CAPITAL UNIVERSITY OF SCIENCE AND TECHNOLOGY, ISLAMABAD

Partial Replacement of Cement with Eggshell and Marble Dust Powder in Pine-Needle Fiber Reinforced Concrete

by

Muhammad Irfan

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in the

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This thesis is dedicated to:

My respected brother and Parents

And everyone supported me in this journey, Who have been always a symbol of Affection, Happiness, and Bliss.

CERTIFICATE OF APPROVAL

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(Muhammad Irfan)

Abstract

Cement is a highly utilized material in the construction industry; however, its production contributes to the generation of carbon dioxide, resulting in environmental issues such as greenhouse gas emissions, acid rain, and ozone layer depletion, which negatively impact human health. To reduce CO_2 emissions, cement can be partially replaced with filler materials like marble dust and eggshell powder. Concrete is also susceptible to flaws such as spalling, cracking, and brittleness. Natural fibers such as pine needles can be added to concrete with marble dust and eggshell powder to produce more sustainable construction material. This approach has the potential to make construction more eco-friendly while enhancing the flexural and compressive strength of concrete.

In this research, the utilization of commercial waste such as marble dust, eggshell powder, and pine-needle natural fiber is added to concrete to enhance its mechanical properties of concrete. Marble dust and eggshell powder are used in concrete as a filler material. For this purpose, three cylinders and three beamlets are cast for plain concrete (PC). Similarly, three cylinders and 3 beams are cast for marble dust with 15% replacement of cement to prepare PMC. The same cylinder and beamlets have been cast for PNRC to prepare PN-FRC1 with 30mm long fiber which has taken 1% by volume of wet concrete in all specimens of PESPMDP-FRCs The water-cement ratio (W/C) of 0.45 and 1.5% super-plasticizers is used with a mix design ratio of 1:2:3 (cement: sand: aggregate) along all specimens. The Slump, dynamic, mechanical, water absorption (WA), linear shrinkage (Ls) and mass loss (ML) are performed to check the influence of combinations of natural fibers with filler material on the properties of concrete. Slump results showed that PNESPMDP-FRCs have less value of slump as compared to PC. The decrease in slump value is observed with the utilization of pine-needle fiber with 30mm lengths and the utilization of marble dust and eggshell powder in different combinations. The results have shown that PNESPMDP-FRCs have dominant dynamic, compressive, and flexural properties as compared to PC. The PNESPMDP-FRCs with 10% eggshell powder and 15% marble dust powder with a combination of 30mm long fiber have shown better performance against dynamic loading. While the PNESPMDP-FRCs with 10% of eggshell powder and 15% of marble dust with 30mm length of fiber 1% by volume of wet concrete showed more (C-S) as compared to the PESPMDO-FRCs and PC. The increase in flexural strengths is observed in pine-needle fiber compared to PC. Hence, it is concluded that the percentage of eggshell powder 10%, 15% MDP with pine-needle fiber achieves good results under compressive, flexural loading, and dynamic loadings. For application in compression members, 30mm pine-needle fiber with 10% eggshell powder and 15% marble dust powder by replacement of cement has shown better properties than all other PESPMDP-FRCs. The PESPMDP-FRC, which incorporates pine needle fiber and filler such as marble dust and eggshell powder, as partial substitution of cement, can effectively resist small surface cracks in concrete and improve its flexural strength. PESPMDP-FRC4 can be utilized in different concrete structures such as rigid pavement in streets, canal lining, lean concrete and concrete slab, etc.

Keywords: Sustainable Construction, Commercial Waste, Environmental Issues, Marble Dust Powder, Eggshell Powder, Pine Needle, Fiber Reinforced Concrete.

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Abbreviations

CE1	Compressive Energy Before Failure
CE2	Compressive Energy After failure
CS	Compressive Strength
CTE	Compressive Total Energy
CTI	Compressive Toughness Energy
ESP	Eggshell Powder
FS	Flexural Strength
FE1	Flexural Energy Before Failure
FE2	Flexural Energy After Failure
FTE	Flexural Total Energy
FTI	Flexural Toughness Index
GPa	Giga Pascal
KN	Kilo-Newtons
MOE	Modulus of Elasticity
MOR	Modulus of Rupture
MPa	Mega Pascal
MDP	Marble Dust Powder
ML	Mass-Loss
mm	Milimeter
OPC	Ordinary-Portland Cement
PCC	Portland Cement Concrete
PMC	Cement + Marble Powder
PN-FRC1	Pine Needle Fiber Reinforced Concrete
PESPMDP-FRC	Cement, Marble Powder, Eggshell Powder-

	Fiber Reinforced Concrete
PNMDP-FRC	Cement + Marble Powder with Pine Needle Fiber Reinforced Concrete
RFL	Longitudnal Resonance Frequancy
RFR	Rotational Resonance Frequancy
RFT	Transverse Resonance Frequancy
RD	Modulus of Rigidity
SP	Super-Plasticizers
SEM	Scaning Electron Microscopy
V%	Damping Ratio
WA	Water Absorption
W/C	Water Cement Ratio

Chapter 1

Introduction

1.1 Background

Concrete is the second highest naturally consumed material after water. Almost 503 million tons of cement are generated globally per year. Many environmental problems are created due to cement concrete production, which is not sustainable [1]. Nearly 9% of carbon dioxide emissions related to greenhouse gases are caused due to production of cement. Cement production pollutes our environment deprives us of our renewable energy sources. Because there are finite natural resources available on the earth that are needed to develop sustainable construction [2]. Industrial waste material, which includes marble waste, ceramic waste, granite waste, lime waste, brick waste, and concrete waste recycle material, is present here on the earth [3]. Developing sustainability in the construction industry is an interesting topic in civil engineering. Over the past few decades, most waste has been generated from different construction industries, which impacts the environment negatively [4]. Many researchers worldwide are searching for an alternate solution to reduce the contamination caused due to use of cement in the construction industry. Cement concrete is a conventional material with many adverse effects on the environment. Due to the growth of the construction industry, many researchers have predicted that the use of cementitious material will drastically increase in the future. The marble industry creates a considerable amount of waste throughout the year, which produces pollution. Concrete has been the primary engineering material in the construction industry for the past few decades [5, 6]. Concrete is a brittle material that is stronger in compression and weak in tension. Micro shrinkage cracks are caused in the early stage of concrete, which reduces the service life of the concrete element. The effective use of pine-needle pine needle natural fibers and eggshell in concrete enhances the properties of concrete to reduce the appearance of micro shrinkage cracks in concrete.

The production of cement is increasing day by day due to the demand of the construction industry. Production of one ton of cement produces the same amount of carbon dioxide, which causes carbon emissions, which have polluted our environment and caused many serious issues such as global warming, greenhouse gas emission, ozone layer depletion, etc. [7]. Adding marble waste, pine needle natural fiber, and eggshell powder enhanced the concrete's durability and mechanical properties [3, 7]. Concrete products offer many advantages, including durability, high compressive strength, low price, long-lasting lifetime, good forming, good mechanical–chemical–thermal properties, good energy absorption, and good corrosion resistance [8]. Synthetic fibers are not eco-friendly and harmful to human life. They do not readily undergo biodegradation. Pine needle fiber is a by-product of a pine tree and is readily available. Whereas eggshell and marble waste is a by-product easily available in the market, these materials are eco-friendly and have no harmful effects on human life [9]. Pine needle fiber and eggshells provide advantages like local availability, non-toxicity, and low cost. Using pine-needle fiber and eggshell with marble waste can reduce the cement content used in the production of concrete. Many researchers reported enhancing resistance against fatigue, cracking, and spalling, along with increased flexural strength. Hence, the performance of concrete can be improved for desired applications. Combining pine needle fibers with eggshells in concrete can reduce macro and micro cracking by introducing a bridging effect in concrete.

A large amount of cement is produced worldwide, which has a negative impact on our environment. Marble dust, natural fiber, and eggshell-based concrete are naturally neighborly newly developed building materials [10]. Due to the lack of cement used in concrete, suggestions to the industry given many researchers have believed that marble-based concrete will be the next concrete. Several products have been tried and tested to produce high performance eggshell, marble dust-based fiber-reinforced concrete. Finally, the eggshell became accustomed to it as an option for this purpose due to its high availability and low cost [11]. Eggshell and marble dust waste will significantly solve the problems associated with cement production Carbon emissions during the mixing of Ordinary Portland cement cause pollution and ozone layer depletion. This waste must be managed appropriately to protect the environment, which must be included in cement-reinforcing materials like granite waste, silica fume, etc. The use of eggshell and marble dust waste can greatly alleviate the issues related to cement production, particularly the emission of carbon that contributes to pollution and depletion of the ozone layer during the mixing of Ordinary Portland cement. Proper management of this waste is crucial to environmental protection and it should be incorporated into cement-reinforcing materials such as granite waste and silica fume. As well as the manufacturing of other bonding materials in OPC. Many researchers have suggested that marble-based concrete could be the future of the industry, as there has been a shortage of cement used in traditional concrete. Eggshell and marble dust-based fiber-reinforced concrete, which has demonstrated excellent performance. Eventually, eggshell was selected as a viable option due to its low cost and high availability [12]. In order to safeguard the environment, it is crucial to handle this waste properly and utilize it in cement-reinforcing materials. The consistent feature of the marble waste shows that it has a higher strength than conventional concrete. Destructive (DT) and Non-destructive tests (NDT) were performed on marble dust-based concrete to assess the best mix proportions that bring in the maximum strength and quality of the concrete. To ensure environmental protection, proper management of waste is crucial, and incorporating it into cementitious materials like granite waste, silica fume, and other similar substances is an effective approach. Moreover, this waste can also be utilized in the manufacture of bonding materials in Ordinary Portland Cement (OPC) production. Some experts suggest that marble-based concrete may offer a viable solution to the industry's cement shortage in traditional concrete [13]. Additionally, recent experiments have demonstrated the exceptional performance of fiber-reinforced concrete made from eggshell and marble dust.

1.2 Research Motivation and Problem Statement

Natural resources are depleted significantly in the manufacturing of cement in bulk quantities to meet the requirements of the construction industry, but its consumption cannot be avoided as it is the primary constituent of concrete. However, to attain sustainable development, the hour of need is to reduce the consumption of cement to conserve natural resources and mitigate the adverse impacts on the environment. Accordingly, this study's motivation is to develop sustainable construction materials by partially replacing cement with sustainable alternatives extracted from the waste materials such as marble dust, eggshell powder and pine needle fibers, which otherwise are useless and impact negatively on the environment.The objective of this research is to create sustainable building materials through the utilization of environmentally-friendly alternatives to cement. These alternatives, derived from waste materials such as marble dust, eggshell powder, and pine needle fibers, would otherwise have no practical use and could harm the environment.In order to achieve sustainable development, it is crucial to decrease the use of cement, which will help to conserve natural resources and minimize the negative effects on the environment. Utilizing sustainable alternatives derived from waste materials, such as marble dust, eggshell powder, and pine needle fibers, not only provides effective substitutes but also mitigates the environmental impact of these waste materials.

So, the problem statement is as follows.

Conventional concrete has reported with several flaws, such as low tensile strength and brittle nature. Furthermore, the increasing demand for cement in the construction industry causes the significant consumption of natural resources and generation of CO_2 *emissions in bulk quantity. To address this issue, different alternatives are recommended by the researchers for improving the concrete properties and reducing the cement requirement. The incorporation of short discrete fibers as dispersed reinforcement in concrete for enhancing concrete properties is also reported in the literature. The natural fibers are come out as a comparable, low cost and environmentally friendly alternative of steel/artificial fibers. But, detailed information on pine needle fibers in concrete is missing. Furthermore, the* *utilization of waste materials such as marble dust and eggshell powder is also reported as an effective partial substitution for cement. However, the combined effect of marble dust and eggshell powder as cement replacement and pine needle fiber as dispersed reinforcement in concrete is not explored yet. Therefore, there is a need to experimentally investigate the combined effect of marble dust and eggshell powder in pine needle fiber reinforced concrete in detail.*

1.3 Research Question

1. What is the combined effect of marble dust and eggshell powder on the dynamic properties of concrete?
2. What effect do pine-needle fiber and eggshell powder affect post-crack energy absorption?
3. How much can the mechanical properties be enhanced by incorporating waste material such as marble dust, eggshell powder, and pine-needle fibers?
4. What effect do pine-needle fiber and eggshell powder affect the compressive toughness index, and flexural toughness index?

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

The overall goal of the research program is to take a step toward sustainable development, economical precisely, and environmentally friendly concrete for various construction and civil engineering applications. Also, provide a platform for waste materials, like marble dust, eggshell powder, and natural fiber production increasing, to be used instead of dumping them.

"The specific aim of this MS research work is to study the combined effect of eggshell and marble dust powder in pine-need fiber reinforced concrete by evaluating its mechanical, dynamic and micro-structure analysis of concrete."

1.5 Scope of Work and Study Limitations

The mechanical and workability characteristics, dynamic properties, and absorption properties are examined by selecting three samples from marble dust, pine-needle fibers, and eggshells. The combined impact of these combinations is also measured. Dynamic qualities are explored before looking into the mechanical and absorption characteristics. Following the first fracture on the specimen, it is deemed to have failed after the load application. In the current study, additional features like linear shrinkage, mass loss, and visual examination of shattered specimens are also looked at. Upon the occurrence of the initial fracture in the specimen, it is regarded as having failed under the applied load. In this study, additional characteristics, including linear shrinkage, mass loss, and visual analysis of the fractured specimens, were also considered to provide a comprehensive understanding of the failure behavior. The mechanical, dynamic, and absorption properties will be investigated by taking three specimens for each parcel of marble dust-based concrete, eggshell with marble dust, and marble dust with natural fiber and eggshell concrete. Mechanical dynamic and absorption properties will be considered after the appearance of the first crack on the specimen, it will be regarded as a failure after load application. SEM and XRD may also be performed. Six specimens will be cast by every combination of replacement of cement total number of specimens is 42 with different combinations.
"The study is limited to mechanical, dynamic, and absorption properties of marble dust eggshell-based natural fiber reinforced concrete. In this scope of the study, the durability of pine needle-reinforced concrete is not included. Only fiber of specific region will be used."

1.5.1 Rationale Behind Variable Selection

Marble dust and eggshell powder are selected on the superiority of physical properties compared to others [3]. Furthermore, pine-needle fiber is compatible with marble dust and eggshell powder [7]. The same length and size of fiber will help in good mixing to achieve better-improved properties.

1.6 Novalty of Work, Research Significance and Practical Implementations

Concrete is a brittle material with low strain capacity and toughness. Owing to the fact of having low tensile strength, it becomes vulnerable to amalgamation in micro-cracking [14]. Another experimental study has revealed that natural fiber has improved concrete's impact loading resistance ability [15]. Natural fiber has the ability to generate dispersed reinforcement to enhance the mechanical properties of concrete previous studies have indicated that the properties of concrete can be enhanced by the addition of natural fibers. This study may contribute for understanding the hybridization of commercial and agriculture waste. The use of these Commercial/agricultural waste as sustainable construction materials to minimize the ecological effects of concrete and the harmful impacts of these commercial/agricultural wastes if not disposed properly. This study may also contribute to counter the flaws of concrete by using these agricultural wastes after hybridization process.

To the best of the author's knowledge, no research has been reported that observed the combined effect of marble dust and eggshell powder with pine-needle fiber-reinforced concrete. Therefore, this study aims to address this research gap by exploring the combined effect of marble dust and eggshell powder in pine-needle fiber-reinforced concrete. Specifically, this study investigates the impact of fixed-length fiber, marble powder, and various contents of eggshell powder on the mechanical, dynamic, and absorption properties of concrete. The objective is to develop a superior material that can be used in the civil engineering and construction industry. The findings of this study may contribute to the optimization of sustainable concrete composition and have practical implications for the development of environmentally friendly and cost-effective building material.

Despite of having many flaws like low tensile and flexural strength and less resistance against lateral loading concrete is also not an eco-friendly material. On the other hand, burning or dumping of commercial/agricultural wastes is also causing environmental pollution. The fiber-reinforced concrete made of natural fibers has shown better properties as compared with PC. The main concern of this research program is to introduce commercial/agricultural waste as sustainable construction material for enhancing the properties of concrete. For mitigating the flaws of concrete; avoiding structural failures to save human lives. This is the continuation of the research which was applied on rigid pavements and provided better properties.

1.7 Brief Methodology

In this experimental study, the mechanical, dynamic, and absorption properties of marble dust-based, eggshell, and natural fiber-reinforced concrete will be determined in the laboratory. For the production of marble dust eggshell concrete by mass of cement in concrete with the mix design of 1:2:4.The Prepared sample will be cured for 28 days, and testing will be performed to check the properties of the concrete. In this experimental study, the primary mechanical, dynamic, and absorption properties of plain concrete (PC), marble dust, pine-needle fiber reinforced concrete (PNFRC), and eggshells are determined in the laboratory. Pine-needle fibers and eggshell powder are used to prepare fiber-reinforced concrete (FRC). The exact lengths of 30 mm pine needle fiber are used in the preparation of the FRC. These lengths are selected based on the literature survey [16]. **Figure 1.1** shows the brief description of current study. This methodology is adopted by different researcher to achieve thw mile stone of the research.
Whereas eggshells powder (ESP) is ground and properly sieved with the help of a sieve shaker for 5-7 mint, the passing weight from sieve 100 and retained weight on sieve 200 and pan are considered for measurement of ESP and the same procedure are used for preparation marble dust. Workability is essential in the hardened properties of concrete and easy handling, pouring, and transporting of the concrete [17]. So, the workability of fresh PC and all determined specimens by slump cone test. All samples are cast as per the ASTM standards. After the workability test, a total 42 number of samples of PC, marble dust, eggshell powder, and PNFRC. Three beamlets and three cylinders are cast for each combination. Of these six cylinders, three are used for testing compressive properties. Flexural properties of specimens with controlled material such as marble dust, eggshell powder, and

a combination of controlled material with PNFRC are explored by a three-point loading setup on casted specimens of beamlets three-point loading test.

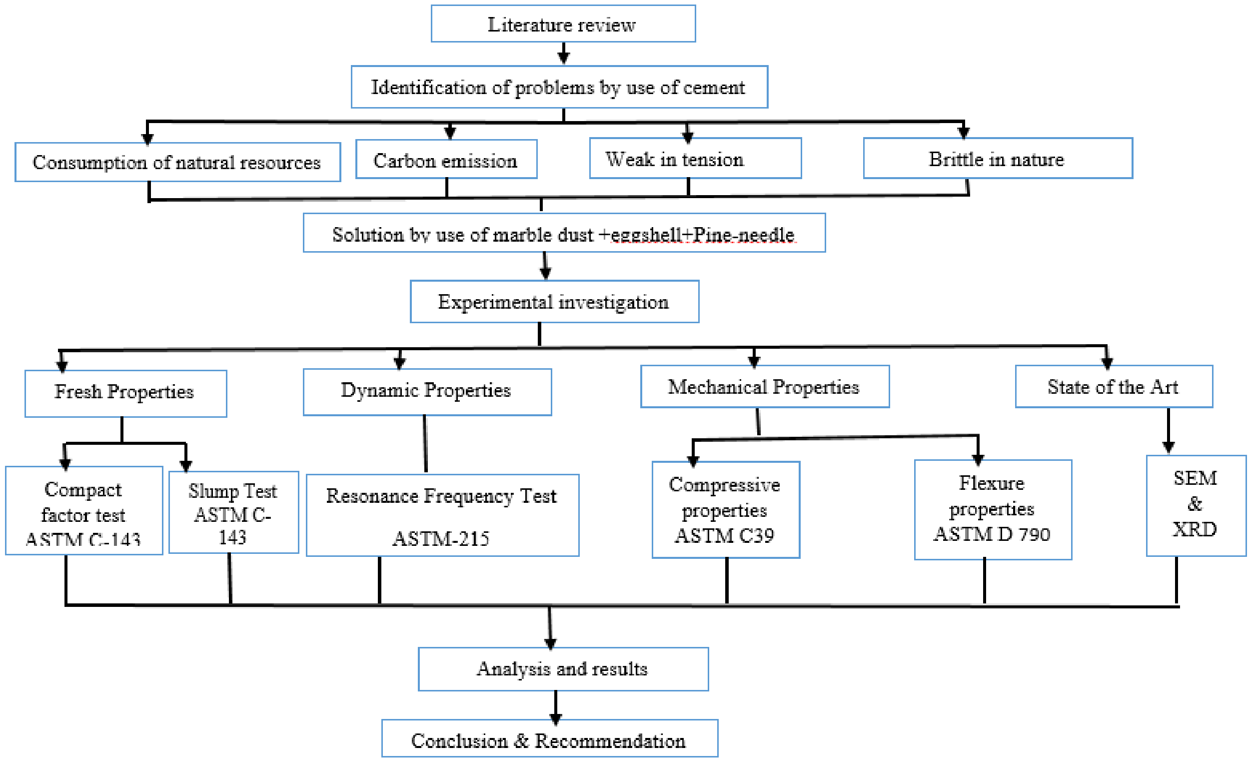

FIGURE 1.1: Adopted Methodology

1.8 Thesis Outline

This study has six chapters, which are as follows:

Chapter 1 consists of an introduction section. Flaws in concrete, carbon dioxide emission due to the production of cement. It also on research motivation and problem statement, objectives and scope-of work, methodology, and thesis outline.

Chapter 2 contains the literature review. It comprises of background, Commercial wastes, sustainable construction materials, latest trends in use of these wastes as construction materials, combination of different filler material with pine-needle fiber, use of equavelent lengths natural fibers in concrete, flaws in concrete and their remedies and summary.

Chapter 3. This chapter consists of the experimental scheme, raw ingredients in concrete, mix design casting of specimens, 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 and PNESPMDP-FRC) , 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, optimum combination of ESP , MDP and Pine-needle fiber application of this research in real life, and summary of chapter 5.

Chapter 6 consists of conclusions and future recommendations.

Chapter 2

Literature Review

2.1 Background

Cement due to its abundantly available material its use is increasing day by day due to the demand of the construction industry which produce a lot of carbon dioxide ($C0_2$) emission which affect our environment very badly. Over the past few decades, commercial waste materials like eggshell powder (ESP), marble waste, and pine-needle natural fiber have been used in concrete to enhance the mechanical properties of concrete and improve its performance. Utilization of eggshell powder and marble dust with a combination of pine-needle fiber in concrete is preferred due to their eco-friendly and low cost in nature. Commercial waste, such as marble dust and eggshells, generates millions of tons every year. So it is the need for sustainable construction to use the waste for a useful purpose. After conducting a lot of literature studies that the utilization of commercial waste improves the mechanical properties of concrete as compared to conventional concrete. Every year, there are millions of tons of commercial waste produced, including materials like marble dust and eggshells. It is therefore essential for sustainable construction practices to make use of this waste in a beneficial way. There is a need to explore the potential of commercial wastes as sustainable material There is a necessity to investigate the capacity of commercial waste. The chapter evaluates the use of waste materials in construction and their impact when integrated into concrete.

2.2 Flaws in Concrete

2.2.1 Issues in Concrete

Cement, due to its abundantly available material its use is increasing day by day due to the demand of the construction industry, which produces a lot of carbon dioxide CO_2 emissions that affect our environment very severely [18]. So vast amounts of CO_2 cause greenhouse gases, global warming, and ozone depletion, which is very harmful to human health [19–22]. Concrete is a brittle material with low strain capacity. Owing to low tensile strength, it becomes vulnerable to amalgamation in micro-cracking, making it a less durable material. The emission of a large amount of carbon dioxide CO_2 is nearly equal to cement production. This process requires an immense amount of energy which adversely affects the environment [23, 24]. Concrete, due to its abundantly available components and due to large applications is a widely used material but still, it has some drawbacks. It is a brittle material with low strain capacity and low toughness. The main flaw in concrete have sudden failure due to its brittle nature and low tensile strength minor cracks appear in the early stage of concrete due to external chemical attacks. **Figure 2.1** shows the cracking mechanism in rigid pavement or slab [25]. Various techniques were used to study the cracking pattern of concrete. Minor

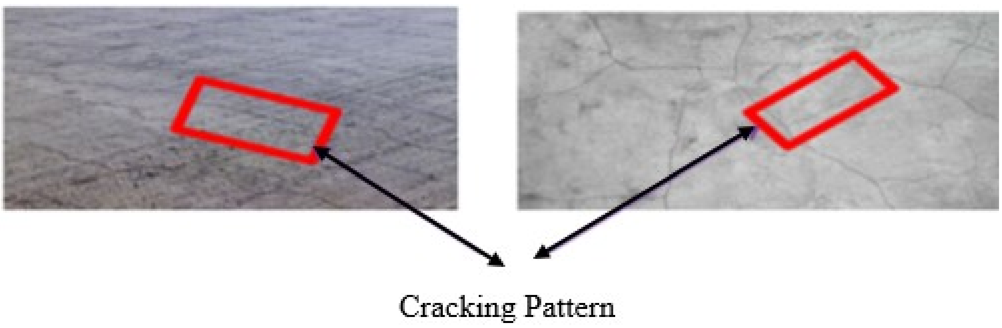

FIGURE 2.1: Cracking in Rigid Pavement [25]

cracks appeared on the surface of the concrete in the early stage due to shrinkage plane concrete have less durable [25]. The most frequent occurrence of concrete cracking can happen for several reasons. The structure's surface is affected by cracks which reduce the load-bearing capacity of structural elements like beams, columns, walls, slab, etc. the presence of excessive cracks on the surface of concrete, the structure element has responded to poor performance. Concrete is a brittle material with high compressive strength and low tensile strength [17, 26]. The combined effect of pine-needle natural fiber with marble dust and eggshell powder has good potential to be used in concrete. Pine-needle fiber have act as a crack resistor in concrete and tries to create a bridging effect toward cracking. Using same-length pine-needle natural fibers can bridge micro and macro cracks [27, 28].

Fiber-reinforced concrete has high toughness and energy absorption as compared to conventional concrete [12, 29]. During split tensile and flexure strength, the fiber-reinforced concrete composite has high tensile strength compared to plain concrete specimens. Plain concrete has more compressive strength than fiber-based composites because of its density [30, 31]. Pine-needle natural fiber-reinforced concrete increased the structural integrity and shrinkage crack resistance. Replacing eggshell powder and marble waste dust with cement enhances the mechanical properties of concrete. The engineering properties of concrete can be improved, to the desired ability, by the addition of natural fiber in it [32]. This is caused by the properties of the fiber's type, quantity, orientation, geometry, and distribution. Pine-needle natural fiber-reinforced composites play a vital role in the delay of corrosion initiation due to their high propensity for crack resistance. It led to a reduction in the corrosion rate.

2.2.2 Remedial Measures

The use of commercial raw materials such as marble dust and eggshells with a combination of pine-needle natural fiber in concrete has gained attention to achieve sustainable development. Pine-needle fiber is increasing the crack-resisting ability of concrete against dynamic and static loading to generate a bridging effect in concrete [28]. Although concrete performance is increased by using synthetic fiber it has to originate from non-renewable and expensive natural resources [33, 34]. Marble dust and eggshell powder is used in concrete as a control material with cement replacement [35, 36]. Nano-particle of eggshell powder with a combination of palm oil fuel ash with replacement of cement as a supplementary cementitious material to reduce environmental pollution and enhanced the mechanical properties of concrete [37]. Generally, marble dust is used in concrete as a cement replacement, and also with sand replacement in the production of concrete gradually enhances the physical and mechanical properties of concrete, especially with a lower w/c ratio.

Marble dust plays a role in concrete as a filler material, replacing sand and cement. Concrete made with marble dust as cement replacement performed better than sand replacement [38]. The toughness of concrete can be enhanced by introducing dispersed fibers in concrete which play a vital role in bridging effect towards crack resistance [39, 40]. The addition of fibers and admixture's additive influence may improve the properties of concrete [41]. The use of pine needle fiber eggshell powder and marble waste in concrete can lead to the utilization of waste products and the production of eco-friendly low-cost material by reduction of cement content. The addition of pine-needle fiber in cementitious concrete composites has contributed to obtaining enriched mechanical properties using the same length of pine-needle fiber content [42, 43].

The compressive strength of concrete is enhanced while using treated pine-needle fiber in concrete treatment with caustic soda pine-needle fiber has good results comparatively with untreated fiber. Many researchers have used different fiber percentages using the wet concrete volume from 0.5% to 2%. The high compressive strength of fiber-reinforced concrete is reported at 0.5% and 1%, which gives a good result with the treatment by dilute solution or caustic soda [44]. Sustainable construction is the current trend in civil engineering. In the last few decades, many researchers have tried to reduce the amount of cement in concrete without compromising its strength parameters of concrete [45]. The utilization of commercial waste in concrete is a step toward sustainable development to minimize the use of cement and replace it with a control material, that is, eggshell powder and marble dust [46].

Many researchers try to use marble dust in concrete from 0% to 40% constantly. High compressive strength is reported in the 15% replacement of marble dust with cement [47–49]. Eggshell powder is used as the control material in concrete from

0% to 30%. The higher compressive strength is reported at 5% and 10% with the combination of eggshell powder in concrete [49]. The highest compressive strength is reported on 15% of marble dust in concrete by mass of cement, which is 42.4 KN/mm2 [50]. Due to the low tensile strength of concrete, it needs reinforcement. Cement is used as binding material in concrete, which adversely impacts on ecological system and is not an environmentally friendly material [40]. Utilizing of same-length pine-needle natural fiber with a combination of marble dust and eggshell powder in concrete to reduce energy consumption is a positive step towards sustainable development. The tensile strength and tensile strain capacity of concrete depend on the cracking evaluation of the concrete structure. The tensile strain that a concrete structure can withstand before developing fractures across the structure is known as the tensile strain capacity. Tensile strain rather than the concrete's tensile strength should be considered when evaluating the cracking process since the process expresses forces as volumetric changes[41]. The tensile strain capacity of concrete is measured through the modulus of rupture.

2.2.3 Sustainable Construction Material

Sustainable construction is a need of the modern era. The construction industry is focusing to secure the consumption of natural resources and reduce (CO_2) emissions to produce eco-friendly construction. Cement is the main constituent of concrete and it emits Carbon dioxide (CO_2) which is very harmful to human health. Natural resource consumption is increasing according to the demand of the cement industry so the current trend moves towards minimization of cement to make sustainable construction. The utilization of concrete cannot be stopped and no material may counter concrete in the construction industry. There is a need to reduce cement content. Concrete is an indispensable material in the construction industry, and no alternative has yet emerged to replace it. Millions of tons of cement were generated every year which has a very adverse ecological impact on the environment. The cement industry from 7%-9% has construction in carbon dioxide emission [51–53]. Commercial and industrial waste produce a huge amount of disposal which has played a vital role in the production of environmental problems.

The recycling of waste into useful products is the solution to the crisis of dumping waste. It is impossible to completely eliminate the use of concrete, as no other material can effectively replace it in the construction industry. The byproducts like silica fume, fly ash, granulated blast furnace slag and palm oil fuel ask had been used as sustainable construction materials [51, 54].

In the last few decades, the production of cement had imposed a negative impact on the environment which is very dangerous for human health. Marble dust, natural fiber, and eggshell-based concrete are naturally neighborly newly developed building materials. Due to the lack of cement used in concrete suggestions to the industry given by many researchers have believed that marble-based concrete will be the next concrete. Several products have been tried and tested to produce eggshell, marble dust-based fiber-reinforced concrete with high performance and finally, the eggshell became accustomed to it as an option for this purpose due to its high availability and low cost [55]. Eggshell and marble dust waste will be greatly solving the problems associated with cement production Carbon emissions during the mixing of Ordinary Portland cement cause pollution and ozone layer depletion. Proper management of this waste must be needed to protect the environment. Which must be included in the addition of cement-reinforcing material like granite waste silica fume etc. As well as the manufacturing of other bonding materials in ordinary portland cement production play a vital role in production of environmental problems.

The application of fiber can enhance the properties to some extent; however, natural fiber concrete may provide better mechanical properties. In the last few decades, several efforts have been implemented toward sustainable construction techniques to reduce the use of cement. Thereby reducing, the total efficiency of global warming and CO_2 emission was decreased by partial replacement with different percentages of concrete reduced with marble dust, Eggshell, and natural fiber such as pine needle by different researchers and get a beneficial result. According to their test results, many researchers have found that using marble dust significantly improved the properties of high-performance concrete. The highest level of compressive strength, dynamic modulus of elasticity, and pulse velocity were all facilitated by marble dust and Eggshell [56–58]. Additionally, marble dust demonstrated good endurance by producing the lowest initial surface absorption and drying rate. On the other hand, Eggshells could only significantly enhance high-performance concrete's properties. However, the hardened characteristics of concrete were enhanced by the combination of eggshells, marble dust, and natural fibers. This research aimed to enhance the properties of marble dust-based concrete through the usage of eggshells. The content of marble dust-based concrete dosage with varying percentages of ingredients by weight was chosen. **Table 2.1** shows the study conducted on pine-needle fiber-reinforced concrete.

TABLE 2.1: Results Obtained by Incorporating Pine-Needle Fiber in Concrete Composites

Element	**Fiber Matrix**	**Fiber Re-inforced Composites Properties**	**Obtained Values**	**Applications**	**References**
	Cement concrete	Compressive strength properties	42.13MPa	Building material	Li et al. [5]
	Cement concrete	Flexure Tensile strength properties	2.85-2.93MPa	Building material	Li et al.[5]
Pine needle Fibers	Concrete	Residual Strength	2.33MPa Deflection=0.055mm	Ground Floor	Shiferaw et al.[59]
	Cement concrete	Splitting Tensile Strength properties	2.85-2.93MPa	Building material	Shiferaw et al.[59]

These materials are further used in construction for different structural elements. Pine-needle fiber was used by [60] as a sustainable material to resist cracks in plaster and mortar for repair purposes in old houses to resist hairline cracks. Another study conducted by [61] used pine-needle natural fiber as an environmentally friendly material and cost-effectively due to the addition of pine-needle fiber enhancing the mechanical properties of concrete comparatively plain concrete and also changing the fracture process in concrete. The eggshell powder was used by [62, 63] to develop green concrete and replace the eggshell powder with cement as a binder material for environmentally friendly concrete with a varying percentage from 0% to 30% replaced. The results showed that eggshell powder significantly improved the strength of developed green concrete. Water absorption capacity is reduced due to the utilization of eggshell powder, but it has enhanced the durability characteristics of concrete. The highest strength is reported at 5% and 10% after 28 days because of the pozzolanic reaction. Another experimental study was conducted by [64, 65] to create self-compacting high-performance concrete by the combination of eggshell powder (ESP) and ground granulated ballast furnace slag (GGBS) to produce sustainable self-compacting concrete SCC with 20 wt% partial replacements had the highest compressive strength at 41.34 kN/mm2 and 42.4 kN/mm2 for ESP and GGBFS respectively after 28 days of curing. SCC with 20 wt% partial replacements had the highest flexural strength at 3.2 kN/mm2 for both ESP and GGBFS after 28 days of curing. **Table 2.2** shows the study conducted on eggshell powder concrete. the below table has explain the effect of eggshell powder on flexure and compressive strength of concrete.

Table 2.2: Results Obtained by Incorporating Eggshell Powder in Concrete Composites

Element	**Eggshell Powder Matrix**	**Eggshell Powder Reinforced Composites**	**Obtained Values**	**Applications**	**References**
Eggshell powder	Cement concrete	Compressive strength properties	42.4MPa	Building material	Hamada et al.[64]
	Cement concrete	Flexure Tensile strength properties	3.2MPa	Highs trength performance concrete	Hamada et al.[64]

Table 2.3: Results Obtained by Incorporating Marble Dust in Concrete Composites

Element	Marble Dust Powder Matrix	Marble reinforced composites properties	Obtained Values	Applications	References
Marble dust powder	Cement concrete	Compressive strength properties	34.7MPa	Building material	Jamshaid et al.[66]
	Cement concrete	Flexure Tensile strength properties	7MPa	Building material	Jamshaid et al.[66]
	Concrete	Splitting tensile strength	5MPa	Building Material	Jamshaid et al.[66]

Marble waste powder with a combination of rice husk ash was used by [67] for sustainable construction techniques to reduce construction costs and produce environmentally friendly concrete. Marble dust is used as a filler material in concrete by replacement of cement from 0% to 30% maximum enhancement is reported at 44.4%, and 60%, in compressive, tensile, and flexural strength for the optimum combination. In addition, porosity and water absorption were reduced with the inclusion of rice husk ash and marble waste powder.The pine-needle natural fiber was used as a sustainable construction material for making eco-friendly high-performance concrete. Eggshell powder (ESP) increased the hydration process in cement because of the reaction of CaCO3 with C3A and it change the hydration products of the paste to decrease sitting time and increase autogenous shrinkage [13]. Coconut, sisal, jute, sugarcane, and pine-needle natural fibers can be used as sustainable construction materials and enhance the tensile as well as compressive properties of concrete [56,57,58]. **Table 2.3** shows the study conducted on marble dust waste-based concrete. To develop sustainable and environmentally friendly concrete to reduce the consumption of natural resources. So much waste has been generated worldwide which needs good management in to reproduce new of new product marble dust powder and eggshell powder is also that material that has cementitious properties. Cement is one of the most utilized materials worldwide which has drastically reduced our natural resources. utilization of waste material in concrete with partial cement replacement is a new trend to reduce the production of cement without compromizing strength properties.Effective management of the enormous amount of waste generated globally is crucial, especially in the production of novel materials such as marble dust powder and eggshell powder.

2.3 Utilization of Waste Material in Concrete

2.3.1 Pine Needle Fiber

Consideration of sustainable development is a need of the current era. Each step plays a vital role in sustainable development, and every action has its importance. Focus is being placed on reducing waste in this world's effort to find sustainable solutions, which ultimately contribute to global warming. Reusing and recycling are currently the main subjects capturing people's attention in the fight against environmental problems [68, 69]. The pine-needle natural fiber is used in cement composites for attaining sustainable building alternative materials. This tremendous interest has been generated over the past few decades. Flaws in conventional concrete have been catered to while using pine-needle natural fiber as an alternative material in concrete. Cementitious concrete products have brittle pine-needle fiber and can enhance toughness and absorption energy. Many researchers have used natural fiber in concrete for various construction material applications. Agriculture waste/natural fibers like banana, jute, coir, vakka, palm, cannabinus, abaca, dates, pineapple leafs, wheat straw, kenaf bast, etc are used as an alternative material in cement composite [70–72].
The exhaustion of environmental issues and waste material utilization is increasing day by day. Using waste material for construction instead of dumping is a positive step towards sustainable construction. Steel fiber has been used in concrete for the last few decades because of its capability to arrest cracks in concrete and introduced ductility to concrete structures [73]. Steel fibers are one of the most

basic and effective materials for strengthening concrete's flexural performance and resilience to impact loads among the commercially available fiber. When steel fibers are used in the building industry, a tremendous quantity of raw materials are required for their industrial-scale manufacture, which raises serious environmental issues regarding their carbon footprint. In recent years, difficulties relating to environmental implications during the manufacture of industrial steel fibers have drawn researchers to develop alternate solutions. These topics include sustainability, resource conservation, and recycling [74, 75]. The properties of natural fibers are discussed in **Table 2.5** synthetic fiber like steel fiber, glass fiber, and polypropylene fiber is used in concrete due to their unique properties, which enhance the structure's ability towards cracks resistance mechanism and enhance toughness but large-scale production of synthetic fiber generates carbon dioxide emission (CO_2) emission therefore significant improvement are being made to use alternatives such as waste and natural fibers. Coconut fibers have the highest toughness behavior among all natural fibers [76]. The real-life application of coconut fiber is preferable in concrete for road construction due to its high toughness and good tensile strength. Among the various commercially available fibers, steel fibers are considered to be one of the most fundamental and efficient materials for improving the flexural strength and impact resistance of concrete. Steel fibers have been utilized in concrete for several years due to their ability to prevent cracks in concrete and enhance the ductility of concrete structures.[53].

2.3.2 Marble Dust Powder

Using waste materials like slag, limestone, ground quartz, brick powder, and ceramic dust in concrete to replace cement is a promising way to reduce carbon emissions from concrete production. Limestone was used by [68] as a replacement for cement. The limestone increases the early strength of concrete due to the nucleation and filling effect. Another study by [78] investigated the combined impact of limestone and fly ash in concrete for blended cement and provided a mix proportion of up to 30% by cement mass. The compressive strength was observed

TABLE 2.4: Natural Fiber and Their Properties

S.No	Fiber Type	Properties	References
1	Pine nnedle	Lighter than synthetic fibers, good breaking strength, high energy absorption, easily available	Wu et al.[70]
2	Wheat straw	High toughness index, strong, easily available, high water absorption capacity, high energy absorption	huzuria et al.[77]
3	Coconut fiber	High toughness index, high damping ratio, economical good flexural strength	Keith et al.[71]

by 3, 7, and 28 days. The compressive strength of the binary blended mortar specimen was reported to be lower than that of reference specimens because of the pozzolanic reaction. The compressive strength was increased gradually due to the increase of limestone content compared to 30% fly-ash content. At the early stage, fly-ash content has a low or poor pozzolanic reaction. Fly ash showed a common pozzolanic response until seven days of compressive strength. Furthermore, limestone act as a filler material that has a denser microstructure. After 28 days of hydration, the compressive strength of ordinary Portland cement specimens compares with 30% fly-ash specimens and 30% limestone specimens with each other. The properties of some natural fibers are given in **Table 2.5** . Ordinary Portland cement has higher compressive strength than fly ash and limestone specimens. It is decreased significantly due to the increase of limestone content being lower than that of 30% fly-ash sample 46.6 MPa This is due to the rise of the pozzolanic effect of FA, which would dissolve more amorphous silica and reflect with calcium hydroxide generated [79–81].

Due to the production of cement, CO_2 emission are increasing day by day, subsequently disposed of our environment to develop sustainable construction, and reduction of CO_2 cement need replacement with commercial waste material to develop sustainable construction. An experimental study conducted by [82] to replace cement with various material such as marble dust powder, ceramic waste powder, and brick dust powder with a different replacement that is 5%,7.5%, 10%, 12.5%, 15%, and 20%.

Table 2.5: Application of Marble Dust with Replacement of Cement

S.No	**Replacement**(%)	**Applications**	**References**
1	2.5, 5, 7.5, 10	Replacement of cement was done to produce marble waste concrete. Cement mortar specimens were tested by 7, 14, and 28 days. The dimension of the specimens was 40mm x 40mm x 160 mm. result of 10% was best.	Kumar et al.[83]
2	0, 5, 7.5, 10, 12.5, 15	Marble dust-based concrete investigation was done by various percentage replacement of cement. The highest compressive and splitting tensile strength was observed by 15% with a 0.45 w/c ratio.	Tayeh et al.[82]
3	10, 20, 25, 30	Marble dust-based cementitious concrete is taken as a reference for testing concrete mechanical properties and the research concluded that with a 25% replacement of marble dust there had been observed an increase in the compressive, splittensile, and also flexural strength of concrete.	Gurumoorthy[84]

To study the mechanical properties of concrete with the help of compressive strength and splitting tensile strength to observe the behavior under consideration on the different percentages of waste. Various percentages tested a minimum of three samples of each composition. The highest compressive strength after 28 days was reported on marble dust-based specimens because of their chemical composition. Marble dust consists of 59.51% calcium oxide, which increases the strength of concrete. The highest compressive strength is recorded at 7.5%, 10%, 12.5%, and 15% by replacement of cement. Strength properties are increased by up to 33% comparatively to conventional concrete. Marble dust powder has shown good mechanical properties compared to brick and ceramic powder [85]. Splitting tensile strength increasing and decreasing were observed in the same pattern as compressive strength highest splitting tensile strength was observed at 10%, 12.5%, and 15%, by replacement of cement with marble dust, ceramic dust powder, and brick dust. The highest splitting tensile strength is observed on a 10% replacement of marble dust.

2.3.3 Eggshell Powder

Concrete is the main constituent of construction material. Cement is the main ingredient in the concrete product, which creates bonding strength among the material. But, the utilization of cement has an adverse impact on the environment. Carbon dioxide emissions are caused due to production of cement. Partial cement replacement in concrete is considerably reduced CO_2 by pozzolanic material. Eggshell powder is used in concrete as a cement replacement for construction purposes to minimize cement and energy consumption and CO_2 emission. The mechanical properties of concrete, such as compressive, split, and flexure tensile strength, were observed by testing specimens of various cement replacement percentages after 28 days of curing. Concrete compressive strength was decreased by early age due to low pozzolanic reaction. But furthermore, the compressive and flexure strength have enhanced at a late age. After 28 days, it shows further improvement [83, 86, 87] The durability properties of agro-based concrete depend upon water absorption, which is important to evaluate the internal environmental condition of various proportions of eggshell powder in concrete. The sample must be kept in the oven for 48 hours before the test and kept in water for 30 mint to get the water absorption values of the specimens. The eggshell powder can reduce the water absorption of specimens' capacity when curing time increases [79].

2.4 Hybrid Effect of Pine-Needle Natural Fiber with Marble Dust and Eggshell Powder in Concrete

Combining natural fiber with filler material is accomplished to get the combined effect of two or more materials. Natural fibers can enhance the desired properties of concrete. Wang et al. [30] used the same length of pine-needle natural fiber with different treatment methods such as boiled water treatment, dilute solution treatment method, and soaked pine-needle fiber in water with 2% of a dilute solution (caustic soda) for 2 hours to get the best result comparatively boiled water treated fiber. Adding pine-needle fiber to concrete considerably enhanced mechanical properties such as flexure strength and splitting tensile strength, revealing an improvement in plain concrete specimens. The maximum strength is reported on a 30mm length of the fiber. Another experimental study was conducted by Gokcer et al. [88] on combining marble dust with glass fiber in concrete. Glass fiber was used by 0.25%, 0.5%, and 0.75%, and marble dust was used. Sand replacement in concrete by variation of 10%, 20%, 30%, and 40% to get the best result, and drastic improvement in the flexure strength of concrete is reported. Marble dust in concrete has decreased the porosity value of concrete, but pine-needle natural fiber increased the porosity value and decreased compressive strength [89, 90]. Marble dust and eggshell powder are extensively used as partial substitutes for cement in concrete due to their favorable bonding characteristics. The bonding of these materials with cement is influenced by various factors such as particle size, shape, and chemical composition [15, 91]. As both marble dust and eggshell powder are primarily composed of calcium carbonate, they can be used as fine powders in concrete. The addition of these materials to concrete can enhance its mechanical properties, including compressive strength and modulus of elasticity. The bonding characteristics of marble dust and eggshell powder with cement are also influenced by their particle size and shape, with smaller particles showing better bonding behavior with cement[92, 93]

Shukla et al. [94] investigated the partial replacement of cement with marble dust and eggshell powder by a combination of steel fiber used in concrete to reduce carbon footprint and enhance the mechanical properties of concrete. Partial replacement of cement is 0%, 5%, 10%, 15%, and 20% by marble dust, and steel fiber has used 1% by volume of concrete. The highest mechanical strength of concrete is revealed by 1% steel fiber and 15% replacement of marble dust over ordinary cement concrete. A certain amount of marble dust combined with steel fiber generates a good dense, interlocking mechanism between aggregate particles [95]. Furthermore, fiber length from 5mm-30mm has observed considerable improvement in flexure strength reported with a combination of marble dust in concrete [96]. Thus pine-needle fiber reinforced concrete with fiber length have better strength with a length of 10mm-30mm. The combination of pine-needle natural fiber with filler materials (marble dust eggshell powder) has been carried out. It was found that the combination of natural fiber with filler material has improved the flexure strength of concrete comparatively with conventional concrete [97, 98]. The combination of the materials depends upon the chemical properties of concrete, affecting the filler material's strength and the fiber's composition. **Table 2.6** shows the element in marble dust, eggshell powder, and cement. Natural fiber-reinforced concrete has been used to replace plain concrete (PC). Pine-needle natural fibers can reduce the propagation of micro-cracks on the surface of concrete products in the early stage and increase the toughness of concrete. Plain concrete has certain flaws like weak tension, shrinkage cracks, etc., and has tackled remedial measures with the use of fiber. During the crack propagation resistance, fiber experience frictional slippage, de-bonding, and breaking effect [100]. After post-cracking, the presence, and energy dissipation on the surface of fiber control and deformation phenomenon [101]. Fiber pull-out from the matrix promotes the ductile behavior of concrete because of energy dissipation during post-cracking [102]. **Table 2.7** shows the chemical composition of eggshell powder and cement.

Fiber-reinforced concrete has high tensile strength compared to plain concrete just

TABLE 2.6: Chemical Composition of Marble Dust and Cement [99]

S.No	Chemical Composition	Cement(%)	Marble Dust(%)	Eggshell Powder(%)
1	Calcium Oxide (Cao)	65.3	41.54	33.1-99.8
2	Silicon Dioxide (SiO2)	22.06	5.85	less than 1
3	Aluminium Oxide (Al2O3)	6.13	0.56	less than1
4	Iron Oxide (Fe2O3)	2.57	0.8	less than1
5	Sulphur Tri-Oxide (SO3)	1.25	0.11	0-1.3
6	Magnesium Oxide (MgO)	0.81	15.55	less than1
7	Potassium Oxide (K2O)	0.45	0.073	less than1
9	Sodium Oxide (Na2O)	0.9 0.07	0-2.9	
10	Titanium dioxide (TiO)	1	-	less than1

TABLE 2.7: Chemical Composition of PN-FRC [41]

Sr.No	Chemical Composition	Percentage Weight (%)
1	Lignin	33.37
2	Holocellulose	67.29
3	Ash	2.71
4	Extractives	15
5	Pentosan	11.57

because of the addition of fibers in the concrete product. Many researchers have used different types of fiber in concrete with a combination of marble dust and eggshell powder. A combination of marble dust with glass fiber and marble dust with sisal fiber but the highest compressive strength and flexure tensile strength is investigated by combining marble dust and eggshell powder with steel fibers. PN-Fiber enhanced the flexure strength of concrete to 34% marble dust, and eggshell powder used as filler material in concrete to replace cement ingredients. The results show that a combination of filler material can be used in pavements and flooring slab as a sustainable construction material [99]. According to the findings, combination of filler material serve as a viable sustainable construction material. A combination of filler materials is a feasible for sustainable material.

many literature have claimed that marble powder with combine effect of fiber and another filler material has reduce the amont of cement and enhance the mechanical properties of concrete.

2.5 Summary

From the above discussion, it has been concluded that the use of commercial waste in concrete can improve the mechanical properties of concrete. The combination of pine-needle natural with a filler material such as marble dust and eggshell powder to get a combined effect to compare with PCC. It is important that the mechanical and dynamic properties of concrete resist crack propagation and also reduce the use of cement in concrete to achieve sustainable construction. Commercial waste has caused serious issues to our environment. Burning or dumping of agriculture and commercial waste is a matter of concern. This waste can utilize in concrete for construction purposes. From this literature, it is concluded that the flaws of concrete can be mitigated by commercial waste. The combination of pine-needle natural fiber with filler material can enhance the flexure and splitting tensile strength of concrete. The combination of same-length natural fibers can arrest the micro as well as macro cracking resulting in an improvement in concrete performance.

Chapter 3

Experimental Methodology

3.1 Background

Commercial waste such as pine-needle natural, marble dust, and eggshell powder is commercially available. The use of these commercial wastes with different combinations has generally increased with time due to their being environmentally friendly in nature, easy availability, and easy handling. The utilization of this commercial waste has enhanced the desired mechanical properties of concrete. In this research pine-needle fiber with a combination of natural marble dust and eggshell powder has been used. The pine-needle natural fiber is used to reinforce concrete and marble dust and eggshell powder are used as filler material in replacement of cement. Superplasticizers have been used for the improvement of workability. From the previous research, the different types of commercial waste material are used in concrete to enhance the mechanical properties of concrete. Prior studies have utilized various types of commercial waste materials to improve the mechanical characteristics of concrete. The combination of pine-needle natural fiber in concrete with filler material (MD+ESP) with the same length combination of fiber has been explored. For this purpose, slump cone tests, compact factor tests, mechanical tests, and water absorption tests are considered. These tests are taken to study the combination of marble dust, eggshell powder, and pine-needle fiber in concrete this chapter has explain treatment process preparation of specimens etc.

3.2 Raw Material of Concrete

For preparing normal plain concrete (PC), ordinary Portland cement, Lawrence pours sand, and locally available margalla crush is used for preparing PC. The maximum size of coarse aggregate is selected to pass from 25mm and retain at 10mm for the preparation of all specimens. All entireties have been cleaned with the help of water in mixing to remove the dust particles in 3-4 cycles. To start with, pine-needle natural fiber has been selected due to its local availability. **Table 3.1** shows the mechanical properties of pine-needle fiber reported by [30]. Pine-needle fibers in the fresh form are cut in a length of 30mm and then soaked in a 2% NaOH (caustic soda) solution for 2 hours. **Figures 3.1a, 3.1b, 3.1c,** and **3.1d** show the raw fiber, combed, treated, and cut fibers. Water has been used to mix and clean all objects completely in order to eliminate any dust particles. Marble dust is taken from the marble industry, sieving to pass from sieve # 100. Eggshells are collected from the restaurant to wash and dry with natural sunlight. The super-plasticizer is collected from the sika company in Rawalpindi Pakistan. The properties of pine-needle fibers are given in **Table 3.1**.

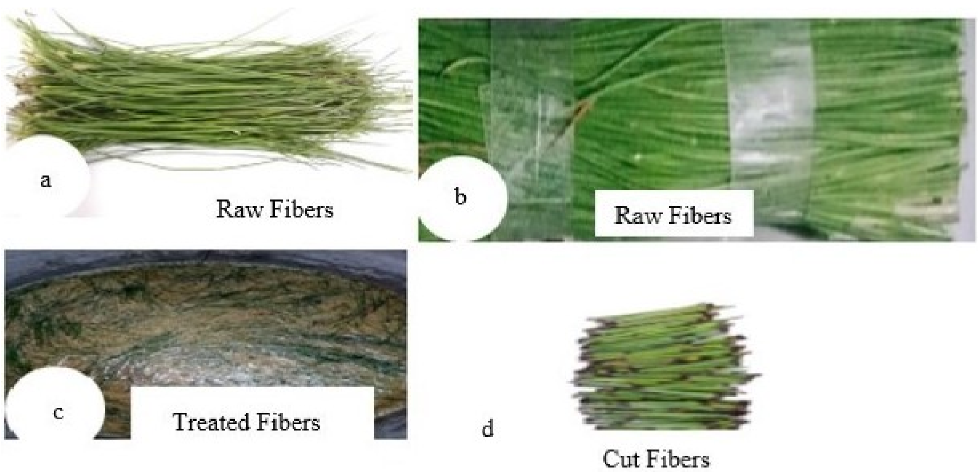

FIGURE 3.1: Pine-Needle Fiber; a) Raw Fiber, b) Combed Fiber, c) Treated with NaOH, d) Cut Ciber

Eggshells are commonly discarded as waste from restaurants and hostels, leading to their accumulation in landfills and contributing to environmental pollution worldwide. However, researchers are exploring the utilization of eggshell powder

TABLE 3.1: Properties of Pine-Needle Natural Fiber [30]

Sr.No	Parameters	Obtained Values
1	Diameter (mm)	0.7-1.3mm
2	Density (kg/m3)	73
3	Tensile modulus (Mpa)	35.8
4	Young modulus (Gpa)	4-8
5	Max elongation (%)	5.94
6	Specific Gravity (g/cm3)	0.34-0.45
7	Water absorption (%)	0.62

as a partial replacement for cement in concrete to enhance the mechanical properties of the material. This approach could provide a solution for the disposal of eggshells while reducing the environmental impact of cement production. **Figure 3.2a, 3.2b, 3.2c, 3.2d, 3.2e, 3.2f, 3.2g, 3.2h, 3.2 I, 3.2j, 3.2k** and **3.2l** shows the untreated aggregate, washing process of aggregate, treated aggregate collected eggshell, and the sieving process of eggshell powder and marble dust powder, measuring method of PN-FRC, cut fibers, sieved sand and sieved sand dust an in the same image. The same length of pine-needle fiber has been prepared to be cut in equal lengths of 30mm for the preparation of fiber-reinforced concrete FRC. At the same time, marble dust and eggshell powder have passed from sieve# 100 to prepare the combination by varying percentages of eggshell powder such as 5%, 10%, and 15% replacement of cement. Marble percentage is fixed in all specimens, that is, 15% replacement with cement. Pine-needle fiber has been taken by 1% of wet concrete volume as recommended by [30, 50, 103]. The water/cement (W/C) ratio is the same for all specimens, which is 0.45 for PC specimens. And super-plasticizers are used 1.5% by weight of cement used in FRC with a combination of marble dust and eggshell powder. A blend of marble dust and eggshell powder is combined with 1.5% by weight of cement as super-plasticizers in the production of FRC. In FRC with a blend of marble dust and eggshell powder, super-plasticizers are applied at a rate of 1.5% by weight of the cement but many studies has also reported by volume of concrete. Super-plasticizers have enhanced concrete workability by utilizing the fiber's absorption property. The higher w/c ratio caused bleeding in concrete and reduces the compressive strength of concrete [104].

FIGURE 3.2: a) Untreated Aggregate, b) Wash Aggregate, c) Washed Aggregate, d) Treated Aggregate, e) Collected Eggshell, f) Sieving Process of Eggshell, g) Prepared Eggshell Powder, h) Sieved Marble Dust, i)Measure Length of Fibers, j) Cut Fibers, and k) Sieved Sand, l) Sieved Sand Dust

The treatment process of coarse aggregate is reported by literature to remove all the dust from the surface of the aggregate for better bonding. The washing process of aggregate is completed in the 4th to 6th times after a 3 to 4-minute rotation of mixture. The washing process continues until the water completely drains to its original color. The eggshell powder has been collected in raw form from restaurant and hostels and washed properly with warm water, dry it in natural light for 48 hours, and grind to pass from sieve# 100. Marble dust is collected in raw form from the marble industry and properly sieved in the CUST lab with the help of a sieve shaker. Marble dust and eggshell powder are used as filler materials in concrete to achieve sustainable construction techniques and reduce the amount of cement in concrete. Pine-needle fiber is used in concrete to enhance the tensile properties of concrete. All fibers are cut in the same length to achieve good mixing and enhance the tensile behavior of concrete. Pine-needle fiber is available in subtropical regions of Pakistan. It is collected from the pine tree and cut in equal lengths with the help of a seasor. Sand has been prepared properly to sieve it. All dust is removed and has passed from sieve 100 to remove the dust.

3.3 Preparation of Concrete

3.3.1 Mix Design

Plan concrete (pc) specimens have been prepared by ratio 1:2:3 (cement: sand: aggregate) mix design ratio with a w/c ratio of 0.45. For the preparation of marble dust-based specimens, which are 15% by replacement of cement, super-plasticizers have used 1.5% by weight of cement. W/c cement ratio is used the same in all combinations, and super-plasticizers are used in all combinations except pc. Eggshell percentage varies by cement replacement, i.e., 5%, 10%, and 15%. For the preparation of PNFRC along with a 30mm length of fiber long pine-needle fiber, 1% by volume of wet concrete is used. The addition of super-plasticizers makes it more workable due to the water absorption capacity of marble dust eggshell powder and pine-needle fiber. In addition, the workable mix is compact properly to obtain good strength. The actual w/c ratio of PNFRC is referred optimum, as further water addition has caused bleeding. In this study dosage of pine-needle fiber, marble dust, and eggshell powder is purposely linked with a mass of cement in the concept of binding characteristics.

Researchers have widely used the natural fiber from agriculture plants with greater pozzolanic reactivity to consume natural resources. Natural fiber is used in concrete as a partial cement replacement, taking a high quantity of silicates and minerals from the earth during growth. The amount of filler material (marble dust + eggshell powder), fiber length contents, and water cement ratio are selected based on previous literature [30, 61, 67] to achieve sustainable construction techniques and enhanced energy absorption and toughness index. The tensile strength has been increased as per the referenced literature comparatively PC. The reason for the enhancement of tensile strength is to achieve economic construction and achieve high energy absorption is beneficial. So, filler material with a combination of PNFRC by replacement of cement has been used in concrete like lean concrete, concrete cover, etc.

3.3.2 Casting Procedure

Preparing PNFRC with a combination of marble dust and eggshell powder. All the material is placed in the form of layers in a mixer machine to achieve good mixing of fiber-reinforced concrete with filler material. For good mixing of PNFRC with filler material, three layers are required for mixing concrete. One-third set of layers of aggregates, sand, pine needle, cement, and filler material (MD+ESP) are placed in a mixer machine. The remaining layers (2nd and 3rd layer) of aggregate, sand, cement, and filler material are placed in a mixer drum in the same manner. Then the mixer machine is turned on to start rotating. Two third of the water is added with the start of the machine. After three-minute of continuous rotations of the mixer machine remaining one-third quantity of the water is added. Superplasticizers are used after water to apply the same approach. The mixture machine is kept rotating for a further two minutes. Slump cone and compact factor tests are performed to check the properties of fresh concrete.

3.4 Testing Methodology

The testing methodology is adopted in this section, compact factor test, slump test, mechanical test, and water absorption test are performed for the determination of different properties of concrete. All these tests are performed as per the ASTM standard and referred by researchers the average of three samples are taken by every test **Figure 3.3a** and **3.3b** shows the test setup of the dynamic test and mechanical test. The dynamic properties of plan concrete and pine-needle fiber reinforced concrete with a combination of filler materials have purposed to determine the longitudinal, literal, and rotational frequency are observed with the

help of an accelerometer and hammer determination of each type of above resonance frequencies measured under these three set up of test. An accelerometer is attached to one cross-section side of specimens to measure longitudinal frequency and the hammer is a strike to the other cross-section side of specimens (cylinder or specimens). For measuring the transverse frequencies, the accelerometer is placed on the length of the specimen 25 cm away from the cross-sectional edge and then a stroke of the hammer is given parallel to the accelerometer on the other edge of the specimen. To determine the torsional frequencies by the third type of test setup, the accelerometer is attached in the same way as it is arranged in a longitudinal setup. But then the stroke of the hammer is given on the length of the specimen which is perpendicular to the accelerometer.
The mechanical properties of concrete are explored to perform compressive strength test and flexure strength test of plain concrete (pc) and all type of PNFRC. The compressive strength test is performed on cylinder specimens which are placed vertically between the test machine so that it acts as a prototype of a compression member or a column. Beamlet specimens are laid down between the testing plates for performing flexure tensile test. So, the flexural tensile properties may be observed by this setup. The average of the values of three specimens is taken to get t precise value of any results obtained from these tests. In this way, the average of obtained results from dynamic and mechanical properties is taken to get precision and to check deviation in results.

3.5 Dynamic Testing

The dynamic test is performed before the destructive testing of the specimens as per ASTM standard 215-14, as shown in **Table 3.3**. **Figure 3.3a** shows that the response frequency rotational (RFR), response frequency transverse (RFT), and response frequency literal (RFL) are measured with the help of an accelerometer and hammer. Both beamlet and cylinder specimens undergo non-destructive testing, where an accelerometer is affixed to one side of each specimen to measure RFL. Additionally, the opposite side of the specimens is struck with a hammer to obtain readings, which are then transmitted to a computer attached to the accelerometer. The technique used to determine RFT and RFR, which links the accelerometer and hammer striking position, varies for beamlet and cylinder specimens.

Both the beamlet and cylinder specimens undergo a non-destructive test where an accelerometer is affixed to one side to measure RFL. Simultaneously, the opposite side of the specimens is struck with a hammer to obtain readings. The frequencies observed by the accelerometer are recorded by the computer that is connected to it. The accelerometer is mounted to the side of the cylinder that faces the length of the cylinder, at least 25 cm before the edge, in the case of cylinders for RFT. Then the hammer is struck at the same side, revealing the face in the middle of the length of the cylinder. An accelerometer is attached to the top surface along the length of the cylinder for measuring RFR with the same space from the edge as RFT. The accelerometer is attached perpendicularly along the length of the cylinder and strikes it from the opposite side. An accelerometer is mounted perpendicular to the cylinder's length and then struck from the opposite end. In the case of beamlets, the accelerometer is attached at one side of the length at the same margin for the cylinder to determine RFT. The hammer's strike is given at the center of the length of the same side to which the accelerometer is attached. The hammer is struck at the opposite side's bottom corner of the same side of the rectangle in such a manner that the diagonal of the rectangle is formed by the line connecting the hammer's striking point and accelerometer. The damping ratio, dynamic modulus of rigidity, and Poisson's ratios are computed from these measured frequencies. These estimated parameters help to explain how PC and other varieties of PNFRC with filler material behave and withstand dynamic loading. The marble waste-substituted concrete has a slightly stronger relationship between resonant frequency and dynamic properties than other substituted concretes[83]. The hammer is struck at the midpoint of the same side of cylinder. Both the beamlet and cylinder specimens undergo a non-destructive test where an accelerometer is affixed to one side to measure RFL. Simultaneously, the opposite side of the specimens is struck with a hammer to obtain readings. The frequencies observed by the accelerometer are recorded by the computer that is connected to

it. The accelerometer is mounted to the side of the cylinder that faces the length of the cylinder, at least 25 cm before the edge, in the case of cylinders for RFT. Then the hammer is struck at the same side, revealing the face in the middle of the length of the cylinder. An accelerometer is attached to the top surface along the length of the cylinder for measuring RFR with the same space from the edge as RFT. The accelerometer is attached perpendicularly along the length of the cylinder and strikes it from the opposite side. An accelerometer is mounted perpendicular to the cylinder's length and then struck from the opposite end. In the case of beamlets, the accelerometer is attached at one side of the length at the same margin for the cylinder to determine RFT. The hammer's strike is given at the center of the length of the same side to which the accelerometer is attached. The hammer is struck at the opposite side's bottom corner of the same side of the rectangle in such a manner that the diagonal of the rectangle is formed by the line connecting the hammer's striking point and accelerometer. The hammer is struck on the opposite bottom corner of the same side of the rectangle in a way that the diagonal of the rectangle is aligned with the line connecting the hammer's point of impact and the accelerometer. For cylinder testing, the accelerometer is mounted perpendicular to the length of the cylinder, at least 25 cm away from the edge for RFT measurement, and struck from the opposite end. In beamlet testing, the accelerometer is attached to one side at the same position as the cylinder for RFT measurement, and struck at the center of the same side. The hammer is struck at the bottom corner of the opposite side, forming a diagonal line between the hammer's striking point and the accelerometer. The damping ratio, dynamic modulus of rigidity, and Poisson's ratios are computed from these measured frequencies. These estimated parameters help to explain how PC and other varieties of PNFRC with filler material behave and withstand dynamic loading. The marble waste-substituted concrete has a slightly stronger relationship between resonant frequency and dynamic properties than other substituted concretes[83]. The hammer is struck at the midpoint of the same side of cylinder [105]. The estimated parameters facilitate comprehension of the dynamic behavior and resistance of PC and various types of PNFRC that incorporate filler materials. Compared to other substituted concretes, marble waste-substituted concrete displays a slightly.

TABLE 3.2: Studied Parameter and Testing Standard

Test	**Allowed Standards**	**Focused Parameters**	**Additional Parameters Considered for the Study**
Compressive strength	ASTM C39	Compressive strength	Stress–strain curves, compressive pre-cracking energy absorption (CE1), compressive post-crack energy absorption (CE2), compressive total energy absorption (CTE), compressive toughness indexes (CTI), and modulus of elasticity (MOE).
Flexure properties	ASTM C78 ASTM C1609	Flexure strength	Load-deflection curves, flexural pre-crack energy absorption (FE1), flexural post-crack energy absorption (FE2), flexural total energy absorption (FTE), and flexural toughness indexes (FTI).
Dynamic Properties	ASTM C215-14	RFL, RFT and RFR, damping ratio	No additional parameter studied.
Dynamic properties	ASTM-C1548	modulus of rigidity, and Poisson ratio	No additional parameter studied
Water absorption and mass loss test	ASTM C622-13	Water absorption and density	No additional parameter studied

3.6 Mechanical Properties

3.6.1 Compressive Strength Test

A universal testing machine (UTM) is used to determine the compressive strength of PC and PNFRC with filler material. The test is performed under the specification of ASTM C39. In this test, compressive strength properties have determined, which are included, post cracking energy (CE1), compressive pre-cracks (CE2), compressive toughness index (CTI), compressive total absorbed energy (CTE) of pc, and all PNFRC.The cylinder is capped using Plaster of Paris to ensure even distribution of the load during mechanical testing. Capping of the cylinder is done with the help of plaster Paris to distribute the load uniformly throughout the cylinder mechanical test set up shown in **Figure 3.3b**.

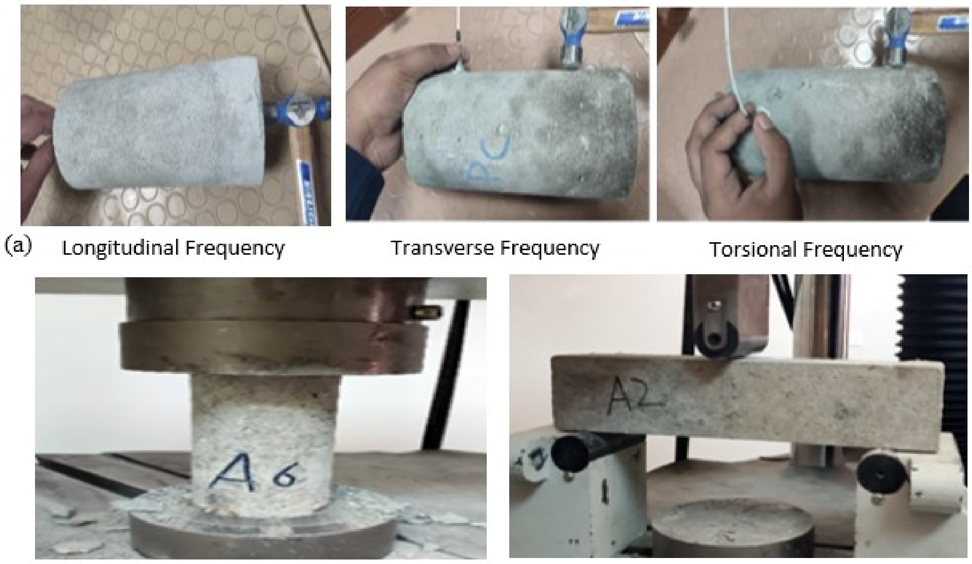

FIGURE 3.3: Test Setup (a) Dynamic Test (b) Mechanical Test Setup

3.6.2 Flexure Strength Test

Flexural testing is done as per ASTM C78 criteria. It uses the three-point loading system. The PC and PNFRC beamlets are used for the test. In this test, the load-deflection curves, the flexural strength (F-S), the flexural post-crack energy absorption (FE2), the flexural total energy absorption (FTE), and the flexural toughness indices were examined (FTI).

3.6.3 Water Absorption and Mass Loss Testing

Properties of water absorption are measured for PC and PNFRC to calculate the water absorption capacity of specimens (cylinder and beamlet) as per the ASTM C642 is followed in **Table 3.5**. Firstly, specimens are dried in the oven and then these dried specimens are placed in water at room temperature. The water absorption properties of PC and PNFRC are determined by measuring the water absorption capacity. All types of specimens' water absorption are measured through this method. The determination of mass loss of PC and PNFRC in all combinations with filler material has been determined under the specification of ASTM C157M-08. Variations and shrinkage in the reference line are documented after completing the test process before being assessed.Each type of concrete mix specimen is heated to a high temperature. The temperature increases by 3 degrees Celsius every minute from 20-degree centigrade to 100 degree centigrade and is held there for an hour. To get more accurate data, this is done. To prevent thermal cracking, specimens are cooled down at the same pace at 30^0C. **Figure 3.4** shows the oven used for drying samples for water absorption and mass loss tests. The mass loss of PC and PNFRC, in combination with various filler materials.

FIGURE 3.4: Drying Samples in Oven for Water Absorption and Mass Loss Test

3.7 Summary

For the preparation of PC and PNFRC, the mix design ratio was decided at 1:2:3. For the preparation of PC, 0.45 W/C is used, whereas 0.45 W/C along with 1.5% super-plasticizers is used for all types of PNFRC specimens. Pine-needle fibers with 30 mm, lengths are used along with marble dust and eggshell powder as a filler material. Pine-needle fiber is taken as 1% by volume of concrete, while the marble dust is taken as 15% by mass of cement kept fixed in all combinations, and eggshell powder is taken as 5%, 10%, and 15% by mass of cement. Both marble dust and eggshell powder are cement replacements for concrete. A total of 42 samples are cast, of which 21 are cylinders with 7 combinations and 21 beamlets for a total of 7 combinations PNFRC with filler material. ASTM standard test followed for determining slump, dynamic, mechanical, and miscellaneous tests for PC and PNFRC. The results obtained are discussed in detail in chapter 4.

Chapter 4

Results and Analysis

4.1 Background

All the mechanical and dynamic testings are performed according to ASTM standards and properties of PESPMDP-FRCs are compared with the properties of PC. In this chapter, mechanical, dynamic, water absorption, mass loss and linear shrinkage properties of PC and PESPMDP-FRCs are studied experimentally. Characteristics of PESPMDP-FRCs are discussed by SEM and XRD analysis. In this chapter, a detailed analysis is presented of the tests that were performed in accordance with ASTM standards.

4.2 Fresh Properties

4.2.1 Compact Factor Test

The workability of concrete is measured with the help of the slump cone test. **Table 4.1** The compacting factor test is used to find out the low workability of concrete. The same approach is implemented for all combinations with a fixed amount of marble dust (15%) and the same amount of pine-needle fiber (PNFRC). The slump cone test is used to measure the workability of concrete. The slump test is performed for pc, and all combination with PNFRC is always performed to measure the consistency of concrete. Slump cone and compact factor tests are performed before concrete placement in molds. A slump cone test is performed to measure the fresh properties of concrete under the specification of ASTM standard C-143/ C143M-15a. The bottom diameter of the slump cone is 8 inches, and the top surface is 4 inches the height of the slump cone is 12inch which is used to perform the test. Compacting factor test is used for the workability of concrete. it is more precise and sensitive than the slump test. It is commercially available but used rarely. It is particularly useful for concrete mixes of very low workability and normally used for normal-weight concrete, lightweight concrete, and heavy concrete. The compaction factor test is carried out to measure the degree of workability of fresh concrete concerning the internal energy required for compacting concrete thoroughly.

TABLE 4.1: Compact Factor Test Values

Concrete Sample	**Compaction Factor Values**	**Workability**
PCC	0.94	Plastic
PMC	0.92	Plastic
PN-FRC1	0.87	Stiff-Plastic
PNMDP-FRC2	0.83	Stiff-Plastic
PESPMDP-FRC3	0.85	Striff-Plastic
PESPMDP-FRC4	0.8	Stiff
PESPMDP-FRC5	0.84	Stiff-Plastic

4.2.2 Slump Test

The slump cone test is performed to measure the workability of concrete. The diameter of the tamping rod is 16mm (5/8in) from both ends, and its maximum length is 600mm (25in). The concrete layers have been placed equally in molds and each layer is compacted by 25 strokes used to fill the cone. The molds were filled with concrete layers in equal amounts, and each layer was compacted by 25 strokes using a cone filler. After applying the third layer compact it with 25 strokes of the tamping rod. Similarly, the additional two layers of the cone are filled and tamped down with a tamping rod. The excess concrete was removed by hitting it with a tamping rod, and the surface was smoothed by screeding and rolling the rod over it. The Cone of the droop is thereafter raised vertically upward. The slump cone's concrete molds are next to the upside-down cone. Using a ruler, the tamping rod is positioned to remove the slump cone so that its length may be measured over the slumped concrete. The value of the slump is measured carefully shown in **Figure 4.1**. To the best of the author's knowledge, there is not any standard test available for the determination of the workability of PNFRC fresh properties. Hence, the same procedure and test standard are used for the determination of the workability of all PNFRC combinations with filler material. The relation between the observed slump values and determined hard densities is shown in **Table 4.2**. It can be seen that the PC has maximum density and slump value. Whereas keeping the fixed 30 mm length of PN-FRC and marble dust powder the changing percentage of eggshell powder such as 5%, 10%, and 15% as 17 mm, 13 mm, 7mm, 3mm, and 9mm the value of slump is decreased along with the value of density. Similarly, by the keeping fixed marble dust 15% by weight of cement there is decrease in slump and density of PNMDPESP-FRCs as compared to PC. The combinations of reinforced concrete is shown with lines. For measuring the densities, an average of three specimens is taken for each mix design. The volume of the beamlets is determined in terms of m^3 by taking the internal volume of the molds that are used for the casting of the beamlets.

FIGURE 4.1: Measuring Value of Slump of PNMDPESP-FRC

Table 4.2: Specimens Labelling, Density and Slump of Fresh Concrete, Density of Hard Concrete

Labeling of Specimen	**C:S:A**	**Percentage of Fiber(%)**	**Percentage of Marble Dust Powder(%)**	**Percentage of Eggshell Powder**	**W/C Ratio**	**Percentage of Super-Plasticizers(%)**	**Slump of Concrete (mm)**	**Harden Density**
PCC	1:2:3	-	-	-	0.45	1.5	17	2337.196
PMC	1:2:3	-	15	-	0.45	1.5	13	2338.186
PN-FRC1	1:2:3	1	-	-	0.45	1.5	7	2329.079
PNMPC-FRC2	1:2:3	1	15	-	0.45	1.5	9	2332.112
PNMDPESP1-FRC3	1:2:3	1	15	5	0.45	1.5	3	2326.039
PNMDPESP2-FRC4	1:2:3	1	15	10	0.45	1.5	0	2338.793
PNMDPESP3-FRC4	1:2:3	1	15	15	0.45	1.5	0	2310.856

This table has explain the percentages of contents such as S.P, ESP, MDP and PN-FRC in PESPMDP-FRC specimens densities.

The densities are found by taking ratio of weight (kg) and volume (m^3). The determined values of densities and slumps are shown in **Table 4.2**. To the best of the authors' knowledge, there are no such standard tests available to find out the workability and density of fresh PNMDPESP-FRCs. Hence, the same procedure and test standards are used for the determination of the workability and densities of all PNMDPESP-FRCs.

4.3 Dynamic Properties

The combination of PNFRC in concrete with filler material by cement replacement has been investigated to evaluate concrete's dynamic properties. ASTM standard C215-14 has investigated the dynamic properties of plain concrete. There is no other specific standard is available to determine the dynamic properties of PN-FRC. The dynamic properties of PNFRC are adopted to determine the dynamic properties [106]. Accelerometers have recorded the graphical response while performing the test, which has been shown in **Figure 4.2**.
The damping ratio refers to the rate at which the frequency of vibrations decays from one oscillation to the next. The damping ratio denotes how rapidly the frequency of vibrations decreases from one oscillation to the following one. When a filler material composed of a combination of marble dust and eggshell powder is incorporated into concrete, it generates an interfacial transition zone that resists the frequency and reduces resonance. Calculated dynamic properties of PC and all PNFRC combinations with a filler material such as marble dust and eggshell powder are explained in **Table 4.3**. The average and appropriate values of each PN-FRC specimen corresponding values have been obtained from dynamic properties. The difference between the damping ratio of PCC, PMC with 15% combination of marble dust, PN-FRC-1, PNMDP-FRC-2 with a combination of pine-needle fiber with 15% marble dust, PNESPMDP-FRC-3 with a combination of 5% ESP and 15% MDP with pine-needle fiber, PNESPMDP-FRC-4, with a combination of 10% ESP and 15% MDP with pine-needle fiber PNESPMDP-FRC-5 is the combination of 15% ESP and 15% MDP with pine-needle fiber. In **Figure 4.3** and **Figure 4.4**

shows that the properties in percentages the damping ratio of PMC with a combination of marble dust have 15%.PN-FRC1, PNMDP-FRC2, PNMDPESP-FRC3, PNMDPESP-FRC4, PNMDPESP-FRC5 are increased by 18.56%, 96.4%, 28.47%, 240%, 263%, and the above damping ratio it can be noted that the damping ratio has maximum in all combinations of PNESPMD-FRC. Concrete cylinders have high resistance against the same length of PNFRC against high dynamic loading resistance by increasing the percentage of eggshell powder to 10% [18]. In the case of beamlets, the specimens with 30 mm pine-needle fiber lengths show more resistance against dynamic loading than those with PC and PCMD. The pine needle fiber has ability to reduce vibration and enhance the damping ratio due to interfacial transition zone. it has depend on the interface of different material. **Figure 4.5** shows that the test set up to observe dynamic properties. Pine needle fibers dampen vibration via interfacial transition zone enables pine needle fibers to reduce vibration enhanced.

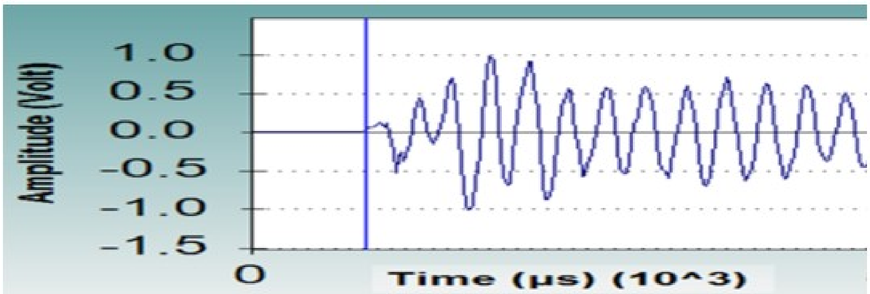

FIGURE 4.2: Damping Properties of PC and PNMDPESP-FRCS

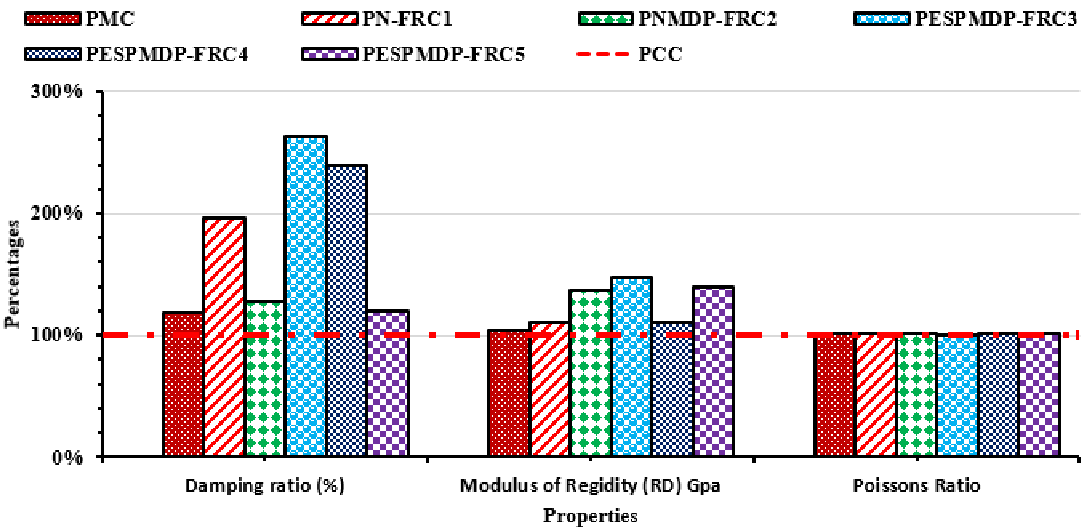

FIGURE 4.3: Dynamic Properties of Concrete Cylinder

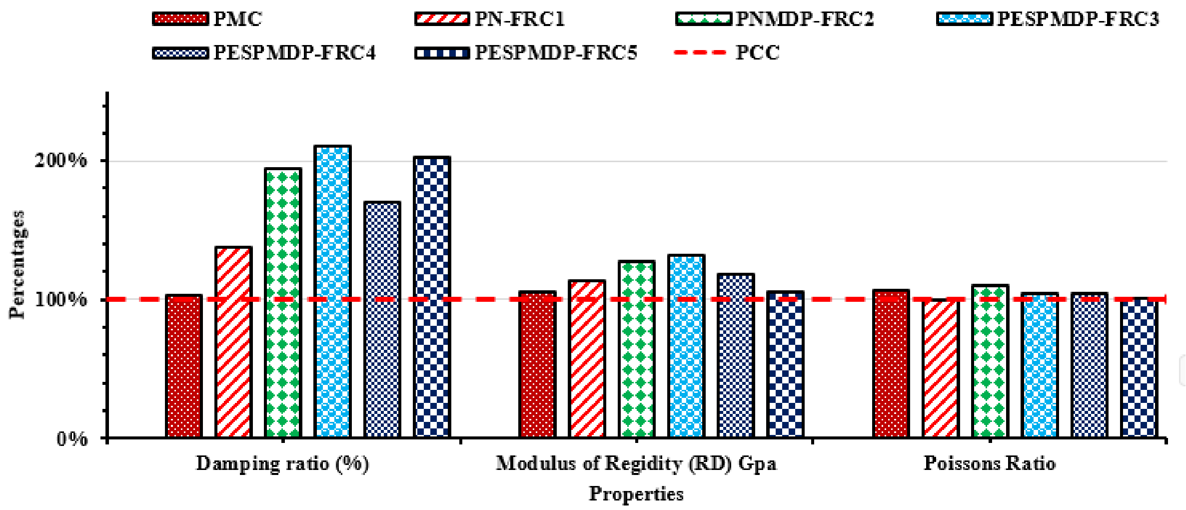

FIGURE 4.4: Dynamic Properties for Beamlet

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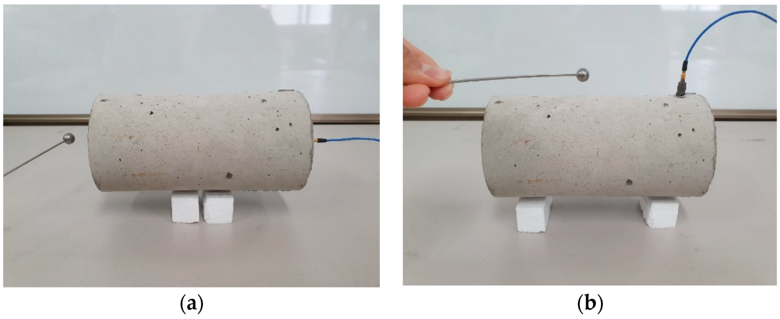

FIGURE 4.5: Dynamic Test Setup (a) Longitudinal Frequency (b) Transverse Frequency

The above test has been performed in the laboratory the ASTM C215 standard has been strictly followed to measure the frequency and dynamic properties such as damping ratio, modulus of rigidity, and poisson ratio. The damping ratio pertains to the speed at which vibration frequency diminishes from one cycle to the next. Incorporating a filler material made up of both marble dust and eggshell powder into concrete results in the formation of an interfacial transition zone that opposes frequency and lessens resonance The damping ratio denotes the speed at which the oscillation frequency diminishes over consecutive cycles of damping ratio. The damping ratio indicates the rate at which the oscillation frequency decreases over successive damping cycles.

TABLE 4.3: Dynamic Properties of PC and PNMDPESP-FRCs

Concrete Specimens	Studied Parameter					
	RFL (HZ)	RFT (HZ)	RFR (HZ)	ζ%	RD (GPa)	Poisson Rtio (-)
Cylinder						
PCC	3843	3392	3607	1.63	4.636	0.5028
PMC	3412	3371	3349	1.92	4.495	0.49735
PN-FRC1	3137	2952	2743	3.18	5.133	0.51079
PNMDP-FRC2	3538	3318	3159	2.08	6.858	0.50957
PNMDPESP-FRC3	2946	2961	2673	3.903	5.123	0.5012
PNMDPESP-FRC4	2687	2183	1764	4.27	6.344	0.5129
PNMDPESP-FRC5	3491	3356	3127	1.94	6.43	0.50817

TABLE 4.4: Dynamic Properties of PC and PNMDPESP-FRCs

Concrete Specimens	**Studied Parameter**					
	RFL(HZ)	RFT (HZ)	RFR (HZ)	ζ%	RD (GPa)	Poisson Rtio (-)
Beamlet						
PCC	3857	3234	3448	1.79	24.89486	-0.50819
PMC	3473	3423	3348	1.77	26.1234	-0.53583
PN-FRC1	3269	3127	3012	2.482	28.21816	-0.50059
PNMDP-FRC2	3378	3217	3108	3.49	31.51292	-0.5575
PNMDPESP-FRC3	3131	2984	2759	3.644	32.92521	-0.52718
PNMDPESP-FRC3	3259	3251	3152	3.032	29.39229	-0.52718
PNMDPESP-FRC4	3048	2996	2853	4.719	26.49768	-0.50368

4.4 Mechanical Properties

4.4.1 Properties Under Compressive Loading

The stress-strain graph relationship between PC, PCMD, PN-FRC1, PNMDP-FRC2, PNESPMD-FRC3, PNESPMD-FRC4, and PNESPMD-FRC5, are described in **Figure 4.6**. The compressive strength of PMC and PESPMDP-FRC4 with a combination of 10% ESP has shown maximum in comparison with all types of PNESPMD-FRCs. The compressive strength of PCMD, PESPMDP-FRC4, and PESPMDP-FRC5 significantly increased 22.22%,33%, and 1.8%, PN-FRC1 without eggshell and marble powder, PNMDP-FRC2 and PESPMDP-FRC3 have slightly reduced the compressive strength utilization of natural fiber reduce the compressive strength of concrete [4]. PESPMDP-FRC4 has significantly increased the compressive strength of concrete with 10% eggshell powder and 15% marble dust these two constituents reduce the amount of cement by 25% and the compressive strength is 33% increased. The incorporation of 5% eggshell powder into the concrete mix led to a reduction in compressive strength attributed to a weak interfacial transition zone, which was caused by the increased porosity of the mortar and aggregate. Similar findings have been reported by previous studies [106-108]. However, this study observed that adding 10% eggshell powder to the mixture of concrete resulted in the highest compressive strength of 25.11 MPa after curing age of 28 days. The content of eggshell powder, used as a partial cement substitution of cement, has increased the compressive strength of concrete. However, adding more than 10% eggshell powder decreased the compressive strength. In fact, the mix containing 15% eggshell powder exhibited the lowest compressive strength at 28 days. Therefore, the study concluded that the optimal percentage of eggshell powder to enhance compressive strength in concrete is 10%. Further increase in the content of eggshell powder cause a reduction in compressive strength. The eggshell powder acts as a filler and performs similar to limestone in replacing concrete, which has also been observed in other studies[107–110]. The PNESPMD-FRC4 has shown the maximum strength compared to other types of PNESPMD-FRCs.

When the percentage of ESP increased up to 10%, the compressive strength increased by 33% compared to PCC, and marble dust with a 15% replacement of cement included in all combinations. After the increment of eggshell powder to 15% in PNESPMD-FRCs, the compressive strength value slightly improved as compared to PC and increased from PN-FRC by 14%. Similarly, an increase in compressive strength was observed in PESPMDP-FRC4, with the compressive strength value significantly increasing up to 33%. The overall compressive strength value of PCC, PN-FRC1, PNMD-FRC2, and PNESPMD-FRC3 is less than that of PMC and PNMD-FRC4 and PESPMDP-FRC 5. The compressive strength value increased due to the presence of eggshell powder because of its high content of calcium oxide (CaO) [111]. The 30mm length of pine-needle fiber has acted as a crack arrestor in concrete [113]. Different researchers have reported that using eggshell powder as a filler material with a combination of marble dust to replace and enhance compressive strength by 10% replacement of cement has increased the compressive strength comparatively to PCC. Hence, eggshell powder has enhanced the compressive strength of concrete up to a 10% replacement of cement. Marble dust and eggshell powder are extensively used as partial substitutes for cement in concrete due to their favorable bonding characteristics. The bonding of these materials with cement is influenced by various factors such as particle size, shape, and chemical composition[18, 112]. As both marble dust and eggshell powder are primarily composed of calcium carbonate, they can be used as fine powders in concrete. The addition of these materials to concrete can enhance its mechanical properties, including compressive strength and modulus of elasticity. The bonding characteristics of marble dust and eggshell powder with cement are also influenced by their particle size and shape, with smaller particles showing better bonding behavior with cement [95, 96].

The modulus of elasticity (MOE) of PC, PCMD, and all combinations of PNESP-FRCs is shown in **Table 4.5** the modulus of elasticity is observed in all combinations of PNESPMD-FRCs are increased in PMC, PESPMDP-FRC2, PESPMDP-FRC4, PESPMDP-FRC5 by 9.8%, 1.8%, 18.93% and 1%than the MOE of PC except PN-FRC1 and PESPMDP-FRC3. The MOE of PMC and PNMD-FRC2 and PESPMDP-FRC5 is reduced as compared to other PNESPMD-FRC4. This may be due to the presence of 15% ESP and 30mm length of fiber in concrete. the PC specimens have saplled with due to applied loading.

Figure 4.7 shows the typical compression failures of PC and PNESPMDP-FRCs. **Table 4.5** shows the values of compressive pre-crack absorbed energy (CE1), compressive post-crack absorbed energy (CE2), compressive total absorbed energy (CTE), and compression toughness index (CTI). **Figure 4.8** represent that All these compressive absorbed energies are calculated by the method described by [105] and [42]. There is the increase of 14%, ,and PN-FRC1 has reduced by 17%, PNMDPFRC2 has increased by 13% and all PESPMDP-FRCs are increased by 15%, 33%, and 8%, in the values of CE1 for PNESPMD-FRC2, PNESPMD-FRC3, PNESPMD-FRC4, PNESPMD-FRC5, respectively, when compared with PC. On the other hand, the respective CE2 decreased by 85%, 96%, 94%, 89%, 92.7% and 91.8% as compared to PC. In **Figure 4.9** PNESPMD-FRCs have more CTI value as compared to PC and PCMD this reduction in compressive toughness may be due to the presence of eggshell powder of spalling like PC, the appearance of diagonal and share cracks on the surface of samples of PNESPMD-FRCs under compressive loading. Under compressive loading, PNESPMD-FRC samples display diagonal and shear cracks on their surface, similar to spalling.

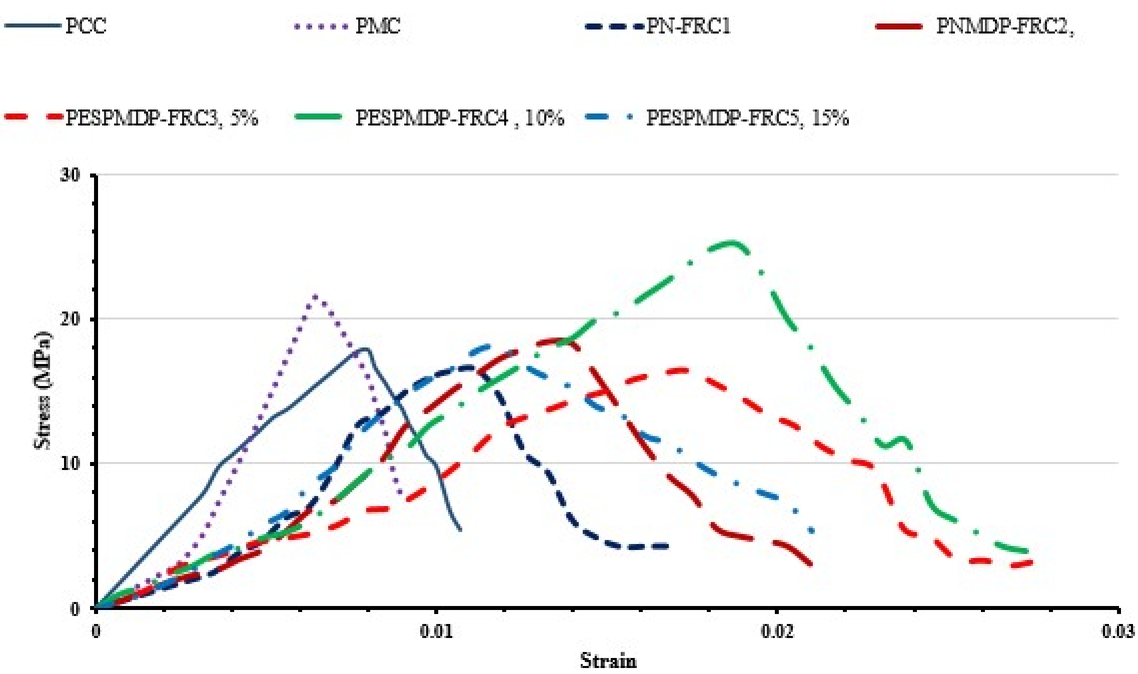

FIGURE 4.6: Compression Response of PC and PNESPMD-FRCs

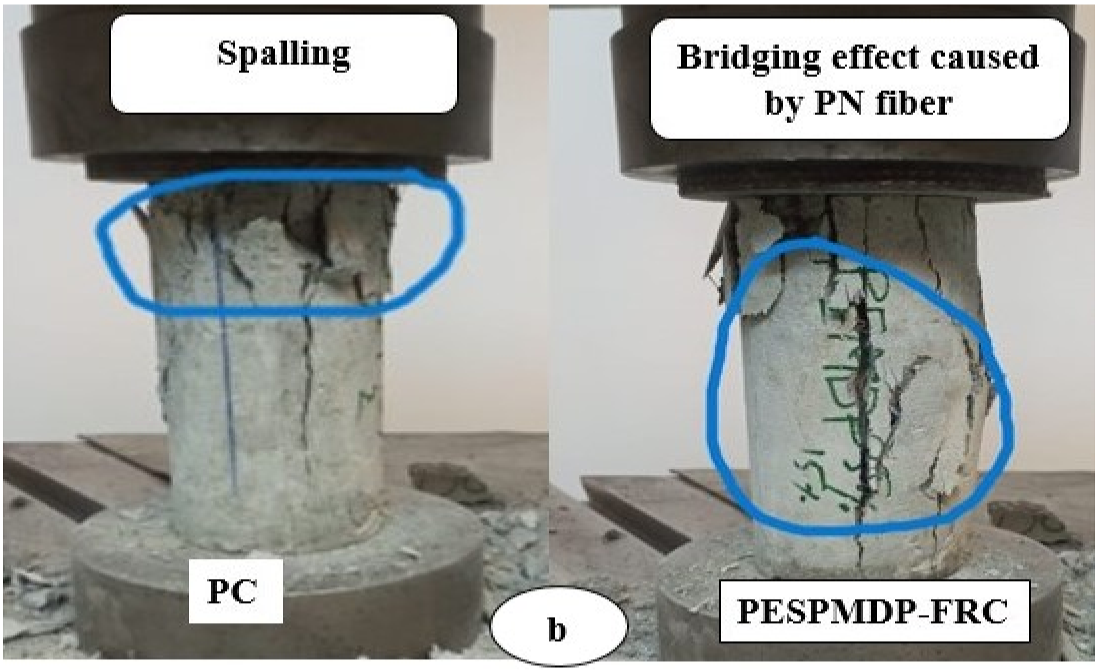

FIGURE 4.7: Typical Compression Failures of PC and PNESPMD-FRCs,

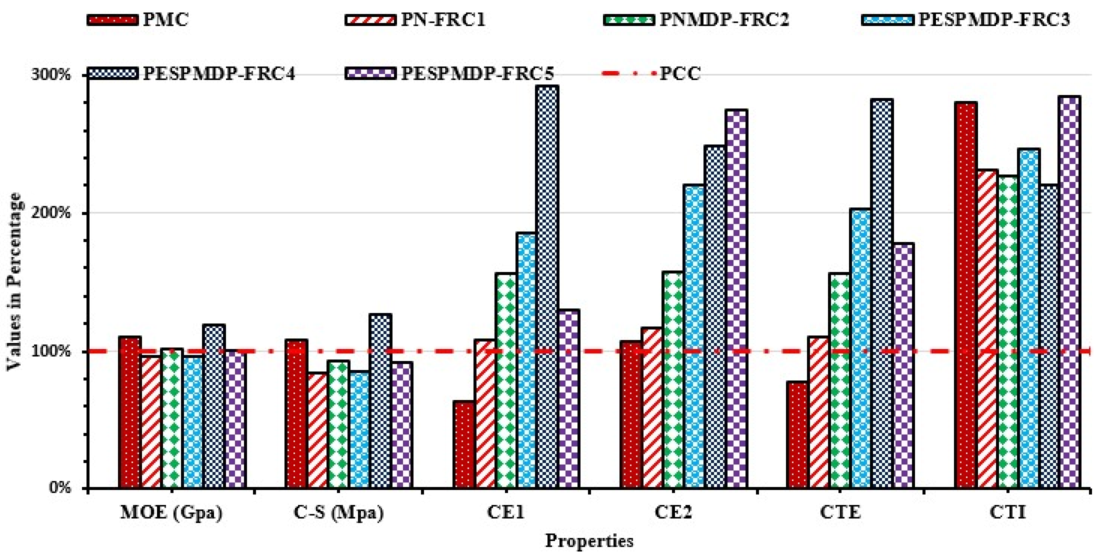

FIGURE 4.8: Mechanical Properties of Concrete Under Compressive Loading

4.4.2 Flexural Strength

The load-deformation curve for PC, PCMD, PN–FRC1, PNMDP-FRC2, PNESPMD-FRC3, PNESPMD-FRC4, and PNESPMD-FRC5, is given in **Figure 4.9**. The loading rate is recommended to apply for testing according to ASTM standard C78 with a loading rate of 1.03MPa/min [4] but in this study, a loading rate of 1KN/sec is applied. It may be noted that in **Figure 4.10** PNESPMD-FRC2 carries the maximum load. Due to the bridging effect of pine-needle fiber and a combination of marble dust and eggshell powder have shown maximum load-carrying capacity. Flexural strength (F-S), flexural pre-crack absorbed energy (FE1), flexural post-crack absorbed energy (FE2), flexural total absorbed energy (FTE), and flexural toughness index (FTI) are shown under the section on flexural properties in **Table 4.5**. The PNESPMD-FRC2 has maximum flexure strength. The F-S is increased by 7%, 16%, 11%, 3.5%, 14.7%, 15.9% respectively this may be due to the same length of fiber with a combination of filler materials.

The flexure strength of concrete has increased due to the bridging effect of fiber [4] which is generated in all combinations of PNESPMD-FRCs. The FE1 PNESPMD-FRC1 has increased flexure strength by 16% compared with that of PC. There is no flexural post-crack energy in the case of the PC because, under peak loading, the PC is broken apart into two pieces. On the other hand, PNESPMD-FRCs have shown post-crack absorbed energies. These energies are due to the presence of agricultural wastes pine-needle fiber and commercial waste which are eggshell powder and marble dust in concrete. It may also predict that the PNESPMD-FRCs can sustain a little longer against flexural loading as compared with PC and PCMD because fibers present in the concrete act as crack arrestors and resist crack propagation. In **Figure 4.11** represent that the toughness indexes and absorb energies of PN-FRC1, PNESPMD –FRC3, PNESPMD –FRC4, PNMD-FRC5, and are more than that of PC and PCMD. The PN-FRC1 and PNESPMD-FRC3 have the maximum toughness index because it has maximum pre-crack and post-crack energies. This may be due to the presence of same-length pine-needle fiber which arrested crack after flexural loading better than PC and PCMD. The loading rate throughout the test is the same. The reason behind the nonlinear pre-crack behavior of concrete is the presence of natural fibers of different lengths. As deflection changes the load is also increasing. While in the areas where a strong bridging effect and bond of fibers with the surrounding matrix is present, the sample takes more load and crack propagation is delayed. PNESPMD-FRC2 exhibits the highest load capacity due to the bridging effect of pine-needle fiber and the use of a marble dust and eggshell powder mixture. In the presence of a surrounding matrix, the sample can withstand a greater load, and the propagation of cracks is slowed down. This may be due to the presence of same-length pine-needle fiber which arrested crack after flexural loading better than PC and PCMD. The presence of pine-needle fibers of the same length may have contributed to better crack arrest after flexural loading than PC and PCMD. The loading rate throughout the test is the same and measure all the parameter. The same-length pine-needle fibers present in the sample may have contributed to arresting the crack after flexural loading more effectively than PC and PCMD, with the loading rate is constant throughout the test.

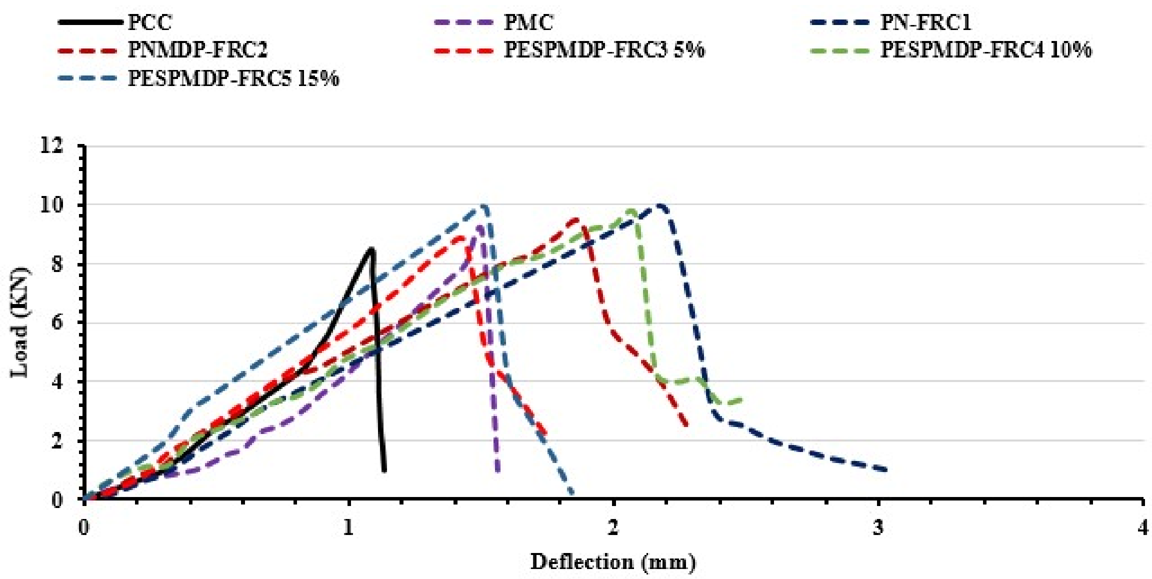

FIGURE 4.9: Flexural Response of PC and PESPMDP-FRCs

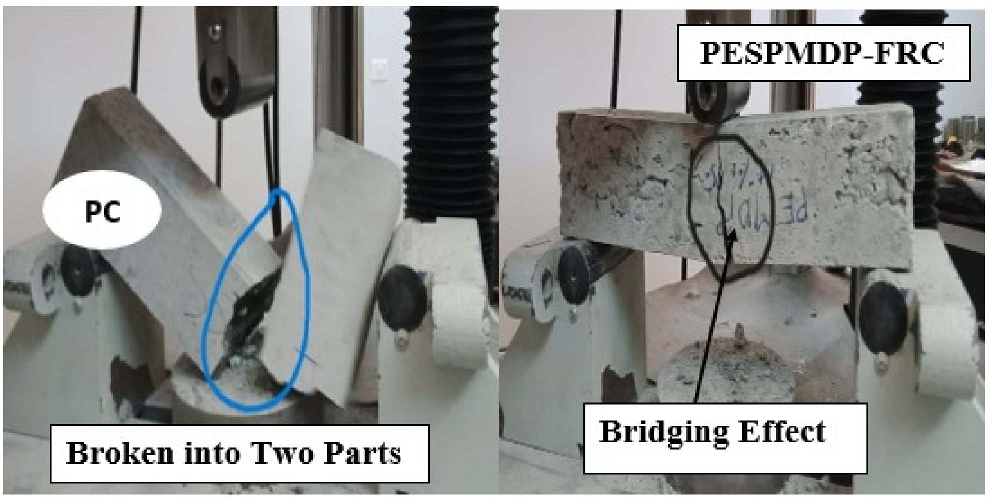

FIGURE 4.10: Typical Flexural Failures of PC and PESPMDP-FRCs,

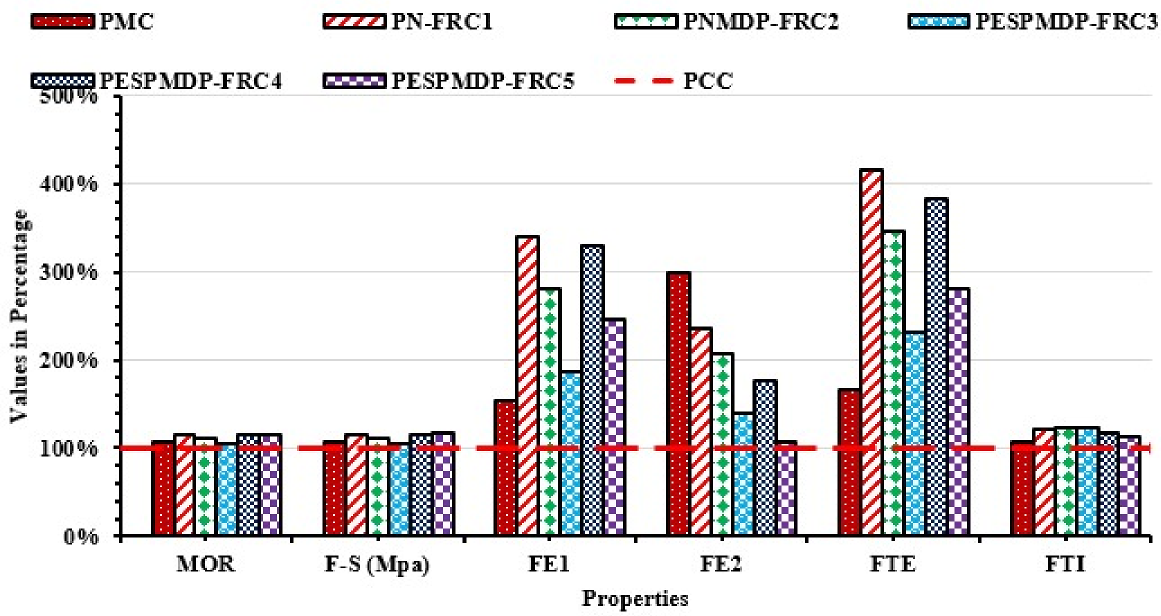

FIGURE 4.11: Flexural Properties of Beamlets

The reason behind the nonlinear pre-crack behavior of concrete is the presence of natural fibers of different lengths. As deflection changes the load is also increasing. While in the areas where a strong bridging effect and bond of fibers with the surrounding matrix is present, the sample takes more load and crack propagation is delayed. The PMDP, PN-FRC1, PESPMDP-FRC3 and PNESPMD-FRC5 with 30 mm pine-needle fibers have maximum values of toughness index. So, the 30 mm long pine needle fibers with a combination of marble dust and eggshell powder have a positive impact on toughness index. The toughness indexes and energy absorption of PN-FRC1, PNESPMD-FRC3, PNESPMD-FRC4, PNMD-FRC5, are higher than those of PC and PCMD. PN-FRC1 and PNESPMD-FRC3 exhibit the highest toughness indexes, owing to their greater pre-crack and post-crack energies. This may be attributed to the presence of pine-needle fibers that are of the same length, which effectively arrest cracking after flexural loading compared to PC and PCMD. The loading rate throughout the test remains constant. The load rate remains constant throughout the test. The presence of natural fibers of different lengths leads to non-linear pre-cracking behavior in concrete. As the deflection increases, so does the load. In areas where strong bridging effects and fiber bonding with the surrounding matrix occur, the sample can carry more load, and crack propagation is slowed down.

Table 4.5: Mechanical Properties of PC and PESPMDP-FRCs

Specimens	**Compressive Strength**						**Flexural strength**						
	MOE (GPa)	**C-S (MPa)**	**CE1**	**CE2**	**CTE**	**CTI**	**MOR**	**F-S (MPa)**	δ **(mm)**	**FE1**	**FE2**	**FTE**	**FTI**
PCC	19.8	17.794	0.0783	0.0398	0.127	0.6634	579	1.9003	1.132	3.1534	0	3.1534	1
PMDP	21.748	21.413	0.0491	0.042	0.092	1.86	624	2.048	1.62	4.91	0.333	5.2434	1.06788
PNRC-FRC1	19.13	16.57	0.0847	0.0455	0.13032	1.538	671	2.203	3.04	10.8	3.362	13.16	1.219
PNMDP-FRC2	20.16	16.57	0.122	0.0616	0.184	1.51	641	2.104	2.27	8.87	2.07	10.94	1.24
PESPMDP-FRC3,5%	19.19	16.5	0.146	0.0928	0.238	1.64	605	2	1.76	5.9	1.4	7.293	1.2355
PESPMDP-FRC4,10%	23.55	25.12	0.2288	0.1052	0.33407	1.5	664	2.18	2.48	10.366	1.78	12.145	1.17
PESPMDP-FRC5,15%	20	18.124	0.1014	0.1080	0.20955	2.065	671	2.203	1.84	7.8	1.086	8.8836	1.14

Table 4.5 shows the properties under compressive loading and flexural loading the compressive strength properties include MOE modulus of elasticity, C-S compressive strength , CE1 and CE2 energy before and after cracking, and CTI represent compressive toughness index.

4.5 Water Absorption, Mass Loss, and Linear Shrinkage

The liquid transportation through the capillary action is given as water absorption and is determined by the mass of absorbed water by the specimen divided by the actual mass of the specimen after oven drying (ASTM standard C642-13) [113]. The water absorption of PC, PCMD, and all PNESPMD-FRCs is given in **Table 4.3**. It can be noted that PNESPMD-FRC5 has maximum water absorption and PC has minimum water absorption value. Natural fibers like pine-needle have the characteristics to absorb water. So, the water absorption of all PNESPMD-FRCs is higher than PC and PCMD. It also can be noted that by an increment of pine-needle fiber same lengths the water absorption of PNESPMD-FRC specimens is increased. The PNESPMD-FRC6 has a maximum length combination i.e., 30 mm pine-needle fiber and 15% marble dust, and 15% eggshell powder so it has maximum water absorption which is more than from the water absorption of PC . Several studies have concluded that adding marble dust and eggshell powder as partial replacements for cement in concrete can increase the water absorption of specimens due to their ability to increase the porosity of the cement matrix. However, the extent of water absorption depends on several factors, such as the particle size and quantity of these materials added to the cement [95, 113]. The linear shrinkage of PC and PNESPMD-FRCs is given in **Table 4.3**. There is an overall decrease in the values of linear shrinkage of PNESPMD-FRCs as compared to PC. It can be observed that with the increment in pine-needle fibers length from PNESPMD-FRC1 to PNESPMD-FRC3 the linear shrinkage is reduced. While from PNESPMD-FRC4 to PNESPMD-FRC6 the increment in fiber lengths have more effect towards the reduction of linear shrinkage value. This may be due to the presence of the same length of the fiber and various percentages of eggshell powder i.e 5%, 10, and 15% of the fiber length such as 30 mm pine-needle natural fiber. It can be presumed that the use of the same length of pine-needle fiber with a combination of filler materials may reduce the vulnerability of concrete to cracks. It is possible to assume that by combining filler materials with pine-needle fibers of the same length, the susceptibility of concrete to cracks may be reduced.

The mass loss of PNESPMD-FRCs is given in **Table 4.3**. It can be observed that the maximum mass loss occurred at the temperature of 100^0C. PC has shown minimum mass loss and PNESPMD-FRC6 has shown maximum mass loss. From PNESPMD-FRC1 to PNESPMD-FRC3 as the pine-needle fiber length is the same from 30mm the mass loss is increased. But this increment is less than the increment shown by PNESPMD-FRC4 to PNESPMD-FRC6 because PNESPMD-FRC1 to PNESPMD-FRC3 has PN of 30 mm lengths while long pine-needle fiber is present in PNESPMD-FRC4 to PNESPMD-FRC6. It may be noted that the presence of longer i.e., 30 mm long PN has a positive influence towards mass loss when used with ESP and MD of 5%, 10%, and 15% of filler material. The ML at 50 degree Centigrade is approximate 65% less than the ML at 100 degree Centigrade. This is due to the continuous heating of specimens to achieve the temperature of 100 degree Centigrade. The reason for this is the specimens being continuously heated until they reach a temperature of 100 degrees Celsius. The use of pine-needle fibers of identical length, combined with materials for the susceptibility of concrete.

Table 4.6: Water Absorption, Mass Loss and Linear Shrinkage of PC and PESPMDP-FRCs

			ML Temperatures		
Specimens	**WA (%)**	**LS(%)**	**50%**	**75%**	**100%**
PCC	1.2	1.359	-0.003	-0.004	-0.005
PMC	1.6	1.167	-0.0038	-0.0052	-0.0064
PN-FRC1	2.14	0.978	-0.014	-0.018	-0.024
PMDP-FRC2	2.68	0.816	-0.018	-0.024	-0.031
PESPMDP-FRC3, 5%	2.81	0.513	-0.018	-0.024	-0.032
PESPMDP-FRC3,10%	2.83	0.381	-0.027	-0.035	-0.043
PESPMDP-FRC3,15%	2.94	0.198	-0.033	-0.044	-0.054

4.6 State of the Art

4.6.1 Scanning Electron Microscopy (SEM)

The use of scanning electron microscopy (SEM) allowed for microstructural analysis of cement concrete mixed with marble dust powder. The SEM images presented in **Figure 4.12** and **Figure 4.13** displayed the internal features of both the marble dust and the modified cement paste after 28 days. The results indicated that the incorporation of marble dust led to a denser and less porous mixture compared to the control samples. At this stage, the microstructure of the paste consisted of vast layers of amorphous calcium hydroxide (CH) and calcium silicate hydrate (C-S-H) crystals, while ettringite (E) needles were observed within the pores [4]. In the destructive testing of specimens, SEM was used to investigate the interface of marble dust and eggshell powder with pine needle fiber reinforced concrete and the damaged structure of the specimens, as shown in **Figure 4.13**.
The SEM images showed that the concrete matrix fractured around the fibers due to the applied loading and the load was transferred throughout the samples. Observations from SEM images indicated that the concrete matrix experienced fractures around the fibers as a result of the applied load, and the load was distributed throughout the samples. The brittle nature of the concrete caused cracking and loss of adhesion with the fiber surface, resulting in a peripheral hollow along the length of the implanted fiber. Additionally, the applied load caused cracks on the external surface of the concrete specimen, which led to the separation of the concrete from the fiber surface. Despite this, a strong bond between the fiber and concrete was observed, which utilized the fiber strength against the applied loading. During pull-out, the embedded fibers experienced shear failure, resulting in the splitting of nano-strands. Fractured strands of the fiber were observed to resist the resultant impact force acting perpendicular to their surface. The removal of concrete mass under the embedded fiber caused scratches on the fiber surface. The SEM analysis revealed the interface characteristics and internal structure of the marble dust and eggshell powder with pine-needle fiber-reinforced concrete specimens, highlighting the bonding and failure mechanisms under applied loading.

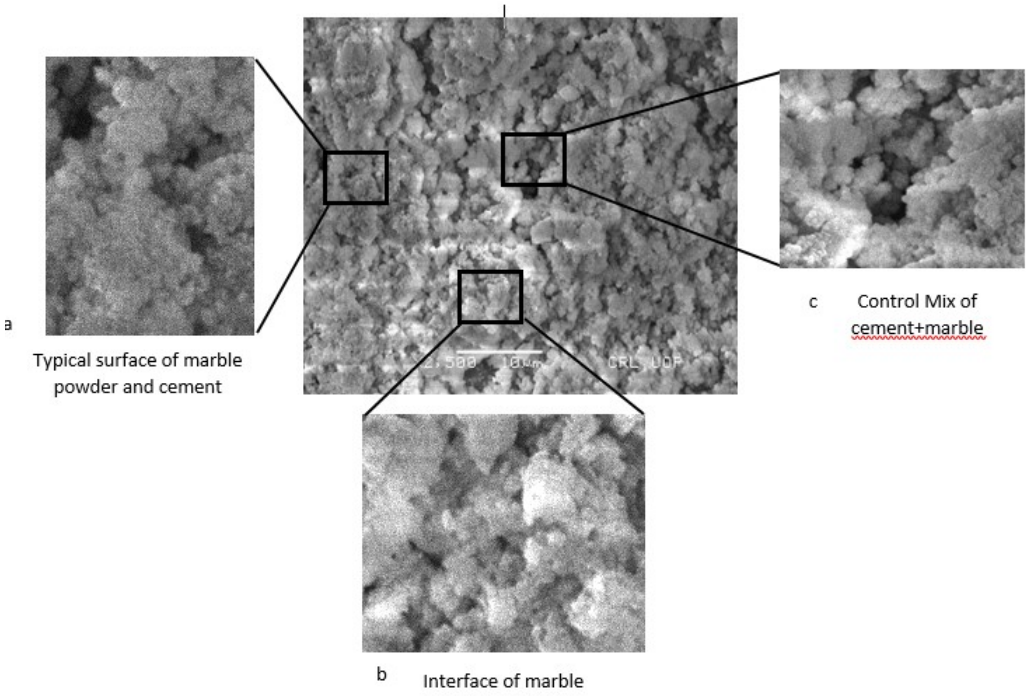

FIGURE 4.12: (a) Typical Surface of Marble Powder and Cement (Interface of Marble Powder on Corner) (c) Control Mix of Cement and Marble Powder

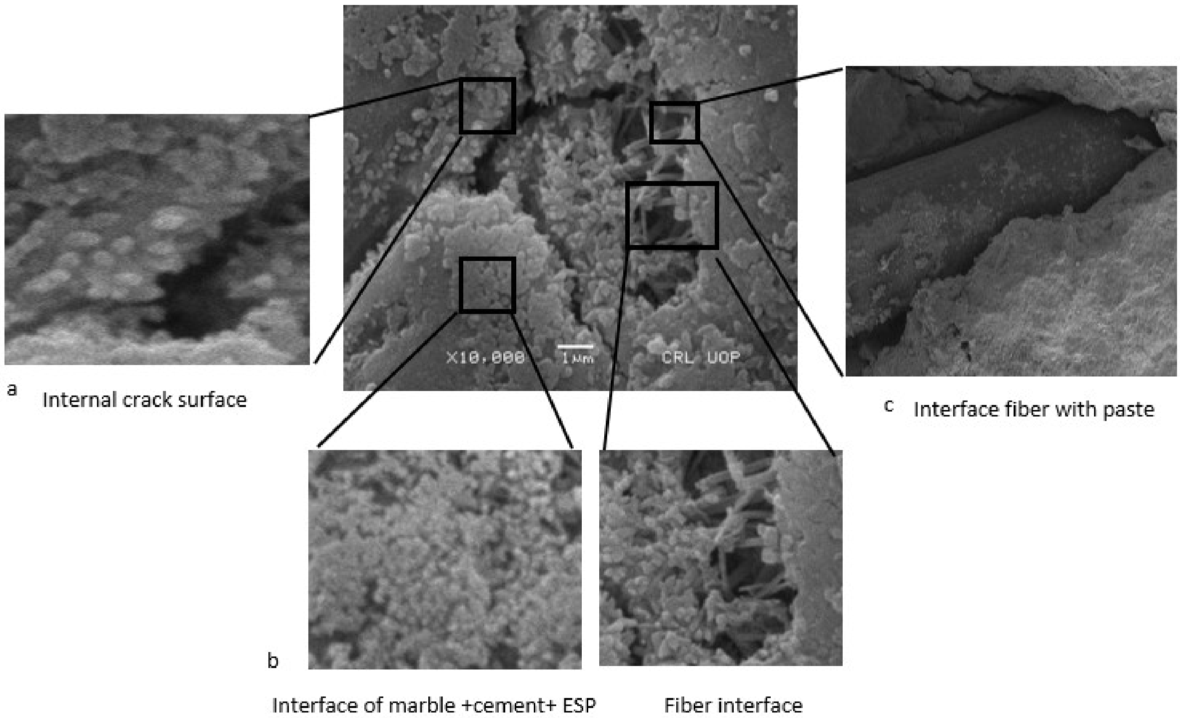

FIGURE 4.13: (a)Internal Crack Surface (b)Interface of Marble + Cement+ESP (c) Internal Bond of Fiber

The above figures has represented the SEM Analysis of cracked specimens to observe the internal properties of specimens.

4.6.2 X-ray Diffraction Analysis

The X-ray diffraction (XRD) technique was employed to identify the phases present in the hardened paste of cement, marble powder, and eggshell powder as partial replacements for cement, as well as in the control group after 28 days. The diffraction pattern was obtained over a range of diffraction angles (2) between 5 degrees and 80 degrees in increments of 0.017 degrees, and the resulting list of d-spacing and relative intensities of diffraction peaks was compared with standard peaks of compounds in the diffraction database released by the International Centre for Diffraction Data (ICDD). **Figures 4.14** and **Figure 4.15** depict the XRD spectra of the powder paste. The main phases detected in the paste were calcium hydroxide (P), calcium silicate hydrate (CSH), calcite (C), and calcium silicate (CS) [114]. The XRD spectra of the powdered paste also showed the presence of quartz (Q) as an aggregate. However, the weak diffraction peaks of calcium silicate hydrate were overshadowed by the diffraction peaks of calcium silicate and aggregates. Qualitatively, no change was observed in the phase composition of the paste when using marble powder and eggshell powder as partial replacements for cement in the mixtures. However, the incorporation of marble powder and eggshell powder in the paste altered the proportions of the phases, indicating that these materials are inert and do not significantly affect the phase composition of the resulting mixture of resulting mixture's phase composition.

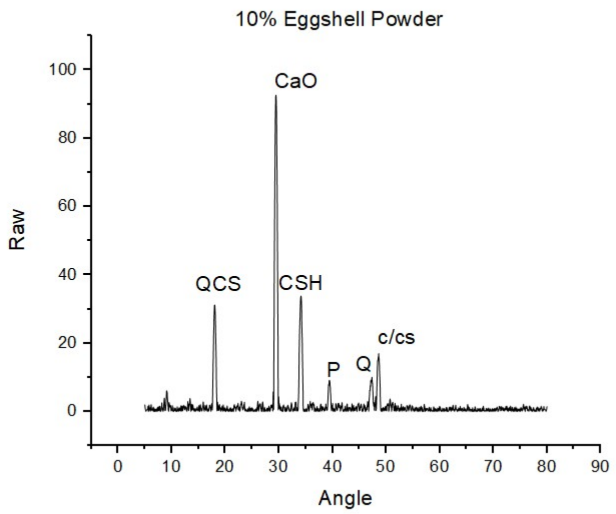

FIGURE 4.14: XRD Patern of 10% Eggshell Powder with Pine-Needle Fiber

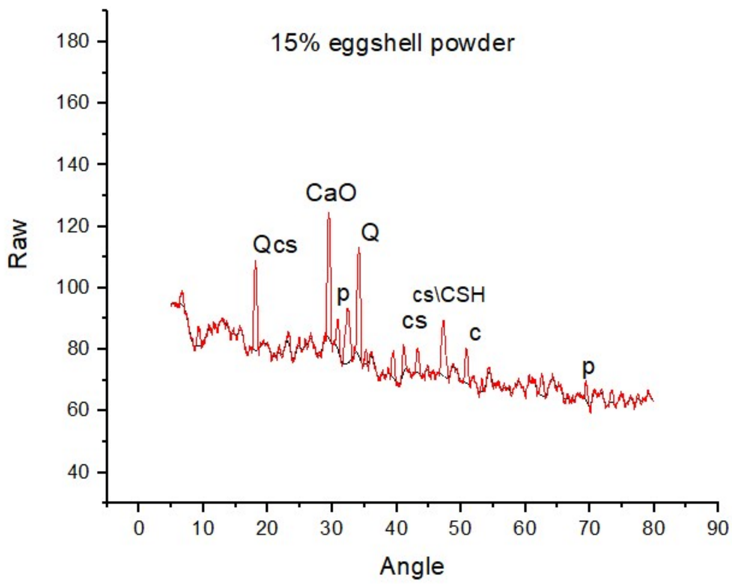

FIGURE 4.15: XRD Patern of 15% Eggshell Powder with Pine-Needle Fiber

4.7 Development of Empirical Relation for PESP MDP-FRC Cylinder and Beam Specimens

PESPMDP-FRC specimens were cast with an optimized percentage of pine-needle fiber as 1% by volume of wet concrete and filler materials such as 15% marble dust powder and various contents of eggshell powder (i.e., 5%, 10%, and 15% as reported by [12, 15, 19]). These specimens were cast along with P.C specimen to evaluate the comparative performance of both P.C and PESPMDP-FRC specimens. However, casting of multiple specimens, such as cylinders and beams, to study the properties of PESPMDP-FRCs is not always feasible due to various constraints. Therefore, there is a need to develop a correlation between cylinder and beam specimens to anticipate the performance of the specimens through laboratory testing and findings. Accordingly, cylinder specimens were cast and tested in the laboratory to examine their properties (i.e., c, CE1, CE2, CET, and CTI). Subsequently, beam specimens were cast at the same time as the cylinder specimens and tested in the laboratory in the same manner as the cylinder specimens. The same flexure properties were determined experimentally (i.e., F.S., FE1, FE2, FET, FTI). Based on the obtained results, an empirical relationship in the form of an equation was developed in the same manner as also done by Sarkar and Hajihosseini [123]. The empirical relationship was devised in the current work using the laboratory's experimental data to obtain the best-fit curve. Using this curve and the simplified input coefficient variable, the numerical prediction of PESPMDP-FRCs flexure strength (i.e F.SPESPMDP-FRCs) can be made from its compressive strength data. The formulated empirical equation is as follows:

$F.S_{PESPMDP-FRCs} = 0.85\ln(c) + 0.7$

The empirical equation (eq. 1) was established based on the average experimental data, for numerically predicting flexural strength from experimental compressive strength data.

4.8 Summary

Mechanical, dynamic, and water absorption properties of PC and PESPMDP-FRCs with mixed design ratio of 1:2:3 and W/C ratio of 0.45 are determined. Values of slump and densities of PESPMDP-FRCs are lower than values of PC. Compressive, and flexural properties are determined and compared with PC. Compressive strength test and flexural strength of PESPMDP-FRCs is more than that of PC. Dynamic properties of PC and PESPMDP-FRCS are also studied. The damping ratio for PESPMDP-FRCS is more than that of PC. Dynamic rigidity modulus and dynamic poisons ratio also increases for PESPMDP-FRCs. SEM have performed to analyze the the internal structure of specimens. XRD has performed to analyze the chemical characteristics of marble dust and eggshell powder with replacement of cement. The mechanical properties of all secimens has compared with reference speciens such as pcc. Modulusof elasticity has improved to in all combinations of PESPMDP-frcs excep PN-FRC1 and PESPMDP-FRC3. compressive and flexural strength have performed according to ASTM international standard very carefully. the highest compressive strength is reported in PESPMDP-FRC4 and PMC as compare to referenced specimens of pcc.

Chapter 5

Discussion and Guidelines for practical Implementations

5.1 Background

The result is obtained after performing quantitative results of specimens of influence of pine-needle fiber that have a constant length of 30mm. Quantitative results were obtained from specimens with a constant length of 30mm of pine-needle fiber, and the concentration of marble dust is the determining factor. The concentration of marble dust is the same at 15% in all specimens except pcc and the varying percentage of eggshell powder such as 5%, 10%, and 15%. The stress-strain and load deflection graph demonstrate the combined effect of marble-dust powder, eggshell powder, and pine-needle fiber-reinforced concrete. The data from dynamic and mechanical testing is further utilized to find the optimum percentage of marble dust and eggshell powder with a combination of pine-needle fibers. All specimens have the same concentration of marble dust at 15%, except for PCC, while the concentration of eggshell powder varies at 5%, 10%, and 15%. The stress-strain and load-deflection graphs depict how the combination of marble-dust powder, eggshell powder, and pine-needle fiber reinforcement affects the concrete. The comprehensive discussions on the practical implementation of this research and recommendation of PNESPMDP-FRC in real life are made in this chapter.

5.2 Optimum Combination of MDP and ESP with PN-FRC

The maximum and minimum values are obtained from both mechanical and dynamic properties as shown in **Table 5.1**. The compression member in the result of this study is act like column PNESPMDP-FRC4 of 10% eggshell powder and 15% marble dust by replacement of cement with 1% pine-needle fiber with 30mm length by volume of wet concrete. Is recommended due to its high compressive strength among all the combinations of PNESPMDP-FRCs. The governing forces such as compression and flexural forces on the specimen of PNESPMDP-FRC4 are recommended due to their highest compressive and flexural strengths.

The addition of the combined effect of marble dust and eggshell powder with pine-needle fiber-reinforced concrete is a positive step towards the influence of compressive and flexural strength. On the other hand, pine-needle fiber without marble dust and eggshell powder negatively impacts the compressive strength of concrete but has enhanced the flexural strength of concrete. **Figure 5.1** shows that the combined effect of marble dust and eggshell powder on the properties of PNESPMDP-FRC's. The compressive toughness of PN-FRC1 is increased and compared to PC.

On the other combinations of PNESPMDP-FRC's have decreased the toughness because of compressive strength increased. From the toughness point of PN-FRC1 is recommended for compressive and flexural loading. Whereas PNESPMDP-FRC4 is recommended for flexural loading because it has maximum toughness under flexural loading. PN-FRC1 is recommended for both compressive and flexural loading. The effect of the addition of varying lengths hybrid fibers has decreased the improved CTI, but the addition of filler material such as marble dust powder and eggshell powder has decreased the toughness value just because of the enhancement of compressive strength and FTI in PNESPMDP-FRC's as compared to a PC percentage increase or decrease of strengths, absorbed energies, and toughness indexes are shown in **Figure 5.1** shows the highest increase at the maximum point it can be noted that the maximum increase in absorbed energies is in PN-FRC1, PNMDP-FRC2, and PNESPMDP-FRC5.

Table 5.1: Optimization of same length in PESPMDP-FRCs

	MOE (GPa)	C-S (MPa)	CTE (MJ/m^3)	CTI	MOR	F-S (MPa)	FTE (MJ/m^3)	FTI	RD	ζ%
PCC	19.8	17.794	0.11765	0.6634	579	1.9003	3.1534	1	4.636	1.64
PMDP	21.748	21.413	0.092	1.86	624	2.04	5.2434	1.06788	4.495	1.93
PNRC-FRC1	19.13	16.57	0.13032	1.538	671	2.203	13.16	1.219	5.133	3.29
PNMDP-FRC2	20.16	16.57	0.184	1.51	641	2.104	10.94	1.24	6.858	2.18
PESPMDP-FRC3,5%	19.19	16.5	0.238	1.64	605	2	7.293	1.2355	5.123	3.91
PESPMDP-FRC4,10%	23.55	25.12	0.33407	1.5	664	2.18	12.145	1.17	6.344	4.3
PESPMDP-FRC5,15%	20	18.124	0.20955	2.065	671	2.203	8.8836	1.14	6.43	1.95

Table 5.1 shows the compression member's mechanical and dynamic properties were analyzed, and the maximum and minimum values were determined. It was found that the compression member behaves similarly to a certain extent. These values has recommended for various application of civil engineering.

Table 5.2: Recommended Combination to industry

Recommended	**Strength point of view**									
PMDP	21.748	21.413	0.092	1.86	624	2.04	5.2434	1.06788	4.495	1.93
PESPMDP-FRC4,10%	23.55	25.12	0.33407	1.5	664	2.18	12.145	1.17	6.344	4.27
Toughness point of view	PESPMDP-FRC5		PESPMDP-FRC3	PESPMDP-FRC2	PN-FRC1	PNMDP-FRC2				
	20	18.124	2.065	2.104	1095	1.25	3.903			
PMC for Column Members	21.7	21.413	0.092	1.86	2.048	5.243	1.78	0.0193	4.495	1.94
PN-FRC for slabs and beams	19.33	16.57	0.1302	1.573	2.203	13.16	1.218	0.0208	5.133	3.18
PESPMDP-FRC4 for rigid pavements	23.55	25.12	0.334	1.460	2.203	8.9	1.14	8.836	6.44	1.94

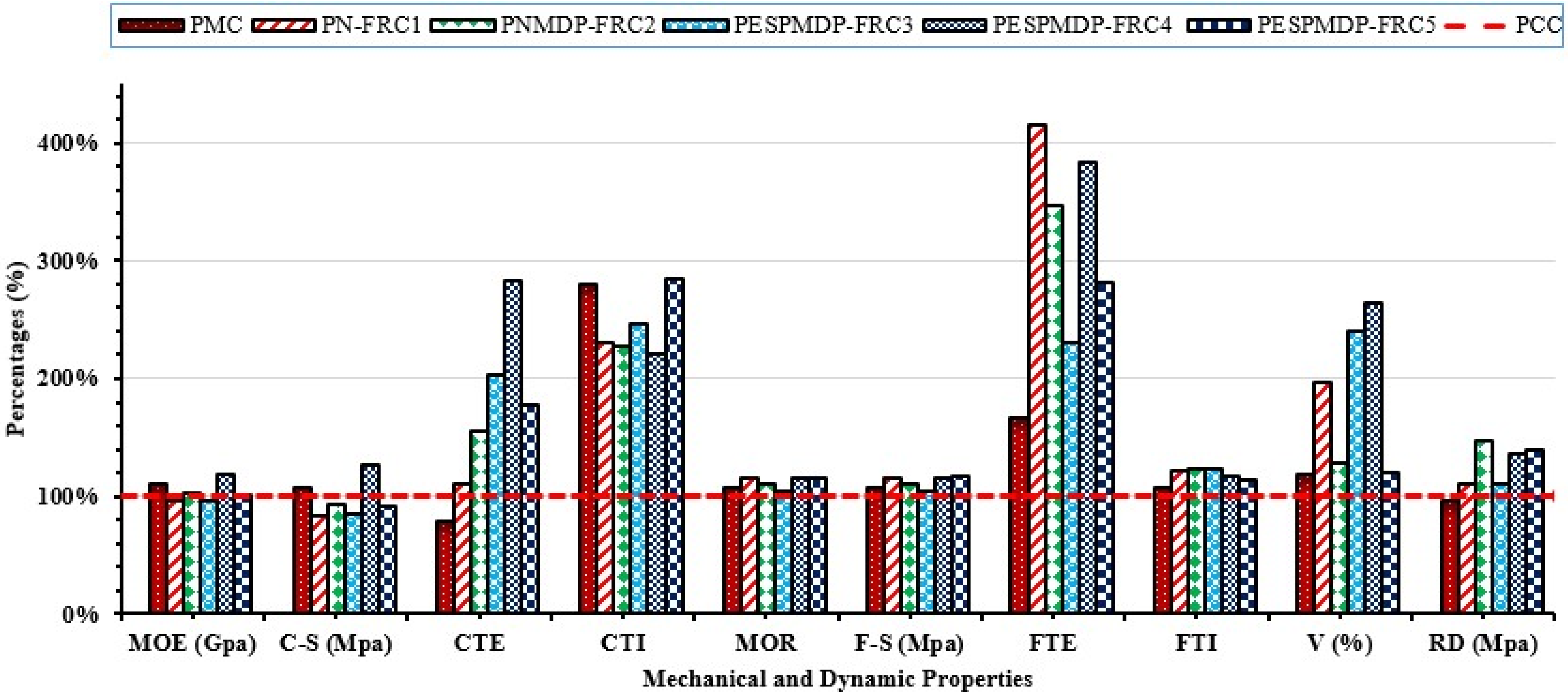

Figure 5.1: Combine Effect of Marble Dust and Eggshell Powder in Pine-Needle fiber reinforced concrete

The highest compressive strength, flexural strength and absorbed energies are determined in PN-FRC1, PNMDP-FRC2, and PNESPMDP-FRC5. PNESPMDP-FRC4 is suggested for flexural loading due to its superior toughness under this loading condition. However, the incorporation of hybrid fibers of different lengths has resulted in a reduction in the improved CTI.

5.3 Application of This Current Research in Real Life

Concrete is the backbone of civil engineering structures utilized under different types of loading together like mechanical and dynamic loadings. Cracks appear due to these loading on the surface as well as the inner portion of concrete. There are several other reasons for cracking like higher water absorption, and higher shrinkage value to decrease the linear strength of concrete in the tension phase. PESPMDP-FRC, which incorporates pine needle fiber and filler such as marble dust and eggshell powder with partial substation of cement can effectively resist small surface cracks in concrete and improve its flexural strength. PESPMDP-FRC4 can be utilized in different concrete structures such as rigid pavement in streets, canal lining, lean concrete and concrete slab, etc. Spalling of concrete is due to exposure of concrete to elevated temperatures. Enhancement of the tensile strength of concrete can reduce spalling, and the combined effect of filler material with pine-needle fiber is used in concrete. The dynamic properties of concrete lead to failure against impact loadings like blasting, of vehicles to the piers of concrete bridges.

The resistance impact loading can be improved by enhancing the dynamic modulus of rigidity and the energy absorption property of the concrete. In this study, the combined effect of pine needle fiber and commercial waste material with a fixed percentage of marble dust and varying percentage of eggshell powder is explored when these materials are used in concrete. The specimen consists of marble dust and eggshell powder with pine-needle fiber-reinforced concrete were showed better performance. The highest compressive strength showed by PESPMDP-FRC4 with 10% eggshell powder. So it can be used in compression members like columns. These columns are either architectural columns or columns for single-story structures where strength capacity is not a big requirement (i.e., the minimum size is fine). The properties of PESPMDP-FRC4 have expressed more improved results as compared with other PESPMDP-FRCs. And PNMDP-FRC Due to these better properties against flexural loading, PESPMDP-FRC4 can be used in slabs and beams. The rigid pavements are designed by keeping in mind the flexural strength and modulus of elasticity of the concrete. PESPMDP-FRC4 is suitable for rigid pavements as it has shown better modulus of rupture and modulus of elasticity which are key factors in the stability and durability of rigid pavements.

5.4 Summary

The optimum percentage of eggshell powder with combinations of pine-needle fiber are determined and recommendations are made from a compressive strength point of view. The recommendation regarding the use of PESPMDP-FRC in real life is made for different structural elements like columns and beams slabs. The combination having superior appropriate properties is recommended for application in rigid pavements.

Chapter 6

Conclusion and Recommendations

6.1 Conclusion

The trend of recycling waste material in the construction industry is increasing day by day to achieve sustainable construction techniques. Burning and damping of commercial waste material exerted serious environmental issues and damage to the ecosystem. There is a need to utilize this waste in an effective manner to minimize environmental problems. It is necessary to find an effective way to utilize this waste material in order to mitigate environmental issues. This study basically concentrates on the effect of pine-needle fiber with the combined effect of filler material and studies the behavior to explore the properties of the material to utilize this waste in concrete. The primary focus of this study is to investigate the impact of pine-needle fiber, along with filler material, on material behavior. The objective is to explore the properties of this waste material and its potential utilization in concrete. A varying percentage of eggshell powder and a fixed percentage of marble dust powder with pine needle fiber have been used in PESPMDP-FRC the workability, dynamic properties, mechanical properties water absorption property, mass loss, and linear shrinkage properties have been considered in this study and the following conclusions have been drawn:

- Values of slump for PMDP, PN-FRC1, PNMDP-FRC2, and PESPMDP-FRC5 are 24%, 59%, 82%, 48%, less than that of PC.PESPMDP-FRC3 and PESPMDP-FRC4 have zero slump Densities of PespMDP-FRCs are condensed than that of PC.

- Compressive strength of PMDP, PESPMDP-FRC4 and PESPMDP-FRC5 have increased than PCC by 18%, 33% and 1.8%and PN-FRC1 PNMDP-FRC2, and PESPMDP-FRC3 hasless than that of PC. Flexural strength of PMC, PNMDP, PESPMDP-FRCs more than that of PC. Flexural strength ofall mixes of PESPMDP-FRCs including PN-FRC1 and PMC mixes are 7%, 16%, 11%, 3.5%, 14.7% and 16% increased from PCC referenced specimen.

- The TE is increased in all specimens of FRC because fibers have ability to produce bridging effect.

- The maximum F-S has been observed with 30 mm long PN-FRC long PESPMDP-FRC. The increment of pine-needle fiber.

- Due to the bridging effect of pine-needle the concrete has avoided the sudden failure and all PNESPMDp-FRCs showed post-crack energy as compared to PC.

- In case of cylinders, PMDP, PN-FRC1, PNMDP-FRC2, and PESPMDP-FRC3, PESPMDP-FRC4, PESPMDP-FRC5 of all 18.56% , 96.4%, 28.47%, 240%, 263%, 119%, mixes damping ratio are more than that of PC. For beam-lets, damping ratio for mixes are 54%, 64%, 75%, 70% , 80% more than that of PC.

- The bonding of pine-needle fiber with the surrounding concrete matrix still exists in destructive samples subjected to mechanical testing which has shown fiber breakage. The bridging effect of fibers is observed in broken samples.

- On the basis of governing properties, PESPMDP-FRC4 is recommended for compressive members. PN-FRC1 is recommended for beams, slabs, rigid pavements and structures prone to dynamic loading due to having improved flexural and dynamic properties.

- PN-FRC performed well under flexure loading.
- SEM has performed to study the internal characteristic of marble dust and eggshell powder with pine-needle fiber reinforced concrete.
- XRD has performed to study in the chemical characteristics of partial replacement of marble dust and eggshell powder with pine-needle fiber reinforced concrete.

  The concrete composed in this research work is the pine-needle fiber of 30mm in length by volume of wet concrete. Marble dust powder has a fixed percentage of 15% by weight of cement and eggshell powder have various percentages such as 5%, 10%, and 15% replacement of cement respectively. So, PN-FRC1 and PESPMDP-FRC4 are recommended for spalling, cracking, and flexural and dynamic loading of concrete. It also has suitable parameters like modulus of elasticity and modulus of rupture so can be used in rigid pavements. Hence, commercial wastes can be utilized in a useful way as sustainable construction material.

6.2 Future Work

The combine effect of filler material with natural fibers with same length of pine-needle fibers have the potential to enhance the dynamic as well as the mechanical propertiesof concrete. The following recommendations should be taken into count for future work to explore the behavior of PESPMDP-FRCs in further detail:

- Experimental work may be carried out by changing the combination with other filler material of or by using two types of admixtures along with combine effect.
- Experimental results may be verified by analytical modeling.
- Consideration of carbon footprint may also be taken into account.

- The Life Cycle Cost Analysis (LCCA) of commercial waste material such as marble dust powder, eggshell powder and Pine-needle fiber reinforced concrete by including the processing and construction should also be done to explore the economic aspect of its utilization as a product.

- In addition, other fibers like coir, glass, and kanaf fiber need to be used with filler materials like eggshell powder and marble dust for potential usage as an alternative building material for civil engineering.

- In parallel for the achievement of sustainable construction other waste materials like fly-ash, and brick dust powder, also need to be effectively utilized in concrete for the application of civil engineering.

Bibliography

[1] V. Singh and V.K Arora. "strength improvement of silt loam using eggshell powder and quarry dust". In *"Recycled Waste Materials: Proceedings of EGRWSE 2018"*, pages 59–68. Springer, 2019.

[2] T. Yong, L.S Kang, L.Y Ling, O.C Fang, and Y.M Kun. "environmental impact and quality assessment of using eggshell powder incorporated in lightweight foamed concrete". *Construction and Building Materials*, Vol, 244:PP, 118–341, 2020.

[3] S. Niyasom and N. Tangboriboon. "development of biomaterial fillers using eggshells, water hyacinth fibers, and banana fibers for green concrete construction". *Construction and Building Materials*, Vol, 283:PP, 122–627, 2021.

[4] W. Long and Y. Wang. "effect of pine needle fibre reinforcement on the mechanical properties of concrete". *Construction and Building Materials*, Vol, 278:PP, 122–333, 2021.

[5] X. Li, D. Qin, Y. Hu, W. Ahmad, A. Ahmad, F. Aslam, and P. Joyklad. "a systematic review of waste materials in cement-based composites for construction applications". *Journal of Building Engineering*, Vol, 45:PP, 103–447, 2022.

[6] D. Yang, J. Zhao, W. Ahmad, M.N. Amin, F. Aslam, K. Khan, and A. Ahmad. "potential use of waste eggshells in cement-based materials: A bibliographic analysis and review of the material properties". *Construction and Building Materials*, Vol, 344:PP, 128–143, 2022.

[7] K Lakshmi Priya and R Ragupathy. ”effect of sugarcane bagasse ash on strength properties of concrete”. *Int. J. Res. Eng. Technol*, 5(4):159–164, 2016.

[8] P Babashamsi, N. Izzi Md Yusoff, H Ceylan, and M. Nor. ”sustainable development factors in pavement life-cycle: highway/airport review”. *Sustainability*, Vol, 8(no, 3):PP, 248, 2016.

[9] M. Khan, M. Cao, C. Xie, and M. Ali. ”effectiveness of hybrid steel-basalt fiber reinforced concrete under compression”. *Case Studies in Construction Materials*, Vol, 16:941, 2022.

[10] M Cao and M Khan. ”effectiveness of multiscale hybrid fiber reinforced cementitious composites under single degree of freedom hydraulic shaking table”. *Structural Concrete*, Vol, 22(1):PP, 535–549, 2021.

[11] J Alex, J Dhanalakshmi, and B Ambedkar. ”experimental investigation on rice husk ash as cement replacement on concrete production”. *Construction and Building Materials*, Vol, 127:PP, 353–362, 2016.

[12] H.J.B Zhou, H Huang, and Y Mou. Experimental study on basic mechanical properties of basalt fiber reinforced concrete. *Materials*, Vol, 13(6):PP, 13–62, 2020.

[13] Gideon O Bamigboye, Odochi Okara, Daniel E Bassey, Kayode J Jolayemi, and David Ajimalofin. The use of senilia senilis seashells as a substitute for coarse aggregate in eco-friendly concrete. *Journal of Building Engineering*, 32:101811, 2020.

[14] W Khaliq and MB Ehsan. Crack healing in concrete using various bio influenced self-healing techniques. *Construction and Building Materials*, 102: PP,349–357, 2016.

[15] 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*, 268:122211, 2020.

[16] W. Long and Y. Wang. "effect of pine needle fibre reinforcement on the mechanical properties of concrete". *Construction and Building Materials*, Vol, 278:PP, 122–333, 2021.

[17] Farhad Aslani and Bijan Samali. High strength polypropylene fibre reinforcement concrete at high temperature. *Fire Technology*, Vol, 50:PP, 1229–1247, 2014.

[18] R Othman, B.W Chong, R.P Jaya, M.R.M Hasan, M.M Abdullah, and M.Z.W Ibrahim. Evaluation on the rheological and mechanical properties of concrete incorporating eggshell with tire powder. *Journal of Materials Research and Technology*, Vol, 14:PP, 439–451, 2021.

[19] M.V Shoubi, A.S Barough, and O Amirsoleimani. Assessment of the roles of various cement replacements in achieving the sustainable and high performance concrete. *International Journal of Advances in Engineering & Technology*, Vol, 6(1):PP, 68, 2013.

[20] T Kim, S Tae, and C Chae. Analysis of environmental impact for concrete using lca by varying the recycling components, the compressive strength and the admixture material mixing. *Sustainability*, Vol, 8(4):PP, 389, 2016.

[21] A Hussain and M.A Kamal. Energy efficient sustainable building materials: An overview. In *Key Engineering Materials*, volume Vol, 650, pages PP, 38–50. Trans Tech Publ, 2015.

[22] N Mohamad, K Muthusamy, R Embong, A Kusbiantoro, and M.H Hashim. Environmental impact of cement production and solutions: A review. *Materials Today: Proceedings*, Vol, 48:PP, 741–746, 2022.

[23] S Hansen and P Sadeghian. Recycled gypsum powder from waste drywalls combined with fly ash for partial cement replacement in concrete. *Journal of Cleaner Production*, Vol, 274:PP, 122–785, 2020.

[24] G Samson, A Phelipot-M, and C Lanos. A review of thermomechanical properties of lightweight concrete. *Magazine of Concrete Research*, Vol, 69 (4):PP, 201–216, 2017.

[25] I Sadrinejad, R Madandoust, and M.M Ranjbar. The mechanical and durability properties of concrete containing hybrid synthetic fibers. *Construction and Building Materials*, Vol, 178:PP, 72–82, 2018.

[26] MZ Naser, RA Hawileh, and JA Abdalla. Fiber-reinforced polymer composites in strengthening reinforced concrete structures: A critical review. *Engineering Structures*, Vol, 198:PP, 109–542, 2019.

[27] W Long and Y Wang. Effect of pine needle fibre reinforcement on the mechanical properties of concrete. *Construction and Building Materials*, Vol, 278:PP, 122–333, 2021.

[28] Y Wang and W Long. Complete stress–strain curves for pine needle fibre reinforced concrete under compression. *Construction and Building Materials*, Vol, 302:PP, 124–134, 2021.

[29] Roberto Merli, Michele Preziosi, Alessia Acampora, M.C Lucchetti, and E Petrucci. Recycled fibers in reinforced concrete: A systematic literature review. *Journal of Cleaner Production*, Vol, 248:PP, 119–207, 2020.

[30] H Hamada, B Tayeh, F Yahaya, K Muthusamy, and A Al-Attar. Effects of nano-palm oil fuel ash and nano-eggshell powder on concrete. *Construction and Building Materials*, Vol, 261:PP, 119–790, 2020.

[31] Guido Silva, Suyeon Kim, Bruno Bertolotti, Javier Nakamatsu, and Rafael Aguilar. Optimization of a reinforced geopolymer composite using natural fibers and construction wastes. *Construction and Building Materials*, Vol, 258:PP, 119–697, 2020.

[32] N Hilal, Doha M Al Saffar, and Taghreed Khaleefa Mohammed Ali. Effect of egg shell ash and strap plastic waste on properties of high strength sustainable self-compacting concrete. *Arabian Journal of Geosciences*, 14:1–11, 2021.

[33] C Signorini, S Marinelli, V Volpini, A Nobili, E Radi, and B Rimini. Performance of concrete reinforced with synthetic fibres obtained from recycling

end-of-life sport pitches. *Journal of Building Engineering*, Vol, 53:PP, 104–522, 2022.

[34] N Makul. Modern sustainable cement and concrete composites: Review of current status, challenges and guidelines. *Sustainable Materials and Technologies*, Vol, 25:PP, e00–155, 2020.

[35] H Hamada, B Tayeh, F Yahaya, K Muthusamy, and Alyaa Al-Attar. Effects of nano-palm oil fuel ash and nano-eggshell powder on concrete. *Construction and Building Materials*, Vol, 261:PP, 119–790, 2020.

[36] Babar A, Erol Y, T.A Raza, Fehmi G, E.M Hechmi, and S Muhammad M Rizvi. The durability of high-strength concrete containing waste tire steel fiber and coal fly ash. *Advances in Materials Science and Engineering*, Vol, 2021:PP, 1–19, 2021.

[37] Majid Ali and Nawawi Chouw. Coir fibre and rope reinforced concrete beams under dynamic loading. In *Annual Australian Earthquake Engineering Society Conference, "Newcastle Earthquake–20 years on*, 2009, PP, 12-24.

[38] Ali A Aliabdo, M Abd Elmoaty, and Esraa M Auda. Re-use of waste marble dust in the production of cement and concrete. *Construction and building materials*, Vol, 50:PP, 28–41, 2014.

[39] B Alsubari, P Shafigh, and M.Z Jumaat. Utilization of high-volume treated palm oil fuel ash to produce sustainable self-compacting concrete. *Journal of cleaner production*, Vol, 137:PP, 982–996, 2016.

[40] G Marras, N Careddu, C Internicola, G Siotto, et al. Recovery and reuse of marble powder by-product. In *Global stone congress*, pages PP, 2–5, 2010.

[41] V Verma and B.M Kumar. Synthesis, microstructure and mechanical properties of al2o3/zro2/ceo2 composites with addition of nickel and titania processed by conventional sintering. *Materials Today: Proceedings*, Vol, 4(2): PP, 3062–3071, 2017.

[42] N Jannat, A Hussien, B Abdullah, and A Cotgrave. Application of agro and non-agro waste materials for unfired earth blocks construction: A review. *Construction and Building Materials*, Vol, 254:PP, 119–346, 2020.

[43] Ahmet Hayrullah Sevinç and Muhammed Yasin Durgun. A novel epoxy-based composite with eggshell, pvc sawdust, wood sawdust and vermiculite: An investigation on radiation absorption and various engineering properties. *Construction and Building Materials*, Vol, 300:PP, 123–985, 2021.

[44] S Hanehara and K Yamada. Interaction between cement and chemical admixture from the point of cement hydration, absorption behaviour of admixture, and paste rheology. *Cement and Concrete Research*, Vol, 29(8):PP, 1159–1165, 1999.

[45] W Long and Y Wang. Effect of pine needle fibre reinforcement on the mechanical properties of concrete. *Construction and Building Materials*, Vol, 278:PP, 122–333, 2021.

[46] M M Kamal and Noha M Soliman. Mechanical properties and microstructural characteristics of concrete made of marble powder as a partial replacement of cement. *ERJ. Engineering Research Journal*, Vol, 45(2):PP, 199–206, 2022.

[47] Ilker Tekin, Osman Gencel, Aliakbar Gholampour, Osman Hulusi Oren, Fuat Koksal, and Togay Ozbakkaloglu. Recycling zeolitic tuff and marble waste in the production of eco-friendly geopolymer concretes. *Journal of Cleaner Production*, Vol, 268:PP, 122–298, 2020.

[48] O Gencel, A Benli, O.Y Bayraktar, and G Kaplan. Effect of waste marble powder and rice husk ash on the microstructural, physico-mechanical and transport properties of foam concretes exposed to high temperatures and freeze–thaw cycles. *Construction and Building Materials*, Vol, 291:PP, 123–374, 2021.

[49] Nadhir Toubal Seghir, Mekki Mellas, Łukasz Sadowski, Aleksandra Krolicka, Andrzej Żak, and Krzysztof Ostrowski. The utilization of waste marble dust

as a cement replacement in air-cured mortar. *Sustainability*, Vol, 11(8):PP, 2215, 2019.

[50] S Ghorbani, S Ghorbani, A Elmi, V Soleimani, I Taji, M Mohammadi-Khatami, M Tavakkolizadeh, and J De Brito. Simultaneous effect of granite waste dust as partial replacement of cement and magnetized water on the properties of concrete exposed to nacl and h2so4 solutions. *Construction and Building Materials*, Vol, 288:PP, 123064, 2021.

[51] S Hansen and P Sadeghian. Recycled gypsum powder from waste drywalls combined with fly ash for partial cement replacement in concrete. *Journal of Cleaner Production*, Vol, 274:PP, 122–785, 2020.

[52] M Amran, S Debbarma, and T Ozbakkaloglu. Fly ash-based eco-friendly geopolymer concrete: A critical review of the long-term durability properties. *Construction and Building Materials*, Vol, 270:PP, 121–857, 2021.

[53] M Ayub, M.H.D Othman, I.U Khan, S.K Hubadillah, T.A Kurniawan, A.F Ismail, M.A Rahman, and J Jaafar. Promoting sustainable cleaner production paradigms in palm oil fuel ash as an eco-friendly cementitious material: a critical analysis. *Journal of Cleaner Production*, Vol, 295:PP, 126296, 2021.

[54] L Li, D Xuan, AO Sojobi, S Liu, SH Chu, and C.S Poon. Development of nano-silica treatment methods to enhance recycled aggregate concrete. *Cement and Concrete Composites*, Vol, 118:PP, 103–963, 2021.

[55] Y Han, R Lin, and X.Y Wang. Sustainable mixtures using waste oyster shell powder and slag instead of cement: Performance and multi-objective optimization design. *Construction and Building Materials*, Vol, 348:PP, 128–642, 2022.

[56] O M Ofuyatan, A.G Adeniyi, D Ijie, J. O Ighalo, and J. Oluwafemi. Development of high-performance self compacting concrete using eggshell powder and blast furnace slag as partial cement replacement. *Construction and Building Materials*, Vol, 256:PP, 119403, 2020.

[57] H.M Hamada, G.A Jokhio, A.A Al-Attar, F.M Yahaya, K Muthusamy, A.M Humada, and Y Gul. The use of palm oil clinker as a sustainable construction material: A review. *Cement and Concrete Composites*, Vol, 106:PP, 103–447, 2020.

[58] FN Costa and DV Ribeiro. Reduction in co2 emissions during production of cement, with partial replacement of traditional raw materials by civil construction waste (ccw). *Journal of Cleaner Production*, Vol, 276:PP, 123–302, 2020.

[59] N Shiferaw, L Habte, T Thenepalli, and J.W Ahn. Effect of eggshell powder on the hydration of cement paste. *Materials*, Vol, 12(15):PP, 24–83, 2019.

[60] B Ali, S.S Raza, I Hussain, and M Iqbal. Influence of different fibers on mechanical and durability performance of concrete with silica fume. *Structural Concrete*, Vol, 22(1):PP, 318–333, 2021.

[61] A.M Alnahhal, U.J Alengaram, S Yusoff, R Singh, M Radwan, and W Deboucha. Synthesis of sustainable lightweight foamed concrete using palm oil fuel ash as a cement replacement material. *Journal of Building Engineering*, Vol, 35:PP, 102–047, 2021.

[62] A K Rana, S Guleria, V.K Gupta, and K Thakur, V. Cellulosic pine needles-based biorefinery for a circular bioeconomy. *Bioresource Technology*, pages PP, 128–255, 2022.

[63] Y Wang and W Long. Complete stress–strain curves for pine needle fibre reinforced concrete under compression. *Construction and Building Materials*, Vol, 302:PP, 124–134, 2021.

[64] H Hamada, B Tayeh, F Yahaya, K Muthusamy, and journal=Construction and Building Materials volume=Vol, 261 pages=PP, 119-790 year=2020 publisher=Elsevier Al-Attar, A. Effects of nano-palm oil fuel ash and nano-eggshell powder on concrete.

[65] P Khongpermgoson, K Boonlao, N Ananthanet, T Thitithananon, W Jaturapitakkul, Cand Tangchirapat, and C.C Ban. The mechanical properties

and heat development behavior of high strength concrete containing high fineness coal bottom ash as a pozzolanic binder. *Construction and Building Materials*, Vol, 253:PP, 119–239, 2020.

[66] Hafsa Jamshaid, Rajesh Kumar Mishra, Ali Raza, Uzair Hussain, Md Lutfor Rahman, Shabnam Nazari, Vijay Chandan, Miroslav Muller, and Rostislav Choteborsky. Natural cellulosic fiber reinforced concrete: influence of fiber type and loading percentage on mechanical and water absorption performance. *Materials*, Vol, 15(3):PP, 874, 2022.

[67] B Kannur and HS Chore. Low-fines self-consolidating concrete using rice husk ash for road pavement: An environment-friendly and sustainable approach. *Construction and Building Materials*, Vol, 365:PP, 130–036, 2023.

[68] G Blasi and M Leone. Inverse analysis-based model for the tensile behaviour of fibre-reinforced concrete with manufactured and waste tyres recovered fibres. *Case Studies in Construction Materials*, Vol, 17:e01297, 2022.

[69] B Ali, A Hawreen, N.B Kahla, M.T Amir, Marc Azab, and Ali Raza. A critical review on the utilization of coir (coconut fiber) in cementitious materials. *Construction and Building Materials*, Vol, 351:PP, 128–957, 2022.

[70] Y Wu, C Xia, L Cai, A.C Garcia, and S.Q Shi. Development of natural fiber-reinforced composite with comparable mechanical properties and reduced energy consumption and environmental impacts for replacing automotive glass-fiber sheet molding compound. *Journal of Cleaner Production*, Vol, 184:PP, 92–100, 2018.

[71] Keith T Sillar, Denis Combes, and John Simmers. Neuromodulation in developing motor microcircuits. *Current Opinion in Neurobiology*, Vol, 29: PP, 73–81, 2014.

[72] M Ali. Use of coconut fibre reinforced concrete and coconut-fibre ropes for seismic-resistant construction. *Materiales de Construcción*, Vol, 66(321):PP, e073–e073, 2016.

[73] B Nepal. *Agricultural Straw Fibre Reinforced Concrete for Potential Industrial Ground-Floor Slab Application.* PhD thesis, University of Liverpool, 2019.

[74] M Singh, A Srivastava, and D Bhunia. Long term strength and durability parameters of hardened concrete on partially replacing cement by dried waste marble powder slurry. *Construction and Building Materials*, Vol, 198:PP, 553–569, 2019.

[75] KM Liew and A Akbar. The recent progress of recycled steel fiber reinforced concrete. *Construction and Building Materials*, Vol, 232:PP, 117–232, 2020.

[76] A.M Moasas, M.N Amin, K Khan, W Ahmad, M.N.A Al-Hashem, A.F Deifalla, and A Ahmad. A worldwide development in the accumulation of waste tires and its utilization in concrete as a sustainable construction material: A review. *Case Studies in Construction Materials*, page e01677, 2022.

[77] K.S.H.S Hazuria, A.K Hashmi, and L.G Patil. Performance based evaluation of reinforced concrete regular structures. *ADBU Journal of Engineering Technology*, Vol, 10, 2021.

[78] C Li and L Jiang. Utilization of limestone powder as an activator for early-age strength improvement of slag concrete. *Construction and Building Materials*, Vol, 253:PP, 119–257, 2020.

[79] D Jiang, X Li, Y Lv, M Zhou, Chenhao He, W Jiang, Z Liu, and C Li. Utilization of limestone powder and fly ash in blended cement: Rheology, strength and hydration characteristics. *Construction and Building Materials*, Vol, 232:PP, 117–228, 2020.

[80] V Rahhal and R Talero. Influence of two different fly ashes on the hydration of portland cements. *Journal of thermal analysis and calorimetry*, Vol, 78 (1):PP, 191–205, 2004.

[81] L Lam, YL Wong, and Chi Sun Poon. Degree of hydration and gel/space ratio of high-volume fly ash/cement systems. *Cement and concrete research*, Vol, 30(5):PP, 747–756, 2000.

[82] S Bae, C Meral, J Oh, J Moon, M Kunz, and P JM Monteiro. Characterization of morphology and hydration products of high-volume fly ash paste by monochromatic scanning x-ray micro-diffraction (μ-sxrd). *Cement and Concrete Research*, Vol, 59:PP, 155–164, 2014.

[83] R Kumar and SK Kumar. Partial replacement of cement with marble dust powder. *International Journal of Engineering Research and Applications*, Vol, 5(8):PP, 106–114, 2015.

[84] N Gurumoorthy. Influence of marble dust as a partial replacement of cement in concrete. *International Journal of Engineering Research and Technology*, Vol, 31(8):PP,31–61, 2014.

[85] U Sharma, N Gupta, and K.K Saxena. Comparative study on the effect of industrial by-products as a replacement of cement in concrete. *Materials Today: Proceedings*, Vol, 44:PP, 45–51, 2021.

[86] B Alsubari, P Shafigh, Z Ibrahim, M.F Alnahhal, and M.Z Jumaat. Properties of eco-friendly self-compacting concrete containing modified treated palm oil fuel ash. *Construction and Building Materials*, Vol, 158:PP, 742–754, 2018.

[87] B.A Tayeh, M.W Hasaniyah, A.M Zeyad, and M.O Yusuf. Properties of concrete containing recycled seashells as cement partial replacement: A review. *Journal of Cleaner Production*, Vol, 237:PP, 117–723, 2019.

[88] H Jamshaid, R.K Mishra, and A and Raza. Natural cellulosic fiber reinforced concrete: influence of fiber type and loading percentage on mechanical and water absorption performance. *Materials*, Vol, 15(3):PP, 874, 2022.

[89] Oğuzhan Keleştemur, Erdinç Arıcı, Servet Yıldız, and Bihter Gökçer. Performance evaluation of cement mortars containing marble dust and glass

fiber exposed to high temperature by using taguchi method. *Construction and Building Materials*, Vol, 60:PP, 17–24, 2014.

[90] A Sharma, M Choudhary, P Agarwal, SK Biswas, and A Patnaik. Effect of micro-sized marble dust on mechanical and thermo-mechanical properties of needle-punched nonwoven jute fiber reinforced polymer composites. *Polymer Composites*, Vol, 42(2):PP, 881–898, 2021.

[91] Harshwardhan Singh Chouhan, Pawan Kalla, Ravindra Nagar, and Pradeep Kumar Gautam. Influence of dimensional stone waste on mechanical and durability properties of mortar: A review. *Construction and Building Materials*, 227:116662, 2019.

[92] Harshwardhan Singh Chouhan, Pawan Kalla, Ravindra Nagar, and Pradeep Kumar Gautam. Gainful utilization of dimensional limestone waste as fine aggregate in cement mortar mixes. *Construction and Building Materials*, 221:363–374, 2019.

[93] Muhammad Nasir Amin, Waqas Ahmad, Kaffayatullah Khan, Mohammed Najeeb Al-Hashem, Ahmed Farouk Deifalla, and Ayaz Ahmad. Testing and modeling methods to experiment the flexural performance of cement mortar modified with eggshell powder. *Case Studies in Construction Materials*, 18:e01759, 2023.

[94] S.K Nayak and A Satapathy. Mechanical and dry sliding wear characterization of marble dust and short kenaf fiber reinforced hybrid polyester composites. *Journal of Natural Fibers*, Vol, 19(14):PP, 9235–9247, 2022.

[95] Ashish Shukla, Nakul Gupta, and Kamal Kishore. Experimental investigation on the effect of steel fiber embedded in marble dust based concrete. *Materials Today: Proceedings*, Vol, 26:PP, 2938–2945, 2020.

[96] S Ghorbani, I Taji, M Tavakkolizadeh, A Davodi, and J De Brito. Improving corrosion resistance of steel rebars in concrete with marble and granite waste dust as partial cement replacement. *Construction and Building Materials*, Vol, 185:PP, 110–119, 2018.

[97] S.C Bostanci. Use of waste marble dust and recycled glass for sustainable concrete production. *Journal of Cleaner Production*, Vol, 251:PP, 119–785, 2020.

[98] K Ganesan, C Kailasanathan, MR Sanjay, P Senthamaraikannan, and SS Saravanakumar. A new assessment on mechanical properties of jute fiber mat with egg shell powder/nanoclay-reinforced polyester matrix composites. *Journal of Natural Fibers*, pages PP, 8–13.

[99] N Sathiparan. Utilization prospects of eggshell powder in sustainable construction material–a review. *Construction and Building Materials*, Vol, 293: PP, 123–465, 2021.

[100] Praveenkumara Jagadeesh, Madhu Puttegowda, Yashas Gowda Thyavihalli Girijappa, Sanjay Mavinkere Rangappa, and Suchart Siengchin. Effect of natural filler materials on fiber reinforced hybrid polymer composites: An overview. *Journal of Natural Fibers*, Vol, 19(11):PP, 4132–4147, 2022.

[101] C Zhang and M Cao. Fiber synergy in multi-scale fiber-reinforced cementitious composites. *Journal of Reinforced Plastics and Composites*, Vol, 33 (9):PP, 862–874, 2014.

[102] C Signorini, A Sola, B Malchiodi, A Nobili, and A Gatto. Failure mechanism of silica coated polypropylene fibres for fibre reinforced concrete (frc). *Construction and Building Materials*, Vol, 236:PP, 117–549, 2020.

[103] M Rafieizonooz, E Khankhaje, and S Rezania. Assessment of environmental and chemical properties of coal ashes including fly ash and bottom ash, and coal ash concrete. *Journal of Building Engineering*, Vol, 49:PP, 104–040, 2022.

[104] M Maalej, Victor C Li, and T Hashida. Effect of fiber rupture on tensile properties of short fiber composites. *Journal of engineering mechanics*, Vol, 121(8):PP, 903–913, 1995.

[105] J Mo, L Zeng, Y Liu, L Ma, C Liu, S Xiang, and G Cheng. Mechanical properties and damping capacity of polypropylene fiber reinforced concrete

modified by rubber powder. *Construction and Building materials*, Vol, 242: PP, 118–111, 2020.

[106] A. Soundhar, K. Jayakrishna, V. Subramani, M. Rajesh, and L. N. Valayapathy. A review on the effect of fabric reinforcement on strength enhancement of natural fiber composites. *Materials*, Vol, 15(9):3025, 2022.

[107] Ashfaque Ahmed Jhatial, Wan Inn Goh, Noridah Mohamad, Samiullah Sohu, and Muhammad Tahir Lakhiar. Utilization of palm oil fuel ash and eggshell powder as partial cement replacement-a review. *Civil Engineering Journal*, 4(8):1977–1984, 2018.

[108] Nadia Razali, Mohd Azri Azizan, Khairul Faizal Pa'ee, Nadlene Razali, and Nurriswin Jumadi. Preliminary studies on calcinated chicken eggshells as fine aggregates replacement in conventional concrete. *Materials Today: Proceedings*, 31:354–359, 2020.

[109] Amarnath Yerramala. Properties of concrete with eggshell powder as cement replacement. *The Indian concrete journal*, 88(10):94–105, 2014.

[110] YH Amran. Mugahed, nima farzadnia, and aa abang ali." properties and applications of foamed concrete; a review.". *Construction and Building Materials*, 101:990–1005, 2015.

[111] H.A Jaber, R.S Mahdi, and A.K Hassan. Influence of eggshell powder on the portland cement mortar properties. *Materials Today: Proceedings*, Vol, 20:PP, 391–396, 2020.

[112] F.M.D.S More and S.S Subramanian. Impact of fibres on the mechanical and durable behaviour of fibre-reinforced concrete. *Buildings*, Vol, 12(9):PP, 14–36, 2022.

[113] A Noushini and A Castel. The effect of heat-curing on transport properties of low-calcium fly ash-based geopolymer concrete. *Construction and Building Materials*, Vol, 112:PP, 464–477, 2016.

[114] Bahar D. The effect of the using waste marble dust as fine sand on the mechanical properties of the concrete. *International journal of the physical sciences*, Vol, 5(9):PP, 1372–1380, 2010.