CAPITAL UNIVERSITY OF SCIENCE AND TECHNOLOGY, ISLAMABAD

Influence of Banana Fiber and Waste Diesel Engine Oil in Mechanical Properties of Concrete

by

Zain Ul Abideen

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

in the

Faculty of Engineering
Department of Civil Engineering

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I want to dedicate this achievement my parents, teachers and friends who always encourage and support me in every crucial time

CERTIFICATE OF APPROVAL

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Abstract

Concrete is the most commonly used material in the construction industry owing to its excellent properties over any other type of construction material. Because concrete is the most superior material in the construction industry, it has some serious flaws caused by its brittle nature. These flaws include crack vulnerability, brittle behaviour, spalling, and more linear shrinkage. The need for traditional construction materials is increasing day after day because of the pressure faced by the construction sectors to achieve an increased growth and property development in construction. These have created the developers option for totally different materials that may be used as an alternate material in construction. Waste Diesel engine oil (WDEO) is some of the poisonous wastes that have an effect on surroundings and human lives. Modern construction practice involves the use of industrial waste or by-products as raw materials for cement and concrete. These offer many advantages for the environment and have economic effects, since the disposal costs are constantly raising due to strict environmental regulations. One of the most essential properties of concrete is its excellent flow ability, which makes it easier to handle and place while also allowing for the removal of unwanted air gaps. With the increased use of concrete, new types of cost-effective admixtures may have a wide range of economic and technological implications for the construction industry as well as global concrete usage. The usage of plastic, glass, and alternative items as fibers in concrete, many different types of by products are considered to prevent cracks, to ensure sustainability, and to achieve durability. The objective of this study is to evaluate the effectiveness of concrete to find out the flaws and innotive items containing banana fibers in percentages ranging from 0 to 2.5 percent, with a difference of 0.5 percent in 5 proportions and 50 mm fiber length fixed and 9.4 fixed percentage of diesel engine oil. In this study banana fiber and waste diesel engine oil as an alternative item is used. The addition of banana fiber have done by taking the percentages 0.5%,1%,1.5%,2%,2.5% of the mass of cement. For PC preparation, a water cement ratio (w/c) of 0.5 was used with a mix design of 1:2:4 (sand: aggregates), and diesel-engine oil plain concrete was used (WDEO-PC). For the preparation of fiber reinforced concrete, the 0.6

w/c is combined with a 1:2:4 mix (WDEO-FRC). A fixed amount of waste diesel-engine oil WDEO is used in the preparation of waste diesel-engine oil and banana fiber reinforced concrete (WDEO-BFRC), while the amount of BF is varied. To determine the effects of BF and WDEO on concrete properties, slump, dynamic, mechanical, water absorption, linear shrinkage, and mass loss tests are carried out. To evaluate each type of observing property, an average of two specimens of each type of concrete and test is taken. As a result, the optimal value of fiber content in concrete which has shown better performance against tensile, flexural, and dynamic loadings. According to the results of the slump test, WDEO-PC only concrete has a higher slump value than other types of concrete. The decrease in FRC workability is observed as the amount of banana Fibers increases. The performance of the WDEO-BFRC with 2.0 percent Fiber content show better results when subjected to dynamic loading. When compared to other results, the results show that WDEO-BFRC with 1.5 percent and 2.0 percent BF has higher tensile and Flexural strengths, respectively. Additionally, as the amount of BF in the concrete increases, the compression toughness index and splitting tensile toughness indicates improve significantly. With an increase in the content of fibers, the compression strength of specimens decreases. Regarding the WDEO-BFRC compression members prepared with 0.5 percent fibers content have demonstrated superior performance to other types of WDEO-BFRCs because of minimum percentage of fiber content.

Keywords: Banana Fibers, Dynamic Properties, Fiber Reinforced Concrete, Mechanical Properties and Waste Diesel Engine Oil.

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Abbreviations and Symbols

BF	Banana Fibers
CE1	Compressive Pre-Crack Energy Absorption
CE2	Compressive Post-Crack Energy Absorption
CS	Compressive Strength
CTI	Compressive Toughness Index
Ed	Dynamic Modulus of Elasticity
FC	Fiber Content
FE1	Flexural Pre-Crack Energy Absorption
FE2	Flexural Post-Crack Energy Absorption
FRC	Fiber Reinforced Concrete
FS	Flexural Strength
FTI	Flexural Toughness Index
MOE	Modulus of Elasticity
PC	Plain Concrete
Rd	Dynamic Modulus of Rigidity
RFL	Response Frequencies Lateral
RFR	Response Frequencies Rotational
RFT	Response Frequencies Transverse
SE1	Splitting-Tensile Pre-Crack Energy Absorption
SE2	Splitting-Tensile Post-Crack Energy Absorption
STI	Splitting-Tensile Toughness Index
STM	Servo-Hydraulic Testing Machine
STS	Splitting-Tensile Strength
UEO	Used Engine Oil

WDEO	Waste Deisel Engine Oil
WDEO-BFRC	Banana Fiber Reinforced Concrete having Waste Diesel Engine Oil
WDEO-PC	Plain Concrete having Waste Diesel Engine Oil
W/C	Water Cement Ratio
Δ	Deflection
ζ	Damping ratio

Chapter 1

Introduction

1.1 Background

Concrete is the most widely used building material in the world. When compared to other common construction materials such as wood and steel, which are susceptible to rotting, corrosion, or fire damage, concrete excels for its durability under hostile conditions. Concrete is a material known for its high structural performance, but its tensile strength is limited, resulting in the formation of cracks throughout the life of the concrete structure [1]. Concrete, one of the most important construction materials in the construction of infrastructure and development facilities, has the potential for significant and positive environmental participation. Concrete, on the other hand, is a semi material with poor tensile strength when compared to compressive strength [2] Another important concern concrete is their brittleness, another significant concern concrete is their weakness. As, increment in strength of concrete outcomes in lower flexibility. The most common forms of concrete deterioration are corrosion of reinforcing steel, freezing and thawing damage, alkali-aggregate reactions, and sulphate attack. These deterioration mechanisms can lead to concrete cracking, spalling, surface scaling, and possibly premature failure. Often, these forms of deterioration can be prevented or minimized if proper concrete design, with regards to its mechanical properties.Because of this fact, cannot be relied on concrete. Also, vulnerability to cracking, loading, and environmental issues are the most promising factors which are causing reduction in functionality and serviceability of concrete [3]. It is required to add fibers and admixtures in concrete to meet with high performance, attaining certain properties, and developing a sustainable material [4]. Authorities have been looking for ways to reuse waste materials for a long time. Numerous studies have advised the use of waste materials in construction among the various applications [5].

Rapid population growth and industrialization have resulted in massive amounts of trash. Current landfill and landfill methods have proven to be harmful due to the environment and the water contamination.Recently, interest in using greener technologies has increased. many wastes are used to replace commercially accessible materials. Industrial, agricultural, and other higher-denomination trash or by-products or other methods which have no economic demand must be disposed off properly. Concrete business has thought of utilization industrial waste to be used as concrete admixtures so as to provide higher quality and additional durable building material[6].

Sometimes the admixture affects on a specific piece of land. generally more than one additive is used in the same mixture and sometimes the addition has a negative impact on concrete's desirable qualities. The choice of additives must therefore be made Wisely. Concrete's outstanding flowability is one of its most important characteristics, which makes it easier to handle and install and allows for the removal of undesirable air spaces by using a superplasticizer. (SPSuper Plasticizers are a type of plasticizer that has been enhanced Super-plasticizers can lower water content by up to 30% while still preserving workability [7].

The inclusion of superplasticizer results in a concrete that is homogeneous and cohesive, with little tendency for segregation or bleeding. whereas the previous researchers have mentioned the powerful operate of super plasticizer, another admixture to exchange it's one thing new be explored. As the use of concrete increases, new types of economical additives could have different economic and technical impacts on development activities in addition to the use of concrete around the world it is claimed that one gallon of Waste engine oil is enough when incorrectly disposed of, it can pollute a million gallons of water [4, 7].

Use of natural fiber ages decades back to improve concretes behavior and properties. Concrete reinforced with natural fiber is proved to be better in durability, shrinkage and enhancing mechanical properties. The mechanical properties of concrete can be enhanced by adding in concrete a calculated proportion of fibers [8]. Lightness, ease of restoration, biodegradability, low cost, low energy requirement, abundant availability, and durability have all been considered as advantages of natural fiber over synthetic fibers. Modulus is high and elastic. Many engineering / mechanical properties of composites (cement paste, mortar, and / or concrete) (bending strength, tensile strength, fatigue resistance, wear resistance, and thermal shock, among others) are due to fiber introduction. It can be effectively improved [9].

One of the positive viewpoints that support the utilization of the fiber for enormous scope is its accessibility and cost. Fiber reinforced polymers (FRP) is a very promising class of additives.Factors such as , vulnerability to cracking, loading, and environmental issues are the most promising which are causing reduction in functionality and serviceability of concrete [10].

It is required to add fibers and admixtures in concrete to meet with high performance, attaining certain properties, and developing a sustainable material [11]. Admixtures are used for different purposes such as enhancing early strength, accelerating or retarding setting times of concrete or to achieve specific property of the concrete such as to reduce the content of cement while having no effect on the physical properties of the concrete. In past few decades, interest had increased in attaining high performance and environmental friendly materials in civil engineering application [12].

Fiber reinforced concrete (FRC) is one of these materials and has become promising material in civil engineering because of its advantages including toughness, tensile strength, durability and energy absorption [13]. Fiber concretes are revolutionizing the market, moreover as lower operative costs, structurally act. the entire or partial replacement of steel with fiber concrete may well be an economical way to give another methodology to realize bigger security in concrete structures, as well as the simplest way to use materials that are energy efficient, economic and ecological. The utilization of natural fibers in concrete lead to reduction of workability of concrete [9]. Workability is the property of concrete which is directly related to the strength factors and quality of work.By the addition of fibers the workability is reduced [14].

Banana fiber is a major source of fiber and in many countries there is a significant increase in fiber derived from forest trees. Fiber utilization in fast growing high biomass plants is an excellent solution as an alternative source of raw materials [15]. Banana fiber is relatively expensive, abundant, and has low extraction energy, Banana fiber is expensive in those areas where it is not available due to involvement of transportotaion cost [16]. Banana fiber bars, which are reinforcements for concrete beams, offer about 25% more bending strength than regular concrete.Banana fiber is suitable for use as a reinforcement with relatively good mechanical properties [17].In addition, industries turn out really injurious and extensive amount of waste. These wastes are widely used in modifying the properties of concrete [18]. The workability of modern self-consolidating concrete was unaffected by the marble mud. They claim that scrap marble will improve certain qualities of fresh and hardened self-consolidating concrete in a cost-effective manner [19]. The mixture with marble waste to form pavers, The paver's physical and mechanical qualities were then examined utilising specimens. Adding marble scraps reduced enhanced compressive strength frost as well as abrasion resistance They came to the conclusion that the type of cement is a vital preservative. that the production of pavement covering blocks that waste marble is desirable for the same old mix used in the production of concrete pavement covering blocks [20].

Same regarding the utilization of industrial waste motor oil, concrete immersed in an oil solution or a water/oil combination had a reduced compression rate and strength, according to the researchers,however, when immersed in water, it has a stronger corrosion resistance. The concrete samples were subjected to a concentrated crude solution as well as a simulated crude oil/water mixture and cured for 3, 7, 28, and 56 days at different temperatures. The corrosion rate in pure crude oil was higher than in the crude oil/water mix, according to the study [21]. Regarding the utilization of motor oil, the researchers reportable the concrete was immersed in an oil solution and a water/oil mixture had a lower compression rate and strength, however, when not immersed in water, it has a stronger corrosion resistanc.Authors conjointly declared that WEO failed to considerably have an effect on the ultimate load or deflection of structural members.

Chin declared Slump ratio increased by 18 to 38 percent, and air content increased by 26 to 58 percent, because of WEO [22]. Later, researcher says that by adding used motor oil to concrete increased concrete collapse by 18 to 38 percent and air content by 26 to 58 percent[22]. To prolong initial sag and air content while reducing slump rate and initial set, the consistency and porosity were lowered, and the compressive strength was close to that of the same motor oil used in OPC concrete. The review conclude that a small dose of waste engine oil accumulated the concrete collapse [23], [24]. This, they claim, is due to the presence of 37 percent SO3 in waste engine oil, which generated a 20 percent difference in compressive strength when compared to the control combination. BF resists the linear shrinkage. Banana fiber has 69% cellulose that counter the effect of SO3 which causes shrinkage as a result of this BF prevents shrinkage [87]. The review shows that an indefinite small amount of waste engine oil increased long term durability by reducing the oxygen porosity constant and porosity of all concrete mixes [22].

There are enough campaigns around the world for the safe disposal of waste engine oil, but in fact, about 40% of waste engine oil is illegally disposed of and eventually ends up in rivers and seas[25]. Waste Diesel-engine oil (WDEO) has been used as a chemical admixture by many researchers for reducing cement content in concrete or as an admixture.Previous research has shown that the properties of concrete have been changed with WDEO[26]. Concrete emits carbon di oxide approximately equal to clinker for production[27]. The reduction of cement content in concrete results in reduction in emission of CO2 during the sintering process and making the composite less adverse to the environment. Addition of WDEO reduces 9.4% cement content in concrete with comparable properties of plain concrete[28]. Furthermore, no examination of the influence of WDEO on concrete has been reported. As a result, the effectiveness of WDEO on OPC concrete is examined in this study. . Therefore, this study investigates the effects of WDEO on OPC concrete. Thereafter, the optimum amount of WDEO for workability and compressive strength are obtained, and Banana fiber is added by taking the percentages 0.5%,1%,1.5%,2%,2.5% of the mass of cement.

1.2 Research Motivation and Problem Statement

Concrete is one of those materials that has flaws from the start, such as the appearance of cracks in structural members. The service life of the structure and structural members is impacted by these cracks. If such cracks can be delayed, the service life of the product can be extended as well. As a result, the best thing we can do is start with durable concrete that has no or few cracks. As the primary goal of this research project is to mitigate or lessen the impact of these flaws. Concrete structure failure can result in the loss of human lives as well as financial loss. As a result, it is necessary to avoid concrete failure in various application and loading scenarios. Natural fibers have been reported to improve the properties of concrete and prevent it from failing. In the construction industry, modern methods are required. It is also necessary to raise public awareness about high-performance and sustainable materials. Concrete technology should focus on sustainable development; otherwise, the planet Earth will be unable to support the increasing waste of its natural resources. There are also few studies that shows how adding the admixture of concrete for improving its properties.

However, other hazardous/toxic waste materials (such as WDEO) must be used to avoid environmental pollution and to advance the development of sustainable and cleaner production. As a result, the goal of this research is to take a step toward effectively utilising waste materials and avoiding uneconomical dumping of these materials. This research is limited to experimental investigations based on the relative comparison. Furthermore, this research study will help researchers in developing guidelines and a mindset for utilizing wastes and pollution-causing materials in construction materials rather than dumping them. Dumping these materials takes a long time and can be expensive. The main goal is to confirm the effectiveness of the used diesel engine oil with banana fiber in relation to important strength and mechanical properties considerations when designing and constructing new structures, as well as assessing the condition of existing structures. Thus, the problem statement is as follow;

To date, only limited research has been published on the use of WDEO with natural fiber in concrete and most of this focus on concrete strength and workability parameters. The concrete is brittle and weak in tension. It is also less resistant to lateral loading. Temperature changes cause volumetric changes in concrete. The key to the formation of drying shrinkage cracks is this change. There appears to be a gap in the literature with respect to the performance of WDEO The goal of this project is to focus on how waste engine oil with Banana fiber affects the properties of concrete and how it may influence the long-term durability.

1.3 Research Questions

Followings are research questions which are explored in this study;

- Why banana fibers?
- Reason behind using fiber with WDEO?
- How much can the performance of concrete be improved by using used diesel-engine oil in commonly used concrete properties?
- How the properties of WDEO with fiber reinforced will effect in future the economy, environment and sustainability of concrete throughout the world?
- What are the dynamic and mechanical properties of concrete when banana fibers and used diesel-engine oil are combined?
- How can concrete made from used diesel engine oil and banana fibers be used in real-world applications?

1.4 Overall Objective of the Research Program and Specific Aim of this MS Research

The overall aim of the research program is to have sustainable and economical concrete by using locally available natural fibers which have potential to be used as construction material. Concrete has a number of flaws, some of which affect the structure's performance and reduce the concrete's durability. It is necessary to use waste materials in construction materials (rather than dumping them) because they are said to have a high potential for improving cementitious compostie.

The specific aim of MS thesis research program is to investigate the mechanical, properties of concrete by influencing used diesl engine oil and Banana fiber.

1.5 Scope of Work and Study Limitations

An experimental program was developed to study the effect of WDEO-BFRC on the durability of concrete. Several concrete properties were examined of both plastic and hardened concrete properties, along with compositional analyses of Banana fiber and Waste engine oil. Mechanical properties, dynamic properties will be investigated by taking the average of 2 specimens for each property of natural fiber reinforced concrete with waste engine oil (WDEO-BFRC) and also for plain concrete (PC).

The average of two specimens is taken according to acceptance and recommendation of ACI 311.6-18 standards. Also the fibers will be used with different content and length in concrete. The rationale behind the content and length of BF is taken from Literature review [29, 81, 82, 84-86]. The natural fiber (banana fiber) is used for this study.

Mechanical properties with respect to compressive strength and flexural strength. Study is limited to mechanical, dynamic and absorption properties of fiber reinforced waste engine oil concrete specimens. Cracks in concrete are common and cracks develop when stresses in the concrete exceed its strength. But cracks patterns from durability point of view are not in the scope of study.

Compare the freshness and hardening characteristics of concrete with the freshness and hardening characteristics of oil-based concrete. The flexural behavior, compressive strength, flexural behavior of load, and ductility coefficient of concrete using used-diesel oil were studied and compared with simple concrete.

1.5.1 Rationale Behind Variable Selection

The type of fiber was chosen because of its superior physical properties in comparison to others. Among natural fibers, banana fibers have a high tensile strength. Fibers are chosen for their exceptional physical properties when compared to other fibers. Similarly, the fibers chosen are readily available in the area. The use of a variety of fiber lengths will help in the handling of both small and large cracks.

1.6 Brief Methodology

The basic mechanical, dynamic, and absorption properties of Plain Concrete were investigated in this experiment (PC) With in laboratory, the use of diesel-engine oil Plain Concrete (Wdeo-PC), as well as the use of diesel-engine oil Plain Concrete and banana fibers reinforced concrete WDEO-BFRCs, are determined. All WDEO-BFRCs contain varying amounts of banana fibers with a fixed length of 50 mm. In the production of Wdeo-PC and all types of WBFRCs, a fixed amount of used diesel-engine oil plain concrete is used. In the production of PC, Wdeo-PC, and all WDEO-BFRCs, the most commonly used mix design is 1:2:4. For PC and WDEO-PC, a 0.5 water-cement ratio (w/c) is used, whereas all types of WDEO-BFRCs are made with 0.6 percent w/c. The fiber (Banana) and used diesel engine oil are added in concrete mixer for the production of (BFRC) with used diesel engine oil respectively. The workability of mixes of PC and (BFRC) with used diesel engine oil is computed in fresh state by using the standard procedure of slump cone test. Standard specimens are cast and tested for determining the compressive, splitting-tensile, and flexural strengths, of PC and considered (BFRC) with used diesel engine oil in the hardened state. To calculate compressive strength, split tensile strength and flexure test of various models experimentally additional various other tests will be performed. A total of 42 specimens of PC, Wdeo-PC, and WDEO-BFRCs are cast after the slump test is completed. Each type of prepared concrete is cast in four cylinders and two beam lets in total. The compression properties of concrete are investigated with two cylinders of each type, while the splitting-tensile properties of concrete are determined with the remaining two cylinders. Three-point loading setup on casted beamlets is used to investigate the flexural properties of all types of prepared concretes. Servo-hydraulic testing machine is used for the strength testing of all specimens in order to get their pre-crack and post-crack behaviors.

The dynamic properties of the material are investigated using an accelerometer and a hammer before mechanical testing. Attaching the accelerometer to the specimen and using a hammer stroke to determine the desired frequencies yields the response-frequency longitudinal (RFL), response-frequency transvers/lateral (RFT), and response-frequency rotational/torsional (RFR). The dynamic properties of all types of manufactured concrete are then evaluated using these frequencies. The fractured surfaces of broken specimens are also closely examined to check for fiber mixing in the concrete, fiber bonding with the surrounding cementitious matrix, fiber pullout, and fiber breakage, among other objects.

1.7 Novelty of Work, Research Significance and Practical Implementation

The addition of natural fibers to concrete significantly improved the resistance to impact loading, according to an experimental study [29]. The addition of natural fibers to concrete was found to improve its mechanical properties[30]. Various types of natural fibers and admixtures have been shown to improve the properties of concrete and the performance of structures in previous studies. To the best of the author's knowledge, no research has been done on the combined effects of used diesel-engine oil and banana fibers on concrete production and properties. Using used diesel engine oil and banana fibers, the current study aims to investigate the basic mechanical, dynamic, and absorption properties of WDEO-BFRC.This material has resulted in the production of concrete with improved properties for use in civil engineering and construction.

Concrete has a number of flaws, including cracking, spalling, and tension weakness. As a result, there is a need to mitigate these concrete flaws. The addition of fibers to concrete improved its durability as well as its resistance to crack formation and progression [31]. In comparison to the properties of PC, fiber reinforced concrete has shown to have better properties. Fiber reinforced concrete (FRC) beams with fiber reinforced polymer bars as reinforcement have shown to perform better in studies [32]. Previous research has used a single fiber or a combination of two fibers in concrete to improve its properties. There are only a few studies that used natural fibers in combination with an admixture. As a result, using banana fibers and waste diesel-engine oil for improving the properties of concrete , which also cleans the environment by using waste oil. In comparison to other natural fibers, banana fibers have a very high tensile strength [33]. As a result, it's important to look into how it influences concrete's various properties.

Concrete with WDEO can be used directly in locations where it will not come into direct contact with the environment. This can be used as lean concrete beneath the foundation, for example. Lean concrete is also protected from chemical attacks by the environment because it is buried beneath the soil and has no contact with the air. It does, however, appear to have structural applications. If used with caution and consideration of the benefits and drawbacks.

1.8 Thesis Outline

This research work has six chapters:

Chapter 1: This chapter includes an introduction. It covers the background, research motivation and problem statement, overall and specifc research aims, scope of work with study limitations, brief methodology, and thesis outline.

Chapter 2: This chapter includes a literature review. It explain the background, used diesel engine oil, banana fibers, recoverable flaws with waste usage, governing values towards improvement in concrete's properties and their contribution towards durability considerations and design considerations, and summary.

Chapter 3: The experimental scheme, raw constituents, mix design, specimen casting, testing, and a summary of Chapter 3 are all included in this chapter.

Chapter 4: The results of the tests are presented in Chapter 4 along with their analysis. It covers the background, dynamic and mechanical properties of the mixes (PC, Wdeo-PC, and WDEO-BFRCs), miscellaneous properties (water absorption, linear shrinkage, and mass loss), fractured surfaces of tested specimens, and the chapter 4 summary.

Chapter 5: It contains background information, optimization of banana fibers with used diesel-engine oil, empirical relationships, practical implementation, and a summary of chapter 5.

Chapter 6: Conclusions and future recommendations are presented in Chapter 6.

Chapter 2

Literature Review

2.1 Introduction

Fibers are used in concrete to help it achieve its maximum properties. Many researcher have used natural fibers in concrete to improve the properties of the material. Cement is the most important component of concrete because it gives it strength and binds it together. Fibers are used as a concrete additive to improve the mechanical properties. Natural fibres are becoming more popular as a construction material due to their low cost. Banana fibres is natural fibres that are readily available locally. Since ancient times, fibres have been used to improve the mechanical strength parameters and composite performance. It has been demonstrated that fibre reinforced concrete has superior mechanical properties, such as energy absorption, toughness index, and lateral load resistance. Exploring the effects of natural fibres for improving properties for a specific application is a requirement of today's age.

2.2 Concrete Flaws and Their Remedial Measures

Concrete flaws can occur for a variety of reasons, all of which have an impact on the structure's performance. Various researchers looked into various flaws in concrete. The most serious flaw in concrete is its sudden failure due to external chemical attacks and other external factors [34]. There is no good construction or building material that can be utilised as a substitute for concrete. Concrete is regarded as a backbone in the construction industry as a construction material. Despite its advantages, concrete has a number of drawbacks that must be mitigated or decreased. The impact of those flaws like weak in tension, vulnerability to cracking, less resistance against impact loading and spalling, etc. The impact of these flaws, somehow, can be reduced by the addition of the agricultural waste as dispersed reinforcement in concrete[29].

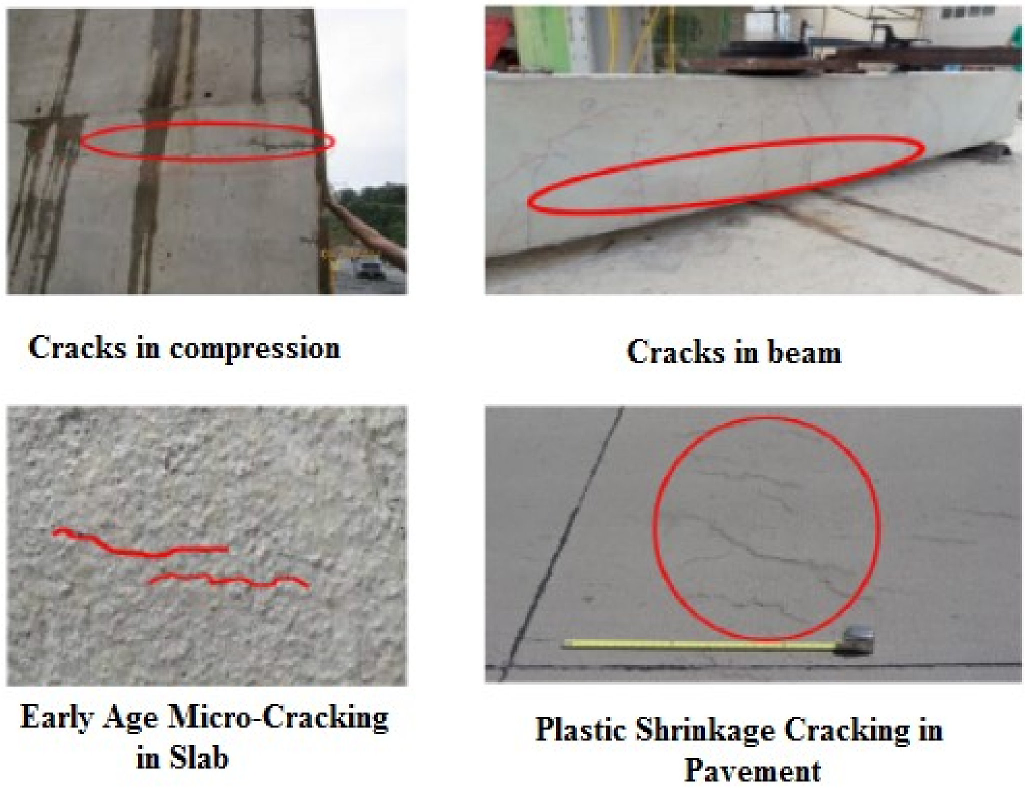


FIGURE 2.1: Cracking in Different Application of Concrete [36]

The combined usage of agricultural waste and glass fiber reinforced polymers bars resulted in an increment in resistance against impact loading [35].The incorporation of agricultural waste in the name of natural fibre resulted in a reduction in the rigid pavement's thickness[36]. Using steel fibre in conjunction with basalt fibres improved the energy absorption property to resist breaking[37].Seismic performance and resistance against impact loading were enhanced by the incorporation of the jute fibers in concrete[38].

Table 2.1: Different types of fibers as construction material and their contribution towards improving concrete flaws

Reference	**Year**	**Fibers**	**Matrix**	**Conclusions**
Zakrai et al.	2018	Jute	Concrete	Jute fiber reinforced concrete (JFRC) can be effective and economical material.
Tokoro et al.	2008	Bamboo	Concrete	The addition of Bamboo fiber improves thermal properties and heat resistance
Chakraborty et al.	2013	Jute	Concrete	Improved the flexural toughness and toughness indices of the fibre reinforced concrete
SM dewi et al.	2018	Bamboo	Concrete	Bamboo fiber can prevent the growth and propagation of cracks.
KMF hassan et al.	2021	Coir	Concrete	The usage of coir in composite materials enhances thermal conductivity
Krishna et al.	2018	Sisal	Concrete	Sisal fibers are chosen to improve the properties of the concrete.
Pusit et al.	2015	Palm	Concrete	Natural fiber cement products can be used to improve energy efficiency in building.
Aziz and Mansur	2019	Banana	Concrete	Improved the mechanical properties Of concrete.
Elbehiry and Mostafa	2020	Banana	Concrete	Banana fibers have a significant effect in reducing cracking in concrete beams. Banana fibers increase flexure strength, which contributes to reduced depth of concrete sections and develops an innovative technique of reinforcement.
Elbehiry et al.	2020	Banana	Concrete	Banana fiber-reinforced mixture is a promising sustainable and affordable construction material with enhanced mechanical properties and fracture toughness with the potential to be used in different structural applications, especially in developing countries.

Replacing fine aggregates with an optimum dosage of the waste marble powder as filler material in concrete showed improved performance of concrete provides a way of sustainable development [19]. The researcher utilized coconut fibers ropes made of agricultural waste to analyze the response of mortar-free blocks against dynamic loading [39]. The ductility and energy absorption properties of concrete were improved by the additive influence of waste plastic and palm oil fuel ash[40].The flexural strength of the concrete was improved by the incorporation of the glass fiber reinforced [41] .Water absorption properties of concrete were improved by the combine effect of glass fiber (GF) and polypropylene fiber (PPF)[42]. Jute fiber reinforced concrete (JFRC) can be effective and economical material[43]. Palm Natural fiber cement products can be used to improve energy efficiency in building [44].

2.3 Use of Waste to Improve Concrete Properties

In associated with environmental conservation, the construction industry's interest in using waste products as raw materials is expanding with the passage of time. Waste material in concrete can be used as cement or aggregate replacement, fillers or fibres. Many researchers investigated the impact of various types of waste materials on concrete characteristics[45]. All around the globe, agricultural wastes as natural fibers have an appreciable economic impact due to their use as construction materials. In an experimental work, plant fiber (especially, wheat straw) was added as a dispersed reinforcement in concrete and explored the effects on properties of concrete [30].

As it is impossible to use only waste material instead of cement in construction, waste material (Plastic) can be reused as an aggregate. Aggregates occupy about 70% of the volume of concrete, thus a large amount of it can be reused[46]. Recycling aggregates (RA) for the production of recycled aggregate concrete (RAC) is a promising technique to reduce environmental impact and increase construction sustainability [47].

Table 2.2: Characterization of Ordinary Portland Cement (OPC) and Waste Engine Oil (WEO)[24][36]

Chemical Composition	**Ordinary Portland Cement** (%)	**Waste engine Oil** (%)
SiO2	21.98	-
Al2O3	4.65	-
Fe2O3	2.27	0.42
CaO	61.55	15.9
MgO	4.27	-
SO3	2.19	37
K2O	1.04	-
Na2O	0.11	-
P2O5	-	8.95
ZnO	-	17.7
Cl-	-	15.9

The use of natural fibers in various types of composites has reduced the impact of the use of other basic hazardous materials and helped in the development of sustainable and environmentally friendly materials [48]. The used lubricant by different types of engines and machines is a hazardous material to the environment. These waste lubricants can be used in concrete for the green production and economical dumping of waste engine oil [4][49]. The research work was conducted to investigate the fresh and hardened properties of concrete having waste engine oil.The durability of concrete containing Waste engine oil will be improved significantly under freezing-thaw cycles [50]. As there are tons of waste engine oil available, it cannot be stored and re-used in an effective way. The waste engine oil should be controlled and avoided its entrance and mixing with the runoff water. Eventually, it may pollute the river and sea environment and may cause danger to the water living life[51].

2.3.1 Waste Diesel Engine OIL

The potential of engine oil as an additive for concrete has been discovered by completely different research. Second, in older grinding units, the loss of oil in the cement resulted in concrete that was more resistant to freezing and thawing, implying that adding used motor oil to the new combine could be equivalent to adding a chemical air release additive to improve some of the durability properties of concrete while also serving as an alternative technique [22].Waste motor oil poured into household drains, or directly onto the ground, can work itsway into the waterways and ground waters. Illegally disposed of oil can pollute the groundwater with contaminants such as lead, magnesium, copper, zinc, chromium,arsenic, chlorides, cadmium and polychlorinated biphenyls. It was reported that one quart of oil can pollute up to 250,000 gallons of drinking water [52].

Table 2.2 shows the composition/charaterization of waste engine oil in comparison with ordinary portland cement. The inclusion of waste diesel engine oil (having metals that is toxic materal) can reduce the PH of concrete due to its acidic nature. Okash et al. [4] and Yaphary et al. [28] used engine oil in concrete and it showed positive effect on strength.

Vehicle usage is expanding on a daily basis. The engine is the most important component of the car, and it need proper lubrication to perform properly.These lubricants must be replaced after a set period of motor/engine operation. Because it contains polluted heavy particles, waste diesel engine oil (waste engine oil) is more hazardous to the environment than crude oil [53]. The addition of WEOs to OPC concrete improved its workability while lowering its compressive strength as the percentage of WEOs raised. Slump values and compressive strengths of OPC concrete with WEOs were evaluated to determine the optimal amount of WEOs. The optimal WDEO and UPEO weight of cement values were 0.8 percent and 0.6 percent, respectively. These volumes of WEOs were added to OPC concrete, along with SF of 10% and 15% cement replacement, respectively.

The addition of SF to OPC concrete with WEOs decreased the slump values of the concrete, according to the findings. The concrete's workability was further harmed by increasing the amount of SF from 10% to 15%[26]. As shown in Fig 2.1, soil contaminated with diesel engine oil produces a variety of cement-based compounds. This showed that fine aggregates solid contaminated with waste diesel engine oil can be utilized in cement-based materials to increase performance such as consistency and strength while also improving environmental protection and benefits. At the start of development, diesel oil contaminating fine aggregate improved the total heat of hydration of bulk cement and the rate of heat release from a unit mass of cement.

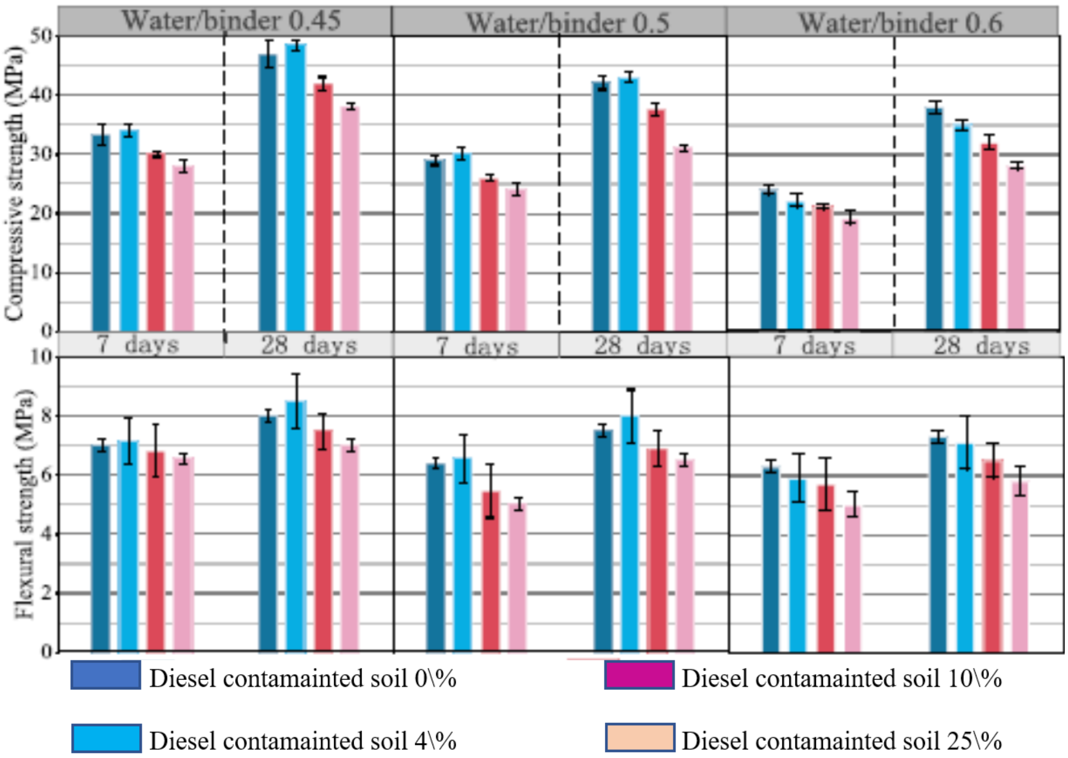


FIGURE 2.2: Contaminated diesel oil compressive and flexural strength soil [54][55].

The waste Diesel-engine oil (WDEO) was used along with the banana fibers (BF) to check the influence on the workability of the concrete. The workability was improved with the incorporation of WDEO[56].Different forms of waste oil have been proposed in road building to counter act the stiffening effect of reclaimed asphalt pavement component. However, choosing an effective rejuvenator based on a comparative study will help you make better use of your resources. Following the present greatest industrial adaptability, waste cooking oil and waste engine oil are used to renew three various percentages (30%, 40%, and 50%) of reclaimed asphalt pavement[57]. The viability of using WEO as an expansive addition in the manufacturing of expanded clay aggregates (ECAs) for lightweight concrete (LWC) applications is evaluated, as well as the effects of these ECAs on concrete physical parameters [58].

As we seen the physical apperance of waste diesel engine oil in figure 2.3 Slump test, porosity, air entraining, and compressive strength are among these qualities. The chemical makeup of modern diesel engine oil, as well as the processes it undergoes, are considerably different.

FIGURE 2.3: Waste Diesel Engine Oil Physical Appearance [55]

According to this research, up to 9.4% mass of cement can be reduced and replaced with the WDEO. It can be observed clearly that WDEO enhanced the slump value of concrete. The initial setting was not affected but a delay observed in final setting time in comparison to normal plain concrete. The 28 days compressive strength was improved but a minor decrease was observed in 28 days flexural strengths. As per the results, the cement in concrete can be replaced up to 9.4% by mass and comparable properties can be achieved[28].

2.3.2 Banana Fibers

Researchers have utilized natural fibres in concrete to substitute steel in a variety of applications. The use of polymer composites reinforced with natural fibres in engineering applications has expanded dramatically in recent decades, owing to the benefits of not only good composite qualities, but also fibre durability and environmental responsibility[59].Natural fibres used in technology include coir,sisal,pine, banana,bamboo,date,wheat straw, jute, and palm. There are many reasons for applying natural fibers in concrete[14]. Synthetic fibers, such as carbon, glass, aluminium, aluminium oxide, boron, and others, natural fibres, such as banana, jute, coir, silk, bamboo, coconut, and others, are the two forms of fibre. While synthetic fibres are the most frequent and are widely utilised despite their high cost, this study looks into banana fibres, which are made from plant waste and thus less expensive [60]. Natural fibers are nature friendly and usually obtained from plants and trees. They are cheaper and have good mechanical properties i.e. tensile strength, flexural strength and compressive strength [14][48]. The use of natural fibres in concrete reduces the workability of the material. Workability is a concrete attribute that is closely related to the strength elements and work quality [56][61]. Because banana fibre (BF) is a lignocellulose natural fibre, adding it to the concrete makes it less workable. This is due to the presence of banana fibre, which increases water absorption[60]. The more quantity of banana fibers along with jute fibers in the composite resulted in an increase in the splitting-tensile strength, flexural strength, and impact resistance of the composite[62]. In comparison with other fibers, banana fiber has more average tensile-strength than coconut fiber, bamboo fiber, palm fiber, and sisal fiber [63].The addition of banana fibers has caused an improvement in tensile strength of composite. A research study was conducted using the banana fiber bars as reinforcement. According to this study, the ability of concrete to resist cracking and spalling was increased [64][65].

A research study was conducted using the banana fiber bars as reinforcement. According to this study, the ability of concrete to resist cracking and spalling was increased. The use of banana fibers significantly enhanced the resistance against cracking in the concrete beams[66].This shows that the addition of natural fibers contributed to the reduction of depth of the concrete section by improving the flexural strength of the concrete. According to experimental research work, the additional water hyacinth fiber and banana fiber were done on the basis of bio fillers in concrete [8]. Banana fibre is a major source , and fibre derived from forest trees is on the rise in many countries. Fiber utilization in high biomass, fast-growing plants is an excellent alternative source of raw materials. Banana fibre is relatively inexpensive, abundant, and requires little energy to extract, so it offers significant engineering benefits. [15][67].Another study concludes that hybridization of banana fibers in the jute and epoxy composites results in better mechanical and thermal properties and shows improvement in water absorption property [68]. According to a study, banana fibers have a substantial impact on minimizing cracking in concrete beams. Natural fibers improve flexure strength, which contributes to decreased concrete section depth and provides a unique reinforcement technique [60]. The flexural strength was increased using banana fibres and wood bottom ash (WBA). The ductility of the composites was improved through polymer modification. The created composite had excellent thermal insulation qualities and may be employed in a variety of cement-based applications [69].

Table 2.3: Physical and mechanical properties of banana fiber [70].

Mechanical and Physical Properties	**Banana Fibers**
Elongation (mm)	2-2.5
Tensile Modulus (GPa)	24-32
Density (g/m3)	25-1.35
Fiber Diameter (m-4)	50-250
Tensile Strength (MPa)	529-914

Table 2.4: Tensile Strength Comparison of Bannaa Fibers [88].

Fiber	**Tensile Strength (MPa)**	**Reference**
Banana	550	
Sisal	350	Senthilkumar et al. (2018)
Coconut	88.63	

2.4 Sustaianbility with Reuse of WDEO and BF

Vehicle usage is expanding every day in the transportation industry.The engine is the most important component of the car, and it need lubrication to perform properly. These lubricants must be replaced after a specific period of motor/engine usage. Because it contains polluted heavy particles, waste diesel engine oil (waste engine oil) is more hazardous to the environment than crude oil[71]. As there are tons of waste engine oil available, it cannot be stored. The waste engine oil should be controlled and avoided its entrance and mixing with the runoff water. Eventually, it may pollute the river and sea environment and may cause danger to the water living life. The damping or used oil needs special treatments which costly is [51]. On the other hand, agricultural waste is growing day by day. It has been observed that about 21% of greenhouse gas is emitted by agricultural waste. The adverse effects of agricultural waste on the eco-system, human health and aquatic life have necessitated the appropriate dumping.

Dumping of this waste covers a large part of precious land and also this is dangerous to human health [72]. The other method to dump the agricultural waste is to burn it. When a large amount of the agricultural is burnt up it releases a large amount of heat making which is dangerous to the global environment and can boost the global warming effect.Many researchers had utilized agricultural waste differently in the research works related to the development of sustainable construction materials. Agricultural wastes, like coconut fibers and ropes made of these fibers, were used to develop a sustainable construction material and cleaner production [73].

This method of using WDEO and BF to manufacture construction materials is environmentally friendly because it supports in the disposal of agricultural waste and motor lubricant waste. Agricultural waste disposal is a cost-effective task that requires a large amount of valuable land. It can't be dumped in the sea or river because it would pollute the aquatic environment. During the sintering process, normal concrete emits a lot of heat[74]. By substituting WDEO for some of the cement, this effect can be reduced [28]. Property enhancements Instead of disposal, agricultural waste/fibers can be used in concrete to create a new material. When compared to plain concrete, the seismic performance of FRC with coconut fibre ropes (agricultural waste) was improved [39][75].

It was observed that sustainable concrete made from agricultural waste, such as coconut fibres, helped to reduce the thickness of road construction when compared to conventional concrete[61]. This made it more cost-effective, as the number of expensive materials needed was reduced due to the volume reduction induced by the thickness. Natural fibre reinforced concrete offers strength properties that are comparable to synthetic fibre reinforced concrete. It is determined by fibre qualities like as orientation, size, and production procedures[76]. By using waste materials as raw materials, this study aided in the development of a sustainable construction material. Dumping and recycling the materials stated above are also uneconomical. As a result, using these minerals as raw materials aided in the development of sustainable construction materials, environmental clean up from hazardous compounds, and cost control.

2.5 Contribution of this Work

Concrete with WDEO can be used directly in situations where it will not come into direct touch with the environment. This can be utilised as lean concrete beneath the foundation, for example. Lean concrete is also shielded against chemical attacks by the environment because it is buried beneath the soil and has no interaction with the air. It does, however, appear to have structural applications. If used with caution and consideration of the benefits and drawbacks.

2.6 Significance of Work

Concrete has a number of faults, including cracking, spalling, and tension weakness. As a result, there is a need to mitigate these specific weaknesses. The addition of fibres to concrete improved its durability and resistance to the formation and propagation of cracks[30]. In comparison to the qualities of PC, fibre reinforced concrete has shown to have better properties. Fiber reinforced concrete (FRC) beams with fibre reinforced polymer bars as reinforcement have demonstrated to perform better in a study[77]. Previous studies used a single fibre or a combination of two fibres in concrete to improve its properties. There are only a few studies where artificial fibres were used in conjunction with an admixture. As a result, the use of natural fibres and used diesel-engine oil is far superior for improving the properties of concrete, as it also cleans the environment by using the WDEO. Banana fibers has the high tensile strength in comparison with the other natural fibers [78]. As a result, it is necessary to investigate its impact on various concrete properties.

2.7 Summary

The use of natural fibres in combination with an admixture can improve concrete properties related to structural durability, as shown in the preceding discussion. To resist cracking and the progression of micro cracks into macro cracks, it is necessary to improve the mechanical and dynamic properties of the material. Banana fibre improves the splitting-tensile strength of concrete and resists cracking, as demonstrated in this chapter. Diesel engine oil, on the other hand, can be used as a chemical admixture in concrete. Used diesel-engine oil improves the concrete's compressive strength to a certain extent. According to the literature, used diesel-engine oil and banana fiber has potential to improves the performance of the concrete.

Chapter 3

Experimental Scheme

3.1 Background

Natural fibres are increasingly being used in concrete due to their low cost, ease of handling, good mechanical properties, ease of availability, and environmentally friendly nature. In this study, banana fibre is used as reinforcement, and diesel engine oil is used as a chemical admixture in the production of concrete. The use of banana fibres and used diesel engine oil in several studies is discussed in detail in the previous chapter.

However, the combined influence of banana fibres and used diesel engines has yet to be investigated. As a result, the slump cone test, dynamic test, mechanical test, water absorption, linear shrinkage, and mass loss test are all taken into account. An examination of the fractured surfaces of broken specimens is also performed. This chapter discusses raw materials, fibre treatment, and mixing methods.

3.2 Raw Materials

Ordinary Portland cement, Margalla crush, and locally available sand are used to make normal plain concrete (PC). The maximum aggregate size used in the production of both plain concrete and fibre reinforced concrete is 20 mm (FRC).

WDEO is used as an admixture in the production of WDEO-PCs and Wdeo-BFRC. It should be noted that this study makes use of commercially available WDEO. Because WDEO is classified as a waste material industry, no information on its characterisation is available. These fibers are treated one that is (washed and soacked) and available in requird length. Because there are no visible impurities on the fibres, no additional treatment is required (dust etc).

Banana fibre is utilised in the manufacture of FRC. The fibre is cut to a pre-determined length of 50 mm and utilised to make the FRC. To prepare used diesel-engine oil added plain concrete (PC-WDEO) and FRC, WDEO is mixed with plain concrete. The PC, PC-WDEO, and Wdeo-BFRC are made from tap water (at room temperature). Distinct types of specimens are made with two different water-cement ratios. PC and WDEO-PC are made with a 0.5 water-cement ratio, while the Wdeo-BFRC are made with a 0.6 water-cement ratio. According to the literature review, the water ratio for Wdeo-BFRC is raised due to the BF (natural fibres) having a higher water absorption property.

3.3 Mix Design, Casting and Samples Preparations and Specimen Labelling

A 1:2:4 mix design ration (cement: sand: aggregate) is used to prepare PC. In order to make WDEO-PC, 9.4% WDEO content by mass of cement is added to the mixture and the mix design ratio is adopted form the litearture [28]. For the production of used diesel engine oil banana fibre reinforced concrete, different quantities of BF (0.5 percent, 1.0 percent, 1.5 percent, 2.0 percent, and 2.5 percent) are mixed in with the WDEO (WDEO-BFRCs). To make the PC mix, all of the materials are combined in a drum. After that, water is poured to the mixture machine 30-45 seconds after it begins to rotate. For five minutes, the mixing machine is rotated. After PC preparation, the slump cone test is carried out. The identical technique is used to prepare the WDEO-PC, and that therefore diesel engine oil is added one minute after the water is injected. The mixing time is retained at the same five minutes as the PC mix. To ensure a good mixing of fibre within the concrete, the materials are arranged in the shape of layers while making BFRC with 0.5 percent banana fibre by mass of cement.

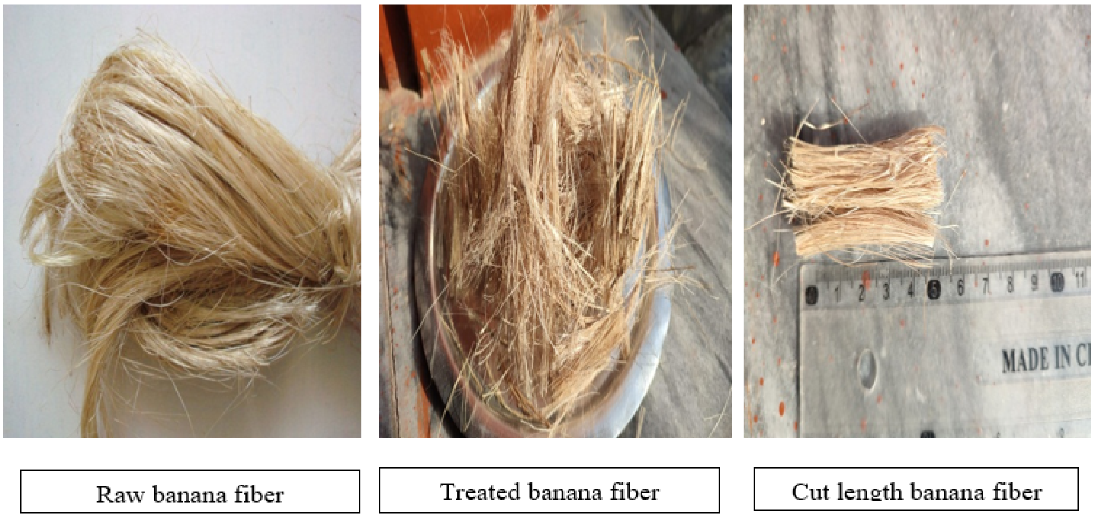


FIGURE 3.1: Natural Banana Fiber (Raw, Treated and Cut Length)

To achieve a suitable WDEO-BFRC blend, three layers are used. In the mixer machine, place the one third batch of aggregates, sand, banana fibres, and cements. Then, using the same method, the second and third layers of aggregate, sand, banana fibres, and cement are applied. The mixture machine then began to rotate after being turned on. With the machine turned on, the second third of the water is added. After three minutes of continuous mixer machine rotation, the remaining one-third of the water and WDEO are added, and the mixture machine is rotated for another two minutes before a slump cone test is performed to determine the WDEO-BFRC fresh workability. The additional varieties of WDEO-BF with varied amounts of banana fibres were treated in the same way.The slump cone test is used to determine whether a manufactured PC is workable or consistent. Before pouring into moulds, the slump test for PC, WDEO-PC, and WDEO-BF is always done. The slump cone test is used to determine the workability of fresh concrete, according to ASTM standard C143/C143M-15a[79]. The test is carried out with a slump cone with a bottom diameter of 200 mm (8 in), a top diameter of 100 mm (4 in), and a height of 300 mm (12 in). The non-absorbent cone mould should be used. The tamping rod is hemispherical on both ends, with a diameter of 16 mm (5/8 in) and a maximum length of 600 mm (25 in).

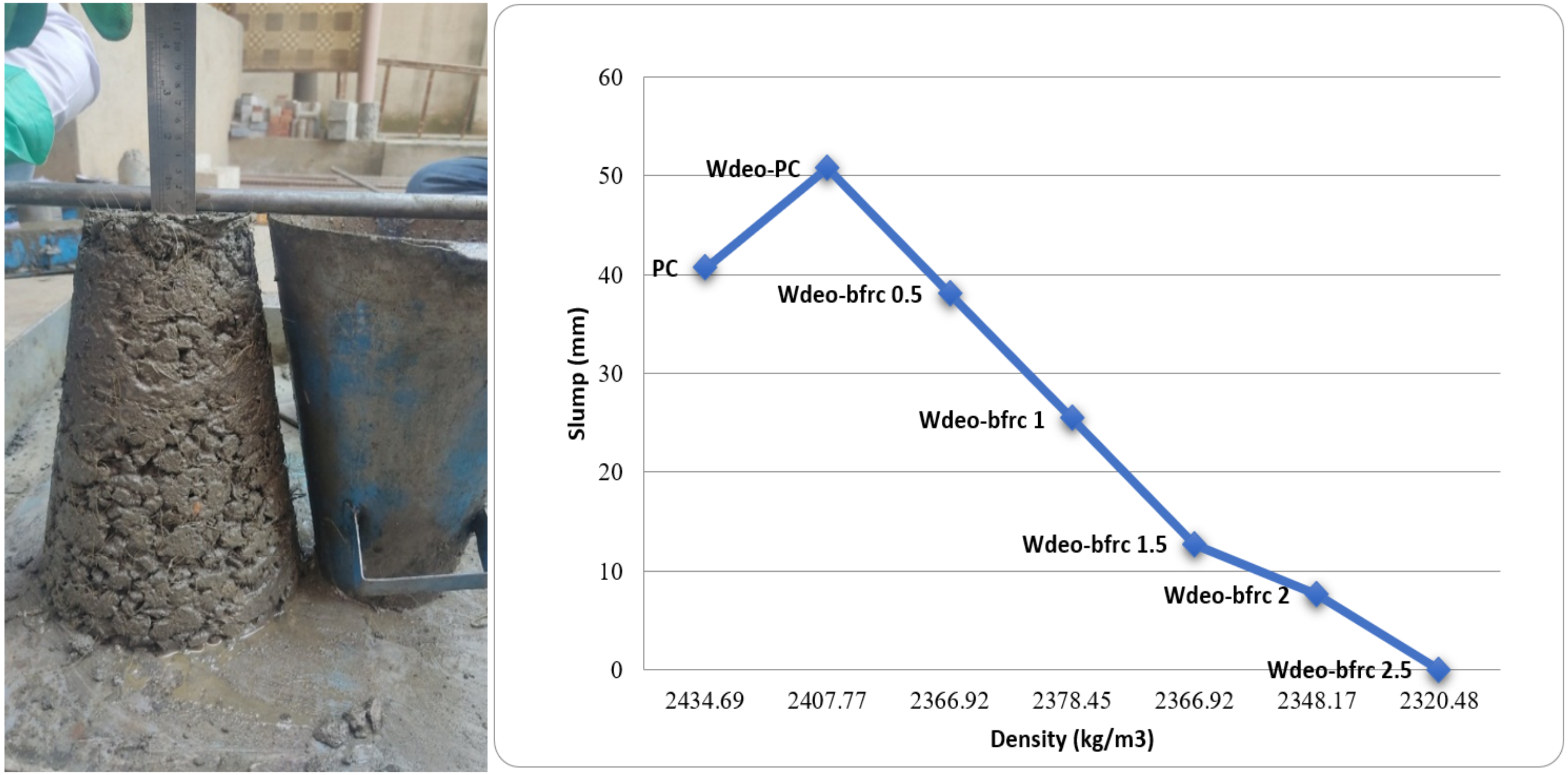
Three equal volumetric layers of concrete are poured into the cone. After placing the first third layer, compaction is achieved by dropping a tamping rod 25 times randomly on the layer's surface from a height of 25 mm (1 in). With the help of the tamping rod, the remaining two levels of the cone are filled and compacted. By striking off the tamping rod and screeding and rolling the rod over it, I was able to remove the excess concrete and smooth it out. Later, the slump cone is raised vertically.

The cone is flipped over and set on top of the concrete in the slump cone's mould. The tamping rod is positioned over the upturned slump cone so that the length of reach over the slump concrete is as long as possible as shown in Fig 3.2a The value of slump is carefully measured with the help of the ruler.

The test is carried out with a slump cone with a bottom diameter of 200 mm (8 in), a top diameter of 100 mm (4 in), and a height of 300 mm (12 in). The non-absorbent cone mould should be used. The tamping rod is hemispherical on both ends, with a diameter of 16 mm (5/8 in) and a maximum length of 600 mm (25 in). To the best of the authors' knowledge, there is no standard test that can be used to determine if fresh WDEO-PC and WDEO-BFRC are workable. As a result, the workability of WDEO-PC and Wdeo-BFRC is determined using the same process and test standard as shown in Fig 3.2b.

For measuring the densities, an average of two specimens is taken for each mix design. The volume of the beamlets is determined in terms of m3 by taking the internal volume of the moulds that are used for the casting of the beamlets. After the final setting time of the concrete, moulds are then removed and the mass in kilograms of each specimen is noted by using the weighing balance. The least count of weighing balance used for the determination of the masses is 5 grams.

The densties are found by taking ratio of weight (kg) and volume (m3). Table 3.2b. shows the densities and slumps that were determined. There are no such standard assays available to determine the workability and density of fresh WDEO-PC and WDEO-BFRC, to the best of the authors' knowledge. As a result, the workability and densities of WDEO-PC and WDEO-BFRC are determined using the same process and test standard.



a) **b)**

FIGURE 3.2: a) Measuring the Value of Slump of WDEO-BFRC, b) Combined Effect of WDEO and BF on the Relation between Slump of Fresh concrete and Density of Hard Concrete

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

Labelling	**C:S:A**	**Addition of Percentage Content by Mass of Cement of**		**W/C**	**Slump of Fresh Concrete**	**Density of Hard Concrete**
		WDEO	**Banana fiber**	(-)	(**mm**)	(**kg/m3**)
PC	1:2:4	0	0	0.5	40.64	2434.69
WDEO- PC	1:2:4	9.4	0	0.5	50.8	2407.77
WDEO -B0.5%	1:2:4	9.4	0.5	0.6	38.1	2366.92
WDEO -B1.0%	1:2:4	9.4	1	0.6	25.4	2378.45
WDEO -B1.5%	1:2:4	9.4	1.5	0.6	12.7	2366.92
WDEO -B2.0%	1:2:4	9.4	2	0.6	7.62	2348.17
WDEO -B2.5%	1:2:4	9.4	2.5	0.6	0	2320.48

Note: Addition of WDEO content and Banana Fiber content done by taking percentage by mass of cement. Density is calculated by taking an average of two specimens.

For all types of testing, cylinders and beamlets are used. Resonant frequency apparatus is used to calculate the dynamic properties of cylinders and beamlets. The cylinders are put through a water absorption test. Cylinders and beamlets have their compressive, splitting tensile, and flexural properties determined. It's worth noting that all of the tests are carried out on two specimens of the same combination, with the average of the two values taken. Other researchers use a two-value average as well [80][36]. There are 28 cylinders and 14 beamlets among the 42 specimens. PC, WDEO-PC, WDEO -B0.5 %, WDEO -B1.0 %, WDEO -B1.5 %, WDEO -B2.0 %, and WDEO -B2.5 % are used to identify specimens during testing. The specimen labelling scheme is shown in Table 3.1. The WDEO-PC combination does not contain fibres, whereas other samples contain 9.4% diesel oil and varying percentages of fibre with fixed length.

3.4 Testing

To study the various relevant properties against these tests, dynamic testing, mechanical tests, water absorption tests, linear shrinkage tests, mass loss, and investigation of breakage and role of fibres in concrete are performed in this part. These test settings are carried out in accordance with industry standards or as a reference to past research. In the current investigation, the average of two specimens is taken. Other researchers have also reported using the average of two values[29][30][81]. The test setups for dynamic and mechanical tests are shown in Figures 3.2a and 3.2b. Following the mechanical test, the role of fibres in concrete was investigated using shattered concrete surfaces. Longitudinal, lateral, and rotational frequencies are measured with a hammer and an accelerometer during dynamic testing.

For determining each type of resonance frequency, different types of setups are employed. The accelerometer is attached to one cross-sectional side of the specimen and a light stroke is applied to the other cross-sectional side of the specimen in the longitudnal frequency configuration. The accelerometer is placed on the length of the specimen, 25 cm away from the cross-sectional edge, and then the stroke is given parallel to the accelerometer on the other edge of the specimen.

FIGURE 3.3: Tests Setups; a) Dynamic Test, and b) Mechanical Testing

The rotational frequency accelerometer is attached to the same setup as the longitudinal frequency setup for the third setting of observing rotational frequency. However, the hammer stroke is based on the length of the specimen perpendicular to the acceleometer. The mechanical properties of PC, WDEO-PC, and all varieties of Wdeo-BFRC are investigated using compression, split-tensile, and flexural tests. The cylinders are arranged vertically between the test machine for compression, acting as a column or proto-type compression member. Between the testing plates, cylinders are laid down to observe the splitting-tensile qualities of casted specimen. Flexural testing employs a three-point loading configuration. The flexural characteristics of concrete are determined by performing a flexural test on beamlets. According to ASTM standards, the average of two values can be used to get the precise value of any type of concrete property. As a result, for each type of property of dynamic and mechanical testings, the average of two results is used in the current study.

3.4.1 Dynamic Test

According to "ASTM 215-14 [Table 5], a dynamic test is performed before destructive (mechanical) testing of the specimens. The hammer and accelerometer are used to calculate lateral response frequencies (RFL), transverse response frequencies (RFT), and rotational response frequencies (RFR). Both cylinders and beamlets are subjected to the test. The accelerometer is attached to one side of the cross section of cylinders and beamlets for determining the RFL, while a hammer stroke is administered to the other side of the cross section of specimens. The accelerometer detects frequencies and sends a record of them to the computer that is connected to it. The RFT and RFR procedures for attaching the accelerometer and hammer strike position differ for cylinders and beamlets. In the case of cylinders, the accelerometer is mounted to the side of the cylinder with the face of the length of the cylinder at least 25 cm away from the edge for RFT. Then, with the same side towards the centre of the cylinder's length, a hammer hit is given. In RFR, the accelerometer is mounted to the top of the cylinder, facing the length of the cylinder, with the same distance from the edge as in RFT. The strike is delivered at a perpendicular accelerometer on the cylinder's opposite edge. For RFT determination in the case of beamlets, an accelerometer was mounted to one side of the length at the same margin as for cylinders, on the length of beamlets from the edge. The hammer strike is given at the centre of the length of the same side where the accelerometer is mounted. The accelerometer is affixed to the upper corner of the rectangle for RFR (side face of the beamlet). A strike is made at the opposite side bottom corner of the same side of the rectangle in such a way that the line connecting the point of the hammer's strike and the accelerometer forms the rectangle's diagonal. The damping ratio, dynamic modulus of elasticity, dynamic modulus of modulus of rigidity, and poisson's ratios are derived using these measured frequencies. These estimated parameters aid in the understanding of PC, WDEO-PC, and all types of WDEO-BFRC behaviour and resilience to dynamic loading. These characteristics are critical in the design of structures that will be subjected to dynamic loading and earthquake.

TABLE 3.2: Testing Standards and Studied Parameters

Test	**Standards**	**Parameters considered for study**
1. Mechanical properties		
a. Compressive properties	ASTM C39	Stress–strain curves, compressive strength (C-S), compressive pre-crack energy absorption (CPE1), compressive post-crack energy absorption (CPE2), compressive total energy absorption (CTE), compressive toughness indexes (CTI) and modulus of elasticity (MOE).
b. Splitting-tensile properties	ASTM C496	Load-deformation curves, splitting-tensile strength (STS), splitting-tensile pre-crack energy absorption (SPE1),

Continued Table 3.2 Testing Standards and Studied Parameters

Test	**Standards**	**Parameters considered for study**
		Splitting-tensile post-crack energy absorption (SPE2), splitting-tensile total energy absorption (STE) and splitting tensile toughness indexes (STI).
c. Flexural properties	ASTM C78	Load-deflection curves, flexural strength (F-S), flexural pre-crack energy absorption (FPE1), flexural post-crack
	ASTM C1609	energy absorption (FPE2), flexural total energy absorption (FTE) and flexural toughness indexes (FTI).
2. Dynamic properties	ASTM 215-14	Resonant frequency longitudinal (RFL), Resonance frequency transverse (RFT), Resonance frequency torsional (RFR), damping ratio, dynamic modulus of elasticity (DME), Dynamic modulus of rigidity (DMR), Poisson ratio.
3.Miscellaneous properties		
a.Water absorption	ASTM C642-13,	Water absorption (%)
b.Linear shrinkage	ASTM C157,	Linear shrinkage (percentage decrease)
c.Mass loss	ASTM C157M-08	Mass loss by gradually increasing temperature.

3.4.2 Mechanical Properties

a) Compression

The compressive strengths of PC, WDEO-PC, and WDEO-BFRCs are determined using a servo-hydraulic testing machine (STM). The test is carried out on PC, WDEO-PC, and WDEO-BFRCS cylinders in accordance with ASTM C39. Compressive strength (CS), compressive behaviour, compressive pre-crack (CE1) and post-crack energy (CE2), compressive total absorbed energy (CTE), and the compressive toughness index (CTI) of PC, WDEO-PC, and WDEO-BFRC are all assessed in this test. Plaster of Paris is used to cap the cylinder in order to distribute the load evenly throughout the cylinder.

b) Split-Tensile

For the splitting-tensile test, the ASTM C496M-02 standard is employed. The test is carried out on the same STM machine. The test is carried out on PC, WDEO-PC, and WDEO-BFRCS cylinders. The splitting-tensile test does not necessitate the capping of cylinders. Load-deformation curves, splitting-tensile strength (SS), splitting-tensile pre-crack energy absorption (SE1), splitting-tensile post-crack energy absorption (SE2), splitting-tensile total energy absorption (STE), and splitting tensile toughness indexes (STI) are all calculated based on the results of this test.

c) Flexural

The flexural test is carried out in accordance with ASTM C78 norms. It is decided to use a three-point loading method. The test is carried out on PC, WDEO-PC, and WDEO-BFRCS beamlets. Load-deflection curves, flexural strength (FS), flexural pre-crack energy absorption (FE1), flexural post-crack energy absorption (FE2), flexural total energy absorption (FTE), and flexural toughness indexes are among the characteristics investigated in this test (FTI).

3.4.3 Miscellaneous Properties

a) Water absorption

The ASTM C642 standard is used to calculate the water absorption parameters of PC, WDEO-PC, and WDEO-BFRCs [Table 3.2]. Specimens are first dried in the oven, and then placed in water at room temperature. The water absorption property of all types of specimens is determined using this procedure.

b) Linear Shrinkage

ASTM C157 / C157M-08 is used to assess linear shrinkage by monitoring and measuring fluctuations in the length of specimens (OPSS standard LS-435). Before conducting the test, a line of 6 inches is placed on the length of the specimens as a reference. After following the conventional process, the length variation is measured. The % difference in marked lenth before and after the test method is then used to calculate the linear shrinkage.

c) Mass Loss

The ASTM C157M-08 standard is used to determine mass loss in PC, WDEO-PC, and WDEO-BFRCs. Variations and shrinkage in the reference line are marked after following the test protocol before being evaluated. In a high-temperature heating oven, each type of concrete mix specimen is placed. The temperature is raised from 20○C to 100○C at a rate of 3○C per minute, and then held at that degree for one hour. This is done in order to gather data that is more realistic. The specimens are then cooled at 3C at the same rate as the temperature drops to eliminate thermal cracking.

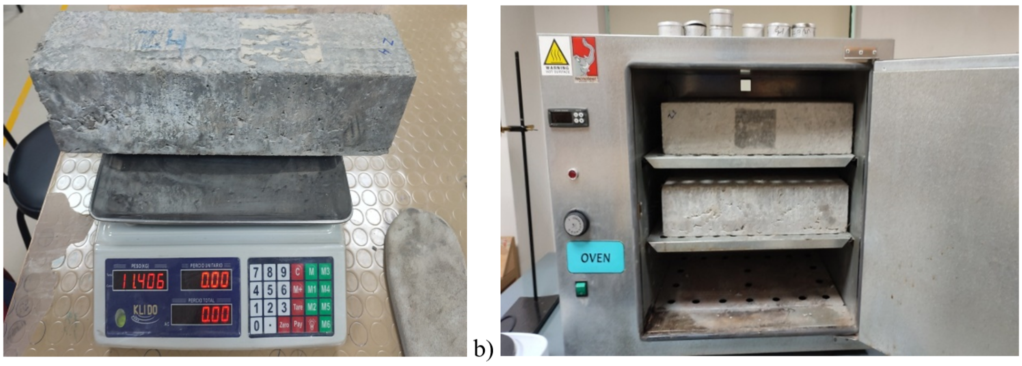
a)


FIGURE 3.4: a) Measurement of Weight for Water Absorption, b) Drying Specimens in Oven for the Mass Loss

3.4.4 Fractured Surface Examination

After the mechanical testing, the fractured surfaces of the broken specimens are carefully examined. Fiber breakage, pullouts, and bridging effects caused by fibres are investigated in this study. Micro analysis is performed on the broken surfaces of the tested samples for this purpose. The mixing of all the ingredients can be seen on the fracture surfaces, indicating whether it is a good mix or not. If the ingredients are mixed properly, the desired property is achieved; otherwise, the property may degrade rather than increase. The main goal of this research is to better understand fibre failure mechanisms and fibre bonding with the surrounding matrix.

3.5 Summary

For the preparation of PC, Wdeo-PC, and Wdeo-BFRCs, the most widely used mix design is 1:2:4. 0.5 w/c is used for the PC and Wdeo-PC, while 0.6 w/c is used for the Wdeo-BFRCs. The normal strength of this mix is up to 15 MPa. Due to lack of saturated surface dry condition of aggregates, 1:2:4:0.5 showed little less strength and it can be regarded with in acceptable range. Also the purpose of investigation is relative comparison. Therefore all other mixes are also prepared with same procedure. For the preparation of Wdeo-PC and Wdeo-BFRCs, a fixed amount of 9.4 percent of Wdeo-PC by mass of cement is used. In the production of Wdeo-BFRCs, different amounts of banana fibres (0.5 percent, 1.0 percent, 1.5 percent, 2.0 percent, and 2.5 percent) are added, based on the mass of the cement. There are 42 specimens in total, 28 of which are cylinders and 14 of which are beamlets. In slump, dynamic, mechanical, and other tests of PC,Wdeo-PC, and Wdeo-BFRCs, ASTM standards are followed. The results of each of the corresponding tests are discussed in detail in the following chapter (i.e., chapter 4).

Chapter 4

Results and Analysis

4.1 Background

For the preparation of PC, WDEO-PC, and WDEO-BFRCs, the most widely utilised mix design is 1:2:4. 0.5 w/c is utilised for the PC and WDEO-PC, whereas 0.6 w/c is used for the WDEO-BFRCs. For the manufacture of WDEO-PC and WDEO-BFRCs, a fixed amount of 9.4% WDEO by mass of cement is employed By taking the mass of the cement, different amounts of banana fibres (0.5 percent, 1.0 percent, 1.5 percent, 2.0 percent, and 2.5 percent) are added to make WDEO-BFRC0.5, WDEO-BFRC1.0, WDEO-BFRC1.5, WDEO-BFRC2.0, and WDEO-BFRC2.5. Each type of WDEO-BFRC uses a fixed length of BF of 5 cm. This task is focusing on comprehensive results from testing all PC, WDEO-PC, and WDEO-BFRC specimens.

4.2 Dynamic Behaviour

The combined effect of WDEO and BF on the characteristics of concrete specimens is examined using dynamic properties. ASTM C215-14 is used to determine the dynamic characteristics of concrete (PC) specimens. Because there is no unique standard for establishing the dynamic properties of the WDEO-PC and WDEO-BFRC, the dynamic properties of the WDEO-PC and WDEO-BFRC are calculated using the same standards.

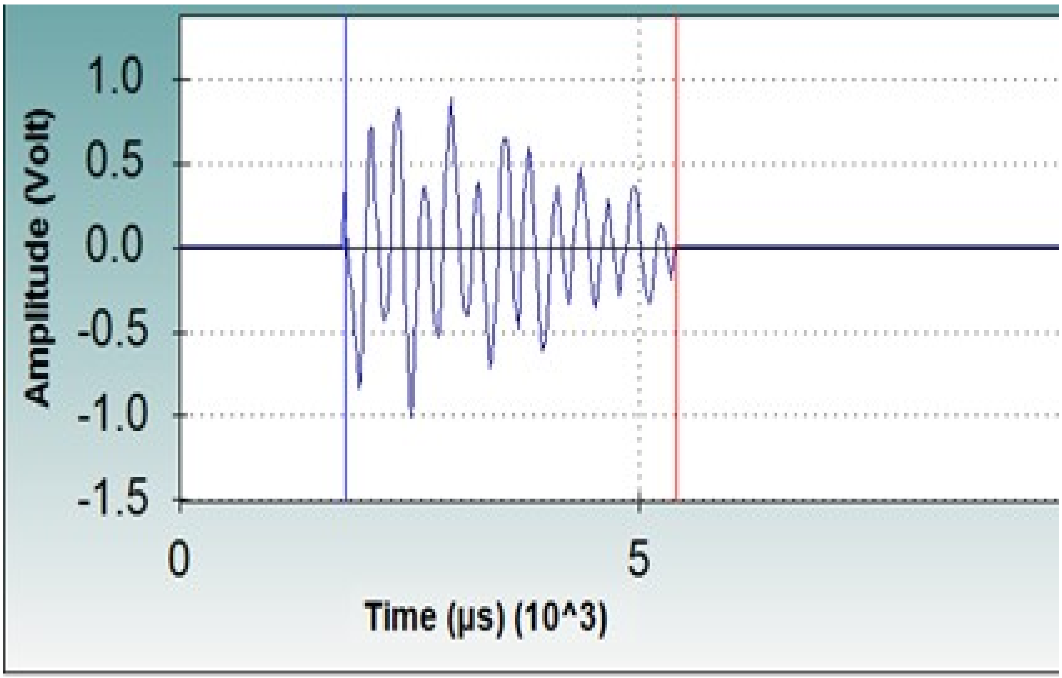


Figure 4.1: Typical Response Graph of Dynamic Testing

Figure 4.1 shows a typical graphical response captured on the accelerometer while executing the test. The examined dynamic properties of the PC, WDEO-PC, and WDEO-BFRCs are shown in **Table 4.1**. To acquire adequate results of matching dynamic properties, an average of two values is used. In the case of cylinders and beamlets, the damping ratio (ζ) of WDEO-PC is lowered by 35 percent and 15 percent, respectively, when compared to PC. As comparing the values with PC, the damping ratio of WDEO-BFRC0.5 WDEO-BF1.5 is reduced by 4.54% and 7%, while the values of damping ratios of WDEO-BF1.0, WDEO-BF2.0, and WDEO-BF 2.5 are increased by, 16%, 20%, 30% in the case of cylinders respectively.

In the case of beamlets, the damping ratio of WDEO-BF0.5, WDEO-BF1.0, WDEO-BF1.5, WDEO-BF2.0, and WDEO-BF2.5 are increased by 8.2%, 10.27%, 14.41%,24.72%, 29.82% in comparison with the damping ratio of PC respectively. Increment/decrement in damping ratio is directly related to resistence against dynamic loading. The resistance against the dynamic loading has been reduced by the additive influence of the WDEO. On the other hand, the addition of the BF has improved the resistance against the dynamic loading impact in comparison to the simple plain concrete.

Table 4.1: Dynamic Properties of PC, WDEO-PC, and WDEO-BFRCs

Concrete Specimen Type	**Parameter** RFL (Hz)	**RFT (Hz)**	**RFR (Hz)**	**(ζ) (%)**	**Ed (GPa)**	**Rd (GPa)**	**Poisson Ratio (-)**
Cylinders							
PC	3506±0	3350±66.5	3417±0	2.80±0.001	4.6±0	4.55±0.1	0.47±0
WDEO –PC	4416±86	3373±33	3506±0	1.80±0.002	6.75±2.3	4.55±0.1	0.31±0.18
WDEO -B0.5%	3395±22	3395±22	3506±44.5	2.14±0.008	7.5±2.8	4.4±0	0.53±0.03
WDEO -B1.0%	4127±13	4216±43	3129±19	2.62±0.014	7.05±2.5	3.65±0.2	0.385±0.105
WDEO -B1.5%	3307±22	3284±44.5	4083±87	3.35±0.003	6.75±2.3	6.4±2.7	0.435±0.035
WDEO -B2.0%	4216±54	3329±13	3906±64	3.56±0.019	4.3±.1	5.9±2.6	0.4±0.06
WDEO -B2.5%	3218±22	4128±22	3728±13	4.0±0.001	3.55±0.1	4.75±0.2	0.625±0.035

Continued Table: 4.1 Dynamic Properties of PC, WDEO-PC, and WDEO-BFRCs

Concrete	**Parameter**						
Specimen Type	**RFL**	**RFT**	**RFR**	**(ζ)**	**Ed**	**Rd**	**Poisson Ratio**
	(Hz)	**(Hz)**	**(Hz)**	**(%)**	**(GPa)**	**(GPa)**	**(-)**
Beamlets							
PC	3506±33	3395±11	3417±88.5	1.52±0.003	22.2±1.3	26.75±0.9	0.55±0.015
WDEO- PC	3306±15	3462±0	3417±44.5	1.37±0.001	24.2±1.8	23.35±0.2	0.515±0.055
WDEO -B0.5%	3395±21	3350±66.5	3173±22.5	1.82±0.002	24.1±0.1	23.55±0.4	0.515±0.55
WDEO -B1.0%	3506±0	3240±89	3240±89	2.13±0.001	24.1±0.8	27.15±1.3	0.55±0.02
WDEO -B1.5%	3373±17	3373±36	3240±89	2.21±0.004	22.85±1.9	28.15±1.7	0.6±0.05
WDEO -B2.0%	3461±44.5	3328±44.5	3262±24	3.62±0.021,	22.65±2.1	25.7±0.51	0.53±0.02
WDEO -B2.5%	3328±88.5	3240±44	3284±0	3.74±0.007	21.45±0.8	24.75±0.3	0.56±0.025

In the case of cylinders, the impact of dynamic modulus of elasticity (Ed) is enhanced by 6 % the 14.62 % addition of WDEO in concrete. The increament is observed in values of Ed of WDEO-BF0.5, WDEO-BF1.0, WDEO-BF1.5 ,3.12%,6 %,7.89% and after that WDEO-BF2.0, and WDEO-BF2.5 decreases by 2.85%,3 % respectively. The dynamic modulus of rigidity has shown better values in the case of WDEO-BF 1.5 % the cylinder than the beamlets. From this experiment, it is observed that the addition of the BF in concrete has improved the dynamic properties of the fiber reinforced concrete than that of plain concrete.

The increments are observed in both types, cylindrical test specimens and beamlets test specimens. This is an indication that the members made of WDEO and BF can resist and withstand more against the lateral loading in either it is a cylendrical or a bleamlet. These improved properties are the indications that the occupancy of some portion of BF in WDEO-BF can sustain more against impact loading and may enhance the durability against earthquake loading as compared to that of plain concrete.

4.3 Mechanical Behaviour

4.3.1 Compressive Strength Behaviour

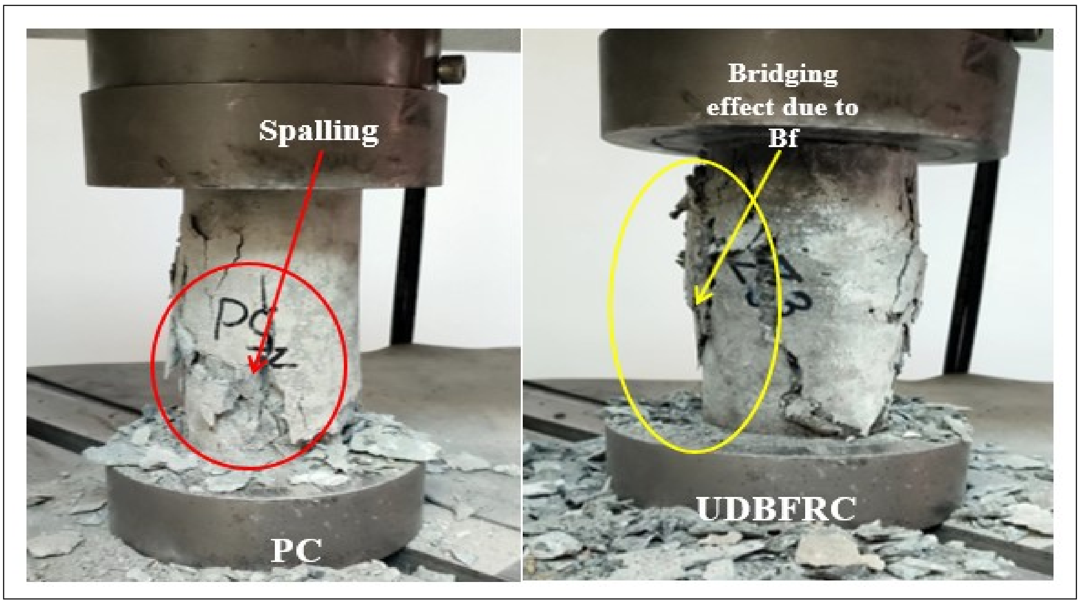
Figure 4.2 b. demonstrates the relationship between the stress-strain graphs of PC, WDEO-PC, WDEO-BF0.5, WDEO-BF1.0, WDEO-BF1.5, WDEO-BF2.0, and WDEO-BF2.5. It may be noted that WDEO-PC has shown the maximum value of the compressive strength (CS) in comparison with PC and all types of WDEO-BFRC. CS decreased by 16.49 % and 11.20 % in WDEO-PC, and WDEO-BF 0.5, respectively, in comparison with PC. However, there is a reduction of 20.49%, 27.70 %, 43.13 % and 64.70 % in CS of WDEO-BF1, WDEO-BF1.5, WDEO-BF 2 and WDEO-BF2.5 respectively. From this, it can be observed that the addition of WDEO decrease the CS and the addition of BF resulted in the reduction of the CS. The modulus of elasticity (MOE) of PC, WDEO-PC, and all types of WDEO-BF is shown in **Table: 4.2**. It can be observed that the MOE of WDEO-PC is 4 % more than the PC. On the other hand, the MOE of

WDEO-BF keeps on reducing with increase in the value of BF in the concrete. The values of MOE and CS are improved with the addition of WDEO in concrete while the addition of the BF has resulted in a decrease in the above-mentioned values. **Figure 4.2** shows comparison between typical failure of PC and WDEO-BF under maximum compressive loading under compression, shows the values of compressive pre-crack absorbed energy (CE1), compressive post crack absorbed energy (CE2), compressive total absorbed energy (CTE), and compression toughness index (CTI).

Figure 4.2 b illustrates relationship between stress and strain. It is easy to differentiate between elastic and plastic behavior of specimens under compressive loading. The CS of concrete has decrease when WDEO is added in normal concrete. On the other way around, the addition of BF has caused in negative effect. Hence, CS is decreased with an increase in content of BF. All these types of compressive absorbed energies are calculated as per criteria and method described by in the research studies[82]. There is an increment in CE1 0%, 25%, 15%, 45%, and 25% of WDEO-PC, WDEO-BF0.5, WDEO-BF1.0, WDEO-BF1.5, and WDEO-BF2.0, and a reduction of 62 % is observed in the case of WDEO-BF2.5. The most CE2 is noticed in WDEO-BF2.0 in comparison to the CE2 of the PC. The comparison between the compressive properties has been shown in Figure: 4.2 b. The increase in the values of the CE1, CE2, and CTI is due to the addition of the varied proportion of the BF. Further improvement is also caused by the incorporation of WDEO.

4.3.2 Split Tensile Behvaiour

The load-deformation curves for PC, WDEO-PC, WDEO-BF0.5, WDEO-BF1.0, WDEO-BF1.5, WDEO-BF2.0, and WDEO-BF2.5 are presented in **Figure 4.3** b. The graph of PC has moved towards zero after resisting peak loading. This means that the specimens of PC has not resisted any loading after occurance of first crack and it has failed suddenly. In **Figure 4.3** b, it can be observed thath WDEO-PC has followed and behaved same way as that of PC. The graph of WDEO-PC has also gone to zero after resising the its maximum load. Same



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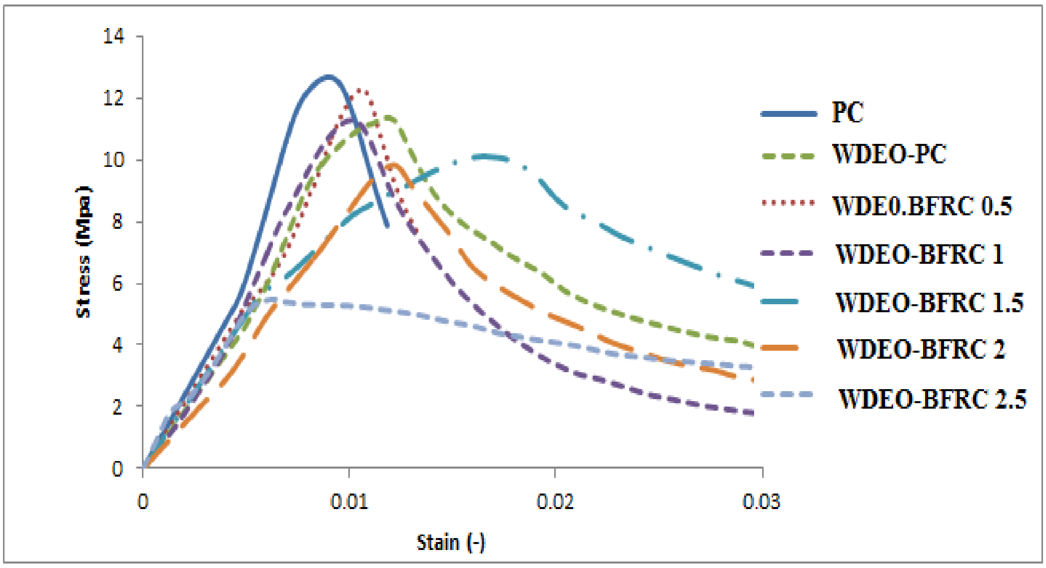
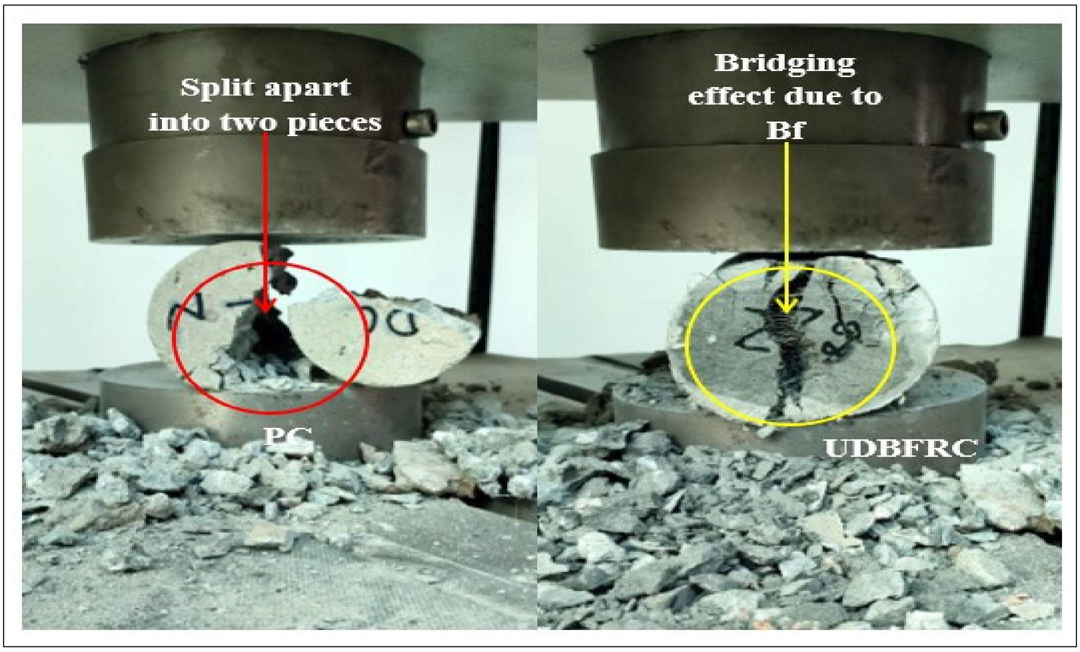


b

FIGURE 4.2: a) Typical Compression Behaviour of PC and WDEO-BFRC, (b) Compression Response of PC, WDEO-PC, and WDEO-BFRC

phenomenon is applied on WDEO-PC as that of PC. The PC has withstand and resisted more split-tensile loading as compared to WDEO-PC. This has indicated that the addition of WDEO has shown negative effect on splitting-tensile strength and caused a reduction splitting-tensile stregnth of concrete. SS reduced by 22.95 % and 8.74 % in WDEO-PC, and WDEO-BF 0.5, respectively, in comparison with PC. However, there is a increament of 22 %, 70 %, 66 % and 30 % in SS of WDEO-BF1, WDEO-BF1.5, WDEO-BF 2 and WDEO-BF2.5 respectively. This has proved that the addition of banana fibers has improved the splitting tensile strength. Also, it has absorbed some energy after appearance of first crack and did not failed suddenly as compared to PC and WDEO-PC. The addition of more quantity of BF has absorbed more post-crack energy along with more splitting-tensile strength. Figure 4.3a. shows comparison between typical failure of PC and WDEO-BF under maximum split tensile loading.



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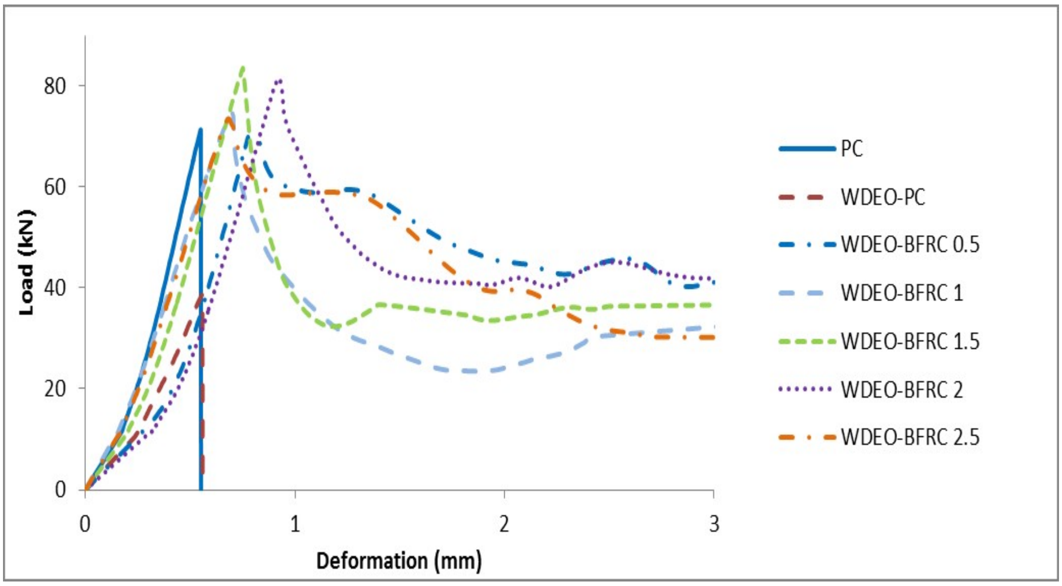


b

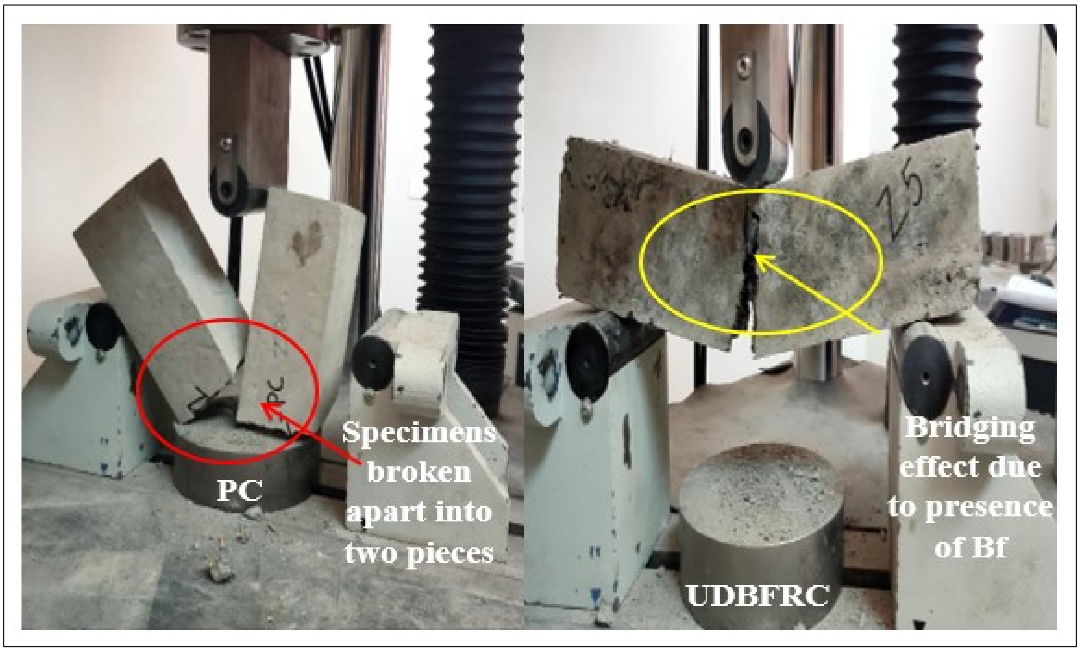
FIGURE 4.3: a) Typical Splitting-Tensile Behaviour of PC and WDEO-BFRC (b) Splitting-Tensile Response and Typical Failures of PC, WDEO-PC, and WDEO-BFRC

It can be noted that WDEO-BFs 1.5% has the maximum load as shown in **Figure. 4.3(a)** Also, after the maximum load, the WDEO-BF have shown load-carrying capability due to the bridging effect of BF.Under the section of splitting-tensile properties, splitting-tensile strength (SS), splitting-tensile pre-crack absorbed energy (SE1), splitting-tensile post crack absorbed energy (SE2), splitting-tensile total absorbed energy (STE) and splitting- tensile toughness index (STI) have shown in **Table 4.3.** These perameters are calculated as per the procedures describes by the research studies [37][82]. The presence of BF enhanced the spiliting-tensile strength of concrete.

4.3.3 Flexural Strength Behvaiour

Figure.4.4 shows the relationship between load-deflection curves of PC, WDEO-PC, WDEO-BF0.5, WDEO-BF1.0,WDEO-BF1.5, WDEO-BF2.0, and WDEO-BF 2.5 samples undeflexural loading. WDEO-BF2.0 has resisted the maximum flexural load as shown in **Figure.4.4**. It may be observed that maximum flexural strength in the case of the WDEO-BF 2.0 as shown in **Table 4.2**. The more deflection is experienced in WDEO-BF than the PC and WDEO-PC. This is just because of the bridging effect caused by the BF. Under the section of flexural properties, flexural strength (FS), flexural pre-crack absorbed energy (FE1), flexural post crack absorbed energy (FE2), flexural total absorbed energy (FTE) and flexural toughness index (FTI) has shown in **Table 4.2**.

The FS is increased and has shown maximum value in the case of WDEO-BFRC2.0 as compared with the other FS values of other specimens. This increase in FS is caused by the addition of the optimum value of BF in concrete. Beyond this, the value of FS is reduced due to the incorporation of the high content of BF other than the optimum content. FS increased by 7.5 %, 7.64 %, 11.76 %, 23.52 %, 33.52 % and 17.05 % in WDEO-PC, and WDEO-BF 0.5, WDEO-BF1, WDEO-BF1.5, WDEO-BF 2 and WDEO-BF2.5 respectively, in comparison with PC.The flexural pre-crack absorbed energy (FE1), flexural post crack absorbed energy (FE2), flexural total energy absorption (FTE), flexural toughness indexes (FTI) are calculated and shown in **Table 4.2**. The flexural pre-crack absorbed energy of WDEO-BF2.0, is increased , in comparison with FE1 of PC. This increament is caused by the presence of optimum content of BF. As, the WDEO has significantly reduced the FE1, WDEO-PC in comparison to that of PC. There is no flexural post crack absorbed energy in PC samples because PCs' samples are broken into two pieces under peak flexural loading. While All types of WDEO-BF have shown some of the FE2.



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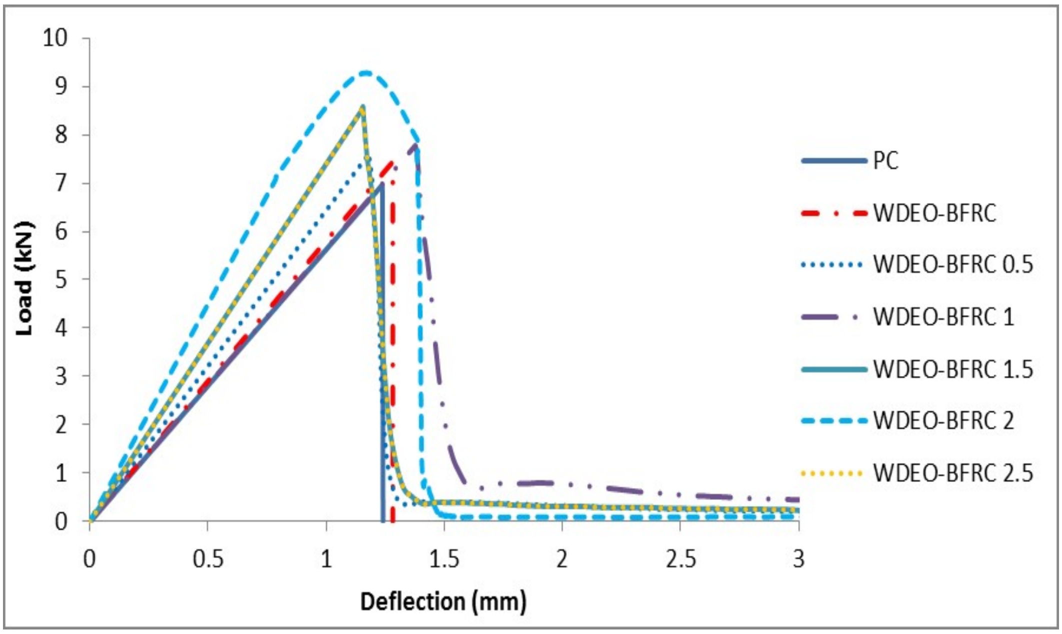

b

FIGURE 4.4: a) Typical Flexural Behaviour of PC and WDEO-BFRC, (b) Flexural Response and Typical Failures of PC, WDEO-PC, and WDEO-BFRC

Table 4.2: Compressive, Splitting-Tensile, and Flexural Properties of PC, UPC, and all WDEO-BFRCs

Concrete Type	Parameters: Compression Properties						Splitting-tensile Properties					Flexural Properties					
	MOE (GPa)	C-S (MP)	CPE1	CPE (Mj/m3)	CTE (Mj/m3)	CTI (-)	STS (MPa)	SPE1 (Mj/m3)	SPE2 (Mj/m3)	STE (Mj/m3)	STI (-)	F-S (MP)	Δ (mm)	FPE1 (Mj/m3)	FPE2 (Mj/m3)	FTE (Mj/m3)	FTI (-)
PC	25	12.67	0.04	0.02	0.072	1.68	1.83	14.56±	0	14.56	1	0.17	1.237±	1.664±	0	1.664	1
	±1.3	±1.4	±0.02	±0.009	±0.006	±0.54	±0.4	1.12		±1.12		±0.03	0.22	0.16		±0.11	
WDEO- PC	26	10.58	0.04	0.02	0.062	1.56	1.41	15.24	0	15.24	1	0.182	1.272	0.877	0	0.877	1
	±1.5	±1.8	±0.01	±0.14	±0.009	±0.61	±0.3	±1.2		±1.2		±0.025	±0.35	±0.14		±0.13	
WDEO-B0.5%	25.8	11.25	0.05	0.091	0.146	2.65	1.67	13.42	12.34	25.72	1.916	0.183 ±	1.821±	3.795 ±	2.203 ±	5.999±	1.580±
	±1.3	±2.3	±0.06	±0.021	±0.017	±0.83	±0.1	±1.49	±0.86	±2.53	±0.06	0.013	0.42	0.34	0.06	0.24	0.02
WDEO-B1.0%	26.9	9.82	0.046	0.082	0.026	2.76	2.24	17.31±	21.43	38.74	2.23	0.19	1.376	3.549	4.775	8.325	2.345
	±1.2	±1.8	±0.04	±0.017	±0.019	±0.94	±0.23	1.61	±1.43	±3.45	±0	±0.023	±0.67	±0.21	±0.05	±0.07	±0.01
WDEO-B1.5%	26	9.16	0.058	0.114	0.173	2.94	3.12	23.62	35.87	59.49	2.51	0.21	1.155	0.728	1.499±	2.227	3.058
	±0.4	±1.3	±0.02	±0.014	±0.021	±1.1	±0.4	±0.92	±2.23	±3.12	±0.05	±0.012	±0.43	±0.2	0.07	±0.16	±0.01
WDEO-B2.0%	25.9	7.205	0.05	0.118	0.177	3.01 ±	3.04	21.47±	31.63	53.1	2.47	0.227 ±	1.152	3.105 ±	7.64	10.74±	3.46
	±1.4	±3.1	±0.03	±0.013	±0.017	0.87	±0.21	1.39	±1.02	±2.64	±0.01	0.013	±0.13	0.09	±0.02	0.13	±0.03
WDEO-B2.5%	25.4	4.472	0.15	0.311	0.461	3.07	2.39	18.93±	26.44	45.17	2.38	0.199 ±	1.496	4.2	8.13	12.33±	2.93
	±0.3	±2.04	±0.09	±0.018	±0.002	±0.04	±0.12	1.29	±1.06	±2.23	±0.03	0.1	±0.55	±0.13	±0.09	0.21	±0.02

4.4 Absorption Properties

4.4.1 Water Absorption

Water absorption is given as a process of liquid transportation through the capillary action and is given as the total mass of absorbed water divided by the actual mass of the specimen after oven-dry (ASTM standard C642-13). **Table 4.3** shows the values of water absorption percentage of PC, WDEO-PC, and WDEO-BF; these are 1.36, 1.63, 1.90, 2.20, 3.52, 6.34 and 6.91 respectively. The water absorption for the WDEO-BF2.0 and WDEO-BF2.5 are relatively higher. And the water absorption values are increased with the increase in the fiber content. So, this shows that the water absorption property of concrete increased with the increase in the content of BF.

TABLE 4.3: Water Absorption, Linear Shrinkage, and Mass Loss of PC, WDEO-PC, and WDEO BFRCs

Concrete Type	Water absorption (%)	Linear shrinkage (%)	Mass Loss		
			@50°C	@75°C	@100°C
PC	1.36	0.147	-0.018	-0.137	-0.174
WDEO-PC	1.63	0.115	-0.021	-0.022	-0.192
WDEO -B0.5	1.9	0.11	-0.022	-0.035	-0.233
WDEO -B1.0	2.2	0.107	-0.024	-0.043	-0.425
WDEO -B1.5	3.52	0.105	-0.028	-0.046	-0.44
WDEO -B2.0	6.34	0.103	-0.029	-0.082	-0.465
WDEO -B2.5	6.91	0.081	-0.031	-0.086	-0.523

4.4.2 Linear Shrinkage

The high temperature oven is used for performing the mass loss test. The method decribed by ASTM standard C157M-08 is adopted to measure linearshrinkage and mass loss in PC, WDEO-PC, and WDEO-BF. The values of linear shrinkage PC, WDEO-PC and WDEO-BF are0.147, 0.115,0.110, 0.107, 0.105, 0.103 and 0.081 respectively. The decrease in the linear shrinkage's value with the increment in fiber content shows that the BF resists the linear shrinkage. The tensile stress is induced on concrete surface undergoing phenomenon of shrinkage. Less linear shrinkage is observed, with more BF, in concrete so it can be presumed that the use of BF may reduce the vulnerability to cracks of concrete. The value of linear shrinkage of WDEO-PC decrease in comparison to PC. This shows that voids are reduced by the addition of WDEO in concrete.

4.5 Role of Fibers in Concrete at Fractured Surface

The broken surfaces of fibrous concrete after applying mechanical loading are shown in Figure 11 WDEO-BFRC failure patterns and surfaces are discovered to be quite different from PC failure patterns and surfaces. Figure 4.5 shows after-mechanical-test images of fractured surfaces. These images investigate the interaction of banana fibres with the surrounding concrete. The images of the fractured surfaces show fibre pullout clearly. The banana fibres and the surrounding concrete matrix have a strong bonding strength, as seen in these images. On the broken surfaces of the tested specimens, there are very few and of extremely small size voids. These images can be used to check for proper and thorough mixing of concrete ingredients.

WDEO-BFRCs specimens are broken into small pieces after mechanical testing. Other minor and/or major broken particles are attached to these broken minor particles. The strong bridging effect of banana fibres with the composite caused this attachment of pieces/particles. These types of changes are caused by the presence of fibres and are not visible in plain concrete. Instead of fibre breakage, fibre pullout occurs at the location of the fracture surface after the failure. This shows that the specimen lasted a little longer than the PC due to the presence of fibres. Because of the bridging effect of banana fibres between the cracks, the sample continues to resist loading after the WDEO-BFRC specimen fails. After conducting the experiment, it was discovered that the presence of BF helps in the prevention of micro crack formation and progression.

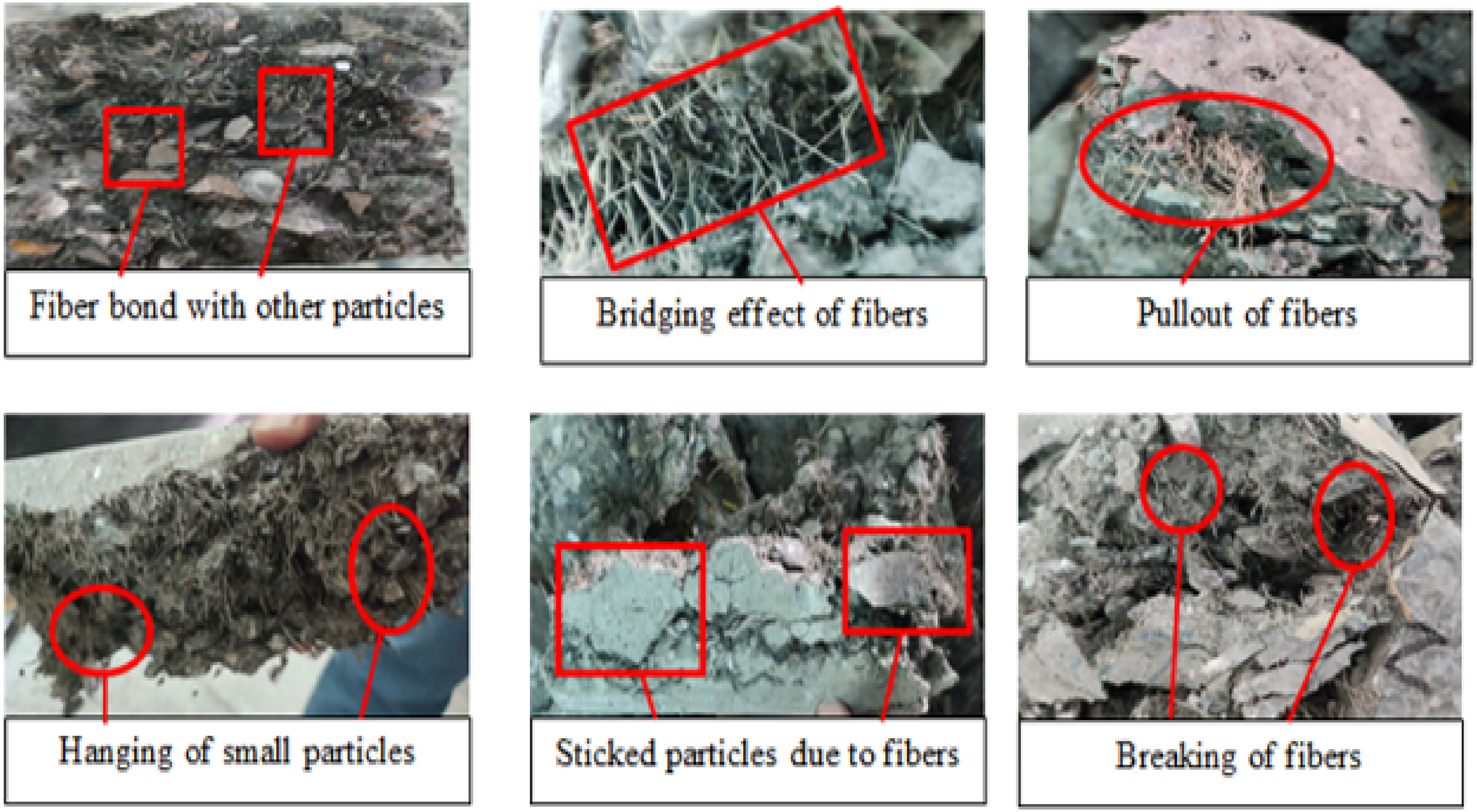

FIGURE 4.5: Fractured Surfaces of Different Tested Specimens

The fibres are added and mixed according to the method described in section 3.3. On the broken surfaces of the tested specimens, well-distributed fibres can be seen in each image of figure 4.5. Some small fragments (shown in the bottom right image of figure 4.5) are attached to the broken surface of the tested specimens via fibres. As a result, structural members with BF can withstand spalling. Due to the bridging effect caused by the BF, small fragments are attached to the broken surface of tested specimens.

4.6 Summary

Workability properties, hard concrete densities, dynamic properties, mechanical properties, water absorption, linear shrinkage, and mass loss properties are calculated using a 1:2:4 mix design with 0.5 w/c for PC and WDEO-PC and 0.6 w/c for WDEO-BFRCs in this chapter. Increased BF content in concrete improved the dynamic modulus of rigidity. The addition of WDEO increased the slump value of concrete due to liquid characteristics, whereas the addition of BF decreased the slump value of concrete for all WDEO-BFRCs. There is decreasing trend in slump due to addition of fiber content. Splitting-tensile strength, splitting-tensile toughness index, splitting-tensile pre-crack energy absorption property, splitting-tensile post-crack energy absorption property, and compressive toughness index have all increased in WDEO-BFRCs. The addition of WDEO reduced the flexural strength, while banana fibre improved the flexural strength. Concrete's splitting-tensile and flexural load resistance capacity was improved by BF. Water absorption has a direct relationship with fibre content, so increasing the BF content in concrete increases the water absorption property. However, linear shrinkage has shown that increasing the BF content has the opposite effect. When the amount of BF in concrete is increased, there is a greater loss of mass in the concrete. When the broken surfaces fractured specimens are examined, the BF has good bonding with the surrounding matrix.

Chapter 5

Guidelines for Practical Implementation

5.1 Background

Mechanical properties including compressive, split tensile, and flexural properties of PC and WDEO-BFRCs are studied in chapter 4. The results of the tests indicated quantitative data on the effect of fibre ratio on the qualities of Waste diesel-engine oil and banana fibre reinforced concrete.

The stress-strain, load-deflection, and load-deformation graphs show how fibres affect the mechanical and dynamic properties of WDEO-BFRC. This also includes discussions on WDEO-BF's practical implementation, optimization and recommendations in real-world applications.

5.2 Optimization of Banana Fiber Content with Waste Diesel Engine Oil

Table 5.1 provides details of maximum and minimum values obtained from mechanical and dynamic tests in comparison to values of PC. From the conducted study, for compression members like columns WDEO-BF having 0.5% of BF along with 9.4% of WDEO by mass of cement is recommended on the base high compressive strength than other WDEO-BF. The WDEO-BF composed having 2.0% proportion of BF is recommended for such structural members where the tension and flexural forces govern. In the case of the dynamic loading, the WDEO-BF having 2.0% of banana fibers along with 9.4% of waste diesel-engine oil has shown better properties. The **Figure 5.1** shows the variation of studied parameters comparison to that of PC.

It can be observed clearly that the addition of BF, by taking the mass of cement, in concrete has significantly influenced the properties of the concrete. The effects of the addition of different proportions of banana fibers can be seen in Figure 5.1. Some of the properties are significantly improved and others have an adverse effect on the banana fibers. The compressive strength (CS) decreases with the more quantity of BF but at the same time, the compression toughness index (CTI) improved with the addition of the banana fibers. The splitting- tensile properties of WDEO-BF are highly improved than compression and flexural properties. The flexural properties are affected in a progressive manner with the addition of the fibers. The addition of BF in percentages of 0.5%, 1.0%, 1.5% and 2.0% have improved both FS and FTI. By the addition of 2.5% of BF in concrete has shown that the addition of fibers more than 2.0% is the turning point of effect from positive to the negative the FS is reduced than the FS of 2.0% addition of the banana fiber.

5.3 Implementation in Real Life

Concrete is subjected to a variety of loading conditions in civil engineering applications, including mechanical and dynamic loading. These forms of loadings, such as compressive strength, tensile strength, and flexural strength, affect and control performance efficiency. These types of loadings have an impact on the concrete's durability. Due to excessive water absorption, more linear shrinkage, and reduced concrete strength in tension, cracks form in concrete [81]. Differential settlement can also induce cracking in rigid pavements, which can be addressed by increasing the flexural strength of the concrete. Concrete spalling is one of the problems.

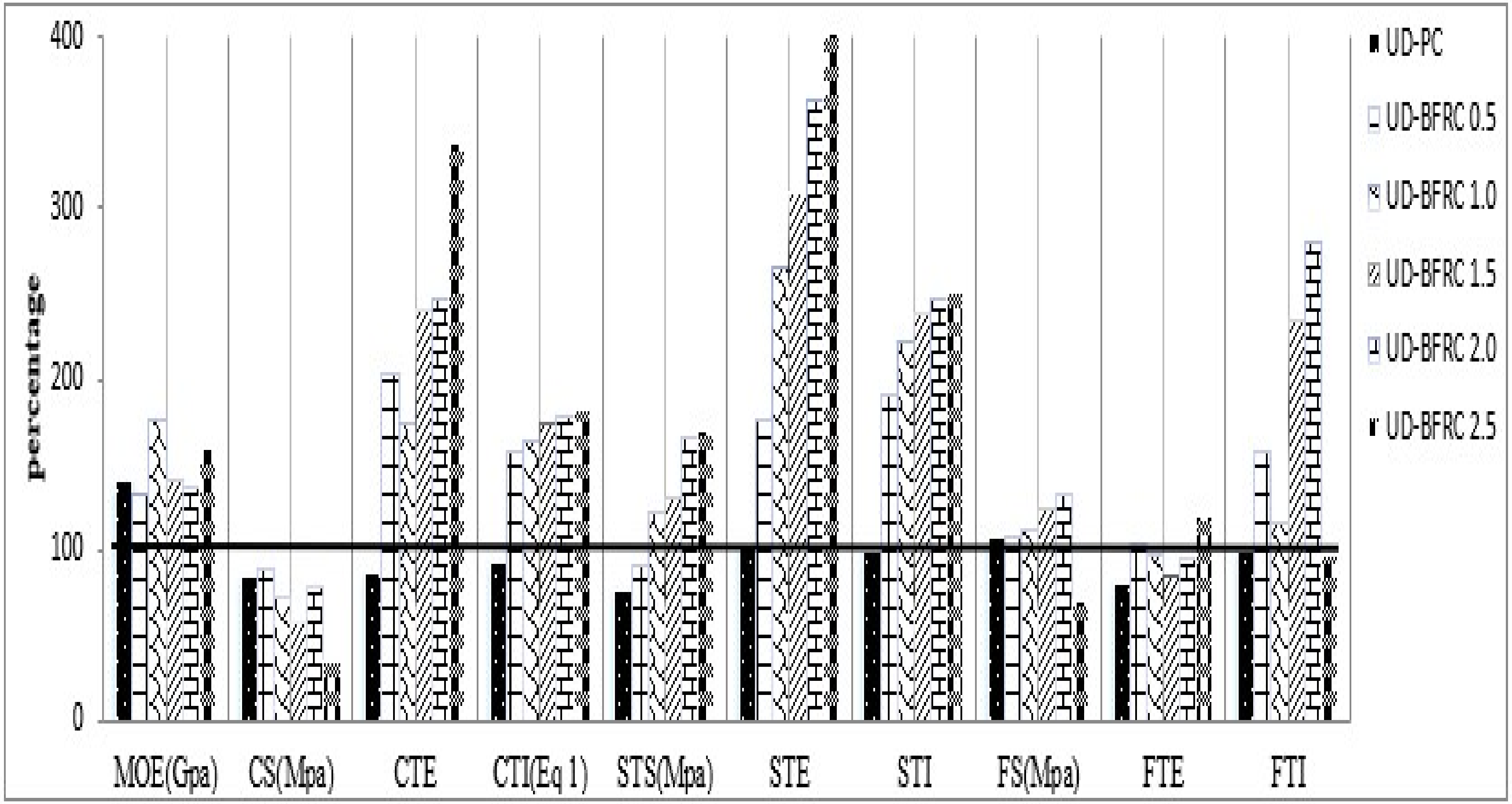

FIGURE 5.1: Effect of Percentage Difference of Banana Fibers Contents in WDEO-BFRCs

Table 5.1: Optimization of Banana Fiber Content with Waste diesel engine oil in WDEO-BFRCs

Concrete	**Compression**				**Splitting tensile**			**Flexural**			**Dynamic**		
Type	MOE (GPa)	C-S (MPa)	CTE (MJ/m3)	CTI (–)	STS (MPa)	STE (MJ/m3)	STI (–)	F-S (MPa)	FTE (MJ/m3)	FTI (–)	Damping ratio	DME	DMD
PC's Values	25	10.58	0.072	1.68	1.83	14.56	1	0.17	1.664	1	2.8	4.6±0	4.55±0.1
	±1.3	±1.8	± 0.006	± 0.54	±0.4	±1.12		±0.03	±0.11		±0.001		
WDEO-pc values	26	12.67	0.062	1.56	1.41	15.24	1	0.182	0.877	1	1.8	6.75	4.55
	±1.5	±1.4	± 0.009	± 0.61	± 0.3	± 1.12		± 0.025	±0.13		±0.0022	±2.35	±0.1
WDEO -B with minimum values	25.4	4.472	0.146	2.655	1.67	25.72	1.916	0.183	2.227	1.58	1.82	21.45	23.55
	±0.3	± 2.04	± 0.017	±0.83	± 0.1	±2.53	0.06	± 0.013	± 0.16	±0.02	±0.00,	±0.85	±0.45
	2.50%	2.50%	0.50%	0.50%	0.50%	0.50%	0.50%	0.50%	1.50%	0.50%	0.50%	2.50%	0.50%
WDEO -B with maximum values	26.9	11.25	0.1775	3.01	3.12	59.49	2.51	0.227	504.8	120.1	3.7 0.007	±24.1 0.8	±28.15 ± 1.75
	±1.2	±2.3	± 0.017	±0.87	± 0.4	±3.12	± 0.05	± 0.013	± 0.21	± 0.02			
	1%	0.50%	2%	2.00%	1.50%	1.50%	1.50%	2.00%	2.50%	2.50%	2.50%	1.00%	1.50%

Recommended	**WDEO-BFRC(0.5%)**				**WDEO-BFRC(1.5%)**			**WDEO-BFRC(2.0%)**			**WDEO-BFRC(2.5%)**		
For Strength Point of view	25.8	11.25	0.1467	2.655	3.12	59.49	2.51	0.227	10.74	3.46	3.7	21.45	24.75
	±1.3	±2.3	±0.017	±0.83	±0.4	±3.12	± 0.05	±0.013	± 0.13	± 0.03	±0.007	±0.85	±0.35
		0.50%				1.50%			2%			2.50%	
	WDEO-BFRC(2.0%)				**WDEO-BFRC(1.5%)**			**WDEO-BFRC(2.5%)**			(–)		
For toughness	25.9	9.82	0.1775	3.01	3.12	59.49	2.51	0.199	12.33	2.93	(-)	(-)	(-)
point of view	±1.4	±3.1	±0.017	±0.87	±0.4	±3.12	±0.05	±0.1	± 0.21	± 0.02			
			2%			1.50%			2.50%				
WDEO – BFRC (1.0%) for	26.9	9.82	0.026	2.764	2.24	38.74	2.23	0.190 ±	8.325	2.345	2.13	24.1	27.15
coloumns/compression member	±1.2	±1.8	± 0.019	±0.94	± 0.23	±3.45	±0	0.023	±0.07	± 0.01	±0.001	±0.8	±1.35
WDEO – BFRC (2.0%) for slabs and beams	25.9	7.205	0.177	3.01	3.04	53.1	2.47	0.227	10.74	3.46	3.6	22.65	25.7
	±1.4	±3.1	± 0.017	±0.87	±0.21	± 2.64	±0.01	±0.013	± 0.13	± 0.03	±0.021,	±2.15	±0.51
WDEO – BFRC (1.5%)	26	9.16	0.1734	2.94	3.12	59.49	2.51	0.21	2.227	3.058	2.2	22.85	28.15
for rigid pavements	±0.4	±1.3	± 0.021	±1.1	±0.4	±3.12	± 0.05	±0.012	±0.16	± 0.01	±0.046	±1.95	±1.75
WDEO –BFRC (0.5%) for	25.8	11.25	0.146	2.65	1.67	25.72	1.916	0.183	5.999	1.58	1.82	24.1	23.55
strucuture prone to lateral loading	±0.4	±1.3	±0.021	±1.1	± 0.1	±2.53	±0.06	±0.013	±0.24	±0.02	±0.002	±0.1	±0.4

Concrete spalling affects the durability of concrete and is caused by a variety of circumstances including exposure to high temperatures. Concrete spalling can be considerably decreased by increasing the tensile strength of the concrete with the addition of fibres in the composite[83]. Impact loads, such as blasting and car collisions with concrete bridge piers, can cause the structure to fail. The impact resistance of concrete can be enhanced by increasing its dynamic modulus of stiffness and energy absorption property[29].The behaviour of PC, WDEO-PC, and WDEO-BF is investigated in this study utilising waste diesel-engine oil WDEO and various banana fibre contents (BF). The WDEO-BF0.5 specimens performed better when subjected to compressive loading. WDEO-BF2.0 has better qualities against tension loading and can be used for members such as beams and slabs.

The flexural strength and modulus of elasticity of the concrete are taken into consideration while designing rigid pavements. As a result, WDEO-BF1.5 is more suitable since it has a higher modulus of rupture and modulus of elasticity, both of which are important aspects in the rigid pavement's stability and durability. The WDEO-BF0.5 is appropriate for compression members. These coloumns are either architectural coloumns or coloumns for single-story structures when strength capacity is not a major need (i.e., minimum size is fine). The WDEO-BF1.0 has proven acceptable compression strength as well as some resistance to moment forces. As a result, for those types of members where compressive loading is regarded critical, WDEO-BF1.0 is recommended.

5.4 Summary

The strength and toughness index are used to optimise in banana fibres, as well as the Waste Diesel-engine oil. The toughness is a property of material that can be analyzed in-terms of critical-stress intensity factor and also the ability of a material to absorb energy and plastically deform without fracturing. Separate recommendations are made in Table 5.1 for different type of mix. The fibers in concrete results in high post-crack energy absorption.The recommendations are also created for a specific application, allowing WDEO-BFRCs to be used in real-world scenarios.

Chapter 6

Conclusions and Recommendations

6.1 Conclusions

With the passage of time, the value of waste materials rises. Some of these wastes are extremely harmful to the environment. Waste Diesel-engine oil is one of these hazardous wastes. There is a need to dump these waste in an environmentally compatible manner in order to reduce the impact of environmental pollution-causing events. Waste Diesel engine oil plain concrete (WDEO-PC) and waste Diesel engine oil and banana fibers plain concrete (WDEO-BFRC) are inspected to evaluate the effects of waste Diesel engine oil WDEO and banana fibers (BF).

The properties of plain cement concrete are taken as reference. The dynamic properties, mechanical properties, water absorption property, linear shrinkage property, and mass loss of banana fibres (BF) were investigated using various percentages of banana fibres (BF) and waste Diesel-engine oil WDEO. By taking mass of cement, the different proportions of BF and WDEO are mixed in concrete.

- The addition of fibres improved the ability to withstand lateral loading as the valuve of damping ration increases with the addition of natural fiber content i.e., banana fiber.

- By increasing the BF content, the damping ratio improves, the dynamic modulus of elasticity improves, and the dynamic modulus of rigidity decreases in both cylinder and beam but it is greater at WDEO-BFRC 1.5%.

- The mechanical properties of concrete are influenced by the incorporation of the BF and WDEO.

  - Increases in BFRC had the opposite effect on concrete's compressive strength. The use of low density fibre results in a reduction in compressive strength when compared to pc.

  - When 1.5 percent and 2.0 percent of BF, respectively, are combined with 9.4 percent of WDEO, maximum splitting tensile and flexural strengths have been observed. The high tensile properties of the BF cause the increase in splitting tensile strength. Flexural and split strengths have been shown to be inversely related to the addition of fibres greater than 2.0 percent and 1.5 percent.

- The water absorption property of concrete has shown direct relationships with the increase in fibre content in concrete. Conversely, the presence of fibres has slightly increased resistance to linear shrinkage in concrete by increasing the value of fibres in concrete.

  - An increase in water absorption caused by an increase in the quantity of BF in FRC is one of the factors causing the concrete's workability to decrease.

  - WDEO-BFRCs have demonstrated good performance by not being vulnerable to spalling at high temperatures. This effect is observed as a result of the BF's enhanced resistance to linear shrinkage.

  - With increasing BF, mass loss is observed more in WDEO-BFRC. Mass loss has negative impact. This is due to BF's high water absorption capacity.

- The following recommendations are made based on a comparison of governing properties for a specific aspect while keeping other non-governing properties in mind. - WDEO-BFRC 1 for compressive and columns members.

  - WDEO-BFRC 1.5 for rigid pavements.

- WDEO-BFRC 2.0 for tensile structural members like beams and slabs.

- The Fexural qualities of WDEO-BFRC 2 are superior to any other form of WDEO-BFRCS.

- Based on a comparison of qualities with other WDEO-BFRCs, WDEO-BFRC 0.5 is recommended for members and/or structures prone to lateral loading.

According to the findings, concrete with 9.4% WDEO as an additive and 1.5% BF as reinforcement is advised to resist cracking, spalling, and flexural loading. This is also appropriate for rigid pavements since it has a high modulus of rupture and a reasonable modulus of elasticity. It has the highest splitting-tensile and acceptable flexural strengths compared to other variations, as well as better energy absorption and impact resistance.

6.2 Future Works

As a result, admixtures with natural fibre reinforced concrete have the potential to improve concrete properties by varying their content in the mix. The following works should be considered for future research to better understand the behaviour of WDEO-BFRCs:

- With a fixed content of banana fibre and varying proportions of WDEO, WDEO-BFRC should be investigated along with durability point of view.
- For each of the constant fibre contents, WDEO-BFRCs should be studied with varying fibre lengths.
- WDEO-BFRC should be studied with by using same admixture along with hybrid fibers.
- In addition to banana fibres, any other suitable admixture can be used in concrete. .

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