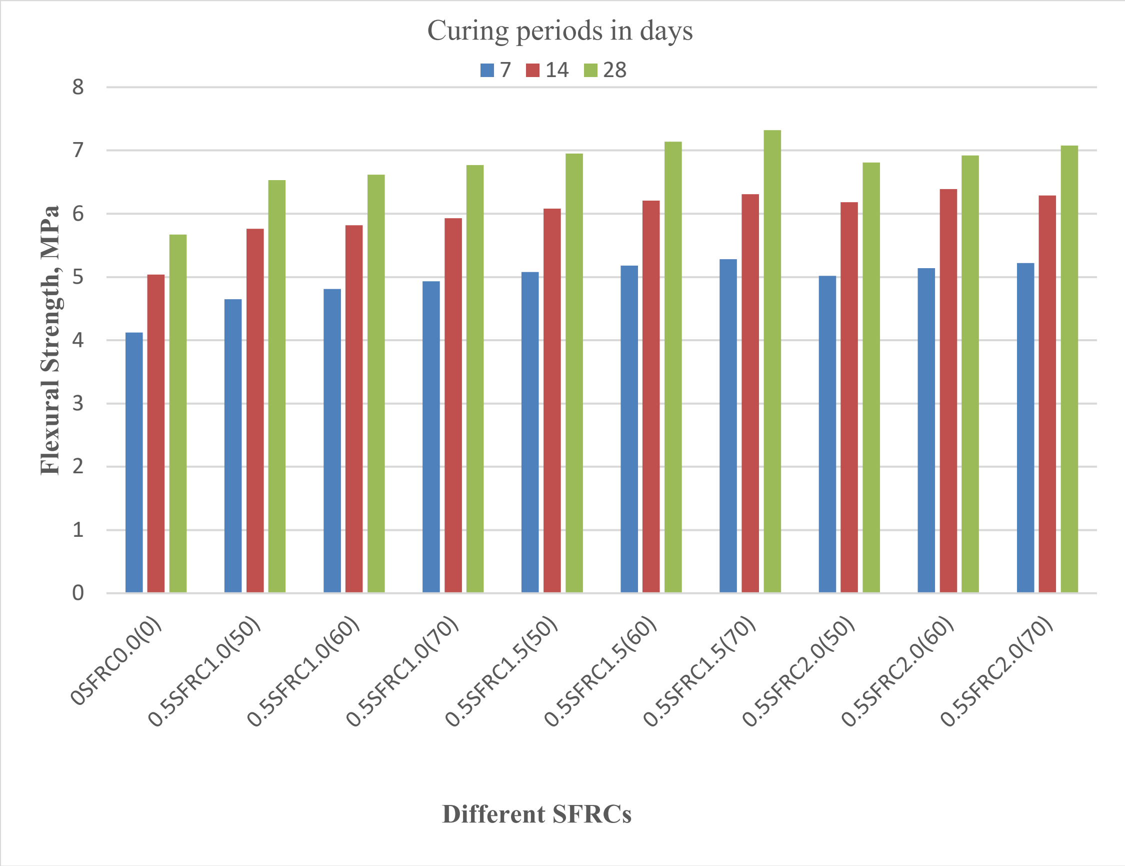

Figure 4.9: The behavior of concrete's split tensile strength at varying percentages of 0.5 mm steel fiber, aspect ratios, and curing period

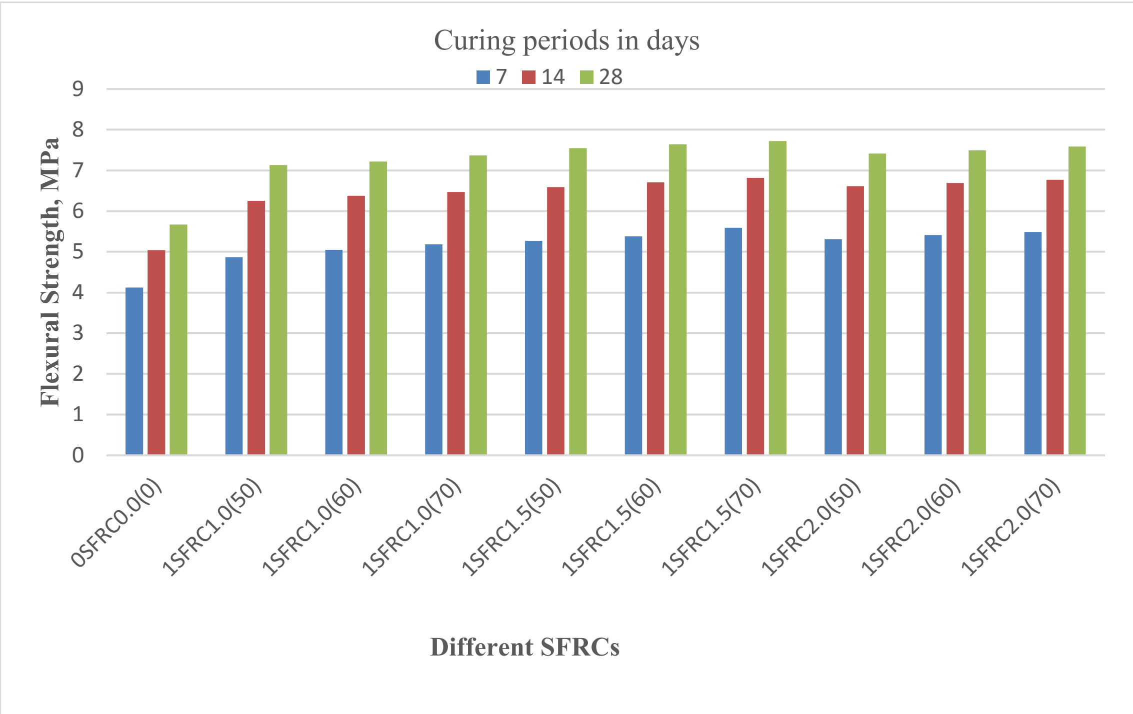

Figure 4.10: The behavior of concrete's split tensile strength at varying percentages of 0.5 mm steel fiber, aspect ratios, and curing period

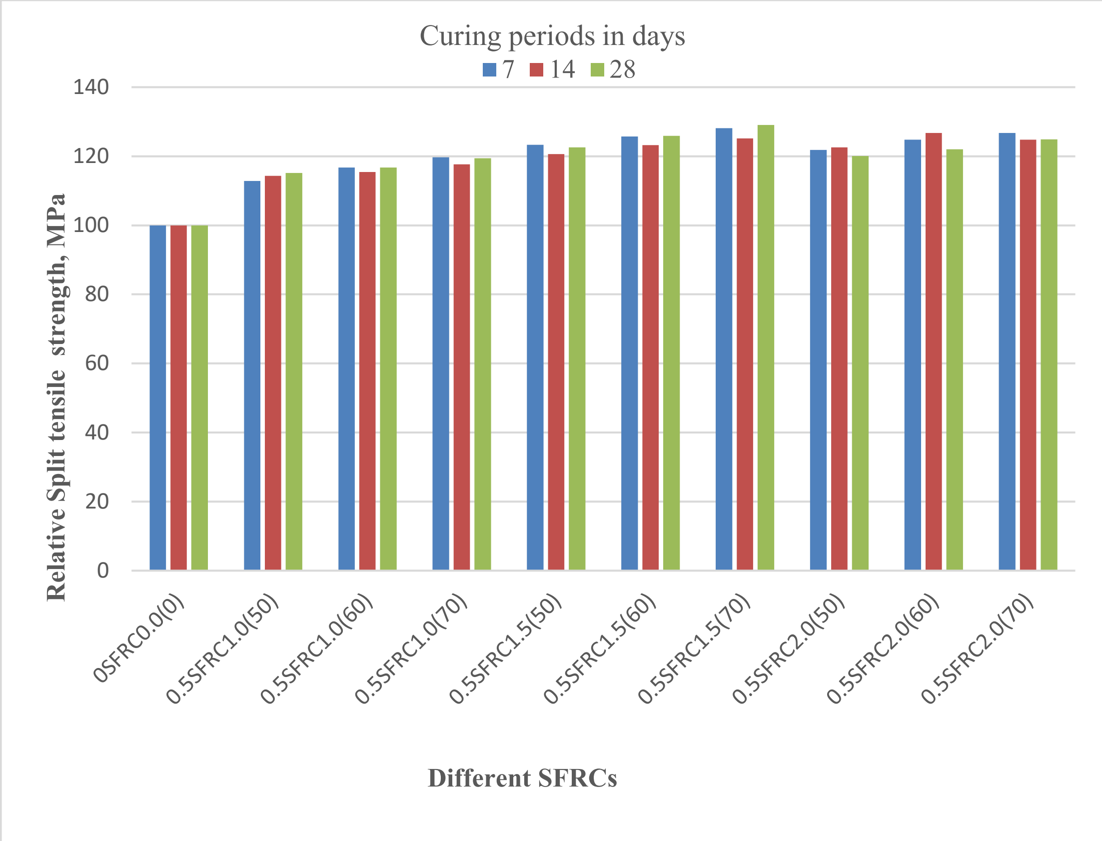

Figure 4.11: Relative Split Strength for 0.5 mm diameter steel fiber with different aspect ratios

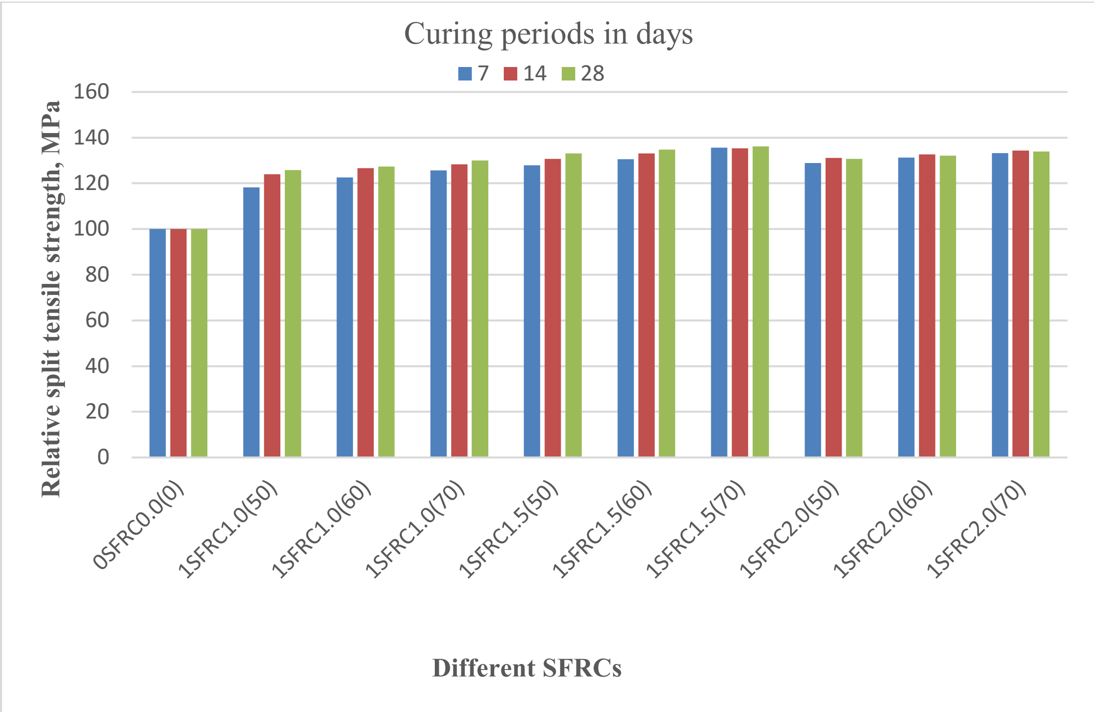

Figure 4.12: Relative split tensile Strength for 1 mm diameter steel fiber with different aspect ratios.

It is evident from the data that the specimen with 1 mm steel fibers 1.5% by weight of concrete and aspect ratios of 70 can achieve the largest percentage improvement in split tensile strength (+35%). It is therefore advised to add 1.5% of steel fibers by weight to concrete in order to maximize the improvement in split tensile strength. It has been observed that when aspect ratio rises, split tensile strength also rises. A.M. Shende et al. (2012) [1] published similar results, demonstrating a 41% improvement in split tensile strength.

4.4 FLEXURAL STRENGTH

The flexural strengths of SFRC and OPC concrete subjected to a plain water curing are shown graphically in **Figure 4.13** to **Figure 4.18** and are illustrated in **Table A- 5** to **Table A- 6**. In **Figure 4.17** to **Figure 4.18** and **Table A- 5** to **Table A- 6**, the relative flexural strengths are also displayed for convenience of comparison. SFRC flexural strength was obtained by adding 1%, 1.5% and 2% steel fibers at 7, 14 and 28 days of curing. **Figure 4.13** shows that the flexural strengths that were developed after 7 days of curing were 4.12 MPa, 4.65 MPa, 4.81 MPa, 4.93 MPa, 5.08 MPa, 5.18 MPa, 5.28 MPa, 5.02 MPa, 5.14 MPa, and 5.22 MPa, in that order. The flexural strengths that were established during the period of 14 days of curing were 5.04 MPa, 5.76 MPa, 5.82 MPa, 5.93 MPa, 6.08 MPa, 6.21 MPa, 6.31 MPa, 6.18 MPa, 6.39 MPa, and 6.29 MPa, successively. Additionally, flexural strength developed for 28 days of curing was 5.67 MPa, 6.53 MPa, 6.62 MPa, 6.77 MPa, 6.95 MPa, 7.14 MPa, 7.32 MPa, 6.81 MPa, 6.92 MPa, and 7.08 MPa, in that order. **Figure 4.14** shows that the flexural strengths that were developed after seven days of curing were 4.12 MPa, 4.87 MPa, 5.05 MPa, 5.18 MPa, 5.27 MPa, 5.38 MPa, 5.59 MPa, 5.31 MPa, 5.41 MPa, and 5.49 MPa, in that order. In the same way, flexural strengths of 5.04 MPa, 6.25 MPa, 6.38 MPa, 6.47 MPa, 6.59 MPa, 6.71 MPa, 6.82 MPa, 6.61 MPa, 6.69 MPa, and 6.77 MPa were achieved after 14 days of curing. Additionally, flexural strength generated throughout 28 days of curing was 5.67 MPa, 7.13 MPa, 7.22 MPa, 7.37 MPa, 7.55 MPa, 7.64 MPa, 7.72 MPa, 7.41 MPa, 7.49 MPa, and 7.59 MPa, in that order. It has been noted that the 1.0%, 1.5%, and 2.0% steel fiber beams with concrete exhibit greater flexural strength than the beams without steel fibers.

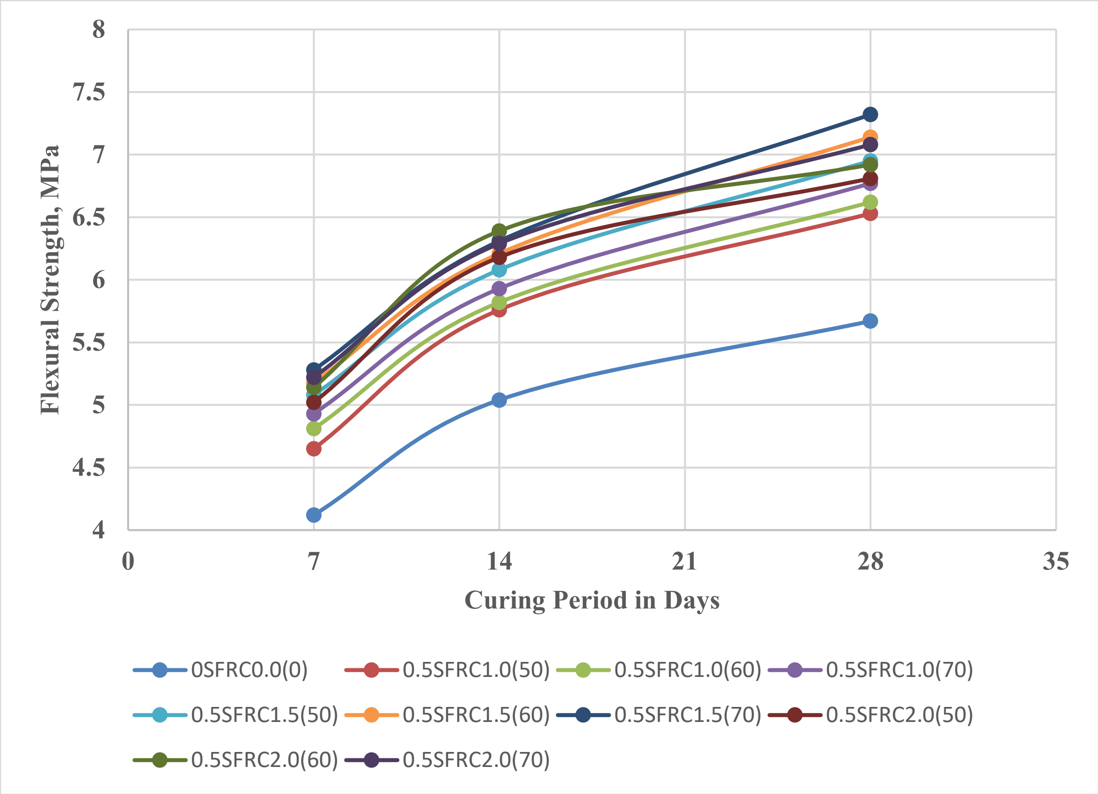

Figure 4.13: Flexural strength behaviour of SRFCS at varying percentages of 0.5 mm steel fiber, aspect ratios and curing periods.

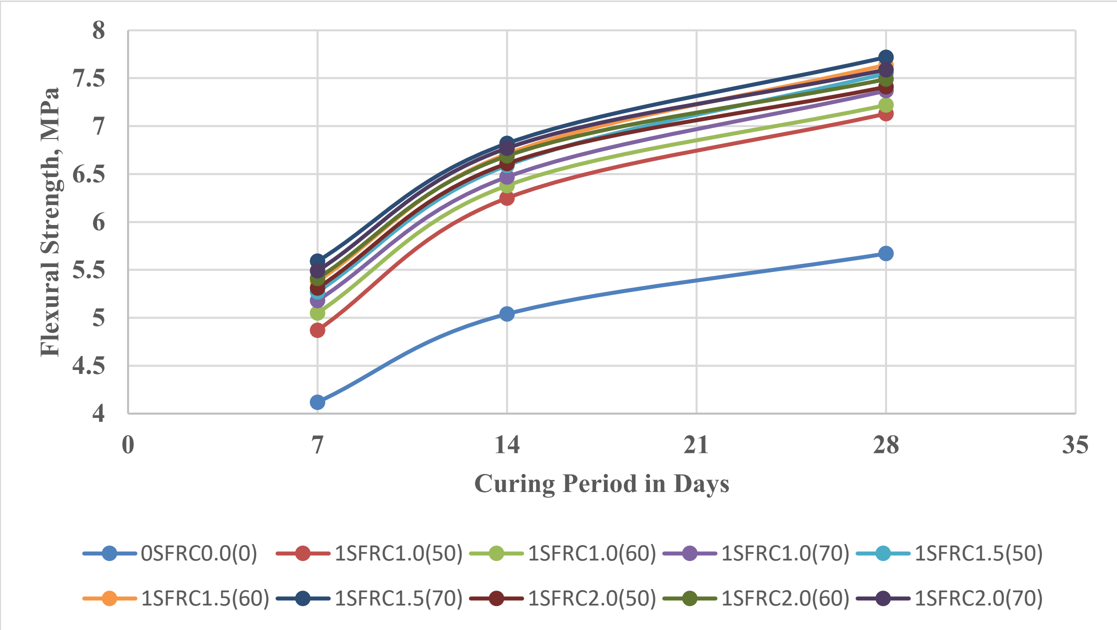

Figure 4.14: Flexural strength behaviour of 1 mm steel fiber, aspect ratios and curing periods.

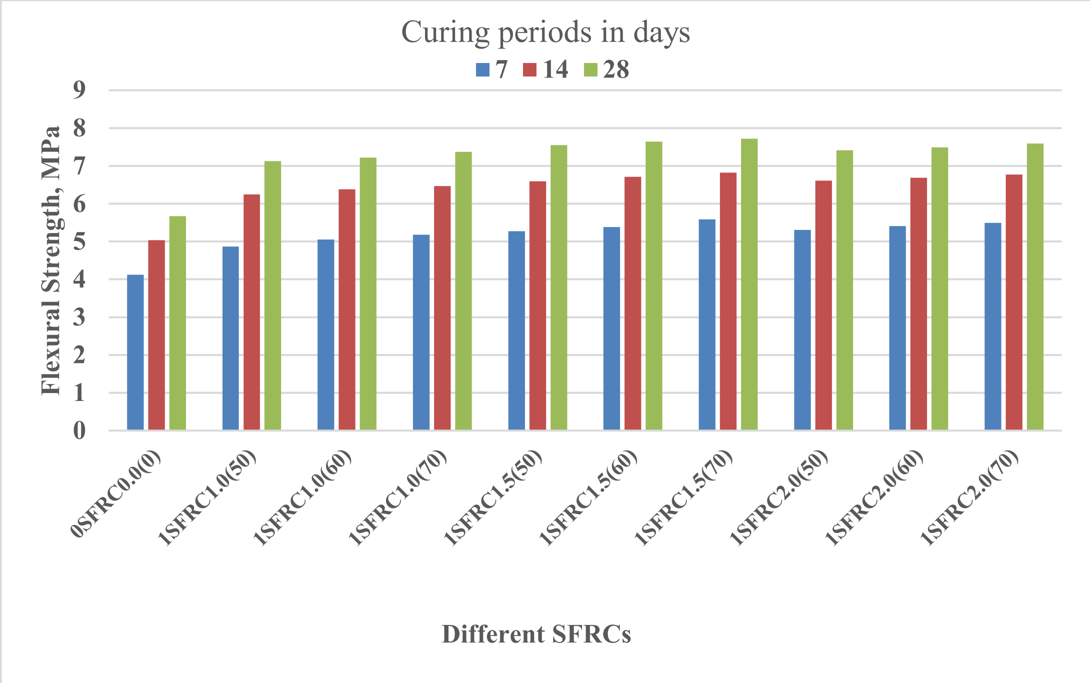

Figure 4.15: The behavior of concrete's flexural strength at varying percentages of 0.5 mm steel fiber, aspect ratios, and curing period.

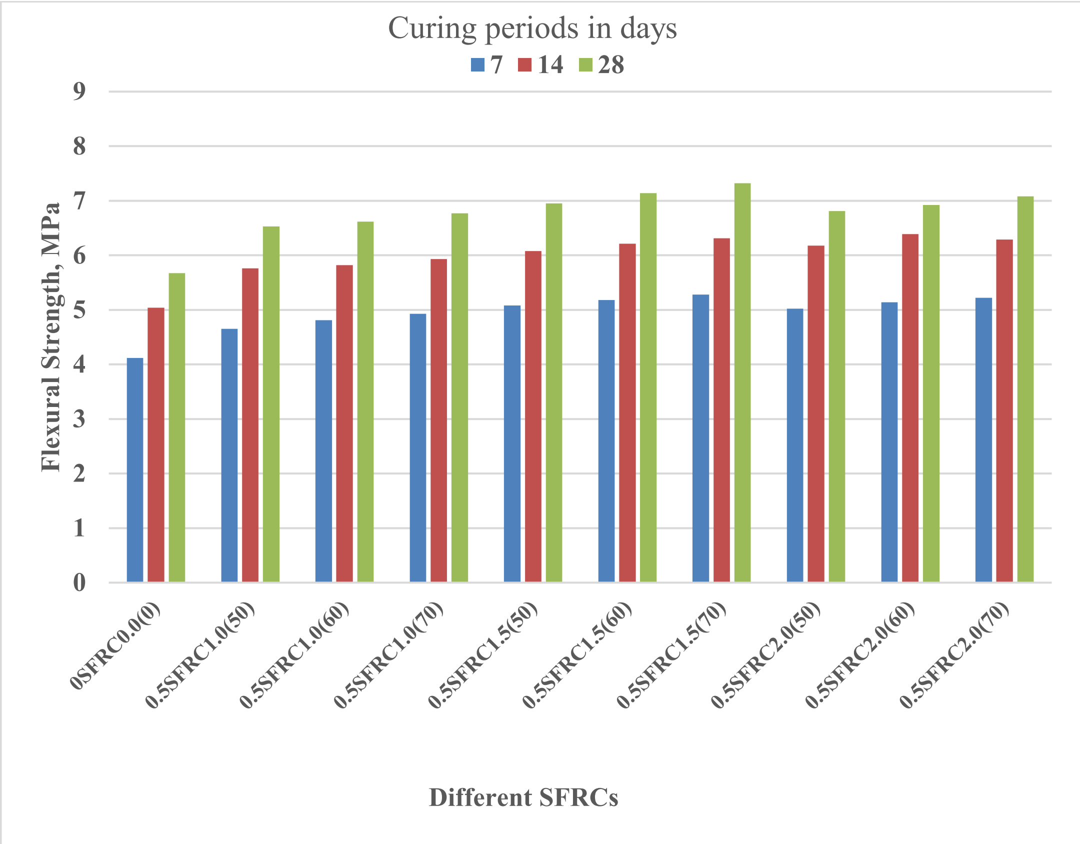

Figure 4.16: The behavior of concrete's flexural strength at varying percentages of 1 mm steel fiber, aspect ratios, and curing period.

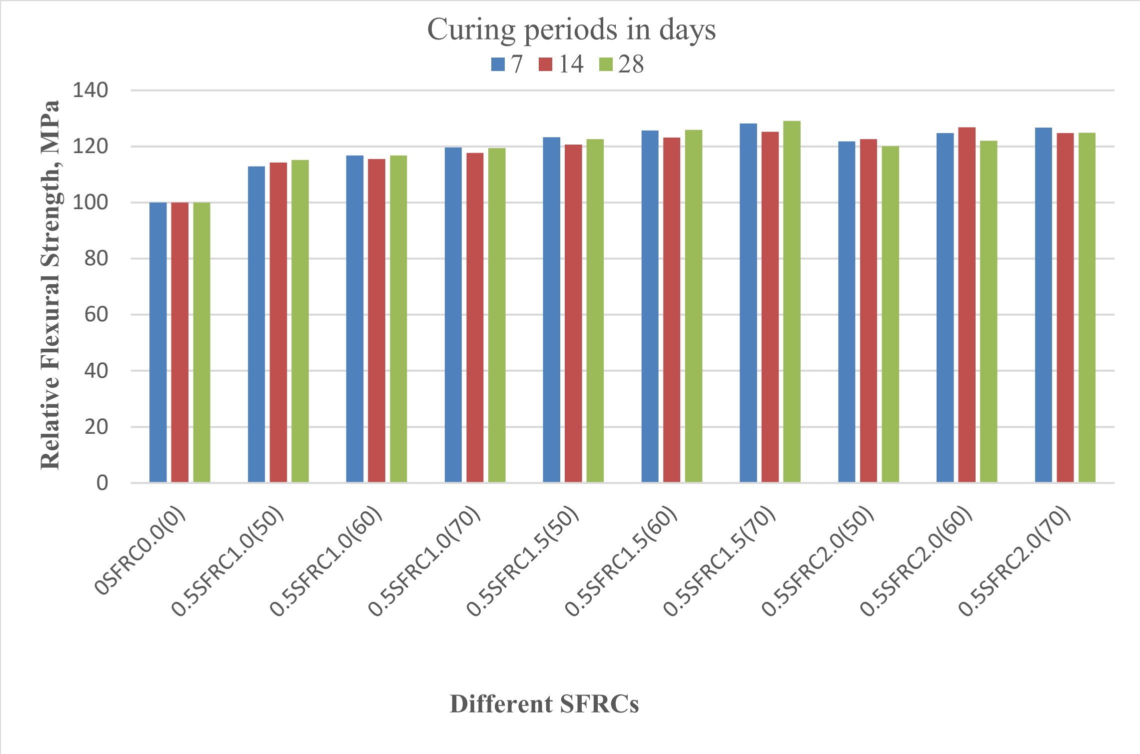

Figure 4.17: Relative Flexural Strength for 0.5 mm diameter steel fiber with different aspect ratios

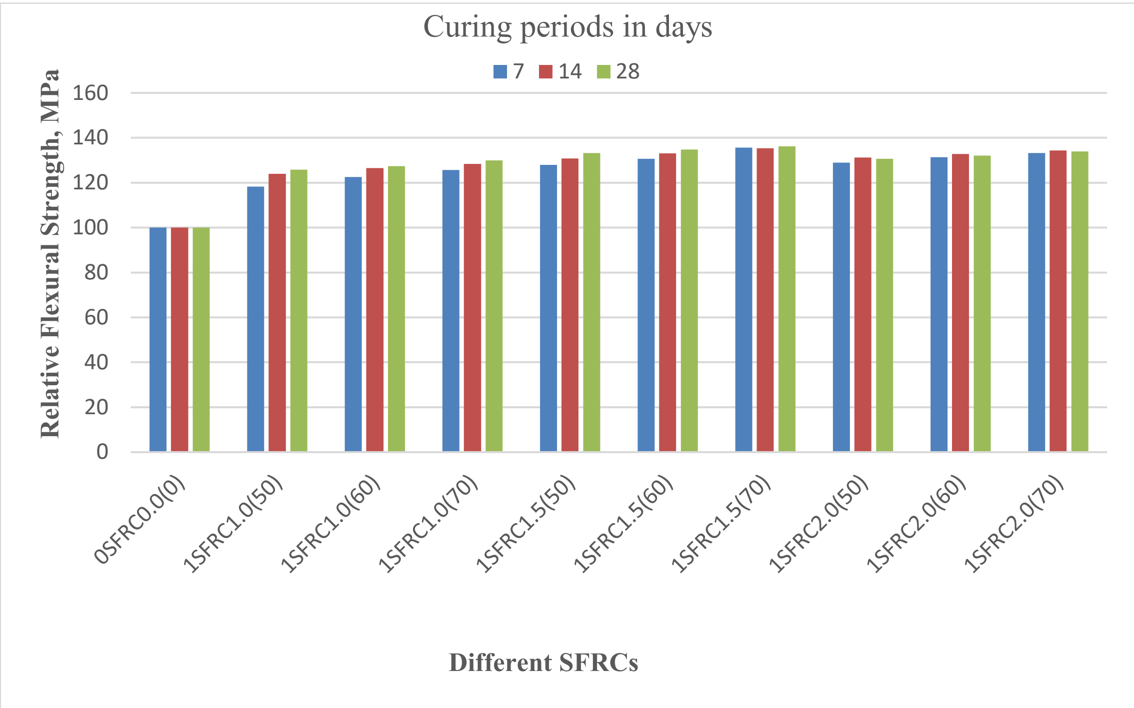

Figure 4.18: Relative Flexural Strength for 1 mm diameter steel fiber with different aspect

The observations show that the beams with 1 mm steel fibers, 1.5% by weight of concrete, and aspect ratios of 70 have the greatest percentage gain in flexural strength (+36). To maximize the benefit of strengthening flexural strength, steel fibers should be included at a rate of 1.5% by weight in concrete. Flexural strength has been shown to increase when the aspect ratio increases. Similar findings were published by S. A. MAHADIK et al. (2014) [3], who discovered that flexural strength improved up to 43.29%.

4.5 CONCLUDING REMARKS

Test result of various destructive strength tests of different types of concrete exposed to plain water for different exposure periods have been presented in this chapter. After performing the various tests, some useful conclusions on the basis of observed test results regarding the performances of steel fibers reinforced concrete in plain water environments have been made.

CHAPTER 5: CONCLUSION AND RECOMMENDATIONS

5.1 GENERAL

Given its proneness to deterioration, concrete is most frequently utilized in the construction of various structures that are exposed to a variety of environmental factors. This is due mainly to its improved performance in terms of strength, rebar protection, durability and economy. Good quality concrete has the capacity to provide resistance against the chemical action of the environments. The main determinant of deterioration resistance principally hinges on the quality of the concrete, which comprises factors such as the grade of the aggregate, the makeup of the mixing water, the type of cement, the mixing traits, the inclusion of admixtures if necessary, and construction approaches. The ingredient materials ought to be devoid of detrimental salt ions, like chlorides and sulphates, as they can cause expansive material formation and trigger the corrosion of rebar. Concrete cube compressive strength, concrete cube splitting tensile strength, and concrete beam flexural strength measurements have been made in order to assess the physical and chemical changes that the specimens exposed to plain water environment underwent. These tests are conducted to assess the strength development nature of the concrete test specimens made of OPC and SFRC. The findings of the study are presented graphically as well as in tabular form for ease of interpretation.

5.2 CONCLUSION

The findings of the study undertaken on different steel fibers concrete for different curing period up to 28 days have been provided in the previous chapters. The following conclusions are drawn from the small number of variables that were examined. These discoveries include the following crucial details regarding the application of steel fibers in concrete:

a) In comparison to specimens without steel fibers, the compressive strength of concrete for specimens containing 1%, 1.5%, and 2% of steel fibers is greater. In comparison to the control sample, The compressive strength increases by around 18% with the inclusion of steel fibers.

b) When SFRCs with a 1.5% fiber content are compared to a control specimen with a 0% fiber content, all the concrete strength parameters—concrete cube compressive strength, concrete cube split tensile strength, and concrete beam flexural strength—show higher values.

c) When considering aspect ratios of 70 as opposed to 50 and 60, it is also observed that the strength properties of SFRCs are higher at the latter value..

d) The flexural strength of SFRCs increases by roughly 36% with the addition of steel fibers in comparison to the control sample.

e) Concrete cube split tensile strength increases by about 35% with the addition of steel fibers.

f) SFRC concrete having 1.5% steel fiber and 70% aspect ratio is found to be effective from strength development point of view.

5.3 RECOMMENDATIONS FOR FURTHER RESEARCH

The use of reinforced concrete with steel fibers in structural applications in natural environments has been the subject of numerous investigations. Contextualized within the current studies are the recommendations that follow for additional research concerning SFRC concrete.

a) The effects of different steel fiber types—hooked, paddled, deformed, crimped, and irregular fibers—on the characteristics of concrete could be investigated.

b) Durability study can be carried out in different aggressive environment with normal and enhanced concentration of the ambient aggressive environment.

c) The durability qualities of SFRC concrete in seawater can be further investigated. Investigating the engineering characteristics of concrete, such as permeability, creep, stress-strain ratio, static and dynamic modulus of elasticity, poisons ratio, shrinkage characteristics, freezing and thawing, and thermal resistivity of SFRC concrete, may be part of the study.

d) Laboratory investigation as well as field exposure studies are necessary to corelate the laboratory data to actual field data. The effectiveness of steel fiber concrete in various aggressive environments can be predicted by organizing a combined project that compares laboratory and field research on SFRC concrete exposed to those environments.

e) The present investigation may be carried out by varying the grade and w/c ratio of concrete.

f) The study may be conducted by taking varying aspect ratio of such as 80, 90 and 100, also percent of fiber contents.

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APPENDIX A: TABLES OF RESULTS

Table A- 1: Compressive strength for 0.5 mm diameter steel fiber for different curing period

Sample Designation	Compressive Strength, MPa			% increase of compressive strength as compare to control Sample, MPa		
	7 Days	14 Days	28 Days	7 Days	14 Days	28 Days
0SFRC0.0(0)	21.5	26.9	30.7	0	0	0
0.5SFRC1.0(50)	23.6	28.7	33.1	10	07	8
0.5SFRC1.0(60)	23.9	29.7	33.4	11	10	9
0.5SFRC1.0(70)	24.3	30.4	34	13	13	11
0.5SFRC1.5(50)	25.2	30	34.6	17	12	13
0.5SFRC1.5(60)	25.4	31.9	34.9	18	19	14
0.5SFRC1.5(70)	25.9	31.5	35.3	20	17	15
0.5SFRC2.0(50)	24.4	30.7	33.9	13	14	10
0.5SFRC2.0(60)	24.7	32.3	34.2	15	20	11
0.5SFRC2.0(70)	25	31.1	34.5	16	16	12

Table A- 2: Compressive strength for 1 mm diameter steel fiber for different curing period

Sample Designation	Compressive Strength, MPa			% increase of compressive strength as compare to control Sample, MPa		
	7 Days	14 Days	28 Days	7 Days	14 Days	28 Days
0SFRC0.0(0)	21.5	26.9	30.7	0	0	0
1SFRC1.0(50)	24.3	29.7	33.9	13	10	10
1SFRC1.0(60)	24.6	30.3	34.4	14	13	12
1SFRC1.0(70)	25	30.8	34.8	16	14	13
1SFRC1.5(50)	26.3	31.7	35.3	22	18	15
1SFRC1.5(60)	26.7	32.3	35.8	24	20	17
1SFRC1.5(70)	27.1	33.3	36.3	26	24	18
1SFRC2.0(50)	25.2	32.4	35	17	20	14
1SFRC2.0(60)	25.6	32.8	35.3	19	22	15
1SFRC2.0(70)	25.9	33.8	35.6	20	26	16

Table A- 3: Split Tensile strength for 0.5 mm diameter steel fiber for different curing period

Sample Designation	Split Tensile Strength, MPa			% increase of split tensile strength as compare to control Sample, MPa		
	7 Days	**14 Days**	**28 Days**	**7 Days**	**14 Days**	**28 Days**
0SFRC0.0(0)	2.36	3.11	3.63	0	0	0
0.5SFRC1.0(50)	2.8	3.57	4.12	19	15	13
0.5SFRC1.0(60)	2.88	3.69	4.19	22	19	15
0.5SFRC1.0(70)	2.97	3.77	4.28	26	21	18
0.5SFRC1.5(50)	3.06	3.91	4.42	30	26	22
0.5SFRC1.5(60)	3.15	4.03	4.52	33	30	25
0.5SFRC1.5(70)	3.24	4.09	4.61	37	32	27
0.5SFRC2.0(50)	3.3	4.11	4.37	40	32	20
0.5SFRC2.0(60)	3.17	4.15	4.46	34	33	23
0.5SFRC2.0(70)	3.21	4.21	4.54	36	35	25

Table A- 4: Split Tensile strength for 1 mm diameter steel fiber for different curing period

Sample Designation	Split Tensile Strength, MPa			% increase of split tensile strength as compare to control Sample, MPa		
	7 Days	**14 Days**	**28 Days**	**7 Days**	**14 Days**	**28 Days**
0SFRC0.0(0)	2.36	3.11	3.63	0	0	0
1SFRC1.0(50)	2.72	3.52	4.25	15	13	17
1SFRC1.0(60)	2.81	3.61	4.43	19	16	22
1SFRC1.0(70)	2.93	3.81	4.65	24	23	28
1SFRC1.5(50)	3.04	3.92	4.74	29	26	31
1SFRC1.5(60)	3.11	4.01	4.81	32	29	33
1SFRC1.5(70)	3.23	4.12	4.89	37	32	35
1SFRC2.0(50)	3.27	4.05	4.51	39	30	24
1SFRC2.0(60)	3.09	3.75	4.59	31	21	26
1SFRC2.0(70)	3.16	3.98	4.78	34	28	32

Table A- 5: Flexural strength for 0.5 mm diameter steel fiber for different curing period

Sample Designation	Flexural Strength, MPa			% increase of flexural strength as compare to control Sample, MPa		
	7 Days	14 Days	28 Days	7 Days	14 Days	28 Days
0SFRC0.0(0)	4.12	5.04	5.67	0	0	0
0.5SFRC1.0(50)	4.65	5.76	6.53	13	14	15
0.5SFRC1.0(60)	4.81	5.82	6.62	17	15	17
0.5SFRC1.0(70)	4.93	5.93	6.77	20	18	19
0.5SFRC1.5(50)	5.08	6.08	6.95	23	21	23
0.5SFRC1.5(60)	5.18	6.21	7.14	26	23	26
0.5SFRC1.5(70)	5.28	6.31	7.32	28	25	29
0.5SFRC2.0(50)	5.02	6.18	6.81	22	23	20
0.5SFRC2.0(60)	5.14	6.39	6.92	25	27	22
0.5SFRC2.0(70)	5.22	6.29	7.08	27	25	25

Table A- 6: Flexural strength for 1 mm diameter steel fiber for different curing period

Sample Designation	Flexural Strength, MPa			% increase of flexural strength as compare to control Sample, MPa		
	7 Days	14 Days	28 Days	7 Days	14 Days	28 Days
0SFRC0.0(0)	4.12	5.04	5.67	0	0	0
1SFRC1.0(50)	4.87	6.25	7.13	18	24	26
1SFRC1.0(60)	5.05	6.38	7.22	23	27	27
1SFRC1.0(70)	5.18	6.47	7.37	26	28	30
1SFRC1.5(50)	5.27	6.59	7.55	28	31	33
1SFRC1.5(60)	5.38	6.71	7.64	31	33	35
1SFRC1.5(70)	5.59	6.82	7.72	36	35	36
1SFRC2.0(50)	5.31	6.61	7.41	29	31	31
1SFRC2.0(60)	5.41	6.69	7.49	31	33	32
1SFRC2.0(70)	5.49	6.77	7.59	33	34	34