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STUDY ON BEHAVIOUR OF STEEL FIBER CONCRETE UNDER ELEVATED TEMPERATURE

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CANDIDATE'S DECLARATION

I, Ashish Kumar, Roll No. 2K21/STE/24, student of M.Tech (Structural Engineering), hereby declare that the project dissertation entitled "**Study on Behaviour of Steel Fiber Concrete Under Elevated Temperature**" which is submitted by me to the Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfillment of the requirement for the award of the degree of Master of Technology is original and not copied from any source without proper citation. This work has not previously formed the basis for the award of any Degree, Diploma Associateship, Fellowship, or other similar title or recognition.

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CERTIFICATE

I hereby certify that the Project Dissertation entitled "**Study on Behaviour of Steel Fiber Concrete Under Elevated Temperature**" which is submitted by Ashish Kumar, Roll No. 2K21/STE/24, to the Department of Civil Engineering, Delhi Technological University, Delhi in partial fulfilment of the requirement for the award of the degree of Master of Technology, is a record of the project work carried out by him under my supervision. To the best of my knowledge, this work has not been submitted in part or full for any Degree or Diploma to this University or elsewhere.

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ABSTRACT

Concrete, as the predominant building material worldwide, is widely utilized but exhibits weakness in tension due to its inherently brittle nature. To address this concern, the incorporation of steel fibers into concrete has emerged as a viable solution to enhance its ductility. Given the extensive usage of concrete and its exposure to elevated temperatures resulting from fire incidents and other factors, investigating the impact of temperature on concrete with steel fiber reinforcement assumes significant importance. Although numerous studies have investigated this subject, limited emphasis has been placed on exploring the influence of the aspect ratio of steel fibers in concrete. Hence, the present study aims to investigate the efficacy of incorporating steel fibers with different aspect ratios into the concrete through experimental methods. The objective is to evaluate the performance enhancement of concrete components subjected to both low and high temperatures.

The experimental work was conducted in multiple stages, in the initial stage, several tests were carried out at ambient temperature, including workability, compressive strength, and split tensile strength tests. The intent was to investigate the response of concrete and determine the optimum fiber dosage for aspect ratios of 65 and 55 mixed in the range of 0% to 1.50% at intervals of 0.25%. The subsequent stage focused on evaluating the mechanical properties of the specimens with the determined optimum fiber dosages. This evaluation was conducted at elevated temperatures of 125°C, 250°C, and 375°C. The mechanical tests performed included compressive strength, split tensile strength, and flexural strength tests. The results indicated that the inclusion of steel fibers with various concentrations and aspect ratios significantly impacted the mechanical properties of concrete.

It was observed that the workability of the concrete decreased as the fiber aspect ratio increased. The maximum decrease, compared to the control mix, was 39% and 36% for the 65 and 55 aspect ratio mixes, respectively. However, the inclusion of steel fibers improved the compressive strength by approximately 13% to 38% and the split tensile strength by 7% to 65% at ambient temperature. Based on the results obtained, the optimum fiber volume percentages for achieving maximum increases in compressive and split tensile strength were determined to be 0.75% for aspect ratio 65 and 0.50% for aspect ratio 55.

When the specimens were exposed to elevated temperatures for 3 hours, ranging from 125°C to 375°C, a reduction in weight was observed. This weight loss could be attributed to the evaporation of water content from the concrete at higher temperatures. Mild cracks were also observed on the surface of the specimens exposed to 375°C due to the loss of water and the generation of stresses at high temperatures. The compressive strength of the fiber-reinforced concrete increased with rising temperatures, although the rate of increase decreased. However, the split tensile strength and flexural strength exhibited an increase up to 250°C, followed by a decrease at higher temperatures.

Furthermore, a mathematical model was developed to predict the residual strength of steel fiber-reinforced concrete for each mix proportion under elevated temperatures. The model took into consideration factors such as temperature, fiber volume, and fiber content. The established relationship between these factors and the residual strength was compared to the experimental results. The analysis revealed that the developed mathematical model provided a rational and accurate prediction of the residual strength of steel fiber-reinforced concrete under elevated temperature conditions, as it aligned well with the experimental findings.

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Before I commence with the presentation of this study, it is imperative that I express my gratitude to all the individuals whose contributions were indispensable in bringing this work to fruition. Foremost, I would like to express my heartfelt gratitude to God for the wisdom, strength, and inspiration provided throughout the course of this research.

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ASHISH KUMAR

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CHAPTER 1

INTRODUCTION

1.1 GENERAL

Concrete is a versatile and widely used construction material with many advantages. It is a mixture of cement, water, and aggregates (such as sand, gravel, or crushed stone) that can be molded into any form or size before setting up into a solid mass. Concrete has been used for centuries, and it is one of the most durable and cost-effective building materials available. One of the main benefits of concrete is its strength and durability. It is a substance that can support a great deal of weight and pressure without breaking or collapsing. Concrete constructions are renowned for their durability and toughness, making them perfect for various uses, including buildings, bridges, roads, and pavements.

Concrete is also a highly versatile material that can be customized to meet specific requirements. It can be colored, stamped, or textured to create a variety of finishes and styles. This makes it popular for adorning applications such as flooring, countertops, and walls. Concrete also has the benefit of being fire-resistant and capable of offering excellent fire protection. Additionally, because it is an excellent insulator, it may help keep buildings warm in the winter and cool in the summer, lowering energy expenses. Overall, concrete is a reliable and cost-effective material that has numerous benefits. Its strength, durability, versatility, and fire resistance make it a popular choice for construction projects of all sizes and types.

1.2 STEEL FIBER REINFORCED CONCRETE

The use of steel fiber reinforced concrete (SFRC) can be traced back to the early 1900s when steel fibers were added to concrete to improve its mechanical properties. However, it was not until the 1960s that significant advancements were made in the development of SFRC, leading to its widespread use in construction. Researchers started looking at using steel fibers to reinforce concrete in the 1960s. In order to increase the flexural strength of concrete, straight, smooth steel fibers were employed for the first time as a reinforcing material in 1963. In the following years, various types of steel fibers were developed, including hooked, crimped, and twisted fibers, each with unique mechanical properties that could be tailored to specific applications. Additionally, advancements were made in the production and distribution of steel fibers, which led to their increased availability and affordability. The SFRC composite material was created in the 1970s, and the fibers were utilized to increase concrete's tensile strength and flexibility. By the 1980s, SFRC was widely employed in the construction sector and had a number of uses, such as bridge decks, airport runways, and industrial floors. In the decades that followed, SFRC continued to evolve, with new fiber types and manufacturing processes being developed to further enhance the performance characteristics of the material. Today, SFRC is widely recognized as a versatile and effective material for enhancing the mechanical and durability properties of concrete structures. But the story of steel fiber doesn’t end there. Researchers and engineers continue to push the boundaries of what is possible with this remarkable material, exploring new ways to optimize its properties and improve its performance in a range of different applications.

SFRC is a composite material consisting of cement, aggregates, and discrete steel fibers. The addition of steel fibers in concrete improves its mechanical properties such as ductility, toughness, and resistance to cracking. Steel fibers serve as a reinforcement in concrete by bridging microcracks that develop under stress, improving performance and durability. The use of SFRC has gained popularity in recent years due to its advantages over traditional reinforcement methods, such as increased durability, improved crack resistance, and reduced maintenance costs. Additionally, SFRC has been shown to have superior performance in harsh environmental conditions, making it a desirable material for infrastructure projects in areas prone to corrosion. In order to achieve the desired performance characteristics of SFRC, it is important to carefully design and proportion the mix to ensure optimal fiber dispersion and bonding. Additionally, using low-alkali cement might lessen the possibility of alkali-silica interaction, which can cause fractures to form in concrete. Overall, the use of SFRC is a practical way to improve the mechanical and durability characteristics of concrete while reducing the requirement for conventional reinforcing techniques.

However, its benefits are not limited to ambient temperature conditions alone. SFRC has proven to be effective in providing high mechanical strength and thermal stability at elevated temperatures. Steel fibers provide SFRC additional ductility, toughness, and energy absorption capacity, which increases its resistance to cracking and spalling in high-temperature environments. This is due to the ability of steel fibers to maintain their structural integrity and tensile strength even at high temperatures, unlike conventional reinforcement materials such as steel bars. Furthermore, the thermal conductivity of steel fibers in SFRC allows for faster and more efficient heat dissipation, preventing excessive heating and damage to the concrete. High-temperature applications like furnace linings, blast furnace shells, and chimneys benefit greatly from this property. In conclusion, using steel fiber-reinforced concrete at high temperatures offers a variety of advantages, including improved mechanical strength, thermal stability, and resistance to cracking and spalling. Its ductility and toughness, combined with efficient heat dissipation, make it a reliable and effective material for high-temperature applications in construction.

1.3 TYPES OF FIBER

There are various types of fiber available some of the different types of fibers used in construction:

i. **Synthetic Fibers:** These fibers are made from materials such as polypropylene, nylon, and polyester. Synthetic fibers are the best choice for use in concrete constructions exposed to hostile conditions because of their great resistance to chemicals, UV radiation, and moisture.

ii. **Natural Fibers:** Natural fibers are derived from plants such as coconut, jute, and hemp. These fibers are environmentally friendly and have good tensile strength, but they are less durable than synthetic fibers and are therefore typically used in non-structural applications.

iii. **Glass Fibers:** Glass fibers are made from fine strands of glass and are commonly used to reinforce concrete structures that require high resistance to impact and abrasion. Glass fibers offer high dimensional stability and are resistant to chemicals.

iv. **Carbon Fibers:** Carbon fibers are composed of carbon atoms bonded together in a crystalline structure. These fibers are perfect for reinforcing constructions that need high strength-to-weight ratios, such as bridges and aircraft parts since they have extraordinarily high strengths and stiffness.

v. **Steel Fibers:** Steel fibers are made from thin, flexible steel strands and offer excellent resistance to impact and fatigue. They are commonly used in industrial flooring, tunnel linings, and precast concrete products. These fibers come in various shapes and sizes, each with its unique benefits and limitations. Here are some of the different types of steel fibers used in construction:

A. **Hooked Steel Fibers:** These fibers have a hooked shape, which helps them bond more effectively with the concrete matrix. Hooked steel fibers are often used in precast concrete panels, industrial flooring, and shotcrete applications.

B. **Straight Steel Fibers:** Because they are smooth and straight, straight steel fibers are perfect for reinforcing concrete in high-traffic locations like airport runways, bridge decks, and commercial floors.

C. **Crimped Steel Fibers**: Crimped steel fibers have a wavy shape, providing increased surface area for bonding with the concrete. These fibers are frequently utilized in precast concrete goods, shotcrete applications, and tunnel linings.

D. **Deformed Steel Fibers:** Deformed steel fibers have a twisted shape that creates more friction between the fibers and the concrete. Higher bond strength and enhanced toughness are the results of this increased friction.

E. **Micro Steel Fibers:** Micro steel fibers are extremely small fibers that are often added to concrete to improve its durability and resistance to cracking. These fibers are employed in high-performance concrete applications and generally have a diameter of less than 0.3 mm.

1.4 OBJECTIVES OF THE STUDY

The main objectives of the study are:

- To investigate the mechanical properties of steel fiber-reinforced concrete with different aspect ratios.
- To assess the effect of elevated temperature on the mechanical properties of the concrete embedded with steel fiber.
- To perform a regression analysis aimed at establishing a relationship for residual mechanical properties.

1.5 ORGANIZATION OF THESIS

Chapter 1 Gives a concise explanation of fiber-reinforced concrete and outlines the goals of the research as well as the parameters of the study.

Chapter 2 Provides a comprehensive literature review associated with fiber-reinforced concrete at ambient and elevated temperatures.

Chapter 3 Describes the methodology used and provides information on the experimental and theoretical procedures.

Chapter 4 Presents the results of the experimental work and discussions of the outcomes.

Chapter 5 Address the findings of the present study and some recommendations for potential future research.

CHAPTER 2

LITERATURE REVIEW

2.1 GENERAL

In order to comprehend the phenomena and the state of the utilisation of steel fiber in concrete today, a thorough literature review was conducted for this chapter. A literature assessment was necessary to determine the research gaps in the suggested topic of study and to comprehend the technique for carrying out future experimental studies to investigate the impact of steel fiber aspect ratio at various temperatures.

2.2 REVIEW OF STUDIES ON THE EFFECT OF STEEL FIBER IN CONCRETE AT AMBIENT TEMPERATURE

Ranj Baran et al (2018) investigated the cyclic performance of steel-fiber-added reinforced concrete beams. The results showed that the maximum strength and ultimate displacement improved with the accumulation of steel fibers, up to a maximum of 2% fiber volume percentage. Steel fibers also improved damping, energy absorption, and stiffness preservation properties. These findings show that steel fibers have the ability to improve the cyclic performance of reinforced concrete beams. Higher fiber fractions and implications for long-term durability in this context can be explored in further study.

Wasim et al (2018) concluded that the insertion of steel fibers can lower the brittleness and low tensile strength of concrete. Superior performance is provided by SFRC, which exhibits great toughness, improves ductility and residual strength and prevents crack propagation. The mechanical characteristics of concrete were examined in this study in relation to various steel fiber lengths, diameters, and volume fractions. Significant improvements were found, including a 10–25% rise in compressive strength, a 3–47% increase in direct tensile strength, and a rise of up to 140% in flexural strength. With good agreement to experimental findings, a mathematical framework for strain and stress relationships in fiber-reinforced concrete was suggested.

Li et al (2017) In order to increase the performance of PC in shear keys of submerged tunnels, a study was conducted to optimize the fiber composition in HFRC. We found that adding steel and basalt fibers greatly boosted toughness, shear strength and residual load via extensive tests, including direct shear, flexure, tensile, compression, and breaking tests. The strongest and toughest group was C2, which had 4.5 kg/m3 basalt fibers and 180 kg/m3 steel fibers.

Dahak and Charkha (2016) explored the effects of various steel fiber kinds on various concrete strength levels. The experimental study consistently used 2.5% of cement weight for various fibers. Compressive strength and flexural strength were among the strengths that were investigated. The findings from numerous studies and their experimental comparisons showed that mixing steel fiber to concrete significantly improved its compressive and flexural strengths. These enhancements were noted with various aspect ratios, constant volume fractions, and different kinds of steel fibers.

Gupta et al (2016) investigated how steel fiber effect the property of concrete. Their experimental examination revealed that the functioning of concrete in terms of tensile strength and flexural strength is greatly improved by the inclusion of steel fibers. Steel fibers added to concrete increase its ductility and energy absorption capabilities, making it more resilient to failure and cracking under different loading scenarios. The study also emphasises how important fiber quantity and aspect ratio are in enhancing the mechanical characteristics of mix.

Xu et al (2009) evaluated the practicability of previously presented empirical relationships for mechanical properties in regular concrete, PFRC, and GFRC to SFRC. The relationships between the mechanical characteristics of SFRC were examined after extensive experimental data had been gathered from published literature. The findings showed that the stated empirical connections did not apply to SFRC. With coefficients of determination of 0.94 and 0.90, accordingly, regression analysis produced novel power relations.

Thomas et al (2005) constructed models using a regression analysis of 60 test data points to estimate the impact of fiber addition on the mechanical characteristics of concrete. Split tensile strength, Compressive strength, modulus of rupture, modulus of elasticity, post-cracking performance, Poisson's ratio, and peak compressive stress-strain were among the attributes that the models correctly predicted. The work cast doubt on previously accepted theories centred around the law of mixtures by highlighting the major role that fiber-matrix contact plays in increasing mechanical characteristics.

2.3 REVIEW OF STUDIES ON THE EFFECT OF STEEL FIBER IN CONCRETE AT ELEVATED TEMPERATURE

Tao et al (2022) investigated the impact of the steel fiber volume ratio, four HSCSBSF specimens, including one without steel fiber, were evaluated. According to the findings, HSCSBSF with higher steel fiber volume ratios displayed greater cracking loads and a 34.3% increase in bending capacity in comparison to HSCSBSF with a 0% volume ratio. Flexural stiffness greatly increased, and the ductility coefficient of the HSCSBSF with a 2% volume ratio of steel fiber was 25% higher. A trustworthy bearing capacity prediction model was created, showing a satisfactory level of agreement with test results. Overall, steel fiber reinforcement in HSCSBSF improved ductility, flexural stiffness, bearing capacity, and cracking load, offering helpful information for evaluation of structure and prediction.

Cao et al (2022) examined the effects of high temperatures on Steel-Basalt Hybrid Fibres Reinforced Cement-Based Composites (SBFRCC). Important outcomes include: SBFRCC has outstanding mechanical capabilities at room temperature, but as the temperature increases, the colour and mass of the steel and basalt fibres drastically alter. However, a high basalt fibre content has a detrimental effect on compressive strength. The inclusion of steel and basalt fibres significantly increases residual flexural and splitting tensile strength. Models were developed to assess the relationship between relative strength, fibre content, and temperature. The multi-stage cracking resistance of basalt and steel fibres effectively inhibits the initiation and propagation of fractures. At 900 degrees Celsius, hybrid fibres may still cross fissures despite some deterioration. Overall, these findings advance knowledge of SBFRCC's behaviour at high temperatures and its potential for use in buildings as a fire-resistant material.

Zhang et al (2021) investigated the effects of flax and steel fibers mixed on mechanical properties of ultra-high-performance concrete (UHPC) after being exposed to high temperatures. The findings shown that utilising steel and flax fibres together completely prevented spalling even at low fibre levels, whereas using either fibre alone did not do so even at high fibre concentration. The synergistic effect of hybrid fibres was considered to be caused by the increased permeability of flax fibres and the bridging action of steel fibres at high temperatures. The enhanced permeability was brought on by both the larger flax and steel fibre interfacial spaces. The connection of the matrix and steel fibres decreased spalling.. The loss in compressive strength brought on by the inclusion of flax fibers was further affected by the combination of steel and flax fibers. These results offer insightful tips for preventing spalling in UHPC applications.

Deshpande et al (2019) observed that combining steel and polymer fibers in a specific FRC improved both compressive and tensile characteristics at high temperatures. After being exposed to temperatures of up to 800 °C, the residual compressive and tensile characteristics of HFR-SHCC were experimentally assessed. Tests comparing ordinary concretes, steel FRC, and conventional SHCC were performed. These materials were surpassed by HFR-SHCC, which showed greater residual tensile strength after being exposed to high temperatures while preserving the advantages of traditional SHCC. The study demonstrates how HFR-SHCC may improve structural integrity and toughness in high-temperature settings, opening the door for novel building applications.

Novak et al (2018) examined the mechanical characteristics of concrete composites with fiber additions at both low and high temperatures. In order to establish the heating periods to 200 °C, 400 °C, and 600 °C, heat transfer experiments were conducted after specimens had been aged and dried. On 150 mm cubes, compression and splitting tensile tests were performed. Results showed maximum and minimum strength at various temperatures, advancing information for the construction of fire-resistant concrete.

Yermak et al (2017) examined the mechanical characteristics of concrete composites with fiber additions at both low and high temperatures. In order to establish the heating periods to 200 °C, 400 °C, and 600 °C, heat transfer experiments were conducted after specimens had been aged and dried. On 150 mm cubes, compression and splitting tensile tests were performed. Results showed maximum and minimum strength at various temperatures, advancing information for the construction of fire-resistant concrete.s.

Richardson et al (2017) studied how temperature changes affected the characteristics of concrete with steel and synthetic fiber additives. At -20°C, concrete worked well, but at 60°C, it somewhat degraded. Overall, steel fiber concrete fared best, although synthetic fibers had the best flexural strength. This study advances our knowledge of how various fibers affect the characteristics of concrete at various temperatures.

Abdallah et al (2017) studied how high temperature affected the bonding properties of steel fibers with various cementitious matrixes. The strength of ultra-high-performance mortar (UHPM), medium strength concrete (MSC), high strength concrete (HSC), and standard strength concrete (NSC) were tested using pull-out experiments on fibers with straight and hooked ends. It was discovered that there were only minor variations in compressive strength and pull-out response up to 400 °C after heating the specimens to temperatures ranging from 100 to 800 °C. The pull-out strength, however, significantly decreased at temperatures over 400 °C, with maximum loads for HSC, NSC, and MSC respectively, falling by 56%, 54%, and 64% at 800 °C. These results emphasise how the steel fiber-matrix bond in concrete buildings is affected by high temperatures.

Haktanir et al (2015) studied how hot temperatures affected concrete with steel fiber reinforcement. Steel fibers increased ductility, but high temperatures (900–1200 °C) significantly decreased toughness, compressive strength, and elastic modulus. The samples with 1.0% steel fiber saw the smallest reduction in strength. The greatest harmful effects occurred at temperatures between 1100 °C and 1200 °C. Steel fibers can reduce strength at high temperatures, but not entirely. Better resistance is provided with 1.0% steel fiber incorporation. The mechanical qualities of the concrete are more difficult to maintain in hotter climates.

Khaliq et al (2011) investigated how temperature affected the thermal and mechanical properties of both SCC and FRSCC. Gathered knowledge on the behaviour of these materials by measuring thermal conductivity, thermal expansion, specific heat, compressive strength, tensile strength, and elastic modulus between 20 and 800 °C. Four different SCC combinations, including plain SCC, steel fibre reinforced SCC, polypropylene fibre reinforced SCC, and hybrid fibre reinforced SCC, were examined. Mechanical testing showed that adding steel fibres significantly improved SCC's splitting tensile strength and elastic modulus at high temperatures. Additionally, results showed that in the 20–1000 °C temperature range, FRSCC displayed somewhat greater thermal expansion than SCC. These empirical data made it possible to develop straightforward relationships that depict the thermal and mechanical characteristics of SCC and FRSCC in response to temperature. This research offers important insights for upcoming applications and designs in the realm of concrete technology by illuminating the complex interplay between temperature and the characteristics of SCC and FRSCC.

2.4 GAP OF THE STUDY

From the literature study, it was concluded that:

- To date, limited research has been conducted to thoroughly investigate the impact of varying aspect ratios of hook-ended steel fibers. This gap in the existing literature calls for a more comprehensive exploration of the effects of different aspect ratios on various parameters.
- Minimal research has been done on the elevated temperature of the different aspect ratios of hook-ended steel fiber.
- At the crux of the matter lies a contentious issue: the discord surrounding the optimal equation for accurately predicting the residual mechanical strength of concrete when exposed to elevated temperatures.

CHAPTER 3

METHODOLOGY

3.1 GENERAL

A comprehensive experimental investigation program was devised and executed to examine the behavior of plain and fiber-reinforced concrete under various temperature conditions, including ambient and elevated temperatures. This study focuses on conducting experimental studies encompassing diverse parameters such as varying volume fractions of fibers, different aspect ratios, and multiple temperature levels. By exploring these factors, aim to gain deeper insights into the performance and characteristics of concrete specimens, thereby pushing the boundaries of knowledge in this field.

3.2 METHODOLOGY

The methodology employed in this study encompasses a systematic and well-structured approach to investigate and analyze the subject matter. This section outlines the steps undertaken to achieve the objectives of the research, ensuring the reliability, validity, and accuracy of the findings.

By examining existing scholarly works, research articles, and relevant sources, a solid understanding of the current state of knowledge is established. This process not only allows for the identification of existing research gaps but also provides valuable insights and establishes a contextual framework for the subsequent stages. Upon recognizing these research gaps, the next phase involves procuring the necessary materials and resources for experimentation. Rigorous attention is paid to selecting suitable materials that align with the objectives of the study, ensuring their availability and compatibility with the research design.

Testing plays a crucial role in assessing the properties and characteristics of the selected materials. Through a series of well-defined and meticulously conducted tests, the performance, durability, and mechanical properties of the materials are thoroughly evaluated. These tests provide valuable data and insights, forming the basis for subsequent decision-making processes. The subsequent step revolves around mix design, specifically focusing on achieving the desired concrete strength and durability. Meticulous calculations, evaluations, and adjustments are made to determine the optimal proportions of various components, aiming to achieve the desired characteristics and performance of the concrete mixture. Once the mix design is finalized, concrete samples are carefully cast and allowed to cure over a specified period, typically 28 days. This period enables concrete to attain its maximum strength and stability. Following the curing process, the samples undergo a battery of tests to evaluate their mechanical properties, including compressive strength, tensile strength, and other relevant factors.

To explore the impact of temperature on the optimized concrete mixture, additional samples are cast and subjected to controlled temperature conditions. These temperature experiments simulate real-world scenarios and provide insights into the behavior and performance of the concrete under varying thermal conditions. The final phase entails a comprehensive analysis of the collected data, where statistical techniques and analytical tools are employed to derive meaningful conclusions. The results obtained from the tests and experiments are scrutinized, compared, and interpreted to shed light on the performance and behavior of the concrete mixture.

The methodology employed in this study ensures a rigorous and scientific approach to obtain reliable and valid results. It serves as a roadmap for the research process, guiding through the necessary steps to uncover new knowledge, bridge existing gaps, and contribute to the advancement of the field. The flow diagram of methodology is show in figure 3.1.

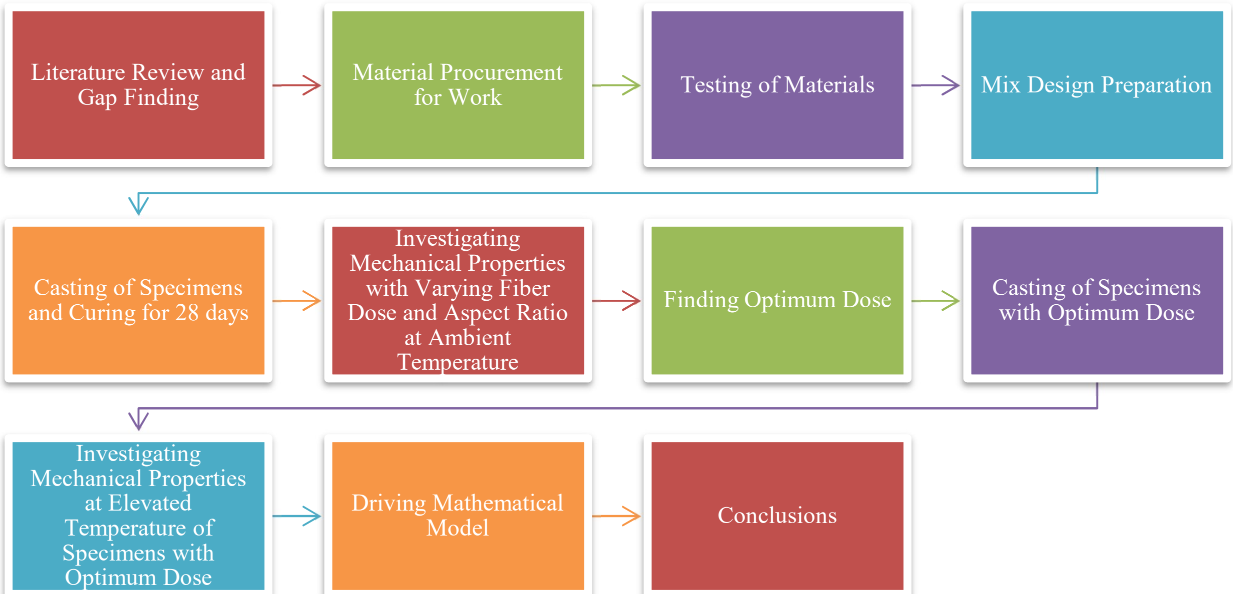


Figure 3. 1 Working Methodology

3.3 MATERIAL TESTING

Material characterization is crucial for assessing the absence of harmful elements and ensuring compliance with performance standards. Thorough testing and adherence to specifications outlined in IS codes play a pivotal role in evaluating material properties. Here, we present an overview of the conducted tests and associated specifications.

3.4 CEMENT

The experimental investigation exclusively utilized 53-grade Ordinary Portland cement conforming to IS: 12269 2013, consistently following the prescribed guidelines outlined in as per IS: 4031 (Part 4) 1988, the standard consistency of the cement was found as per IS: 4031 (Part 5) 1988, the setting time (initial and final) of cement was found. As per IS: 4031 (Part 6) 1988, the compressive strength of cement was tested (IS 4031- Part IV, 1988; IS 4031- Part V, 1988; IS 4031- Part 6, 1988). For casting all the specimens, the cement was purchased from the same source. The specific gravity of the cement was 3. 15. The obtained test results showcasing the properties are presented in the following Table 3.1

Table 3. 1 Physical properties of ordinary Portland cement

Physical properties	Experimental values	Recommended values
Normal consistency (% by weight of cement)	34	30-35
Setting time (minutes) (i) Initial (ii) Final	 65 min 450 min	 30 min (minimum) 600 min (maximum)
Compressive strength (MPa) (i) 7- days (ii) 28 days	26 42.4	33 43
Bulk density (kg/m^3)	1438 (kg/m^3)	-
Specific Gravity	3.15	-

3.5 FINE AGGREGATE

The experimental investigation utilized locally sourced manufactured sand, also known as M-sand, as the fine aggregate. This M-sand adhered to the specifications outlined in IS: 383:2016 (IS 383, 2016). Its specific gravity was determined to be 2.65, indicating its density relative to water. A sieve analysis confirmed that the M-sand fell under the classification of grade Zone II. To assess its specific gravity, the fine aggregate was subjected to testing in accordance with IS: 2386(PIII)-1963 (IS:2386 (PART III)-1963, 2002). The results indicated that the quality of the M-sand used was deemed satisfactory. For a comprehensive overview of the fine aggregate's characteristics, refer to Table 3.2 and Table 3.3.

Table 3. 2 Sieve analysis of fine aggregate

S. No.	Weight Retained (g)	Cumulative weight retained (g)	% of cumulative weight retained	% Passing	Recommended values by IS Code for zone 2
10 mm	0	0	0	100	100
4.75 mm	0	0	0	100	90-100
2.36 mm	110	110	10.14	89.86	75-100
1.18 mm	175	285	26.27	73.37	55-90
600 µ	265	550	50.69	49.31	35-59
300 µ	140	690	63.59	36.40	8-30
150 µ	170	860	79.26	20.73	0-10/20

Table 3. 3 Physical properties of fine aggregate

Physical properties	Observed values	Recommended values
Grading zone	2	-
Fineness modulus	2.59	2.2-2.6
Specific Gravity	2.65	2.6-2.75

3.6 COARSE AGGREGATE

Our fiber concrete mixes incorporated two distinct single-sized uniformly graded crushed stone aggregates. These aggregates spanned a range of 20 mm to 12.5 mm, commonly referred to as 13 mm aggregate, and 12.5 mm to 10 mm, known as 10 mm aggregate. These aggregates were readily available in the market and primarily composed of granite. For a comprehensive understanding of the coarse aggregates, including their physical properties, consult Table 3.4.

Table 3. 4 Physical properties of coarse aggregate

Physical properties	Observed values		Recommended values
	10 mm aggregate	20 mm aggregate	
Specific Gravity	2.72	2.74	2.6-2.8
Water Absorption (%)	0.35	0.25	0.5-1%
Dry density (kg/m^3)	1574.10	1618	-
Aggregate crushing value (%)	17.63	19.5	Not more than 45%
Aggregate impact value	24	20.2	Not more than 45%

3.7 WATER

We employed standard potable water for both the casting and curing processes of our specimens. Water, a crucial component in concrete development, fulfills a vital role by acting as a cohesive paste that binds all the aggregates together. Its quality, conforming to the stipulations set forth by IS 456:2000 (Bureau of Indian Standard (BIS), 2000), was carefully ensured throughout the study. The significance of water in the concrete mixture cannot be overstated, as it interacts with the other constituents to create a robust and durable final product. Rest assured, our utilization of high-quality water contributes to the integrity and longevity of our research findings.

3.8 SUPERPLASTICIZER

Superplasticizers, an advanced evolution of plasticizers, belong to a distinctive and relatively recent category. Chemically distinct from conventional plasticizers, superplasticizers offer remarkable benefits. One notable advantage is their ability to reduce water content by up to 30% while maintaining optimal workability, surpassing the potential water reduction of only 15% achievable with regular plasticizers. For this particular study, we employed the SikaPlast-5061 NS2 superplasticizer, which boasts a modified polycarboxylate chemical base. This cutting-edge formulation exhibits a density of 1.08 kg/l, contributing to its excellent performance. Additionally, the pH level of this superplasticizer hovers around 6, ensuring compatibility with various concrete compositions and enhancing its overall effectiveness. Through the implementation of SikaPlast-5061 NS2, we aimed to harness the full potential of superplasticizers to optimize our experimental outcomes.

3.9 FIBER VOLUME FRACTION

The determination of fiber quantity in a concrete mix is more accurately defined by considering the volume occupied by the fiber fraction in relation to the overall volume of the structural element. Within the scope of this study, the volume fraction of fibers ranged from 0% to 1.5% with increments of 0.25%. An essential parameter in fiber technology is the aspect ratio, denoted as the L/D ratio, which signifies the ratio of fiber length to diameter. This aspect ratio plays a critical role in influencing the properties and behavior of Fiber Reinforced Concrete (FRC). The present investigation aims to examine the effects of hook-end steel fibers with distinct aspect ratios (65 and 55) on the strength of concrete under both ambient and elevated temperatures physical appearance of which is shown in figure 3.2. The steel fiber with an aspect ratio of 65 exhibits a tensile strength of 1250 Pa, while the one with an aspect ratio of 55 possesses a higher tensile strength of 1500 Pa. These varying aspect ratios entail diverse properties, as detailed in table 3.5, which further highlights the characteristics of the steel fibers under consideration. By exploring the correlation between fiber content and concrete strength, this study aims to provide comprehensive insights into the optimal utilization of steel fibers in FRC applications, particularly with respect to the aspect ratio's influence on material performance. Through an extensive examination of concrete behavior under different temperature conditions, this research endeavors to enhance the understanding of how varying aspect ratios impact the mechanical properties and structural integrity of FRC.

Table 3. 5 Fiber Properties

S.No.	Length (mm)	Diameter (mm)	Aspect Ratio	Strength (N/mm^2)
1	35	0.55	65	1250
2	50	0.9	55	1500

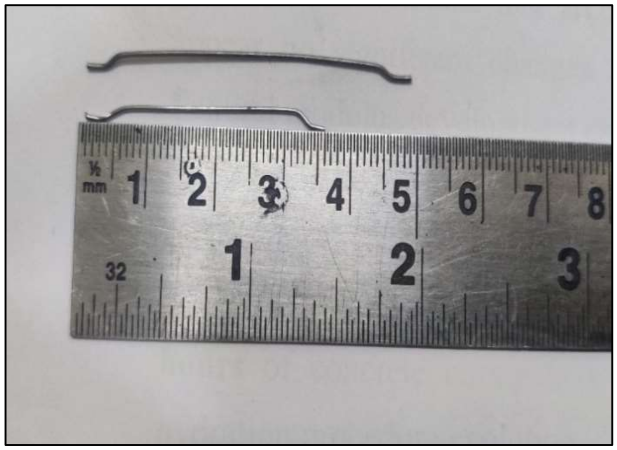


Figure 3. 2 Physical appearance of hook-ended steel fiber

3.10 EXPERIMENTAL PROGRAM AND WORK

The subsequent section provides a detailed explanation of the experimental methodology employed. Elaboration on the instruments employed for the experiment and the specific conditions under which the tests were conducted will be provided.

3.11 MIX DESIGN

The mix design for the given project was meticulously calculated in compliance with the Indian Standard (IS) code IS 10262:2019. The resulting quantities of materials are presented in Table 3.6. Efforts were made to ensure technical accuracy and adherence to the specified standard throughout the mix design process. By employing the methodology outlined in IS 10262:2019, the appropriate proportions of materials were determined, considering factors such as strength requirements, durability considerations, and workability constraints.

Table 3. 6 Mix Proportions for 1 m^3

Material	Proportions for 1 cubic meter by weight (kg)						
	Mix-1	Mix-2	Mix-3	Mix-4	Mix-5	Mix-6	Mix-7
Cement	362	362	362	362	362	362	362
Sand	600.9	600.9	600.9	600.9	600.9	600.9	600.9
Coarse Aggregate	1336.3	1336.3	1336.3	1336.3	1336.3	1336.3	1336.3
Water	162.4	162.4	162.4	162.4	162.4	162.4	162.4
w/c	0.43	0.43	0.43	0.43	0.43	0.43	0.43
Admixture	3.4	3.4	3.4	3.4	3.4	3.4	3.4
Steel fiber Dose	0 (0)	0.25% (19.63)	0.50% (39.25)	0.75% (58.88)	1.00% (78.50)	1.25% (98.13)	1.50% (117.75)

3.12 SPECIMEN PREPARATION

This study focuses on the utilization of M30-grade concrete. The water-binder ratio for cement-based composites is set at 0.43, while the sand-to-cementitious material ratio is 0.62. To adjust the fluidity of the fresh slurry, a water-reducing agent is employed. Various mixtures are prepared with different fiber inclusion rates, specifically 0.25%, 0.50%, 0.75%, 1.00%, 1.25%, and 1.50%. These mixtures are labelled as 65AR0.25, 65AR0.50, 65AR0.75, 65AR1.00, 65AR1.25, and 65AR1.50 for fibers with an aspect ratio of 65, and 55AR0.25, 55AR0.50, 55AR0.75, 55AR1.00, 55AR1.25, and 55AR1.50 for fibers with an aspect ratio of 55. A group named PCS, which does not contain any fiber, is included for comparison purposes to evaluate the effectiveness of the enhancement. The preparation process involves the use of a concrete mixer. Initially, cement, sand, and aggregates are added to the mixer and mixed for a duration of 90 seconds. Subsequently, steel fibers are gradually introduced into the mixture and thoroughly combined. Following this, water and the water-reducing agent are added to the mixer, and the mixture is swirled for 120 seconds to attain the desired fluidity. The freshly mixed material is then poured into moulds and subjected to vibration for 30 seconds. After 24 hours of air-curing, the specimens are demoulded and placed in a standard water curing tank for a duration of 28 days some of the casted specimens are sown in figure 3.3 and figure 3.4. Table 3.7 and table 3.8 illustrates the total number of specimens required to study the effect of aspect ratio on the mechanical properties of steel fiber concrete at normal and elevated temperature.

Table 3. 7 Specimens required for Objective 1

S.No.	Fiber Dose (%)	No of Cubes	No of Cylinder
1	0.25	3*2	3*2
2	0.5	3*2	3*2
3	0.75	3*2	3*2
4	1.00	3*2	3*2
5	1.25	3*2	3*2
6	1.50	3*2	3*2
Total		**36**	**36**

Table 3. 8 Specimens required for Objective 2

S.No.	Temperature	No of Cubes	No of Cylinders	No of Beams
1	0	3*2	3*2	3*2
2	125	3*2	3*2	3*2
3	250	3*2	3*2	3*2
4	375	3*2	3*2	3*2
Total		**24**	**24**	**24**

Figure 3. 3 Moulded and Unmoulded specimens

Figure 3. 4 Cubes, Cylinder, and Beams for Testing

3.13 TEST TO EVALUATE PROPERTIES OF FIBER-REINFORCED CONCRETE

3.13.1 WORKABILITY TEST

On-site compaction techniques and setting conditions are key factors impacting the workability of concrete mixes. Workability is influenced by various factors, such as the quality and quantity of fiber present in the concrete, as well as the size and shape of the mold used. In accordance with IS 1199:1959, the slump is systematically measured and recorded at each stage of the mixing process.

3.13.2 REBOUND HAMMER TEST ON CUBES

The rebound hammer test is a widely adopted non-destructive technique for evaluating the compressive strength of concrete. Renowned for its simplicity and convenience, this method provides a rapid assessment of concrete strength. To conduct the test, a plunger is firmly pressed perpendicular to the concrete surface, imparting a force that releases the latch and generates an impact on the concrete as shown in figure 3.5. The resulting rebound number, an output of the rebound hammer, directly corresponds to the surface hardness of the concrete. This surface hardness, in turn, correlates with the concrete’s compressive strength. The relationship between the rebound number and compressive strength is defined by EN 13791 – 2007, a recognized standard in the field. This relationship is mathematically expressed by the following equation:

$$fc = 1.73\ X\ R - 34.5$$

Where, fc is the compressive strength and R is the rebound number.

By leveraging the rebound hammer test in accordance with the prescribed standards, the compressive strength of concrete can be estimated promptly and accurately. This technique offers a valuable means of assessing the structural quality and durability of concrete elements without the need for destructive sampling.

Figure 3. 5 Rebound Hammer Testing

3.13.3 COMPRESSIVE STRENGTH TEST ON CUBES

In order to comprehensively evaluate the compressive strength of concrete, an innovative and meticulous approach was employed. The research utilized M30 grade nominal mix as the foundation, and thirteen distinct concrete mixes were meticulously crafted to examine the influence of different volume percentages of steel fiber and aspect ratios on the concrete's performance. To establish a reliable baseline, one mix was meticulously designed as the Control Mixture, devoid of any steel fiber. Meanwhile, the remaining twelve mixes were formulated based on a thorough literature review and industry best practices, ensuring their alignment with established guidelines.

Once the optimal dosage of steel fiber was determined for each aspect ratio, an additional phase commenced. Specifically, six mixes were meticulously prepared, incorporating the determined optimal dosage of steel fiber. Subsequently, concrete cubes were subjected to varying temperatures, namely 125°C, 250°C, and 375°C, for a duration of

3 hours each. This temperature exposure aimed to assess the performance of the concrete under elevated thermal conditions.

To ensure reliable and precise results, each mix underwent a stringent testing procedure at the age of 28 days, adhering strictly to the guidelines provided by IS: 516-1959. A 2000kN compression testing machine as displayed in figure 3.6 (a) was employed to conduct all the strength tests. Meticulously prepared cube moulds with dimensions of 150 mm x 150 mm x 150 mm were used, meticulously cleaned and adequately oiled to prevent any interference with the concrete's behavior. Rigorous attention was paid to the preparation process, guaranteeing accurate and consistent results. The concrete mixture was carefully poured into the moulds, ensuring complete filling, followed by meticulous compaction using a vibration table to eliminate any voids or inconsistencies.

3.13.4 SPLIT TENSILE STRENGTH ON CYLINDER

A technique for testing concrete's tensile strength that involves employing a cylinder with a divided vertical diameter. It is an indirect approach used in CTM to measure the tensile strength of concrete, as shown in figure 3.6(b). The split tensile strength and durability investigations were conducted using a cylinder that had a 150mm diameter and 300mm height. The IS: 5816-1999 standard was followed when conducting this test. To make it simple to extract specimens from the mould, crude oil was placed along the inside surfaces of the mould. Along its whole length, concrete was poured and tightly compressed. The load must be applied without shock and raised continuously at a nominal rate between 1.2 N/mm2/min and 2.4 N/mm2/min. The load at which the cylinder failed must be documented in order to use the following equation to get the split tensile strength:

$$T = \frac{2P}{\pi L d} \qquad 3.1$$

T: Splitting tensile strength, MPa,

P: Maximum applied load indicated by testing machine,

L: Length in m and

d: Diameter in m

(a) **(b)**

Figure 3. 6 Testing Using CTM (a) Cube Test and (b) Cylinder Test

3.13.5 FLEXURAL STRENGTH TEST ON BEAMS

To comprehensively investigate the impact of different fibers on the flexural strength of concrete under elevated temperature conditions, an extensive study was conducted. Flexural strength, which characterizes a beam's ability to withstand failure when subjected to bending loads, serves as a critical measure of the material's resilience. For the experimental setup, rectangular specimens were employed and subjected to a two-point loading system, where the loads were precisely positioned at the midpoint (one-third) of the support span. Each mix was utilized to cast three beams measuring 500x100x100mm. To ensure precise moulding and dimensional accuracy, cast iron moulds were employed, tailored to accommodate the designated beam size. Following the casting process, the formwork sides were carefully removed after a curing period of 24 hours, allowing the specimens to set and gain strength. Subsequently, water curing was carried out for a duration of 28 days to foster optimal concrete hydration.

To simulate elevated temperature conditions, the cured specimens were then subjected to an exposure regimen in accordance with the ISO 834 curve (ISO 834-1, 1999). This standardized curve represents the time-temperature relationship for fire resistance testing. During the testing phase, the prism specimens were subjected to progressive loading until failure, utilizing a computerized Universal Testing Machine (UTM) as shown in figure 3.7. The ultimate loads at failure were meticulously recorded, providing crucial data for the evaluation and comparison of flexural strength characteristics across various fiber-reinforced concrete compositions under elevated temperature conditions. Flexural strength is calculated with the equation:

If a is greater than 20 cm for a 15 cm and 13.3 cm for 10cm specimen,

$$f_b = \frac{Pl}{bd^2} \quad 3.2$$

And if a is less than 20cm and greater than 17 cm for 15 cm, 11< a < 13.3cm for 10 cm specimen,

$$fb = \frac{3Pa}{bd^2} \quad 3.3$$

Where "a" is the distance between the line of fracture and nearest support, P is the load at failure, l is the support length, b is the width of the specimen and d is the failure point depth.

Figure 3. 7 Testing of Beams Using UTM

CHAPTER 4

RESULT AND DISCUSSION

4.1 GENERAL

In this chapter, a comprehensive examination of the mechanical properties and behavior of fiber-reinforced concrete is presented, encompassing three distinct sections. The first segment concentrates on the meticulous evaluation of the compressive and tensile strength characteristics of fiber-reinforced concrete composite cubes and cylinders. Notably, the investigation encompasses fiber dosages ranging from 0% to 1.50%, encompassing increments of 0.25%, 0.5%, 0.75%, 1.0%, 1.25%, and 1.50%. Additionally, both 65 and 55 aspect ratios of fiber are considered, ensuring a comprehensive understanding of their influence. The second section provides a detailed analysis of fiber-reinforced concrete specimens, namely cubes, cylinders, and beams, incorporating hook-ended steel fibers. These specimens are subjected to elevated temperatures for a duration of 3 hours. The investigation specifically focuses on fiber dosages of 0.75% and 0.5%, encompassing both aspect ratios. Through this analysis, a comprehensive understanding of the performance and behavior of fiber-reinforced concrete under elevated temperature conditions is obtained. In the final section, mathematical equations are derived to predict the strength characteristics of concrete. These equations are specifically developed to describe and model the behavior of fiber-reinforced concrete under both ambient and elevated temperature conditions. By formulating these equations, valuable insights into the strength properties and performance of fiber-reinforced concrete are obtained, facilitating enhanced understanding and predictive capabilities.

4.2 MECHANICAL PROPERTIES OF FRC AT AMBIENT TEMPERATURE

The mechanical properties of the fiber reinforced are derived by calculating the compressive strength and split tensile strength of fiber-reinforced concrete. This will give an overview of the effect of the aspect ratio of steel fiber in concrete.

4.2.1 WORKABILITY TEST

The measured slump values for each concrete mixture, indicating the degree of subsidence observed in millimeters (mm) are mentioned in Table 4.1. These measurements serve as indicators of the fluidity and cohesiveness of the fresh concrete. A higher slump value typically signifies increased workability, facilitating easier placement and compaction during construction processes. Moreover, the table demonstrates the varying quantities of steel fibers employed in each concrete mixture. The inclusion of steel fibers allows for assessing their impact on the slump characteristics of the concrete, thereby gauging their influence on workability.

Table 4. 1 Slump Values

Fiber Dose (%)	Slump value for 65 AR Fiber (mm)	Slump value for 65 AR Fiber (mm)
0	100	100
0.25	93	95
0.50	89	90
0.75	82	84
1.00	76	79
1.25	69	72
1.50	61	64

By incorporating fiber into the concrete mix, Figure 4.1 demonstrates the impact on the workability of fresh concrete. The workability of concrete is influenced by the aspect ratio of fibers used in the mix. When considering a 65-aspect ratio and a 55-aspect ratio, the workability is found to be 39% and 36% lower, respectively, compared to the control mix. This indicates that the addition of fibers with a 65-aspect ratio at a rate of 1.5% by volume of concrete results in a maximum decline in concrete workability, which is approximately 3% less than the decline observed with fibers of a 55-aspect ratio. It is observed that fibers with higher aspect ratios have a greater impact on reducing concrete workability for a given volume fraction. The addition of fibers to concrete can introduce a network structure that hinders the flow and segregation of the mixture. Due to their significant content and wide surface area, fibers tend to absorb more cement paste and form a wrapping effect. The increased viscosity of the mixture, caused by the absorption of cement paste by the fibers, leads to a reduction in the slump of the concrete.

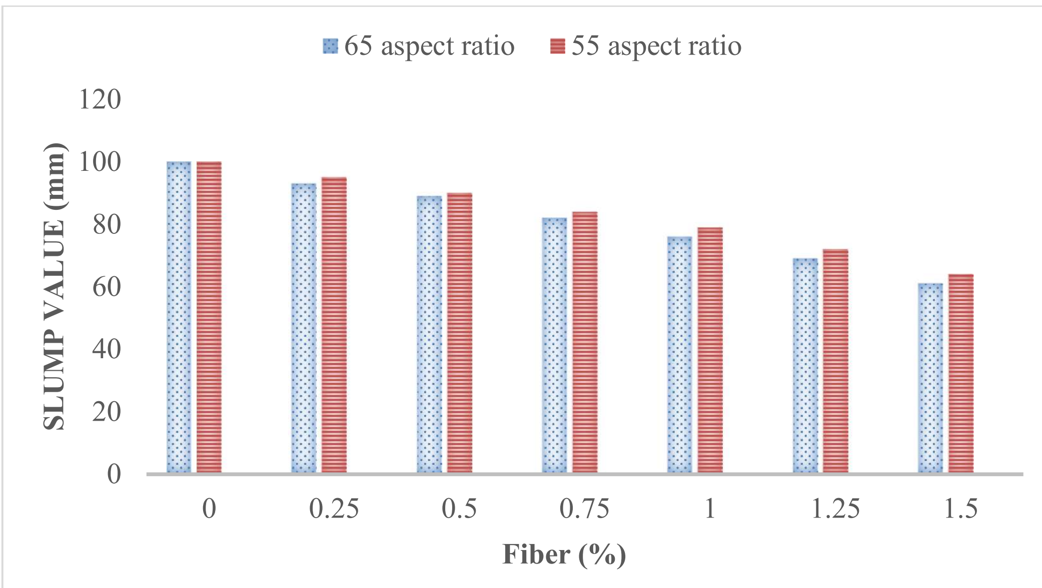


Figure 4. 1 Workability of Concrete on Adding Different Fibers.

4.2.2 COMPRESSIVE STRENGTH OF FIBER-REINFORCED CONCRETE CUBES

The average compressive strength results obtained from three specimens of different concrete mixtures with varying fiber contents at a testing period of 28 days are presented in Table 4.2, Table 4.3, and Figure 4.2. The measurements were performed using a compression testing machine (CTM) and a Rebound hammer. The inclusion of fibers in the concrete mixture improved compressive strength, as evident from the data. The maximum compressive strength recorded for cubes tested with a CTM, containing fibers with an aspect

Table 4. 2 Compressive strength by CTM

Fiber Dose (%)	65 AR (MPa)	% Increment	55 AR (MPa)	% Increment
0	45.76	-	45.76	-
0.25	54.93	20.04	51.77	13.13
0.50	61.26	33.87	62.12	35.75
0.75	63.29	38.31	61.43	31.60
1.00	62.07	35.64	60.22	31.6
1.25	60.50	32.21	58.19	27.16
1.50	58.71	28.30	56.67	23.84

Table 4. 3 Compressive strength by Rebound Hammer

Fiber Dose (%)	65 AR (MPa)	55 AR (MPa)
0	47	47
0.25	51.9	50.37
0.50	54.3	52.18
0.75	54.79	50.07
1.00	49.6	49.77
1.25	48	48
1.50	48.3	48.65

ratio of 65, was 63.29 MPa. Similarly, cubes with fibers having an aspect ratio of 55 achieved a compressive strength of 62.12 MPa when the fiber dosage was 0.75% and 0.5%, respectively. This indicates an overall variation in compressive strength ranging from 20% to 38.3% for cubes containing fibers with a 65-aspect ratio and 13.13% to 35.75% for cubes with fibers having a 55-aspect ratio. Conversely, when the Rebound Hammer was employed, the measured strength values were 54.79 MPa and 52.18 MPa for cubes with fiber aspect ratios of 65 and 55, respectively. These figures exhibited an overall variation of 3% to 16% and 3% to 11% for the two respective fiber aspect ratios. The increase in compressive strength resulting from the addition of fibers can be attributed to the enhanced bond between the steel fibers and the concrete matrix, which effectively halted the propagation of cracks.

The higher aspect ratios of the fibers contributed to more efficient prevention of fracture formation, thereby increasing compressive strength.

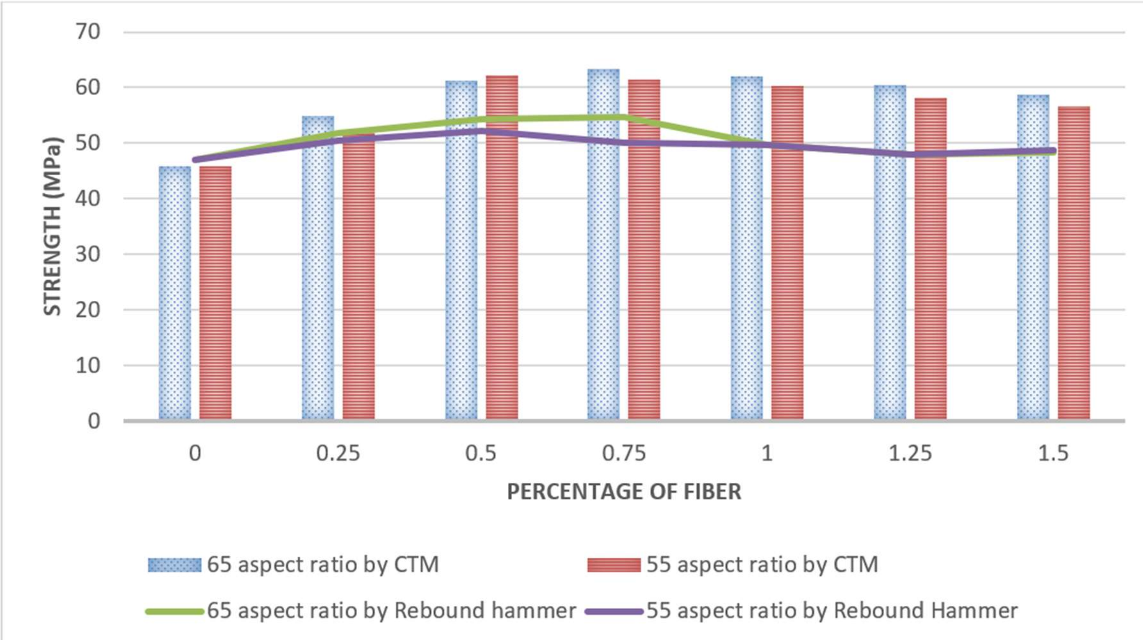


Figure 4. 2 Compressive strength comparison

4.2.3 SPLIT TENSILE STRENGTH OF FIBER-REINFORCED CONCRETE CYLINDER

The outcomes of tests to evaluate the splitting tensile strength of M-30 grade concrete incorporated with varying volume fractions of steel fibers are presented in Figure 4.3 and Table 4.4. The findings demonstrate that the highest split tensile strength values recorded were 6.70 MPa and 6.10 MPa for cylinders with aspect ratios of 65 and 55, respectively, at a dosage of approximately 1.25%. These values indicate a considerable enhancement in strength, around 65.43% and 50.62% higher than the strength achieved by the design mix. The introduction of steel fibers into the control mix yields a significant increase in split tensile strength. Figure 4.4 shows that in the fiber-reinforced concrete specimens, cracks propagate parallel to the applied load, ultimately causing failure along the longitudinal direction. This phenomenon can be attributed to the ability of fibers to impede the formation of microcracks at specific locations, thereby enhancing the apparent tensile strength of the matrix. The results demonstrate the positive influence of steel fibers on the splitting tensile strength of M-30 grade concrete. The incorporation of fibers effectively mitigates crack formation and propagation, resulting in a substantial improvement in the overall tensile behavior of the concrete matrix.

Table 4. 4 Split Tensile Strength by CTM

Fiber Dose (%)	65 AR (MPa)	% Increment	55 AR (MPa)	% Increment
0	4.05	-	4.05	-
0.25	4.32	6.67	4.68	15.56
0.50	5.81	43.46	5.77	42.47
0.75	5.96	47.16	5.84	44.20
1.00	6.38	57.53	5.96	46.91
1.25	6.70	65.43	6.10	50.62
1.50	6.40	58.27	5.99	47.90

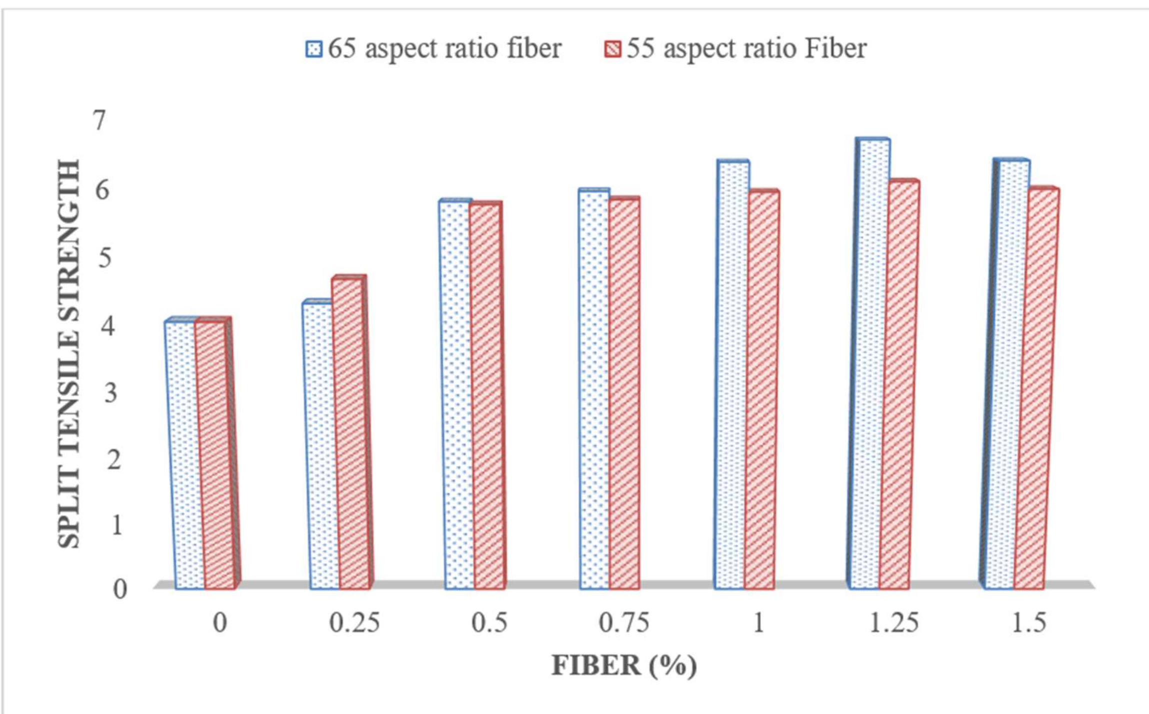


Figure 4. 3 Average Split Tensile Strength (MPa) of cylinder With Different Fiber Content

Figure 4. 4 Crack Pattern in Cylinder

4.3 EFFECT OF ELEVATED TEMPERATURE ON FRC

Temperature is a crucial parameter that substantially impacts concrete's mechanical and physicochemical properties. Consequently, a comprehensive research investigation was undertaken to explore the temperature effects at three distinct levels: 125°C, 250°C, and 375°C, with the inclusion of 0.50% and 0.75% of hook-ended steel fibers having aspect ratios of 65 and 55.

4.3.1 PHYSICAL CHANGES

Visual examination of specimens subjected to prolonged exposure to elevated temperatures reveals noticeable physical alterations. These changes primarily manifest as alterations in coloration and the presence of surface cracks.

4.3.2 CHANGE IN COLOR

The visual analysis of the test specimens definitively verified a progressive alteration in the color of the concrete as both the temperature and exposure levels were heightened. The outcomes derived from the meticulous visual inspection, focusing on the variables of temperature and volume fraction for Fiber-Reinforced Concrete (FRC), have been systematically presented in Table 4.5, documenting the observed color changes.

Table 4. 5 Results of visual inspection on specimens for change in color

Temperature (^{0}C)	Color as Observed			
	65 Aspect Ratio		55 Aspect Ratio	
	0.50%	0.75%	0.50%	0.70%
0	Grey	Grey	Grey	Grey
125	Grey	Grey	Grey	Grey
250	Light Pink	Light Pink	Light Pink	Light Pink
375	Pink	Pink	Pink	Pink

Based on the data presented in Table 4.5, it can be deduced that concrete maintains its original grey color without undergoing any noticeable color alteration when exposed to temperatures of up to 125°C. However, when the temperature rises to 250°C and 375°C, a discernible change in color is observed in specimens of fiber-reinforced concrete which can be clearly seen in figure 4.5. This significant observation strongly suggests that the extent of temperature exposure is a pivotal factor in the evaluation of concrete performance following exposure to elevated temperatures.

Figure 4. 5 Change in Color at Various Temperature

4.3.3 SURFACE CRACKING

Surface cracks were observed on the specimens exposed to an elevated temperature of 375°C for all types of concrete mixes. These cracks can be attributed to differential movements occurring as the specimens reach a steady state condition. The differential movements occur due to higher moisture losses in the outer layers of the test specimens compared to the inner layers. The results of the visual examination, specifically the occurrence of surface cracking, are presented in Table 4.6 and can be seen in figure 4.6.

Table 4. 6 Results of visual inspection on specimens for surface cracking

Temperature (^{0}C)	Surface Crack Observed			
	65 Aspect Ratio		55 Aspect Ratio	
	0.50%	0.75%	0.50%	0.70%
0	No Surface cracks	No Surface cracks	No Surface cracks	No Surface cracks
125	No Surface cracks	No Surface cracks	No Surface cracks	No Surface cracks
250	No Surface cracks	No Surface cracks	No Surface cracks	No Surface cracks
375	Mild surface cracks	Mild surface cracks	Mild surface cracks	Mild surface cracks

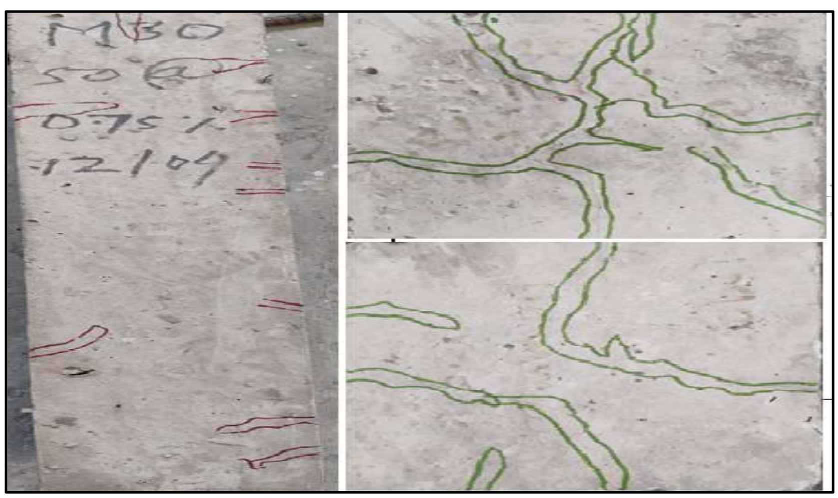


Figure 4. 6 Surface Cracks at 3750 C

Interestingly, no visible surface cracks were observed on the fiber-reinforced concrete (FRC) specimens subjected to elevated temperatures up to 250°C. From a physical perspective, the concrete undergoes thermal dilations, thermal shrinkage, and creep as a result of water loss.

These processes result in significant volume changes, generating internal stresses and strains that lead to the formation of microcracks and fractures. Chemically, high temperatures promote dehydration and the decomposition of hardened cement paste and aggregates.

4.3.4 WEIGHT LOSS OF CUBES

The weight of cement-based fiber-reinforced composites (FRC) exhibited variations in response to temperature changes, as illustrated in table 4.7 and variation can be seen in figure 4.7 showed a significant decrease in weight as the temperature increased, which was measured using a precise weighing machine immediately after reaching the desired temperature and before placement in the furnace. The highest weight losses were observed in the following specimens: 0.236 kg, 0.241 kg, 0.249 kg, and 0.245 kg for the 65AR0.75, 55AR0.75, 65AR0.5, and 55AR0.5, respectively. Expressed as a percentage of weight loss, the approximate values were 1.67%, 2.32%, 2.82%, and 1.72%, 2.37%, 2.82% for the mixtures containing 0.75% fiber with aspect ratios of 65 and 55, respectively. Similarly, the weight losses were approximately 1.76%, 2.41%, 2.91%, and 1.70%, 2.40%, 2.87% for the mixtures containing 0.50% steel fiber with aspect ratios of 65 and 55, respectively.

Table 4. 7 Weight loss of Cubes

Fiber Dose (%)	Aspect Ratio	Temperature (^{0}C)				
		0	125	250	375	
0.75	65	8.611	8.470	8.416	8.375	Avg Weight (kg)
		0	0.141	0.195	0.236	Loss in wt. (kg)
	55	8.781	8.633	8.578	8.540	Avg Weight (kg)
		0	0.148	0.203	0.241	Loss in wt. (kg)
0.50	65	8.798	8.646	8.588	8.549	Loss in wt. (kg)
		0	0.152	0.210	0.249	Avg Weight (kg)
	55	8.760	8.614	8.554	8.515	Loss in wt. (kg)
		0	0.146	0.206	0.245	Avg Weight (kg)

These results indicate that specimens with the ideal fiber content experienced less weight loss compared to other specimens containing the same type of fiber. This difference can be attributed to the superior bonding of the mix in cubes with the optimal fiber dosage, resulting in reduced water loss. Furthermore, it was observed that weight loss was more pronounced when the temperature increased from ambient to 125°C. However, as the temperature continued to rise, the percentage of weight loss showed a comparatively slower increase.

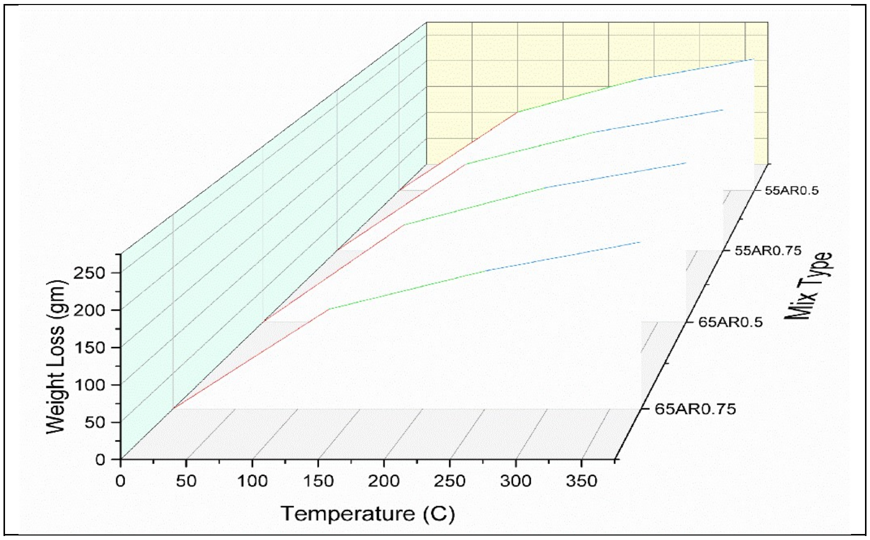


Figure 4. 7 Change in weight of cubes

4.3.5 COMPRESSIVE STRENGTH OF CUBES

Apart from its role in assessing, reinforcing, and repairing structures after fires, the residual compressive strength of steel fiber-reinforced concrete (SFRC) under high-temperature conditions is crucial for designing structures with effective fire protection. Figure 4.8 and Table 4.8 illustrate the compressive strength of SFRC at various temperatures. It was observed that as the temperature increased, the maximum increase in compressive strength, relative to specimens not subjected to elevated temperatures, was 18.10%, 22.87%, 19.64% and 20.23% for the 65AR0.75, 55AR0.75, 65AR0.5, and 55AR0.5 mix types, respectively, at a temperature of 375^0 C. For specimens with a fiber content of 0.75%, the relative increases in compressive strength were 4.68%, 7.18%, and 5.24% for the 65-aspect ratio and 7.2%, 10.45%, and 3.78% for the 55-aspect ratio. In the case of specimens with a fiber content of 0.50%, the increases in compressive strength were 7.62%, 8.71%, 2.26% for the 65-aspect ratio and 8.26%, 8.25%, 2.6% for the 55-aspect ratio. Thus, it can be concluded that the rate of strength increase diminishes as the temperature rises. The highest increases in strength were observed in specimens with lower aspect ratios, while at room temperature, specimens with higher aspect ratio fibers exhibited greater strength gains. The increase in strength with temperature can be attributed to the overall stiffening of the cement gel or the enhancement of surface forces between gel particles resulting from the removal of adsorbed moisture, which accelerates hydration and increases compressive strength. Additionally, fiber expansion at elevated temperatures fills voids, leading to increased strength up to a certain threshold.

Table 4. 8 Compressive strength at elevated temperature

Fiber Dose (%)	Aspect Ratio	Temperature (^{0}C)/ Compressive strength (MPa)						
		0	125	Relative % Increment	250	Relative % Increment	375	Relative % Increment
0.75	65	63.29	66.25	4.68	71.01	7.18	74.73	5.24
	55	61.43	65.85	7.20	72.73	10.45	78.07	3.78
0.50	65	61.26	65.93	7.62	73.63	8.71	81.2	2.26
	55	62.12	67.25	8.26	74.99	8.25	82.01	2.60

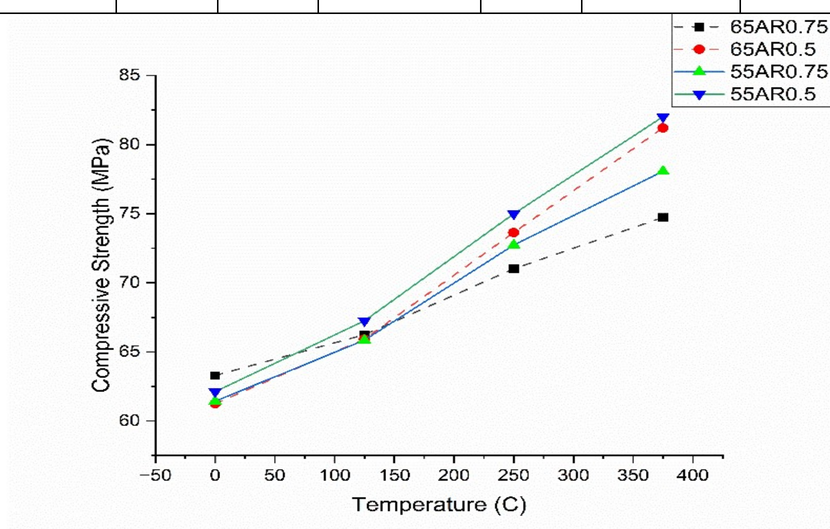


Figure 4. 8 Average Compressive Strength at Elevated Temperature

4.3.6 WEIGHT LOSS OF CYLINDERS

The weight variations of FRC in response to temperature changes are depicted in Table 4.9, while Figure 4.9 illustrates the significant decrease in weight observed as the temperature increases.

Table 4. 9 Weight Loss in Cylinders

Fiber Dose (%)	Aspect Ratio	Temperature (^{0}C)				
		0	125	250	375	
0.75	65	14.77	14.59	14.51	14.47	Avg Weight (kg)
		0	0.180	0.260	0.300	Loss in wt. (kg)
	55	14.49	14.28	14.20	14.11	Avg Weight (kg)
		0	0.210	0.290	0.380	Loss in wt. (kg)
0.50	65	14.64	14.45	14.39	14.30	Loss in wt. (kg)
		0	0.190	0.250	0.340	Avg Weight (kg)
	55	14.55	14.31	14.25	14.19	Loss in wt. (kg)
		0	0.240	0.300	0.360	Avg Weight (kg)

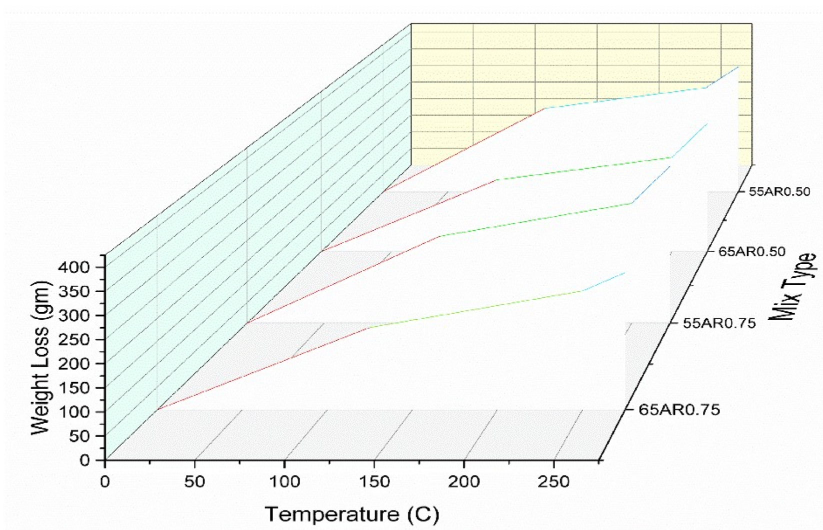


Figure 4. 9 Change in Weight of Cylinders

Precise weighing measurements were conducted immediately after reaching the desired temperature and prior to placement in the furnace. Among the specimens tested, the highest weight losses were recorded as follows: 0.300 kg, 0.380 kg, 0.340 kg, and 0.360 kg for the 65AR0.75, 55AR0.75, 65AR0.5, and 55AR0.5, respectively. The weight loss values can be expressed as a percentage of the initial weight, yielding approximate figures of 1.22%, 1.76%, 2.03%, and 1.45%, 1.80%, 2.63% for mixtures containing 0.75% fiber with aspect ratios of 65 and 55, respectively. Similarly, the weight losses for mixtures containing 0.50% steel fiber with aspect ratios of 65 and 55 were approximately 1.30%, 1.71%, 2.32%, and 1.65%, 2.07%, 2.48%, respectively.

4.3.7 SPLIT TENSILE STRENGTH OF CYLINDERS

The effect of elevated temperatures on the residual split tensile strength of concrete with different steel fiber doses was investigated. Two fiber dosages, namely 0.50% and 0.75%, were considered. The concrete specimens were exposed to temperatures of 125°C, 250°C, and 375°C for a duration of 3 hours. The results of this study are summarized in Tables 4.10 and 4.10.

At an elevated temperature of 250°C, the concrete specimens containing steel fibers with aspect ratios of 65 and 55 exhibited maximum increases in residual split tensile strength. Specifically, a 17.78% increase was observed for the specimens with a fiber volume of 0.75% and an aspect ratio of 65, while an 18.49% increase was noted for the specimens with a fiber volume of 0.75% and an aspect ratio of 55. Similarly, when the fiber volume was reduced to 0.50%, the maximum increases recorded were 19.62% and 19.41% for aspect ratios 65 and 55, respectively. These increases were calculated relative to the specimens that were not subjected to elevated temperatures. In terms of the effect of temperature on the residual split tensile strength, different trends were observed depending on the fiber volume and aspect ratio. For the concrete specimens with a fiber volume of 0.75% and aspect ratios of 65 and 55, relative increases of 9.56%, 7.50%, 18.22%, and 9.49% were observed at temperatures of 125°C and 250°C. However, a decrease of 1.85% and 1.59% was observed at a temperature of 375°C compared to 250°C for aspect ratios 65 and 55, respectively. Similarly, for the concrete specimens with a fiber volume of 0.50% and aspect ratios of 65 and 55, relative increases of 11.36%, 7.42%, 8.67%, and 9.89% were observed at temperatures of 125°C and 250°C. In contrast, a decrease of 1.44% and 1.89% was observed at a temperature of 375°C compared to 250°C for aspect ratios 65 and 55, respectively. These findings provide valuable insights into the performance of concrete with different steel fiber doses under elevated temperature conditions. It is evident that the aspect ratio and fiber volume play significant roles in determining the residual split tensile strength of the concrete after exposure to elevated temperatures.

Table 4. 10 Split tensile strength at elevated temperature

Fiber Dose (%)	Aspect Ratio	Temperature (^{0}C)/ Split Tensile Strength (MPa)						
		0	125	Relative % Increment	250	Relative % Increment	375	Relative % Decrement
0.75	65	5.96	6.53	9.56	7.02	7.5	6.89	1.85
	55	5.84	6.32	8.22	6.92	9.49	6.81	1.59
0.50	65	5.81	6.47	11.36	6.95	7.42	6.85	1.44
	55	5.77	6.27	8.67	6.89	9.89	6.76	1.89

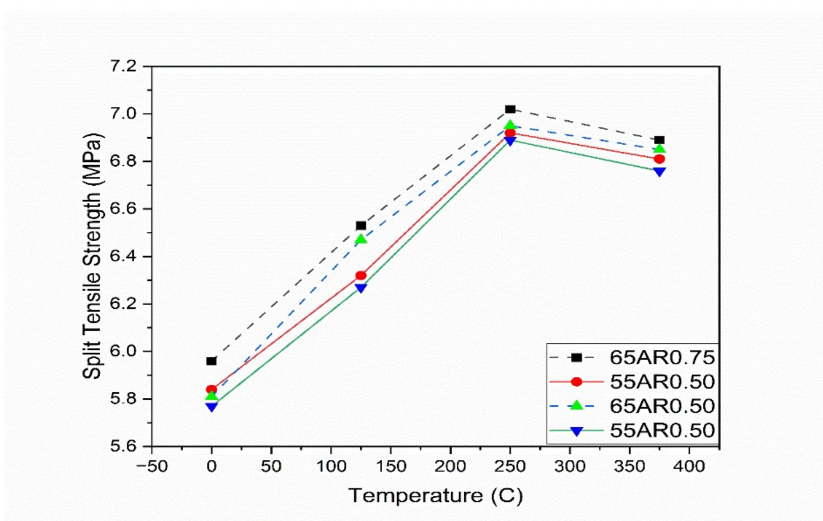


Figure 4. 10 Average Split Tensile Strength at Elevated Temperature

4.3.8 WEIGHT LOSS IN BEAMS

The weight of fiber-reinforced composites (FRC) made with cement-based materials displayed variations in response to changes in temperature, as depicted in Figure 4.11. The table 4.11 clearly demonstrates a substantial decrease in weight as the temperature increases. To ensure accuracy, precise weighing equipment was used to measure the weight immediately after reaching the desired temperature and prior to placing the composites in the furnace. Significant weight losses were observed in specific specimens: 0.38kg, 0.41kg, 0.44kg, and 0.39kg for the mixtures designated as 65AR0.75, 55AR0.75, 65AR0.5, and 55AR0.5, respectively.

Table 4. 11 Weight loss in Beams

Fiber Dose (%)	Aspect Ratio	Temperature (^{0}C)				
		0	125	250	375	
0.75	65	12.79	12.58	12.47	12.41	Avg Weight (kg)
		0	0.21	0.32	0.38	Loss in wt. (kg)
	55	12.68	12.45	12.33	12.27	Avg Weight (kg)
		0	0.23	0.35	0.41	Loss in wt. (kg)
0.50	65	12.73	12.49	12.37	12.29	Loss in wt. (kg)
		0	0.24	0.36	0.44	Avg Weight (kg)
	55	12.64	12.42	12.33	12.25	Loss in wt. (kg)
		0	0.22	0.31	0.39	Avg Weight (kg)

Expressing these losses as a percentage of weight, the approximate values were 1.64%, 2.50%, 2.97%, and 1.81%, 2.76%, 3.23% for the mixtures containing 0.75% fiber with aspect ratios of 65 and 55, respectively. Similarly, for mixtures with 0.50% steel fiber and aspect ratios of 65 and 55, the weight losses were approximately 1.88%, 2.83%, 3.45%, and 1.74%, 2.45%, 0.31%, respectively. These results suggest that specimens with the optimal fiber content experienced less weight loss compared to other specimens containing the same type of fiber. This disparity can be attributed to the superior bonding of the mixtures in beams with the ideal fiber dosage, resulting in reduced water loss. Moreover, it was observed that weight loss was more pronounced when the temperature increased from ambient to 125°C. However, as the temperature continued to rise, the percentage of weight loss demonstrated a relatively slower increase.

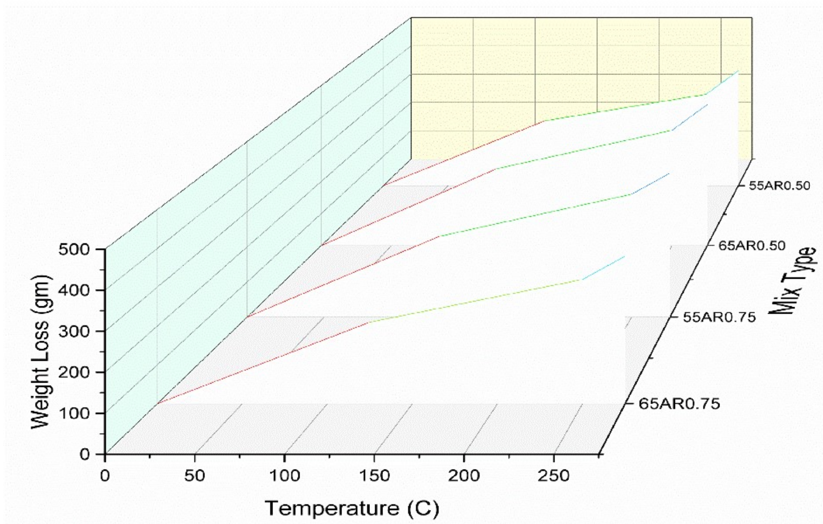


Figure 4. 11 Change in Weight of Beams

4.3.9 FLEXURAL STRENGTH OF BEAMS

The study aimed to investigate the impact of elevated temperatures on the flexural strength of concrete with varying doses of steel fibers. Two different fiber dosages, specifically 0.50% and 0.75%, were examined. Concrete specimens were subjected to temperatures of 125°C, 250°C, and 375°C for a duration of 3 hours. The findings of this investigation are summarized in Tables 4.12 and, with the subsequent discussion outlining the key observations from figure 4.12. At an elevated temperature of 250°C, the concrete specimens incorporating steel fibers with aspect ratios of 65 and 55 demonstrated the highest increases in residual flexural strength. Notably, the specimens with a fiber volume of 0.75% and an aspect ratio of 65 exhibited an 18.93% increase, while those with a fiber volume of 0.75% and an aspect ratio of 55 displayed an 17.37% increase. Similarly, a reduction in fiber volume to 0.50% resulted in maximum increases of 18.78% and 20.88% for aspect ratios 65 and 55, respectively. These increases were calculated relative to specimens not exposed to elevated temperatures. Regarding the impact of temperature on residual flexural strength, diverse trends were observed depending on the fiber volume and aspect ratio.

Table 4. 12 Flexural strength at elevated temperature

Fiber Dose (%)	Aspect Ratio	Temperature (^{0}C)/ Compressive strength (MPa)						
		0	125	Relative % Increment	250	Relative % Increment	375	Relative % Decrement
0.75	65	6.21	6.78	9.18	7.30	7.67	7.15	2.05
	55	6.10	6.57	7.70	7.16	8.98	7.07	1.26
0.50	65	6.07	6.72	10.71	7.21	7.29	7.11	1.39
	55	5.89	6.52	10.70	7.12	9.20	6.99	1.83

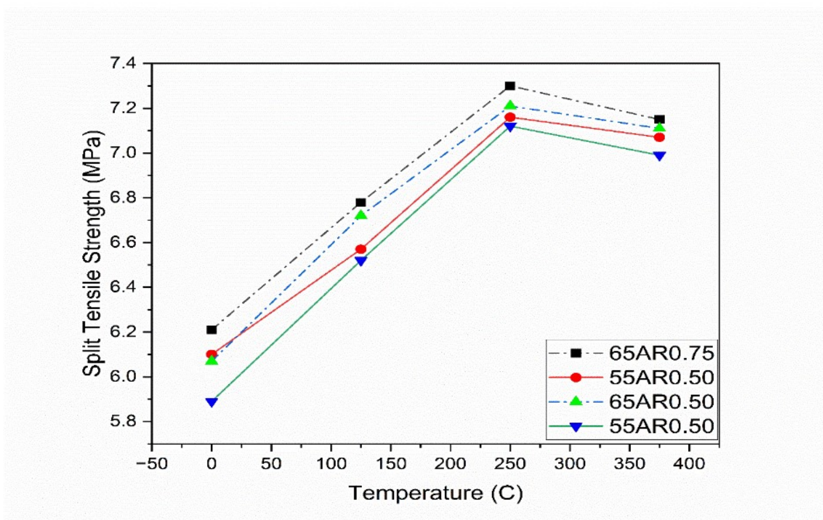


Figure 4. 12 Average flexural strength of Beams

For concrete specimens with a fiber volume of 0.75% and aspect ratios of 65 and 55, relative increases of 9.18%, 7.67%, 7.70%, and 8.98% were observed at temperatures of 125°C and 250°C. However, a decrease of 2.05% and 1.26% was noted at a temperature of 375°C compared to 250°C for aspect ratios 65 and 55, respectively. Similarly, for concrete specimens with a fiber volume of 0.50% and aspect ratios of 65 and 55, relative increases of 10.71%, 7.29%, 10.70%, and 9.20% were observed at temperatures of 125°C and 250°C. Conversely, a decrease of 1.39% and 1.83% was recorded at a temperature of 375°C compared to 250°C for aspect ratios 65 and 55, respectively. These findings provide valuable insights into the performance of concrete with different steel fiber doses under elevated temperature conditions. It is evident that the aspect ratio and fiber volume significantly influence the residual flexural strength of concrete following exposure to elevated temperatures.

4.4 MATHEMATICAL MODELING

A proposition is put forth to develop an equation that can determine the percentage residual strength of steel fiber reinforced concrete (FRC) when exposed to elevated temperatures of 125°C, 250°C, and 375°C considering different fiber volumes of 0.75% and 0.50%. These equations aim to provide more reliable and comprehensive estimations. Furthermore, graphical representations have been generated to compare the predicted values derived from the equations with the actual values of residual strength for FRC. This visual analysis aids in evaluating the accuracy and effectiveness of the proposed equations, offering a clearer understanding of the relationship between the influential factors and the resulting residual strength of FRC. The intention behind these endeavors is to establish robust and precise predictions for the residual strength of FRC, ensuring the advancement of the field and facilitating the design and implementation of fiber-reinforced concrete structures.

A multitude of researchers have put forth a range of equations to estimate the residual compressive strength, split tensile strength, and flexural strength of Fiber-Reinforced Concrete (FRC). Variations in these equations arise due to the influence of different fiber properties and constituent materials, as well as the geographical variability in available materials. As a result, researchers have formulated their predicted equations based on the specific outcomes they have obtained from their experiments, customizing them to suit their findings. Presented below are a few examples of these equations:

$$\frac{f_C}{f_C'} = 0.96 + 2.09\left(\frac{T}{1000}\right) - 8.71\left(\frac{T^2}{1000}\right) + 6.06\left(\frac{T^3}{1000}\right) \tag{4.1}$$

$$\frac{f_C}{f_C'} = 0.99 - 1.02\left(\frac{T}{1000}\right) \tag{4.2}$$

$$f_{Ck} = 42.58 + 1.13A - 0.0057B + 0.004AB + 1.96A^2 - 0.0000157B^2 \tag{4.3}$$

$$\frac{f_t}{f_t'} = 0.98 - 0.925\left(\frac{T}{1000}\right) \quad 4.4$$

$$\frac{f_t}{f_t'} = 0.972 - 0.82\left(\frac{T}{1000}\right) \quad 4.5$$

4.4.1 PREDICTION MODEL FOR COMPRESSIVE STRENGTH

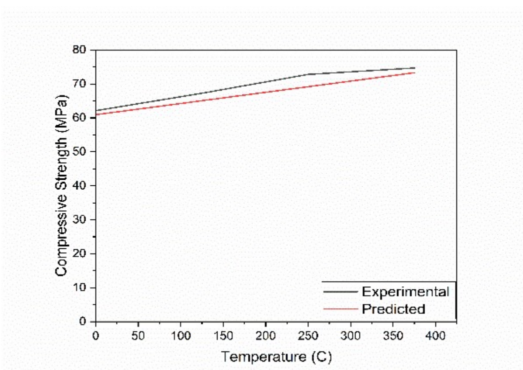
The most appropriate regression equation for predicting the compressive strength of Fiber-Reinforced Concrete (FRC) at elevated temperatures is determined based on rigorous technical analysis, considering factors such as temperature, fiber volume, and fiber content by using the previous results in Table 4.8 is:

$$\boldsymbol{f_C = 60.212 + 0.033T + 0.012A_R + 11.278F_D} \quad 4.6$$

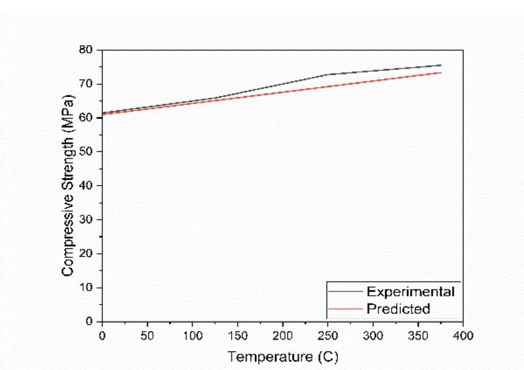
Where, A_R= Aspect Ratio of Fiber, F_D= Fiber Dose

fc= Compressive Strength (MPa), T= Temperature

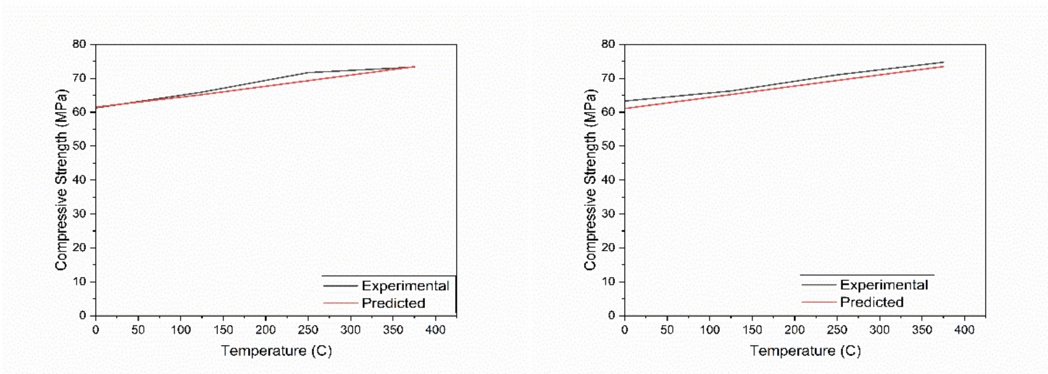
From Table 4.13 and Figure 4.13 it can be clearly seen that error is not more than plus mins 5%.



(a)



(b)



(c) (d)

Figure 4. 13 Actual and Predicted Compressive Strength for (a)55AR0.50 (b)55AR0.75 (c)65AR0.50 (d) 65AR0.75

Table 4. 13 Comparison of Experimental and Predicted Compressive Strength`

Fiber Dose (%)	Aspect Ratio	Temperature (°c)	Experimental Compressive Strength (MPa)	Predicted Compressive Strength (MPa)	% Error
0.75	65	0	63.29	61.08	3.49
		125	66.25	65.21	1.58
		250	71.01	69.36	2.37
		375	74.73	73.45	1.71
	55	0	61.43	60.96	0.77
		125	65.85	65.08	1.17
		250	72.73	69.21	4.84
		375	75.48	73.33	2.85
0.50	65	0	61.26	61.5	0.34
		125	65.93	65.17	1.15
		250	71.67	69.29	3.31
		375	73.29	73.42	0.182
	55	0	62.12	60.93	1.92
		125	67.25	65.05	3.27
		250	72.8	69.18	4.97
		375	74.69	73.31	1.85

4.4.2 PREDICTION MODEL FOR SPIT TENSILE STRENGTH

The most appropriate regression equation for predicting the split tensile strength of Fiber-Reinforced Concrete (FRC) at elevated temperatures is determined based on rigorous technical analysis, considering factors such as temperature, fiber volume, and fiber content by using the previous results in Table 4.10 is:

$$\boldsymbol{f_t = 4.85 + 0.011T + 0.012A_R + 11.278F_D} \quad 4.7$$

Where,

ft= Split Tensile Strength (MPa), T= Temperature

A_R= Aspect Ratio of Fiber, F_D= Fiber Dose

From Table 4.14 and Figure 4.14, it can be clearly seen that error is not more than plus mins 5%.

Table 4. 14 Comparison of Experimental and Predicted Split Tensile Strength

Fiber Dose (%)	Aspect Ratio	Temperature (^{0}C)	Experimental Split Tensile Strength (MPa)	Predicted Split Tensile Strength (MPa)	% Error
0.75	65	0	6.21	5.96	3.95
		125	6.78	6.46	4.65
		250	7.3	6.96	4.59
		375	7.15	7.46	4.39
	55	0	6.1	5.84	4.18
		125	6.57	6.34	3.43
		250	7.16	6.84	4.40
		375	7.07	7.34	3.88
0.50	65	0	6.07	5.93	2.20
		125	6.72	6.43	4.22
		250	7.21	6.93	3.79
		375	7.11	7.43	4.59
	55	0	5.89	5.81	1.24
		125	6.52	6.31	3.12
		250	7.12	6.81	4.26
		375	6.99	7.31	4.66

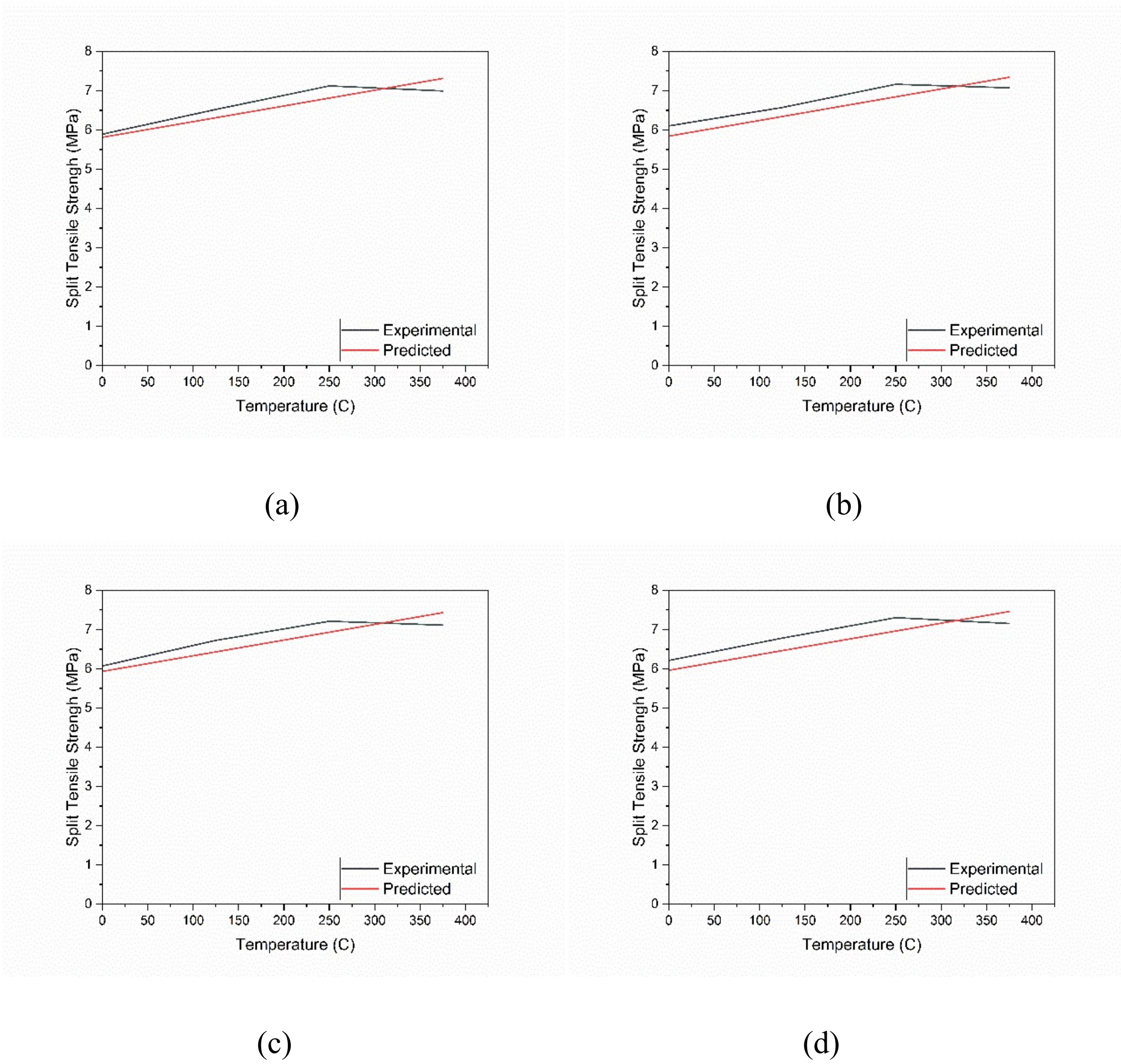


Figure 4. 14 Actual and Predicted Split Tensile Strength for (a)55AR0.50 (b)55AR0.75 (c)65AR0.50 (d) 65AR0.75

4.4.3 PREDICTION MODEL FOR FLEXURAL STRENGTH

The most appropriate regression equation for predicting the flexural strength of Fiber-Reinforced Concrete (FRC) at elevated temperatures is determined based on rigorous technical analysis, considering factors such as temperature, fiber volume, and fiber content by using the previous results in Table 4.12 is:

$$f_f = 5.1 + 0.011T + 0.012A_R + 11.278F_D \quad \textbf{4.8}$$

Where,

f= Split Tensile Strength (MPa)

T= Temperature

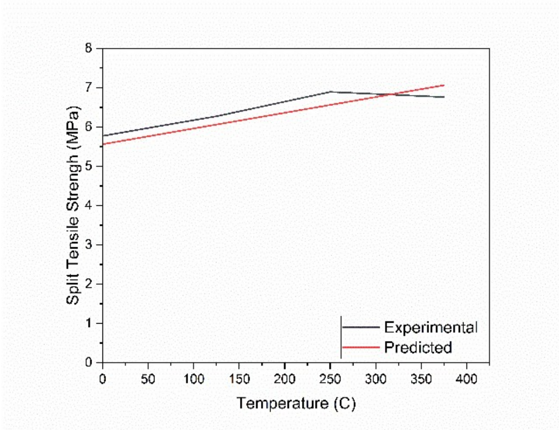
A_R= Aspect Ratio of Fiber

F_D= Fiber Dose

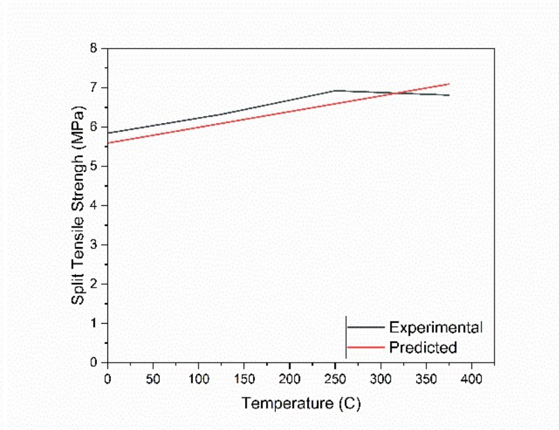
From Table 4.15 and Figure 4.15, it can be clearly seen that error is not more than plus mins 5%.

Table 4. 15 Comparison of Experimental and Predicted Flexural Strength

Fiber Dose (%)	Aspect Ratio	Temperature (^{0}C)	Experimental Flexural Strength (MPa)	Predicted Flexural Strength (MPa)	% Error
0.75	65	0	5.96	5.71	4.11
		125	6.53	6.21	4.83
		250	7.02	6.71	4.35
		375	6.89	7.21	4.71
	55	0	5.84	5.59	4.20
		125	6.32	6.09	3.56
		250	6.92	6.59	4.70
		375	6.81	7.09	4.17
0.50	65	0	5.81	5.68	2.12
		125	6.47	6.18	4.38
		250	6.95	6.68	3.79
		375	6.85	7.18	4.91
	55	0	5.77	5.56	3.52
		125	6.27	6.06	3.24
		250	6.89	6.56	4.96
		375	6.76	7.06	4.53



(a)



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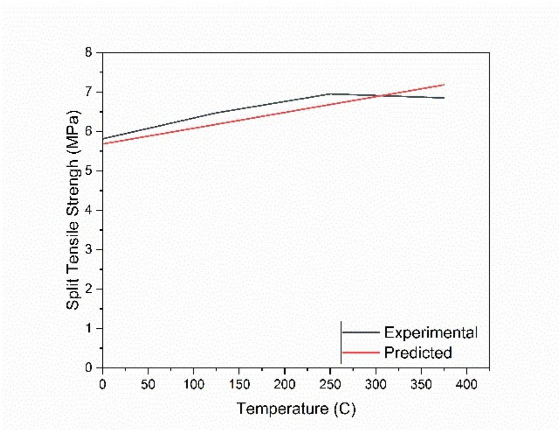
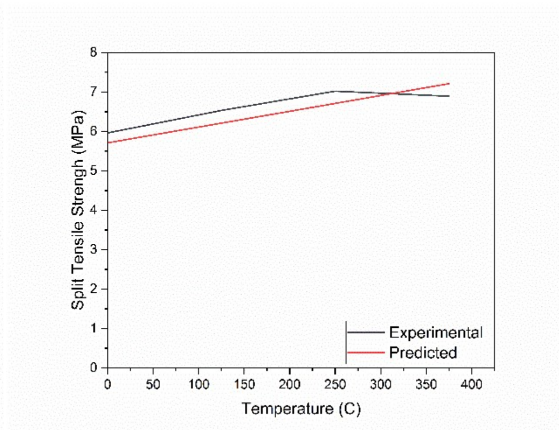


(c)



(d)

Figure 4. 15 Actual and Predicted Split Tensile Strength for (a)55AR0.50 (b)55AR0.75 (c)65AR0.50 (d) 65AR0.75

CHAPTER 5

CONCLUSION AND SCOPE FOR FUTURE WORK

5.1 CONCLUSION

The following findings have been derived from the comprehensive analysis and experimental exploration conducted on plain concrete and fiber-reinforced concrete specimens exposed to elevated temperatures:

- The experimental findings unequivocally demonstrate a discernible inverse relationship between workability and fiber content, where an increase in fiber concentration corresponds to a noticeable decrease in workability. Intriguingly, an intriguing observation emerges from the study, revealing a more pronounced reduction in workability for mixtures featuring larger aspect ratio steel fibers. This phenomenon can be elucidated by the propensity of longer fibers to engage in heightened inter-fiber interactions, engendering augmented frictional forces among neighbouring fibers. Consequently, this augmented friction impedes the facile separation and reorientation of fibers during processing, thereby exerting an adverse influence on the overall workability of the material.
- The strength of Fiber Reinforced Concrete increases significantly as fiber volume increases until a certain threshold. However, beyond this point, inadequate bonding between fibers and the matrix material hampers load transfer, reducing the overall effectiveness of the fibers in enhancing strength.
- In the study, cubes incorporating fibers with different aspect ratios showed promising results for compressive strength. Cubes with a higher aspect ratio of 65 achieved maximum strengths of 63.29 MPa (CTM) and 54.79 MPa (rebound hammer), while cubes with a slightly lower aspect ratio of 55 reached strengths of 62.17 MPa (CTM) and 52.18 MPa (rebound hammer).

- The maximum split tensile strength after 28 days was observed to be 6.70 MPa for cylinders with a 65-aspect ratio fiber mixed at a volume of 1.25%. This represents an impressive 65.43% increase compared to normal concrete cylinders. Similarly, cylinders with a 55-aspect ratio fiber at a volume of 1.25% exhibited a split tensile strength of 6.10 MPa, showing a remarkable 50.62% improvement over normal concrete cylinders.
- The higher aspect ratio steel fiber exhibits greater strength at room temperature as well as when subjected to an elevated temperature due to its increased surface area, which enhances bonding and stress transfer with the surrounding matrix material, resulting in improved resistance against cracking and failure.
- Visual inspection of concrete structures considers crucial parameters such as color changes and surface cracking to determine the extent of temperature exposure. Extensive literature confirms that there are no discernible variations in color when concrete is subjected to temperatures up to 300°C for a duration of 2 hours. However, experimental investigations have demonstrated a noticeable change in color when concrete is exposed to 250°C for a duration of 3 hours. These findings highlight the significant influence of exposure duration on the assessment of structures subjected to elevated temperatures. Thus, careful consideration of exposure time is essential in accurately evaluating the impact of high temperatures on structural integrity.
- The experimental findings indicate that the compressive strength of concrete cubes exhibits an increase at elevated temperatures, albeit with diminishing rates as the temperature surpasses 250°C. The observed increments in compressive strength were recorded as 7.18%, 10.45%, 8.71%, and 8.25% for mixes 65AR0.75, 55AR0.75, 65AR0.75, and 55AR0.50, respectively.
- Experimental observations indicate that FRC exhibits an increase in split tensile and flexural strength up to 250°C when exposed to elevated temperatures. However, beyond this threshold, the split tensile and flexural strength of FRC begin to decline.

- The derived residual strength relationship for FRC at elevated temperatures is formulated based on a modified model, incorporating specific adjustments. This model is developed by utilizing proposed relationships for compressive, tensile, and flexural strength, which have demonstrated excellent concordance with experimental test results conducted on FRC specimens subjected to varying temperatures.
- The systematic evolution of structure can be achieved through a thorough understanding of the modified values of fundamental properties of FRC, specifically compressive strength, split tensile strength, and flexural strength. This understanding requires considering the effects of temperature, aspect ratio, and volume.

5.2 FUTURE SCOPE OF WORK

- Further research can be undertaken to explore the impact of exposure duration on the complete strength degradation of plain and fiber-reinforced concrete.
- The scope of this study can be expanded to examine the impact of plain concrete and fiber-reinforced concrete when subjected to elevated temperatures until reaching a steady state. This investigation will encompass both pre-loaded stressed and unstressed conditions, allowing for a comprehensive analysis of the material's behavior under thermal stress.
- The potential utilization of hybrid fibers comprising various combinations, volume fractions, and increased exposure to elevated temperatures over extended durations can be systematically examined and researched.

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SCOPUS INDEXED CONFERENCES BASED ON THE PRESENT RESEARCH

1. Kumar, A., and Pal, S., (2023), “Impact of Hook-ended Steel Fiber of Various Aspect Ratio on Concrete”. Sustainable Concrete Infrastructure: International UKIERI Concrete Congress.

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