

CAPITAL UNIVERSITY OF SCIENCE AND
TECHNOLOGY, ISLAMABAD



Properties of Concrete with a Fixed Proportion of Banana Fibers and Varying Percentages of Used Petrol-Engine-Oil

by

Yousaf Khan

A thesis submitted in partial fulfillment for the
degree of Master of Science

in the

Faculty of Engineering

Department of Civil Engineering

2026

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Acknowledgement

In the Name of **Allah**, The Most Gracious, The Most Merciful. Praise be to God, the Cherisher and Sustainer of the worlds. All thanks to Almighty **Allah**, The Lord of all that exist, who bestowed me with His greatest blessing i.e. knowledge and Wisdom to accomplish my task successfully. Thousands of salutations and benedictions to the **Holy Prophet Hazrat Muhammad (PBUH)** the chosen through by whom grace the sacred Quran was descended from the Most High.

I am very thankful to **Engr. Prof. Dr. Majid Ali**, a great teacher, supervisor and trainer who made a difference in all aspects of my life. I am indebted to **Engr. Prof. Dr. Majid Ali** for his valuable guidance, encouragement and dedicated support that enabled me to complete my MS Degree Program.

I would like to thanks **Engr. Muhammad Jawad khan** for his helping hand. I want to express my heartiest regards to my parents, my family specially my elder brother **Engr. Zahir khan** who always supported me morally, spiritually & prayed for my success.

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Abstract

Because of its superior properties compared to other construction materials, concrete is the most widely used material in the construction industry. Despite its advantages, the brittleness of concrete introduces several significant weaknesses. These include increased linear shrinkage, brittle behavior, spalling, and susceptibility to cracking. Although concrete exhibits high compressive strength, it remains weak in tension. Cracking is one of the major issues that reduces the lifespan and resilience of concrete structures. The incorporation of natural fibers and suitable admixtures can improve the splitting-tensile and flexural properties of concrete. Meanwhile, developing nations are increasingly interested in utilizing waste materials as raw resources for producing sustainable construction materials. Among these wastes are environmentally hazardous substances such as spent motor oil and gasoline. Banana fibers, a type of agricultural waste, are another abundant resource in developing countries. Using such waste materials can contribute to the development of eco-friendly products. Banana fibers can serve as dispersed reinforcement to enhance the mechanical properties of concrete, while used motor oil or gasoline can act as a chemical additive during the concrete manufacturing process

In this study, natural fibers and chemical admixtures were incorporated into concrete to enhance its properties and performance. Used petrol-engine oil was added as a chemical admixture, while banana fibers were used as reinforcement. This was achieved by preparing two beamlets and four cylinders for plain concrete and incorporating a fixed amount of 2% banana fibers into concrete mixes containing varying percentages of UPEO (8.4%, 9.4%, 10.4%, and 11.4%). For the preparation of plain concrete and UPEO-modified concrete, a water-to-cement ratio (w/c) of 0.5 was used with a mix proportion of 1:2:4 (cement:sand:coarse aggregates). To prepare fiber-reinforced concrete, the mix was adjusted to a w/c ratio of 0.6. A fixed amount of banana fibers and varying quantities of UPEO were used in the production of banana fiber-reinforced concrete. The effects of banana fibers and UPEO on concrete properties were evaluated through dynamic, linear shrinkage, slump, water absorption, mechanical, and mass-loss tests. Two specimens

of each concrete type were tested, and the average results were reported for each parameter.

Analytical and empirical equations were developed based on the experimental results to establish correlations between fiber content and the flexural, splitting-tensile, and compressive strengths of concrete. According to the slump test results, concrete containing only UPEO exhibited a greater slump value than the other types of concrete. A reduction in the workability of fiber-reinforced concrete was observed with the addition of banana fibers. The UBFRC containing 2% fiber content and 10.4% UPEO demonstrated superior performance under dynamic loading. The results indicated that, compared to other mixes, UBFRC with 8.4% and 10.4% UPEO achieved higher tensile and flexural strengths, respectively. Furthermore, as the amount of banana fiber in the concrete increased, both the splitting-tensile toughness and compressive toughness indices improved significantly. However, an increase in fiber content was associated with a reduction in compressive strength. Concrete with higher fiber content also showed greater water absorption and reduced linear shrinkage. Therefore, it can be concluded that concrete containing 2.0% banana fibers is most suitable for tension members, as it performs better under dynamic, tensile, and flexural loading conditions. Additionally, UBFRC with 2% fiber content exhibited superior performance among other mixes in compression members.

Keywords : Banana Fibers, Dynamic Properties, Fiber Reinforced Concrete, Mechanical Properties, Used Petrol-Engine Oil.

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Abbreviations

BF	Banana Fibers
CE1	Compressive Pre-Crack Energy Absorption
CE2	Compressive Post-Crack Energy Absorption
CPoAE	Compressive Post-Crack Energy Absorption
CPrAE	Compressive Pre-Crack Energy Absorption
CS	Compressive Strength
CTIn	Compressive Toughness Index
CTI	Compressive Toughness Index
Ed	Dynamic Modulus of Elasticity
FC	Fiber Content
FE1	Flexural Pre-Crack Energy Absorption
FE2	Flexural Post-Crack Energy Absorption
FPoAE	Flexural Post-Crack Energy Absorption
FPrAE	Flexural Pre-Crack Energy Absorption
FRC	Fiber Reinforced Concrete
FS	Flexural Strength
FTIn	Flexural Toughness Index
FTI	Flexural Toughness Index
MOE	Modulus of Elasticity
PC	Plain Concrete
RFL	Response Frequencies Lateral
RFR	Response Frequencies Rotational
RFT	Response Frequencies Transverse
Rd	Dynamic Modulus of Rigidity

SE1	Splitting-Tensile Pre-Crack Energy Absorption
SE2	Splitting-Tensile Post-Crack Energy Absorption
SPoAE	Splitting-Tensile Post-Crack Energy Absorption
SPrAE	Splitting-Tensile Pre-Crack Energy Absorption
SP	Superplasticizer
SS	Splitting-Tensile Strength
STIn	Splitting-Tensile Toughness Index
STI	Splitting-Tensile Toughness Index
STM	Servo-Hydraulic Testing Machine
STS	Splitting-Tensile Strength
UBFRC	Used Petrol-Engine Oil Banana Fiber reinforced concrete
UEO	Used Engine Oil
UPEO	Used Petrol-Engine Oil
UVBFRC	Used Petrol-Engine Oil and varying length Banana Fiber

Symbols

ζ	Damping Ratio
Δ	Deflection
δ	Deformation

Chapter 1

Introduction

1.1 Background

Concrete is the most extensively used material in the construction industry. It serves as the fundamental component of modern building construction. It is difficult to foresee the emergence of any material that could completely replace concrete. However, concrete itself has a low tensile strength compared to its compressive strength, making it a quasi-brittle material [1]. Due to this characteristic, concrete alone cannot be fully relied upon for structural performance. Furthermore, its susceptibility to cracking, excessive loading, and environmental effects are the key factors that reduce its functionality and serviceability [3]. To achieve high performance, specific properties, and sustainability in concrete, the addition of admixtures and fibers is necessary [4]. Admixtures can be used to improve early strength, accelerate or retard setting time, or achieve specific concrete characteristics such as reducing cement content without compromising physical performance. In recent decades, the pursuit of environmentally friendly and high-performing materials for civil engineering applications has gained considerable attention. Among these innovations, fiber-reinforced concrete (FRC) has emerged as a promising material due to its enhanced durability, toughness, and tensile strength [4].

FRC consists of short, discrete fibers uniformly dispersed throughout the concrete matrix, and therefore, its performance must be carefully analyzed with respect to the functionality of the fibers within the mix. To produce high-performance concrete, numerous researchers have sought to enhance its fundamental properties. Many studies have employed used motor oil as an admixture to reduce the amount of cement required in concrete. The production of concrete releases approximately the same amount of CO₂ as the clinker manufacturing process [5].

Reducing the cement content in concrete decreases CO₂ emissions during sintering and minimizes the overall environmental impact of the composite. The addition of used petrol-engine oil can reduce cement content by up to 9.4% while maintaining comparable properties to concrete without fibers [6].

Both the inclusion of UPEO and the reduction in cement content contribute to more economical concrete production. Moreover, several researchers have found that fiber-reinforced concrete exhibits improved flexural and tensile strength and demonstrates greater resistance to fatigue, cracking, and spalling. Enhanced flexural, tensile, and compressive properties collectively improve concrete performance for various structural applications.

In fact, increasing tensile strength helps prevent the initiation and propagation of cracks. The incorporation of fibers significantly enhances the material's flexural strength, splitting-tensile strength, and resistance to impact loads [5]. Therefore, fibers can be effectively added to cementitious composites to improve a wide range of mechanical properties.

1.2 Research Motivation and Problem Statement

Concrete is a material that inherently exhibits certain deficiencies, such as the early formation of cracks in structural elements from the very first day of placement. Figure 1.1 illustrates the different structural members affected by these issues. The presence of such cracks significantly influences both the service life of the structural members and the overall durability of the structure. However, if the

development of these cracks can be delayed, the service life of concrete structures can be substantially extended. Therefore, the optimal approach is to develop sustainable concrete that minimizes or eliminates cracking.

Mitigating or reducing the effects of these deficiencies is the central objective of this research. Consequently, there is a need to explore innovative methods that can minimize cracking and enhance the durability of concrete under various environmental and loading conditions. Previous studies have shown that incorporating natural fibers into concrete can improve its mechanical performance and prevent premature failure. To achieve this, modern and sustainable construction techniques must be adopted, and greater awareness must be promoted regarding the use of environmentally friendly, high-performance materials in the construction industry.



Cracks in Compression Member



Cracks in Beams



Early Age Micro-Cracking in Slab



Plastic Shrinkage Cracking in Rigid Pavement

FIGURE 1.1: Cracking in Different Application of Concrete [35]

Several research studies are available that focus on enhancing the properties of concrete through the addition of various admixtures. However, to minimize environmental contamination and promote cleaner and more sustainable production

practices, it is essential to utilize alternative waste products such as used petrol-engine oil. Furthermore, this study aims to provide researchers with a framework and guidelines that encourage the use of waste materials those typically considered environmental pollutants in construction applications rather than their disposal. Disposing of such materials can often be costly and time-consuming. Consequently, the following problem statement has been formulated

With the growing age, urbanization is increasing, resulting in the increase of construction material like concrete which is not environment friendly. Burning of wastes also emits Carbon dioxide (CO_2). Wastes like use petrol engine oil and banana fiber can be utilized in concrete to improve the physical properties of concrete. The combine use of natural fibers and use petrol engine oil can lead to reduction of micro and macro-cracking in concrete resulting enhancing the ability to withstand loads, improving tensile strength and toughness. Use petrol engine oil and banana fibers may provide better results by their combined effect. There is no such study that has been conducted which relates to the effects of varying percentage of use petrol engine oil and fix length of 2% of banana fibers on the mechanical, dynamic and absorption properties of concrete. Construction can never be stopped but the agricultural wastes can be utilized to enhance the properties, saving environment and providing the sustainable materials for sustainable development.

1.2.1 Research Questions

- i. What is combined effect of varying percentage of use petrol engine oil and fixed proportion of banana fibers on the dynamic properties of concrete?
- ii. What are the combined effects of use petrol engine oil and banana fibers on dynamic and mechanical properties of concrete?
- iii. How much splitting tensile and flexural strength can be enhanced in comparison to compromise with compressive strength after incorporation of varying percentage of use petrol engine oil and fixed proportion of banana fiber?

- iv. How concrete made of banana fibers and used petrol-engine oils suitable for the particular real-world uses.?

1.3 The General Goal of the Research Program and the Particular Objective of this Master's Thesis

The overall objective of the research program is to take a precise step toward the development of high-performance concrete using waste materials for building construction and civil engineering applications. As concrete has several flaws, some of these defects affect the performance of structures and reduce the durability of concrete. There is a need to utilize waste materials (instead of dumping them) in construction because they have shown good potential for creating a positive impact on cementitious composites. By incorporating waste materials into the construction industry, we can not only reduce the amount of waste directed to landfills but also contribute to the development of more sustainable and eco-friendly construction practices.

The specific aim of this research work is to study the combined effect of varying percentage of used petrol engine oil and fixed proportion of banana fibers on properties of concrete.

1.4 Scope of Work and Study Limitations

The workability, mechanical properties, dynamic properties, and absorption properties of concrete are investigated by taking two specimens of UEO and UBFRC for each type of concrete. Two specimens are averaged in accordance with the accepted and recommended ACI 311.6-18 standards. Prior to examining the mechanical and absorption properties, the dynamic properties are evaluated. Following the application of load, the samples are considered to have failed when the

first visible crack appears. This study also examines other parameters, including mass loss and linear shrinkage. The experimental program does not include a direct lateral load test (such as shear wall or lateral cyclic loading). Instead, the dynamic properties (ASTM C215-14) and mechanical properties (compression, splitting tensile, and flexural) were evaluated, as they are closely related to the concrete's resistance to lateral and dynamic effects.

Only the mechanical, dynamic, and absorption characteristics of UBFRC specimens are considered in this investigation. The durability of UBFRC is not included within the scope of this study. This study also does not take into account the performance and resistance to impact loading. For fixed UBFRCs with varying quantities of UPEO, fibers of fixed length and variable composition are utilized.

1.4.1 Basis for Choosing Variables

The type of fiber was chosen based on its superior physical characteristics [42]. Among natural fibers, banana fibers have a high tensile strength. Additionally, it is probable that these banana fibers can be used with UPEO [41]. The acidic nature of UPEO can readily harm numerous other natural fibers [35].

1.5 Brief Methodology

The fundamental dynamic, mechanical, and absorption characteristics of PC were investigated in this experimental work. In the laboratory, both PC and UBFRC were tested. Each UBFRC specimen has a fixed fiber length of 50 mm and contains a constant amount of banana fibers. The production of PC and all types of UBFRCs includes a fixed quantity of used petrol-engine oil. The most common mix design of 1:2:4 was employed for manufacturing both plain concrete and fiber-reinforced concrete. All types of UBFRCs were prepared with a w/c ratio of 0.6, while PC was prepared with 0.5. According to [71], the high water absorption capacity of banana fibers increases the w/c ratio. Due to the inclusion of UPEO, which is also a liquid, the w/c ratio was limited to 0.6. Otherwise, because natural

fibers in cement composites absorb water, a 0.7 w/c ratio was recommended [46]. PC and UBFRCs were tested for workability using the slump cone test method in accordance with ASTM C496/C496M-17 for cylindrical concrete specimens CS, STS, and FS.

At least two specimens are required for each test condition, and the average value is reported. A total of 42 specimens of PC and UBFRCs were cast after performing the slump test. Each type of prepared concrete was used to cast four cylinders and two beamlets. Two cylinders of each type were tested to determine the compressive strength of concrete, while the remaining two were used to evaluate the splitting-tensile strength.

Three-point loading tests were conducted on the cast beamlets to investigate the flexural characteristics of all types of prepared concrete. Cement: Ordinary Portland Cement.

Fine Aggregate: Natural sand. Coarse Aggregate: Margalla crush (maximum size 20 mm). Banana Fibers: Fixed length of 50 mm, added at 2% by weight of cement. UPEO added at 8.4%, 9.4%, 10.4%, and 11.4% by mass of cement. Water: Tap water at room temperature.

The mix design used in this study included four types of concrete: PC with a 1:2:4 mix and a w/c of 0.5; UPEO Concrete with the same mix and w/c = 0.5 but containing UPEO; Banana Fiber Reinforced Concrete with a 1:2:4 mix and w/c = 0.6 containing banana fibers; and UBFRC (UPEO + BF) with a 1:2:4 mix and w/c = 0.6 containing both UPEO and banana fibers.

Cylindrical specimens measuring 150 × 300 mm (6 × 12 in) were prepared for compression and splitting tensile tests, while beamlets of 100 × 100 × 500 mm were cast for flexural testing. The slump test was conducted to assess workability before casting. For each mix type, two cylinders were tested for compressive strength, two for splitting tensile strength, and two beamlets for flexural strength, and the average of two specimens was reported for each result.

The testing program included the following: fresh properties were evaluated using the slump test (ASTM C143); dynamic properties were determined through the

resonant frequency method (ASTM C215); mechanical properties were assessed using compressive strength (ASTM C39), splitting tensile strength (ASTM C496), and flexural strength (ASTM C78, third-point loading); and physical properties were measured using water absorption (ASTM C642), linear shrinkage (ASTM C157), and mass loss tests. Fracture analysis was performed using microscopic examination of broken surfaces to observe fiber pull-out and bonding characteristics. All mechanical tests were conducted using servo-hydraulic testing equipment, while dynamic properties were evaluated prior to mechanical testing using an accelerometer and hammer. The accelerometer was attached to the specimen, and a hammer stroke was applied to record the response-frequency transverse (RFT), response-frequency longitudinal (RFL), and response-frequency rotational/torsional (RFR). A flow chart provides a brief description of the study methodology, as shown in Figure 1.2.

The dynamic qualities of all varieties of produced concrete are then assessed using these frequencies. In order to verify that the fibers are mixed inside the concrete, bonded to the surrounding cementations matrix, pulled out, shattered, etc. Detailed observation is carried out on the fractured surfaces of the broken.

1.6 Research Impact on Industry

This research offers significant contributions to the construction industry by introducing a sustainable, cost-effective, and performance-enhancing solution for concrete production. By incorporating banana fibers and used petrol engine oil into concrete, the study demonstrates improved tensile and flexural properties, enhanced dynamic performance, and reduced linear shrinkage key factors in increasing the durability and resilience of structural components.

This innovation not only helps to reduce the reliance on high cement content, thereby lowering CO₂ emissions, but also recycles hazardous and agricultural waste that would otherwise harm the environment.

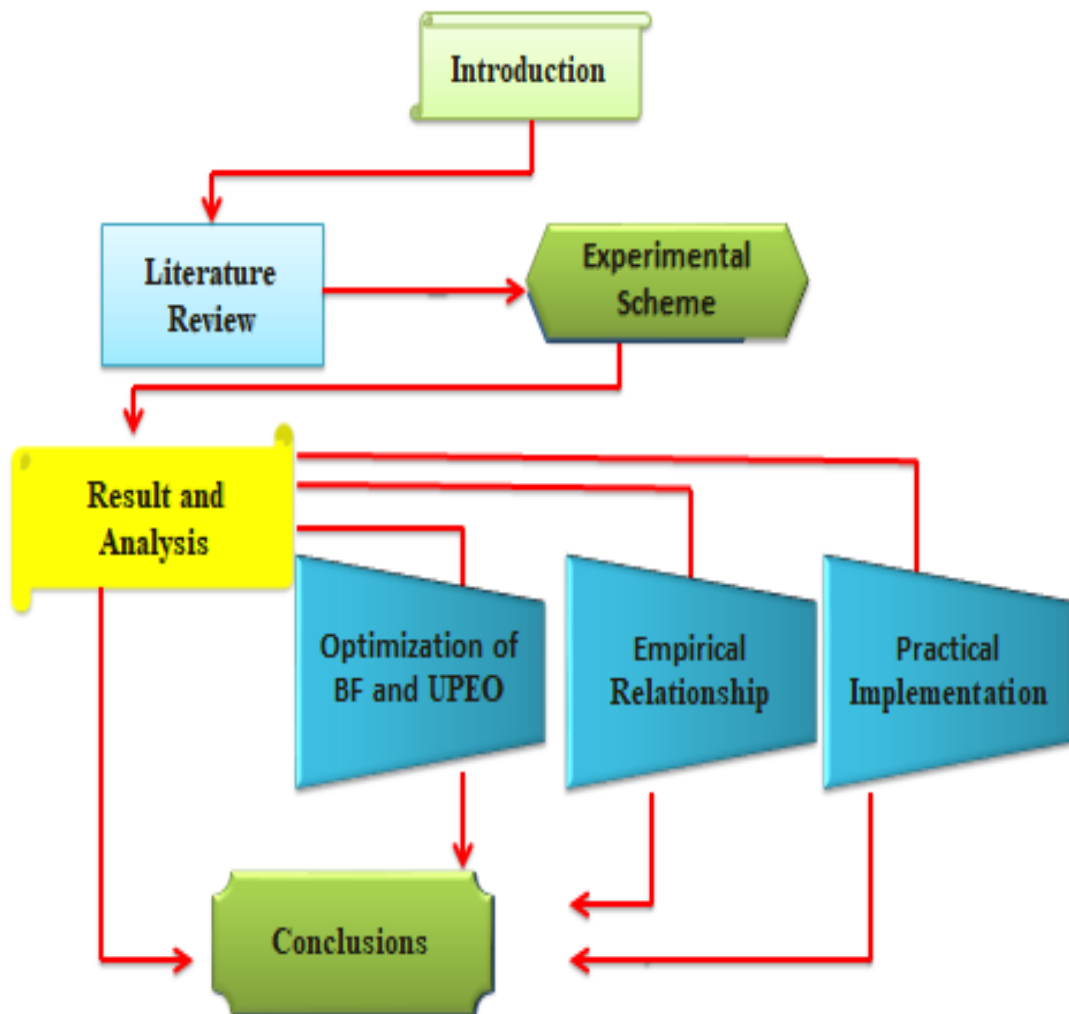


FIGURE 1.2: Process Diagram of this Experimental Study

The practical application of such modified concrete in non-exposed structural elements like sub-foundations and lean concrete has the potential to lower material costs, improve structural performance, and promote sustainable construction practices in developing and industrializing countries.

1.6.1 Research Novelty and Uniqueness

The novelty of this research lies in its first of its kind combined use of agricultural and hazardous waste materials BF and UPEO to enhance the mechanical and dynamic performance of concrete. While prior research has independently investigated effects of natural fibers or waste oils in cementations materials, no prior

research has systematically explored their synergistic impact on critical concrete properties such as CS, FS, STS, dynamic modulus, and crack resistance.

Study introduces a practical, scalable method for producing modified fiber - reinforced concrete using locally available and low-cost waste resources. Furthermore, the research provides empirical and analytical models that correlate fiber content with mechanical behavior, offering valuable design guidance.

This unique integration not only advances sustainable material development but also addresses two environmental challenges waste fiber disposal and engine oil pollution making the research both technically innovative and environmentally impactful.

1.6.2 Research Significance and Benefits

This research holds considerable significance in both academic and practical domains by addressing the dual challenge of improving concrete performance and promoting environmental sustainability. The incorporation of BF and UPEO into concrete not only enhances mechanical properties such as splitting-tensile strength, flexural strength, and energy absorption, but also offers a meaningful solution for the reuse of hazardous and agricultural waste. This innovation supports the global shift toward green construction practices, particularly in developing countries where resource optimization and cost reduction are essential. By reducing cement content through UPEO and improving durability through BF, the study contributes to lower CO₂ emissions, increased structural life, and reduced maintenance costs. Furthermore, the findings offer practical insights for construction engineers and materials scientists, enabling the design of more efficient concrete structures that perform well under dynamic and tensile loading conditions. The research also sets the groundwork for future studies on sustainable waste-based construction materials. Even if the availability of agricultural biomass like banana fibers is reduced, the prospect of such sources remains attractive because they are renewable, locally available, and low cost compared to synthetic fibers. Their use

in concrete helps convert agricultural waste into value added construction material, reducing disposal and environmental problems.

1.6.3 National and Global Impact with SDG Relevance

This research contributes meaningfully to both national development priorities and global sustainability efforts by promoting the use of waste based construction materials that are economical, locally sourced, and environmentally responsible. At the national level, particularly in developing countries like Pakistan, the integration of agricultural waste banana fibers and hazardous waste used petrol engine oil into concrete supports waste management, cost effective infrastructure development, and employment in rural fiber processing sectors. Globally, the study aligns with multiple United Nations Sustainable Development Goals (SDGs), including SDG 9 (Industry, Innovation and Infrastructure) by enhancing material innovation, SDG 11 (Sustainable Cities and Communities) through eco friendly construction, and SDG 12 (Responsible Consumption and Production) by utilizing industrial and agricultural waste. Furthermore, by reducing cement content and CO₂ emissions, the research contributes to SDG 13 (Climate Action), encouraging low carbon construction practices. This work not only addresses technical challenges in civil engineering but also supports policy frameworks aimed at circular economy, green building certification and climate resilience in infrastructure both nationally and globally.

1.6.4 Practical Implementation

The findings of this research can be practically implemented in a range of construction applications, particularly in non-exposed structural elements such as lean concrete under foundations, sub-base layers, flooring beds, and internal partitions. The modified concrete incorporating UPEO and BF demonstrates enhanced tensile and flexural performance, making it suitable for elements subjected to dynamic loading and crack control requirements. Since UPEO is chemically reactive and

may have long term durability concerns under environmental exposure, its application is best suited for areas protected from direct atmospheric or chemical contact, such as buried or enclosed structures.

1.6.5 Research Challenges

This research encountered several challenges, both technical and practical, throughout its experimental and analytical phases. One major difficulty was maintaining uniform dispersion of BF in the concrete mix, as their natural tendency to clump and absorb water affected both workability and consistency. Achieving an optimal fiber-matrix bond while preventing segregation posed further complexity during mixing and casting. Additionally, UPEO introduced variability due to its inconsistent chemical composition, which is influenced by engine type, operational conditions, and degradation level making standardization difficult. Controlling the w/c was also challenging, especially with the absorptive nature of natural fibers and the liquid properties of UPEO. Experimentally, the accurate measurement of dynamic and post-crack energy absorption parameters required precision instruments and careful calibration to avoid errors in test results. Finally, since both BF and UPEO are considered non-traditional materials, sourcing them in a consistent, contaminant free form and ensuring safe laboratory handling added to the logistical challenges.

1.6.6 Ethical and Management Considerations Including Risk Management

The ethical and management aspects of this research were carefully considered to ensure compliance with responsible scientific conduct and safe laboratory practices. The use of UPEO posed potential environmental and health risks due to its toxic and flammable nature. Therefore, proper handling protocols, storage guidelines and personal protective equipment (PPE) were strictly followed to mitigate

any hazards during mixing and testing procedures. Waste disposal from the laboratory was managed according to institutional environmental safety policies to prevent contamination. Ethically, the research promotes sustainability by reusing hazardous and agricultural waste, aligning with principles of environmental stewardship and resource conservation. From a project management perspective, careful scheduling was implemented to accommodate the curing time of specimens, access to specialized equipment, and coordination of testing procedures.

Risk management also involved ensuring mechanical test machine calibration, data integrity, and repetition of tests where inconsistencies were observed, minimizing the chance of errors and improving the reliability of the results. The study was conducted in accordance with institutional guidelines, maintaining transparency, safety, and accountability throughout the research process. All mechanical testing machines were calibrated regularly. Data integrity checks were performed throughout testing. Any inconsistent results were retested to confirm accuracy. This reduced the likelihood of error and improved data reliability.

All research activities adhered to institutional policies and ethics. Transparency, accountability, and safety were prioritized at every stage. Overall, the study reflects a strong commitment to responsible research practices.

Due to the flammable nature of UPEO special precautions were taken during storage and handling, keeping it away from open flames and heat sources. Structures incorporating such materials should ensure adequate fire resistance, using non-combustible matrices and protective surface coatings to minimize ignition risks and enhance structural safety.

1.6.7 Research Deliverables, Sales and Marketing Potential

This research delivers a novel, eco-friendly concrete formulation using BF and UPEO that enhances key structural properties such as splitting-tensile strength, flexural performance, and dynamic resistance, while also promoting sustainability

and cost reduction. The main deliverables include: An experimentally validated mix design for sustainable concrete, analytical models correlating fiber content with mechanical properties and a set of guidelines for practical application in structural and sub structural elements.

The research has significant sales and marketing potential, especially in the low-cost housing sector, rural infrastructure projects, and eco-construction markets where affordability, waste reduction, and performance matter. By offering a concrete solution that reduces cement consumption and utilizes waste materials, it appeals to construction firms aiming to achieve green certifications, meet environmental regulations, and align with corporate social responsibility (CSR) goals.

With increasing global emphasis on sustainable development and circular economy, the proposed concrete mix can be positioned as a market-ready innovation for both public and private sector infrastructure projects.

1.7 Thesis Outline

Six chapters make up this thesis, outlined as follows:

Chapter one includes introduction. The backdrop, problem statement and research motivation, general and particular research goals, study restrictions, work coverage, concise method, research framework are all covered.

Chapter two includes the review of the literature. Background information, spent motor oil, banana fibers, recoverable defects, controlling values for improving the qualities of concrete and the role they play durability and design considerations, and a summary are all included.

Chapter three presents the experimental plan, describes the materials used, outlines the mix design and specimen casting procedures, details the testing methodologies, and provides a summary of the key aspects covered in Chapter Three.

Chapter four include test results and their interpretation. Chapter 4 is summarized, the background is explained, This section addresses the mechanical and

dynamic performance of PC and UBFRC mixes, the analysis of fractured specimen surfaces, and assessments of key durability parameters such as water absorption, linear shrinkage, and mass loss.

Chapter Five provides a comprehensive discussion on the background of the study, the optimization process of incorporating banana fibers with spent gasoline engine oil, the formulation of empirical relationships, and practical guidelines for implementation. The chapter concludes with a summary of key findings.

Chapter six includes recommendations for the future and conclusions. All sources and literature cited in this work are compiled and listed in the final section under References.

Chapter 2

Literature Review

2.1 Overview

Since ancient times, used petrol-engine oil has been employed to improve the mechanical strength parameters and performance of composites. Better mechanical properties, such as energy absorption, toughness index, and increased resistance to loading, have been demonstrated through the combined effect of UPEO and BF in concrete. Investigating the influence of UPEO to enhance specific performance characteristics is essential for its effective application in the construction industry.

2.2 Utilization of Waste Materials in Construction

As time goes on, the building industry is becoming more and more interested in using waste materials as raw materials in terms of environmental protection. Numerous scholars looked into the impact various waste products have been studied for their effects on concrete properties, with recycled aggregates being widely utilized in experimental research as a step toward cleaner production and sustainable development of building materials [1, 12, 13]. Glass fiber plastic waste and ceramic

waste have been used in concrete by many researchers [14, 15]. Because they are used as building materials, agricultural wastes as natural fibers have a significant economic influence everywhere in the world.

The effects of adding plant fiber as a distributed reinforcement to concrete on its characteristics were investigated in an experimental study [8]. Utilizing natural fibers in a variety of composites has lessened the negative effects of using other fundamentally dangerous materials and aided in the creation of ecologically friendly and sustainable products. The lubricant that various motors and machinery utilize poses a risk to the environment. For environmentally friendly manufacture and cost effective disposal of spent Waste lubricants such as used engine oil have shown potential for use in concrete as chemical admixtures in concrete [6]. Other waste materials, such as engine coolants, can be utilized as raw materials for construction instead of UEO [16]. Investigating the fresh and hardened properties of concrete that has been treated with engine oil was the goal of the study [17]. Studies examining the influence of waste gasoline lubricant as an additive in reinforced concrete have shown. it does not cause significant deterioration or adverse effects on the structural performance of the elements [18].

There are lots of leftover engine oil accessible, making it impossible to store and reuse efficiently. Effective measures should be taken to ensure that waste engine oil does not infiltrate runoff water, thereby avoiding potential environmental contamination. Eventually, might contaminate ecology of the sea and rivers and endanger aquatic life. This waste's disposal endangers human health in addition to occupying a sizable portion of valuable land [19]. Burning the agricultural waste is another way to dispose of it. A significant amount of heat is released when agricultural land is burned, endangering the ecosystem and contributing to the global warming effect.

2.2.1 Used Petrol-Engine Oil

The utilization of automobiles in the transportation industry is increasing daily. As the central component of any automobile, the engine requires consistent and

effective lubrication to reduce friction, minimize wear, and maintain efficient operation. After a certain period of engine use, these lubricants must be replaced. Because it contains heavy and polluted particles, used petrol engine oil poses a greater environmental risk. Waste oil, a by product of crude oil usage, not only carries heavy particulate matter but also contains small concentrations of polycyclic aromatic hydrocarbons (PAHs), which are compounds associated with toxicity and long term environmental impact. Used engine oil, also known as used petrol engine oil, has been shown to negatively affect male reproductive parameters [24]. The composition and characteristics of used petrol engine oil are presented in Table 2.1, in comparison with ordinary Portland cement.

TABLE 2.1: Chemical Composition of Ordinary Portland Cement and Used Engine Oil [24]

Chemical Composition	Ordinary Portland Cement (%)	Used Engine Oil (%)
SiO ₂	21.98	–
Al ₂ O ₃	4.65	–
Fe ₂ O ₃	2.27	0.42
CaO	6.55	15.9
MgO	4.27	–
SO ₃	2.19	37
K ₂ O	1.04	–
Na ₂ O	0.11	–
P ₂ O ₅	–	8.95
ZnO	–	17.7
Cl ⁻	–	15.9

It is possible to use used engine oil as a chemical additive in concrete. Research has shown that waste oil satisfies. The ASTM C494 standard specifies requirements for Type a water-reducing admixtures used in concrete.[6]. employed UPEO was employed in various composites by the various researchers. UPEO and BF are used simultaneously because each material compensates for the deficiencies of the other. UPEO enhances workability, bonding, and durability properties, while BF contributes to crack resistance, tensile strength, and dimensional stability. When combined, they overcome the limitations of using either one alone such as reduced strength with UPEO or poor workability with BF resulting in a more balanced

structural performance. Waste cooking oil and UPEO were used in several studies to evaluate and enhance the asphalt pavement's performance [30]. Studies have demonstrated that the addition of used engine oil UPEO in asphalt pavement formulations has minimal impact on the susceptibility of the material to low temperature cracking, maintaining its structural integrity under cold conditions [21, 22]. UPEO typically has a flash point around 200–230 °C, meaning it can catch fire if exposed to an ignition source above this temperature [30].

However, there have been a number of studies published on concrete that include UPEO. Concrete was mixed with waste from the fat and oil industries as an economical method of disposal and environmental cleanup [23–25]. With the aid of UPEO, enlarged clay aggregates were created for application in lightweight concrete manufacturing during research [27]. BF and UPEO were utilized to test the impact on the concrete's workability. UPEO was incorporated to increase the workability [28]. The impact of UPEO on the concrete's mechanical qualities and workability is displayed in Table 2.2. Comparing concrete manufactured with UPEO to concrete made with super plasticizer, it was shown that the use of UPEO increased compressive strength and decreased crack width in flexure failure and slump value [29]

Used engine oil has the ability to enhance the qualities of concrete, as Table 2.2 demonstrates. In an experiment, scientists made concrete by substituting cement for 9.4% of UPEO. It is noted that the flexural strength dropped by 2% and the compressive strength increased by 5% [6]. The researcher saw a 19% decrease in the concrete's compressive strength when adding 0.15 percent UPEO by mass of cement throughout the manufacturing process. To investigate various concrete strength parameters, 0.15 percent UEO was added in a distinct study [17]. The flexural and compressive strengths decreased by 7.81% and 3.72%, respectively. A 4.76% improvement in splitting tensile strength was noted with incorporation of UPEO within the concrete mixture.

The findings of an experiment to assess the additive effects of UPEO in concrete are displayed in Figure 2.1. Compressive and flexural strengths were examined when a certain proportion of cement was substituted with UPEO. Workability, initial

setting time, air content, drying shrinkage, compressive and flexural strengths, and durability of UPEO added concrete in comparison to ordinary concrete are among the parameters that were examined. Figure 2.1 illustrates how UPEO affects concrete. UPEO can be used as a water reducing additive and satisfies ASTM C494.

This study suggests that the UPEO can replace up to 9.4% of the mass of cement. It is evident that UPEO improved the concrete's slump value. There was a delay in the ultimate setting time compared to regular plain concrete, although the early setting was unaffected. While the 28 day flexural strengths showed a slight decline, the 28 day compressive strength showed an improvement. According to the findings, concrete's cement content can be increased by up to 9.4% by mass while maintaining equivalent qualities. Used petrol-engine oil does contain toxic compounds (sulfur, chlorine, PAHs, heavy metals), which in theory could affect natural fibers.

However, in this study, banana fibers were not directly exposed to raw UPEO. Instead, both UPEO and BF were mixed within the alkaline cementitious matrix, where cement hydration products (mainly $\text{Ca}(\text{OH})_2$) buffer and neutralize acidic effects. This prevents chemical burning or degradation of the fibers. Our experimental results confirm this: the banana fibers retained their crack bridging ability, and concrete with UPEO+BF showed improved tensile and flexural strength, not deterioration. This indicates that the cement environment protects the fibers from UPEO toxicity, allowing both materials to complement each other [50].

2.2.2 Banana Fibers

Numerous studies have examined the anticipated impacts of adding fibers and have employed natural fibers in composites in various ways. Researchers plastered the surface of walls and structural elements using coconut fiber [30]. Using natural fiber plaster on the column improved the out plane lateral loading of the column in a study [31]. In one study, the researchers demonstrated how treated fiber reinforcement in cement mortar resulted in improved composite durability and

qualities [32]. Studies using coconut fibers and coconut fiber ropes found that they significantly improved resistance to dynamic loads [33, 34].

The impact of natural fibers on self compacting concrete was examined in a study [35]. Pullout peak load and pullout energy increased with increasing wheat straw fiber length [36]. In cement mortar and lime mortar, natural fiber behaves differently. Natural fibers contributed to the cement mortar's strength and durability [37]. The composite's high toughness and good strength are a result of a well designed mix, more fibers, and a high water cement ratio (for natural fibers) [38].

The STS, FS and IRof the composite all increased with the inclusion of more banana and jute fibers [41]. Compared to other fibers, banana fiber has a higher average tensile performance compared to sisal, coconut, bamboo, and palm fibers [11]. The composite's tensile strength has increased as a result of the addition of banana fibers [43, 44]. Banana fiber bars were used as reinforcement in a research study. This study found that concrete's resistance to spalling and cracking was enhanced [44]. The concrete beams' resistance to cracking was greatly increased by the addition of banana fibers [45]. This demonstrates that by increasing the concrete's flexural strength, The incorporation of natural fibers contributed to a reduction in the required depth of the concrete section. According to this reduction is attributed to the enhanced tensile properties and crack bridging ability provided by the fibers, which improve the structural efficiency of the concrete experimental research, the extra banana and water hyacinth fibers were added to concrete as biofillers.

Concrete's mechanical properties MBLC, STS, FS, and CS and physical properties TD, BD, and WA improved with the addition of water hyacinth and banana fibers. Banana leaf ash was also used as a partial cement replacement. Mechanical tests were performed on concrete reinforced with banana fiber. The results indicated an increase in tensile strength. Flexural strength also showed a significant improvement [?]. UPEO does contain acidic and toxic compounds, which in free form could damage natural fibers. However, in this research the banana fibers were not directly exposed to raw UPEO both were embedded in the alkaline cement matrix. Cement hydration produces calcium hydroxide ($\text{Ca}(\text{OH})_2$), which has a

strong alkaline nature that neutralizes the acidic effect of UPEO. This protective environment prevents the banana fibers from burning or degrading.[35]

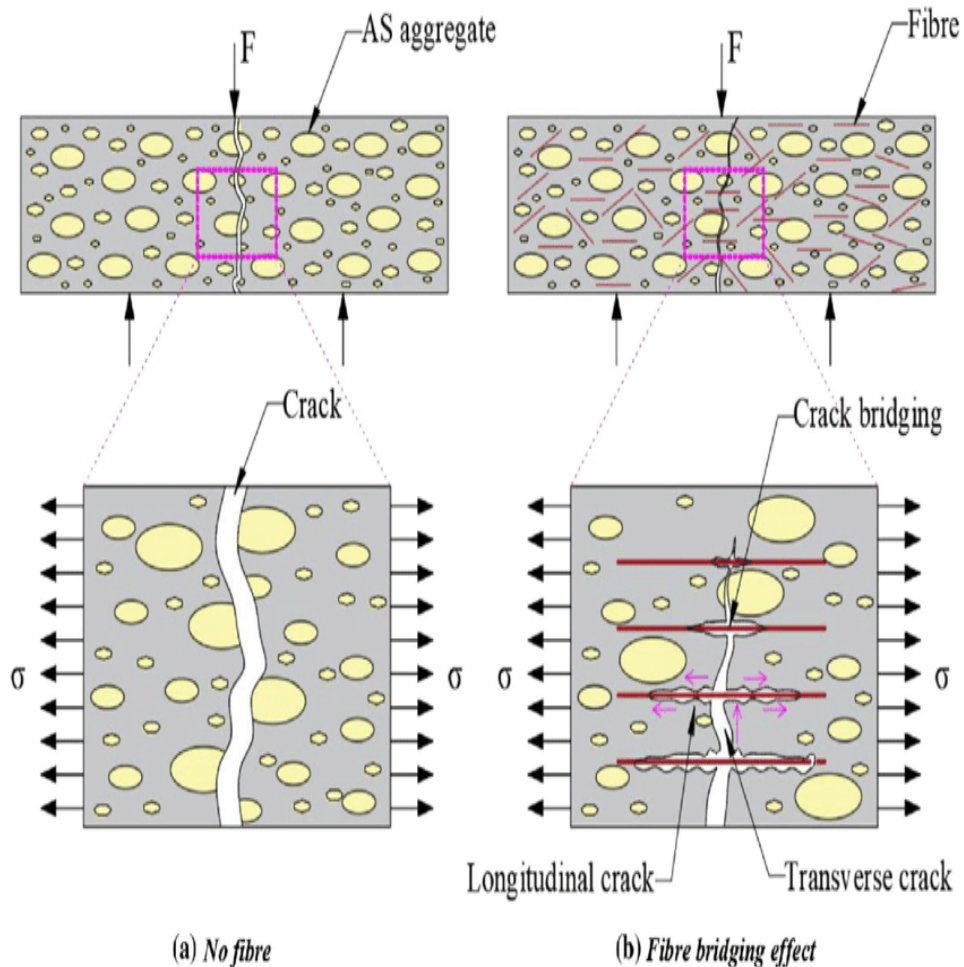


FIGURE 2.1: Schematic Representation of the Fibre Bridging Effect [43]

2.3 Addressing Concrete's Deficiencies through Waste Utilization

There aren't any high quality building and construction materials that can be utilized in place of concrete. In the field of construction, concrete is widely recognized as a foundational material because of its versatility, strength and durability. Notwithstanding its excellence, concrete has a number of shortcomings that must be lessened or minimized. The effects of those defects, such as their low tension strength, susceptibility to cracking, decreased resistance to impact loading

and chipping, etc. Inclusion of farming by products as distributed strengthening in concrete can somewhat lessen the effect of these defects. Improvement in resistance against impact loading when glass fiber reinforced polymer bars and agricultural waste were used together [7, 45].

Using the steel fiber in addition to the basalt fibers enhanced the energy absorption property prevent cracking apart [46]. Thickness stiff pavement decreased when the agricultural waste was incorporated under the guise of natural fiber [47]. The addition of jute fibers to concrete improved its seismic performance and resilience to impact loads [48, 49]. Concrete performed better when fine aggregates were substituted with an ideal dosage of leftover marble powder as a filler material, which offers a path toward sustainable growth [50].

Waste plastic and palm oil fuel ash were added to concrete to increase its ductility and energy absorbing capabilities [51]. To examine how mortar free blocks responded to dynamic loading, the researcher used ropes manufactured from coconut fibers and agricultural debris [51]. Incorporation of glass fiber reinforced plastic trash enhanced concrete's FS [15].

Moreover, addition of glass fiber reinforced plastic (GFRP) waste to concrete mixtures led to a marked increase in flexural strength, demonstrating the material's ability to resist bending forces more effectively. This enhancement makes GFRP waste a viable additive for structural applications where tensile and bending stresses are significant.

2.4 Approaches Governing the Enhancement of Concrete's Performance

The accumulation of micro cracks results in macro cracks. Cracking and its independent magnitude have an impact on the characteristics and functionality of concrete. Concrete strength is impacted by crack propagation. The characteristics of concrete determine the occurrence of concrete cracking. CS, STS, and

FS are among characteristics affect structure's performance. Concrete cracking is prevented and controlled by splitting tensile strength. The aforementioned characteristics of the concrete have a limited impact on the structure's longevity and design.

Concrete's qualities can be changed by making specific adjustments to the production process. To a certain extent, this can be accomplished by altering and adding elements that take durability and design into account.

2.4.1 Durability Considerations

Durability refers to concrete's capacity to resist weathering, chemical attacks, and abrasion, allowing it to maintain performance over an extended service life. It goes without saying that the mechanical characteristics of the concrete are crucial to obtaining a long-lasting building material and a long service life for the project. A study examined how concrete's tensile and flexural qualities affect its durability because it is a brittle material with lower tensile and flexural strengths than compressive strength [1].

Surface cracks were observed within 24 hours after the concrete was placed [57]. The composite was not strong enough at the time to withstand these microcracks in its early age. Concrete must have some extra ingredients added in order to prevent and withstand these kinds of cracks. Concrete's durability and linear shrinkage are inversely correlated. Conversely, concrete's high water absorption capacity directly affects its longevity and, in extreme weather, can lead to the rusting of steel reinforcement within cracked concrete. The width of the fractures that are created and the structural characteristics of the concrete also affect how long a structure will last [58].

2.4.2 Design Consideration

The governing properties that affect the strength and design of structural elements include FS, STS and CS. The concrete is incredibly robust under compression as

compared to its tensile strength. Therefore, the STS and FS of the material are provided more weight when developing concrete structural parts. [?].

Splitting tensile strength and flexural strength are prioritized over compressive strength in many applications and strength related factors, such as rigid pavement and beams, respectively. Cracks brought on by shrinkage pressures are resisted by this splitting tensile strength. Concrete's mechanical qualities can be improved by adding banana fiber to create a high strength, sustainable material. The researchers looked at the possibility of producing concrete by substituting cement similar to PC for a certain proportion of UPEO. In order to minimize manufacturing costs, Used menhical oil serves as an admixture that can decrease the required cement proportion in concrete [6]. Concrete deterioration can be prevented by improving its mechanical and durability qualities.

2.5 Summary

The findings discussed throughout this chapter clearly support the conclusion that the incorporation of natural fibers into concrete, particularly when combined with a chemical admixture, can significantly enhance the material's durability and structural performance. Natural fibers, such as banana fibers, not only provide a sustainable alternative to synthetic materials but also contribute mechanical reinforcement that helps prevent the propagation of micro cracks into more severe macro cracks. This ability to arrest crack formation is critical for improving extended integrity of concrete structures. Banana fibers, due to their high tensile strength and favorable bonding characteristics, have demonstrated a noticeable enhancement STS in concrete matrix. Their fibrous nature allows them to bridge internal cracks, which delays crack widening and reduces the overall brittleness of the composite. As a result, the presence of banana fiber contributes to better energy absorption and resistance to dynamic stresses. In parallel, the use of used petrol engine oil as a chemical additive in concrete has shown potential benefits. While its effect on compressive strength is moderate, it appears to contribute positively to the workability and internal compaction of the mix. More importantly,

used engine oil contains certain acidic compounds that interact with the cementitious matrix in a way that may help reduce pore sizes or fill micro voids, thereby enhancing density and potentially reducing permeability. Interestingly, both banana fiber and used petrol engine oil exhibit somewhat similar chemical behavior, particularly in terms of acidity, which may explain their compatibility when used together in a concrete mix. Their combined application creates a synergistic effect where the physical benefits of fibers complement the chemical action of the admixture. This study reinforces the notion that sustainable materials can play a vital role in modern concrete technology. Collective use of BF and use petrol engine oil not only improves specific mechanical properties but also contributes to a more environmentally responsible approach to construction material design. Further research is encouraged to optimize proportions and explore long term performance in real world structural applications.

Chapter 3

Experimental Scheme

3.1 Background

Inexpensive Because of their, ease of controlling, excellent MP wide accessibility, and environmental sustainability, the use of natural fibers in concrete has gained significant attention in recent years. Among these, banana fiber stands out as a promising reinforcement material owing to its high tensile strength, biodegradability, and abundance as an agricultural by product. In parallel, the incorporation of industrial waste materials into construction applications is being actively explored to promote sustainability and reduce environmental impact. One such waste material is used petrol engine oil, which, when appropriately treated, can act as a chemical admixture in concrete. In this study, BF are employed natural reinforcement, while refuse use petrol engine oil is utilized chemical additive in the preparation of concrete mixtures. This chapter presents a comprehensive overview of the materials used in the study, including the source and properties of banana fibers and use petrol engine oil. It also outlines the fiber treatment methods, mix design formulations concrete without fiber reinforced and concrete with fiber reinforced, casting procedures, and methodology followed for each of the testing protocols. The aim is to provide a clear and structured understanding of how the combination of natural and waste-based additives influences the behavior and performance of concrete.

3.2 Raw Constituents

Normal plain concrete PC is made from readily available sand, Margalla crush, and regular Portland cement.. The aggregate used to make fiber-reinforced concrete and regular concrete has a maximum size of 20 mm.and UBFRCs are made with UPEO as an admixture. It should be mentioned that this study used UPEO that is sold commercially. There is no information available regarding UPEO's characterization because it is regarded as a waste material industry. However, table 2.1 provides the reported characterization from the literature along with a comparison to cement. The banana fibers are trimmed length and commercially available. Since there are no visible contaminants on the fibers (dust, etc.), no further treatments are being performed.

Figure 3.1 depicts BF's course of treatment. The fiber from bananas is used to make FRC. The fiber's fixed length of 50 mm is utilized to create the FRC. BF and use engine oil added plain concrete are made with in plain concrete. The concrete without fiber, concrete with fiber reinforced are mixed using tap water at room temperature. distinct kinds samples are prepared using two separate water cement ratios. All UBFRCs are made with a water cement ratio of 0.6, while PC are made with a ratio of 0.5. According to the literature review, the concrete without fiber have a higher capacity to absorb water, which raises the water ratio for the UBFRCs.

3.3 Mix Design Casting Specimens Slump Test, w/c Ratio and Density Determination

A conventional mix design ratio of 1:2:4 (cement, sand and coarse aggregate) is used for the preparation of plain concrete. To produce concrete incorporating used petrol engine oil, varying percentages of UPEO specifically 8.4%, 9.4%, 10.4%, and 11.4% by mass of cement are added to the mix. For making (WBFRC), banana fibers are introduced at a constant proportion of 2.0% by weight of cement. All

materials required for the PC mix are measured accurately and placed into a drum mixer to ensure uniform blending. The same mixing process is followed for UBFRC, with the respective additions of UPEO and banana fibers as per the desired formulation. After the mixture machine has been revolving for 30 to 45 seconds, water is added. For five minutes, the mixing machine rotates. After the PC is prepared, the slump cone test is conducted. The same process is performed for the preparation, except this time, use engine Oil is poured in one minute following the addition of water. The mixture undergoes rotation for the unchanged five minute time span as the concrete without fiber mix.

Components are arranged in layers to provide adequate fiber mixing in the concrete while making BFRC with 2% banana fiber by mass percent of cement. To create a proper blend of the UBFRC, three sets of layers are used. The mixer machine was filled with a third layer of cement, sand, banana fibers, and aggregates. Subsequently, the same procedure is followed for the second and third batches, where banana fibers, sand, and coarse aggregates are layered over the cement in the mixing drum. The mixer is then switched on to initiate rotation. At this stage, approximately two thirds of the total mixing water is gradually added to the mixture.

After continuous mixing for three minutes, the remaining one third of the water along with the measured quantity of used petrol engine oil is introduced. This staged addition ensures better dispersion of fibers and uniform distribution of UPEO throughout the mix, thereby enhancing the consistency and homogeneity of the final concrete blend. Then rotate the mixture machine for two more than minutes, and then slump test is conducted to see whether the new UBFRC is workable. The remaining UBFRC variants with different amounts of banana fibers were treated in the same way.

The uniformity or workability of the produced PC is examined using the slump cone test. Prior to pouring into molds, the PC and UBFRC slump tests are always conducted. The ASTM standard C143/C143M-15a states that the slump cone test is used to determine if fresh concrete is workable [19]. The test is conducted using a slump cone with a 200 mm (8 in) bottom and the top 100 mm (4 in) and the

300 mm (12 in) is the height slump cone. It is recommended that the cone mold be non absorbent. With a diameter of (5/8 in) 16 mm and a maximum length is (25 in) 600 mm, the tamping rod is hemispherical on both ends. Three equal volumetric layers of concrete are poured into the cone. Compaction is achieved by randomly dropping a tamping rod 25 times from a height of 25 mm (1 in) on the layer's surface after the initial 1/3 layer has been placed. Likewise, two more cone layers are filled and crushed using a tamping rod. used the tamping rod to strike off excess concrete, then screeded and rolled the rod over the concrete to smooth it off. Later on, the droop cone is raised vertically. The cone is set upside down next to the slump cone mold's concrete. As seen in figure 3.2a, the tamping rod is placed over the overturned slump cone so that it extends over the slump concrete. The slump value is meticulously measured with the use of the ruler.

Therefore, the workability of PC and UBFRCs is determined using the same process and test standard. Figure 3.2b illustrates the relationship between the calculated hard densities and the observed slump values. Two specimens are averaged for each mix design in order to measure the densities. By measuring the inner volume of the molds used to cast the beam lets, the volume of the beam lets is calculated in m³. Following the concrete's final setting period, the molds are taken out, and each specimen's mass in kilos is recorded using a weighing balance. Five grams is the lowest weight on the weighing balance that is used to determine the masses. The ratio of volume (m³) to weight (kg) is used to determine densities. Table 3.1 displays the obtained slump and density values. As far as the authors are aware, no such standard tests exist to measure the density and workability of new WBFRC. Accordingly, the determination of WBFRC's workability and density follows the same method and standard.

3.4 Testing Methodology

In order to examine the many comparable qualities against these tests, the following tests are conducted in this section: dynamic, mechanical, water absorption, linear shrinkage, mass loss, and breakage and fiber role in concrete. These test

configurations are carried out in accordance with standards or references from earlier studies.

TABLE 3.1: Density of Hard Concrete, Slump of Fresh Concrete, Mix Design, and Specimen Labeling

Labeling	C:S:A	UPEO (%)	BF (%)	BF Length (cm)	W/C	Slump (mm)	Density (kg/m ³)
PC	1:2:4	–	–	–	0.36	29	2271
UBFRC8.4%	1:2:4	8.4	2	5	0.6	23	2274
UBFRC9.4%	1:2:4	9.4	2	5	0.6	25	2234
UBFRC10.4%	1:2:4	10.4	2	5	0.6	28	2188
UBFRC11.4%	1:2:4	11.4	2	5	0.6	32	2164

In the current investigation, two specimens are averaged. Other researchers similarly report the average of two readings [7, 8, 48].

The dynamic and mechanical test sets are displayed in Figures 3.2a and 3.2b. Following the mechanical test, the function of fibers in concrete was investigated using the concrete's fractured surfaces.

Using an accelerometer and a hammer, longitudinal, lateral, and rotational frequencies are observed for the dynamic testing. Every kind of resonance frequency is determined using a variety of configurations. In a longitudinal frequency setup, one cross sectional side of the specimen has an accelerometer attached to it, and the other cross sectional side receives a light stroke. By positioning an accelerometer 25 cm from the cross sectional edge on the length of the specimen and then placing a stroke parallel to the accelerometer on the opposite edge, lateral frequencies are detected. An accelerometer is connected to the third rotational frequency observation configuration, which is comparable to the longitudinal frequency arrangement. However, the hammer stroke is then applied to the specimen's length perpendicular to the accelerometer. To investigate the mechanical characteristics of PC and all varieties of UBFRCs, compression, split-tensile, and flexural tests are conducted. The cylinders are positioned vertically between the test apparatuses to serve as a column or prototype compression component. In order to observe the splitting tensile characteristics of cast specimens, cylinders are placed between the testing plates. Flexural testing uses a three point loading arrangement. Beamlets

are put through a flexural test to determine the concrete's flexural characteristics. According to ASTM standards, the precise value of any concrete property can be obtained by averaging two values. Thus, for each type of dynamic and mechanical testing property, the average of two values is used in the current study. **Figure 3.1** shows different test setups.



FIGURE 3.1: Tests Setup; a) Dynamic Test, and b) Mechanical Properties

3.4.1 Dynamic Tests

According to ASTM 215-14 [Table 3.2], a dynamic test is conducted prior to the specimens destructive (mechanical) testing. A hammer and accelerometer are used to estimate RFR, RFT, and RFL. Both beamlets and cylinders are put through the test. An accelerometer is mounted on the cross sectional edge of both cylinders and beamlets in order to determine the RFL, and the other side of the cross section of sample hit by a hammer.

Accelerometer records the frequencies it detects, sends the information to the computer that is connected to it. For cylinders and beamlets, the RFT and RFR

methods for mounting the accelerometer and hammer strike location differ. In RFT, accelerometer mounted on cross sectional edge of cylinder, positioned at least 25 cm from its edge along the length. Next, a hammer blow is delivered toward the same side that displays the surface located at the midpoint of the cylinder's length.

Alike to RFT, accelerometer for RFR affixed at upper side, displaying cylinder's length face at the same distance from the edge. The impact occurs at the opposite edge of the cylinder length, perpendicular to the accelerometer. An accelerometer is mounted to (1) face of the beamlets at the same margin as the cylinders on the length of the beamlets from the side in order to determine the RFT.

Mid length of edge where the accelerometer is mounted is where the hammer strike occurs. Accelerometer for RFR is affixed to the upper corner of the rectangle (the beamlet's side face). A strike is applied at the positioned at the bottom edge along the same side of the rectangle so that its diagonal formed by connecting line by accelerometer and the hammer's striking mark. The (DR, DMoE, DMoR, and P's.R) are computed based on these measured frequencies. Understanding the behavior and resistance of concrete without fiber and all varieties of concrete with fiber reinforcement against dynamic loading is made easier by these computed properties. These characteristics are essential for designing a structure that will withstand earthquakes and dynamic loads.

3.4.2 Mechanical Tests

3.4.2.1 Compression Test

The compressive strengths CS of Plain Concrete and Used Banana Fiber Reinforced Concretes are evaluated using a servo-hydraulic testing machine, which provides precise control over the loading process. The testing procedure is carried out on cylindrical specimens of both PC and UBFRC in strict accordance with the ASTM C39 standard, ensuring consistency and reliability of results. In addition to CS, other parameters such as Compressive Pre-Elasticity CbPrE, CPoE, CTaE, and CTIn for both PC and Waste Banana Fiber Reinforced Concrete (WBFRC)

TABLE 3.2: Standards Testing and Studied Parameters

Test	Guideline Source	Variables Evaluated in the Study
1. Properties that are Dynamic	ASTM C215-14	Dynamic modulus of elasticity and rigidity (E_d , R_d), damping ratio (ζ), Poisson's ratio, and resonant frequency (longitudinal, transverse, torsional).
2. Miscellaneous		
a. Absorption of Water	ASTM C642-13	Absorption of water (%).
b. Linear Shrinkage	ASTM C157	Linear shrinkage (percentage decrease).
c. Significant Loss	ASTM C157M-08	Loss of concrete specimen mass due to gradual temperature rise.
3. Mechanical Properties		
a. Properties of Compression	ASTM C39	Compressive strength (CS), stress-strain curve (SSC), modulus of elasticity (MoE), and compressive pre-aging effect (CPrAE).

are also determined during this test. To guarantee uniform load application across the specimen surface, the cylinders are capped with Plaster of Paris (POP). This capping method helps eliminate irregularities on the cylinder ends, thus preventing localized stress concentrations and ensuring accurate measurement of the concrete's true compressive behavior.

3.4.2.2 Splitting Tensile Test

The Splitting Tensile strength of the specimens is determined in accordance with the ASTM C496M-02 standard, which outlines the procedure for evaluating the tensile capacity of cylindrical concrete samples under diametral compression. The

TABLE 3.3: Continued from previous page

Test	Guideline Source	Variables Evaluated in the Study
		Measures of compressive toughness (CTAE, CTIn) and compressive post-crack energy absorption (CPoAE).
b) Properties of Splitting Tensiles	ASTM C496M-02	Splitting tensile strength (STS), splitting pre-crack and post-crack energy absorption (SPrAE, SPoAE), toughness indices, load–deformation curves, and splitting tensile total energy absorption (STAE, STIn).
c) Flexural Characteristics	ASTM C78	Load–deflection curves, flexural strength (FS), flexural toughness indices, total energy absorption (FTAЕ), pre-crack and post-crack energy absorption (FPrAE, FPoAE).
4. Role of Fibers in Concrete	Affan, M. (2019)	Specimen fracture patterns, fiber failure mechanisms, and bonding behavior of fibers with the surrounding matrix.

test is performed using the same servo-hydraulic testing machine employed for the compressive strength evaluation, ensuring consistency in loading and measurement accuracy.

Both Concrete without fiber and waste Fiber Reinforced Concrete cylinders are tested without the need for capping, as the method applies load along the vertical diameter rather than across the cylinder ends. From this test, multiple mechanical parameters are computed, including SPrE, SPoE, STAE, and STIn.

Additionally, load deformation curves are generated, enabling a detailed assessment of the tensile behavior and energy absorption characteristics of the tested materials.

3.4.2.3 Flexural Test

The Flexural strength of the specimens is determined in accordance with the ASTM C78 standard, which specifies procedures for assessing the flexural performance of concrete.

The test is carried out using the three point loading method, applying load at the mid span of the beamlets until failure occurs. Both concrete without fiber and concrete with fiber beamlets are tested to evaluate their bending performance.

Parameters obtained from the test include FPrAE, FPoAE, FTAE, and FTIn. Additionally, load deflection curves are generated to analyze stiffness, ductility, and energy absorption capacity under flexural loading. This method allows for a clear understanding of how fiber reinforcement influences crack development and propagation.

This method allows for a clear understanding of how fiber reinforcement influences crack development and propagation. It also provides insight into the overall structural integrity and serviceability of the concrete under bending stresses.

3.4.3 Fractured Surface Examination

The cracked surfaces of the broken specimens are closely inspected following the completion of the mechanical testing. This analysis investigates fiber breakage, fiber pull out, and the bridging effect produced by the fibers. The tested samples' fractured surfaces are carefully examined under a microscope for this reason.

The fracture surfaces show whether or not all of the ingredients have been mixed well. When ingredients are mixed well, the intended property is achieved; when they are not, the property may deteriorate rather than improve.

This investigation's primary goal is to clarify the fibers' failure mechanism and how they link to the surrounding matrix.

3.5 Summary

Concrete without fiber and concrete with fiber are prepared adopting the most used mix design, 1:2:4. They use 0.5 w/c for the PC and 0.6 w/c for the UBFRCs. Varying amounts of 8.4%, 9.4%, 10.4%, and 11.4% of UPEO are incorporated based on the mass of cement for the preparation of UBFRCs. When creating UBFRCs, varying amounts of banana fibers (2.0%) are added by calculating the mass of the cement. Twenty cylinders and eight beamlets make up a total of 28 specimens that have been created. Slump, dynamic, mechanical, and other tests of concrete without fiber and concrete with fiber are conducted in accordance with ASTM standards. In the following chapter (i.e., Chapter 4), the evaluated outcomes of each related test are covered in depth.

Additionally, the effect of fiber inclusion on the workability, density, and strength properties of the concrete is thoroughly analyzed. The interaction between UPEO and banana fibers, and their combined influence on the performance of UBFRCs, is also examined. All findings are compared with plain concrete to highlight the improvements achieved through the use of fibers and waste admixtures. Furthermore, microscopic and surface analyses are conducted to observe fiber distribution and bonding within the concrete matrix, providing insights into crack bridging and failure mechanisms. The results are intended to guide practical applications of sustainable and high performance concrete in construction.

Chapter 4

Experimental Results and Discussion

4.1 Overview

Concrete without fiber, banana fiber reinforced concrete is prepared by the most used mix design, 1:2:4. They use 0.5 w/c for the PC and 0.6 w/c for the UBFRCs. PC and UBFRCs are made using a varying quantity of 8.4%, 9.4%, 10.4%, 11.4% UPEO by mass of cement. UBFRC 2% is made by adding fixed amounts of banana fibers. The 2.0% based on the mass of the cement. For every type of UBFRC, a fixed length of BF is employed. This chapter is based on comprehensive findings from testing every plain concrete, banana fiber reinforced concrete samples.

4.2 Dynamic Behavior of Concrete

To assess the synergistic influence use petrol engine oil and banana fiber concrete's dynamic performance, the ASTM C215-14 standard was employed. This method, traditionally used to assess the dynamic properties of plain concrete, was uniformly applied to both PC and the modified concrete mixes containing UPEO and BF, referred to as UBFRCs. Since no dedicated standard exists for UBFRCs,

the use of ASTM C215-14 ensures consistency across all specimen types. The experimental setup involved the use of an accelerometer to capture vibrational responses, with typical response patterns shown in Figure 4.1. To enhance reliability, the final reported values were based on the average results of two tests for each specimen type. The dynamic characteristics analyzed include the damping ratio (ζ) and the dynamic modulus of elasticity (Ed). The damping ratio reflects the material's ability to dissipate energy under dynamic loading, with higher values indicating improved resistance to vibrations and better overall structural performance under dynamic stress. For cylindrical specimens, the inclusion of 8.4% BF resulted in a 4.54% reduction in damping ratio compared to PC, which may be attributed to the adverse effects of UPEO. However, with increased BF content, notable improvements were observed: damping ratios increased by 1.74%, 8.74%, 15.03%, and 20.27% for 9.4%, 10.4%, and 11.4% fiber additions, respectively. This trend demonstrates that while UPEO may initially reduce damping efficiency, the incorporation of BF effectively counteracts this, particularly at higher fiber percentages.

In beamlet specimens, the enhancement in damping ratio was even more pronounced. Compared to PC, the damping ratios of UBFRC beamlets rose by 4.32%, 10.27%, 13.51%, 21.62%, and 25.94% with increasing BF content from 8.4% to 11.4%. These increases indicate that banana fibers significantly contribute to improved damping behavior, making the composite more suitable for structures exposed to cyclic or dynamic loading. The fibrous network arrests crack propagation and dissipates energy efficiently, enhancing durability under dynamic conditions. Conversely, the results for the dynamic modulus of elasticity, which indicates the stiffness of the material, showed a slightly different trend. The addition of 9.4% UPEO without fibers led to a 5.71% increase in Ed compared to PC, suggesting a stiffening effect likely due to the oily matrix enhancing initial rigidity. However, as BF content was introduced and increased, Ed values began to decline. For UBFRCs containing 8.4%, 9.4%, 10.4%, and 11.4% BF, the Ed decreased by 2.85%, 5.71%, 7.85%, 10.00%, and 14.28%, respectively, in comparison to PC. The reduction in stiffness is likely due to fiber-induced voids or matrix discontinuities, even though fibers improve damping and crack resistance.

TABLE 4.1: Variation in the dynamic properties of plain concrete and used engine oil blended fiber reinforced concrete (UBFRC).

Concrete Samples	RFL (Hz)	RFT (Hz)	RFR (Hz)	ζ (%)	Ed (GPa)	Rd (GPa)	Poisson Ratio (-)
Cylinders							
Plain Concrete	3417±44	3417±45	3298±22	3.88±0.104	4.30±0.040	4.40±0.165	0.52±0.005
UBFRC8.4%	3506±23	3232±23	3245±44	3.83±0.056	3.70±0.015	4.91±0.006	0.53±0.005
UBFRC9.4%	3535±89	3255±42	3263±65	3.73±0.203	3.70±0.014	4.80±0.022	0.51±0.015
UBFRC10.4%	3478±22	3384±82	3392±28	3.71±0.211	4.10±0.035	4.00±0.033	0.49±0.003
UBFRC11.4%	3412±52	3333±66	3205±62	3.29±0.017	4.00±0.023	3.70±0.748	0.46±0.012
Beamlets							
PC	3395±88	3231±67	3385±26	1.76±0.022	21.3±1.785	26.6±0.645	0.60±0.004
UBFRC8.4%	3245±25	3340±38	3332±57	3.35±0.052	21.6±0.486	27.5±0.002	0.61±0.010
UBFRC9.4%	3288±38	3418±28	3298±86	2.83±0.057	22.3±0.745	25.9±0.112	0.57±0.018
UBFRC10.4%	3312±78	3408±98	3357±24	2.78±0.033	22.5±0.552	24.6±0.052	0.54±0.014
UBFRC11.4%	3535±89	3360±55	3205±36	2.72±0.014	21.9±0.912	24.3±0.122	0.55±0.012

4.3 Various Properties, Including Water Absorption, Loss of Mass and Linear Shrinkage

Water absorption in concrete is defined as the movement of liquid through capillary action and is calculated by dividing the total mass of absorbed water by the oven dry mass of the specimen, as outlined in ASTM standard C642-13. Table 4.2 presents the water absorption percentages for PC and UBFRCs, which are recorded as 2.44%, 2.68%, 2.82%, 3.05%, 3.78%, 3.89%, and 3.97%, respectively. Notably, UBFRC10.4% and UBFRC11.4% display higher water absorption values. The data indicates a trend of increasing water absorption as the banana fiber content increases, suggesting that BF contributes to enhanced capillary uptake in the concrete mix. The mass loss test is conducted using a high temperature oven. For evaluating linear shrinkage and mass loss, the procedure specified in ASTM standard C157M-08 is followed for PC and UBFRCs.

TABLE 4.2: Absorption of water, linear shrinkage, and mass loss of plain concrete and UBFRC specimens with used engine oil.

Concrete Specimens	Water Absorption (%)	Linear Shrinkage (%)	Mass Loss @ 50°C	Mass Loss @ 75°C	Mass Loss @ 100°C
Plain Concrete	1.55±0.5	0.188	-0.034	-0.037	-0.104
UBFRC8.4%	2.10±0.5	0.122	-0.053	-0.067	-0.147
UBFRC9.4%	2.71±0.5	0.098	-0.059	-0.071	-0.156
UBFRC10.4%	2.65±0.6	0.092	-0.069	-0.078	-0.185
UBFRC11.4%	2.61±0.2	0.095	-0.078	-0.087	-0.195

The recorded values of linear shrinkage for these mixes are 1.78%, 0.156%, 0.112%, 0.091%, 0.082%, 0.076%, and 0.073%, respectively. A progressive reduction in linear shrinkage with increased fiber content implies that banana fibers effectively mitigate shrinkage in concrete. This reduction occurs because tensile stress develops on the surface of concrete during shrinkage, and the presence of fibers helps counteract this effect. As the BF content increases, shrinkage is further minimized,

indicating that incorporating BF may reduce the risk of cracking in concrete. Additionally, the PC shows a noticeable decline in linear shrinkage values.

These results imply that the addition of UEO facilitates void reduction within the concrete matrix, leading to greater dimensional stability.

4.4 Mechanical Characteristics

4.4.1 Compressive Characteristics

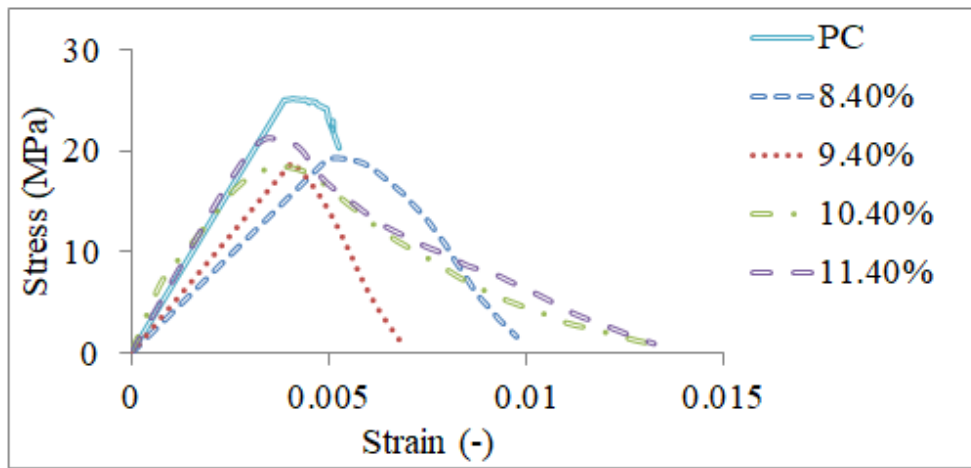
Illustrates in the (Figure 4.1a) stress–strain behavior of PC and UBFRC mixes containing varying percentages of banana fiber at 8.4%, 9.4%, 10.4%, and 11.4%. Among all the mixes, UBFRC11.4% exhibited the highest compressive strength, significantly outperforming PC.

Among all the mixes, UBFRC11.4% exhibited the highest compressive strength, significantly outperforming PC. Compared to PC the CS of UBFRC8.4%, UBFRC 9.4%, and UBFRC10.4% decreased by approximately 22%, 25%, and 19%, respectively.

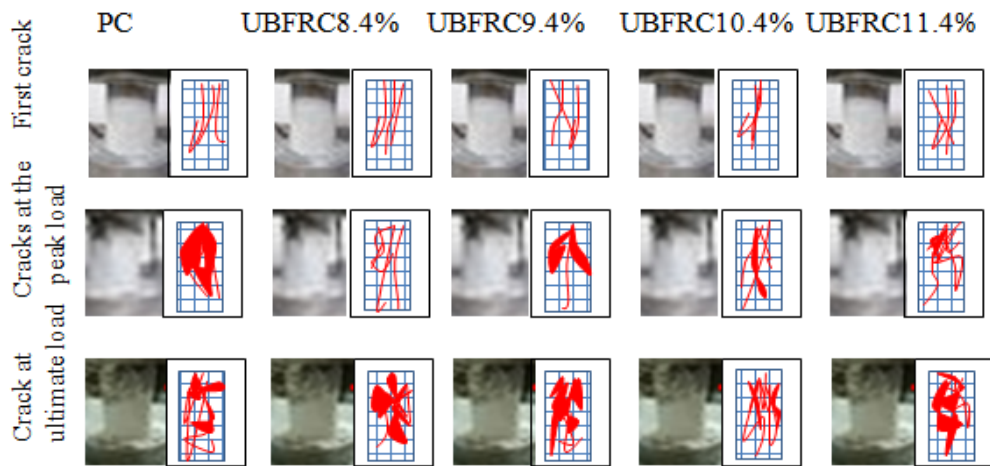
This clearly indicates that a moderate addition of BF in combination with UPEO, enhances the compressive strength of the composite. However, when the BF content was either too low UBFRC8.4% or too high UBFRC10.4% and UBFRC11.4%, a decline in compressive strength was observed.

Specifically, in comparison to UBFRC8.4%, the CS of UBFRC8.4%, UBFRC9.4%, and UBFRC 11.4% dropped by 7.5%, 22%, and 40%, respectively. This decline suggests a threshold effect, beyond which the inclusion of fibers adversely affects the matrix integrity.

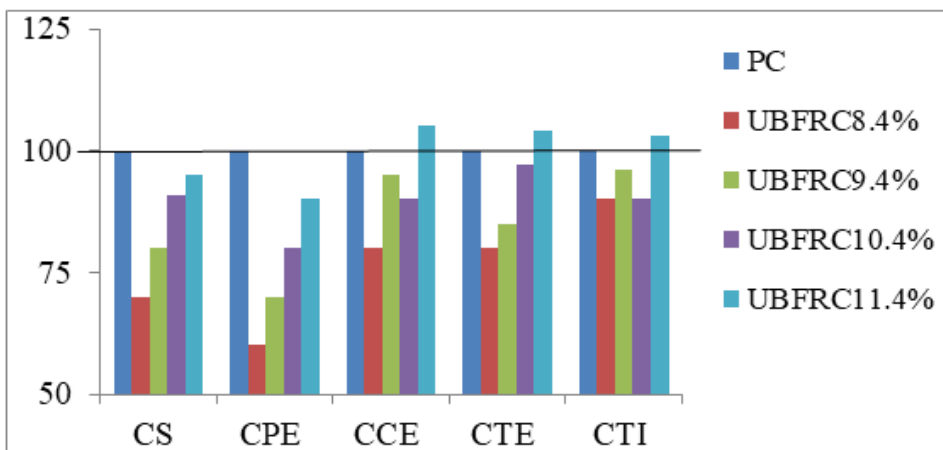
The initial rise in CS can be attributed to the bridging effect of BF, which helps resist crack propagation, while UPEO enhances bonding within the matrix. However, excessive fiber content may lead to agglomeration, poor dispersion, and increased porosity, ultimately weakening the overall structure.



(a)



(b)



(c)

FIGURE 4.1: Compressive behavior: (a) Strain–Stress curve; (b) Crack development; (c) Percentage difference.

The results confirm that the optimal UPEO content lies near 11.4%, balancing strength enhancement and workability. The link between stress and strain is seen in Figure 4.1b. When specimens are subjected to compressive loading, it is simple to distinguish between their elastic and plastic properties. When UPEO is added to regular concrete the concrete's CS increases. Conversely, the inclusion of BF has had a detrimental impact. As a result, when BF content increases, CS decreases. The criteria and methodology outlined in the research papers [47, 62] Figure 4.2b displays the comparison of the compressive characteristics. The addition of the various proportions of UPEO is what causes the increase in CE1, CE2 and CTI values. The addition of UPEO also results in further improvement. The link between PC, UBFRC8.4%, UBFRC9.4%, UBFRC10.4%, and UBFRC11.4% stress-strain graphs is shown in Figure 4.2b. It should be mentioned that, when compared to PC and all varieties of UBFRC demonstrated the highest compressive strength value. Comparing UBFRC8.4%, and UBFRC9.4% to PC, CS rose by 50%, 25%, and 18%, respectively. Nevertheless, the CS of UBFRC10.4%, and UBFRC11.4% has decreased by 22%, and 40%, respectively. This indicates that the CS is increased by the addition of UPEO and decreased by the addition of BF.

TABLE 4.3: Compressive Strength (CS), CPrAE, CPoAE, CTAE, and CTIn of PC and UBFRC

COMPRESSION										
Parameter	PC	UBFRC 8.4%		UBFRC 9.4%		UBFRC 10.4%		UBFRC 11.4%		
CS (MPa)	26.12 ± 0.13	18.18 ± 0.19		18.63 ± 0.14		19.01 ± 0.02		20.01	±	0.02
E (GPa)	24.17 ± 0.21	20.30 ± 0.31		20.28 ± 0.29		20.48 ± 0.49		21.02	±	0.03
ε_0 (-)	1.13 ± 0.14	1.33 ± 0.34		1.69 ± 0.70		1.86 ± 0.87		1.98 ± 0.99		
CPrAE (MJ/m ³)	0.055 ± 0.056	0.037 ± 0.038		0.036 ± 0.037		0.027 ± 0.028		0.038 ± 0.039	±	
CPoAE (MJ/m ³)	0.062 ± 0.063	0.041 ± 0.042		0.027 ± 0.028		0.036 ± 0.037		0.012 ± 0.013	±	
CTAE (MJ/m ³)	0.68 ± 0.069	0.078 ± 0.079		0.063 ± 0.064		0.066 ± 0.067		0.05 ± 0.006	±	
CTIn (-)	12.36 ± 0.37	2.10 ± 0.11		1.75 ± 0.76		2.44 ± 0.45		1.31 ± 0.32		

Table 4.3 displays the MoE for PC, and all varieties of UBFRCs. However, amount of banana fiber content is increases in the concrete mix, a reduction in workability is observed. MOE of UBFRCs continues to decrease.

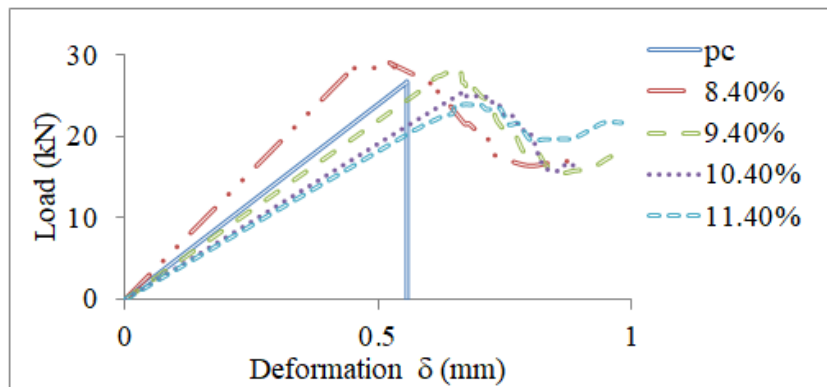
The addition of UPEO to concrete improves the values of MOE and CS, whereas the addition of BF has caused the aforementioned values to fall. A comparison is made between the failure behavior of plain concrete and UBFRC under peak splitting-tensile loading conditions in Figure 4.2a. CAE, CPE, CTAE, and CToI data are displayed under compression in Table 4.3. The link between stress and strain is seen in Figure 4.2b. When specimens are subjected to compressive loading, it is simple to distinguish between their elastic and plastic properties. When UPEO is added to regular concrete, the concrete's CS increases.

Conversely, the inclusion of BF has had a detrimental impact. As a result, when BF content increases, CS decreases. The criteria and methodology outlined in the research papers [47, 62] are used to determine all of these kinds of compressive absorbed energy. The CE1 of UBFRC8.4%, UBFRC9.4%, UBFRC10.4%, and UBFRC11.4% increases by 57%, 52%, 50%, and 13. In contrast to the CE2 of the PC, the highest CE2 is observed in UBFRC8.4%, which is 0.16%. Figure 4.2b displays the comparison of the compressive characteristics. The addition of the various BF proportions is what causes the rise in the CPrAE, CPoAE, and CTIn values. The addition of UPEO also results in further improvement.

4.4.2 Splitting Tensile Properties

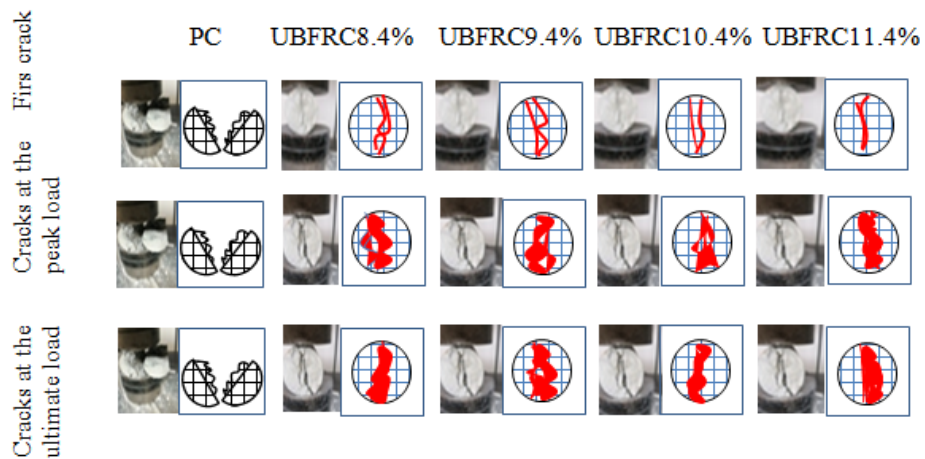
Figure 4.3b displays the load-deformation curves for PC, UBFRC8.4%, UBFRC 9.4%, UBFRC10.4%, and UBFRC11.4%. Following its resistance to peak loading, the PC graph has shifted towards zero. This indicates that the PC specimens failed abruptly and did not withstand any loading following the occurrence of the first crack. This has demonstrated that the inclusion of UPEO has a detrimental influence on concrete's splitting tensile strength and results in a decrease in that strength. The splitting tensile strength is somewhat increased and may withstand certain loads after the initial break appears when two percent of banana fibers

are added, coupled with the same amount of UPEO. This demonstrates that the splitting tensile strength has increased with the inclusion of banana fibers.

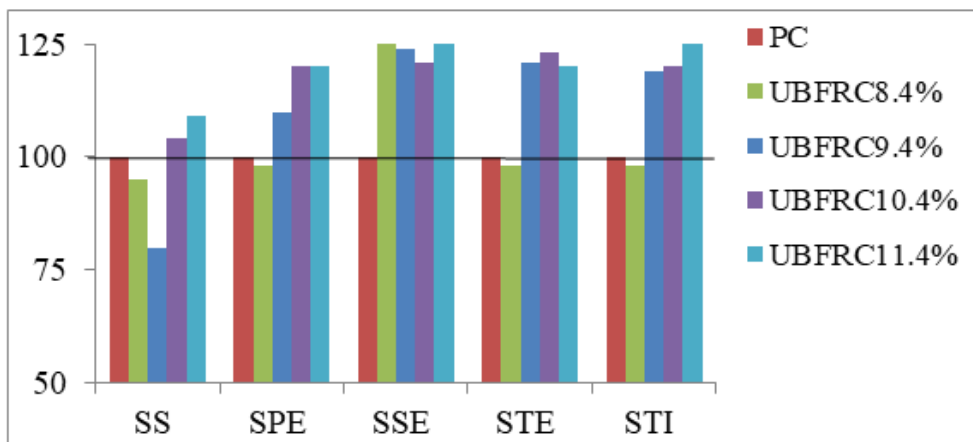


a)

(a)



(b)



(c)

FIGURE 4.2: Split tensile behavior: (a) Load–deformation curve; (b) Crack development; and (c) Percentage difference.

Both the splitting tensile strength and the amount of post crack energy absorbed have increased with the inclusion of additional BF. A comparison of the usual failures of PC and UBFRC at maximal splitting tensile loading is shown in Figure 4.3a. It is evident from Figure 4.3b that UBFRC11.4% has the largest burden. Additionally, because of the bridging action of BF, the UBFRCs have demonstrated load-carrying capabilities after the maximum load. STS, SPrE, SPoE, STAE, and STIn all displayed in (Table 4.4) under section on STP.

According to methods outlined in the research works, these parameters are computed [47, 62]. The concrete's tensile strength and splitting strength were improved by the addition of BF. Figure 4.2c presents a comparison of the splitting tensile strength (SS), splitting plastic energy (SPE), total energy (STE), and toughness index (STI) for PC and UBFRC mixes with 8.4%, 9.4%, 10.4%, and 11.4% fiber content.

Compared to PC, the 9.4% mix shows notable increases of 19% in SS, 39% in SPE, and 37% in STE, along with a 2% improvement in STI. On the other hand, UBFRC8.4% exhibits reductions of 10%, 23%, and 21% in SS, SPE, and STE respectively, while its STI remains slightly improved.

The 10.4% mix reflects a 2% rise in STI compared to PC. UBFRC11.4% shows enhanced performance with gains of 5% in SS, 8% in SPE, 10% in STE, and 3% in STI. This improvement across UBFRC mixes is largely due to their higher capacity for post crack energy absorption compared to plain concrete, as reflected by STI. In contrast, PC shows an STI of 1, since its initial crack load coincides with the peak load. The inclusion of fibers in concrete enhances post cracking behavior and crack arresting capability. Among all the mixes, UBFRC11.4% performs best across all evaluated properties SS, SPE, SSE, STE, and STI.

This superior performance is likely due to the effective random distribution and high tensile strength of fibers, which help optimize their structural contribution. Hence, UBFRC11.4% is recommended for improved crack resistance under tensile stress conditions due to its strong splitting tensile characteristics. This improvement across UBFRC mixes is largely due to their higher capacity for post crack

energy absorption compared to plain concrete, as reflected by STI values greater than 1.

TABLE 4.4: Splitting-tensile properties (STS, SPrAE, SPoAE, STAE, and STIn) of PC and UBFRC

Splitting-Tensile Properties						
Parameter	PC		UBFRC 8.4%	UBFRC 9.4%	UBFRC 10.4%	UBFRC 11.4%
STS (MPa)	25.11	± 0.12	28.10 ± 0.11	27.15 ± 0.16	26.10 ± 0.11	22.16 ± 0.17
SPrAE (J)	7.50 ± 0.51		6.75 ± 0.76	7.84 ± 0.85	7.15 ± 0.16	9.12 ± 0.13
SPoAE (J)	0		6.04 ± 0.05	9.45 ± 0.46	6.11 ± 0.12	6.21 ± 0.22
STAE (J)	7.50 ± 0.51		12.79 ± 0.80	17.29 ± 0.30	13.26 ± 0.27	15.23 ± 0.24
STIn (-)	1		1.88 ± 0.89	2.20 ± 0.21	1.85 ± 0.86	1.66 ± 0.67

In contrast, PC shows an STI of 1, since its initial crack load coincides with the peak load. The inclusion of fibers in concrete enhances post cracking behavior and crack-arresting capability. Among all the mixes, UBFRC11.4% performs best across all evaluated properties SS, SPE, SSE, STE, and STI. This superior performance is likely due to the effective random distribution and high tensile strength of fibers, which help optimize their structural contribution. Hence, UBFRC11.4% is recommended for improved crack resistance under tensile stress conditions due to its strong splitting tensile characteristics.

4.4.3 Flexural Properties

The load deflection curves of the PC, UBFRC8.4%, UBFRC9.4%, UBFRC10.4%, and UBFRC11.4% samples under flexural stress are related in Figure 4.4b. As seen in Figure 4.4b, UBFRC11.4% has withstood the maximum flexural load. It is evident from Table 4.5 that the UBFRC11.4% has the highest flexural strength. Compared to PCs and UBFRCs endure more deflection. This is only as a result of the BF bridging effect. FS, FPrAE, FPoAE, FTAE, and FTIn are displayed

in Table 4.5. Under the flexural properties section. In contrast to the other FS values of other specimens, the Flexural Strength elevated and attained its peak performance in UBFRC11.4%. The rise in FS is attributed to the incorporation of the optimal banana fiber content in the concrete. Beyond this, the addition of a high content of BF that is not the ideal content lowers the value of FS. Figure 4-9 illustrates a comparison of FPE, FTE, and FTI values among PC, and UBFRCs with 9.4%, 10.4%, and 11.4% fiber content.

When compared to PC, the 8.4% mix exhibits increases of 8%, 53%, and 86% in FTE and FTI, respectively, while FP1 of the 9.4% mix shows a reduction of 18%. The flexural performance of the 9.4% mix surpasses that of PC, with gains of 10% in MoR, 68% in FTE, and 91% in FTI. For the 10.4% mix, improvements of 34%, 0.5%, 100%, and 99% are observed in MoR, FPE, FTE, and FTI, respectively, over PC. Among the tested mixes, UBFRC11.4% displays the most significant enhancement in flexural properties, including FPE, FTE, and FTI, outperforming both 9.4% and 10.4% mixes. The inclusion of PPF in the 11.4% mix effectively enhances both the pre-peak and post-peak phases of the load-deflection curve, leading to a higher toughness index. Load-deflection curves of the PC, UBFRC8.4%, UBFRC9.4%, UBFRC10.4%, and UBFRC11.4% samples under flexural stress are related in Figure 4.4b. As seen in Figure 4.4b, 11.4% has withstood the maximum flexural load.

Table 4.5 shows that the 11.4% BF mix achieves the highest flexural strength, mainly due to the fiber bridging effect. While optimal BF content enhances crack resistance and deflection capacity, exceeding this dosage reduces FS because of voids and matrix discontinuities.

Table 4.5 displays the computed flexural toughness indexes (FTIn), flexural total energy absorption (FTE), flexural post crack absorbed energy (FPrAE) and flexural pre crack absorbed energy (FPoAE). In contrast to PC's FE1, 11.4%'s flexural pre-crack absorbed energy is reduced by 15.3%. The presence of UPEO is the cause of this decline. In contrast to PC, the UPEO has considerably decreased the FPoAE and UPEC. Because PC samples break into two pieces under peak flexural pressure, there is no absorbed energy in flexural post crack. However,

some FPrAE has been observed in all varieties of UBFRCs. This indicates that after the concrete cracks occur, the UBFRC might hold up better than PC and UBPEO. In contrast to PC and UPFRC has resisted the abrupt breakdown of concrete subjected to flexural tensile stress.

TABLE 4.5: Modulus of Rupture (MoR), δ_0 , FPrAE, FPoAE, FTAE, and FTIn of PC and UBFRC

Flexural Properties					
Parameter	PC	UBFRC 8.4%	UBFRC 9.4%	UBFRC 10.4%	UBFRC 11.4%
MoR (MPa)	0.89 ± 0.93	0.93 ± 0.30	0.87 ± 0.32	0.98 ± 0.99	1.19 ± 0.20
K (N/m)	4.32 ± 0.33	3.47 ± 0.48	5.63 ± 0.64	5.23 ± 0.24	6.12 ± 0.13
δ_0 (mm)	0.75 ± 0.76	1.41 ± 0.42	1.31 ± 0.32	1.21 ± 0.20	1.10 ± 0.09
FPrAE (J)	2.14 ± 0.15	3.25 ± 0.26	2.91 ± 0.92	3.75 ± 0.76	2.41 ± 0.42
FPoAE (J)	0	1.51 ± 0.52	1.51 ± 0.52	2.66 ± 0.67	1.81 ± 0.82
FTAE (J)	2.14 ± 0.15	4.76 ± 0.74	4.42 ± 0.44	6.41 ± 0.42	4.22 ± 0.23
FTIn (-)	1	1.46 ± 0.47	1.51 ± 0.52	1.71 ± 0.72	1.75 ± 0.76

4.5 Role of Fibers in Concrete at Fractured Surface

Figure 4.4 illustrates the fractured surfaces of fibrous concrete specimens after being subjected to mechanical loading. A clear distinction can be observed between the failure patterns and surface characteristics of Used Banana Fiber Reinforced Concretes and Plain Concretes, with UBFRCs exhibiting more complex and irregular fracture modes.

Similarly, Figure 4.5 presents detailed photographs of cracked surfaces following various mechanical tests. These images provide valuable insights into the interaction between banana fibers and the surrounding concrete matrix. In several cases,

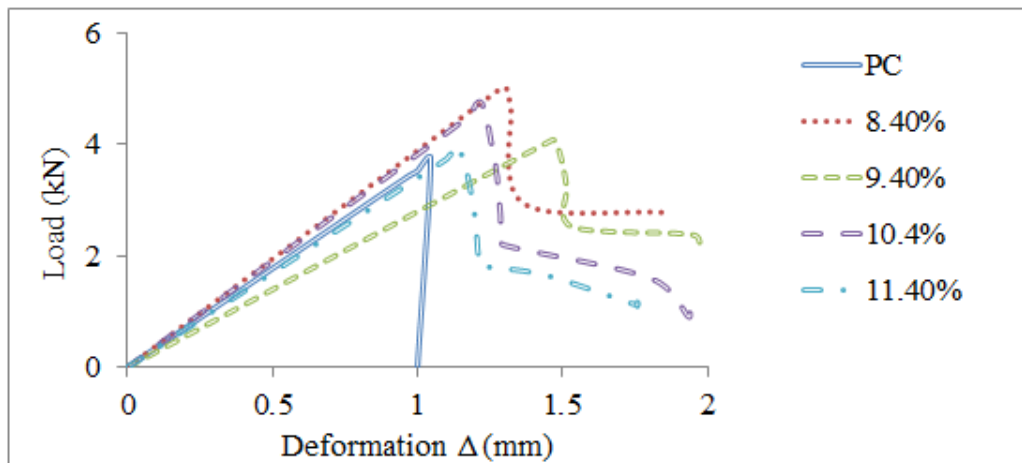
clear evidence of fiber pull out is visible, highlighting the role of fibers in bridging cracks and enhancing post cracking behavior.

The photographs also reveal that the banana fibers form a strong interfacial bond with the cementitious matrix, contributing to improved load transfer and crack resistance. On the fractured surfaces of the tested specimens, small voids and gaps can be observed, likely formed during fiber pull out, which also indicate areas of stress concentration and energy dissipation during fracture.

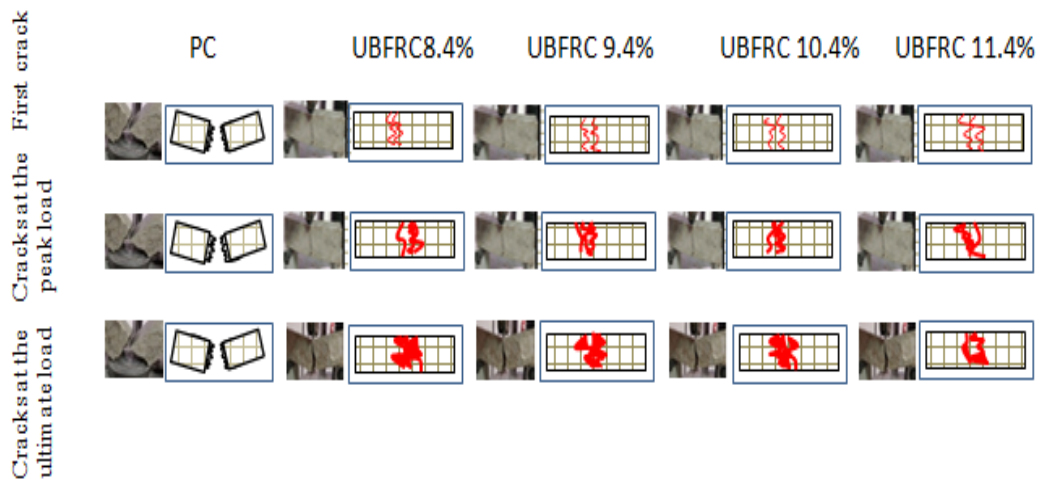
Furthermore, these visual observations enable an assessment of the quality of mixing and distribution of concrete constituents, including aggregates, cement paste, and fibers. The uniform dispersion of fibers, along with the strong fiber matrix bond, underscores the contribution of banana fibers to the mechanical performance and durability of UBFRCs. Specimens of UBFRCs are broken up into tiny bits following mechanical testing. Other minor and big broken particles are coupled to these broken minor particles. Specimens of UBFRCs are broken up into tiny bits following mechanical testing. Other minor and big broken particles are coupled to these broken minor particles. The strong bridging effect of banana fibers with the composite is what caused this adhesion of pieces or particles.

The presence of the fibers causes these kinds of alterations, which are not seen in regular plain concrete. Following the failure, withdrawal of the fibers occurs at the fracture surface rather than fiber breakage. This demonstrates that the fibers allowed the specimen to endure a little longer than the PC. Because of the bridging mechanism of BF spanning the cracks, Sample continues to resist loading even after the UBFRC specimen fails. After conducting the experiment, it was determined that BF presence aids in preventing the formation and spread of micro cracks. Fibers are added and mixed using the procedure described in section 3.3.

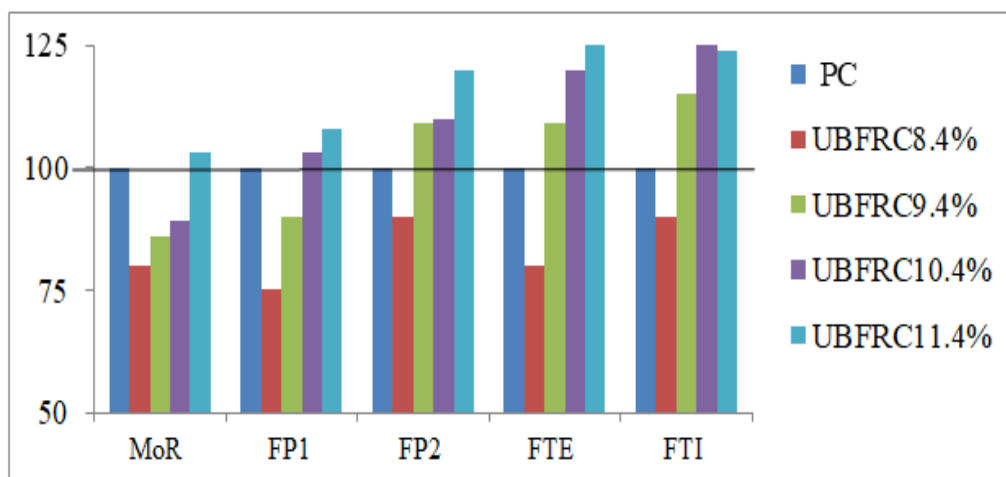
Fibers are evenly distributed across the fractured surfaces of the tested specimens in each of the images in figure 4.5. A few tiny pieces are attached through fibers from the fractured surface of the examined specimens (see the bottom right image of figure 4.4).As a result, the spalling process can be resisted by structural components with BF.



(a)



(b)



(c)

FIGURE 4.3: Flexural Performance: (a) load–deflection curve, (b) crack pattern, and (c) percentage difference.

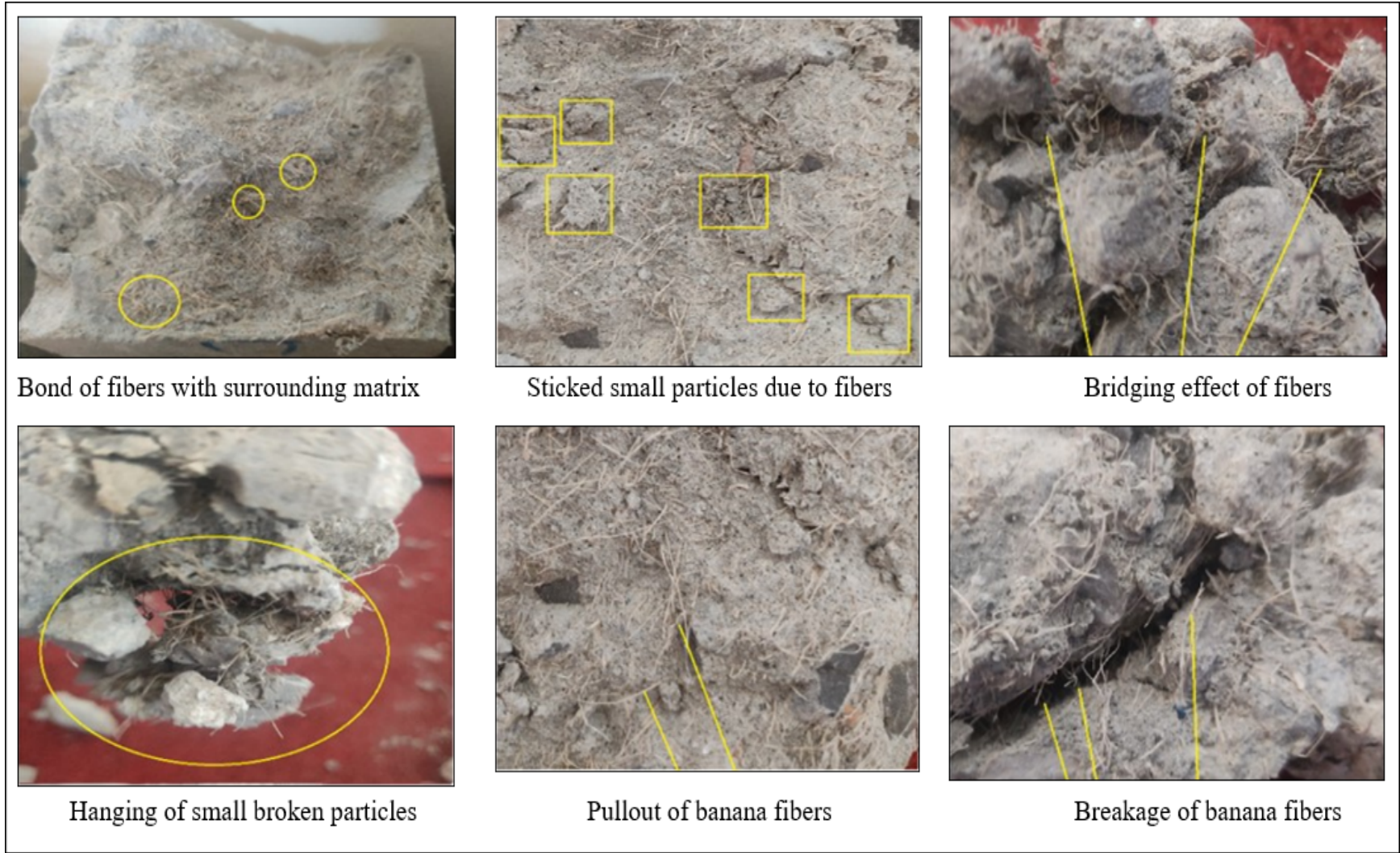


FIGURE 4.4: Comparative Fracture Characteristics Observed in Samples [41]

4.6 Summary

This chapter uses a 1:2:4 mix design with 0.5 w/c for PC, and 0.6 w/c for the UBFRCs to determine the workability, density, mechanical, dynamic, water absorption, linear shrinkage, and mass loss parameters of hard concrete. By adding more BF to concrete, the dynamic modulus of stiffness is increased. The incorporation of UPEO enhanced the workability of concrete, as indicated by higher slump values while it decreased with the addition of BF. UBFRCs have demonstrated improvements in compressive toughness index, STS, STI, and SPrE absorption and post crack energy absorption properties. The inclusion of UPEO has decreased the flexural strength, while banana fiber has increased it. Concrete's ability to withstand splitting tensile and flexural loads was improved with BF. Since water absorption and fiber content are directly correlated, increasing the amount of BF in concrete would increase its water absorption properties. However, when the BF content has increased, linear shrinkage has demonstrated the reverse relationship. When the amount of BF added to concrete increases, more mass loss is seen. Additionally, when the cracked specimens with broken surfaces are investigated, the BF exhibits strong bonding with the surrounding matrix.

Chapter 5

Instructions for Real-World Implementation

5.1 Overview

Results of tests provided quantifiable information about how the Proportion of fiber affected characteristics of UEO and BF reinforced concrete. Impact of fibers on the mechanical and dynamic properties of UBFRCs is depicted by the stress strain, load deflection, and load deformation graphs. The gathered data is then used to establish an empirical relationship between the various mechanical properties of UBFRC and its fiber content FC. This chapter also discusses UBFRC's actual implementation and recommendations for real world applications.

5.2 Utilization of UEO and BF for Concrete Optimization

Information on maximum, minimum values derived from the dynamic, mechanical tests in relation to PC values are given in Table 5.1. According to the study's findings, UBFRC columns with 0.5% BF for compression members.

TABLE 5.1: Enhancement of the (BF) Percentage in (BFRC)

Concrete Type	Compression				Splitting Tensile			Flexural			Dynamic		
	CS (MPa)	MOE (GPa)	CTE (MJ/m ³)	CTI (-)	SS (MPa)	STE (N·m)	STI (-)	FS (MPa)	FTE (N·m)	FTI (-)	ζ (%)	Ed (GPa)	Rd (GPa)
PC	25.12	27.77	0.20	2.22	16.10	13.20	1.00	3.22	0.78	1.00	1.76	21.3	26.6
	±0.5	±1.4	±0.002	±0.02	±0.1	±0.2		±0.02	±0.1		±0.012	±1.785	±0.645
UBFRC (minimum values)	6.8	14.9	0.141	3.43	0.96	15.4	2.23	2.64	1.46	1.10	2.83	21.6	24.3
	±0.9	±1.2	±0.01	±0.02	±0.1	±1.2	±0.2	±0.1	±0.1	±0.1	±0.077	±0.486	±0.052
	9.4%	9.4%	9.4%	9.4%	11.4%	9.4%	11.4%	9.4%	11.4%	11.4%	9.4%	9.4%	11.4%
UBFRC (maximum values)	12.09	19.81	0.235	6.25	1.66	30.5	2.65	4.21	3.31	1.28	3.35	22.5	27.5
	±0.2	±1.2	±0.02	±0.01	±0.2	±3.2	±0.2	±0.2	±0.2	±0.1	±0.082	±0.912	±0.002
	10.4%	9.4%	9.4%	11.4%	11.4%	10.4%	9.4%	9.4%	9.4%	8.4%	10.4%	11.4%	11.4%

Guidelines for practical implementation, For the base high compressive strength compared to other UBFRCs, 9.4% UEO weight of cement is advised. Structural members where tension and flexural pressures are dominant, UBFRC with a 2.0% BF percentage is advised. The UBFRC with 2.0% banana fibers and 9.4% used petrol engine oil has demonstrated superior qualities in the dynamic loading scenario. Figure 5.1 illustrates how the parameters under study differ from those of PC. By calculating the mass of cement in the concrete, it is evident that the addition of BF has had a substantial impact on the concrete's characteristics

Figure 5.1 illustrates the results of adding varying amounts of banana fibers. While some of the qualities are greatly enhanced, others negatively impact the banana fibers. With the addition of banana fibers, the compression toughness index increased while the compressive strength decreased as the amount of BF increased. Compared to compression and flexural qualities, UBFRCs have far better splitting tensile properties. With the addition of the fibers, the flexural characteristics are gradually altered. Both FS and FTI have improved since BF was added in percentages of 2.0%. By adding 2.0% BF to concrete, it has been demonstrated that the addition of fibers over 2.0% is the point at which the effect shifts from positive to negative, and the FS is lower than that of adding banana fibers at 2.0%.

5.3 Empirical Relationship

The mechanical characteristics of the materials employed in the structure's construction determine its performance. The performance of the structure is directly impacted by the characteristics of the concrete. Energy absorption, toughness indexes, CS, STS, and FS other characteristics can all be linked to performance. Concrete fragments can occasionally begin to spall before the steel fails. Therefore, it is crucial that concrete bonds with all of its elements.

To improve the concrete's strength and bonding under various loading scenarios, fibers are added. Furthermore, because toughness and ductility are similar, toughness and spalling can be linked. Fibers have the ability to transform brittle

concrete into ductile. Fibers also aid in reducing the quantity and size of cracks. More energy absorption is needed for improved post-crack behavior. Fibers are also used in concrete because they improve the material's post-crack behavior by increasing energy absorption.

In order to quantitatively forecast STS and FS of UBFRCs, empirical equations are created using experimental results from mechanical testing of specimens. The values of PC characteristics are not incorporated in the development of these equations because the UPEO is utilized in all kinds of cast UBFRCs.

To obtain the exact and error-free equation, this is done. The addition of UPEO to all UBFRCs also alters the characteristics of concrete. Therefore, instead of using PC to create the empirical equation, UBFRC data is employed to avoid the uninfluenced features of PC. The following are developed empirical equations:

$$CS\& = 3.65UPEO + 15 \quad (5.1)$$

$$SS\& = 0.71UPEO + 1.40 \quad (5.2)$$

$$FS\& = 0.28SS + 0.36or \quad (5.3)$$

$$FS\& = 0.20UPEO + 0.75 \quad (5.4)$$

where FS stands for flexural strength, UPEO for use ptrol engine oil content, and SS for splitting tensile strength. With the aid of best fit curves containing experimental values from the current investigation, the empirical equations for CS, SS, and FS are created. Other scholars have reported on this method of creating empirical equations [7, 53, 69, 70]. The discrepancies between empirical and experimental values have been examined following the creation of equations.

Table 5.2 shows a comparison of the experimental and empirical values for flexural strength, splitting-tensile strength, and compressive strength. All of the properties' values differed from experimental values by less than 10% when comparing empirical and experimental values. The link between the numerical value obtained using the derived empirical equations and the experimental value obtained through testing is depicted in Figure 5.2. Figure 5.2 shows that not a single result

is greater than or less than 10% of the experimental values. The precision of the established equations is defined by this phenomena.

5.4 Practical Implementation

Concrete is subjected to a variety of loading conditions in various civil engineering applications, including dynamic and mechanical loading. These loading types, such as compressive strength, tensile strength, and flexural strength, influence and regulate performance efficiency. These kinds of loads also affect how long concrete lasts. Concrete cracks are caused by increased linear shrinkage, high water absorption, and decreased tensile strength [63].

Enhancing the concrete's flexural strength property can help limit the phenomena of differential settling, which can also lead to cracking in rigid pavements. Concrete spalling is one of the problems. Concrete spalling, which can be caused by a variety of circumstances, including exposure to high temperatures, shortens the concrete's lifespan.

Varying amounts of use petrol engine oil this study investigates behaviour, several concrete types, The experimental program includes three types of concrete mixes: plain concrete, used gasoline engine oil and banana fiber reinforced concrete UBFRCs. UBFRC 11.4% specimens have demonstrated superior performance against compressive stress, and their qualities are enhanced against tension loading, making them suitable for usage in members such as beams and slabs. The concrete's modulus of elasticity and flexural strength are taken into consideration while designing rigid pavements. Because UBFRC 10.4% has demonstrated superior modulus of rupture and modulus of elasticity two critical components of rigid pavement stability and durability it is therefore more appropriate for rigid pavements. UBFRC containing 9.4% UPEO is suitable for use in compression members subjected to uniaxial loading, as it exhibited higher compressive strength compared to all other UBFRC variants. UBFRC 11.4% has demonstrated strong comprehension. By increasing the concrete's tensile strength with the fibers in the composite, concrete spalling can be considerably decreased [64].

Similar to blasting, impact loading can cause a structure to fail when a car collides with the piers of a concrete bridge. Concrete's dynamic modulus of stiffness and energy absorption properties can be increased to increase the material's resistance to impact loading [7].

This study uses waste UEPO and varying amounts of fibers to investigate, behavior's PC and UBFRCs. Better performance against compressive loading has been demonstrated by the UBFRC0.5 specimens. UBFRC2.0 has better qualities against tension loading and can be applied to parts such as slabs and beams.

The concrete's modulus of elasticity and flexural strength are taken into consideration while designing rigid pavements. Because UBFRC2.0 has demonstrated superior modulus of rupture and modulus of elasticity two critical components in the stability and longevity of rigid pavements it is therefore more appropriate. The UBFRC2% is appropriate for compression members that only experience uniaxial loading because it has demonstrated the highest CS among the UBFRC mixtures the UBFRC2% has demonstrated adequate compression strength and a degree of resistance to moment forces. Therefore, for those kinds of members where compressive stress is regarded as critical loading, UBFRC2.0 is advised.

5.5 Summary

This research focuses on the systematic optimization of banana fibers and use petrol engine oil to enhance mechanical characteristics concrete composites, specifically targeting improvement of more eco friendly and high efficiency materials. The optimization process involves a detailed analysis of various mix proportions, examining how different percentages of BF and UEPO influence key mechanical criteria such as CS, STS, FS, and overall toughness. Particular attention is given to strength indices and energy absorption capacity, which are critical in assessing the ductility and post cracking behavior of the composite material. Through experimental testing and performance evaluation, the study identifies optimal combinations of BF and UEPO that provide.

The most effective balance between strength, durability, and workability. From this analysis, practical and case specific recommendations are developed for the application of Used Banana Fiber Reinforced Concrete in real world construction. These recommendations are not generic but are instead carefully tailored to address different structural needs and environmental exposures. For instance, in structures where dynamic loading, cracking potential, or seismic activity is a concern such as pavements, earthquake prone zones, or lightweight partitions higher fiber content is recommended to enhance crack resistance, energy dissipation, and flexural performance. Conversely, for components where compressive strength and ease of casting are prioritized, such as columns or footings, a lower fiber content with a controlled amount of UEPO is advised to maintain optimal workability and compaction. The study thus provides a performance based framework for the selection and application of BF and UEOP modified concrete, contributing to both improved structural performance and environmentally responsible material use in modern construction practices.

Chapter 6

Conclusion and Recommendations

6.1 Conclusion

This study explored the potential of using banana fibers and use petrol engine oil as sustainable additives in concrete mixtures. Ecology is severely affected by some of these wastes. Used engine oil is one of these dangerous pollutants. In order to lessen the effects of environmental pollution causing phenomena, these wastes must be disposed of effectively. This study's objective is to look at the Performance of concrete reinforced with banana fibers and modified using UPEO as a waste resource. In addition to varying proportions, waste from used petrol engine oil combined with banana fiber has been used to examine mechanical, dynamic, water absorbing, linear shrinkage, and mass loss capabilities. By calculating the mass of cement, the various ratios of UPEO and are blended into the concrete. The study has led to the following conclusions.

- i. By the damping ratio, the inclusion of use petrol engine oil and banana fibers has improved the capacity to withstand lateral loads
- ii. Water absorption, linear shrinkage, mass loss is affected by the addition UPEO and BF.

- i. Among all mixes, 8.4% UPEO resulted in the minimum water absorption.
 - ii. Among all proportions, 11.4% UPEO resulted in the minimum linear shrinkage
 - iii. The lowest weight loss was recorded at 11.4% UPEO
- iii. Addition of BF and UPEO affects the mechanical characteristics of concrete.
- i. Concrete's compressive strength has demonstrated the opposite effect of an increase in UPEO. The use of low density fiber is what caused the decrease in compressive strength.
 - ii. When combined with 8.4% UPEO, the highest splitting tensile and flexural strengths were noted at 2.0% BF concentrations, respectively. The strong tensile characteristics of the BF are what lead to the rise in splitting tensile strength. Flexural strengths have been found to be inversely correlated with the additions exceeding UPEO. The addition of UPEO more than 10.4% has shown inverse relation with flexural strengths.
 - iii. The concrete's ability to absorb energy has improved as a result the addition of use petrol engine oil and banana fibers in the FRC.
- iv. Concrete's ability to absorb water has been directly correlated with its fiber content. Conversely, by increasing the UPEO content of concrete, the presence of combine effect of UPEO and BF has marginally improved resistance to linear shrinkage. Because one of the factors increases the concrete's workability is the increase in water absorption brought on by the addition of UPEO to FRC. UBFRCs have performed well because they are not susceptible to spalling at high temperatures. This impact is brought about by the UPEO increased resistance to linear shrinkage.
- v. UBFRCs have performed well because they are not susceptible to spalling at high temperatures. This impact is brought about by the combine use of use petrol engine oil and banana fiber increased resistance to linear shrinkage. In

damaging samples that are put through dynamic, mechanical, and other tests, the bonding of BF with the surrounding concrete matrix is still present.

From this research work, the concrete composed of 8.4% UPEO as an admixture and 2.0% of BF as reinforcement is recommended to resist cracking, spalling, and flexural loading. Also, this is suitable for rigid pavements by having a high value of modulus of rupture along with a suitable value of modulus of elasticity. It has shown maximum splitting tensile and flexural strengths, more energy absorption, and resistance against impact loading. Crack resistance and toughness.

The recommendation of different mixes for different applications is based on the principle that the mechanical and durability requirements vary according to structural demand. For instance, in applications where higher flexural strength and crack resistance are critical, a mix with optimum banana fiber and use petrol engine oil content is suggested. Conversely, in areas where compressive strength and workability are more important, a lower fiber dosage with UPEO modification is preferred. Thus, the mixes are tailored on the basis of balancing strength, durability, and workability to meet the specific requirements of each structural application.

6.2 Future Works

- i. Alternative admixtures like superplasticizers, silica fume, fly ash metakaolin can be combined with banana fibers.
- ii. Investigating the material's performance under impact loading conditions.
- iii. To enhance reliability, the experimental outcomes should be cross-verified using analytical simulations.

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