Effects of steel fiber types on flexural tensile behavior of notched concrete beams

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DEDICATIONS

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List of Abbreviations

Abbreviation	Meaning
FRC	Fiber-Reinforced Concrete
FR, i	Residual Flexural Strength
Kg/m^3	Kilograms per Cubic Meter
LOP	Load-Crack Mouth Opening Displacement
MPa	Mega Pascals
mm	Millimetres
MOR	Modulus of Rupture
N	Newtons
RC	Reinforced Concrete
RI	Reinforcing Index
SFRC	Steel Fiber Reinforced Concrete

Effects of steel fiber types on flexural tensile behavior of notched concrete beams

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ABSTRACT

This study addresses the imperative investigation into how diverse steel fiber types influence the flexural tensile behavior of concrete beams. The application of fiber reinforcement in concrete beams has garnered attention for its potential to augment strength, resilience, and resistance to cracking. However, there are lingering uncertainties regarding the effectiveness of distinct fiber types in enhancing flexural tensile performance. This research endeavors to bridge this knowledge gap by meticulously examining the impact of various fiber types on reinforced concrete beams, encompassing no fibers (Control), 3D Hooked-end steel fibers, 4D Hooked-end steel fibers with varying characteristics, and the non-steel Master Fiber MAC 2200CB.

Key findings from this study demonstrate that steel fiber reinforcement yields substantial improvements in the flexural tensile behavior of concrete beams:

- The introduction of 4D hooked-end steel fibers with an aspect ratio of 65 (0.9mm diameter) results in an impressive 73% increase in the maximum flexural load compared to fiber-free beams. - Incorporating 3D (80/60), 4D (80/60), and macro-synthetic polypropylene fiber into the concrete mixture enhances the maximum flexural load by 16.6%, 42%, and 11.7%, respectively. - The shift from 3D to 4D steel fibers is associated with a significant 21.8% increase in the maximum flexural load and a 16.4% improvement at a deflection of 0.65mm, highlighting the superior bridging effect of 4D steel fibers. Increasing the diameter of 4D hooked-end specimens from 0.75mm to 0.90mm while maintaining a consistent 60mm length contributes to a 21.5% boost in the maximum flexural load and an impressive 111.7% improvement at a deflection of 0.65mm.

In conclusion, the thesis underlines the merits of fiber reinforcement in concrete beams, including enhanced durability, augmented structural performance, cost-effective maintenance, prolonged service life, and expanded design possibilities. These findings carry substantial implications for the construction sector, enabling well-informed choices regarding incorporating fiber-reinforced concrete in diverse structural applications.

CHAPTER ONE

INTRODUCTION

1.1 Overview

Chapter One serves as an introduction to the research study, which delves into the influence of diverse fiber types on the flexural tensile behavior of beams. The chapter commences by providing a contextual backdrop to the research, underscoring the paramount importance of investigating the flexural tensile behavior of beams in the construction industry and elucidating the pivotal role fibers play in enhancing this behavior. The core research challenge centers around identifying the most suitable fiber types for augmenting the flexural tensile strength of beams. The research objectives encompass an in-depth exploration of the properties inherent in various fiber types, a comprehensive evaluation of their impact on the flexural tensile behavior of beams, and a succinct delineation of the thesis's structure and contributions to the field.

1.2 Introduction

The use of fibers as a reinforcement material in the construction industry has gained increasing popularity due to their ability to enhance the mechanical properties of concrete. Adding fibers to concrete significantly improves the flexural tensile behavior of concrete beams, leading to increased flexural strength, ductility, and energy absorption capacity. It's worth noting that the type and characteristics of fibers can substantially impact the flexural tensile behavior of reinforced concrete beams (Zhang et al., 2020).

In recent years, there has been a growing focus on studying the influence of fiber types on the flexural tensile behavior of beams. Researchers have explored various fiber types, including hooked-end, crimped, straight, and corrugated fibers, to assess their effects on the flexural behavior of concrete beams (Abdullah et al., 2022).

The history of fiber reinforcement dates to the mid-20th century when researchers began experimenting with adding fibers to concrete to enhance its mechanical properties. However, it wasn't until the 1970s that steel fibers in concrete gained more widespread use, primarily due to the development of the first generation of hooked-end steel fibers (Revuelta et al., 2021).

Since then, research has been dedicated to developing new types of steel fibers and examining their impact on the mechanical properties of concrete. The influence of steel fiber types on the flexural tensile behavior of beams has become a crucial area of study, providing insights for engineers and designers looking to optimize the use of steel fibers in reinforced concrete structures (Zhang et al., 2020).

The influence of steel fiber types on the flexural tensile behavior of beams has been the subject of several studies, investigating parameters such as fiber geometry, aspect ratio, volume fraction, and steel fiber type on the flexural behavior of concrete beams reinforced with steel fibers.

Steel fibers can be produced through different processes, including cold drawing, melt extraction, and powder metallurgy, resulting in fibers with varying properties, including aspect ratio, diameter, and tensile strength. These properties, in turn, can affect the flexural behavior of reinforced concrete beams (Zhang & Xing, 2020).

Adding steel fibers to concrete substantially enhances its mechanical properties, particularly in tension. These fibers help distribute the load evenly throughout the material, increasing its strength and toughness (Abbass et al., 2018).

Furthermore, fibers, by bridging the naturally occurring cracks in concrete, improve its tensile strength. This is especially important, as tensile strength is typically a weak point for concrete. Fibers reduce brittleness and enhance ductility by preventing crack propagation, enabling the concrete to withstand greater forces without failure.

Beyond improving mechanical properties, incorporating steel fibers enhances concrete's durability and resistance to various forms of degradation, such as cracking, abrasion, and corrosion. This makes it well-suited for multiple applications, including construction, infrastructure, and industrial settings (Shin & Yoo, 2020).

This study delves into the flexural performance of Fiber Reinforced Concrete (FRC) beams, focusing on different types of fibers. Maintaining a constant compressive strength of 45 MPa and fiber dosage of 0.5% by volume, Fiber dosage is expressed as a percentage of the sample volume and includes options such as hooked-end steel fibers of 3D and 4D steel fibers, and the research utilizes three-point bending tests to evaluate the behavior of prisms under monotonic loading. The investigated variables encompass fiber type, and fiber diameter.

The three-point bending test represents a standardized approach for examining the flexural behavior of concrete beams. This test involves the application of a load to the center of a beam, inducing bending. Measuring the load required to cause the beam to fail provides valuable insights into the material's strength and ductility.

1.3 Problem Statement

The main issue addressed in this study is the need to thoroughly investigate the influence of various novel multiple hooked-end steel fibers on the flexural tensile behavior of reinforced concrete beams. While fibers have been increasingly utilized as reinforcement in Fiber Reinforced Concrete (FRC), questions persist about their efficacy in enhancing the flexural tensile performance of beams. This knowledge gap poses significant challenges in designing reinforced concrete structures that incorporate fibers, as the effectiveness of different fiber types in improving flexural tensile behavior remains uncertain (Shao & Billington, 2022).

In the context of this study, the primary fiber types examined are as follows:

1. Control (None)

2. 3D Hooked-end steel fiber with an aspect ratio of 80 and a diameter of 0.75mm

3. 4D Hooked-end steel fiber with an aspect ratio of 80 and a diameter of 0.75mm

4. 4D Hooked-end steel fiber with an aspect ratio of 65 and a diameter of 0.9mm

5. Master Fiber MAC 2200CB

The research endeavors to bridge this knowledge gap by conducting a comprehensive exploration of the impact of these diverse fiber types on the flexural tensile behavior of reinforced concrete beams. Ultimately, this investigation will provide invaluable insights for designing and optimizing reinforced concrete structures that leverage the benefits of fibers.

The lack of a clear understanding of the most effective fiber type for enhancing the flexural tensile behavior of beams presents a substantial challenge within the construction industry. Without this clarity, design professionals and engineers may find it challenging to make informed decisions regarding utilizing FRC in their projects. Consequently, there is a critical need for research to thoroughly investigate the influence of different fiber types on the flexural tensile behavior of reinforced concrete beams (Tahenni et al., 2020).

1.4 Significance of Study

The investigation into the effect of fiber types on the flexural tensile behavior of beams holds great significance for several compelling reasons. Foremost, it addresses a crucial concern within the realm of construction engineering: understanding how diverse fiber types influence the mechanical characteristics of concrete beams.

The outcomes of this study have the potential to offer valuable insights into how different fiber types perform in enhancing the flexural tensile strength of concrete beams. These insights empower engineers and construction practitioners to make well-informed choices regarding selecting fibers for specific construction applications.

Furthermore, this research can contribute to developing novel and enhanced fiber types, which could profoundly influence the future of construction engineering. By comprehending the mechanical behavior of distinct fiber varieties, researchers can pinpoint the key properties that must be optimized to enhance their overall performance.

Additionally, the study's implications extend to the safety and longevity of concrete structures. Including fibers in concrete beams enhances their resilience against cracking and various forms of damage, ultimately fortifying these constructions' structural integrity and lifespan.

In summary, examining how different fiber types influence the flexural tensile behavior of beams is of paramount significance. It delivers essential insights into the mechanical attributes of various fibers and their role in shaping the performance of concrete beams. This knowledge, in turn, optimizes the design and construction of concrete structures, thereby enhancing their safety, durability, and longevity.

1.5 Study Objectives

The study's objectives, in exploring fiber types and their influence on the flexural tensile behavior of beams, encompass several critical aspects.

Firstly, the research seeks to ascertain the impact of various fiber types on the flexural behavior of reinforced concrete beams. This involves a thorough investigation into the performance of fibers, ranging from the absence of fibers as a control to 3D Hooked-end steel fibers with specific dimensions, 4D Hooked-end steel fibers with different characteristics, and the non-steel Master Fiber MAC 2200CB. The primary aim is to discern whether the choice of fiber type significantly affects the flexural strength and toughness of the beams.

Secondly, the study delves into the novel 4D hooked-end steel fiber, comparing it to the conventional 3D hooked-end steel fiber. Additionally, it explores the impact of varying fiber diameters while keeping the fiber length constant.

Thirdly, the research broadens its scope by venturing into non-steel fiber types, opening the avenue for comparisons with various steel fiber types.

The study's overarching objectives revolve around a comprehensive understanding of how diverse factors influence the performance of fiber-reinforced concrete beams in flexure. By dissecting these variables, the study provides insights for informed decisions in designing and utilizing fiber-reinforced concrete in structural applications.

1.6 Research Questions

The research inquiry into "The influence of fiber types on the flexural tensile behavior of beams" gives rise to several pertinent questions:

1. What were the overarching objectives underpinning the study's exploration of how fiber types impact the flexural tensile behavior of beams?

2. Could you delve into the methodologies employed to discern the effect of different fiber types on the flexural performance of reinforced concrete beams? What specific fiber types were subjected to investigation?

3. Within the realm of exploring fiber types, what was the primary aim? Did the study seek to ascertain whether the choice of fiber type exerted a discernible influence on the flexural strength and resilience of the beams?

4. How did the research set out to compare the recently introduced hooked-end steel fiber, 4D, with its traditional counterpart, 3D? What significant findings emerged from this comparative analysis?

5. What aspects received focus when investigating the impact of fiber diameter while maintaining constant fiber length?

6. Offer deeper insights into examining a distinct non-steel fiber type and its comparative assessment against various steel fiber types. What pivotal discoveries surfaced in this context?

By addressing these research questions, the study endeavors to illuminate the utility of fibers as reinforcement materials in concrete beams, ultimately contributing to developing more effective and reliable design guidelines for this application.

1.7 Thesis contribution

The thesis titled "The Influence of Fiber Types on the Flexural Tensile Behavior of Beams" is a substantial and noteworthy contribution to construction engineering and materials science. This study delves into the profound impact of different fiber types on the flexural tensile behavior of beams, offering key insights that advance our understanding of these domains.

This thesis's primary and pivotal contribution lies in the comprehensive dataset it presents, along with its analytical results. The study's experimental phase involves testing reinforced concrete beams fortified with various fibers, including Control (None), 3D Hooked-end steel fiber with an aspect ratio of 80 and a diameter of 0.75mm, 4D Hooked-end steel fiber with an aspect ratio of 80, 4D Hooked-end steel fiber with an aspect ratio of 65 and a diameter of 0.9mm, and Master Fiber MAC 2200CB. These beams underwent rigorous testing under a three-point bending setup, with a meticulous analysis of their load-deflection behavior.

Furthermore, the thesis substantially contributes to elucidating the intricate mechanisms that underlie the behavior of fiber-reinforced concrete beams. It offers profound insights that can be harnessed for optimizing the utilization of fibers in concrete mixes for structural applications. This study's findings are poised to significantly impact the design and construction of concrete structures, particularly in regions characterized by high flexural tensile stresses, such as bridge decks, pavements, and industrial floors. As such, this research extends beyond academic inquiry, manifesting its practical relevance and real-world applicability.

1.8 Thesis structure

The thesis structure comprises five chapters, each serving a distinct purpose:

Chapter 1: Introduction

This opening chapter introduces the research's backdrop, encompassing the problem statement, research questions, objectives, and the study's significance. It offers an overview of the application of fiber reinforcement in concrete structures, emphasizing its potential advantages in bolstering the flexural tensile behavior of beams.

Chapter 2: Literature Review

The second chapter delves into the existing literature on using fiber reinforcement in concrete beams. It explores the various types of fiber reinforcement, elucidating their impact on the flexural tensile behavior of beams. Additionally, it scrutinizes the factors that influence the effectiveness of fiber reinforcement in beams while delving into relevant experimental and analytical studies conducted in this domain.

Chapter 3: Methodology

This chapter expounds upon the research methodology employed for evaluating the influence of different fiber types on the flexural tensile behavior of beams. It encompasses discussions regarding the experimental program, the materials employed, the testing protocols, and the techniques applied for data analysis.

Chapter 4: Results and Discussion

The fourth chapter serves as the platform for presenting the research findings and engaging in a comprehensive discussion based on the investigations detailed in Chapter 3. Here, the flexural tensile behavior of beams reinforced with various fiber types is meticulously analyzed, offering valuable insights into how the choice of fiber type impacts the beams' performance.

Chapter 5: Conclusions, Recommendations, and Future Works

In the concluding chapter, the study's principal findings are succinctly summarized, leading to the formulation of conclusions drawn from the results. It also furnishes recommendations for future research endeavors and underscores the potential implications and advantages of employing fiber reinforcement to elevate the flexural tensile behavior of beams within concrete structures.

CHAPTER TWO

LITERATURE REVIEW

2.1 Overview

Using steel fibers as a reinforcing material in concrete has become increasingly popular due to its numerous advantages over traditional reinforcement methods, such as improved durability, ductility, and crack resistance. However, the performance of SFRC depends on various factors, such as the type, shape, and size of the fibers used. This chapter presented a literature review focusing on the influence of steel fiber types on the flexural tensile behavior of beams. The flexural tensile strength is an essential property of SFRC as it determines its ability to resist bending and cracking under load. Steel fibers commonly used in SFRC include hooked end, crimped, straight, and corrugated fibers.

2.2 Introduction

Concrete is widely used as a building material due to its high compressive strength. However, it has low tensile strength, and as such, it tends to crack under tension. Steel fibers have been added to concrete to overcome this limitation and improve tensile strength and flexural behaviour. This literature review examined the use of steel fiber reinforcement in concrete beams, its types, and its impact on the flexural tensile behaviour of beams.

- Types of Steel Fibers

Several steel fibers can reinforce concrete beams, including hooked, crimped, straight, and deformed fibers. Hooked and crimped fibers have better bonding properties with concrete than straight fibers. Deformed fibers, conversely, have a larger surface area and offer better bonding with concrete. In addition, the aspect ratio, diameter, and length of steel fibers can affect their effectiveness as reinforcement (Abdallah et al., 2018).

- Impact of Steel Fibers on Flexural Tensile Behaviour of Beams

Adding steel fibers to concrete can significantly improve its flexural tensile behaviour. Steel fibers can reduce the formation of microcracks and delay the initiation and propagation of macrocracks. Moreover, they can increase the toughness and ductility of concrete, allowing it to deform under load without collapsing. Steel fibers can also improve the post-cracking behaviour of concrete beams, enabling them to withstand higher loads after cracking (Chen et al., 2021).

- Factors Affecting the Effectiveness of Steel Fiber Reinforcement

Several factors can affect the effectiveness of steel fiber reinforcement in concrete beams, including the type and aspect ratio of fibers, the amount and distribution of fibers, the curing conditions, and the concrete mix design. The effectiveness of steel fibers can also depend on the loading conditions, such as the rate and magnitude of the applied load, the loading duration, and the beam's size and geometry (Abdallah et al., 2018).

- Experimental and Analytical Studies

Numerous experimental and analytical studies have been conducted to investigate the effectiveness of steel fiber reinforcement in concrete beams. Experimental studies have shown that adding steel fibers can increase concrete beams' load-bearing capacity, flexural strength, and ductility (Xu et al., 2019). Analytical studies have also demonstrated the effectiveness of steel fibers in reducing crack formation and improving the post-cracking behaviour of concrete beams. However, the point of steel fiber reinforcement can vary depending on the abovementioned factors.

2.3 Previous study

SFRC has recently gained acceptance as an alternative composite material for constructing reinforced concrete (RC) structures. Research suggests that steel fibers improve various mechanical properties of RC members. Specifically, steel fibers enhance RC structural members' bending moment strength, ductility, failure toughness, and energy absorption capacity. Straight and short mill-cut steel fibers with a relatively low aspect ratio of 40 added to a volume fraction of up to 2% effectively enhance sectional flexural stiffness and increase ductility related to the lateral deformations of RC columns under eccentric compression(Gatabi et al., 2021). The flexural cracking performance of SFRC beams with longitudinal steel reinforcing bars can be improved with the increased crack number, reduced crack width and height, restricted crack propagation, and delayed concrete spalling. High aspect ratio steel fibers with deformations or hook-ends are most effective in increasing cracking resistance, energy dissipation, and ductility index (K. Kytinou et al., 2020). Therefore, the selection of steel fiber types is crucial for enhancing the mechanical properties of SFRC members. The type of steel fiber used in beams can significantly impact their flexural tensile behavior. Research has shown that adding steel fibers to concrete can increase the first cracking load, ultimate load, stiffness, and ductility of concrete beams, improving their strength and overall performance (Yoo et al., 2019).

Moreover, the tensile strength and aspect ratio of steel fibers are crucial factors that affect the flexural behavior of the beams. A study found that using steel fibers with a high tensile strength and aspect ratio can provide excellent flexural behavior for the beams (Gao & Zhang, 2018). It is also important to note that the effects of steel fiber reinforcement on ultra-high-performance concrete's compressive and tensile strength have been extensively studied. A review paper presented the impact of steel fiber reinforcement on the compressive and tensile strength of UHPC, an essential area of research for improving the performance of beams (Abbass et al., 2019). Overall, the type of steel fiber used in beams can significantly impact their flexural tensile behaviour, and selecting the appropriate variety of steel fiber can lead to improved structural performance. In addition, some studies that dealt with the influence of steel fiber types on the flexural tensile behaviour of beams clarified in more detail.

Guler and Akbulut (2022) presented a paper about steel fibers being widely used as a reinforcement material in concrete to enhance its strength, ductility, and toughness properties. Conventionally, single-hooked (3D) steel fibers have been used in concrete applications. However, recent advancements have developed multi-hook 4D and 5D steel fibers with modified end geometries that offer improved mechanical properties. In this study, the researchers aimed to compare the performance of 3D, 4D, and 5D of SFRC at room conditions and after exposure to high-temperature effects. The specimens were prepared by adding fibers at 0.5% and 1.5% by volume to cement mortars. The samples were exposed to 300, 500, and 800 °C temperature effects. The study results showed that the control and SFRC specimens experienced a significant decrease in residual strength and toughness capacities after exposure to high temperatures of 500 and 800 °C. However, compared to control concrete, the SFRC specimens containing 3D, 4D, and 5D steel fibers had higher residual compressive and flexural strength and residual toughness capacity after high-temperature effects.

Moreover, the 5D steel fibers were more effective than 3D and 4D steel fibers in enhancing concrete's residual compressive and flexural strength and residual toughness capacity due to their superior end geometry and higher tensile strength. The increase in performance was pronounced when the fiber volume ratio increased from 0.5% to 1.5%. In conclusion, using multi-hook 4D and 5D steel fibers with modified end geometries in concrete applications can improve mechanical properties, especially at high temperatures. The findings of this study can have practical implications for the design and construction of concrete structures exposed to high-temperature environments.

Mujalli et al. (2022) presented a paper about concrete being a widely used construction material due to its durability, versatility, and low cost. However, conventional concrete suffers from low tensile and shear strengths, which can result in cracking and brittle failure under tension and shear forces. Steel fibres are commonly added to concrete to address these issues to enhance its mechanical properties and resistance to cracking. Steel fibres in concrete can partially or fully replace traditional steel reinforcement, providing a cost-effective solution to improve the strength and durability of concrete structures. Steel fibres are available in various shapes, sizes, and mechanical properties, and selecting the appropriate type and dosage of fibres is crucial in ensuring the adequate performance of the composite material. The bond behaviour between steel fibres and the concrete matrix is a critical factor in determining the strength and durability of SFRC. Steel fibers' physical and mechanical properties influence the bond behaviour, including geometry, inclination angle, embedded length, diameter, and tensile strength. For instance, the shape of the fibre can affect its bond behaviour, with hooked and crimped fibres exhibiting better performance than straight fibres.

Additionally, the inclination angle of the fibre and its embedded length can affect the transfer of stress from the matrix to the fibre, impacting the overall strength of the composite material. Several studies have shown that adding steel fibres can significantly enhance concrete components' compressive, tensile, and flexural strength. For instance, adding up to 2% of steel fibres to the concrete mixture can increase its compressive strength by about 20%, tensile strength by 143%, and flexural strength by 167%.

Furthermore, the addition of steel fibres has been shown to improve the pullout performance of concrete, increasing its resistance to cracking and failure under tensile and shear forces. In conclusion, steel fibre-reinforced concrete is a promising solution to enhance the strength and durability of conventional concrete. The bond behaviour between steel fibres and the concrete matrix is a critical factor in determining the overall strength of the composite material. A thorough understanding of steel fibers' physical and mechanical properties and their effects on bond behaviour can aid in properly selecting and applying steel fibres in SFRC.

Venkateshwaran et al. (2018) submit a paper describes an experimental investigation of the effect of concrete compressive strength, reinforcing index (RI), and number of hook-ends in steel fibers on the load-crack mouth opening displacement (LOP) and the residual flexural strengths of SFRC. The study involved 69 pre-notched beams tested under 3-point bending, and empirical equations were proposed to predict the residual flexural strengths of SFRC.

The empirical equations were validated using data from 39 3-point bending tests, and the results showed that the equations accurately predicted the values of residual flexural strengths with a mean and median within 5% of the observed values. The parametric studies showed that the RI had the most significant influence on the residual flexural strength, while the compressive strength of concrete had the most significant impact on the LOP.

The study found that an increase in the compressive strength had a similar influence on the residual flexural strength as increasing the number of hook-ends in steel fibers. The proposed equations for the residual flexural strengths helped determine the simplified constitutive stress-crack opening laws defined by the linear model in Model Code 2010 for the design of SFRC without the need for prism tests.

Chen et al. (2021) studied three-point bending tests on notched concrete beams with low, standard, and high strength. The beams were reinforced with single or multiple hooked-end steel fibers, with a dosage range of 0 to 110 kg/m3, a length range of 35 to 60 mm, and a diameter range of 0.55 to 0.90 mm. The study investigated the effects of concrete strength and fiber properties on the Limit of Proportionality (LOP) and residual flexural tensile strength of SFRC.

The experimental results showed that the LOP, which indicates the onset of initial cracking in the concrete, is mainly influenced by the concrete's strength rather than the fibers' properties. This suggests that adding steel fibers to the concrete does not significantly affect the LOP. On the other hand, increasing the dosage, length, aspect ratio, and number of hooked ends of the fibers positively affected the residual flexural tensile strength of the SFRC. To predict the LOP and residual flexural tensile strength of SFRC, the study proposed new empirical equations that explicitly consider the effects of concrete strength and fiber properties. These equations can be used to analyze the impact of varying concrete strength and fiber properties on the LOP and residual flexural tensile strength in depth. The study concluded that concrete strength mainly governs the LOP, while fiber properties especially dictate the residual flexural tensile strength.

Furthermore, the modified by Venkateshwaran et al. equation was proposed to predict the residual flexural tensile strength (fr, i) of the novel multiple hooked-end SFRC, considering concrete compressive strength, fiber volume fraction, fiber aspect ratio, fiber length, and the number of fiber hook ends. The modified equation was valid for high-strength SFRCs, while the original equation only applied to low-strength and normal-strength SFRCs.

Venkateshwaran and Tan (2018) researched SFRC as a composite material that combines the ductility and energy absorption capacity of steel fibers with the compressive strength of concrete. Discrete steel fibers are commonly used in SFRC to control crack propagation and widening, thereby enhancing the flexural performance of concrete members. Using steel fibers in SFRC can improve the load-carrying capacity of concrete members up to large deflections, making it an attractive material for structural applications.

A study investigated the flexural behavior of SFRC beams reinforced with steel fibers using four-point bending tests on eight beam specimens. The study examined the effect of reinforcing index, fiber type, and beam depth on the load-carrying capacity of SFRC beams. The reinforcing index was defined as the product of the volume fraction and the aspect ratio of steel fibers.

The load-carrying capacity of SFRC beams was predicted using general constitutive stress-strain/crack width laws in tension. However, existing constitutive relations in tension failed to predict the load-carrying ability at large deflections accurately. Therefore, a constitutive law was proposed using a back-calculation technique, validated with the results from four-point bending tests conducted on 24 SFRC beams.

The proposed model demonstrated a deviation of predictions about the average load-carrying capacity at large deflections within 12% of the observed values. This suggests that the proposed model can accurately predict the load-carrying ability of SFRC beams up to large deflections. The authors also suggest that their proposed constitutive law can be used to derive the complete moment-curvature relationship of SFRC flexural members. This relationship could then be used to analyze the behavior of continuous beams and slabs, including moment redistribution.

Simões et al. (2017) submitted the research for the objective described in the paper was to evaluate the effect of concrete compressive strength and steel fibre geometry on the behaviour of the fibre/matrix interface. The researchers designed three definite matrices with varying strengths and used two types of steel fibres (Dramix® 3D and Dramix® 5D) to conduct pullout and axial tensile tests. They also developed a numerical model to expand the scope of the experimental results. The study found that concrete compressive strength strongly influences the fiber/matrix strength. The original 3D fibres with hook-shaped endings provided higher anchorage strength for concrete with lower strength, while bond strength was less influential. The increase in concrete compressive strength led to the rise in the number of original fibres failing by tensile strength, and the difficulty of damaging the adjoining matrix during the hook deformation process also increased.

The study also found that the peak load for specimens with 5D1 fibers was much higher than those with 3D1 fibers, due to their higher diameter and embedded length. The adhesion component of the bond strength of the 3D1 fibers was about 50% higher than that of the 5D1 fibers for matrices with strengths of 60 and 100 MPa. The friction strength increased with slip and presented similar values for both fibers, except for fiber 5D1 and matrix 100 MPa, where matrix strength had a higher influence on friction.

The numerical model for interfaces with 3D fibres with hooks was developed based on several parameters and correlations between the fibres and the compressive strength of the matrix. The researchers calibrated the model using experimental data for each matrix, and it can be used to simulate the structural behaviour of FRC concrete members.

Balendran et al. (2002) The paper presents the results of an experimental study conducted to investigate the effectiveness of fiber inclusion in improving the mechanical performance of concrete in terms of concrete type and specimen size. The study used lightweight aggregate concrete and limestone aggregate concrete with and without steel fibers. The experimental findings indicate that adding a low fiber volume has little effect on compressive strength but significantly improves splitting tensile strength, flexural strength, and toughness.

The study suggests that the effectiveness of fiber reinforcement depends on the properties of the concrete matrix, and the improvement in splitting tensile strength and flexural strength is much more significant for lightweight concrete than for normal-weight concrete. The size effect on prism-breaking tensile strength is insignificant beyond a critical size of 150 mm, but there are apparent size effects on flexural strength and toughness index. As the specimen size increases, splitting and flexural strengths decrease, and fracture behavior tends to be more brittle.

The study concludes that the toughness indices of lightweight fiber-reinforced concrete are not very sensitive to the specimen size, but for fibre-reinforced standard-weight concrete, toughness indices become smaller when the specimen size increases. Therefore, the size effect on toughness must be considered in designing the ductile behavior of fibre-reinforced structures. Further research is required to examine the size effect on toughness. Overall, the study provides valuable insights into the effectiveness of fiber reinforcement in improving the mechanical performance of concrete and the size effect on different mechanical properties.

Karzad et al. (2020) present a research study investigating the flexural behavior of SFRC prisms under various conditions. The study used two steel fibers, hooked-end and straight-end, incorporated into concrete mixes with different dosages and compressive strengths. The study also varied the specimen depth to determine the size effect on SFRC's flexural behavior.

The test results showed that increasing the volume fraction of straight-end steel fibers from 1% to 2% resulted in a 44% and 30% increase in the average modulus of rupture (MOR) and mid-span deflection values, respectively. On the other hand, the longer hooked-end steel fibers (ZP305) showed only a 20% increase in mid-span deflection and the slight rise in MOR value due to the reduced workability of the SFRC mix. The study also found that increasing the concrete compressive strength had a modest effect on the average MOR value but a noticeable effect on the average mid-span deflection at peak load, attributed to the hooked-end geometry of the steel fibers. Additionally, increasing the specimen depth resulted in reduced MOR values, indicating a size effect on the flexural behavior of SFRC.

2.3.1 Summary of Improving Concrete Beam Flexural Tensile Behavior with Novel Multiple Hooked-End Steel Fibers.

A novel approach to enhancing the flexural tensile strength of concrete beams is using multiple hooked-end steel fibers with varying strength grades (Hussain et al., 2022). Compared to other types of fibers, such as polyolefin fibers, hooked and corrugated steel fibers can significantly enhance the tensile strength of concrete beams, particularly in flexural strength (Hussain et al., 2022). The study suggests that using different fibre types in concrete mixes can enhance tensile strength (Hussain et al., 2022). However, when it comes to improving the flexural tensile strength of concrete beams, using hooked or corrugated steel fibres is preferable (Hussain et al., 2022). The shape of the steel fibers can impact the flexural behaviour and tested mechanical properties of the concrete beams, with hook steel fibers producing a more significant improvement than other fiber shapes (Hussain et al., 2022). Therefore, using multiple hooked-end steel fibers can enhance the flexural tensile strength of concrete beams, making it a promising approach for future applications.

2.3.2 Effect of Steel Fiber Types on Flexural Tensile Behavior of Beam: A Comparative Study.

In the study, the researchers developed an efficient FE model in ABAQUS software to investigate the effect of steel fiber types on the flexural tensile behavior of beam structures. The proposed model employed constitutive relationships for SFRC under compression and tension based on experimental data to accurately simulate the flexural performance of SFRC beams reinforced with steel reinforcing bars and stirrups (Kytinou et al., 2020). Seventeen analyses were executed to validate the proposed model, and the results were compared with published experimental results. The researchers found that the proposed model successfully predicted the flexural tensile behavior of SFRC beams by comparing its responses with published experimental results (Kytinou et al., 2020). This study investigated the effectiveness of steel fibers in improving the flexural response of SFRC structural members with conventional steel reinforcement through 3D finite element analysis. It was observed that steel fibers substantially improved the performance of concrete under tension, exhibiting increased tensile strength and pseudo-ductile behavior due to the gradual debonding failure of fibers (K. Kytinou et al., 2020). Adding steel fibers also reduced the deflection and crack width of LWC beams reinforced and prestressed with CFRP bars(Wu et al., 2021). The study also found that inclined deformed steel fibers at 45° correlated with the flexural performance of steel fiber-reinforced concrete beams. However, aligned multiple fibers pullout test data did not show any proportional correlation with the tensile performance of UHPC reinforced with hybrid macro. Single fiber pullout test data can only be correlated with the flexural performance of SFRC in a qualitative sense (Chun & Yoo, 2019). Finally, the authors experimentally verified a smeared crack model for plain concrete with tension softening and modified it to simulate the favorable influence of steel fibers in SFRC under tension (K. Kytinou et al., 2020).

2.3.3 Analyzing the Impact of Steel Fiber Types on the Flexural Tensile Behavior of Beams

For comparative analysis of the flexural tensile behavior of beams reinforced with different steel fibers, the flexural tensile behavior of beams reinforced with varying steel fibres has been studied extensively. Studies have shown no proportional correlation between the pullout test data of aligned multiple fibers and the tensile performance of UHPC reinforced with hybrid macro (Chun & Yoo, 2019). However, single-fiber pullout test data can be correlated with the flexural performance of SFRC, at least in a qualitative sense (Chun & Yoo, 2019). Inclined, deformed steel fibers at 45° can be compared to the flexural behavior of the SFRC beam (Chun & Yoo, 2019).

Furthermore, all steel fiber types' highest bond strengths were found when inclined at 30° or 45°, while their slip capacities increased with increasing inclination angle (Yoo et al., 2019). In UHPFRC, straight steel fibers provide the best tensile performance, followed by twisted, half-hooked, and hooked steel fibers (Yoo et al., 2019). Although twisted steel fibers (twisted, hooked, and half-hooked) provide better pullout resistance in UHPFRC than straight steel fibers, hooked steel fiber exhibited the highest bond strengths at all inclination angles (Yoo et al., 2019).

Moreover, shorter straight fibers provided higher bond strengths and maximum shear stress at the interface than longer fibers (Yoo et al., 2019). Matrix strength positively affected fiber pullout performance, and HPFRCC beams with medium-length straight fibers had the best flexural performance, while those with hooked fibers had the worst

(Chun & Yoo, 2019). However, the correlation between single fiber pullout behavior and flexural behavior of HPFRCC beams was low due to several influential factors (Chun & Yoo, 2019). Finally, hooked fibres exhibited higher bond strengths and pullout work than straight fibers but showed minor shear stress at the interface at large slips (Chun & Yoo, 2019).

2.3.4 The Three-Point Bending Test

The three-point bending test is a flexural strength test commonly used to evaluate the mechanical properties of reinforced concrete beams. This test involves applying a load to the center of a beam span, causing the beam to bend. The load is gradually increased until the beam fails or breaks. In the three-point bending test, the beam is supported at its ends, and a load is applied at the center of the beam span using a hydraulic or mechanical testing machine. As the load increases, the beam begins to bend, and the deflection and strain are measured at several points along the beam. The load-deflection and load-strain curves obtained from the test provide valuable information about the beam's behavior under load and its ultimate strength.

The three-point bending test is widely used to evaluate the flexural strength of reinforced concrete beams because it simulates the bending forces that the beams are likely to experience in real-world applications. Engineers can determine the optimal reinforcement and dimensions required to achieve the desired strength and durability by testing different beam designs and construction techniques.

The results of the three-point bending test are used to determine the beam's modulus of elasticity, flexural strength, and toughness. These parameters are critical for ensuring the beam can withstand the expected loads and bending forces without failure. The test is also used to evaluate the quality of the concrete and the reinforcing steel used in the beam's construction (Grzymski et al., 2019).

2.3.5 Research Findings

The influence of steel fiber types on the flexural tensile behavior of beams has been the subject of numerous research studies. Some of the key findings from these studies are as follows:

- Fiber type

Different steel fiber types, such as hooked, crimped, and straight fibers, have other mechanical properties, and their use affects the flexural behavior of beams (Shin et al., 2021).

- Fiber aspect ratio

The aspect ratio of steel fibers, which is the fiber length ratio to its diameter, significantly impacts the flexural behavior of beams. Longer fibers with a high aspect ratio tend to improve concrete beams' flexural strength and ductility (Yoo & Moon, 2018).

- Fiber volume fraction

Adding steel fibers to concrete improves beams' flexural strength and ductility, but the optimal fiber volume fraction depends on the fiber type, aspect ratio, and other factors (Shin et al., 2021).

- Bond strength

The bond between the steel fibers and the surrounding concrete matrix is critical for the flexural behavior of beams. Different fiber types exhibit different bond strengths, which affects the overall performance of steel fiber-reinforced concrete beams (Tahenni et al., 2020).

- Crack propagation

The presence of steel fibers in concrete reduces crack propagation and improves the ductility of beams. The type of steel fiber affects the crack propagation behavior of beams, with hooked fibers being more effective in controlling crack propagation (Abbass et al., 2018).

2.3.6 Current Study

Research on the influence of steel fiber types on the flexural tensile behavior of beams continues to be an active area of study in civil engineering. Steel fibers are commonly added to concrete to improve its toughness, ductility, and resistance to cracking. The type of steel fiber used can significantly impact the flexural tensile behavior of the resulting concrete beams.

Several studies have investigated the effect of different types of steel fibers on the flexural tensile strength, energy absorption capacity, and crack resistance of concrete beams. The most commonly used steel fibers include hooked-end, crimped, and straight fibers, each with unique geometry and mechanical properties (Shin et al., 2021).

Research has shown that hooked-end fibers are particularly effective in improving the flexural tensile behavior of concrete beams due to their ability to anchor within the factual matrix. They can also reduce crack width and improve crack control, leading to increased durability and longevity of the concrete structure (Chen et al., 2022).

Conversely, cotton fibres are effective in improving the shear strength of concrete beams, although their impact on flexural tensile behavior is less significant (Chen et al., 2022).

Straight fibers are less effective in improving the flexural tensile behavior of concrete beams but can still contribute to the overall toughness and ductility of the concrete (Turker et al., 2019).

In addition to the type of steel fiber used, the fiber's aspect ratio, diameter, and volume fraction can also affect the flexural tensile behavior of the resulting concrete beams (Yoo & Moon, 2018).

Selecting the appropriate steel fiber type and dosage should be based on the specific performance requirements of the concrete application. Experimental testing and analysis can be used to determine the most practical combination of steel fiber type and dosage to achieve the desired performance characteristics (Grzymski et al., 2019).

Experimental and analytical studies have shown the effectiveness of steel fibers in improving the load-bearing capacity, flexural strength, and ductility of concrete beams. However, the point of steel fiber reinforcement can vary depending on the loading conditions and other factors, and further research is needed to fully understand its impact on concrete beams.

2.4 lack of reserch

While there is a substantial amount of research on the influence of steel fiber types on the flexural tensile behavior of beams, there are still some areas where knowledge is lacking.

One area of uncertainty is the long-term durability of concrete beams reinforced with steel fibers. While studies have shown that steel fibers can improve the toughness and ductility of concrete, it is not yet clear how these properties are affected over time by environmental factors such as exposure to freeze-thaw cycles, aggressive chemicals, and weathering.

Another area lacking knowledge is the effect of steel fiber types on the bond strength between concrete and reinforcing steel. It is essential to understand how the addition of steel fibers affects the transfer of stresses between the concrete and steel reinforcement, as this can have significant implications for the overall strength and stability of the concrete structure.

There is also a need for further research on the impact of different steel fiber types on the cracking behavior of concrete beams under various loading conditions. While studies have shown that steel fibers can reduce crack width and improve crack control, it is unclear how different fiber types perform under varying degrees of loading and deformation.

In addition, there is a lack of standardized testing methods for evaluating the flexural tensile behavior of concrete beams reinforced with steel fibers. This can make it difficult to compare results across different studies and to develop consistent design guidelines for engineers.

CHAPTER THREE

METHODOLOGY

3.1 Overview

The research methodology for this study encompassed an experimental investigation to explore how various fiber types impact the flexural tensile behavior of beams. The subsequent sections provide detailed accounts of the materials utilized, the testing protocols, and the data analysis methods employed in this research.

3.2 Methodology

The methodology employed in this thesis to assess the impact of various fiber types on the flexural tensile behavior of beams comprised a series of well-defined steps:

1. The initial step clearly and concisely defined the thesis problem and objectives. The primary aim was to evaluate how different fiber types influenced the flexural tensile behavior of beams.

2. An experimental plan was developed in alignment with the thesis objectives. This entailed the selection of the variables under scrutiny, which encompassed a range of steel fiber types, including Control (None), 3D Hooked-end steel fiber, 4D Hooked-end steel fiber, 4D Hooked-end steel fiber, and Master Fiber MAC 2200CB.

3. The definition of the variables extended to establishing the range of values for each variable and devising the experimental setup.

4. The meticulous selection and identification of materials were pivotal aspects of the study. This encompassed the concrete mix design, the specific steel fibers utilized, and another material integral to the experimental setup.

5. the experiment's design meticulously cast the concrete beams once the materials were in place.

6. Following the casting of beams, they were subjected to the stipulated testing procedures. This entailed loading the beams to the point of failure under a three-point bending arrangement, measuring the load-deflection response, and documenting other pertinent data.

7. The data collected during the testing phase was subjected to thorough analysis employing appropriate statistical techniques. This included the calculation of the mean and standard deviation for the measured parameters and a comparative assessment of the results concerning different steel fiber types and beam dimensions.

8. Drawing upon the data analysis outcomes, conclusions were drawn concerning the influence of varying fiber types on the flexural tensile behavior of beams. This phase included identifying trends and patterns within the data and discussing significant findings.

These methodical steps served as the foundation for a robust and comprehensive investigation into how different fiber types impacted the flexural tensile behavior of concrete beams.

3.3 Materials

Table 3.1 presents the essential material properties of the concrete specimens used in the study. It includes details such as the type of cement, the fineness modulus of sand, the size of coarse aggregates, and various characteristics of the steel fibers (type, length, diameter, and aspect ratio). Potable water is used for mixing. These properties are critical for understanding the composition of the concrete and its potential influence on the flexural tensile behavior of beams.

Table 3.1: Properties of Materials Used

Material	Property
Cement	Type I
Sand	Fineness modulus: 2.7
Coarse aggregates	Maximum size: 20 mm
fibres	Type: Hooked end steel fiber, macrosynthetic fiber.
	Length: 60, mm
	Diameter: 0.9, 0.75, mm
	Aspect ratio: 80,65
Water	Potable water

Table 3.2 provides a succinct summary of materials used in concrete proportioning, detailing their volume (in liters per cubic meter) and oven-dry weight (in kilograms per cubic meter). These materials include cement, water (free and total), coarse and medium aggregates, two fine aggregates, an admixture, and air voids. The totals ensure that the specified volume and weight criteria are met for each cubic meter of concrete, serving as the foundation for evaluating the concrete's behavior in flexural tensile beams.

Table 3.2: Concrete Mixture Design

Materials for proportioning	Volume (L/m3)	Oven-dry Weight (Kg/m3)
Cement	95.2	300.0

Water	138.0 (free water)	178.3 (total water)
Coarse Aggregate (Fouliyah)	170.1	438.5
Medium Aggregate (Adasiyah)	207.1	534.4
Fine Aggregate I (Semsemiyah)	103.6	267.2
Fine Aggregate II (Silica Sand)	258.9	683.1
Admixture (Adcon SP 500)	7.0	8.3
Air Voids	20.0	n/a
Total	1.000.0	2.409.9

Figure 3.1 visually represents the various shapes and types of fibers frequently employed in concrete mixes. These encompass 3D Hooked-end, 4D Hooked-end, and Master Fiber MAC 2200C.

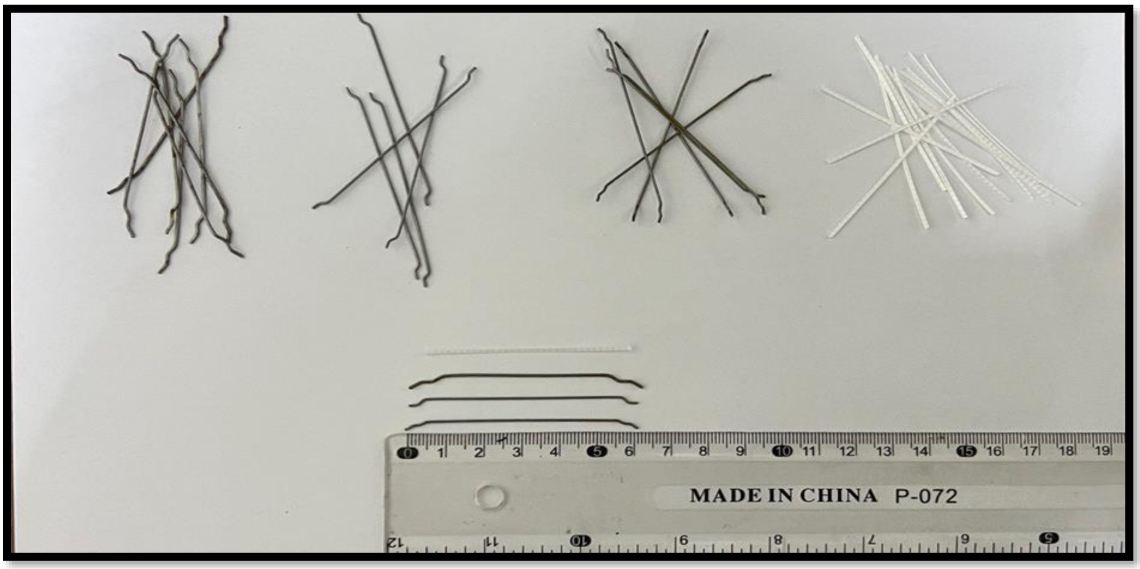

Figure 3.1: Types of Used Fiber.

The following were the systematic steps in this testing procedure, conducted at the "Arab Center for Research and Studies." **These steps were designed to ensure the accuracy and reliability of the results**, contributing to advancements in construction materials and methods.

1. Mold Preparation:

- The molds were meticulously prepared, ensuring they were clean and free of foreign materials or impurities.

- The testing was conducted at the "Arab Center for Research and Studies."

2. Concrete Mixing:

- The concrete mix was meticulously prepared in a controlled environment according to specific requirements. This entailed precise measurements of cement, aggregates, water, and any relevant chemical additives.

- A concrete mixer was employed to ensure the consistent and uniform blending of the constituents. The mixing process continued until the mixture reached a homogeneous state.

3. Adding fiber to the Mixer:

- The designated type and quantity of fibers were introduced into the concrete Mixer, ensuring the fibers were evenly distributed throughout the concrete blend.

- The mixture was then agitated for an appropriate duration to guarantee the uniform dispersion of the fibers within the concrete.

4. Pouring Concrete into Molds:

- The fibre-reinforced concrete blend was gently poured into the prepared moulds, filling them to the desired level. Special attention was given to the even distribution and compaction of the concrete within the moulds.

5. Concrete Consolidation:

- The concrete specimens were consolidated to remove air voids and enhance their density. This was typically achieved by using a vibrating table or equipment.

- The purpose of the consolidation was to create concrete samples with a consistent and solid structure.

6. Curing Process:

- The filled molds were carefully placed in a curing chamber or room where temperature and humidity were controlled. This controlled environment allowed the concrete to cure for the specified duration to achieve the desired strength and durability.

7. Demolding the Specimens:

- To avoid damage, the concrete specimens were gently removed from the molds after the curing period.

8. Sample Transfer:

- The molded concrete specimens were transported to the testing area carefully to prevent any breakage or alteration.

9. Test Setup:

- Established standards for testing concrete specimens and set up the required testing equipment and fixtures. This included apparatus for flexural tests, tensile tests, or other specific tests as needed.

10. Specimen Testing:

- The planned tests, which evaluated parameters such as flexural tensile or compressive strength, were conducted on the concrete specimens.

- The test results were recorded and analyzed, providing valuable data regarding the performance of fiber-reinforced concrete.

Figure 3.2: Meticulous Mold Preparation.

Figure 3.3: Signifies the Exact Preparation of the Concrete Mix, Requiring Precise Measurements of Cement, Aggregate, Water, and any Related Chemical Additives.

Figure 3.4: A Concrete Mixer Ensured Consistent and Uniform Blending of Components, with a Specific type and Amount of Fiber Evenly Distributed Throughout the Mixture.

Figure 3.5:Pouring Concrete into Molds

Figure 3.6: The Concrete Specimens were Carefully Transported to the Testing and Specimen Testing Area.

3.4 Experimental Program

The experiment had two primary phases:

1. During this phase, concrete beams were produced in a controlled laboratory setting, ensuring precise and consistent conditions. A standardized mix design was adhered to, incorporating defined proportions of concrete components, including cement, aggregates, water, and required additives or admixtures. The mix design aimed to attain a 45 MPa compressive strength after 28 days of curing.

- The inclusion of steel fibers was a key variable. Some beams were cast with the addition of steel fibers, while others were not, serving as a control group.

- The casting process involved preparing molds or forms, pouring the concrete mixture into them, and allowing the concrete to set and cure according to established procedures.

2. Testing of Concrete Beams:

- Following adequate curing, the concrete beams underwent testing to assess their performance and properties. A total of 15 beams underwent assessment.

Subsequently, a series of tests were conducted to assess the beams' performance and properties, with the data collected and analyzed for the study's conclusions. The details of the 15 beams and their test results are documented in Table 3.2, providing a comprehensive overview of the experiment's findings.

Table 3.3:Test Matrix

Test	Fiber Type	Volume Fraction (Vf)
Control -1	None	0%
Control -2	None	0%
Control -3	None	0%
3D (80/60)-1	3D Hooked-end steel fiber with an aspect ratio of 80 and diameter of 0.75mm	0.5%
3D (80/60)-2	3D Hooked-end steel fiber with an aspect ratio of 80 and diameter of 0.75mm	0.5%
3D (80/60)-3	3D Hooked-end steel fiber with an aspect ratio of 80 and diameter of 0.75mm	0.5%
4D (80/60)-1	4D Hooked end steel fiber with an aspect ratio of 80	0.5%
4D (80/60)-2	4D Hooked-end steel fiber with an aspect ratio of 80 and diameter of 0.75mm	0.5%
4D (80/60)-3	4D Hooked-end steel fiber with an aspect ratio of 80 and diameter of 0.75mm	0.5%
4D (65/60)-1	4D Hooked-end steel fiber with an aspect ratio of 65 and diameter of 0.9mm	0.5%
4D (65/60)-2	4D Hooked-end steel fiber with an aspect ratio of 65 and diameter of 0.9mm	0.5%
4D (65/60)-3	4D Hooked-end steel fiber with an aspect ratio of 65 and diameter of 0.9mm	0.5%
MAC -1	Master Fiber MAC 2200CB	0.5%
MAC -2	Master Fiber MAC 2200CB	0.5%
MAC -3	Master Fiber MAC 2200CB	0.5%

In this study, concrete beams were infused with fibers at a volume fraction of 0.5%. A hydraulic testing machine was utilized to assess the structural performance of these beams. The testing procedure entailed subjecting the beams to a three-point bending setup and applying the load at a controlled rate of 0.5 kN per second until the beams reached a deflection of 0.65mm.

Throughout the test, careful recording and monitoring of the beams' behavior in response to the applied load were carried out, including precise measurements of deflection concerning the applied force. This data facilitated the analysis and comprehension of how the beams performed under the specified conditions, offering valuable insights into their structural characteristics and durability.

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3.4.1 Data Analysis

The analysis of data from our experimental program focused on key parameters related to the flexural tensile behavior of concrete beams, both with and without the inclusion of fibers:

1. Load-Deflection Behavior:

   - Examined how the beams responded structurally to monotonic loads in terms of deflection.

2. Flexural Strength:

   - Investigated the beams' ability to withstand bending forces, a crucial consideration in structural engineering.

3. Deflection at Maximum Load:

   - Analyzed the beams' performance at their ultimate capacity by studying their deflection at the point of maximum load.

CHAPTER FOUR

RESULTS AND DISCUSSION

4.1 Overview

Chapter 4 unveils the research findings and explores the insights derived from the discussions in Chapter 3. It delves into the flexural tensile behavior of beams reinforced with diverse fiber types, shedding light on how the selection of fiber type impacts beam performance.

4.2 Result of Load-Deflection Behavior

The study implies that fiber reinforcement can serve as a valuable means to enhance the flexural tensile behavior of concrete beams. To optimize beam performance, it is crucial to make thoughtful choices regarding the type and quantity of fibers used.

The addition of fibers in this study improved the beams' load-deflection behavior. This enhancement in load-carrying capacity and deflection reduction is attributed to steel fibers' bridging effect. They effectively hinder crack propagation and contribute to the overall ductility of the beams.

Table 4.1 presents a spectrum of measurements and the forces exerted on different configurations, encompassing 3D (80/60), 4D (80/60), 4D (65/60), MAC (2200 CB), and Control. The "Force (kN)" column delineates the applied force in kilonewtons (kN).

Table 4.1: The Represents Types and Amounts of Force and the Specifications of the Beam.

Type	Specimen No.	Force (N)	L(mm)	Span length (mm)	Width (mm)	Depth (mm)	Modulus of Rupture (MR)	Average MR
3D (80/60)	1	18300	550	500	150	150	4.1	4.9
	2	26000	550	500	150	150	5.8	
	3	22000	550	500	150	150	4.9	
4D (80/60)	1	23210	550	500	150	150	5.2	5.6
	2	26990	550	500	150	150	6.0	
	3	25300	550	500	150	150	5.6	
4D (65/60)	1	30350	550	500	150	150	6.7	6.8
	2	31230	550	500	150	150	6.9	
	3	28920	550	500	150	150	6.4	
MAC (2200 CB)	1	20240	550	500	150	150	4.5	4.5
	2	19700	550	500	150	150	4.4	
	3	21340	550	500	150	150	4.7	
Control	1	18010	550	500	150	150	4.0	3.8
	2	18360	550	500	150	150	4.1	
	3	15360	550	500	150	150	3.4	

Table 4.2 displays the data results for the 3D dataset, illustrating the relationship between force (measured in kilonewtons, kN) and deflection (measured in millimeters, mm). The table also presents average force values derived from three force measurements and includes deflection measurements, which indicate the extent of deformation in millimeters.

Table 4.2: Represent the Data Result for 3D (80/60) Specimens.

Deflection (mm)	Force (kN)(1)	Force (kN)(2)	Force (kN)(3)	Average Force (kN)
0	0.00	0.00	0.00	0.00
0.05	1.00	1.02	1.53	1.18
0.1	2.00	2.02	3.00	2.34
0.15	3.30	3.02	4.20	3.51
0.2	4.50	4.13	6.10	4.91

0.25	6.00	6.30	8.70	7.00
0.3	8.00	9.30	11.80	9.70
0.35	11.53	13.96	17.80	14.43
0.4	15.00	17.50	22.00	18.17
0.45	17.20	24.00	16.39	19.20
0.5	18.30	26.00	13.40	19.23
0.55	9.50	25.90	12.21	15.87
0.6	8.30	15.00	11.01	11.44
0.65	8.10	12.20	10.25	10.18

Figures 4.1, 4.2, and 4.4 depict the force-versus-deflection curve for 3D (80/60), a non-linear graph illustrating the connection between the applied force on a structure and the resulting deflection. This curve is graphed with the force along the y-axis and the deflection on the x-axis.

The curve exhibits two distinct regions:

- The linear region is where the slope of the curve is constant. This region represents the elastic behavior of the structure, where the deflection is proportional to the force.
- The plastic region is where the slope of the curve decreases. This region represents the plastic behavior of the structure, where the deflection continues to increase even though the force is not growing.

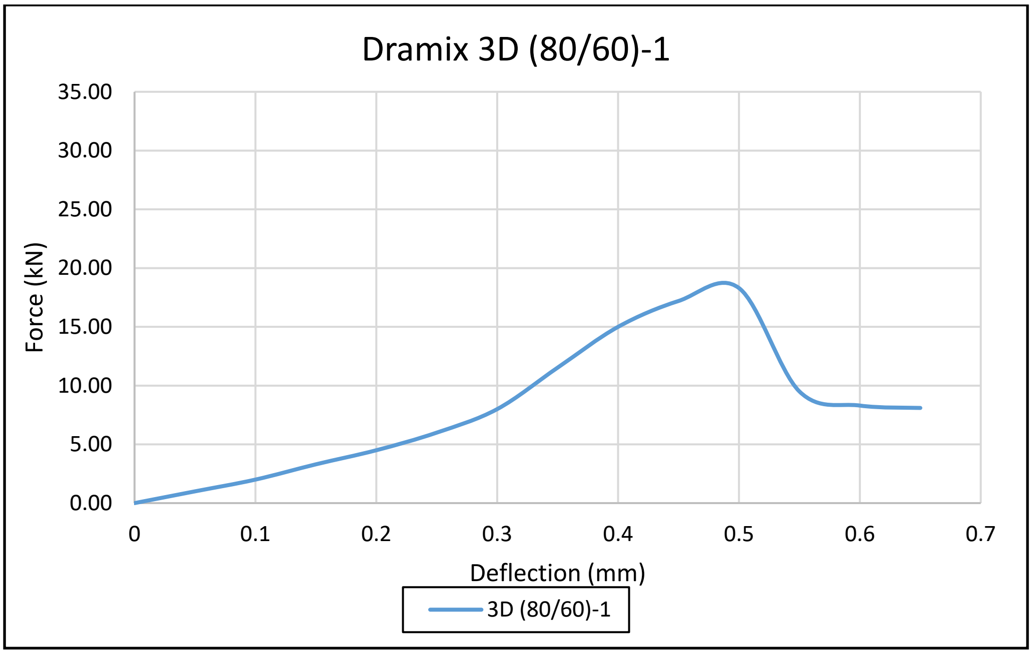

Figure 4.1: The Represent the Force Versus Deflection for 3D of No.1

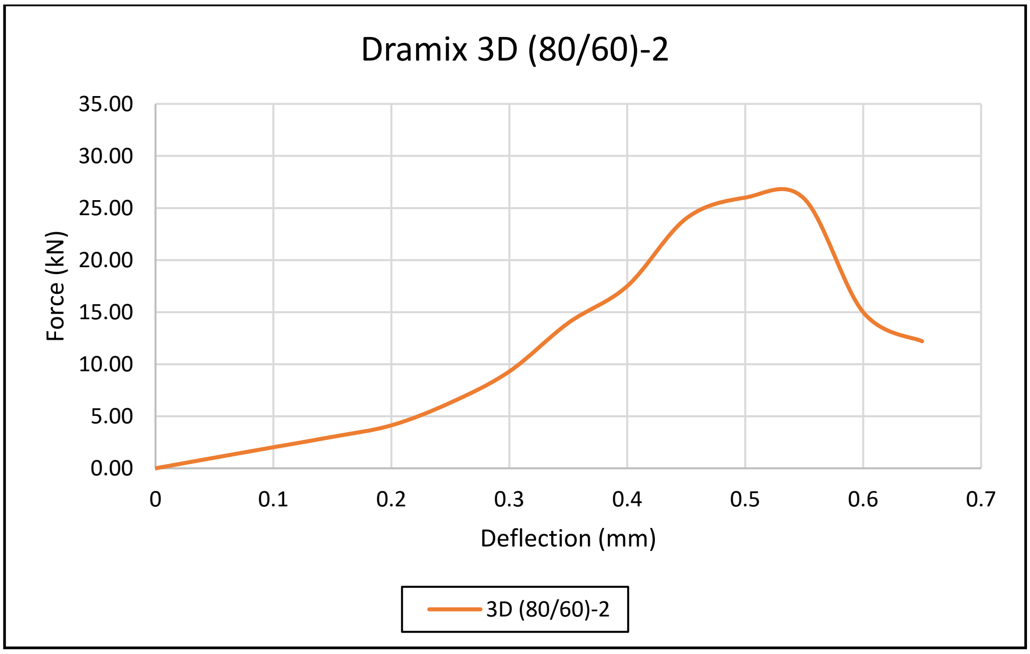

Figure 4.2: The Represent the Force Versus Deflection for 3D of No.2

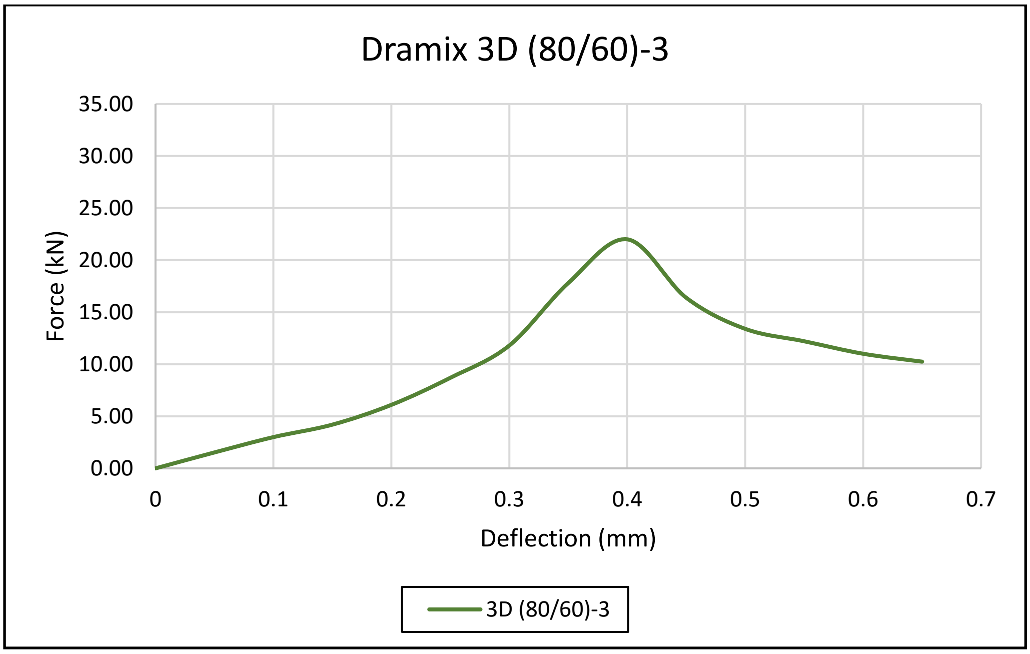

Figure 4.3: The Represent the Force Versus Deflection for 3D No.3

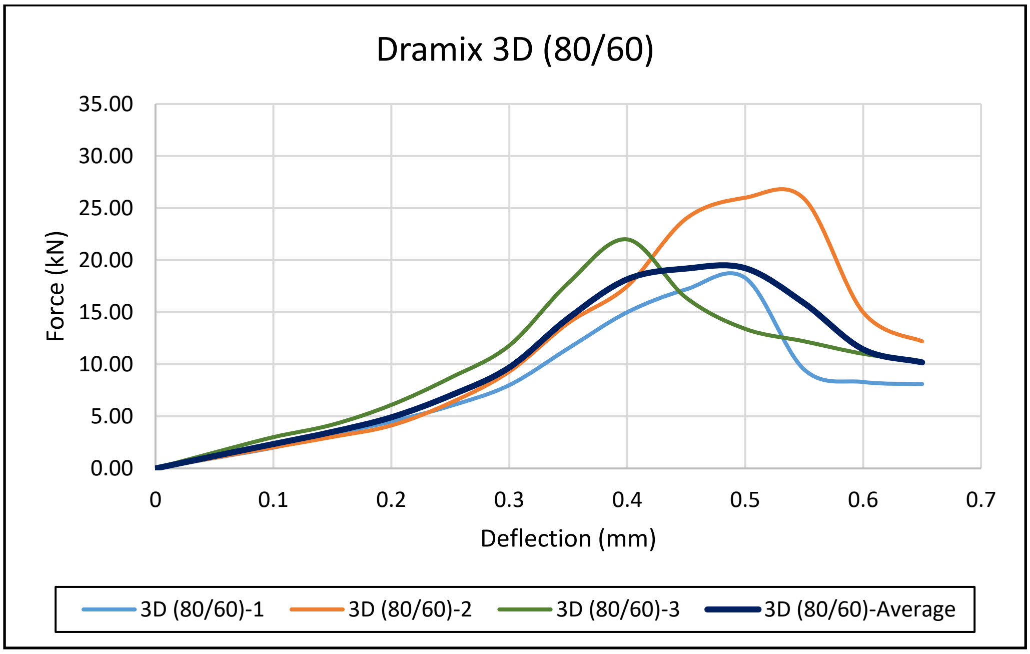

Figure 4.4: Represent the Force Versus Deflection for 3D (80/60) Specimens and the Average.

Table 4.3 furnishes data about 4D (80/60), presenting details concerning the force and deflection of this configuration. Force is quantified in kilonewtons (kN), while deflection is measured in millimeters (mm). This table illustrates the relationship between force and deflection for the 4D (80/60) specimens.

Table 4.3: Represent the Data Result for the 4D (80/60) Specimens.

Deflection (mm)	Force(kN) (1)	Force (kN) (2)	Force(kN) (3)	Average force (kN)
0	0.00	0.00	0.00	0.00
0.05	1.52	1.43	1.37	1.44
0.1	2.98	3.33	3.03	3.11
0.15	4.32	5.03	6.01	5.12
0.2	5.84	7.62	8.88	7.45
0.25	7.27	10.60	12.01	9.96
0.3	9.26	13.93	16.30	13.16
0.35	11.98	17.63	19.26	16.29
0.4	14.49	21.30	24.01	19.93
0.45	17.96	26.99	25.30	23.42
0.5	22.24	17.23	18.00	19.16
0.55	23.21	15.07	13.09	17.12
0.6	12.76	14.12	10.90	12.59
0.65	11.90	13.54	10.10	11.85

Figures 4.5, 4.6, 4.7, and 4.8 depict the force-deflection curve for 4D (80/60) specimens. This non-linear curve illustrates the connection between the applied force and the subsequent deflection. The graph portrays force on the y-axis and deflection on the x-axis.

The curve has two distinct regions.

- The linear region is where the slope of the curve is constant. This region represents the elastic behavior of the structure, where the deflection is proportional to the force.
- The plastic region is where the slope of the curve decreases. This region represents the plastic behavior of the structure, where the deflection continues to increase even though the force is not growing.

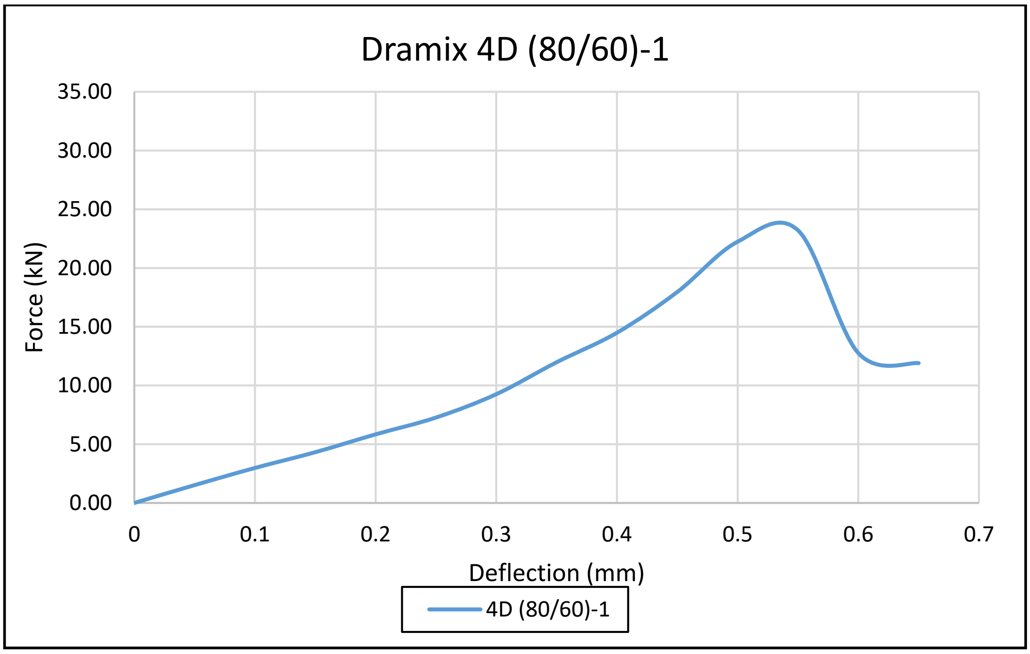

Figure 4.5: The Represent the Force Versus Deflection for 4D of No.1

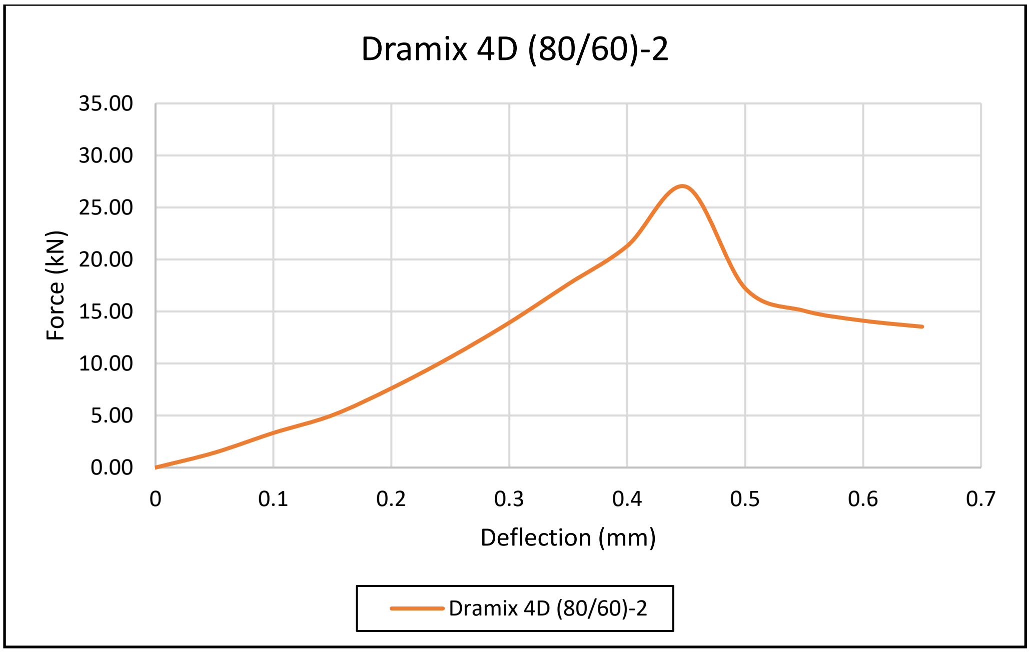

Figure 4.6: The Represent the Force Versus Deflection for 4D of No.2

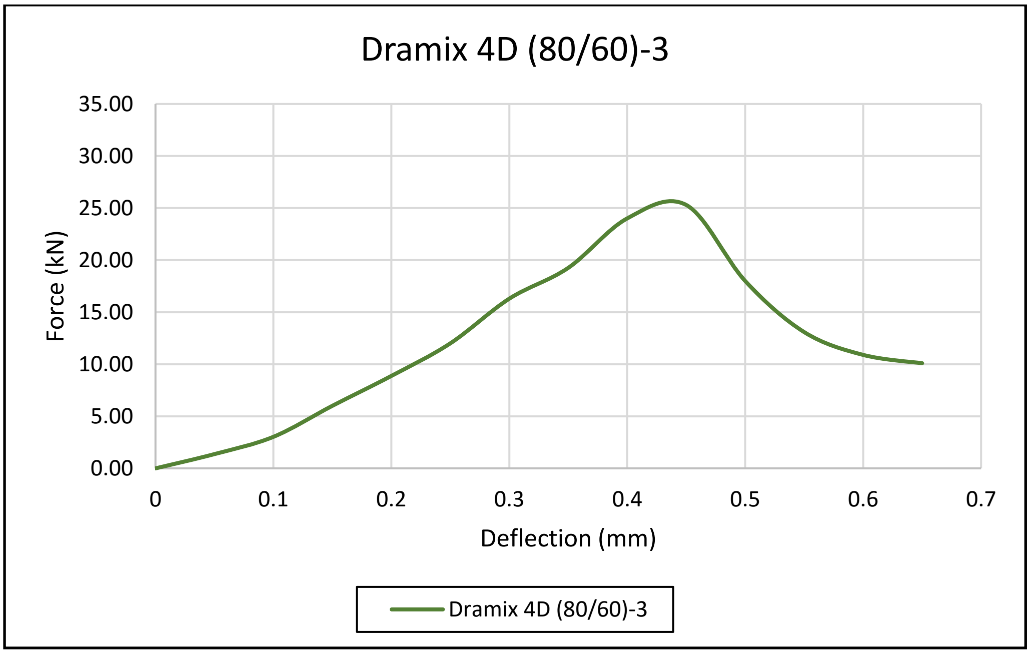

Figure 4.7: The Represent the Force Versus Deflection for 4D of No.2

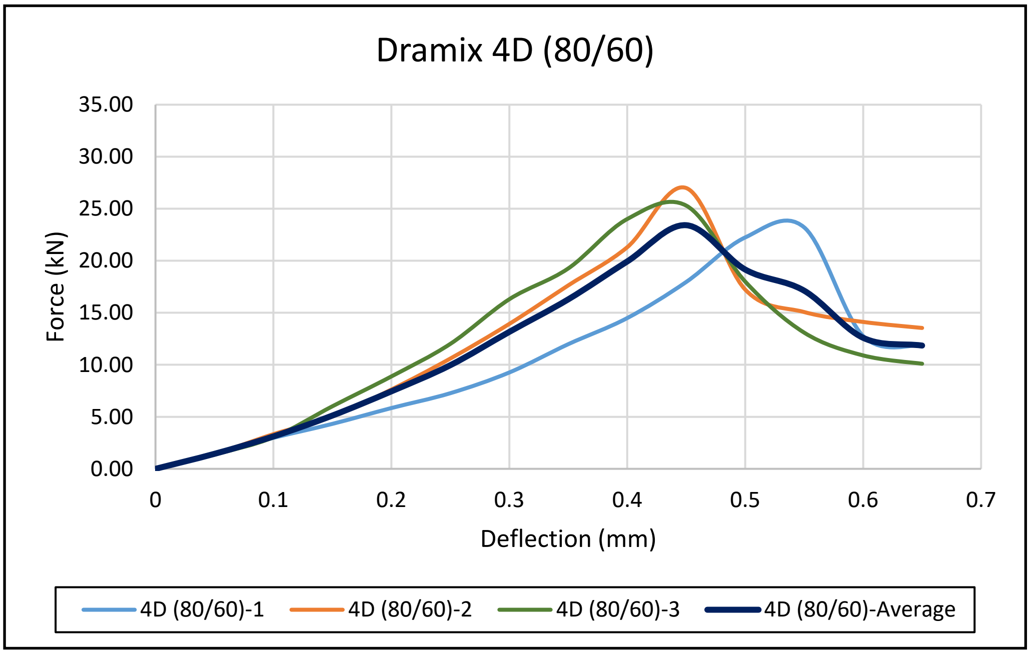

Figure 4.8: The Represent the Force Versus Deflection for Average

Table 4.4 represents the force and deflection of 4D (65/60) specimens, showing that the deflection of the system increases as the applied force to the design increases.

Table 4.4: The Represent the Data Result for 4DS (65/60) Specimens.

Deflection (mm)	Force (kN) (1)	Force (kN) (2)	Force (kN) (3)	Average force (kN)
0	0.00	0.00	0.00	0.00
0.05	0.90	0.92	0.78	0.87
0.1	2.96	2.33	2.06	2.45
0.15	3.32	3.03	3.33	3.23
0.2	4.22	5.95	4.57	4.91
0.25	5.93	9.02	7.39	7.45
0.3	8.98	13.57	14.60	12.38
0.35	11.86	20.35	25.96	19.39
0.4	18.36	24.13	28.92	23.80
0.45	23.26	27.30	27.39	25.98
0.5	27.32	31.23	26.79	28.45
0.55	30.35	27.05	25.12	27.51
0.6	26.03	26.63	24.50	25.72
0.65	25.30	26.00	23.98	25.09

Figures 4.9, 4.10, 4.11, and 4.12 illustrate the non-linear correlation between force and deflection observed in the case of 4D (65/60) specimens. These curves show an initial linear segment, but the slope of the curve decreases as the applied force intensifies. This phenomenon results from the structure undergoing plastic deformation under increased force.

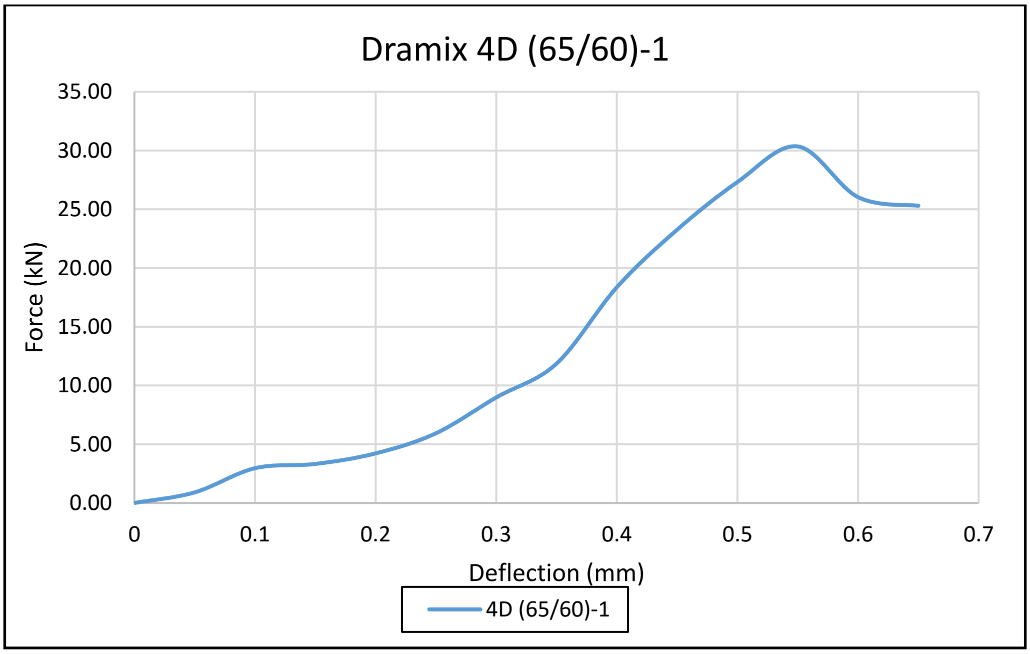

Figure 4.9: The Represent the Force Versus Deflection for 4D (65/60) No. 1

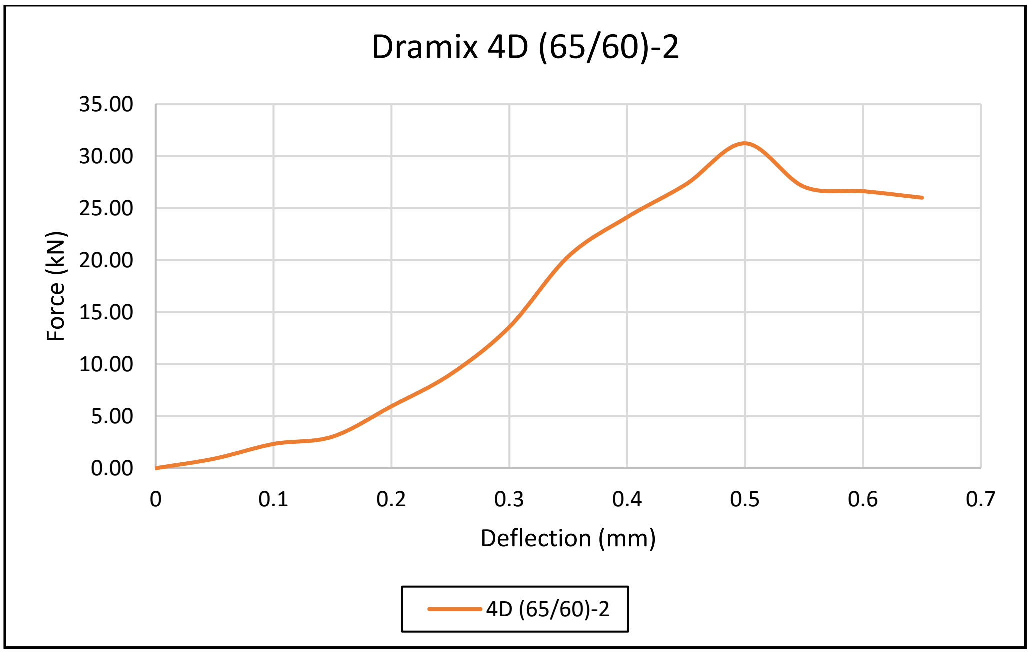

Figure 4.10: The Represent the Force Versus Deflection for 4D (65/60) of No. 2

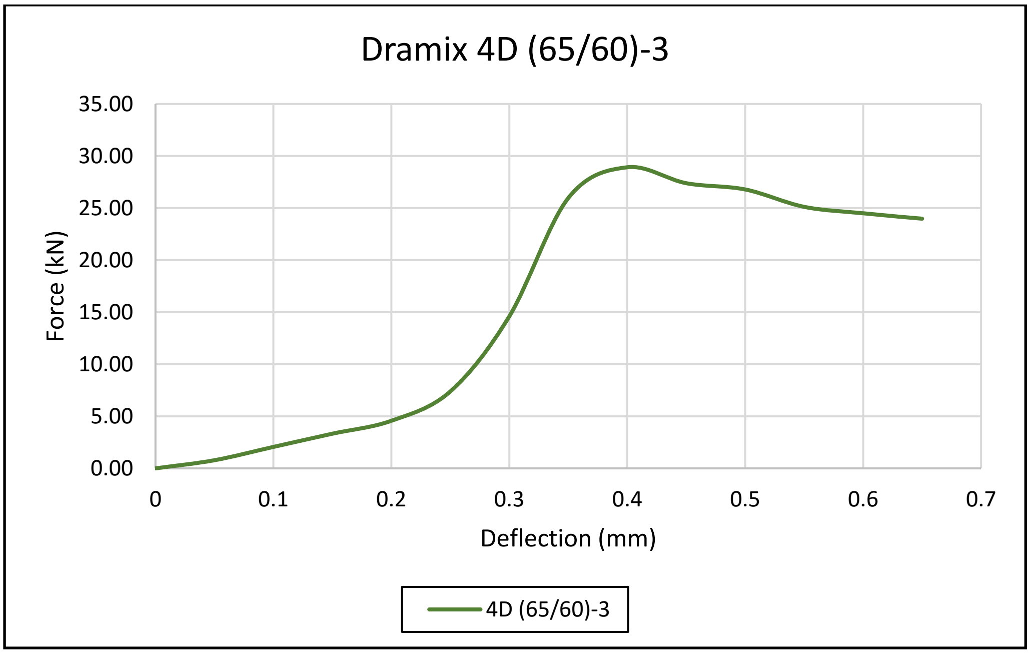

Figure 4.11: The Represent the Force Versus Deflection for 4D (65/60) of NO. 3

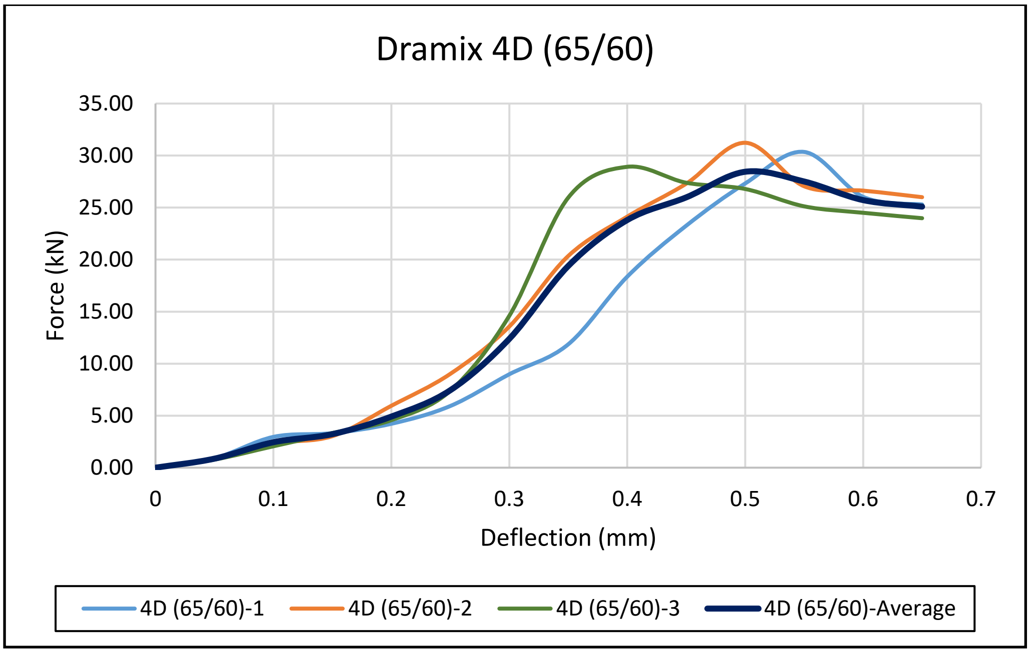

Figure 4.12: The Represent the Force Versus Deflection for 4D(65/60) Specimens and the Average.

Table 4.5 presents the results for MAC (2200 CB) specimens, displaying the relationship between force and deflection of the beams. It is evident that as the applied force to the design increases, the beam deflection also increases.

Table 4.5: The Represent the Data Result for MAC

Deflection (mm)	Force (kN) (1)	Force (kN) (2)	Force (kN) (3)	Average force (kN)
0	0.00	0.00	0.00	0.00
0.05	1.01	1.50	3.00	1.84
0.1	2.32	2.98	5.99	3.76
0.15	5.76	5.93	7.65	6.45
0.2	8.70	6.89	11.22	8.94
0.25	11.78	8.79	14.73	11.77
0.3	15.13	12.32	19.63	15.69
0.35	18.60	15.31	21.34	18.42
0.4	20.24	19.70	12.63	17.52
0.45	12.31	14.50	10.01	12.27
0.5	9.01	8.87	9.15	9.01
0.55	8.85	8.01	8.11	8.32
0.6	8.56	7.32	6.26	7.38
0.65	8.44	7.22	5.63	7.10

The observations from Figures 4.13, 4.14, 4.15, and 4.16 indicate a discernible pattern in the Force-Deflection relationship. Initially, the relationship exhibits linearity until the occurrence of the first crack. Subsequently, the impact of the fiber becomes evident, manifesting in the prevention of collapse of the specimens. Instead, the fiber enables the specimens to withstand a portion of the applied force even after the formation of cracks. This observation highlights the advantageous role of fiber during the post-cracking stage.

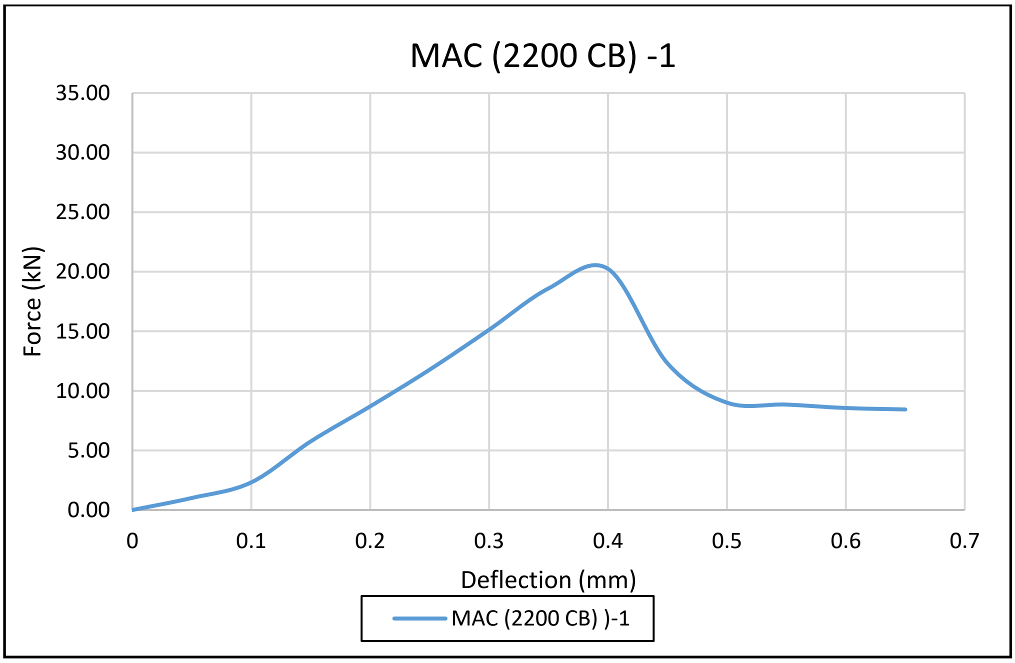

Figure 4.13: The Represent the Force Versus Deflection for MAC of No. 1

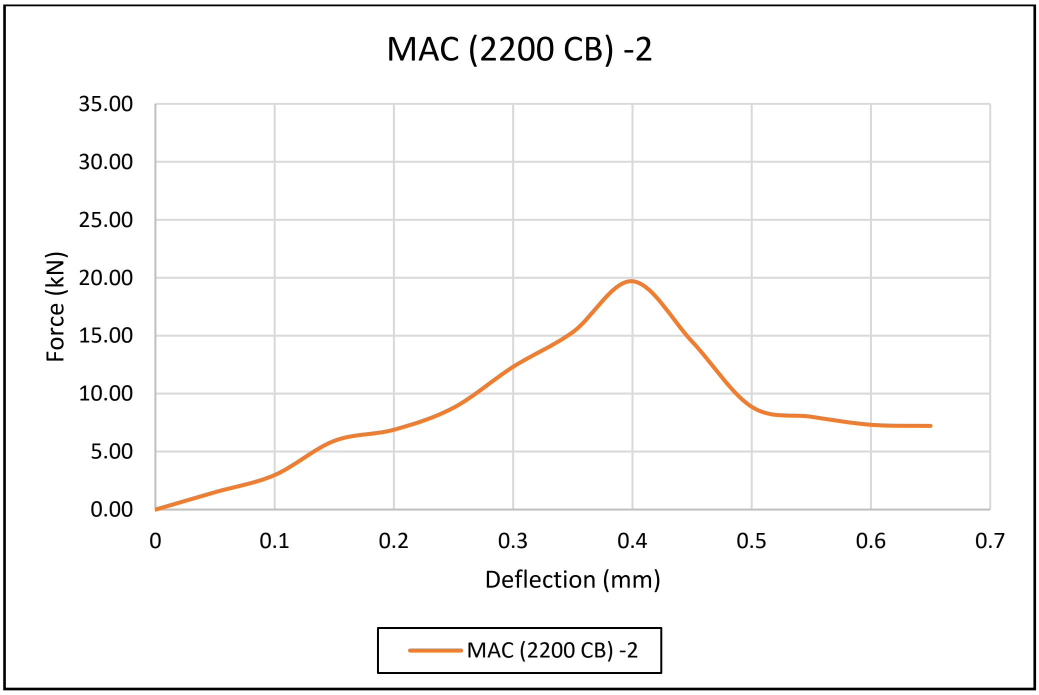

Figure 4.14: The Represent the Force Versus Deflection for MAC of No. 2

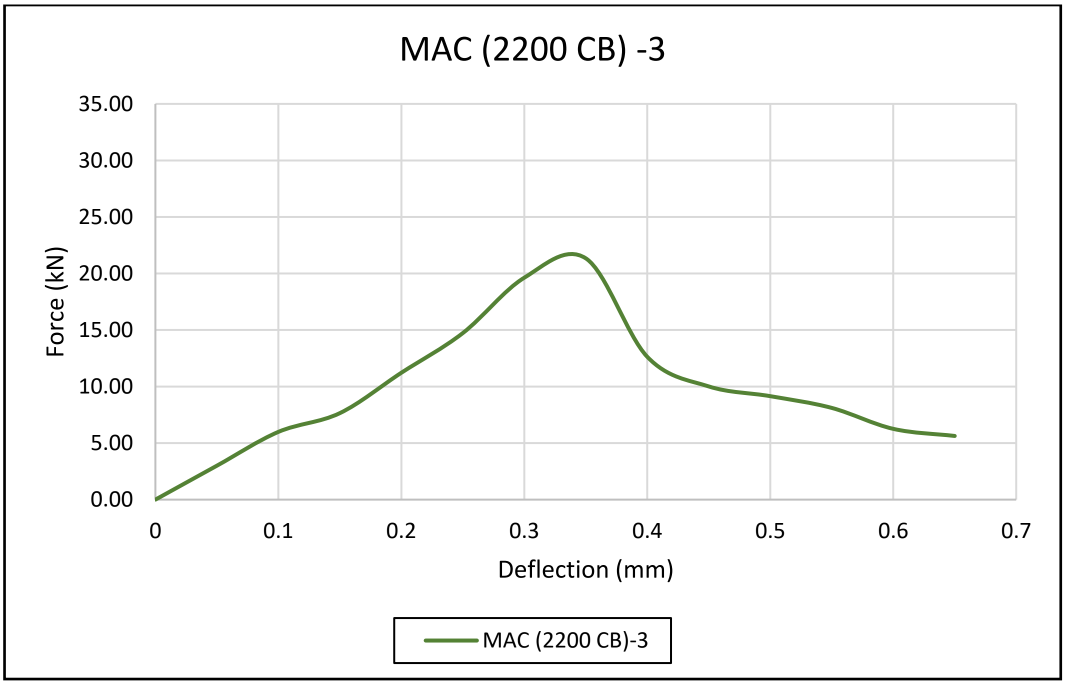

Figure 4.15: The Represent the Force Versus Deflection for MAC of No. 3

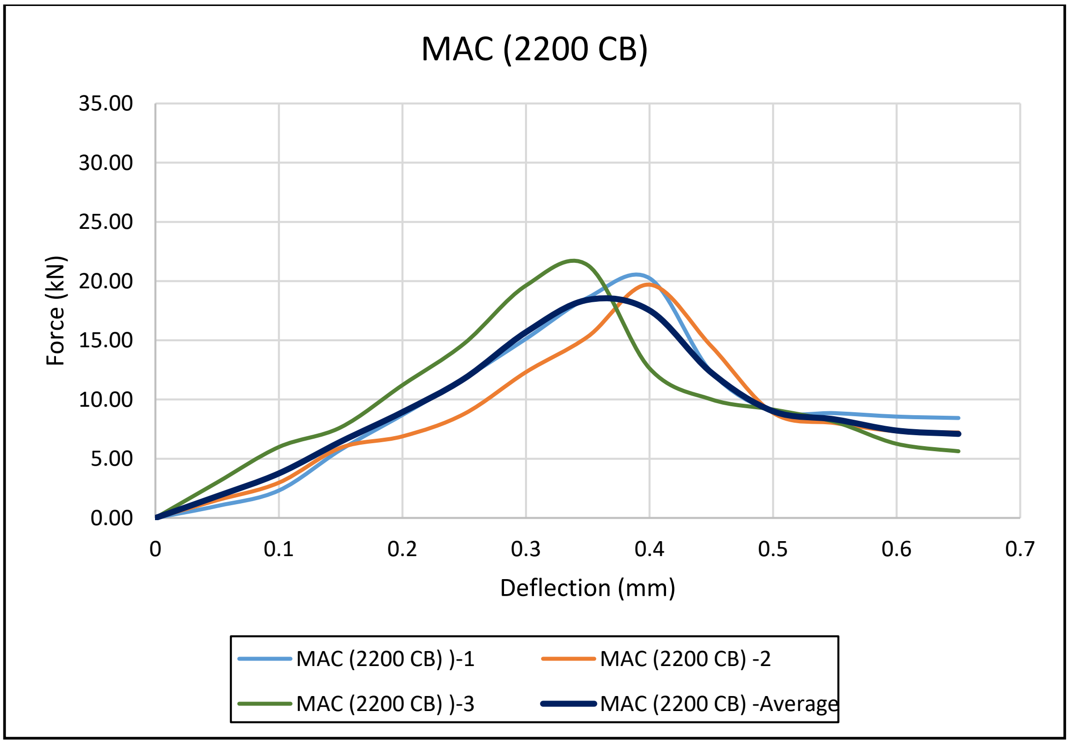

Figure 4.16: The Represent the Force Versus Deflection for Average

Table 4.6 illustrates the outcomes for a structure constructed using fibreless concrete, indicating that as the force applied to the beam increases, there is a corresponding increase in the deflection of the beam.

Table 4.6: The Represent of the Data Result for Concrete Without Fiber (Control Specimens)

Deflection (mm)	Force(kN) (1)	Force (kN) (2)	Force (kN) (3)	Average force (kN)
0	0.00	0.00	0.00	0.00
0.05	2.89	2.09	1.98	2.32
0.1	5.30	3.00	4.23	4.18
0.15	6.73	4.89	5.55	5.72
0.2	8.63	5.91	7.93	7.49
0.25	10.56	10.01	10.33	10.30
0.3	12.56	14.56	12.25	13.12
0.35	15.87	18.36	15.23	16.49
0.4	18.01	0.00	0.00	6.00
0.45	0.00	0.00	0.00	0.00
0.5	0.00	0.00	0.00	0.00
0.55	0.00	0.00	0.00	0.00
0.6	0.00	0.00	0.00	0.00
0.65	0.00	0.00	0.00	0.00

Figures 4.17, 4.18, 4.19, and 4.20 for MAC (2200 CB) illustrate that the specimens will remain in the elastic phase without entering the plastic phase due to the absence of fibers. They will only reach the modulus of rupture before experiencing sudden failure.

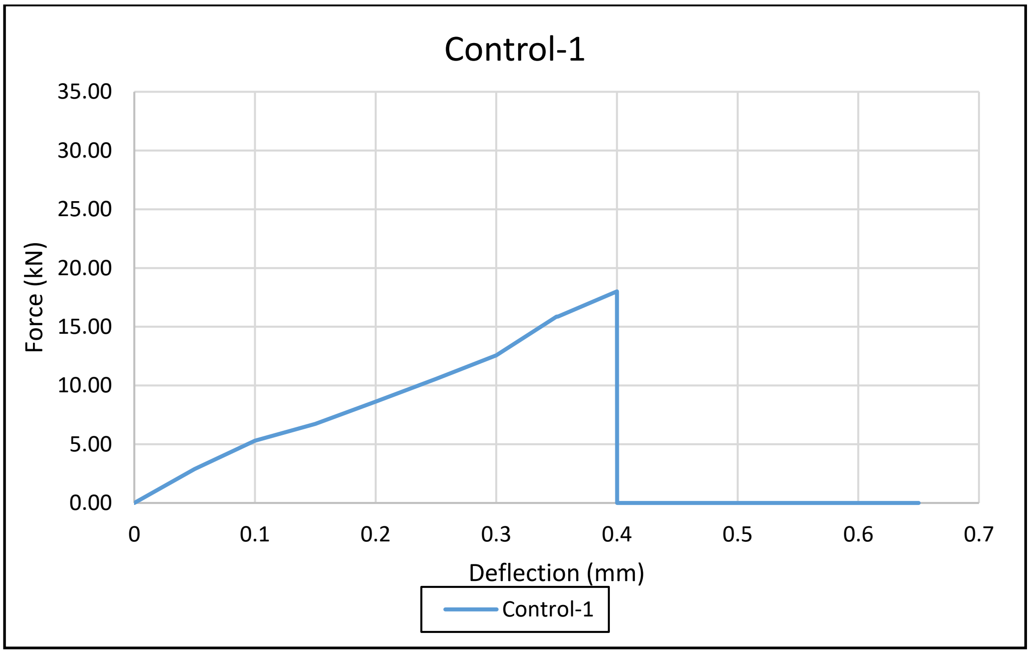

Figure 4.17: The Represent the Force Versus Deflection for Concrete Without Fiber of No. 1

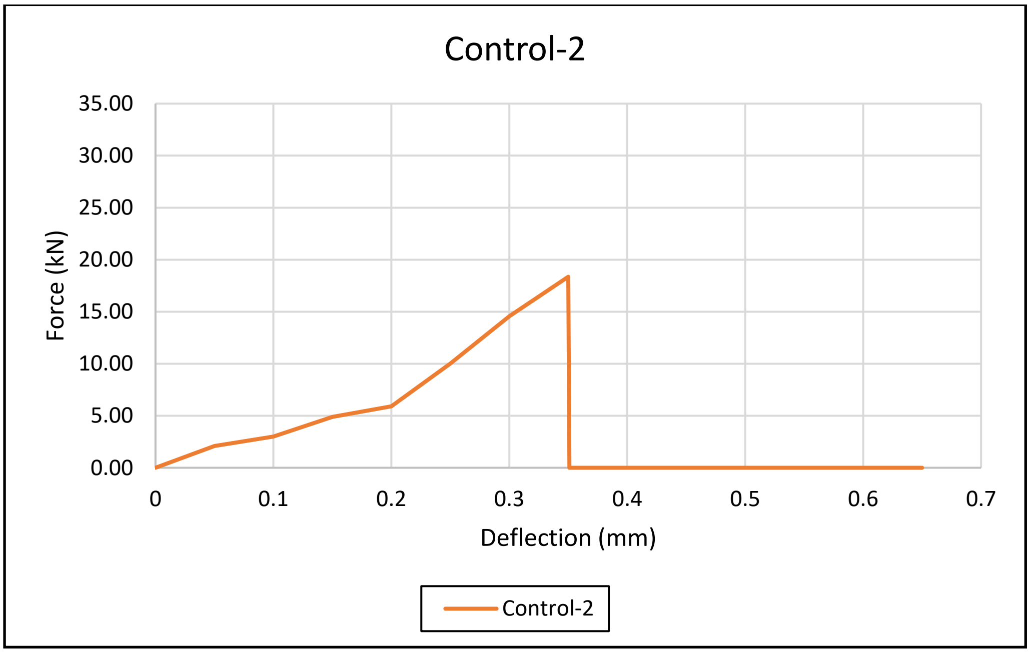

Figure 4.18: The Represent the Force Versus Deflection for Concrete Without Fiber of No. 2

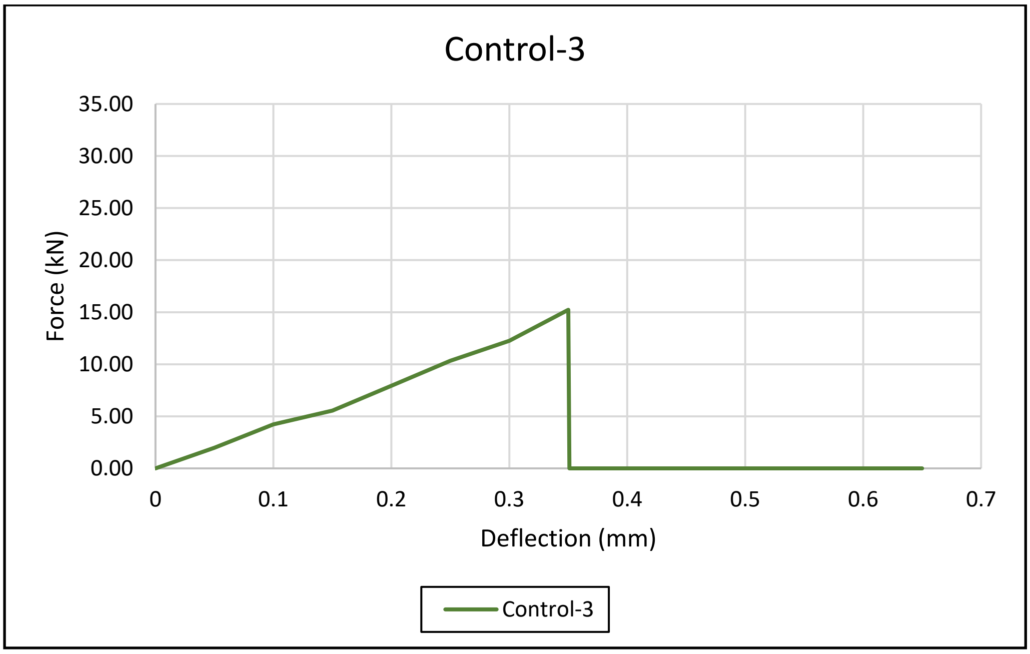

Figure 4.19 :The Represent Force Versus Deflection for Concrete Without Fiber of No. 3

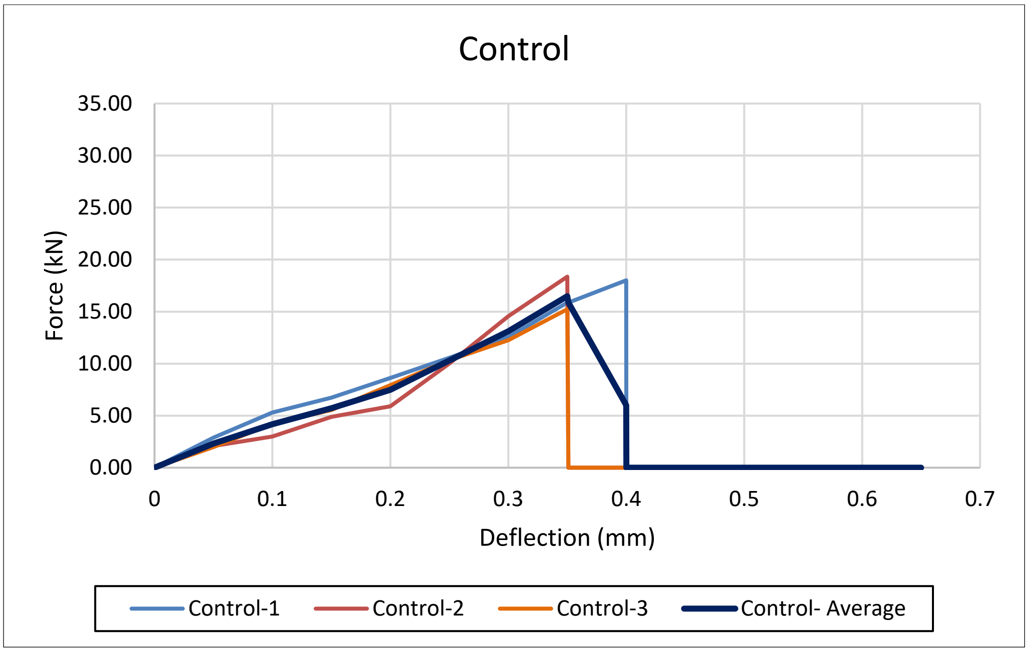

Figure 4.20: The Force Versus Deflection for Control Specimens and the Average.

Table 4.7 provides data on the average force and deflection for various types of concrete. The force is measured in kilonewtons (kN), and the deflection is measured in millimetres (mm).

Table 4.7: The Average Force and Deflection for Different Types of Concrete

Deflection (mm)	Average force (kN)				
	Control	Dramix 3D (80/60)	Dramix 4D (80/60)	Dramix 4D (65/60)	MAC (2200 CB)
0	0.000	0.00	0.00	0.00	0.00
0.05	2.320	1.18	1.44	0.87	1.84
0.1	4.177	2.34	3.11	2.45	3.76
0.15	5.723	3.51	5.12	3.23	6.45
0.2	7.490	4.91	7.45	4.91	8.94
0.25	10.300	7.00	9.96	7.45	11.77
0.3	13.123	9.70	13.16	12.38	15.69
0.35	16.487	14.43	16.29	19.39	18.42
0.4	6.003	18.17	19.93	23.80	17.52
0.45	0.000	19.20	23.42	25.98	12.27
0.5	0.000	19.23	19.16	28.45	9.01
0.55	0.000	15.87	17.12	27.51	8.32
0.6	0.000	11.44	12.59	25.72	7.38
0.65	0.000	10.18	11.85	25.09	7.10

The analysis of Figure 4.21 indicates a significant improvement in the flexural tensile behavior of concrete when fibers are added. This enhancement results in a higher load modulus of rupture for the specimens. Furthermore, the incorporation of fibers enables the concrete to withstand bending forces even after the initial formation of cracks, effectively preventing abrupt specimen failure, which is not the case for control specimens.

Additionally, it's worth noting that including fiber increases the area under the force-deflection curve, indicating enhanced toughness of the specimens. There were observed variations in the performance of different fiber types concerning their impact on the flexural tensile behavior of the specimens. Notably, 4D (65/60) had the most significant effect, followed by 4D (80/60) and 3D (80/60), while MAC 2200 had a comparatively lesser effect.

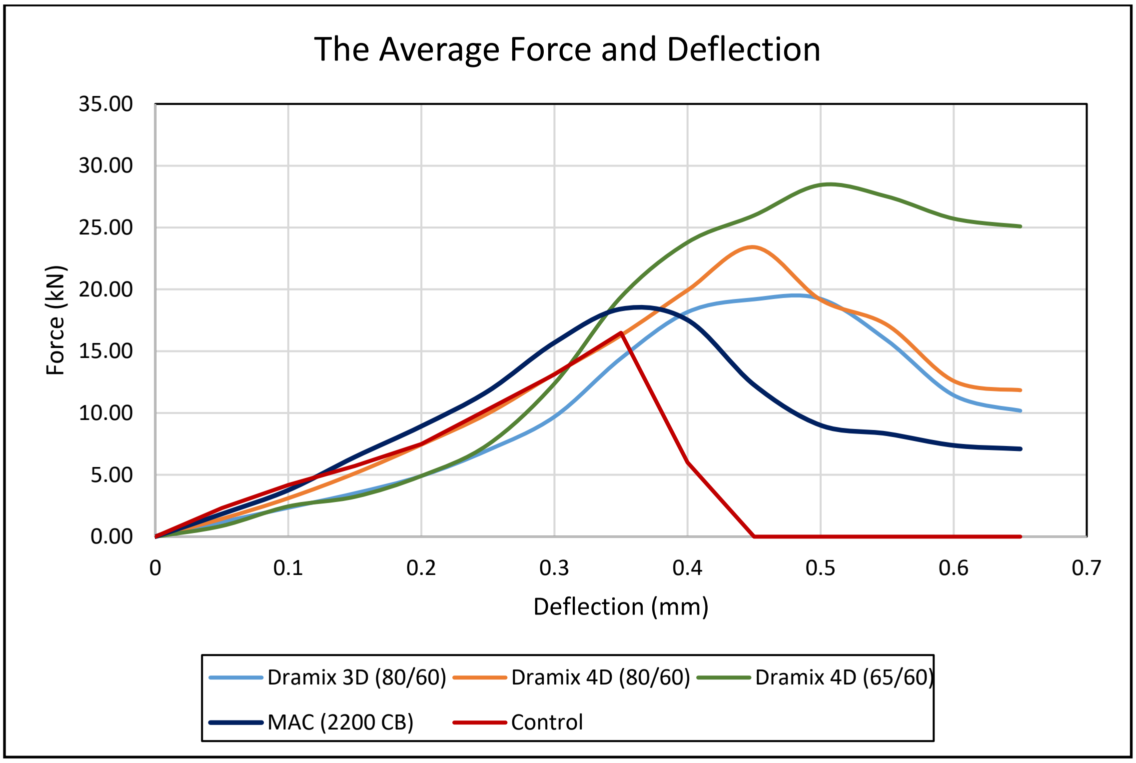

Figure 4.21: The Average Force and Deflection for Different Types of Concrete

The effect of fiber types on the flexural strength of beams

The results from Figure 4.21 illustrate a significant increase in the maximum flexural load when using 4D hooked-end steel fibers with an aspect ratio of 65, primarily due to its larger diameter of 0.9mm. The maximum flexural load showed a substantial 73% increase compared to beams without fibers.

Furthermore, incorporating 3D (80/60), 4D (80/60), and MAC fibers into the concrete mixture also improved the maximum flexural load. Specifically, there was a respective increase of 16.6%, 42%, and 11.7% compared to concrete without fibers.

These findings underscore the effectiveness of fibers in enhancing the flexural performance of concrete structures.

The effect of novel multi-hooked end steel fiber on the flexural strength of beams

The findings in Figure 4.22 and Table 4.7 indicate that the transition from 3D to 4D steel fibers led to a substantial 21.8% increase in the maximum flexural load and a 16.4% improvement at a deflection of 0.65mm. This indicates that 4D steel fibers exhibit a more pronounced bridging effect than their 3D counterparts.

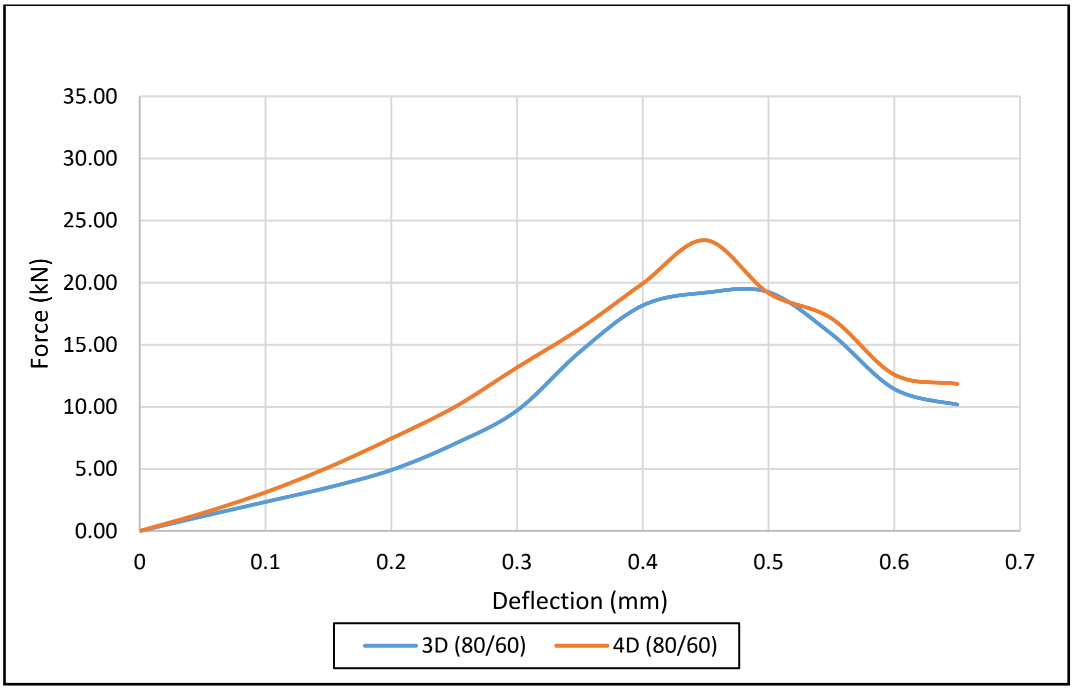

Figure 4.22: The Effect of Novel Multi-hooked End Steel Fiber on Flexural Strength of Beams

The effect of the diameter of steel fiber on the flexural strength of beams

As shown in Figure 4.23 and detailed in Table 4.7, increasing the diameter of 4D hooked end specimens from 0.75mm to 0.95mm (while keeping the length constant at 60mm) resulted in a notable 21.5% increase in the maximum flexural load and a significant 111.7% improvement at deflection of 0.65mm. This indicates that 4D steel fibers with a diameter of 0.9mm exhibit a more pronounced bridging effect than those with a 0.75mm diameter.

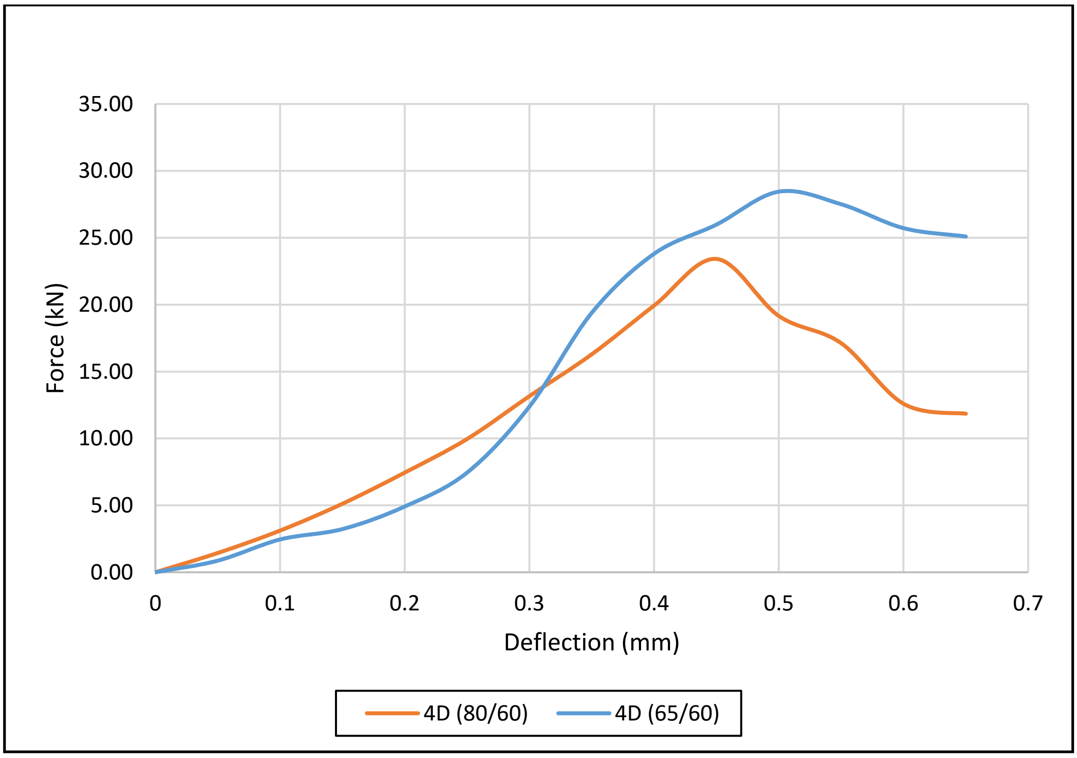

Figure 4.4.23: The Effect of Diameter of Steel Fiber on Flexural Strength of Beams

Figure 4.25 depicts the failure behavior of a plain concrete sample, characterized by a sudden and complete failure resulting in a single crack, dividing the specimen into two distinct parts. In contrast, Figure 4.26 presents the response of fiber-reinforced concrete specimens, which can sustain their load-carrying capacity even after the cracking initiation. A comparative analysis of the performance of fiber-reinforced concrete and unreinforced concrete distinctly underscores the enhanced energy absorption capabilities of the former.

Figure 4.24: Depicts the Failure Behavior of a Plain Concrete Specimen (Control Specimen)

Figure 4.25:Illustrates the Response of Fiber-Reinforced Concrete Specimens.

Table 4.8 data offers valuable insights into the average compressive strength of different concrete mixes. It acts as a useful reference to comprehend the comparative strength properties of these mixtures, essential for evaluating the appropriateness of concrete compositions in various applications.

Table 4.8: provides valuable insights into the average compressive strength of the various concrete mixes.

Mix. type	Control	3D (80/60)	4D (80/60)	4D (65/60)	MAC
Average f_{cu} (Mpa)	47.06	44.63	48.3	49.76	46.48

Upon analyzing the data presented in Table 4.8, it becomes evident that the incorporation of fibers into the concrete mixture does not yield any discernible influence on the compressive strength of the concrete mixes.

Economic feasibility study

Table 4.9 shows the price of the amount of fiber needed for one cubic meter of concrete with a fiber volume equal to 0.5 % by volume for different types of fiber.

Fiber type	3D (80/60)	4D (80/60)	4D (65/60)	MAC
The prise of fiber for 1 cubic meter of concrete * (JOD)	62	69	69	40

***the fiber volume equals to 0.5% by volume.**

Through Table 4.9 and the results obtained from this study, the following becomes evident:

- Firstly, the performance of MAC fiber is very close to that of 3D (80/60) fiber, but there is a price difference. The price of 3D (80/60) fiber per cubic meter is 55% higher than the price of MAC fiber. Therefore, the MAC fiber option is considered more economically viable than the 3D (80/60) fiber option.
- Secondly, the performance of Fiber 4D (65/60) surpasses that of Fiber 4D (80/60), and both have the same cost. Therefore, the Fiber 4D (65/60) option is considered more economically viable than Fiber 4D (80/60).

Incorporating fibers into concrete beams yields significant improvements in their load-deflection behavior. The presence of steel fibers introduces a bridging effect, effectively countering crack propagation, resulting in increased load-carrying capacity and reduced deflection.

The bridging effect transpires as these fibers bridge across cracks in the concrete, effectively halting the cracks from widening. This is critical because concrete exhibits much higher resistance to compression than tension.

Furthermore, adding fibers contributes to an overall increase in the beams' ductility. Ductility is a material's capacity to deform plastically before reaching the point of failure. Ductile materials can absorb substantial energy before failure, rendering them more resilient to sudden structural collapse.

The improved load-deflection behavior of fiber-reinforced concrete beams makes them a good choice for applications where high load-carrying capacity and ductility are essential, such as bridges and buildings.

Some additional benefits of using steel fiber-reinforced concrete beams include:

- They are more resistant to impact and fatigue than plain concrete beams.
- They are less likely to crack, which can lead to water damage and corrosion.
- They are more durable and have a longer lifespan than plain concrete beams.

The study's findings suggest that steel fiber reinforcement can be a valuable tool for improving the flexural tensile behavior of concrete beams. The type and amount of steel fiber used should be chosen carefully to optimize the performance of the beams.

Some additional findings from the study:

- Using fiber reinforcement can significantly increase the flexural strength of concrete beams.
- The fiber reinforcement can also improve concrete beams' ductility, making them more likely to deform before failure.
- The fiber reinforcement can also help prevent concrete beams from cracking under load.

CHAPTER FIVE CONCLUSIONS, RECOMMENDATIONS, AND FUTURE WORKS

5.1 Overview

This chapter summarizes the study's main findings, draws conclusions based on the results, and provides recommendations for future research and the use of fiber reinforcement in concrete beams. It also highlights the potential implications and benefits of using fiber reinforcement to enhance beams' flexural tensile behavior in concrete structures.

5.2 Conclusions

The study investigated the influence of different types of steel fibers on the flexural tensile behavior of concrete beams. The research found that using fiber reinforcement significantly improves the flexural tensile behavior of concrete beams, and the type of fibers used influences the behavior.

Based on the study's findings, the following conclusions can be drawn:

- Using 4D hooked-end steel fibers with an aspect ratio of 65 (diameter 0.9mm) significantly increased the maximum flexural load by 73% compared to beams without fibers.
- Incorporating 3D (80/60), 4D (80/60), and MAC fibers into the concrete mixture improved the maximum flexural load. The maximum flexural load increased by 16.6%, 42%, and 11.7%, respectively, compared to concrete without fibers.

- Increasing the number of hooked ends from 3D to 4D steel fibers resulted in a 21.8% increase in the maximum flexural load and a 16.4% improvement at a deflection of 0.65mm, indicating the higher bridging effect of 4D steel fibers.
- Increasing the diameter of 4D hooked end specimens from 0.75mm to 0.90 mm while maintaining a length of 60mm resulted in a 21.5% increase in the maximum flexural load and a substantial 111.7% improvement at deflection of 0.65mm, indicating the greater bridging effect of 4D steel fibers with a 0.9mm diameter compared to 0.75mm diameter 4D steel fibers.
- Adding fibers to concrete enhances the flexural tensile behavior of beams.
- The type of fibers used significantly affects the flexural behavior of concrete beams.
- The diameter of steel fibers affects the behavior of concrete beams.

The use of fiber reinforcement in concrete beams offers several potential implications and benefits, including:

- Improved durability and resistance to cracking
- Enhanced structural performance and load-carrying capacity.
- Reduced maintenance costs and increased service life
- Greater design flexibility and potential for innovative structural solutions.

5.3 Recommendations

The following are recommendations for this thesis: influence of fiber types on the flexural tensile behavior of beams:

- Investigate the effects of different steel fiber types.

Different types of fibers have other characteristics, such as aspect ratio, surface area, and tensile strength, which can influence the mechanical properties of the reinforced concrete.

- Study the effect of steel fiber dosage rate.

The amount of steel fibers added to concrete is an important parameter that can influence the flexural tensile behavior of beams.

- Investigate the combined effect of steel fibers and other reinforcement materials.

Steel fibers are often combined with reinforcement materials such as rebar or prestressing tendons.

- Study the effect of fiber orientation.
- The orientation of steel fibers in the concrete can also influence the flexural tensile behavior of beams.
- Conduct long-term durability studies.

The long-term durability of steel fiber-reinforced concrete is essential in practical applications.

5.4 Future Works

The influence of fiber types on the flexural tensile behavior of beams is an essential area of research in civil engineering. fiber reinforcement in concrete beams has been shown to significantly improve their strength, durability, and resistance to cracking.

Future research in this area could focus on several different topics, such as:

- Optimization of fiber types and dosage.

While previous research has shown that fibers can improve the flexural tensile behavior of beams, there is still room for optimization in terms of the type and dosage of fibers used.

- Evaluation of long-term performance

While short-term tests have shown the benefits of fiber reinforcement, evaluating the long-term performance of fiber-reinforced concrete beams is essential.

- Comparison of different test methods.

Several different test methods are available for evaluating the flexural tensile behavior of concrete beams, including the three-point bending test, four-point bending test, and beam end test.

- Application to real-world structures.

While laboratory tests help evaluate the behavior of individual beams, it is essential to consider the application of steel fiber reinforcement to real-world structures.

The study's findings suggest that using steel fiber reinforcement is a viable solution for enhancing the flexural tensile behavior of concrete beams. The recommendations for future research highlight the need for further investigation into the conduct of fiber-reinforced concrete, and the potential implications and benefits suggest the importance of considering steel fiber reinforcement in the design of concrete structures.

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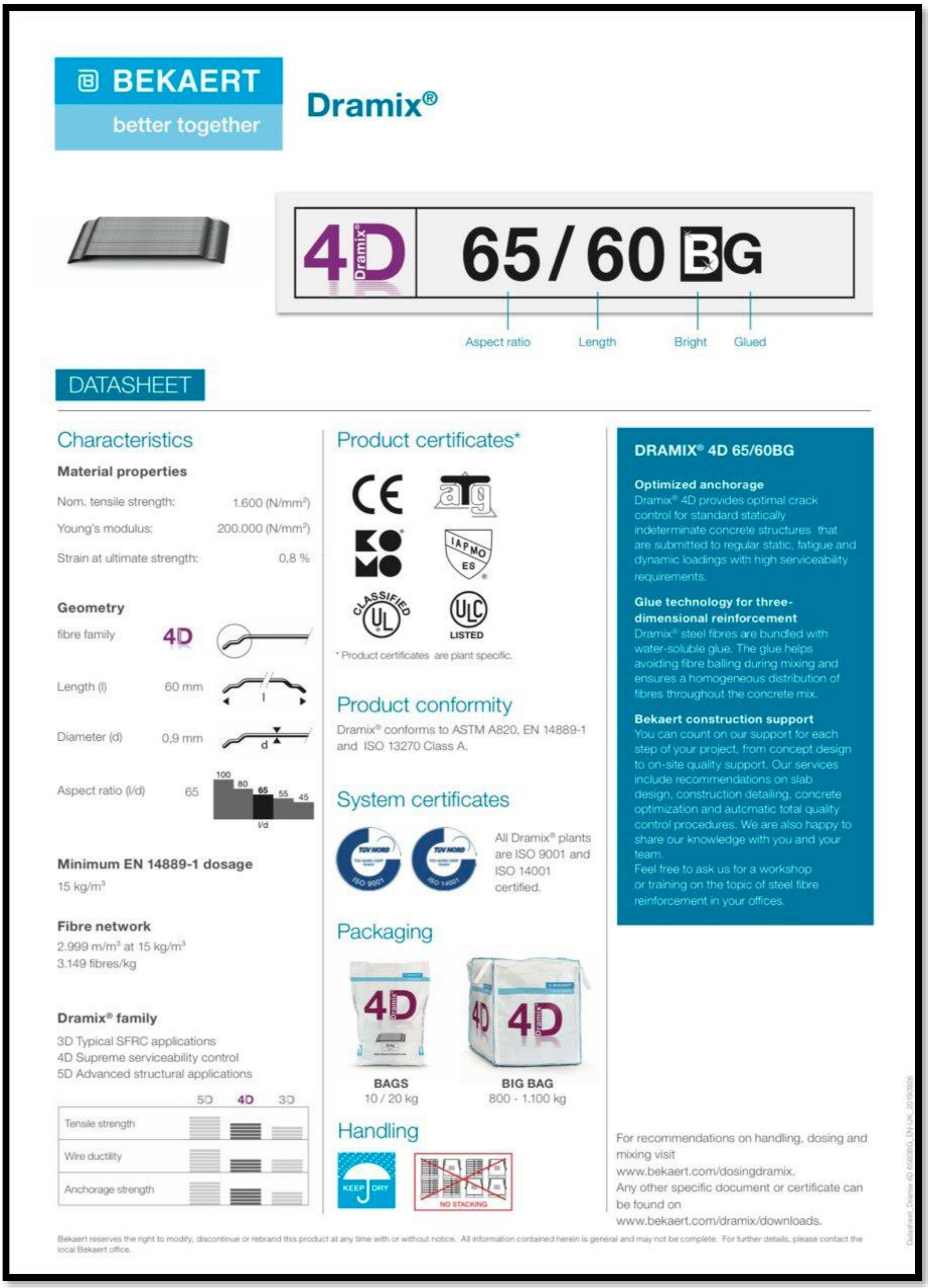
Appendix A

Data sheet for Dramix 4D (65/60) steel fiber .



BEKAERT
better together

Dramix®

4D 65/60 BG

Aspect ratio | Length | Bright | Glued

DATASHEET

Characteristics

Material properties

Nom. tensile strength:	1.600 (N/mm²)
Young's modulus:	200.000 (N/mm²)
Strain at ultimate strength:	0,8 %

Geometry

fibre family	4D
Length (l)	60 mm
Diameter (d)	0,9 mm
Aspect ratio (l/d)	65

Minimum EN 14889-1 dosage

15 kg/m³

Fibre network

2.999 m/m³ at 15 kg/m³
3.149 fibres/kg

Dramix® family

3D Typical SFRC applications
4D Supreme serviceability control
5D Advanced structural applications

	5D	4D	3D
Tensile strength			
Wire ductility			
Anchorage strength			

Product certificates*

LISTED

* Product certificates are plant specific.

Product conformity

Dramix® conforms to ASTM A820, EN 14889-1 and ISO 13270 Class A.

System certificates

All Dramix® plants are ISO 9001 and ISO 14001 certified.

Packaging

BAGS 10 / 20 kg

BIG BAG 800 - 1.100 kg

Handling

KEEP DRY

NO STACKING

DRAMIX® 4D 65/60BG

Optimized anchorage
Dramix® 4D provides optimal crack control for standard statically indeterminate concrete structures that are submitted to regular static, fatigue and dynamic loadings with high serviceability requirements.

Glue technology for three-dimensional reinforcement
Dramix® steel fibres are bundled with water-soluble glue. The glue helps avoiding fibre balling during mixing and ensures a homogeneous distribution of fibres throughout the concrete mix.

Bekaert construction support
You can count on our support for each step of your project, from concept design to on-site quality support. Our services include recommendations on slab design, construction detailing, concrete optimization and automatic total quality control procedures. We are also happy to share our knowledge with you and your team.
Feel free to ask us for a workshop or training on the topic of steel fibre reinforcement in your offices.

For recommendations on handling, dosing and mixing visit www.bekaert.com/dosingdramix.
Any other specific document or certificate can be found on www.bekaert.com/dramix/downloads.

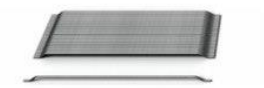
Bekaert reserves the right to modify, discontinue or rebrand this product at any time with or without notice. All information contained herein is general and may not be complete. For further details, please contact the local Bekaert office.

Appendix B

Data sheet for Dramix 3D (80/60) steel fiber

BEKAERT
better together

Dramix®



3D Dramix® 80/60 BG

Aspect ratio — Length — Bright — Glued

DATASHEET

Characteristics

Material properties

Nom. tensile strength: 1.225 (N/mm²)

Young's modulus: 200.000 (N/mm²)

Strain at ultimate strength: 0,8 %

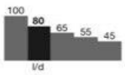
Geometry

fibre family: 3D

Length (l): 60 mm

Diameter (d): 0,75 mm

Aspect ratio (l/d): 80



Minimum EN 14889-1 dosage

10 kg/m³

Fibre network

2.879 m/m³ at 10 kg/m³
4.690 fibres/kg

Dramix® family

3D Typical SFRC applications
4D Supreme serviceability control
5D Advanced structural applications

Product certificates*

* Product certificates are plant specific.

Product conformity

Dramix® conforms to ASTM A820, EN 14889-1 and ISO 13270 Class A.

System certificates

All Dramix® plants are ISO 9001 and ISO 14001 certified.

Packaging

BAGS
20 kg

BIG BAG
800 - 1.100 kg

Handling

KEEP DRY

NO STACKING

DRAMIX® 3D 80/60BG

The original anchorage
Dramix® 3D is the cost-efficient fibre for standard statically indeterminate concrete structures that are submitted to regular static, fatigue and dynamic loadings.

Glue technology for three-dimensional reinforcement
Dramix® steel fibres are bundled with water-soluble glue. The glue helps avoiding fibre balling during mixing and ensures a homogeneous distribution of fibres throughout the concrete mix.

Bekaert construction support
You can count on our support for each step of your project, from concept design to on-site quality support. Our services include recommendations on slab design, construction detailing, concrete optimization and automatic total quality control procedures. We are also happy to share our knowledge with you and your team.
Feel free to ask us for a workshop or training on the topic of steel fibre reinforcement in your offices.

For recommendations on handling, dosing and mixing visit www.bekaert.com/dosingdramix.
Any other specific document or certificate can be found on www.bekaert.com/dramix/downloads.

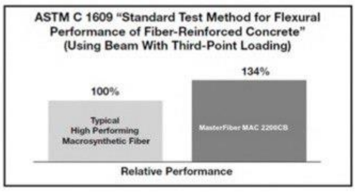
Appendix C

Datasheet for Master Fiber MAC 2200CB

MASTER® BUILDERS SOLUTIONS

MasterFiber® MAC 2200CB

PERFORMANCE DATA



STORAGE AND SHELF LIFE

MasterFiber MAC 2200CB should be stored at temperatures below 60°C. Avoid storing near strong oxidizers and avoid sources of ignition.

Shelf life is 24 months when stored as above.

HEALTH AND SAFETY

MasterFiber MAC 2200CB is extremely stable, presenting little to no hazard to health, however, in fire conditions; carbon monoxide, carbon dioxide, other gases and fumes may be evolved. Use caution when stacking to avoid unstable conditions.

The usual precautions and measures should be taken for handling any chemical substance. Use caution when stacking to avoid unstable conditions. Use protective gloves and glasses. Wash hands before a break and on finishing work. Do not eat, drink or smoke during application.

The disposal of the product and its packaging is the responsibility of the end user and should be carried out according to current legislation.

IMPORTANT NOTES

- It is recommended to test all fibres prior to use.
- Do not use a fibre dosage outside of the recommended dosage range unless specifically advised by our Technical Department

For more information, please consult the Safety Data Sheet of this Product.

QUALITY AND CARE

All products originating from Master Builders Solutions Dubai, UAE facility are manufactured under a management system independently certified to conform to the requirements of the quality, environmental and occupational health & safety standards ISO 9001 and ISO 14001.

* Properties listed are based on laboratory controlled tests.

® = Registered trademark of the MBCC Group in many countries.

MBS_CC-UAE/Fiber_Mac_2200CB_10_17/v1

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تأثير أنواع الألياف الفولاذية على سلوك الشد الانثنائي للكمرات الخرسانية المحززة

أعدت من قبل

المعتصم نايف سليمان الزبن

أشرف عليها

د. ابراهيم فاروقة

الملخص

تتناول هذه الدراسة التحقيق في تأثير أنواع مختلفة من ألياف الصلب على سلوك شد الانحناء للكمرات الخرسانية. يتم التركيز في هذه الدراسة على تطبيق تعزيز الألياف في الكمرات الخرسانية ودورها في زيادة القوة والمرونة ومقاومة التشقق. ومع ذلك، لا تزال هناك تساؤلات حول فعالية أنواع الألياف المختلفة في تحسين الأداء لشد الانحناء. تهدف هذه الدراسة إلى سد هذه الفجوة المعرفية من خلال دراسة تأثير أنواع مختلفة من الألياف على الكمرات الخرسانية ، بما يشمل استخدام عينات لا تحتوي على ألياف ، وألياف الصلب المعكوفة ثلاثية الأبعاد، وألياف الصلب المعكوفة رباعية الأبعاد بخصائص متنوعة، وألياف البولي بروبيلين الاصطناعية.

توضح النتائج الرئيسية لهذه الدراسة أن تعزيز الكمرات الخرسانية بألياف الصلب يؤدي إلى تحسينات كبيرة في سلوك الشد المرن للكمرات الخرسانية، ومن بين هذه النتائج :

- يؤدي استخدام ألياف الصلب المعكوفة رباعية الأبعاد ذات القطر 0.9 مم إلى زيادة ملحوظة تبلغ 73% في أقصى حمولة شد انحناء مقارنة بالكمرات الخرسانية بدون ألياف.

- يتم تعزيز أقصى حمولة شد انحناء بنسبة 16.6%، 42%، و 11.7% عندما يتم إضافة ألياف الصلب ثلاثية الأبعاد (60/80)، وألياف الصلب رباعية الأبعاد (60/80)، وألياف البولي بروبيلين إلى الخليط الخرساني على التوالي.

- يؤدي الانتقال من ألياف الصلب ثلاثية الأبعاد إلى ألياف الصلب رباعية الأبعاد الى زيادة ملحوظة بنسبة 21.8% في أقصى حمولة شد انحناء وتحسن بنسبة 16.4% عند انحناء قدره 0.65 مم، مما يعكس تأثير ألياف الصلب رباعية الأبعاد الفائق في ربط التشققات.

- يسهم زيادة قطر ألياف الصلب رباعية الأبعاد من 0.75 مم الى 0.9 مم الى تحسينًا بنسبة 21.5% في أقصى حمولة لشد الانحناء وتحسينًا مذهلاً بنسبة 111.7% عند انحناء قدره 0.65 مم.

في الختام، تسلط هذه الدراسة الضوء على فوائد تعزيز الألياف في الكمرات الخرسانية، مثل تحسين التحمل وتعزيز الأداء الهيكلي وتقليل التكاليف .تلك النتائج لها تأثير كبير على عملية البناء، مما يساعد في اتخاذ قرارات مدروسة بشأن استخدام الخرسانة المسلحة بالألياف في تطبيقات هيكلية متنوعة.