CAPITAL UNIVERSITY OF SCIENCE AND TECHNOLOGY, ISLAMABAD

Properties of Concrete Having Used Petrol-Engine Oil and Assorted Proportions of Banana Fibers

by

Blawal Hasan

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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 mostly used material in the construction industry due to its good properties which make it superior than any other type of the construction material. As it is the most superior material in construction industry, there are some serious flaws of this superior material caused by the brittle nature of concrete. These flaws include its vulnerability to the cracks, brittle behavior, spalling, more linear shrinkage. As far concrete has high strength in compression, it is weak in tension. Cracking is one of the severe drawbacks of concrete. It reduces the durability and service life of the structure. The splitting-tensile and flexural properties of concrete can be enhanced by using natural fibers along with some admixtures. On the other hand, there is a growing interest of using of residual waste, as a raw material, for the manufacturing of the sustainable material is increasing day by day in the developing countries. These residual wastes include severe damaging chemical to the environment like used petrol-engine oil. The other type of residual materials is agricultural waste (banana fibers) which is abundantly available in developing countries. The use of these types of waste can help in developing the environmentally friendly materials. To improve the properties of concrete banana fibers can be used as dispersed reinforcement and used petrol-engine oil as chemical during the manufacturing of the concrete.

In this research work, natural fibers along with chemical admixture are added in concrete to enhance the properties and improve the performance of the concrete. Banana fibers (BF) are used as a reinforcement and used petrol-engine oil (UPEO) is added a chemical admixture. For this purpose, four cylinders and two beamlets are prepared for plain concrete (PC), with addition of fixed amount (9.4%) of used petrol-engine oil plain concrete and concrete having used petrol engine oil and different proportions of banana fibers (0%, 0.5%, 1.0%, 1.5%, 2.0%, 2.5%). The water cement ratio (w/c) of 0.5 is used with mix design 1:2:4 (cement: sand: aggregates) for preparation of PC and used petrol-engine oil plain concrete (UPC). The 0.6 w/c is used along with the mix 1:2:4 for the preparation of fiber reinforced concrete (FRC). For the preparation of used petrol-engine oil and banana fiber reinforced concrete (UBFRC), fixed amount of UPEO is used while amount of the

BF is varied. The slump, dynamic, mechanical, water absorption, linear shrinkage, and mass-loss tests are performed to determine the influence of BF and UPEO on properties of concrete. Average of two specimen of each type of concrete and test is taken to evaluate the every type of the observing property.

From obtained results of tests, analytical and empirical equations are developed. The relationships of compressive strength, splitting-tensile strength, and flexural strength are developed in these equations with fibers content. From the slump test's results, it is observed that the concrete having UPEO only has shown more slump value than other type of concrete. The decrease in workability of FRC is noticed with the increase in amount of the banana fibers. The performance of the UBFRC with 2.0% content of fibers has shown better performance against the dynamic loading. The results have shown that UBFRC having 2.5% and 2.0% amount of the BF has more tensile and flexural strengths, respectively, comparing with others. Also, the compression toughness index and splitting tensile toughness indicies are enhanced significantly with increase in the quantity of BF in the concrete. The decrease is noticed in compression strength of specimens with the increase in the content of fibers. By increase in fiber content in concrete, water absorption increased and linear shrinkage is decreased. Thus, it is concluded that the optimum value of fiber content in concrete for tension members is 2.0% and has better performance against tensile, flexural and dynamic loadings. For the compression members, UBFRC prepared with 0.5% content of fibers has shown better performance than other types of UBFRCs.

Keywords: Banana Fibers, Dynamic Properties, Fiber Reinforced Concrete, Mechanical Properties, Used Petrol-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
SS	Splitting-Tensile Strength
STI	Splitting-Tensile Toughness Index
STM	Servo-Hydraulic Testing Machine
UBFRC	Used Petrol-Engine Oil Banana Fiber Reinforced Concrete

UEO	Used Engine Oil
UPC	Used Petrol-Engine Oil Plain Concrete
UPEO	Used Petrol-Engine Oil
W/C	Water-Cement Ratio
Δ	Deflection / Deformation
ζ	Damping ratio

Chapter 1

Introduction

1.1 Background

In this modern age, concrete is backbone material for the building construction. It is quite hard to anticipate the phenomenon of the material that might substitute the concrete before long. But concrete itself is a quasi-brittle materials having very low tensile strength compared to compressive strength [1]. 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 [2, 3]. It is required to add fibers and admixtures in concrete to meet with high performance, attaining certaion properties, and developing a sustainable material [4].

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. 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 [4]. FRC is concrete having dispersed short discrete fibers, this makes FRC to be studied carefully taking in consideration functionality of fiber within the mix.

Many researchers attempted to improve the governing properties of concrete for the production of the high-performance concrete. Used petrol-engine oil (UPEO) has been used as a chemical admixture by many researchers for reducing cement content in concrete or as an admixture. Concrete emits carbon di oxide approximately equal to clinker for production [5]. 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 UPEO reduces 9.4% cement content in concrete with comparable properties of plain concrete [6].

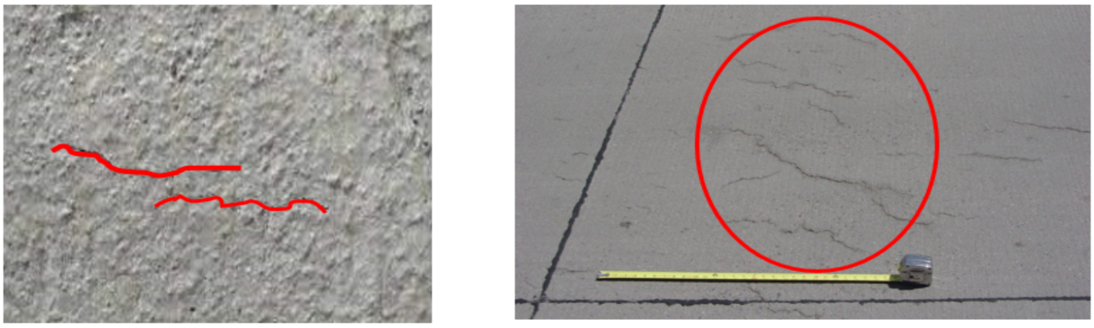
By both, reducing cement content and adding UPEO result in production of more economical production of the concrete. On the other hand, several researchers reported that concrete composed of fibers enhanced the flexural, tensile strength and resistant against spalling, cracking and fatigue. The improved properties, like flexure, tensile and compression, can improve the performance of the concrete for the desire application. In fact, the tensile strength also resists the crack production in concrete. Resistance against impact loading, flexural strength, and splitting tensile strengths are significantly enhanced by the addition of the fibers [5]. Numerous mechanical properties of cementitious composites can be effectively enhanced by introducing fibers in it.

1.2 Research Motivation and Problem Statement

Concrete is a such material which inherent certain issues like appearing of cracks in structural members even from day one. These cracks can be found on different structural members as shown in **figure 1.1**. These cracks affect the service life of structure and structural members. If such cracks can be delayed than service life can also be extended. That's why, what can we do is to have sustainable concrete preferably no or minimum cracks at the start. As, the main concern of this research study is to mitigate or reduce the impact of these shortcomings. The failure of concrete structures can result in the loss of human lives and loss of money. That's why it is required to avoid the failure of the concrete in different scenarios of applications and loadings. The use of natural fibers has been reported to enhance the properties of concrete to avoid its failure. There is need to adopt modern methods in the construction industry. Also, it is needed to aware people regarding high-performance and sustainable material.

Cracks in Compression Member

Cracks in Beams



Early Age Micro-Cracking in Slab

Plastic Shrinkage Cracking in Rigid Pavement

FIGURE 1.1: Cracking in Different Application of Concrete

There are also research studies available on improving concrete properties by the addition of the admixture. But there is a need to use the other hazardous/toxic waste materials (like UPEO) to avoid environmental pollution and to take a step towards the development of sustainable and cleaner production. Thus, this study is aimed to take a step toward utilizing the waste materials in an effective way and to avoid uneconomical dumping of these materials. Based on the relative comparison, this research work is limited to experimental investigations. The requirement of the volumetric concrete can be reduced by enhancing the strength of concrete so the requirement of the volume get reduced by the improved properties of concrete. This is the term directs to enhancement of the mechanical properties of concrete.

Moreover, this study will help researchers to provide guidelines and a way of thinking to utilize the wastes and environmental pollution causing materials in construction materials instead of dumping of these materials. The dumping of these materials is a time taking and can be costly. Thus, the problem statement is as follow;

In the building construction, use of concrete is becoming inevitable day by day. The concrete is weak in tension, less resistive against lateral loading, and quasi-brittle material. The change in temperature cause volumetric change in concrete. This change is the key to production of drying shrinkage cracks. These flaws of concrete are needed to overcome and to improve the properties of concrete.

1.2.1 Research Questions

Followings are research questions which are explored in this study;

- How much performance of concrete can be improved with used petrol-engine oil in normally used properties of concrete (i.e. 1:2:4).
- What are the combined effects of banana fibers and used petrol-engine oil on dynamic and mechanical properties of concrete?
- How much splitting tensile strength can be enhanced in comparison to compromise with compressive strength?
- How concrete made of used petrol-engine oil and banana fibers can be used for the specific real-life applications?

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

The overall goal of the research program is to precisely take a step toward development of the high-performance concrete with the help of waste materials for building construction and civil engineering applications. As concrete has several flaws, and some of these flaws affect the performance of structure and decreases the durability of concrete. There is a need to use the waste materials (instead of dumping them) in construction materials because it is reported to have good potential for bringing better impact in cementitious compostie.

The specific aim of this MS research work is to study the combined effect of banana fibers (BF) and used petrol-engine oil (UPEO) on physical properties of normal plain concrete prepared by BF and UPEO and comparing with plain concrete's properties.

1.4 Scope of Work and Study Limitations

The workability, mechanical properties, dynamic properties and absorption properties of concrete are investigated by taking two specimens for each property of used petrol-engine oil and banana fiber reinforced concrete (UBFRC) and used petrol-engine oil plain concrete (UPC). The average of two specimens is taken according to acceptance and recommendation of ACI 311.6-18 standards. Dynamic properties are studied before investigating the mechanical and absorption properties. After appearance of first crack on specimen, it is considered as failure after load application. Other miscellaneous properties like linear shrinkage and mass loss are also examined in this study.

The study is purely limited to mechanical, dynamic and absorption properties of UBFRC specimens. In this scope of study, durability of UBFRC is not included. Influence on performance and resistance against the impact loading is not considered in this study. The fibers are used of fix length with varying content for different UBFRCs with fix amount of the UPEO.

1.4.1 Rationale Behind Variable Selection

Fiber's type selected on the superiority of physical properties comparison to other [65]. Banana fibers has high tensile strength among the natural fibers. And also, these banana fibers are likely to be compatible to use with UPEO [66]. The many other natural fiber can easily get damaged by acidic property of UPEO [67]. Different length and size will help in better mixing to achieve good improved properties.

1.5 Novelty of Work, Research Significance and Practical Implementation

In an experimental work, it was revealed that resistance against impact loading significantly improved by the addition of the natural fibers in concrete [7]. The mechanical properties of concrete were observed to be improved by the addition of natural fibers [8]. Previous conducted studies show that properties of concrete and performance of structure were improved with different types of natural fibers and admixtures. To the best of author's knowledge, no research has been conducted on combined effect of used petrol-engine oil and banana fibers on production and properties of concrete. Thus, the current study is aimed to study the basic mechanical, dynamic and absorption properties of UBFRC using used engine oil and banana fibers. This material is resulted in production of improved properties of concrete for the use in civil engineering and construction industry.

There are several flaws of concrete like cracking, spalling, weak in tension, etc. So, there is a need to mitigate these flaws of concrete. The addition of fibers in concrete resulted in improved durability and enhanced resistance against production and progression of cracks [9]. Fiber reinforced concrete have shown the improved properties in comparison with respect to the properties of the PC. According to a research, fiber reinforced concrete (FRC) beams along with fiber reinforced polymer bars as reinforcement has shown better performance [10]. In Previous studies, single fiber or combination of two fiber was used in concrete for improving its properties. The very limited studies are available in which artificial fibers were used along with an admixture. Therefore, utilization of natural fibers and used petrol-engine oil are way better to be used for improving the properties of concrete, as it cleaning the environment as well by using the UPEO. Banana fibers has the high tensile strength in comparison with the other natural fibers [11]. Hence, there is need to investigate its effect on different properties of the concrete.

The concrete having UPEO can directly be practically implemented at locations where it does not have direct contact with environment. For example, this can be used as lean concrete beneath the foundation. Also, lean concrete is covered within the soil and it has no contact with the air and protected from the chemical attacks of environment. However it seems to have potential for structural applications. If used with great care about its pros and cons.

1.6 Brief Methodology

In this experimental study, the basic mechanical, dynamic and absorption properties of Plain Concrete (PC) Used petrol-engine oil Plain Concrete (UPC), and used petrol-engine oil Plain Concrete and banana fibers reinforced concrete UBFRC are determined in laboratory. All UBFRCs are prepared with varing contents of banana fibers having fixed length of 50 mm. Fixed amount of used petrol-engine oil plain concrete is used in manufacturing of UPC and all types of UBFRCs. Most conventionaly used mix design 1:2:4 is used in manufacturing of PC, UPC, and all UBFRCs. For PC and UPC, 0.5 water-cement ratio (w/c) is used whereas 0.6% w/c is used in making of all types of UBFRCs. The w/c is enhanced due to high water absorption of banana fiber as reported by [71]. The value of w/c is restricted to 0.6 because of addition of UPEO which is, also, a liquid. Otherwise, 0.7 w/c ratio had been used due the water absorption of natural fibers in cement composites [46]. The slump cone test method is adopted to evaluate the workability of PC, UPC, and UBFRCs. All specimens are cast and tested as per the ASTM standards. After performing the slump test, total 42 number of specimens are cast of PC, UPC, and UBFRCs. Total four cylinders and 2 beamlets are casted of each type of prepared concrete. Two cylinders of each type are used in investigating the compression properties and rest of two are used in determining the splitting-tensile properties of concrete. Flexural properties of every type of prepared concretes are explored by three-point loading setup on casted beamlets. Servo-hydraulic testing is used to conduct the different types of mechanical tests. Following flow chart shows the brief description current study [figure 1.2].

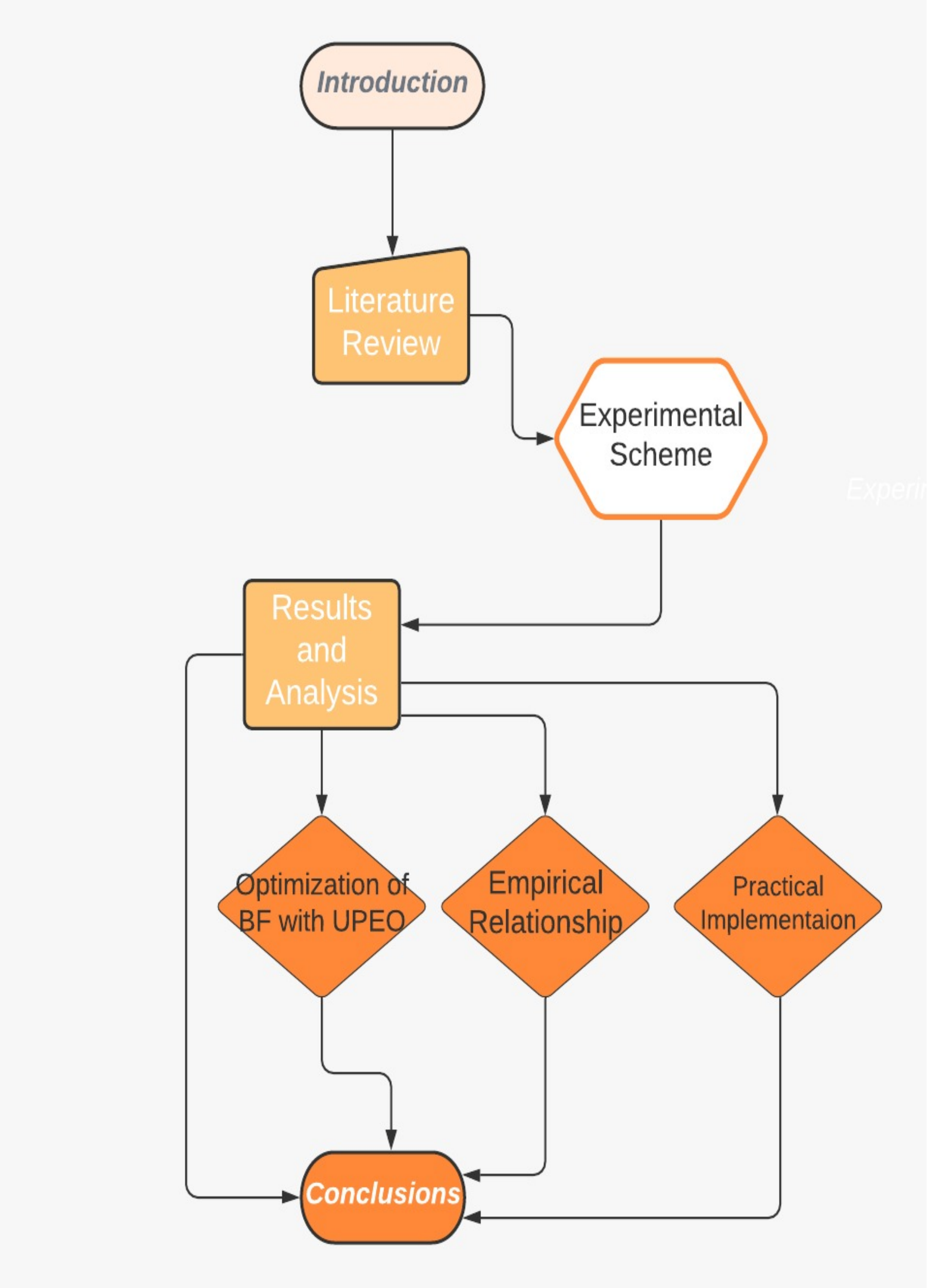


Figure 1.2: Flow Chart of Current Experimental Study

Before the performance of mechanical testing, the dynamic properties are investigated with the help of accelerometer and a hammer. Response-frequency longitudinal (RFL), response-frequency transvers/lateral (RFT), and response-frequency rotational/torsional (RFR) are noted by attaching the accelerometer to the specimen and applying a stroke of hammer for according specific setup of determination of desired frequencies.

These frequencies are than used to evaluate the dynamic properties of the all types of manufactured concrete. The fractured surfaces of broken specimens are closely examined as well to check the mixing of fibers within the concrete, bonding of fibers with surrounding cementitious matrix, fiber pullout, and fiber breakage etc.

1.7 Thesis Outline

The thesis contains six chapters. These are:

Chapter 1 incorporates of introduction. It covers the background, research motivation and problem statement, overall and specific research aims, scope of work with study limitations, brief methodology, and thesis outline.

Chapter 2 contains the literature review. It comprises of background, used petrol-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. This chapter consists of the experimental scheme, raw constituents, mix design casting of specimen, testing, and summary of chapter 3.

Chapter 4 includes the results obtained from tests and their analysis. It describes the background, dynamic properties and mechanical properties of the mixes (PC, UPC, and UBFRCs), miscellaneous properties (water absorption, linear shrinkage, and mass loss), fractured surfaces of tested specimens, and summary of chapter 4. Chapter 5 explains the Guidelines for practical implementation, it has background, optimization of banana fibers with used petrol-engine oil, empirical relationship, practical implementation, and summary of chapter 5.

Chapter 6 consists of conclusions and future recommendation

Chapter 2

Literature Review

2.1 Background

Fibers are being used for enhancing the mechanical strength parameters and performance of composite since ancient time. It has been proved that the fiber reinforced concrete has better mechanical properties, like energy absorption, toughness index and more resistant to lateral loading. It is requirement of current age to explore the effects of natural fibers for improving properties for a specific application.

2.2 Use of Wastes as Construction Materials

In the terms of environmental conservation, the interest in the use of waste materials as raw materials is growing in the construction industry with the passage of time. Many researchers used different types of waste materials to investigate the influence on properties of concrete. To take a step toward sustainable development of construction material and cleaner production, different researchers have used the recycled aggregates within the concrete [1, 12, 13]. Different researchers have utilized ceramic waste and glass fiber plastic wastes in concrete [14, 15]. 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 was added as a dispersed reinforcement in concrete and explored the effects on properties of concrete [8]. 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. 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 [6]. There are waste materials other than UEO which can be used as raw construction materials (like engine coolants) in concrete [16]. The research work was conducted to investigate the fresh and hardened properties of concrete having used engine oil [17]. The additive influence of used/waste engine oil on the behavior of reinforced structural elements was investigated and explored that waste engine oil did not leave significant adverse effects on the structural members [18]. As there are tons of waste engine oil available, it cannot be stored and re-used in an effective way. The used 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. Dumping of this waste covers a large part of precious land and also this is dangerous to human health [19]. 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.

2.2.1 Used Petrol-Engine Oil

In the transportation sector, the use of vehicles is increasing day by day. The main part of the vehicle is the engine that needs good lubrication for good functionality. These lubricants are needed to replace after a specific running of motor/engine. Used petrol engine oil (used engine oil) is more dangerous to the environment than crude oil as it contains contaminated heavy particles. It doesn't only have the contamination of the heavy particle but also polycyclic aromatic hydrocarbons (PAHs) that are insignificant in the unused oil. The used engine oil (or used petrol engine oil) badly affects the male reproductive parameter [19]. **Table 2.1** shows the composition/charaterization of used engine oil in comparison with ordinary portland cement

Table 2.1: Characterization of Ordinary Portland Cement (OPC) and Used Engine Oil (UEO) [72]

Chemical Composition	Ordinary Portland Cement (%)	Use engine Oil (%)
SiO_2	21.98	-
Al_2O_3	4.65	-
Fe_2O_3	2.27	0.42
CaO	61.55	15.9
MgO	4.27	-
SO_3	2.19	37
K2O	1.04	-
Na_2O	0.11	-
P_2O_5	-	8.95
ZnO	-	17.7
Cl^-	-	15.9

Waste engine oil can be utilized as a chemical admixture in the concrete. According to research work, waste engine oil fulfills the requirement of the type A water reducer admixture in the concrete according to standard ASTM C494 [6]. The different researchers utilized used engine oil (UEO) in different types of composites. In different researches, UEO and waste cooking oil was utilized to compare and improve the performance of the asphalt pavement [19, 20]. The results of research work indicated that there was no significant increase observed in the probability of low temperature cracking due to the use of UEO in asphalt pavement [21, 22].

On the other hand, there are several research works were reported on concrete with the addition of UEO. The waste of fat and oil industry was used as an admixture in concrete for the economic way of dumping and cleaning the environment [23–25]. In research work, expanded clay aggregates were produced, with the help of UEO, to use in the production of lightweight concrete [27]. The used petrol-engine oil (UPEO) 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 UPEO [28]. **Table 2.2** shows the effect of UEO on the workability and mechanical properties of the concrete. The reduction in crack width was also observed in flexure failure and slump value and compressive strength was also increased when UEO was used in concrete in comparison with concrete made with super plasticizer [29].

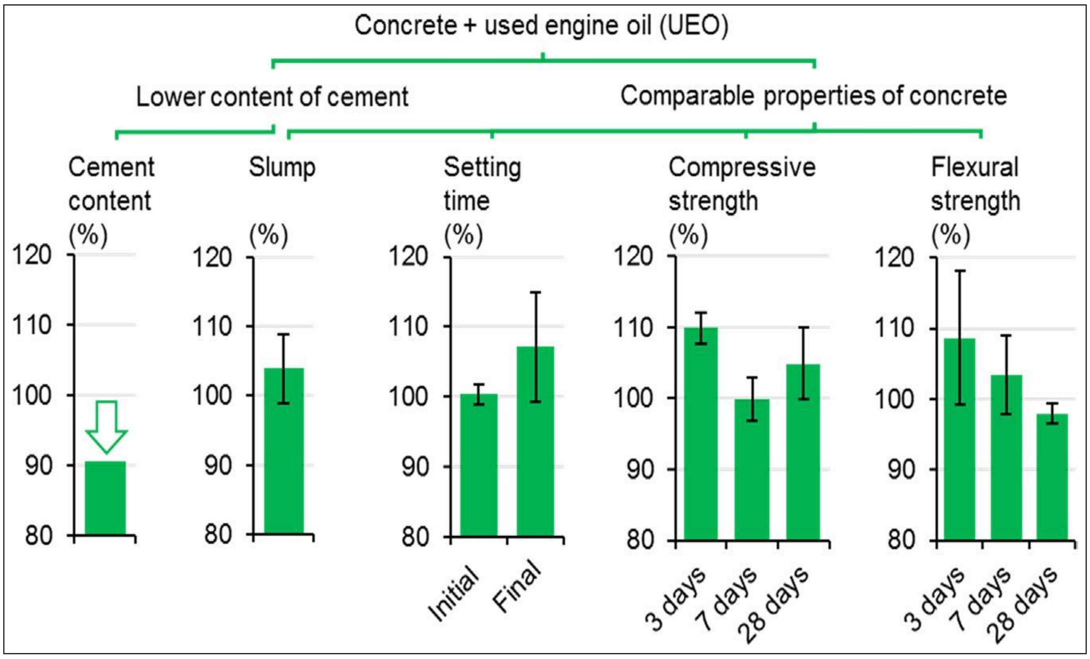


FIGURE 2.1: Effects of Addition of Used Engine Oil (UEO) on Concrete's Properties [6]

Table 2.2 shows the that used engine oil has the potential to improve properties of concrete. In an experimental, researchers replaced 9.4% of UEO with cement in production of concrete. It is observed the compressive strength improved and flexural strength decreased by 5% and 2%, respectively [6]. The researcher added 0.15% of UEO by mass of cement in manufacturing of concrete and observed 19% reduction in compressive strength of concrete. In another study, the addition of 0.15% of UEO was made to explore different strength parameter of the concrete [17]. There was decrease in the compressive strength and flexural strength by 3.72% and 7.81%, respectively. On the other hand, increase of 4.76% was noticed in split tensile strength of concrete by the addition of UEO.

Table 2.2: Effects of Addition of Waste Engine Oil (UEO) on Concrete's Properties

***UEO Content %**	**Addition / Reduction in cement**	**Slump Percentage increment**	**Strength % Value @ 28days with reference to PC**			**References (-)**
			Compressive strength	**Splitting-tensile strength**	**Flexural strength**	
9.4	Reduction	104%	105	-	98	Yaphary et al. (2020)
0.15	Addition	140%	81	-	-	Shafiq et al. (2018)
0.15	Addition	150%	96.28	104.76	92.19	Hamad et al. (2003)

*UEO content percentage is taken by the mass of cement

An experimental work was conducted to evaluate additive effects of used engine oil (UEO) in concrete and affected results are shown in **Figure 2.1**. For this, some amount of cement was replaced with UEO and compressive strength and flexural strengths were investigated. The investigated properties include workability, initial setting time, air content, drying shrinkage, compressive and flexural strengths, and durability of UEO add concrete with reference to the plain concrete. The **Figure 2.1** shows the influence of UEO in concrete. UEO fulfills the ASTM C494 and it can be used as water reducing admixture.

According to this research, up to 9.4% mass of cement can be reduced and replaced with the UEO. It can be observed clearly that UEO 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.

2.2.2 Banana Fibers

Many researchers have utilized the natural fibers in composites in a different manner and analyzed the expected effects caused by the addition of fibers. Researchers used coconut fiber for the plastering of the surface of structural members and walls [30]. In a research study, an improvement was observed in out-plane lateral loading of the column with natural fibrous plaster on the column [31]. The researchers illustrated in a research that the treated fiber within the cement mortar improved the characteristics and durability properties of the composite [32]. Coconut fibers and coconut-fiber ropes were used in studies to enhance the resistance against the dynamic loading and significant improvement was noticed [33, 34].

In a research work the influence of natural fibers on self-compacting concrete was investigated [35]. Increment in the length of wheat straw fiber resulted in an increase in pullout peak load and pullout energy [36]. Natural fiber act differently in cement mortar and lime mortars. Natural fibers acted in favor of durability and the strength of the cement mortar [37]. A good mix design, more amount of fibers, and a large value of the water-cement ratio (for natural fibers) lead toward the great toughness and good strength of the composite [38–40].

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 [41]. In comparison with other fibers, banana fiber has more average tensile-strength than coconut fiber, bamboo fiber, palm fiber, and sisal fiber [11]. The addition of banana fibers has caused an improvement in tensile strength of composite [43, 44].

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 [44]. The use of banana fibers significantly enhanced the resistance against cracking in the concrete beams [45]. 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.

The use of water hyacinth fiber and banana fiber enhanced the mechanical properties (maximum bearing load capacity, splitting-tensile strength, flexural strength, and compressive strength) and the physical properties (true density, bulk density, and water absorption) of concrete. Mechanical tests were conduction on banana fiber reinforced concrete along with the replacement of cement with banana leaf ash. It was observed from the test results that flexural strength and tensile strength were improved [68].

2.3 Recoverable Concrete's Flaws with Waste Usage

There is no such good construction and building material available that can be used as an alternative to concrete. Concrete, as a construction material, is considered as a backbone in the construction industry. Despite the superiority of the concrete, there are several flaws of concrete that are needed to be mitigated or to be reduced. 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. The combined usage of agricultural waste and glass fiber reinforced polymers bars resulted in an increment in resistance against impact loading [7, 45].

The property of energy absorption to resist cracking again was enhanced by utilizing the steel fiber along with the basalt fibers [46]. Incorporation of the agricultural waste in the name of natural fiber caused a reduction in the thickness of the rigid pavement [47]. Seismic performance and resistance against impact loading were enhanced by the incorporation of the jute fibers in concrete [48, 49]. 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 [50].

The ductility and energy absorption properties of concrete were improved by the additive influence of waste plastic and palm oil fuel ash [51]. The researcher utilized coconut fibers ropes made of agricultural waste to analyze the response of mortar-free blocks against dynamic loading [52]. The flexural strength of the concrete was improved by the incorporation of the glass fiber reinforced plastic waste [15].

2.4 Governing Values towards Improvement in Concrete's Properties

Macro cracks are formed by the amalgamation of micro cracks. The properties and performance of concrete are affected by cracking and independent size of crack. The propagation of crack affect the concrete strength [53]. The phenomenon of cracking in concrete depends upon the properties of concrete [54]. The properties, those influence the performance of the structure includes compressive strength, splitting-tensile strength, and flexural strengths. Splitting-tensile strength resists and control the cracking in concrete [55]. The durability and design of structure are affected up to some limits by above mentioned properties of the concrete. By making certain changes in production of concrete can alter the properties of concrete. This can be done, up to certain limits, by changing and/or introducing the ingredients to design consideration and durability considerations.

2.4.1 Durability Considerations

durability of concrete means that ability of concrete to resist and with stand longer against weathering actions, checmical attacks and abrasion during the service. To obtain a durable construction material and service life of structure, it is obvious that mechanical properties of the concrete play important role to durability. In a research study, it was explored that the durability depend upon tensile and flexural properties of concrete are important as concrete is a brittle material, weak in flexural and tensile strength compared to compressive strength [1].

The very first cracks found on the surface of the crack within 24 hours after placing of concrete [57]. At that time, composite does not have sufficient strength so it can resist these early age micro cracks. To avoid and resist these types of cracking there is need to add some additional constituents in concrete. The durability of concrete has inverse relation to linear shrinkage. On the other hand, high water absorption property of concrete has direct relation to durability of concrete and under severe environmental conditions, can cause corrosion of steel reinforcement inside concrete having cracks. The durability of structure also depends upon the width of produced cracks and structural properties of concrete [58].

2.4.2 Design Considerations

The governing properties towards the strength and design of structural members are compressive strength, splitting-tensile strength, and flexural strength. The concrete is very strong in compression as compared to tensile. This is the reason that splitting-tensile and flexural strengths of concrete are given more importance in the design of structural members of concrete [56].

In the different applications and according to strength aspects, splitting-tensile strength and flexural strength are given more importance than the compressive strength like in rigid pavement and beams, respectively. This splitting-tensile strength resist cracks caused by the shrinkage stresses. To obtain sustainable and high-strength material, banana fiber can enhance the mechanical properties of concrete. The researchers have investigated that concrete can be produced by replacing some amount of UPEO with cement comparable with PC. UPEO can be used as admixtures to reduce the cement content within the concrete result in minimize the cost production [6]. Through improved mechanical and durability properties of concrete, the deterioration of concrete can be avoided.

2.5 Summary

It is concluded from the above discussion that the use of natural fibers along with an admixture can improve properties of concrete related to durability of the structure. It is necessary to improve the mechanical properties and dynamic properties to resist cracking and progression of micro crack into macro cracks. From this chapter, it is obvious that banana fiber enhances the splitting-tensile strength of concrete and resists the cracking. On the other hand, used petrol-engine oil can be used in concrete as a chemical admixture. Up to some extent, used petrol-engine oil enhances the compressive strength of the concrete. From this literature, it is concluded that used petrol-engine oil has potential and can be used along with to natural fiber having the similar chemical (acid) nature to that used petrol-engine oil.

Chapter 3

Experimental Scheme

3.1 Background

The trend to utilize natural fibers in concrete is increasing by time due to cheap, easy handling, good mechanical properties, easy availability, and environmentally friendly nature factors. In this research, banana fiber is used as reinforcement and used petrol-engine oil as a chemical admixture in manufacturing of concrete. From previous chapter, the use of banana fibers and used petrol-engine oil in several researches is discussed in detail. But the combine influence o banana fibers and used petrol-engine is not explored till now. Therefore, slump cone test, dynamic test, mechanical test, waster absorption, linear shrinkage, and mass loss test are considered. An examination is also performed on the fractured of surfaces of broken specimens. In this chapter, raw materials, fiber treatment, the methods of mixing of PC, UP, and UBFRCs, casting procedure and methodologies of testing are expressed in details.

3.2 Raw Constituents

For the production of normal plain concrete (PC), ordinary Portland cement and Margalla crush along with locally available sand are used. The maximum size of the aggregate is 20 mm used for manufacturing both plain concrete and fiber reinforced concrete (FRC). UPEO is used as an admixture in making of UPC and UBFRCs. It maybe noted that commercially available UPEO is being used in this research. Since UPO is treated as a waste material industry, so no information about it characterisation is available. However, from literature, in the reported characterisation along with its comparison with cement is given in table 2.1. Commercially available cut length banana fibers are being used. No additional treatmnet is being made becasue of no visual impurities on fibers (dust etc).

Figure. 3.1 shows the treatment process of BF. For the preparation of FRC, banana fiber is used. The fixed length of 50 mm of the fiber is used in the preparation of the FRC. UPEO is used within plain concrete to prepare used petrol-engine oil added plain concrete (UPC) and FRC. Tap water (at normal temperature) is used for preparing the PC, UPC, and UBFRCs. Two different water-cement ratios are used for manufacturing different types of specimens. 0.5 water-cement ratio is used for making PC and UPC, and 0.6 water-cement ratio is used for all UBFRCs. The water ratio for the UBFRCs is increased due to the more water absorption property of the BF (natural fibers) as reported in literature review.

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

For preparation of PC, mix design ration of 1:2:4 (cement: sand: aggregate) is used. UPEO content of 9.4% by mass of cement is added in the mixture for preparing UPC. Varying proportions (0.5%, 1.0%, 1.5%, 2.0% and 2.5%) of BF are added in the mixture along with the UPEO for the manufacturing of used petrol engine oil banana fiber reinforced concrete (UBFRC).

All the material are placed in the drum mixture for preparing the PC mix. Then water is added, in mixture machine, 30-45 seconds after start of rotating the mixture machine. The mixture machine is rotated for the five minutes. The slump cone test is performed after preparation of PC. For the preparation of the UPC, same procedure repeated with a change that used petrol engine oil is added one minute later of addition of the water. The rotating time for mixture is kept same five minutes as for the PC mix.

Raw banana fibers

Treated banana fibers

Cut-length banana fibers

Figure 3.1: Banana Fiber's Images (Raw, Treated, Cut Length)

For the manufacturing of BFRC with 0.5% of banana fiber by the mass of cement, the materials are placed in the form of layers to achieve the good mixing of fiber within the concrete. Three set of layers is used to make a good mix of the UBFRC. One third set of layers of aggregates, sand, banana fibers and cements placed in the mixer machine. Then the second and third set of layers of aggregate, sand, banana fibers and cement are placed with the same approach. Then the mixture machine turned on to start rotating. And the two third water is added with the start of machine. Three minutes after of continuous rotation of mixer machine, remaining one third quantities of water and UPEO are added and mixture machine is kept rotating for further two minutes and slump cone test is performed to check the workability of the fresh UBFRC. Same approach was for the remaining the types of UBFRCs with varying amount of the banana fibers.

Slump cone test is used to investigate the workability or consistency of the manufactured PC. The slump test for the PC, UPC and UBFRC is always performed before the pouring in moulds. According to ASTM standard C143/C143M-15a, slump cone test is performed to evaluate the workability of the fresh concrete [19]. Slump cone of bottom diameter of 200 mm (8 in), top diameter of 100 mm (4 in) and height of 300 mm (12 in) is used to perform the test. The cone mould should be of non-absorbent. Tamping rod is hemispherical from both ends with the diameter of 16 mm (5/8 in) and length not more than 600 mm (25 in).

The cone is filled with three equal volumetric layers of concrete. After the placing the first 1/3 layer, compaction is done by total 25 times randomly dropping tamping rod on surface of the layer from height of 25 mm (1 in). Similarly, further two layers of cone are filled and compacted with the help of tamping rod. Removed the extra amount of concrete with striking off the tamping rod and made it smooth by screeding and rolling the rod over it. Later, slump cone is lifted vertically upward. The cone is placed upside down beside the concrete of slump cone's mould. Tamping rod is placed over the up-turned slump cone in such a way that length of reach over the slump concrete as shown in **figure 3.2a**. With help of the ruler the value of slump is measured carefully.

To the best of the authors' knowledge, there is no standard test is available that help to find the workability of fresh UPC and UBFRC. Hence, the same procedure and test standard is used for the determination of the workability of UPC and UBFRCs. The relation between the observed slump values and determined hard densities is shown in **figure 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 (m^3).

The determined values of densities and slumps are shown in **Table 3.1**. To the best of the authors' knowledge, there are no such standard tests available to find out the workability and density of fresh UPC and UBFRC. Hence, the same procedure and test standard are used for the determination of the workability and densities of UPC and UBFRC.

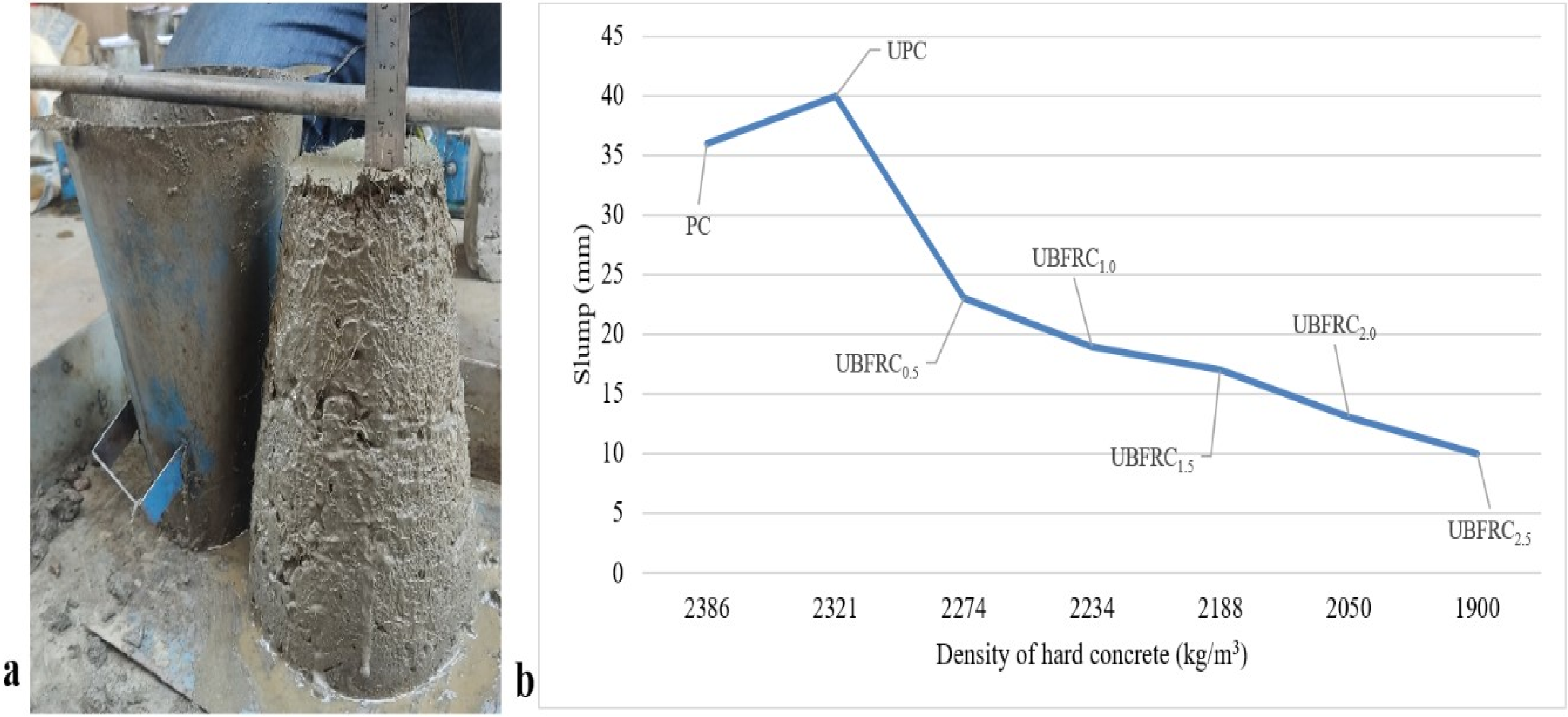


Figure 3.2: a) Measuring the Value of Slump of UBFRC, b) Combined effect of UPEO and BF on the relation between slump of fresh concrete and density of hard concrete

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

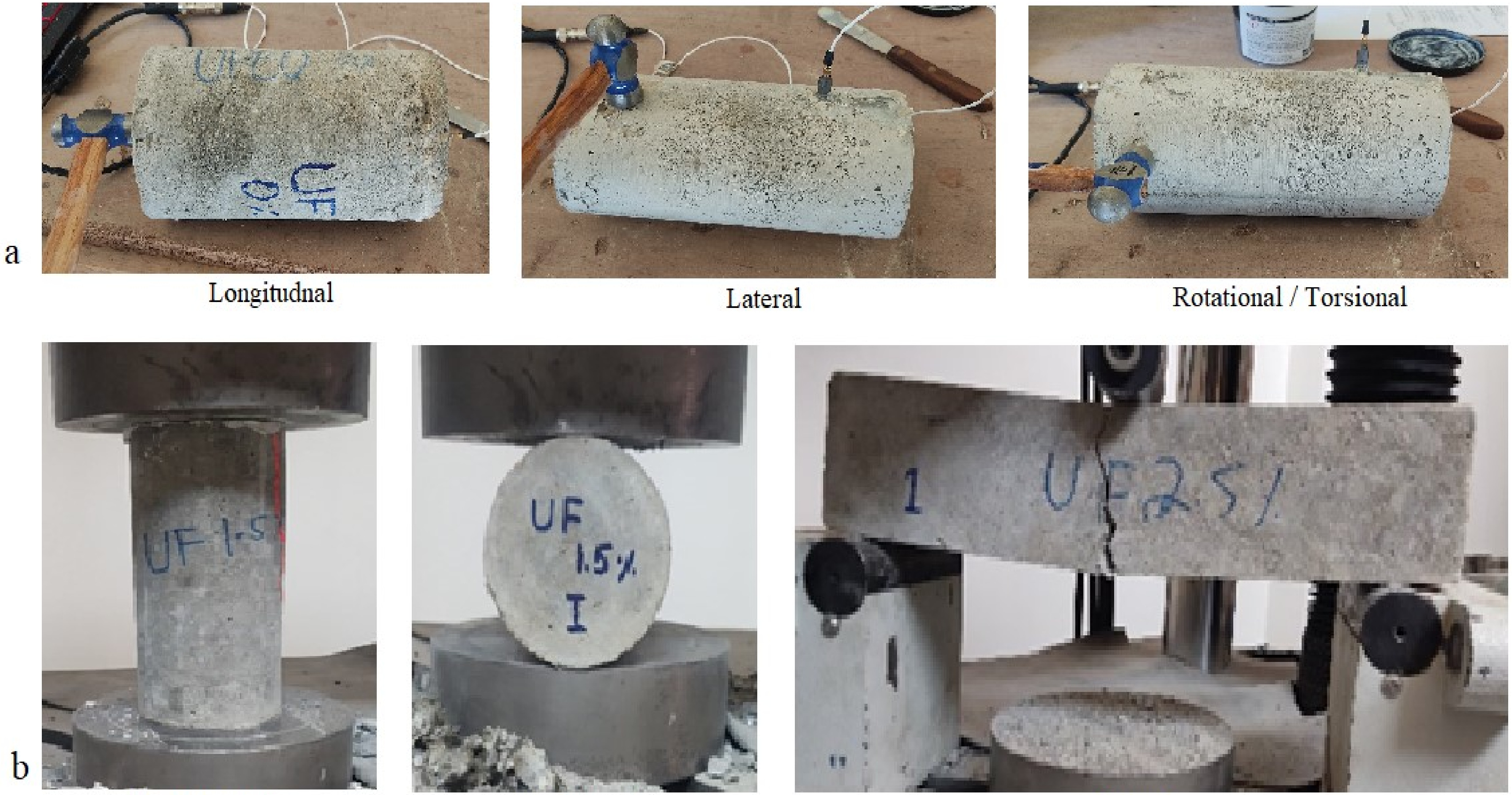
Labeling	C:S:A	Addition of percentage content by mass of cement of		W/C	Slump of fresh concrete	Density of hard concrete
		***UPEO**	****BF**	**(-)**	**(mm)**	**(kg/m3)**
PC	1:2:4	0	0	0.5	36	2386
UPC	1:2:4	9.4	0	0.5	40	2321
UBFRC$_{0.5}$	1:2:4	9.4	0.5	0.6	23	2274
UBFRC$_{1.0}$	1:2:4	9.4	1	0.6	19	2234
UBFRC$_{1.5}$	1:2:4	9.4	1.5	0.6	17	2188
UBFRC$_{2.0}$	1:2:4	9.4	2	0.6	13	2164
UBFRC$_{2.5}$	1:2:4	9.4	2.5	0.6	10	2142

*Note: Addition of *UPEO content and ** BF content done by taking percentage by mass of cement. Density is calculated by taking an average of two specimens.*

3.4 Testing Methodology

In this section, dynamic test, mechanical test, water absorption test, linear shrinkage test, mass loss, and investigation of breakage and role of fibers in concrete are performed to investigate the different corresponding properties against these tests. These test setups are performed as per standard or reference of previous research works. The average of two specimens is taken in current study. The average of two readings is also reported by other researchers [7, 8, 48, 63]. **Figure 3.2a and 3.2b** shows the test setups of dynamic test and mechanical test. After performing the mechnical test, role of fibers explored in concrete through the broken surfaces of concrete.

For the dynamic testing, longitudnal, lateral, and rotational frequencies or oberved with the help of a hammer and accelerometer. The different type of setups a used for determination of each type of resonance frequency. In longitudnal frequency setup, accelerometer is attached to the one cross-sectional side of specimen and a light stroke is given to the other cross-sectional side of specimen. Literal frequencies are observed by placing accelerometer on the lenght of spicemen 25 cm away from the cross-sectional edge and then stroke is given parallel to acceelerometer on the other edge of spicemen. For the third setup of observing rotational frequency accelerometer is attached to the similar to the longitudnal frequency setup. But then the stroke of hammer is given on lenght of specimen perpendicular to the acceleometer. Compression, split-tensile, and flexural testings are performed for exploration of mechnical properties of PC, UPC, and all types of UBFRCs. For the compression, the cylinders are placed vertical between the test machine, so, it act as a column or proto-type of compression member. Cylinders are layed down between the testing plates for observing the spliting-tensile properties of casted spicemens. Three point loading setup is used in flexural testing. Flexural test is performed on beamlets for the dertermination of flexural properties of concrete. ASTM standards allows the average of two values to get precise value of any type of properties of concrete. So in current study, the average of two values is taken for each type of properties of dynamic and mechnical testings.



Longitudnal Lateral Rotational / Torsional

Compression Split-tensile Flexural

Figure 3.3: Tests Setups; a) Dynamic Test, and b) Mechanical Properties

3.4.1 Dynamic Test

Dynamic test is performed before the destructive (mechanical) testing of the specimens as per "ASTM 215-14 [Table 3.2]. Response frequencies lateral (RFL), response frequencies transverse (RFT) and response frequencies rotational (RFR) are determined with the help of hammer and accelerometer. The test is conducted on both cylinder and beamlets. For determining the RFL, the accelerometer is attached to once side of cross section of cylinders and beamlets while a strike of hammer is given to the opposite side of the cross section of specimens.

The accelerometer observes the frequencies and transfer the record of these frequencies to the computer attached with it. The procedure of RFT and RFR attaching the accelerometer and strike location of hammer is different for cylinders and the beamlets. In case of cylinders, for RFT, the accelerometer is attached at side showing face of length of cylinder at least 25 cm away before the edge. Then a strike of hammer is given at same side showing face on the center of cylinder's length.

For RFR, the accelerometer is attached at top showing face of length of cylinder with same space from the edge like RFT. The strike is given at perpendicular accelerometer on opposite edge of the cylinder length. In case of the beamlets, for RFT determination, accelerometer attached at one side of length at same margin, used for cylinders, on length of beamlets from edge.

Strike of hammer is given at center of length of same side at which accelerometer is attached. For RFR, the accelerometer is attached at top corner of rectangle (side face of the beamlet). A strike is given at other side bottom corner of same side of rectangle in such a way that line joining the point of hammer's strike and accelerometer make the diagonal of the rectangle. From these observed frequencies, the damping ratio, dynamic modulus of elasticity, dynamic modulus of modulus of rigidity and poisson's ratios are calculated. These calculated properties support to understand the behavior and resistance of PC, UPC, and all types of UBFRC against the dynamic loading. These properties are key to the design of structure undergoing the dynamic loadings and earthquake.

Table 3.2: Testing Standards and Studied Parameters

Test	**Standards / References**	**Parameters Considered for the Study**
1. Dynamic Properties	ASTM 215-14	Resonant frequency longitudinal (RFL), Resonance frequency transverse (RFT), Resonance frequency torsional (RFR), damping ratio (ζ), dynamic modulus of elasticity (Ed), Dynamic modulus of rigidity (Rd), Poisson ratio.
2. Mechanical Properties		
a) Compressive Properties	ASTM C39	Stress-strain curves, compressive strength (CS), modulus of elasticity (MOE) compressive pre-crack energy absorption (CE1), compressive post-crack energy absorption (CE2), compressive total energy absorption (CTE), and compressive toughness indexes (CTI).
b) Splitting Tensile Properties	ASTM C496M-02	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).

Continued Table 3.2: Testing Standards and Studied Parameters

Test	**Standards / References**	**Parameters Considered for the Study**
c) Flexural Properties	ASTM C78	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 (FTI).
3. Miscellaneous		
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.
4. Role of Fibers in Concrete	Affan, M (2019)	Broken surfaces of specimen, failure mechanism of fibers, and bonding of fiber with the surrounding matrix

3.4.2 Mechanical Testing

a) Compression

A servo-hydraulic testing machine (STM) is used for the determination of the compressive strengths of PC, UPC, and UBFRCs. The test is performed according to ASTM C39 on cylinders of PC, UPC, and UBFRCs.

In this test properties are determined to include compressive strength (CS), compressive behavior, compressive pre-crack (CE1) and post-crack energy (CE2), compressive total absorbed energy (CTE), and the compressive toughness index (CTI) of PC, UPC, and UBFRC. To distribute the load uniformly throughout the cylinder the caping of the cylinder is done with the plaster of paris.

b) Split-Tensile

ASTM C496M-02 standard is used for the splitting-tensile test. The same machine STM is used for performing the test. The test is performed on the cylinders of PC, UPC, and UBFRCs. The capping of cylinders is not required in the case of the splitting-tensile test. From this test, 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 calculated.

c) Flexural

The flexural test is performed on the basis of standards ASTM C78. The three-point loading mechanism is adopted. The test is performed on the beamlets of PC, UPC, UBFRCs. The studied parameters in this test are 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 (FTI).

3.4.3 Miscellaneous Testing (Water Absorption, Linear Shrinkage, and Mass Loss)

To calculate the water absorption properties of PC, UPC, an d UBFRCs, the ASTM C642 standard is followed [Table 3.2]. First of all, specimens are dried in the oven and then these dried specimens are placed, at room temperature, in water. This method is used to determine the water absorption property of all types of specimens. For the evaluation of linear shrinkage, ASTM C157 / C157M-08 is followed by observing and measuring the variations in the length of specimens (OPSS standard LS-435). For this purpose, a line of 6 inches is marked as a reference on the length of specimens before conducting the test. The variation of the length is measured after following the procedure of standard. The linear shrinkage is then measured by taking percentage difference of marked lenth before and after the test procedure.

ASTM C157M-08 is used for the determinantion of mass loss in PC, UPC and UBFRCs. After following the test procedure, variations and shrinkage in the reference line are marked before being evaluated. Each type of concrete mix specimen is placed in a high-temperature heating oven. The temperature is raised from 20°C to 100°C at the rate of increase of 3°C per minute and maintained at 100°C for one hour. This is done to obtain more realistic data. Then specimens are cooled down with the same rate of decrease in temperature at 3°C to avoid thermal cracking.

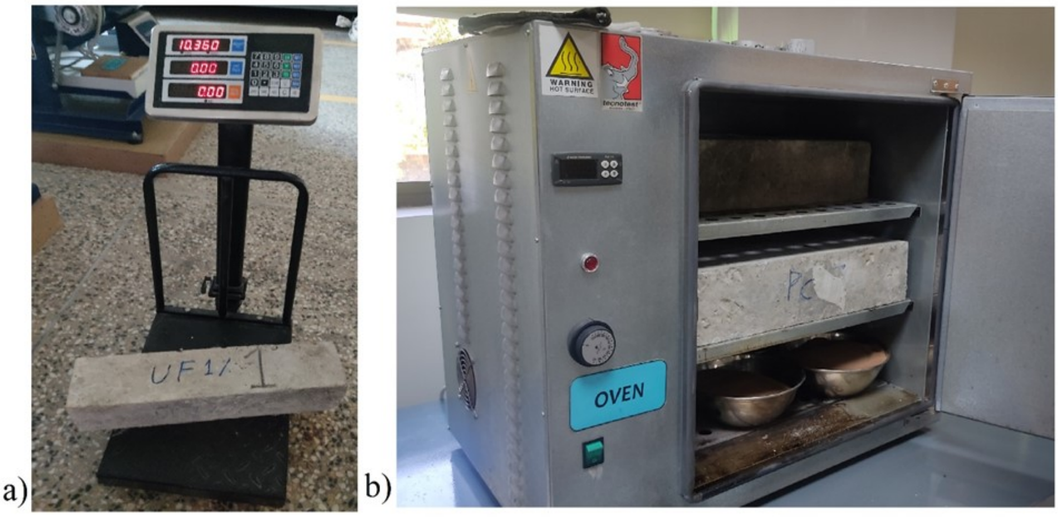


FIGURE 3.4: a) Measurement of Weight for Water Absorption, b) Drying Specimens in Oven for the Mass Loss

3.4.4 Fractured Surface Examination

After performing the mechanical testing, the fractured surfaces of broken specimens are examined carefully. In this examination, fiber breakage, pullouts, and bridging effect due to fibers are investigated. For this purpose, microanalysis is done carefully over the broken surfaces of the tested samples. From the fracture surfaces, mixing of all the ingredients can be observed, either it is a good mix or not. Good mixing of ingredients result in achieving the desired property, otherwise, it can lead to degression of the property instead of increasing it. The basic purpose of this investigation is to elaborate the failure mechanism of fibers and the bonding of the fibers with the surrounding matrix.

3.5 Summary

The most adopted mix design 1:2:4 is used for the preparation of PC, UPC, and UBFRCs. For the PC and UPC, 0.5 w/c is used whereas 0.6 w/c is used for the UBFRCs. Fixed amount 9.4% of UPEO by mass of cement is used for the preparation of UPC and UBFRCs. Different contents of banana fibers 0.5%, 1.0%, 1.5%, 2.0%, and 2.5% are added, by taking mass of the cement, in making of UBFRCs. Total number of 42 specimen are prepared in which 28 are cylinders and 14 are the beamlets. ASTM standards are followed in slump, dynamic, mechanical, and miscellaneous tests of PC, UPC, and UBFRCs. The evaluated results of each corresponding tests are discussed in detail in next chapter (i.e., chapter 4).

Chapter 4

Results and Analysis

4.1 Background

The most adopted mix design 1:2:4 is used for the preparation of PC, UPC, and UBFRCs. For the PC and UPC, 0.5 w/c is used whereas 0.6 w/c is used for the UBFRCs. Fixed amount 9.4% of UPEO by mass of cement is used for the preparation of UPC and UBFRCs. Different contents of banana fibers 0.5%, 1.0%, 1.5%, 2.0%, and 2.5% are added, by taking mass of the cement, in making of UBFRC0.5, UBFRC1.0, UBFRC1.5, UBFRC2.0, and UBFRC2.5. Fixed length of 5 cm of BF is used in each type of UBFRC. This chapter is based on detailed results obtained after testing all specimens of PC, UPC, and UBFRCs.

4.2 Dynamic Properties

Dynamic properties are investigated to evaluate the combined effect of UPEO and BF on the properties of specimens of the concrete. These dynamic properties of concrete (PC) specimens are determined by using ASTM C215-14. As there is no such specific standard available for determining the dynamic properties of the UPC and UBFRC, so the same standards are adopted to calculate the dynamic properties of UPC and UBFRCs.

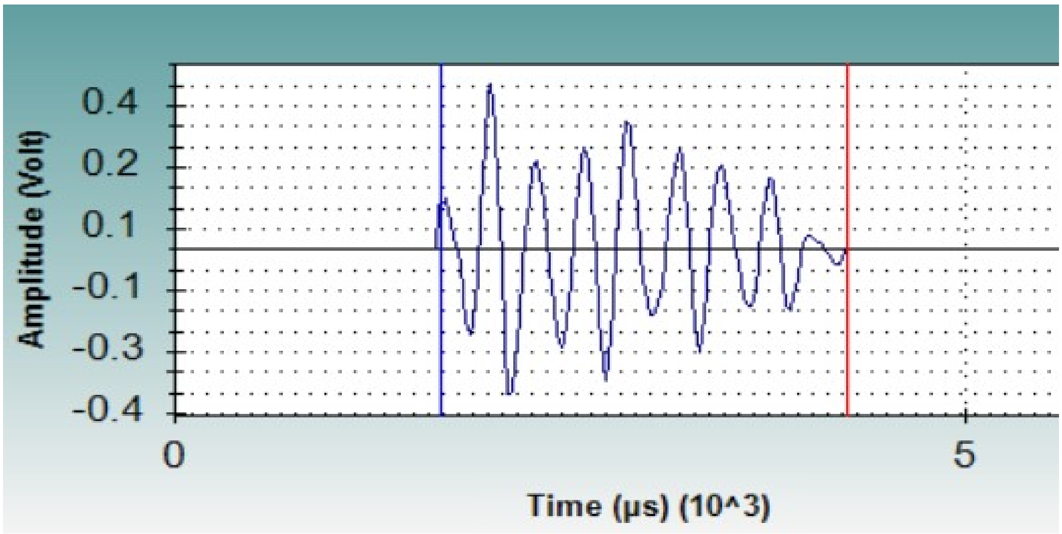


FIGURE 4.1: Typical Response Graph of Dynamic Testing

The typical graphical response recorded on the accelerometer, while performing the test, has been shown in **Figure 4.1. Table: 4.1** shows the investigated dynamic properties of the PC, UPC, and UBFRCs. For this, an average of two values is taken to achieve appropriate results of corresponding dynamic properties. The damping ratio (ζ) of UPC is reduced by 9.44% and 24.11 % in cases of cylinders and beamlets, respectively, as compared with PC. As comparing the values with PC, the damping ratio of UBFRC0.5 is reduced by 4.54%, while the values of damping ratios of UBFRC1.0, UBFRC1.5, UBFRC2.0, and UBFRC 2.5 are increased by 1.74%, 8.74%, 15.03%, 20.27% in the case of cylinders respectively. In the case of beamlets, the damping ratio of UBFRC0.5, UBFRC1.0, UBFRC1.5, UBFRC2.0, and UBFRC2.5 are increased by 4.32%, 10.27%, 13.51%, 21.62%, 25.94% in comparison with the damping ratio of PC respectively. Increment/decrement in demping ratio is directly releted to resistence against dynamic loading. The resistance against the dynamic loading has been reduced by the additive influence of the UPEO. 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. In the case of cylinders, the impact of dynamic modulus of elasticity (Ed) is enhanced by 5.71% the 9.4% addition of UPEO in concrete. Contrarily the reduction is observed in values of Ed of UBFRC0.5, UBFRC1.0, UBFRC1.5, UBFRC2.0, and UBFRC2.5 by 2.85%. 5.71%, 7.85%, 10.0%, 14.28%, respectively.

Table 4.1: Dynamic Properties of PC, UPC, and UBFRCs

Concrete Specimen Type	**Parameters**						
	RFL (Hz)	**RFT (Hz)**	**RFR (Hz)**	ζ (%)	**Ed (GPa)**	**Rd (GPa)**	**Poisson Ratio (-)**
Cylinders							
PC	3462±44	3417±45	3440±22	2.86±0.14	0.70±0.002	4.55±0.165	0.922±0.003
UPC	3528±23	3507±44	3439±23	2.59±0.58	0.74±0.019	4.55±.0.05	0.918±0.001
UBFRC0.5	3306±23	3439±23	3506±0	2.73±0.06	0.68±0.009	4.52±0.006	0.924±0.001
UBFRC1.0	3462±89	3462±44	3329±0	2.91±0.23	0.66±0.014	4.05±0.022	0.915±0.002
UBFRC1.5	3307±22	3506±0	3529±22	3.11±0.21	0.645±0.003	4.36±0.033	0.922±0.001
UBFRC2.0	3373±0	3351±66	3706±289	3.29±0.17	0.63±0.023	4.78±0.748	0.934±0.012
UBFRC2.5	4483±44	4527±45	4505±22	3.44±0.03	0.60±0.02	6.75±0.025	0.920±0.002
Beamlets							
PC	3351±111	1531±67	3440±22	1.85±0.02	14.43±1.7	5.50±0.645	0.311±0
UPC	3417±0	1443±66	3439±23	1.40±0.01	12.43±1.1	4.74±0.412	0.311±0
UBFRC0.5	3351±22	1398±22	3506±0	1.93±0.02	11.33±0.4	4.45±0.002	0.271±0.040
UBFRC1.0	3573±200	1442±22	3329±0	2.04±0.07	11.94±0.4	4.27±0.112	0.398±0.087
UBFRC1.5	3462±0	1398±22	3529±22	2.10±0.33	10.99±0.5	4.32±0.052	0.271±0.040
UBFRC2.0	3595±89	1376±0	3706±289	2.25±0.14	10.53±0	4.14±0.122	0.271±0.040
UBFRC2.5	3462±0	1265±23	1264±23	2.33±0.01	8.86±0.3	3.38±0.133	0.311±0

The dynamic modulus of rigidity has shown better values in the case of 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, cylendrical test specimens and beamlets test specimens. This is and indication that the members made of UPEO and BF can resist and withstand more against the lateral loadin in either it is a cylendrical or a bleamlet. These improved properties are the indications that the occupancy of some portion of BF in UBFRC can sustain more against impact loading and mayo enhance the durability against earthquake loading as compared to that of plain concrete.

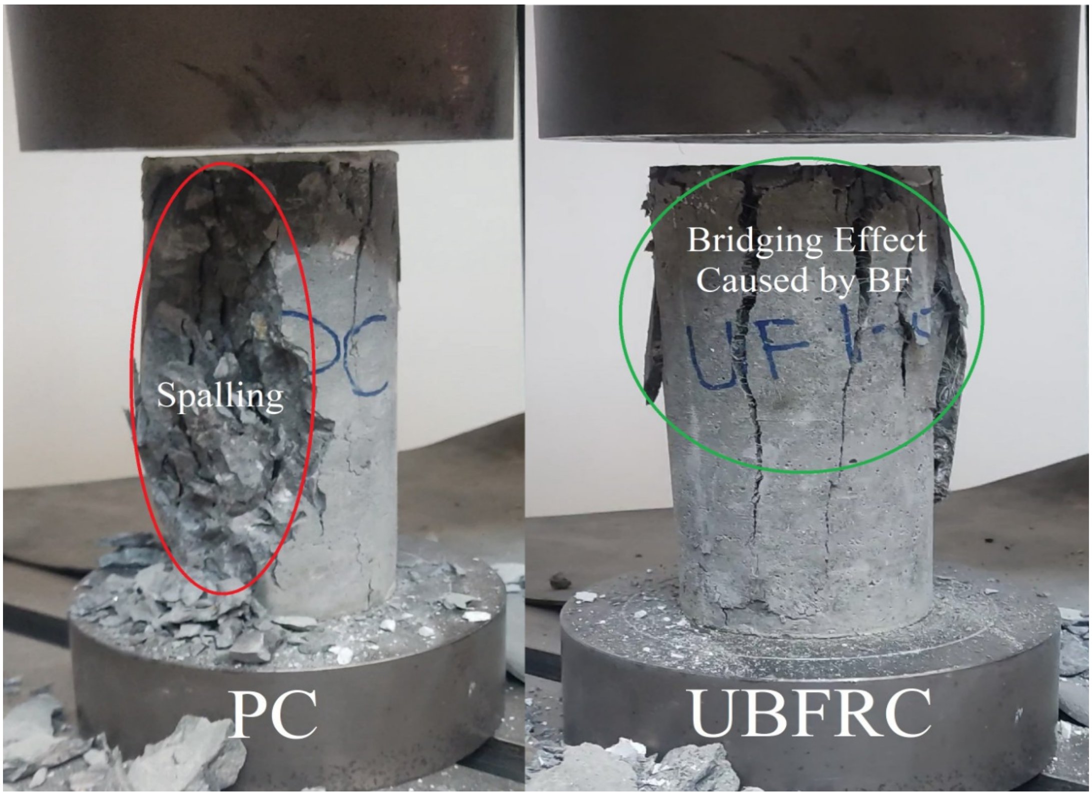
4.3 Mechanical Properties

4.3.1 Compressive Properties

Figure 4.2b demonstrates the relationship between the stress-strain graphs of PC, UPC, UBFRC0.5, UBFRC1.0, UBFRC1.5, UBFRC2.0, and UBFRC2.5. It may be noted that UPC has shown the maximum value of the compressive strength (CS) in comparison with PC and all types of UBFRC. CS increased by 50%, 25%, and 18% in UPC, UBFRC0.5, and UBFRC1.0, respectively, in comparison with PC. However, there is a reduction of 7.5%, 22%, and 40% in CS of UBFRC1.5, UBFRC1.5, and UBFRC2.5 respectively. From this, it can be observed that the addition of UPEO enhances the CS and the addition of BF resulted in the reduction of the CS.

The modulus of elasticity (MOE) of PC, UPC, and all types of UBFRC is shown in **Table: 4.2**. It can be observed that the MOE of UPC is 30% more than the PC. On the other hand, the MOE of UBFRCs 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 UPEO in concrete while the addition of the BF has resulted in a decrease in the above-mentioned values. **Figure 4.2a** shows comparison between typical failure of PC and UBFRC under maximum splitting-tensile loading. **Table**

4.2, 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).



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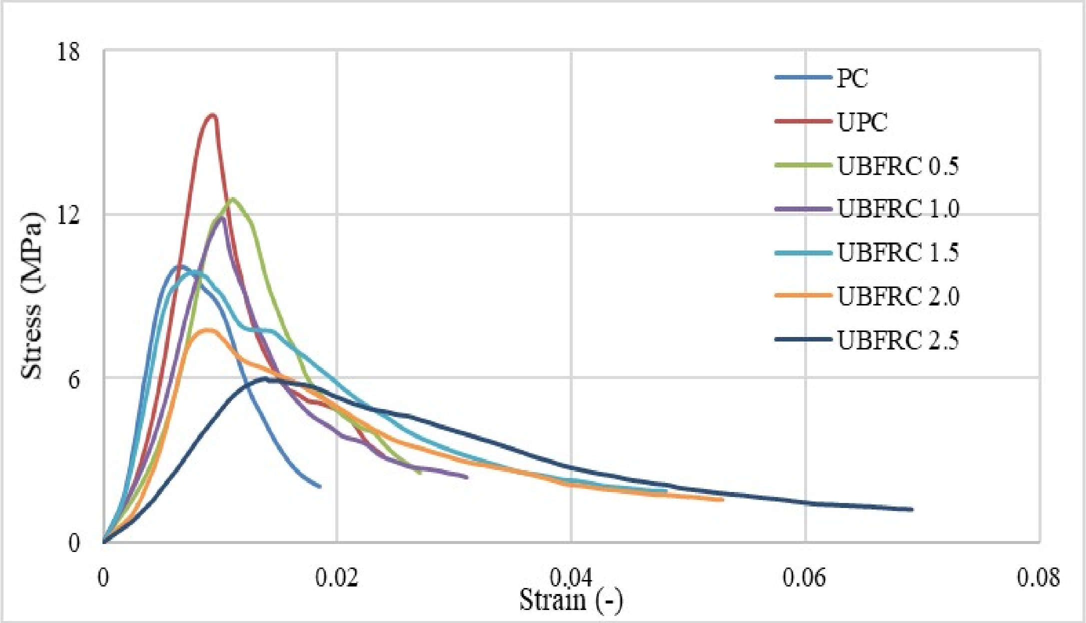


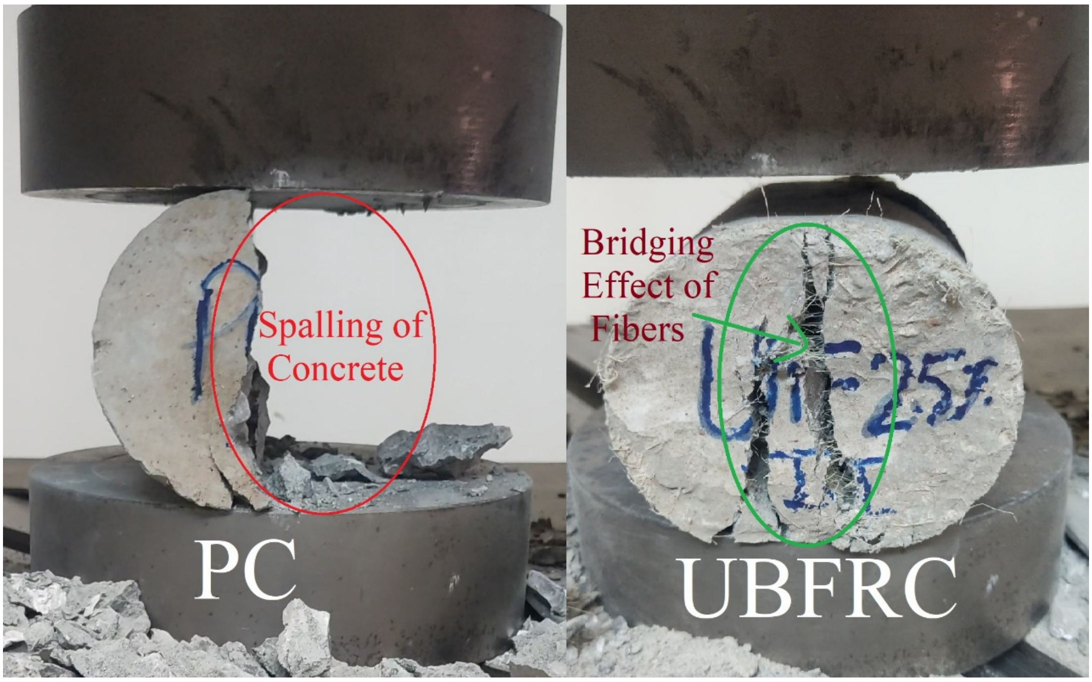
FIGURE 4.2: a) Typical Compression Failures of PC and UBFRCs, (b) Compression Response of PC, UPC, and UBFRCs

Figure 4.2b 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 increased when UPEO 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 [47, 62]. There is an increment in CE1 60%, 57%, 52%, 50%, and 13% of UPC, UBFRC0.5, UBFRC1.0, UBFRC1.5, and UBFRC2.0, and a reduction of 18% is observed in the case of UBFRC2.5. The most CE2 is noticed in UBFRC2.0 which is 0.16% in comparison to the CE2 of the PC. The comparison between the compressive properties has been shown in **Figure: 4.2b**. The increase in the values of the CE1, CE2, and CTI is due to the addition of the assorted proportion of the BF. Further improvement is also caused by the incorporation of UPEO.

4.3.2 Splitting-Tensile Properties

The load-deformation curves for PC, UPC, UBFRC0.5, UBFRC1.0, UBFRC1.5 UBFRC2.0, and UBFRC2.5 are presented in **Figure. 4.3b**. 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. 4.3b**, it can be observed thath UPC has followed and behaved same way as that of PC. The graph of UPC has also gone to zero after resising the its maximum load. Same phenomenon is applied on UPC as that of PC. The PC has withstanded and resisted more split-tensile loading as compared to UPC. This has indicated that the addition of UPEO has shown negative effect on splitting-tensile strength and caused a reduction splitting-tensile stregnth of concrete.

By admixing o.5% of banana fibers along with same content of UPEO used in UPC, the splitting-tensile strength is improved up to some extent and, also, resisted the some loadin after appearance of first crack. 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 UPC. 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 UBFRC under maximum splitting-tensile loading.



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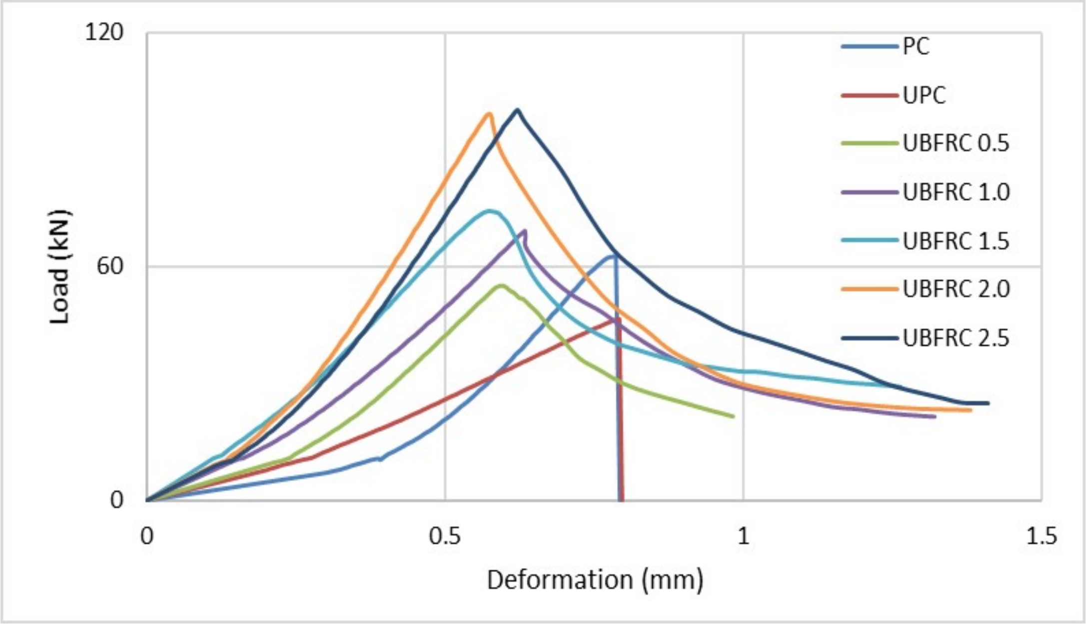


FIGURE 4.3: a) Typical Splitting-Tensile Failures of PC and UBFRCs (b) Splitting-Tensile Response and Typical Failures of PC, UPC, and UBFRCs

It can be noted that UBFRC2.5 has the maximum load as shown in **Figure. 4.3b** Also, after the maximum load, the UBFRCs have shown load-carrying capability due to the bridging effect of BF.

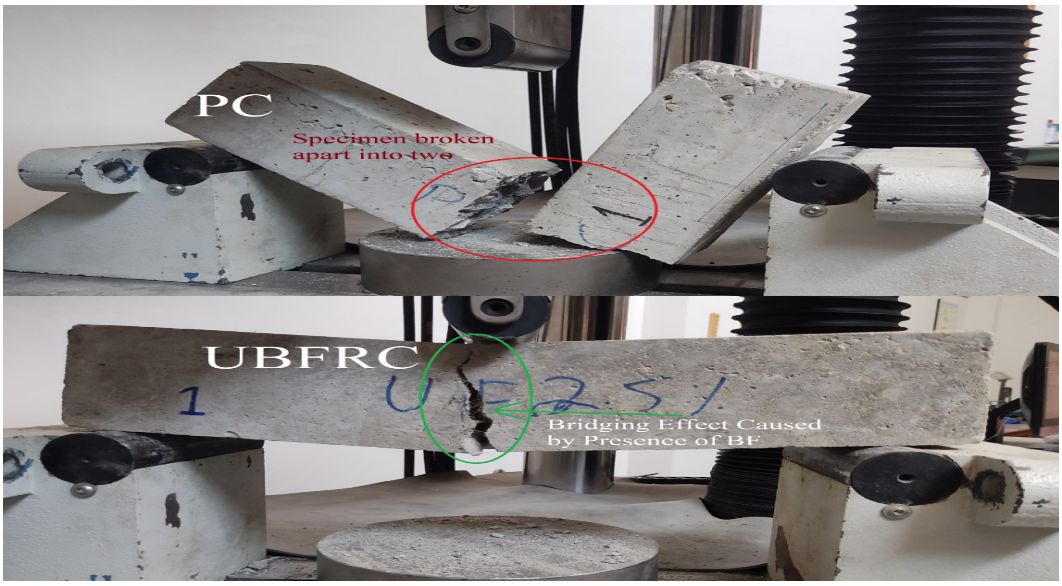
Under the section of splitting-tensile properties, splitting-tensile strength (SS), splitting-tensile pre-crack absorbed energy (SE1), splitting-tensile post crack absorbed energy (SE2), splitting-tensile total absorbed energy (STE) and splitting-tensile toughness index (STI) have shown in **Table 4.3**. These perameters are calculated as per the procedures describes by the research studies [47, 62]. The presence of BF enhanced the spiliting-tensile strength of concrete.

4.3.3 Flexural Properties

Figure. 4.4b shows the relationship between load-deflection curves of PC, UPC, UBFRC0.5, UBFRC1.0, UBFRC1.5 UBFRC2.0, and UBFRC2.5 samples under flexural loading. UBFRC2.0 has resisted the maximum flexural load as shown in **Figure. 4.4b**.

It may be observed that maximum flexural strength in the case of the UBFRC2.0 as shown in **Table 4.2**. The more deflection is experienced in UBFRCs than the PC and UPC. 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 UBFRC2.0 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.

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 UBFRC2.0, is decreased by 15.3%, in comparison with FE1 of PC. This reduction is caused by the presence of UPEO. As, the UPEO has significantly reduced the FE1, UPC 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 UBFRCs have shown some of the FE2.



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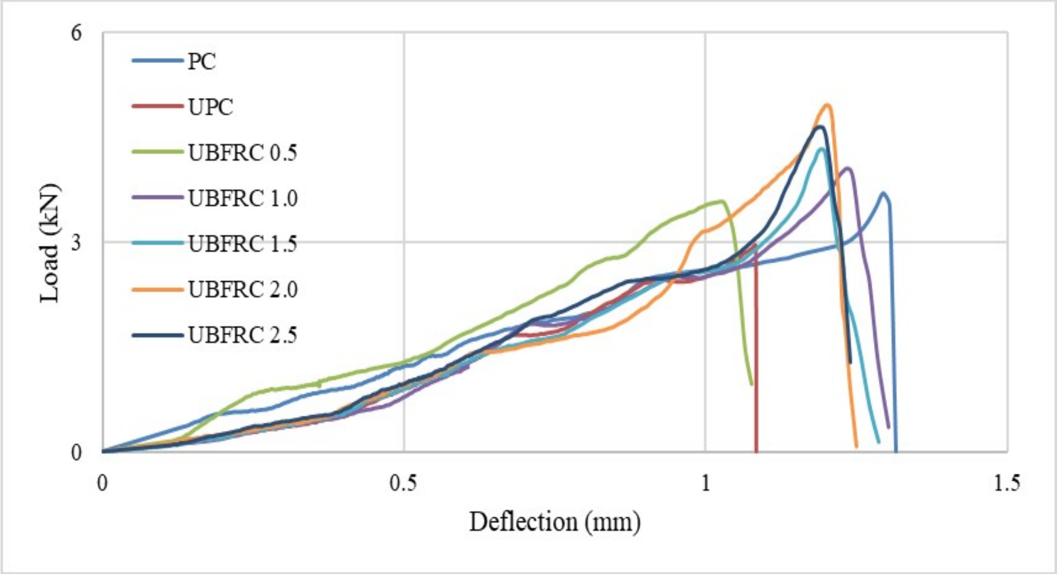

FIGURE 4.4: a) Typical Flexural Failures of PC and UBFRCs, (b) Flexural Response and Typical Failures of PC, UPC, and UBFRCs

This means the UBFRC may sustain better than PC and UPC after the cracks appear in the concrete. BF has resisted the sudden failure of under split-tensile loading concrete comparing to those of PC and UPC.

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

	Parameters																
Concrete	**Compression Properties**						**Splitting-Tensile Properties**					**Flexural Properties**					
Type	**MOE** **(GPa)**	**CS** **(MPa)**	**CE1** Mj/m^3	**CE2** Mj/m^3	**CTE** Mj/m^3	**CTI** (-)	**SS** **(MPa)**	**SE1** Mj/m^3	**SE2** Mj/m^3	**STE** Mj/m^3	**STI** (-)	**FS** **(MPa)**	**Δ** **(mm)**	**FE1** Mj/m^3	**FE2** Mj/m^3	**FTE** Mj/m^3	**FTI** (-)
PC	25 ± 1.4	10 ± 0.8	0.038 ± 0.004	0.06 ± 0.002	0.098 ± 0.003	2.58 ± 0.01	1.94 ± 0.2	15.55 ± 1.1	0	15.55 ± 1.1	1	0.91 ± 0.2	1.32 ±0.52	2.15 ± 0.12	0	2.15 ± 0.12	1
UPC	28.1 ± 0.7	15.3 ± 1.0	0.06 ± 0.004	0.09 ± 0.001	0.15 ± 0.006	2.42 ± 0.05	1.44 ± 0.3	16.26 ± 1.1	0	16.26 ± 1.1	1	0.73 ± 0.2	1.062 ±0.42	1.28 ± 0.13	0	1.28 ± 0.13	1
UBFRC0.5	27.7 ± 1.2	12.5 ± 0.9	0.061 ± 0.002	0.099 ± 0.003	0.161 ± 0.007	2.61 ± 0.04	1.7 ± 0.1	12.4 ± 1.27	13.34 ± 1.02	25.75 ± 2.29	2.07 ± 0.04	0.88 ± 0.1	1.025 ±0.42	1.61 ± 0.24	0.13 ± 0.04	1.74 ± 0.26	1.084 ± 0.01
UBFRC1.0	25.8 ± 1.2	11.8 ± 0.2	0.057 ± 0.005	0.099 ± 0.002	0.157 ± 0.004	2.73 ± 0.02	2.14 ± 0.2	18.41 ± 1.62	23.75 ± 1.53	42.16 ± 3.15	2.29 ± 0.01	0.99 ± 0.2	1.234 ±0.53	1.77 ± 0.10	16 ± 0.03	1.93 ± 0.13	1.09 ± 0.01
UBFRC1.5	26 ± 1.2	9.3 ± 1.3	0.058 ± 0.003	0.166 ± 0.002	0.224 ± 0.004	3.85 ± 0.05	2.29 ± 0.2	19.63 ± 1.69	27.44 ± 1.05	47.07 ± 2.74	2.39 ± 0.02	1.06 ± 0.4	1.192 ±0.77	1.65 ± 0.11	0.2 ± 0.04	1.85 ± 0.07	1.114 ± 0.01
UBFRC2.0	26.9 ± 0.3	7.7 ± 1.0	0.031 ± 0.001	0.158 ± 0.001	0.189 ± 0.002	4.05 ± 0.06	3.06 ± 0.4	22.57 ± 0.92	32.73 ± 2.23	55.3 ± 3.12	2.45 ± 0.05	1.21 ± 0.2	1.202 ±0.23	1.82 ± 0.06	0.12 ± 0.06	1.94 ± 0.03	1.117 ± 0.01
UBFRC2.5	25.8 ± 0.7	5.9 ± 1.3	0.043 ± 0.001	0.14 ± 0.001	0.183 ± 0.002	4.27 ± 0.04	3.09 ± 0.1	24.67 ± 1.59	37.97 ± 0.96	32.65 ± 2.58	2.53 ± 0.04	1.14 ± 0.1	1.191 ±0.55	1.78 ± 0.13	0.16 ± 0.09	1.94 ± 0.21	1.112 ± 0.02

4.4 Miscellaneous Properties (Water Absorption, Mass Loss, and Linear Shrinkage)

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, UPC, and UBFRCs; these are 2.44, 2.68, 2.82, 3.05, 3.78, 3.89, and 3.97 respectively. The water absorption for the UBFRC2.0 and UBFRC2.5 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. The high temperature oven is used for performing the mass loss test.

TABLE 4.3: Water Absorption, Linear Shrinkage, and Mass Loss of PC, UPC, and UBFRCs

Concrete	**Water Absorption**	**Linear Shrinkage**	**Mass Loss**		
Type	**(%)**	**(%)**	**@ 50°C**	**@ 75°C**	**@ 100°C**
PC	2.44	0.178	-0.037	-0.043	-0.103
UPC	2.68	0.156	-0.045	-0.053	-0.11
UBFRC0.5	2.82	0.112	-0.058	-0.06	-0.142
UBFRC1.0	3.05	0.091	-0.062	-0.068	-0.157
UBFRC1.5	3.78	0.082	-0.069	-0.074	-0.184
UBFRC2.0	3.89	0.079	-0.072	-0.079	-0.192
UBFRC2.5	3.97	0.073	-0.076	-0.083	-0.204

The method decribed by ASTM standard C157M-08 is adopted to measure linear shrinkage and mass loss in PC, UPC, and UBFRCs. The values of linear shrinkage PC, UPC and UBFRCs are1.78, 0.156, 0.112, 0.091, 0.082, 0.076, and 0.073 respectively. The decrease in the linear shrinkage's value with the increment in fiber content shows that the BF resists the linear shrinkage. The linear shrinkage is observed in UBFRCs. 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 UPC decrease in comparison to PC. This shows that voids are reduced by the addition of UPEO in concrete.

4.5 Role of Fibers in Concrete at Fractured Surface

After applying, mechanical loading, broken surfaces of fibrous concrete are shown in **Figure: 4.5**. It is discovered that the failure pattern and surfaces in UBFRCs are quite different from that of PC. Images of fractured surfaces after the mechanical testing are shown in **Figure 4.5**. The bonding between banana fibers and surrounding concrete is studied through these images. Fiber pullout can be observed clearly from the images of the fractured surfaces. There is strong bonding strength between banana fibers and the surrounding concrete matrix from these images. There is very little and extremely small size of voids present on the broken surfaces of the tested specimens. Good and proper mixing of ingredients of concrete can be scrutinized from these images.

After mechanical testing, specimens of UBFRCs are broken into small pieces. These broken minor particles are attached with other minor and/or major broken particles. This attachment of pieces/particles has resulted from the strong bridging effect of banana fibers with the composite. These kinds of changes cannot be observed in normal plain concrete and are caused by the presence of the fibers. After the failure fiber pullout is experienced, instead of breakage of fibers, at the location of the fracture surface. This is evidence that the presence of fibers made the specimen withstand a little longer than the PC. After the failure of the UBFRC specimen, the sample is kept on resisting against the loading because of the bridging effect of banana fibers between the cracks. It is perceived after performing the experiment that the existence of BF help in resisting in production and progression of micro cracks.

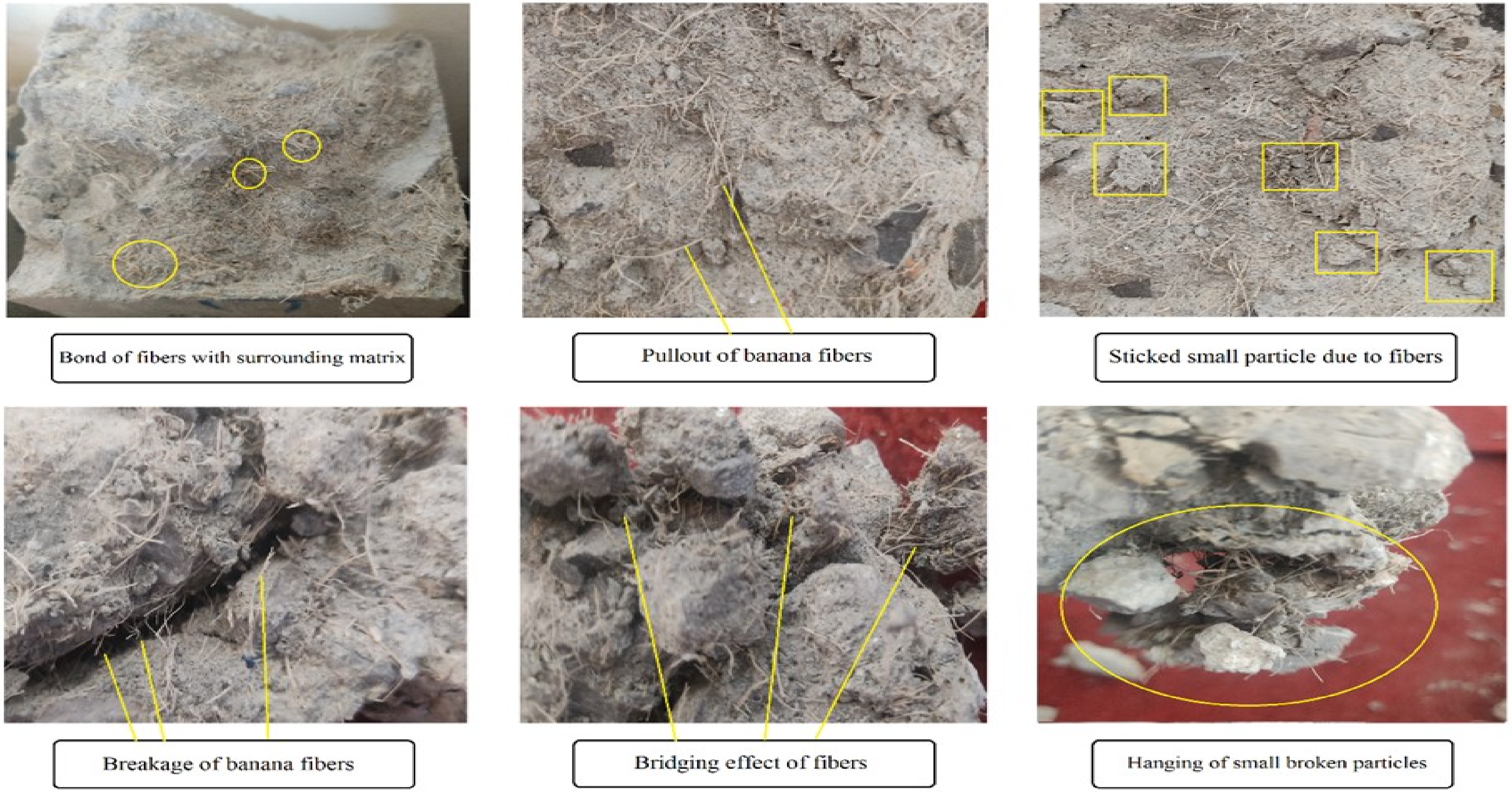

FIGURE 4.5: Fractured Surfaces of Different Tested Specimens

Addition and mixing of fibers is done as per method reported in section 3.3. In each image of figure 4.5, well distribution of fibers can be observed on broken surfaces of tested specimens. There are some small fragments (shown at bottom right image of figure 4.5) attached through fibers from the broken surface of the tested specimens. Thus, structural members having BF can resist the spalling phenomenon. Small fragments are attached with broken surface of tested specimens due to bridging effect caused by the BF.

4.6 Summary

In this chapter, the workability properties, densities of hard concrete, dynamic properties, mechanical properties, water absorption, linear shrinkage, and mass loss properties are calculated with mix design 1:2:4 with 0.5 w/c for PC, and UPC and 0.6 w/c for the UBFRCs. Dynamic modulus of rigidity enhanced by increasing content of BF in concrete. The addition of UPEO resulted and increment in slump value of concrete whereas BF caused reduction in the slump value of concrete. UBFRCs has shown increment in 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. The flexural strength has be reduced by the addition of UPEO and banana fiber has improved the flexural strength. BF enhanced the splitting-tensile and flexural load resistance capacity of concrete. Water absorption has direct relation with the content of fiber which means water absorption property increased by increasing the BF content in concrete. But linear shrinkage has shown the opposite relation with increasing the BF content. The more mass loss is observed in concrete when the content of BF is increased in concrete. Also, the BF has good bonding with the surrounding matrix when the broken surfaces fractured specimens are examined.

Chapter 5

Guidelines for Practical Implementation

5.1 Background

The testing results obtained gave quantitative results of impact of fiber ratio on properties of used petrol-engine oil and banana fiber reinforced concrete. Stress-strain, load- deflection and load deformation graphs represent effect of fibers on mechanical properties and that of dynamic properties of UBFRCs. This data obtained is further utilized to develop an empirical relation between fiber content (FC) and different mechanical properties of UBFRC. Furthermore, discussions on practical implementation and recommendation of UBFRC in real life applications are made in this chapter.

5.2 Optimization of Banana Fibers with Waste Petrol-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 UBFRC having 0.5% of BF along with 9.4% of UPEO by mass of cement is recommended on the base high compressive strength than other UBFRCs. The UBFRC 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 UBFRC having 2.0% of banana fibers along with 9.4% of waste petrol-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 UBFRCs 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 fibers.

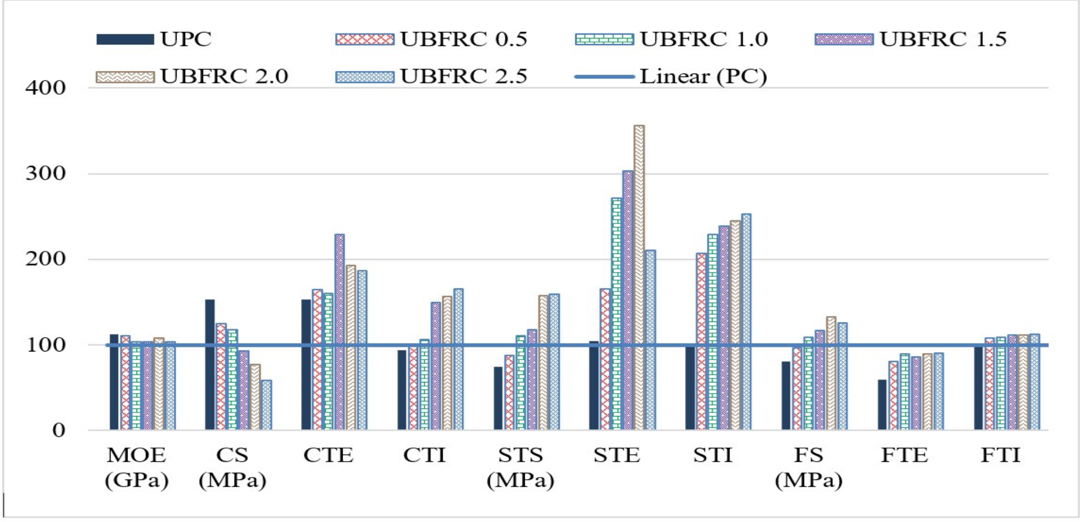

Figure 5.1: Effect of Percentage Difference of Banana Fibers Contents in UBFRCs

Table 5.1: Optimization of Banana Fiber Content in UBFRC

Concrete	**Compression**				**Splitting tensile**			**Flexural**			**Dynamic****		
Type	**MOE (GPa)**	**CS (MPa)**	**CTE (MJ/m3)**	**CTI (–)**	**SS (MPa)**	**STE (MJ/m3)**	**STI (–)**	**FS (MPa)**	**FTE (MJ/m3)**	**FTI (–)**	**ζ (%)**	**Ed (GPa)**	**Rd (GPa)**
PC's values	25 ± 1.4	10 ± 0.8	0.098 ± 0.003	2.58 ± 0.01	1.94 ± 0.2	15.55 ± 1.1	1	0.91 ± 0.2	2.15 ± 0.12	1	1.85 ±0.2	14.43 ±1.7	5.5 ±0.645
UPC's values	28.1 ± 0.7	15.3 ± 1.0	0.15 ± 0.016	2.42 ± 0.05	1.44 ± 0.3	16.26 ± 1.1	1	0.73 ± 0.2	1.28 ± 0.13	1	1.4 ± 0.01	12.43 ± 1.1	4.74 ± 0.412
UBFRC* with minimum values	25.8 ± 0.7 (2.5)	5.9 ± 1.3 (2.5)	0.157 ± 0.004 (1.0)	2.61 ± 0.04 (0.5)	1.7 ± 0.1 (0.5)	42.16 ± 3.15 (1.0)	2.07 ± 0.04 (0.5)	0.88 ± 0.1 (0.5)	1.74 ± 0.26 (0.5)	1.084 ± 0.01 (0.5)	1.93 ±0.02 (0.5)	8.86 ±0.3 (2.5)	3.38 ±0.13 (2.5)
UBFRC* with maximum values	27.7 ± 1.2 (O.5)	12.5 ± 0.9 (O.5)	0.224 ± 0.004 (1.5)	4.27 ± 0.04 (2.5)	3.09 ± 0.4 (2.5)	55 ± 3.12 (2.0)	2.53 ± 0.04 (2.5)	1.21 ± 0.2 (2.0)	1.94 ± 0.03 (2.0)	1.117 ± 0.02 (2.0)	2.33 ±0.01 (2.5)	11.9 ±0.4 (1.0)	4.45 ±0.002 (O.5)

Recommended													
1. For specific property													
a. From a strength	UBFRC0.5				UBFRC2.5			UBFRC2.0			UBFRC0.5		
point of view	27.7	12.5	0.161	2.61	3.09	32.65	2.53	1.21	1.94	1.117	1.93	11.33	4.45
b. From a toughness	UBFRC2.5				UBFRC2.5			UBFRC2.0					
point of view	25.8	5.9	0.183	4.27	3.09	32.65	2.53	1.21	1.94	1.117		(-)	
2. For specific application													
a. UBFRC1.0 for columns / compression members	25.8	11.8	0.157	2.73	2.14	42.16	2.29	0.99	1.93	1.09	2.04	11.94	4.27
b. UBFRC2.0 for slabs and beams	26.9	7.7	0.189	4.05	3.06	55.3	2.45	1.21	1.94	1.117	2.25	10.53	4.14
c. UBFRC2.0 for rigid pavements	26.9	7.7	0.189	4.05	3.06	55.3	2.45	1.21	1.94	1.117	2.25	10.53	4.14
d. UBFRC0.5 for structure prone to lateral loading	27.7	12.5	0.161	2.61	1.7	25.75	2.07	0.88	1.74	1.084	1.93	11.33	4.45

5.3 Empirical Relationship

The performance of the structure depends upon the mechanical properties of material is used in construction of sturcture. Properties of concrete directly affect the performance of the structure. Performance can be related to properties like energy absorption, toughness indexes, compressive strength, splitting-tensile strength, and flexural strength, etc. Sometimes concrete pieces start spalling before steel failure. Hence bonding of concrete with all ingredients is very important.

Fibers are added to concrete to enhance the concrete strength and bonding under different types of loadings. Furthermore, toughness can be related to its spalling as it is similar to ductility. Fibers can change the concrete brittle behavior to ductile. Fibers are also helpful in minimizing the cracks number and their size. For better post crack behavior more energy absorption is required. Another purpose of fibers to use in concrete is that fibers increase the energy absorption as a result to enhance the concrete post crack behavior.

Empirical equations are developed with the help of obtained experimental results from mechanical testing of specimens to numerically predict the splitting-tensile strength (SS) and flexural strength (FS) of UPC and UBFRCs. As the UPEO is used in all types of casted UBFRCs, so the values of PC properties are not included in developing these equations. It is done to get the precise and errorless equation.

The properties of concrete are also disturbed by the UPEO and UPEO is added in all the UBFRCs. So, the data of UPC is used to avoid the uninfluenced properties of PC in developing the empirical equation instead of PC Developed empirical equations are given below:

$$CS = -3.65 * BFC + 15 \tag{5.1}$$

$$SS = 0.71 * BFC + 1.40 \tag{5.2}$$

$$FS = 0.28 * SS + 0.36 \tag{5.3}$$

or

$$FS = 0.20 * BFC + 0.75 \tag{5.4}$$

Where SS is splitting tensile strength, BFC is the percentage of banana fiber content and and FS is flexural strength. The empirical equations for CS, SS, and FS are developed with the help of best fit curves having experimental values of current study. This approach of developing empirical equations was reported by some other researchers [7, 53, 69, 70].

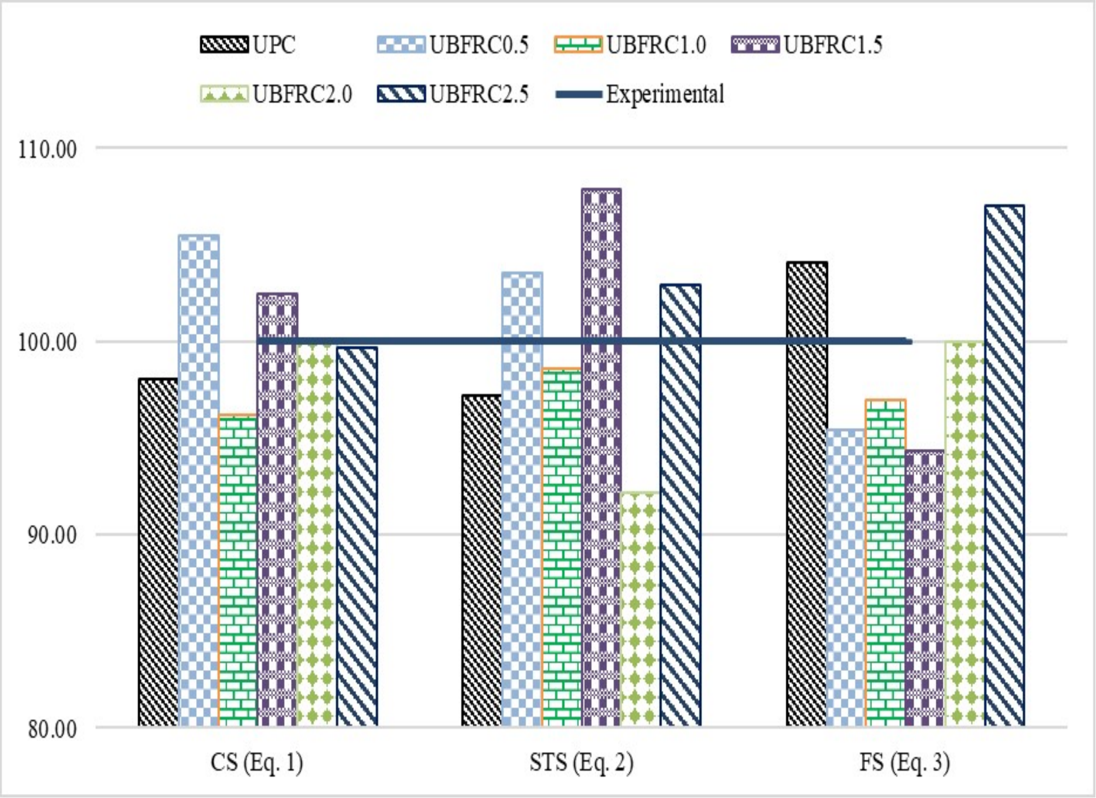

FIGURE 5.2: Relationship between Empirical and Experimental CS, SS, and FS.

After the development of equations, the deviations between empirical to experimental values have been investigated. A comparison of experimental and empirical values of compressive strength, splitting-tensile strength, and flexural strength can be seen in **Table 5.2**. In the comparison of empirical values to experimental values, it is found that the value of every single property deviated less than 10% from experimental values. **Figure 5.2** shows the relationship between experimental found by performing testing and numerical value found by using the developed empirical equations. It can be noticed from the **figure 5.2** that not a single value exceeds or decreases more than 10% of experimental values. This phenomenon defines the accuracy of the developed equations.

TABLE 5.2: Comparison of Empirical and Experimental CS, SS, and FS

	Experimental			**Empirical**		
Specimen	**CS (MPa)**	**SS (MPa)**	**FS (MPa)**	**CS (MPa)**	**SS (MPa)**	**FS (MPa)**
UPC	15.3	1.44	0.73	15	1.4	0.76
UBFRC0.5	12.5	1.7	0.88	13.18	1.76	0.84
UBFRC1.0	11.8	2.14	0.99	11.35	2.11	0.96
UBFRC1.5	9.3	2.29	1.06	9.53	2.47	1
UBFRC2.0	7.7	3.06	1.21	7.7	2.82	1.21
UBFRC2.5	5.9	3.09	1.14	5.88	3.18	1.22

5.4 Practical Implementation

In different civil engineering applications, concrete also goes through several types of loadings together with mechanical loading and dynamic loading. The performance efficiency is affected and controlled by these types of loadings like compressive strength, tensile strength, and flexural strength. The durability of concrete also depends upon these types of loadings. The cracks are produced in concrete due to high water absorption, more linear shrinkage, and less strength of concrete in tension [63].

The phenomenon of differential settlement can also cause cracking in rigid pavements which can be controlled by enhancing the flexural strength property of concrete. One of the issues is spalling of concrete. The spalling of concrete reduces the durability of concrete and it is caused by different factors such as exposure to high temperatures.

The spalling of concrete can be reduced significantly by improving the tensile strength of concrete with the addition of the fibers in the composite [64]. Impact loading like blasting, the collision of the vehicle to the piers of concrete bridges may lead to the failure of the structure. The resistance of concrete against impact loading can be improved by enhancing dynamic modulus of rigidity and energy absorption property of concrete [7].

In this study, the behavior of PC, UPC, and UBFRCs is explored by using waste petrol-engine oil (UPEO) and different contents of the banana fibers (BF). The specimens of UBFRC0.5 have shown better performance against the compressive loading. The properties of UBFRC2.0 are improved against the tension loading and can be used for the members like beams and slabs.

The rigid pavements are designed by keeping in mind the flexural strength and modulus of elasticity of the concrete. So, UBFRC2.0 is more suitable as it has shown better modulus of rupture and modulus of elasticity which are key factors in the stability and durability of the rigid pavements.

The compression members which go purely under uniaxial loading, the UBFRC0.5 is suitable for such kind of members as it has shown high compression strength than any other type of UBFRCs. The UBFRC1.0 has shown compression strength good enough along with some resistance against the moment forces. So UBFRC1.0 is recommended for those types of members where compressive loading is being considered as critical loading.

5.5 Summary

The optimization of in banana fibers along with used petrol-engine oil and separate recommendations are made from strength and toughness index. The recommendations are, also, made for according to specific application so that UBFRCs can be used for in-real life applications. The empirical relations are developed form the experimental data. From these developed equations, strength properties are calculated and compared with the experimental properties.

Chapter 6

Conclusions and Recommendations

6.1 Conclusions

The value of waste materials is increasing with the passage of time. Some of these wastes are severe damaging to the environment. One of these hazardous wastes is used petrol-engine oil. There is a need to dump these waste in an effectice way so that the impact of environmetnal pollution causing phenomenons can be reduced. In this study, the waste materials are utilized to explores the behavior of the waste/used petrol-engine oil and banana fiber reinforced concrete (UBFRC). Various values of banana fibers (BF) have been used along with waste petrol-engine oil (UPEO) to investigate the dynamic properties, mechanical properties, water absorption property, linear shrinkage property, and mass loss. The different proportions of BF and UPEO are admixed in concrete by taking mass of cement. The following conclusions have been drawn from this study:

- The addition of fibers has improved the ability to sustain against the lateral loading by enhancing the damping ratio.
    - By increasing the content of BF the damping ratio is improved, the dynamic modulus of elasticity has improved and reduction has been

  observed in dynamic modulus of rigidity in both cylinders and beamlets cases.

- The mechanical properties of concrete are influenced by the incorporation of the BF and UPEO.
  - The increase in BF has shown the opposite effect on the compressive strength of concrete. The reduction in compressive strength is due to the use of low density fiber.
  - Maximum splitting tensile and flexural strengths have been observed when 2.5% and 2.0% contents of BF, respectively, are used along with the 9.4% of UPEO. The increase in splitting tensile strength is caused by the high tensile properties of the BF. The addition of fibers more than 2.0% has shown inverse relation with flexural strengths.
  - Fibers in the FRC have resulted in an improvement in the energy absorption property of the concrete.
  - The presence of BF in concrete has avoided the sudden failure of UBFRCs by showing some of the post-crack energy in comparison to PC and UPC.

- The water absorption property of concrete has shown direct relationships with the increase of fiber content in concrete. On the other way around, the presence of fibers has slightly increased resistance against linear shrinkage in concrete by increasing the value of fibers in concrete.
  - Since the increase in water absorption due to the increase in the quantity of BF in FRC is one of the reasons causing the reduction in the workability of the concrete.
  - UBFRCs has shown good performance by not showing vulnerability to spalling at high temperature. This effect is observed due to resistance against linear shrinkage enhanced by the BF.
  - The mass loss is observed more in UBFRC with the increase in BF. This is due to the high water absorption property of BF.

- Bonding of BF with surrounding concrete matrix still exists in destructive samples subjected to dynamic, mechanical, and miscellaneous tests.
- On the basis of comparison of governing properties for a specific aspect and keep in view other non-governing properties following recommendations are made;
  - UBFRC1.0 for the compressive and columns member
  - UBFRC2.5 for the tensile structural members like beams and slabs
  - UBFRC2.0 has shown better flexural properties than any other type of UBFRCs.
  - UBFRC0.5 is recommended for the members and/or structures prone to lateral loading based on a comparison of properties to other UBFRCs.
- Empirical equations are developed to predict the influence of banana fibers along with the UPEO in concrete.

From this research work, the concrete composed of 9.4% UPEO as an admixture and 2.0% of BF as reinforcement is recommended to resist cracking, spalling, and flexural loading. Also, this is suitable for rigid pavements by having a high value of modulus of rupture along with a suitable value of modulus of elasticity. It has shown maximum splitting-tensile and flexural strengths, more energy absorption, and resistance against impact loading.

6.2 Future Works

Thus, admixture with natural fiber reinforced concrete have potential to enhance properties of concrete by varying their content in concrete mix. Following works should be given consideration for future working to understand the behavior of UBFRCs in further detail:

- UBFRCs should be studied with varying fiber lengths for each of the constant fiber content.

- UBFRC should be studied with fix content of banana fiber and varying proportions of UPEO.
- Exploring the resistance against the impact loading.
- Any other suitable admixture along with banana fibers in concrete.

Bibliography

[1] F. Aslani, G. Ma, D. L. Y. Wan, and G. Muselin, “Development of high-performance self-compacting concrete using waste recycled concrete aggregates and rubber granules,” *Journal of Cleaner Production,* vol. 182, pp. 553–566, 2018.

[2] C. Zhou et al., “Impact of freeze-thaw environment on concrete materials in two-lift concrete pavement,” *Construction and Building Materials*, vol. 262, p. 120070, 2020.

[3] Q. Nie, C. Zhou, H. Li, X. Shu, H. Gong, and B. Huang, “Numerical simulation of fly ash concrete under sulfate attack,” *Construction and Building Materials*, vol. 84, pp. 261–268, 2015.

[4] P. S. Song and S. Hwang, “Mechanical properties of high-strength steel fiber-reinforced concrete,” *Construction and Building Materials*, vol. 18, no. 9, pp. 669–673, 2004.

[5] F. N. Stafford, F. Raupp-Pereira, J. A. Labrincha, and D. Hotza, “Life cycle assessment of the production of cement: A Brazilian case study,” *Journal of Cleaner Production*, vol. 137, pp. 1293–1299, 2016.

[6] Y. L. Yaphary, R. H. W. Lam, and D. Lau, “Reduction in cement content of normal strength concrete with used engine oil (UEO) as chemical admixture,” *Construction and Building Materials*, vol. 261, p. 119967, 2020.

[7] S. Ahmed and M. Ali, “Use of agriculture waste as short discrete fibers and glass-fiber-reinforced-polymer rebars in concrete walls for enhancing impact resistance,” *Journal of Cleaner Production*, vol. 268, p. 122211, 2020.

[8] M. U. Farooqi and M. Ali, “Contribution of plant fibers in improving the behavior and capacity of reinforced concrete for structural applications,” *Construction and Building Materials,* vol. 182, pp. 94–107, 2018.

[9] A. Ghazy, M. T. Bassuoni, E. Maguire, and M. O’Loan, “Properties of fiber-reinforced mortars incorporating nano-silica,” *Fibers*, vol. 4, no. 1, p. 6, 2016.

[10] A. Abushanab, W. Alnahhal, and M. Farraj, “Structural performance and moment redistribution of basalt FRC continuous beams reinforced with basalt FRP bars,” *Engineering Structures*, vol. 240, p. 112390, 2021.

[11] K. M. M. Rao and K. M. Rao, “Extraction and tensile properties of natural fibers: Vakka, date and bamboo,” Composite structures, vol. 77, no. 3, pp. 288–295, 2007.

[12] M. A. R. Bhutta, N. Hasanah, N. Farhayu, M. W. Hussin, M. bin Md Tahir, and J. Mirza, “Properties of porous concrete from waste crushed concrete (recycled aggregate),” *Construction and building materials*, vol. 47, pp. 1243–1248, 2013.

[13] A. Rao, K. N. Jha, and S. Misra, “Use of aggregates from recycled construction and demolition waste in concrete,” *Resources, conservation and Recycling*, vol. 50, no. 1, pp. 71–81, 2007.

[14] A. Halicka, P. Ogrodnik, and B. Zegardlo, “Using ceramic sanitary ware waste as concrete aggregate,” *Construction and Building Materials*, vol. 48, pp. 295–305, 2013.

[15] P. Asokan, M. Osmani, and A. D. F. Price, “Assessing the recycling potential of glass fibre reinforced plastic waste in concrete and cement composites,” *Journal of Cleaner Production*, vol. 17, no. 9, pp. 821–829, 2009.

[16] S. Saini, M. R. Srivastava, and F. Anjum, “Replacement of water with used engine coolant and its effect on the mechanical properties of hardened concrete,” *Materials Today: Proceedings*, vol. 34, pp. 604–607, 2021.

[17] B. S. Hamad, A. A. Rteil, and M. El-Fadel, “Effect of used engine oil on properties of fresh and hardened concrete,” *Construction and Building materials,* vol. 17, no. 5, pp. 311–318, 2003.

[18] B. S. Hamad and A. A. Rteil, “Effect of used engine oil on structural behavior of reinforced concrete elements,” *Construction and Building Materials,* vol. 17, no. 3, pp. 203–211, 2003.

[19] W. O. Akintunde, O. A. Olugbenga, and O. O. Olufemi, “Some adverse effects of used engine oil (common waste pollutant) on reproduction of male sprague dawley rats,” *Open Access Macedonian Journal of Medical Sciences*, vol. 3, no. 1, p. 46, 2015.

[20] A. Al Mamun, H. I. A.-A. Wahhab, and M. A. Dalhat, “Comparative Evaluation of Waste Cooking Oil and Waste Engine Oil Rejuvenated Asphalt Concrete Mixtures,” *Arabian Journal for Science and Engineering*, vol. 45, no. 10, pp. 7987–7997, 2020.

[21] H. Taherkhani and F. Noorian, “Comparing the effects of waste engine and cooking oil on the properties of asphalt concrete containing reclaimed asphalt pavement (RAP),” *Road Materials and Pavement Design*, vol. 21, no. 5, pp. 1238–1257, 2020.

[22] A. Woszuk, M. Wróbel, and W. Franus, “Influence of waste engine oil addition on the properties of zeolite-foamed asphalt,” *Materials*, vol. 12, no. 14, p. 2265, 2019.

[23] J. Cai et al., “Investigation on high-viscosity asphalt binder for permeable asphalt concrete with waste materials,” *Journal of Cleaner Production*, vol. 228, pp. 40–51, 2019.

[24] R. Ristavletov et al., “Effective multifunctional additives for concrete based on the wastes of the oil industry,” *Structural Concrete*, vol. 20, no. 5, pp. 1541–1550, 2019.

[25] N. Shafiq, C. S. Choo, and M. H. Isa, “Effects of used engine oil on slump, compressive strength and oxygen permeability of normal and blended cement concrete,” *Construction and Building Materials*, vol. 187, pp. 178–184, 2018.

[26] J. J. Assaad, "Disposing used engine oils in concrete–Optimum dosage and compatibility with water reducers," *Construction and Building Materials*, vol. 44, pp. 734–742, 2013.

[27] C. Burbano-Garcia, A. Hurtado, Y. F. Silva, S. Delvasto, and G. Araya-Letelier, "Utilization of waste engine oil for expanded clay aggregate production and assessment of its influence on lightweight concrete properties," Construction and Building Materials, vol. 273, p. 121677, 2021.

[28] B. Hasan and M. Ali, "Workability of Concrete Having Used Petrol Engine Oil and Banana Fibers," *IEECP*, pp. 21–25, 2021.

[29] R. G. Varghese and P. E. Sakaria, "Experimental investigation on the properties of fresh and hardened concrete with used engine oil as super plasticizer," *Int. Res. J. Eng. Technol.*, vol. 5, no. 4, pp. 2230–2236, 2017.

[30] N. Sathiparan, M. N. Rupasinghe, and B. H. M. Pavithra, "Performance of coconut coir reinforced hydraulic cement mortar for surface plastering application," *Construction and Building Materials*, vol. 142, pp. 23–30, 2017.

[31] F. Qamar, T. Thomas, and M. Ali, "Use of natural fibrous plaster for improving the out of plane lateral resistance of mortarless interlocked masonry walling," *Construction and Building Materials*, vol. 174, pp. 320–329, 2018.

[32] A. R. G. de Azevedo, M. T. Marvila, M. L. P. Antunes, E. C. Rangel, and R. Fediuk, "Technological Perspective for Use the Natural Pineapple Fiber in Mortar to Repair Structures," *Waste and Biomass Valorization*, pp. 1–15, 2021.

[33] M. Ali, "Use of coconut fibre reinforced concrete and coconut-fibre ropes for seismic-resistant construction," *Materiales de Construcción*, vol. 66, no. 321, p. 73, 2016.

[34] M. Ali and N. Chouw, "Coir fibre and rope reinforced concrete beams under dynamic loading," 2009.

[35] R. Dávila-Pompermayer, L. G. Lopez-Yepez, P. Valdez-Tamez, C. A. Juárez, and A. Durán-Herrera, "Lechugilla natural fiber as internal curing agent in self

compacting concrete (SCC): Mechanical properties, shrinkage and durability," *Cement and Concrete Composites*, vol. 112, p. 103686, 2020.

[36] D. L. Naik, A. Sharma, R. R. Chada, R. Kiran, and T. Sirotiak, "Modified pullout test for indirect characterization of natural fiber and cementitious matrix interface properties," *Construction and Building Materials*, vol. 208, pp. 381–393, 2019.

[37] F. Kesikidou and M. Stefanidou, "Natural fiber-reinforced mortars," *Journal of Building Engineering*, vol. 25, p. 100786, 2019.

[38] J. Mo et al., "Mechanical properties and damping capacity of polypropylene fiber reinforced concrete modified by rubber powder," *Construction And Building Materials*, vol. 242, p. 118111, 2020.

[39] M. A. Vicente, J. Mínguez, and D. C. González, "Computed tomography scanning of the internal microstructure, crack mechanisms, and structural behavior of fiber-reinforced concrete under static and cyclic bending tests," *International Journal of Fatigue*, vol. 121, pp. 9–19, 2019.

[40] T. F. Lam and J. M. Yatim, "Mechanical properties of kenaf fiber reinforced concrete with different fiber content and fiber length," *Journal of Asian Concrete Federation*, vol. 1, no. 1, pp. 11–21, 2015.

[41] M. Boopalan, M. Niranjanaa, and M. J. Umapathy, "Study on the mechanical properties and thermal properties of jute and banana fiber reinforced epoxy hybrid composites," *Composites Part B: Engineering*, vol. 51, pp. 54–57, 2013.

[42] G. Nilza, J. S. J. Virgo, and V. Buchanan, "Potential of Jamaican banana, coir, bagasse fiber as composite materials," *Materials characterization*, vol. 59, pp. 1273–12738, 2008.

[43] N. Venkateshwaran and A. Elayaperumal, "Banana fiber reinforced polymer composites-a review," *Journal of Reinforced Plastics and Composites*, vol. 29, no. 15, pp. 2387–2396, 2010.

[44] A. Elbehiry, O. Elnawawy, M. Kassem, A. Zaher, N. Uddin, and M. Mostafa, “Performance of concrete beams reinforced using banana fiber bars,” *Case Studies in Construction Materials*, vol. 13, p. e00361, 2020.

[45] A. Elbehiry, O. Elnawawy, M. Kassem, A. Zaher, and M. Mostafa, “FEM evaluation of reinforced concrete beams by hybrid and banana fiber bars (BFB),” *Case Studies in Construction Materials*, vol. 14, p. e00479, 2021.

[46] H. M. Awais, “Optimization of Jute Fibre Content in Concrete Slabs having GFRP Rebars against Impact Loading.” *Capital University*, 2021.

[47] M. Khan, M. Cao, and M. Ali, “Effect of basalt fibers on mechanical properties of calcium carbonate whisker-steel fiber reinforced concrete,” *Construction and Building Materials*, vol. 192, pp. 742–753, 2018.

[48] M. Khan, A. Rehman, and M. Ali, “Efficiency of silica-fume content in plain and natural fiber reinforced concrete for concrete road,” *Construction and Building Materials*, vol. 244, p. 118382, 2020.

[49] T. Hussain and M. Ali, “Improving the impact resistance and dynamic properties of jute fiber reinforced concrete for rebars design by considering tension zone of FRC,” *Construction and Building Materials*, vol. 213, pp. 592–607, 2019.

[50] M. Ali, “Seismic performance of coconut-fibre-reinforced-concrete columns with different reinforcement configurations of coconut-fibre ropes,” *Construction and Building Materials*, vol. 70, pp. 226–230, 2014.

[51] K. Vardhan, R. Siddique, and S. Goyal, “Strength, permeation and microstructural characteristics of concrete incorporating waste marble,” *Construction and Building Materials*, vol. 203, pp. 45–55, 2019.

[52] H. Mohammadhosseini, M. M. Tahir, and A. R. M. Sam, “The feasibility of improving impact resistance and strength properties of sustainable concrete composites by adding waste metalized plastic fibres,” *Construction and Building Materials*, vol. 169, pp. 223–236, 2018.

[53] M. Ali, "Role of post-tensioned coconut-fibre ropes in mortar-free interlocking concrete construction during seismic loadings," *KSCE Journal of Civil Engineering*, vol. 22, no. 4, pp. 1336–1343, 2018.

[54] E. A. Jiya, N. S. N. Anwar, and M. Z. Abdullah, "Detection of cracks in concrete structure using microwave imaging technique," *International Journal of Microwave Science and Technology*, vol. 2016, 2016.

[55] J. Slaitas and J. Valivonis, "Concrete cracking and deflection analysis of RC beams strengthened with prestressed FRP reinforcements under external load action," *Composite Structures*, vol. 255, p. 113036, 2021.

[56] S. Swaddiwudhipong, H.-R. Lu, and T.-H. Wee, "Direct tension test and tensile strain capacity of concrete at early age," *Cement and concrete research*, vol. 33, no. 12, pp. 2077–2084, 2003.

[57] ASTM 215-14, "Standard Test Method for Fundamental Transverse, Longitudinal, and Torsional Resonant Frequencies of Concrete Specimens," *American Society of Testing and Materials.*

[58] ASTM C39, "Test Method for Compressive Strength of Cylindrical Concrete Specimens," *American Society of Testing and Materials*, vol. 04, no. October, pp. 1–7, 2003.

[59] ASTM C 496M-02, "C496-96 Standard Test Method for Splitting Tensile Strength of Cylindrical Concrete," *American Society of Testing and Materials*, vol. 04, no. 02, pp. 91–95, 2002.

[60] ASTM C78, "Standard Test Method for Flexural Strength of Concrete (Using Simple Beam with Third-Point Loading)," *American Society of Testing and Materials*, vol. 04.02, pp. 1–3, 2002.

[61] M. Affan, "Effect of Freeze-Thaw Cycles on Mechanical Properties of Jute Fiber Reinforced Concrete for Pavement," *Capital University of Science and Technology*, 2019.

[62] M. Ali, A. Liu, H. Sou, and N. Chouw, "Mechanical and dynamic properties of coconut fibre reinforced concrete," *Construction and Building Materials*, vol. 30, pp. 814–825, 2012.

[63] A. Zia and M. Ali, “Behavior of fiber reinforced concrete for controlling the rate of cracking in canal-lining,” *Construction and Building Materials*, vol. 155, pp. 726–739, 2017.

[64] J. H. Cui, Z. Q. Xie, and H. J. Xiao, “Cause analysis on the cracks in concrete plate of canal lining,” *In Applied Mechanics and Materials*, 2013, vol. 405, pp. 2596–2599.

[65] K. Senthilkumar, I. Siva, N. Rajini, J. T. W. Jappes, and S. Siengchin, “Mechanical characteristics of tri-layer eco-friendly polymer composites for interior parts of aerospace application,” in *Sustainable Composites for Aerospace Applications*, Elsevier, 2018, pp. 35–53.

[66] M.-A. Arsène, K. Bilba, and C. Onésippe, “Treatments for viable utilization of vegetable fibers in inorganic-based composites,” in *Sustainable and Nonconventional Construction Materials using Inorganic Bonded Fiber Composites*, Elsevier, 2017, pp. 69–123.

[67] R. Abro, X. Chen, K. Harijan, Z. A. Dhakan, and M. Ammar, “A comparative study of recycling of used engine oil using extraction by composite solvent, single solvent, and acid treatment methods,” *International Scholarly Research Notices*, vol. 2013, 2013.

[68] S. Sakhtivel, R. Prameshwari, M. Gomathi, and S. Sangeetha, “Experimental investigation on concrete with banana fiber and partial replacement of cement by banana leaf ash,” *International Research Journal of Engineering and Technology*, vol. 6, no. 3, pp. 3914–3919, 2019.

[69] M. Ali. A. Liu, H. Sou, N. Chouw, ”Mechanical and dynamic properties of coconut fibre reinforced concrete,” *Construction and Building Materials*, 30, 814-825, (2012).

[70] M. Khan, A. Rehman, M. Ali, ”Efficiency of silica-fume content in plain and natural fiber reinforced concrete for concrete road,” Construction and Building Materials, 244, 118382, (2020).

[71] L. A. Pothan and S. Thomad, ”Effect of hybridization and chemical modification on the water-absorption behavior of banana fiber-reinforced polyster

composites," *Journal of applied polymer science*, vol 91, no. 6 pp. 38756-3865, 2004.

[72] S. C. Chin, N. Shafiq, and M. F. Nuruddin, "Effects of used engine oil in reinforced concrete beams: the structural perfromance," International Journal of Civil, Environmental, Structural, Construction and Architectural Engineering, vol. 6, no. 3, pp. 932–938, 2012.

[73] ASTM C642-13, "Standard Test Method For Density, Absorption, And Voids In Hardened Concrete," June, 2015.

[74] ASTM C 157/C 157M–08, "Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and," Annual Book of ASTM Standards, vol. 04, pp. 1–7, 2003.