Development of Green Engineering Cementitious Composite using Marble Dust and Coal Bottom Ash

(Final Year Design Project UG – 2024)

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LIST OF ABBREVIATIONS

CBA	Coal Bottom Ash
CEPs	Complex Engineering Problems
CEAs	Complex Engineering Activities
ECC	Engineering Cementitious Composite
GECC	Green Engineering Cementitious Composite
LD	Limestone Dust
MD	Marble Dust
PLOs	Program Learning Outcomes
SDGs	Sustainability Development Goals
SEM	Scanning Electron Microscopy
UPV	Ultra-sonic Pulse Velocity
UN	The United Nations
WMD	Waste Marble Dust
WGBC	World Green Building Council

Chapter 1

INTRODUCTION

1.1. Background

Concrete has revolutionized the way of constructing buildings and its essence has kept increasing over the years as construction material because it plays a pivotal role in shaping the built environment and infrastructure around us. Its importance lies in providing strength, durability, long life, fire-resistance, and low maintenance qualities to the structure, and withstanding various environmental conditions and loads associated with buildings, bridges, and infrastructure projects. The development of Engineering Cementitious Composite (ECC) further exemplifies the evolution of concrete technology, improving the concrete strength, flexibility, crack resistance, and ductility while minimizing its self-weight. Its unique properties and effective utilization in bridge infrastructures, high-rise buildings, marine structures, energy-efficient buildings, and sustainable structures, especially in seismic-prone regions, have made it a cutting-edge material.

Concrete has a major constituent, Portland Cement, known for its high CO_2 emission and energy-intensive manufacturing process. No doubt, the construction industry is an essential component of societal development, but CO_2 emission by the cement during cement production, and large-scale disposal of Marble Dust (MD) from mining industries and Coal Bottom Ash (CBA) from coal power plants and other furnaces as by-products have contributed significantly to global warming and environmental degradation, which are the worst challenging issues the world is facing these days.

This project aims is to develop Green Engineering Cementitious Composite (GECC) by utilizing waste materials like MD and CBA. It refers to a specific variant or approach of ECC that includes environment-friendly or sustainable constituents into its composition with minimum emission of CO_2, which can pave the way for a more sustainable and eco-friendly construction industry, ultimately leading to a more sustainable and environment-conscious society. By utilizing these waste materials, we not only minimize the burden on landfills but also help to combat climate change, aligning with the principles of green engineering.

Through comprehensive testing and analysis, the project explores the mechanical properties of GECC along with material properties (Physical and chemical) of MD and CBA by incorporating optimum proportions of MD and CBA while minimizing the utilization of cement and evaluating their impact on the mechanical properties like compressive strength, splitting tensile strength, elastic modulus and flexural strength of the resulting composite.

1.2. Problem Statement

The construction industries, especially cement industries, are the major contributors to environmental degradation and global warming effect due to the significant amount of CO_2 emission, energy consumption, and natural resource depletion associated with cement production. Almost 7% of the global CO_2 is emitted by the cement industry which is a huge contribution to world pollution.

Large-scale production of MD as an industrial by-product from the mining industry poses significant environmental challenges as approximately 200 million tons of marble dust is produced annually worldwide (Pappu et al., 2019), which is nothing more than a burden as a landfill and challenges waste management.

Similarly, the production of CBA, a residue from combustion processes, in coal power plants and other furnaces as a by-product also causes environmental issues and necessitates responsible disposal. Almost 730 million tons of coal bottom ash have been produced annually worldwide (Abbas et al., 2020) which is a significant amount. Disposal of such a massive amount of waste product without their utilization result in wasted resources and environmental burden.

This final year design project comprehends these environmental challenges as an opportunity for innovation and proposes the development of GECC that not only provides a sustainable and environment-friendly outlet for the effective utilization of the waste materials, MD and CBA, but also significantly minimizes the environmental impact associated with conventional cement production.

1.3. Aim and Objectives

The project aims to develop GECC using MD and CBA while minimizing the utilization of cement. Therefore, to achieve the aim, the objectives of the project are:

1. To investigate the material properties (physical and chemical) of MD and CBA.

2. To evaluate the mechanical properties of GECC containing MD and CBA.
3. To propose the optimum percentage of MD and CBA in the GECC mixture.

1.4. Scope of the Study

This research study was conducted to develop GECC by incorporating waste materials, MD and CBA, as a replacement for cement. This not only reduces the CO_2 emission during the cement production process and utilizes waste materials like MD and CBA that are environmental burdens but also helps to combat climate change, aligning with the principles of green engineering.

The utilization of cementitious materials and their possible effects during the chemical reaction could be understood comprehensively if material properties, physical and chemical properties, of the cementitious materials are known. Therefore, physical properties like specific gravity, particle size distribution, and fineness modulus while chemical properties like X-Ray Diffraction (XRD) were determined. The mechanical properties like compressive strength, splitting tensile strength, elastic modulus, and flexural strength of the developed GECC were determined. The micro-structural analysis of crushed samples collected after compressive strength was conducted by using Scanning Electron Microscopy (SEM) to examine the effect of MD and CBA on the cementitious composite on a micro-structural level.

From previous research studies, it has been found that up to 15% of the MD and 30% of the CBA can be utilized separately as the partial replacement of cement successfully without compromising on its strength. Therefore, in this research study, cement was partially replaced with CBA at 5%, 10%, 15%, 20%, and 30% respectively by weight of cement along with a combination of MD at 5%, 10%, and 15% collectively by weight of cement.

A total of thirty (30) cubes with dimension of 50 mm x 50 mm x 50 mm were cast to conduct a compressive strength test after 28 days of casting, sixty (60) cylinders with dimension of 75 mm diameter and 150 mm height were cast to find splitting tensile strength (30 cylinders) and elastic modulus (30 cylinders) after 28 days of casting, and thirty (30) prisms with dimensions of 40 mm x 40 mm x 160 mm were cast to determine the flexural strength of the samples after 28 days of casting. Based upon these mechanical tests, the optimum percentage of MD and CBA replaced by cement in the development of GECC was determined.

1.5. Significance

Global warming and environmental degradation are the worst and the most challenging issues the world is facing these days and the dire need for energy-saving, sustainable, and eco-friendly construction materials is increasing promptly with time. The world is looking for sustainable and eco-friendly construction materials to minimize the environmental challenges. Development of GECC has a broader significance and has the potential to provide the world with sustainable and eco-friendly construction material that reduces the usage of conventional concrete and minimizes environmental challenges to a great extent.

The development of GECC not only reduces the emission of CO_2 during cement production and utilizes the waste materials like MD and CBA that are environmental burdens, but also acts as a catalyst for future advancements in sustainable construction materials to protect our environment and enable it worth living while contributing to a greener and more sustainable future. By minimizing the utilization of cement, the project contributes to the reduction of greenhouse gas emissions, combating the climate change concern, and ultimately aligning with the global sustainability agenda.

The incorporation of industrial waste materials like MD and CBA in the development of GECC reduces the demand for raw materials used in the production of cement, contributing to the conservation of natural resources to a great extent. Apart from this, it is not just a project endeavor; it is an innovative and transformative initiative with far-reaching implications for the environment, the economy and the construction industry development if practically acted.

1.6. Sustainable Development Goals

An important and crucial point in our mutual efforts to "advance prosperity while conserving the earth" occurred on January 1st, 2016, when many leaders all over the world adopted the Sustainable Development Goals (SDGs) of the United Nations (WGBC). Buildings' physicality and the construction process provide an opportunity to educate, establish communities, create jobs, reduce carbon emissions, enhance health and wellbeing, and do much more.

As our project, the development of GECC using MD and CBA, meets the 04 SDGs of the United Nations (UN), reflecting its potential to address global challenges and contribute to a more sustainable and eco-friendly future, which are shown in Figure 1.1 and discussed below:

Figure 1.1. United Nation's Sustainable Development Goals (WGBC)

Decent Work and Economic Growth (Goal 8): The development of GECC using waste materials like MD and CBA causes less utilization of steel reinforcement in the structure because of its exceptional tensile strength and ductility, which lessen the cost of construction and ultimately lead to decent work and economic growth.

Industry Innovation and Infrastructure (Goal 9): This goal focuses on the development of resilient infrastructure, the promotion of sustainable industrialization, and the encouragement of innovation to drive economic growth and development. By developing the GECC out of waste resources like MD and CBA, the project promotes innovation in the construction industry by introducing sustainable and eco-friendly alternatives to traditional cement. By converting waste into a useful building material, this innovation lowers the demand for virgin resources while fostering a circular economy.

Sustainable Cities and Communities (Goal 11): Developing GECC supports the construction of a sustainable urban environment that can make healthier, safer, and more resilient human settlements. Through high-quality housing and public/commercial infrastructure, sustainable cities promote harmonious social, environmental, and economic development for all citizens.

Climate Action (Goal 13): Developing GECC in collaboration with individual constructions to achieve clean and energy-efficient cities while also supporting climate action by reducing CO_2 emission during cement production. Sustainable building environments are vital for global climate actions, contributing to decarbonization efforts to remain on track to a 1.5°C warmer future, and functioning as hubs for addressing climate flexibility and adaptations towards unavoidable effects of climate changes.

Chapter 2

LITERATURE REVIEW

MARBLE DUST

Author	Title	Findings
(Shukla et al., 2020)	Development of green concrete using waste marble dust	The study of marble mud powder, as a raw material in concrete to mitigate its adverse environmental impact and enhance environmental efficiency. The marble mud powder acts as a filling agent, effectively filling voids in concrete structures. The study demonstrates that it is possible to achieve 100% replacement of natural sand with marble mud dust in concrete. The research investigates the compressive strength and microstructure of the cement mix. Electron microscopy scanning is employed to detect the hydration products of cement. The strength of the concrete is analyzed based on factors such as curing time, binder composition, and the ratio of vanadium (an element) to aggregate. The results reveal that composite cements exhibit higher strength at 28 days compared to 7 days. The strength of the concrete is positively correlated with the amount of marble dust incorporated; more dust leads to greater strength. Overall, this approach of using marble dust in concrete offers the advantage of reducing natural resource consumption while simultaneously addressing pollution and environmental concerns, making it an environmentally friendly alternative.
(Ashish, 2018)	Feasibility of waste marble powder in concrete as partial substitution of cement and sand amalgam for sustainable growth	The study found that replacing 10% of sand and 10% of cement with 20% marble powder yielded optimal results for both mechanical and durability properties of the concrete. This replacement not only achieved desired performance but also reduced costs since cement is expensive. By replacing cement and sand with marble powder, concrete becomes more economical and sustainable while alleviating waste disposal issues. However, the workability of concrete was slightly reduced due to the large surface area of the waste marble powder. The microstructure investigation showed no significant impact on the hydration process, indicating that marble powder plays a minimal role in this aspect. Overall, the durability parameters improved with the addition of marble powder, making it a suitable additive for concrete. The study cautions against further combinations that may negatively affect the mechanical and durability properties.

(Pal et al., 2016)	Effects of Partial Replacement of Cement with Marble Dust Powder on Properties of Concrete	This research paper focuses on utilizing waste marble dust powder to improve the strength of concrete in a more cost-effective manner. The study used M20 grade concrete and added varying percentages of marble dust powder (0%, 5%, 10%, 15%, 20%, 25%, and 30%) as a partial replacement for cement by weight. The water-cement ratio was kept constant at 0.50 for all concrete mixes. Concrete samples in the form of cubes and cylinders were prepared and tested for compressive strength and split tensile strength after 7 and 28 days of proper curing. The laboratory results indicated that the substitution of cement with marble dust powder led to an increase in both compressive strength and split tensile strength of concrete, with the most significant enhancement observed at a 10% replacement level.
(Arel, 2016)	Recyclability of waste marble in concrete production	Replacing natural sand with marble dust at a ratio of 15% to 75% results in an increase in compressive strength by 20% to 26% and an increase in splitting tensile strength by 10% to 15%. However, the best results are achieved when coarse marble aggregates are used at a 100% replacement ratio. Furthermore, waste marble in coarse aggregate form improves the mechanical properties compared to using it in dust form. When marble powder replaces cement in quantities of 20% or more, it has an adverse effect on the compressive strength and workability of concrete. However, marble dust at a cement-replacement ratio of 5% to 10% not only reduces global annual CO2 emissions by 12% but also lowers costs from US$40/m3 to US$33/m3.
(Kumar & Kumar, 2015)	Partial replacement of cement with marble dust powder	The effects were observed at 0%, 5%, 10%, 15%, and 20% of MDP by weight of cement replaced and keeping water-cement ratio at 0.43 for all mixtures. After observing conducting tests on 7 and 28 days, the compressive strength, indirect tensile strength and flexural strength were increased by 10%, 15%, and 15% respectively.
(Aliabdo et al., 2014)	Re-use of waste marble dust in the production of cement and concrete	The primary objective of this research is to explore the feasibility of utilizing waste marble dust, which is generated during the cutting and polishing process in marble factories, to be recycled in cement and concrete production. The study focuses on examining the physical and mechanical properties of paste, mortar, and concrete, all of which are modified with marble dust-infused cement. Additionally, the research investigates the impact of marble dust inclusion on the internal microstructure and hydration products of paste samples. To conduct the study, test specimens were created by mixing varying percentages of marble dust with cement and sand at replacement ratios of 0.0%, 5.0%, 7.5%, 10.0%, and 15.0%, all measured by weight.
(Vaidevi, 2013)	Study on marble dust as partial	The marble passing from 0.25 mm sieve and 2.3 specific gravity were used. The concrete mixtures were prepared by replacing 5%, 10%, 15%, and 20% of cement with marble dust by using water-

	replacement of cement in concrete	cement 0.47. Test outcomes show that the best results were obtained at 10% of marble dust in concrete. In addition, an increase in curing time will make marble dust concrete stronger than it was after 14 days until 28 days. For every 10 bags of cement, the addition of 10% of marble dust saves 1 bag of cement and 1 bag cost.
(Demirel, 2010)	The effect of the using waste marble dust as fine sand on the mechanical properties of the concrete.	This experimental study investigated the influence of waste marble dust (WMD) as a fine material on the mechanical properties of concrete. Four series of concrete mixtures were prepared, where the fine sand was replaced with WMD at proportions of 0%, 25%, 50%, and 100% by weight. The results showed that incorporating WMD, which replaced fine material passing through a 0.25 mm sieve at specific proportions results were observed that at 3,7,28,90 days the compressive strength, unit weight, modulus of elasticity and ultra sonic pulse velocity (UPV) Increases while the porosity is decreased which gives positive impact.
(Binici et al., 2007)	Influence of marble and limestone dusts as additives on some mechanical properties of concrete	The study involved producing seven concrete mixtures in three series, with control mixes containing 400 kg of cement. Modifications were made by replacing fine sand aggregate with 5%, 10%, and 15% of Marble Dust (MD) and Limestone Dust (LD). Compressive strength tests were conducted at 7, 28, 90, and 360 days, while sodium sulphate resistance was evaluated over 12 months. Additionally, the concretes were tested for abrasion resistance and water penetration. Abrasion resistance of MD concrete with 5, 10 and 15 % fine sand replacement was lower than the LD and control concrete. Generally, abrasion resistance increases as the rate of MD and LD was increased. Measurement of water penetration depths . MD 15% specimens were considerably more resistant to water ingress than those of other specimens. As the MD concretes had higher compressive strength than that of the corresponding LD and control concrete with equivalent w/c and mix proportion, the results indicate that the MD concrete would probably have lower water permeability than the LD and control concrete.

COAL BOTTOM ASH

Author	Title	Findings
(Ghadzali et al., 2020)	Material Characterization and Optimum Usage of Coal Bottom Ash (CBA) as Sand Replacement in Concrete	The main objective of this study is to examine the properties of concrete that includes Coal Bottom Ash (CBA) as a replacement material for sand. The Coal Bottom Ash used in this research is obtained from coal-based power plants. The study revealed that Coal Bottom Ash (CBA) exhibits physical properties similar to sand. It was found that the best replacement percentage of CBA with sand is 10%, which achieved the desired strength in the concrete. Overall, CBA has promising potential as a replacement material for sand. However, as the percentage of CBA in the concrete increased, the workability of CBA concrete decreased because of its porous surface, which absorbed more water during mixing. The compressive strength of the concrete increased with curing age due to the pozzolanic reaction, which was more effective at later stages of curing. Nevertheless, the compressive strength of the concrete decreased as the percentage of CBA increased. The highest compressive strength of 58.3 MPa was achieved with 10% sand replacement with CBA, while the lowest strength of 38.2 MPa was obtained with 50% sand replacement with CBA at 56 days. Therefore, the optimal amount of CBA as a partial replacement for sand was determined to be 10% as it reached the desired strength. Similar to compressive strength, the splitting tensile strength decreased with an increase in the percentage of CBA in the concrete. The highest tensile strength was obtained with 10% sand replacement with CBA. Overall, 10% CBA replacement for sand showed improved strength compared to the control concrete. The study suggests further investigation on the flexural and elasticity strength of concrete containing CBA as a sand replacement material.
(Mangi et al., 2019)	Recycling of Coal Ash in Concrete as a Partial Cementitious Resource	The aim of the study was to recycle CBA in concrete and explore its effect on strength properties like workability, compressive strength and tensile strength of concrete. 120 specimens were prepared in which sand is replaced with CBA with percentage limit of 0 to 30 %. Results show that workability was decreased when the amount of CBA increased. Using ground CBA (a cement replacement

		material) in concrete did not lead to significant early-age strength growth. However, after 28 days, the concrete with 10% ground CBA reached a compressive strength of 35 MPa, while the regular concrete took longer to reach 44.5 MPa. This delay indicates that the pozzolanic reaction (a process that enhances strength) didn't start until after 28 days. In the study, they tested three different proportions (10%, 20%, and 30%) of ground CBA to replace cement. They evaluated the concrete's strength at 7 and 28 days of curing to find the best combination for optimal strength performance.
(Mangi et al., 2018)	Influence of Ground Coal Bottom Ash on the Properties of Concrete	The aim of this study is to use ground Coal Bottom Ash (CBA) as an additional cementing material in concrete. The original CBA was dried and ground for 20 hours to achieve the required fineness. Concrete mixtures were prepared with CBA proportions of 10%, 20%, and 30% by weight of cement. The researchers cast 48 concrete specimens to evaluate density, water absorption, compressive strength, and tensile strength. The workability of fresh concrete mix decreased as the quantity of CBA in the mixture increased. However, when 10% of CBA was used as a replacement, the concrete still attained the desired compressive strength at 28 days. It was observed that the addition of ground CBA had a noticeable impact on the density and water absorption of the concrete. The density of the concrete gradually decreased with the addition of ground CBA, and the concrete containing 10% ground CBA showed similar density to the control mix. Conversely, water absorption showed the opposite trend.
(Maliki et al., 2017)	Compressive and tensile strength for concrete containing coal bottom ash	This study aimed to determine the properties of CBA and to find the optimum percentage of CBA to be used in concrete as a replacement of sand. The researchers conducted mechanical tests (compressive and tensile strength tests) on CBA concrete. They made cubic and cylindrical specimens of different sizes, varying the percentage of CBA from 0% to 100% to replace the fine aggregates. The CBA concrete samples were cured for 7 days and 28 days to maintain proper hydration and moisture levels. After completing the experiments, they found that the best percentage of CBA as a fine aggregate was 60% for both 7 days and 28 days of curing. At this percentage, the total compressive strength was 36.4 MPa and 46.2 MPa, respectively. However, for the best tensile strength, the optimal percentage was 70% CBA for both 7 days and 28 days

		of curing, with tensile strengths of 3.03 MPa and 3.63 MPa, respectively.
(Kumar et al., 2016)	An experimental study on the partial replacement of fine aggregate with coal bottom ash in concrete.	The primary goals of this research were to examine how using coal bottom ash as a replacement for sand in concrete affects its properties. To determine the best percentage of coal bottom ash to be used as a substitute for sand in cement. And to evaluate the mechanical properties of concrete like compressive strength and tensile strength. Concrete achieves its highest Compressive Strength at 20% replacement, with values of 21.25 N/mm^2 and 33.21 N/mm^2 at 7 days and 28 days, respectively. However, as the percentage of replacement increases beyond 20%, the strength of the concrete decreases. The Split Tensile Strength of concrete reaches its peak at 20% replacement, with values of 3.10 N/mm^2 and 3.93 N/mm^2 at 7 days and 28 days, respectively. Nevertheless, with further increase in the percentage of replacement, there is a decline in the strength of the concrete.
(Nadig et al., 2015)	Bottom Ash as Partial Sand Replacement in Concrete- A Review	In this study, the researchers investigate the properties of Concrete that includes Bottom Ash as a partial replacement for fine aggregates. The main emphasis is on examining the mechanical properties of the concrete, such as Compressive strength, splitting tensile strength, and flexural strength. Concrete with bottom ash replacing sand will have lower compressive strength than normal concrete at all ages. The splitting tensile strength of this concrete will also be lower compared to normal concrete throughout its development. Furthermore, when using bottom ash to replace fine aggregate, the flexural strength of the concrete will be less than that of regular concrete at all ages. However, if sand is substituted with bottom ash in the 30% to 50% range, the concrete's compressive strength and flexural strength will be higher at 90 days compared to conventional concrete's strength at 28 days.
(Kumar et al., 2014)	Uses of Bottom ash in the Replacement of fine aggregate for Making Concrete	In this research paper, the author investigated the compressive strength and flexural strength of concrete at different ages: 7 days, 14 days, 28 days, and 56 days. They replaced fine aggregate with varying percentages of Bottom Ash (10%, 20%, 30%, 40%, and 50%). Based on the investigation, it was observed that the maximum compressive strength of the concrete was achieved at 40% replacement of bottom ash, with values of 32.14 N/mm^2, 34.85 N/mm^2, 36.20 N/mm^2, and 39.16 N/mm^2 at 7 days, 14 days, 28 days, and 56 days, respectively. On the other hand, the minimum compressive strength was found to be 23.56 N/mm^2, 28.18 N/mm^2, 30.40 N/mm^2, and 32.87 N/mm^2 at 7 days, 14 days, 28 days, and 56 days, respectively, when no

		bottom ash was replaced in the concrete. Notably, after 40% replacement of bottom ash in the concrete, the compressive strength decreased. Similarly, the maximum flexural strength of the concrete was observed at 40% replacement of bottom ash, with values of 7.94 N/mm^2, 8.80 N/mm^2, 9.04 N/mm^2, and 9.24 N/mm^2 at 7 days, 14 days, 28 days, and 56 days, respectively. Conversely, the minimum flexural strength was found to be 2.20 N/mm^2, 3.10 N/mm^2, 3.40 N/mm^2, and 4.27 N/mm^2 at 7 days, 14 days, 28 days, and 56 days, respectively, when no bottom ash was replaced in the concrete. After 40% replacement of bottom ash in the concrete, the flexural strength also decreased.
(Remya Raju & Aboobacker, 2014)	Strength performance of concrete using bottom as a fine aggregate	The primary objectives of this study were to examine how the incorporation of coal bottom ash as a partial replacement for fine aggregates, in various percentages ranging from 0% to 30%, affects different properties of concrete. The properties under investigation included compressive strength, splitting tensile strength, flexural strength, and modulus of elasticity. The research findings indicated that when using coal bottom ash as a replacement for fine aggregates in concrete the compressive strength of the bottom ash concrete was found to increase at the 28-day curing age compared to the control concrete (concrete without bottom ash). After 7 days of curing, the concrete mixtures incorporating 5%, 10%, 15%, and 20% bottom ash as fine aggregate achieved compressive strength gains equivalent to 67.46%, 67.73%, 68.17%, and 71.6% of their 28 days compressive strength, respectively. In comparison, the control concrete mixtures attained 72% of their 28 days compressive strength after the same curing period. Moreover, the splitting tensile strength of the concrete improved when incorporating certain percentages of bottom ash . After 28 days of curing, the bottom ash concrete mixtures containing 5%, 10%, 15%, 20%, and 25% bottom ash as fine aggregate exhibited splitting tensile strength values that were 14.28%, 12.11%, 10.8%, 11.48%, and 6.21% higher, respectively, compared to the splitting tensile strength of the control concrete mixture On the other hand, the modulus of elasticity showed a decrease with the use of coal bottom ash at all replacement levels.
(Kadam & Patil, 2013)	Effect of coal bottom ash as sand replacement on the properties of	The study examined the effects of using coal bottom ash as a substitute for sand in fine aggregates. They investigated various properties such as compressive strength, split tensile strength, flexural strength, Modulus of Elasticity, Density, and water permeability. The replacement levels of coal bottom ash

	concrete with different w/c ratio	ranged from 0% to 100% by weight. The results revealed that as the percentage of coal bottom ash increased, the compressive strength, split tensile strength, and flexural strength decreased in comparison to the conventional concrete mix (controlled concrete). However, it was observed that up to a 30% replacement level of sand with coal bottom ash, the compressive, flexural, split tensile strengths, and water permeability were similar to those of the controlled concrete. The compressive strength showed an initial increase of up to 20% replacement of natural sand with coal bottom ash at 7, 28, 56, and 112 days. However, beyond the 20% replacement level, the compressive strength started to decrease for all.

Chapter 3

RESEARCH METHODOLOGY

3.1. Introduction

The development of Green Engineering Cementitious Composite (ECC) using marble dust and coal bottom ash demands a thorough and comprehensive research methodology to ensure the success of this innovative research. This chapter describes the methodological techniques that directs our research from the initial stage of material characterization to the final stage of mix design proportion and the evaluation of the mechanical performance of the developed Green ECC. It also states the estimation of the green engineering cementitious composite materials, optimum amount of marble dust and coal bottom ash for cement replacement, mix design procedure and the laboratory test carried out to acquire data and result for the research. The laboratory test were conducted to evaluate the Material properties, physical and chemical properties, and mechanical performance of the developed green engineering cementitious composite using marble dust and coal bottom ash. Physical properties includes specific gravity, particle size distribution and fineness modulus of the materials, while chemical properties includes X-Ray Diffraction (XRD) of the materials like MD and CBA to analyze the crystal structure of the materials. Mechanical properties in terms of compressive strength, splitting tensile strength, elastic modulus and flexural strength were determined. The micro-structural analysis of crushed sample collected after compressive strength was conducted by using Scanning Electron Microscopy (SEM) to examine the effect of MD and CBA on the cementitious composite on a micro-structural level. Figure 3.1 illustrates the research framework of the experimental work.

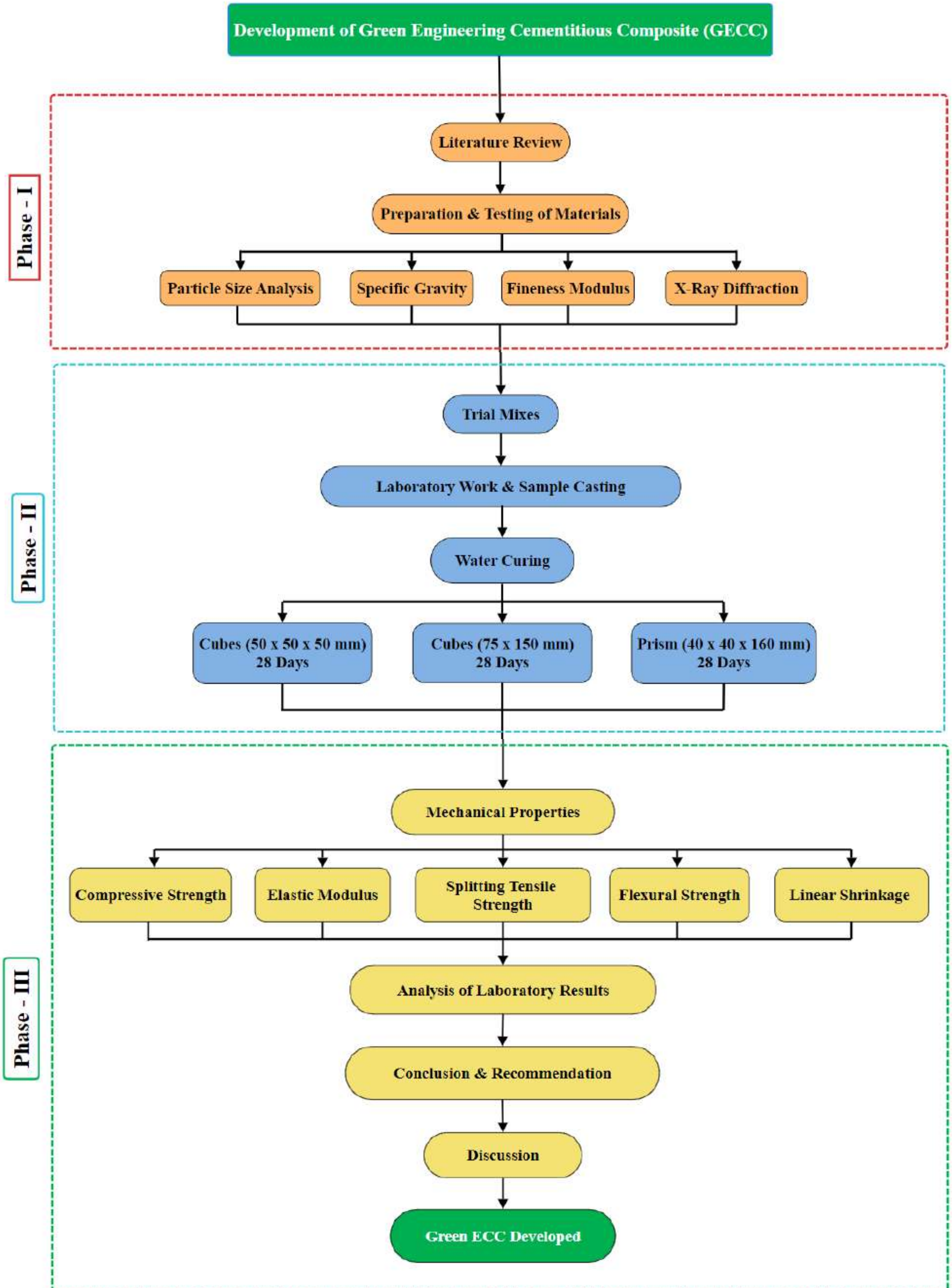


Figure 3.1. Flow Chart illustrates the Research Framework

3.2. Material Preparation

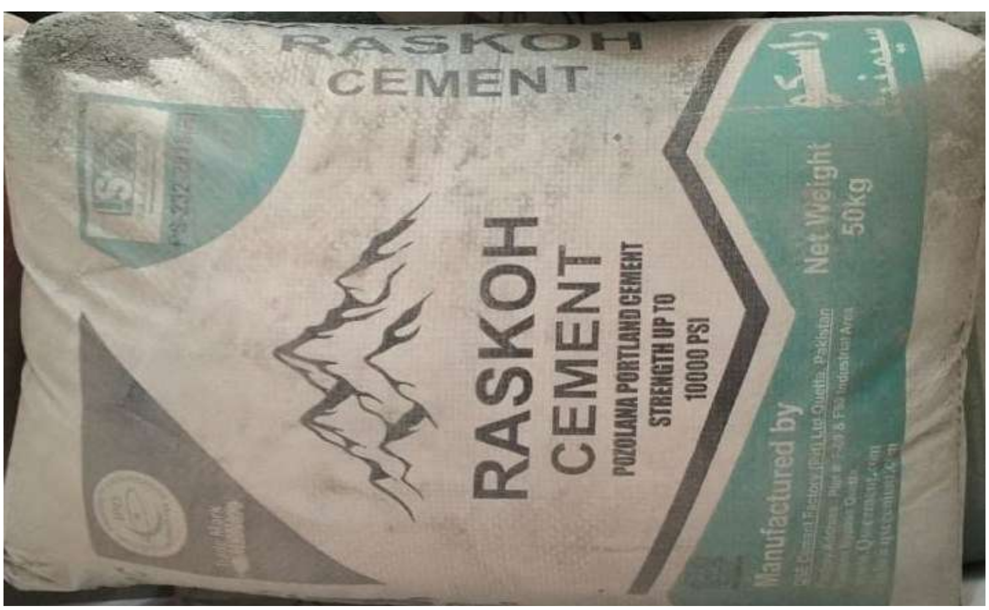
The materials used in the project to develop Green Engineering Cementitious Composite (ECC) is the following:

1. Portland Pozzolana Cement (PPC)
2. Marble Dust (MD)
3. Coal Bottom Ash (CBA)
4. Hardwaste Fiber
5. Sand
6. Water

Each material is discussed in detail below:

3.2.1. Portland Pozzolana Cement (PPC)

PPC is the most crucial constituent of concrete because of its properties of binding, gulling all the other constituents together to form a cementitious composite. There are several types of cement manufactured now a days, ranging from rapid hardening cement to low heat of hydration cement. For this project, we used PPC as it has significantly lower heat of hydration and contained the reactive alumina and silica so that it may react with calcium hydroxide present in by products, coal bottom ash and marble dust, in the presence of water to develop Green ECC. To develop Green ECC, Raskoh Cement was utilized, provided by the Structural Laboratory of National University of Sciences & Technology (NUST) Islamabad, Quetta Campus.



3.2.2. Marble Dust (MD)

Marble, a colorless or light-colored material, is a metamorphic rock composed of calcite or dolomite and a major source of calcium carbonate. Marble dust, a waste material obtained as a result of cutting of marble in the factory, has been used in this project along with coal bottom ash as a partial replacement of cement because of its major composition of calcium carbonate that can react with the alkali present in the cement to form additional binding phase, and pozzolanic properties that enable it to react with calcium hydroxide (a by-product of cement hydration) to form cementitious compound, ultimately contributing to the mechanical properties like strength and durability of the Green ECC. Moreover, it has fine particle size which can enhance the density and fill voids in the mixture. For this project, we obtained marble dust from a marble cutting factory located in Quetta city.

3.2.3. Coal Bottom Ash (CBA)

Coal bottom ash, a by-product and waste material obtained as a result of coal combustion process in the coal power plants or other furnaces, has been used along with marble dust as a partial replacement in the development of green engineering cementitious composite because it contains amorphous silica and alumina content in its composition, which can contribute to the formation of pozzolanic compounds when combine with calcium hydroxide, resulting in improved mechanical properties like strength and durability of developed Green ECC. Further, due to its fine particle size, it reduces porosity, ultimately filling gaps and increasing density of the mixture. For our project, we collected coal bottom ash from one of its suppliers from Karachi city.

3.2.4. Hardwaste Fiber

Hardwaste synthetic fiber is used in this project because of its properties of high tensile strength and flexibility. For our project, we obtained hardwaste fiber from the Structural Laboratory of National University of Sciences & Technology (NUST) Islamabad, Quetta Campus.

3.2.5. Sand

Sand, a fine aggregate, has been used in this project as a constituent to develop Green ECC because it helps to increase the bulk of mortar, prevents shrinkage, increases overall surface area, and contributes to the overall strength of concrete. Sand used in this project was obtained from the Structural Laboratory of National University of Sciences & Technology (NUST) Islamabad, Quetta Campus.

3.2.6. Water

The water-to-cement ratio is very critical, as optimal ratio ensures proper hydration and strength development, while excess water can diminish strength and durability. Typically, the value between 0.4-0.6 of water cement ratio is used. For our project, we took the lowest limit of typical value of water to binder ratio equal to 0.40 as lower water-to-binder ratio is responsible for higher strength.

3.3. Physical and Chemical Properties of Raw Materials

For the effective utilization of the materials used in the development of Green ECC, laboratory tests were conducted to determine the following physical and chemical properties of the materials:

3.3.1. Particle Size Distribution

Gradation test refers to the distribution of the particle sizes present in an aggregate (ACI), is essential for material characterization being used in the concrete mix design as it helps to ensure that the composite has the desired physical properties and performance characteristics. The gradation test is performed in accordance with ASTM C136. A sample of the aggregate is shaken through a series of sieves with square openings, nested one above the other in order of size, with the sieve having the largest openings on the top, the one having the smallest openings at the bottom, and a pan below it to collect the material passing the finest sieve.

For this project, materials used in the development of Green ECC is fine, and gradation test of fine aggregates was performed for materials like sand, marble dust and coal bottom ash. A group of sieves ranging from 3/8-inch sieve having largest openings placed on the top and 75 µm (No. 200) sieve having smallest openings at the bottom along a pan below it was used to perform the test. The set of sieves were shaken in the sieve shaker instead of shaking it manually by hands to enhance the accuracy of the result. This test was conducted in the Geotechnical Engineering Laboratory of National University of Sciences & Technology (NUST) Islamabad, Quetta Campus.

3.3.2. Fineness Modulus (FM)

The fineness modulus is defined as the sum of the total percentages coarser than each of a specified series of sieves, divided by 100 (ACI). The coarser the aggregate the higher the FM (ACI). The fineness modulus is performed in accordance with the ASTM C33. For fine aggregate used in concrete, the FM generally ranges from 2.3 to 3.1 (ACI).

Fineness modulus of sand, marble dust and coal bottom ash were determined in the Geotechnical Engineering Laboratory of National University of Sciences & Technology (NUST) Islamabad, Quetta Campus.

3.3.3. Specific Gravity

Specific gravity, also known as relative density, of an aggregate is defined as the mass of the aggregate in air divided by the mass of an equal volume of water (ACI). Every material in the world must has some value of the specific gravity ranging from 0.1 to 100. Water has a specific gravity of 1. Similarly, the normal range of specific gravity of the cement is between 3.1 to 3.2 but normally a typical value of 3.15 is used for the mix design. It may differ if the cement has been exposed to the extreme weather conditions. Test method for finding specific gravity of the fine aggregate is described in ASTM C128. The specific gravity can be determined using the Le Chatliers flask, density bottle or pycnometer.

The specific gravity of the raw materials, marble dust, coal bottom ash and sand was determined by using the pycnometer in the Geotechnical Engineering Laboratory of National University of Sciences & Technology (NUST) Islamabad, Quetta Campus. Specific gravity test process of MD and sand are shown in Figure 3.2 and Figure 3.3.

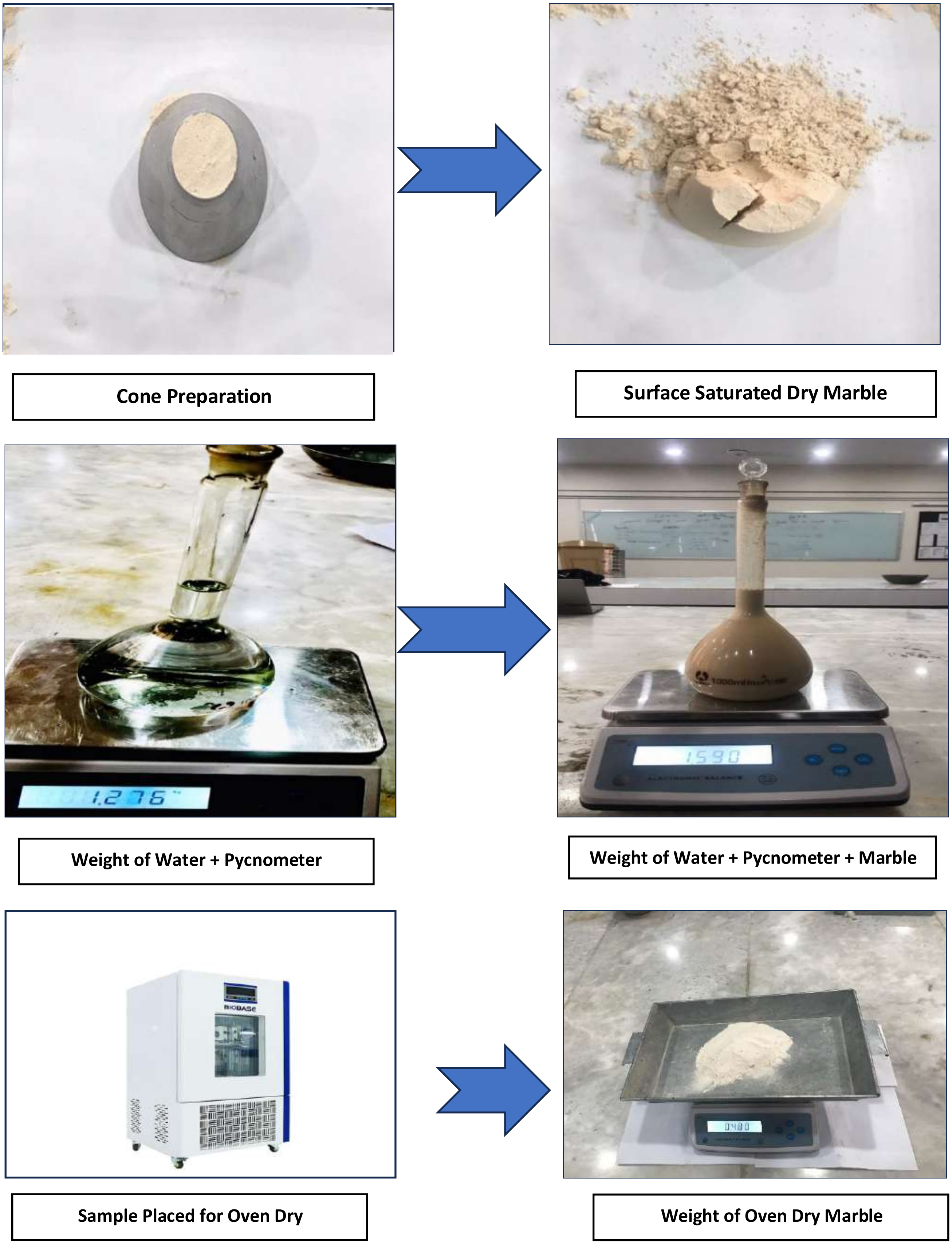


Figure 3.1 Specific Gravity Process of Marble Dust

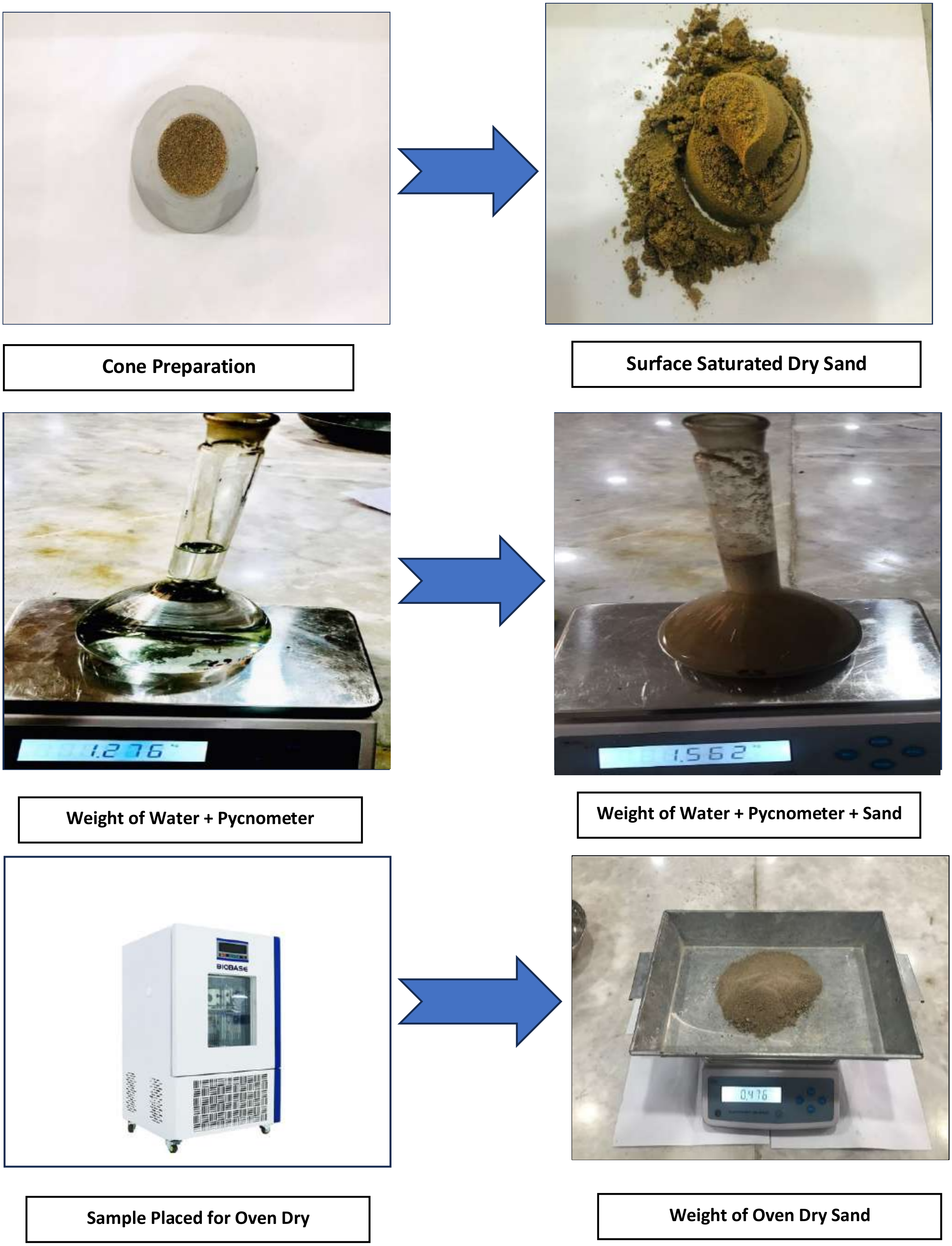


Figure 3.1 Specific Gravity Process of Sand

3.3.4. X-Ray Fluorescence (XRF)

X-Ray Fluorescence (XRF) test is a non-destructive test used to analyze the chemical composition of the samples. XRF test is performed in accordance with ASTM C114-115. It is used to evaluate the chemical content of a sample by measuring the fluorescent X-Ray being emitted by the sample when it is excited by a primary X-Ray source. Unique fingerprints of each constituent present within the samples are produced and because of this uniqueness XRF Spectroscopy is considered as one of the excellent technologies for evaluating the qualitative as well as quantitative analysis of any material composition.

The chemical analysis of waste materials, marble dust and coal bottom ash, will be done by using X-Ray Fluorescence (XRF) available in Geotechnical Engineering Laboratory of National University of Sciences & Technology (NUST) Islamabad, H-12 Campus.

3.3.5. X-Ray Diffraction (XRD)

X-Ray Diffraction (XRD) test is a non-destructive analytical technique used to analyze the crystal structure of material by measuring the diffraction pattern of the X-rays that interact with the atoms in the material. It provides information about the arrangements of atoms in the material, including the identification of the crystal phases, crystallite size and the crystallographic orientation. XRD test is conducted using an X-Ray Diffractometer consisting of an X-ray source, a sample holder and a detector.

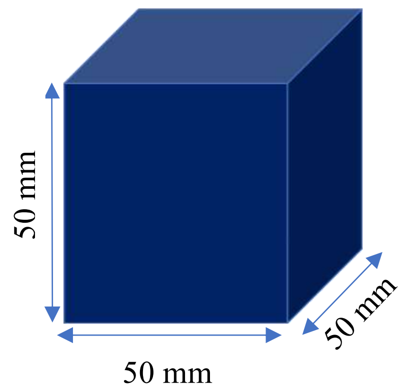
The crystallographic structure analysis of the waste materials, marble dust and coal bottom ash, will be done by using X-Ray Diffractometer available in Geotechnical Engineering Laboratory of National University of Sciences & Technology (NUST) Islamabad, H-12 Campus.

3.4. Specimen Sizes

Specimen used for casting the samples were cubes, cylinders and prism. There specifications are discussed below in detail:

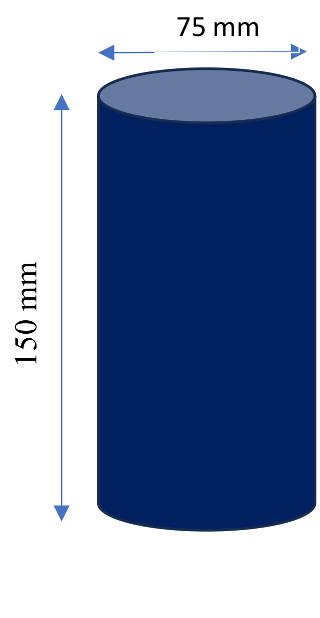
3.4.1. Cube

For this research study, three cubes of 50 mm x 50 mm x 50 mm dimensions were cast to determine the compressive strength of each mix proportion after 28 days of casting the samples. Total dry volume of developing Green ECC for cubes of each mix proportion required was 0.000375 m^3. Dimensions of cube are shown below in the figure:



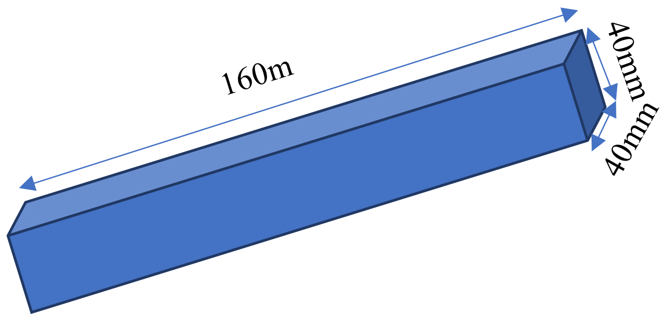
3.4.2. Cylinder

For this research study, six cylinders of 75 mm diameter and 150 mm height were casted for each mix proportion of developing Green ECC, three cylinders for determining the splitting tensile strength and three samples for determining the modulus of elasticity of each mix proportion after 28 days of casting. Total dry volume of developing Green ECC for cylinders of each mix proportion required was 0.003976 m^3. Dimensions of cylinder are shown below in the figure:



3.4.3. Prism

For this research study, three prisms of 40 mm x 40 mm x 160 mm dimensions were casted to determine the flexural strength of each mix proportion of developing Green ECC after 28 days of casting the samples. Total dry volume of developing Green ECC for prisms of each mix proportion required was 0.000768 m^3. Dimensions of prism are shown below in the figure:



3.5. Development of Green Engineering Cementitious Composite (ECC)

From the previous research studies, it has been found that up to 15% of the Marble Dust (MD) and 30% of the Coal Bottom Ash (CBA) can be utilized separately as the partial replacement of cement successfully without compromising on its strength. Therefore, in this research study, cement is partially replaced with CBA at 5%, 10%, 15%, 20% and 30% respectively by weight of cement along with combination of MD at 5%, 10% and 15% collectively by weight of cement. The summary of the materials and number of samples required is tabulated in Table.3.1, and the summary of the mix-design proportions of MD and CBA replacing cement in the development of Green ECC are tabulated in Table 3.2.

Water-Binder (w/b) Ratio	0.4
Binder-Sand Ratio	1:1
Total Cubes Samples Required Per Mix-Design Ratio	3
Total Cylinder Samples Required Per Mix-Design Ratio	6
Total Prisms Samples Required Per Mix-Design Ratio	3

Table 3.1 Materials and Number of Samples Required Per Mix-Design Ratio

Mix Design Proportions for the Development of Green ECC						
Mix Number	**Mix Name**	**Cement Replacement**		**Cement (%)**	**Sand (%)**	**Hardwaste Fiber (% by Volume of Cement)**
		MD (%)	**CBA (%)**			
01	Control	0	0	100	100	2
02	10MD + 10CBA	10	10	80	100	2
03	15MD +10CBA	15	10	75	100	2
04	10MD + 15CBA	10	15	75	100	2
05	15MD + 15CBA	15	15	70	100	2
06	10MD + 20CBA	10	20	70	100	2
07	15MD + 20CBA	15	20	65	100	2
08	5MD + 30CBA	5	30	35	100	2
09	10MD + 30CBA	10	30	60	100	2
10	15MD + 30CBA	15	30	55	100	2

Table 3.2 Mix Design Proportions for the Development of Green ECC

3.5.1. Calculation of Materials

For this research study, Green ECC was developed in 1:1 ratio (one part is binder and the other part is sand), while the w/b (water-to-binder) ratio was kept constant at 0.40 irrespective of waste material, MD and CBA, content in the composition. Wastage loss of 20% was included in each mix-design proportion during the manufacturing process of the development of Green ECC. All materials were measured in term of wet volume by multiplying the dry volume by 1.54 factors. Total materials required for the development of each mix design proportion mentioned in Table 3.1 to produce 1 m^3 cementitious composite by wet volume is tabulated in Table 3.3.

Development of Green ECC (Quantity Required for 1 m^3 wet volume)							
Mix Number	**Mix Name**	**Cement Replacement**		**Cement (Kg/m^3)**	**Sand (Kg/m^3)**	**Hardwaste Fiber (Liter)**	**Water (Kg/m^3)**
		MD (Kg/m^3)	**CBA (Kg/m^3)**				
01	Control	0	0	735	750	8.33	300

02	10MD + 10CBA	75	75	585	750	8.33	300
03	15MD +10CBA	112.5	75	547.5	750	8.33	300
04	10MD + 15CBA	75	112.5	547.5	750	8.33	300
05	15MD + 15CBA	112.5	112.5	510	750	8.33	300
06	10MD + 20CBA	75	150	510	750	8.33	300
07	15MD + 20CBA	112.5	150	472.5	750	8.33	300
08	5MD + 30CBA	37.5	225	472.5	750	8.33	300
09	10MD + 30CBA	75	225	435	750	8.33	300
10	15MD + 30CBA	112.5	225	397.5	750	8.33	300

Table 3.3 Quantities Required to Develop 1 m^3 of Green ECC

3.5.2. Mixing Procedure

Cement, sand (passed from sieve No. 40), marble dust and coal bottom ash were weighed and poured into the concrete mixer in dry condition and kept mixing together until the mixture became uniform. After uniform dry mixing of materials, the measured water was poured into the dry mix. The concrete mixer was allowed to mix for some time such that the wet uniform mix is formed. After that the calculated amount of the hardwaste fiber, segregated into small pieces of up to 10mm, were added slowly and kept on mixing. Finally, the prepared mix was poured into the moulds and then kept in open air to dry for next 24 hours.

3.5.3. Water Curing

After 24 hours, the samples were extracted from the moulds, weighed and kept in water curing tank for 28 days so that the samples may reach their maximum strength.

Curing process is an essential stage for concrete as the hydration process takes place and it gains maximum strength. Concrete gains 99% of its strength in 28 days of curing and keeps on gaining strength in the future.

3.6. Mechanical Properties of Developed Green ECC

Following test of the samples were conducted after 28 days to determine the mechanical properties of developed Green Engineering Cementitious Composite (ECC):

3.6.1. Compressive Strength

Compressive strength test or compression test, can be destructive or non-destructive test, is a measure of the ability of a material to withstand axial loads (pulling or pushing) without deformation. This test is performed in accordance with ASTM C39. It is one of the most critical mechanical properties of the cementitious composite, determined by subjecting the specimen to a compressive force in Universal Tensile Machine (UTM) until the failure occur. The resulting load at failure is then used to compute compressive strength values, used as design criteria to ensure the safety and stability of structures.

To perform the compressive strength test of the developed Green ECC, the cube samples of dimensions 50 mm x 50 mm x 50 mm will be tested for the compressive strength after 28 days of water curing in the UTM available in the Structural Laboratory of National University of Sciences & Technology (NUST) Islamabad, Quetta Campus.

3.6.2. Splitting Tensile Strength

Splitting tensile strength, also known as indirect tensile strength, is a measure of a material's ability to withstand tensile stresses. Splitting tensile strength test is the most important parameter, as concrete is very weak in tension and strong in compression, for analyzing the tensile behavior of the concrete and evaluating the quality and durability of the concrete structures. This test is performed in accordance with the ASTM C496. It is determined by subjecting a cylinder specimen to a loading in the diametral direction causing it to fail in tension along a plane perpendicular to the applied load.

To perform the splitting tensile strength test of the developed Green ECC, the cylinder samples of 75 mm diameter and 150 mm height will be tested for the splitting tensile strength after 28 days of water curing in the UTM available in the Structural Laboratory of National University of Sciences & Technology (NUST) Islamabad, Quetta Campus.

3.6.3. Modulus of Elasticity

Modulus of elasticity, also known as Young's modulus or elastic modulus, is a measure of a material's stiffness and its ability to deform elastically when subjected to applied stress. It is a mechanical property that describes the relationship between stress and strain within the elastic range of deformation. The higher the modulus of elasticity, the stiffer the material. This test is performed in accordance with ASTM C469. It is determined by subjecting the cylindrical concrete specimen to axial compressive loading and the resulting deformations are measured. These measurements are then used to compute the modulus of elasticity and the Poisson's ratio.

To perform the modulus of elasticity test of the developed Green ECC, the cylinder samples of 75 mm diameter and 150 mm height will be tested after 28 days of the water curing in the compression testing machine along a dial gauge to measure the deformation available in the Structural Laboratory of National University of Sciences & Technology (NUST) Islamabad, Quetta Campus.

3.6.4. Flexural Strength

Flexural strength, also known as modulus of rupture, is a measure of material's ability to withstand bending stresses. It is the maximum stress a material can withstand while being bent under a load. This test is performed in accordance with ASTM C78 (third-point loading) or ASTM C293 (center-point loading). It is determined by subjecting the rectangular prism specimen to a specified loading at the center of it creating the bending moment until the specimen fails. These measurements of bending moment are then used to determine the modulus of elasticity. Common modes of failure can be cracking, fracture, or deflection beyond acceptable limit.

To perform the flexural strength test of the developed Green ECC, the rectangular prism samples of dimensions 40 mm x 40 mm x 160 mm will be tested after 28 days of the water curing in flexural testing machine available in the Structural Laboratory of National University of Sciences & Technology (NUST) Islamabad, Quetta Campus.

3.1. Program Learning Outcomes (PLOs)

Following Program Learning Outcomes are involved in the project:

1. **PLO 1 (Engineering 6Knowledge):** Uses in-depth engineering knowledge to develop Green ECC.
2. **PLO 2 (Problem Analysis):** Emission of CO_2 during cement production and large-scale production of MD & CBA as waste materials causes environmental challenges.
3. **PLO 3 (Design/Development of Solutions):** To overcome the issues of CO_2 emission and large-scale waste materials like MD and CBA, we develop Green ECC.
4. **PLO 4 (Investigation):** In the project during experimental work and data analysis, we will investigate the properties of MD, CBA and ECC.
5. **PLO 6 (The Engineer & Society):** Development of Green ECC without CO_2 emission, and usage of waste materials like MD and CBA results in greener and more sustainable societies.

6. **PLO 7 (Environment & Sustainability):** Development of Green ECC will minimize the CO_2 emission in the cement production and will also reduce the waste materials like MD and CBA in the world ultimately leading to a greener and more sustainable environment.
7. **PLO 9 (Individual & Teamwork):** The project involves both individual and teamwork of the group members for the accomplishment of the project.
8. **PLO 11 (Project Management):** Execution of all the tasks in the project timely is essential to complete the project effectively.

3.2. Complex Engineering Problems (CEPs)

Following Complex Engineering Problems are involved in this project:

1. **WP1 (Depth of Knowledge Required):** In-depth understanding of the properties of marble dust, coal bottom ash, and cementitious materials is essential to create an effective green engineering composite for construction.
2. **WP2 (Range of Conflicting Requirements):** Balancing the need for high structural performance with sustainability goals, addressing conflicting requirements such as strength and reduced carbon emissions in the development of the composite.
3. **WP3 (Depth of Analysis):** Thorough analysis, including structural simulations and environmental impact assessments, is necessary to ensure the composite's performance and sustainability meet project objectives.
4. **WP4 (Familiarity of Issues):** A strong grasp of issues related to waste materials and sustainable construction is crucial in developing a green engineering composite using marble dust and coal bottom ash.
5. **WP6 (Extent of Stake Holder Involvement and Conflicting Requirements):** The development of an eco-friendly cementitious composite encounters the complex task of balancing conflicting stakeholder interests, regulatory compliance and material optimization. Successful resolution involves effective stakeholder engagement, compliance management, research and multi-objective optimization.

3.3. Complex Engineering Activities (CEAs)

Following are the Complex Engineering Activities that are related to the project:

1. **EA1 (Range of Resources):** Sourcing sustainable raw materials (marble dust, coal bottom ash and hard waste fiber), securing funding, and acquiring specialized equipment for developing the green engineering cementitious composite.
2. **EA3 (Innovation):** Creating an eco-friendly composite with optimized material ratios and innovative production methods to reduce carbon emissions, providing a sustainable alternative to traditional cement.
3. **EA4 (Consequences to Society and the Environment):** Assessing the environmental impact, health and safety considerations, and societal benefits of using the green engineering composite, including reduced CO_2 emissions and lower construction costs.

Chapter 4

RESULTS AND DISCUSSIONS

4.1. Introduction

This chapter critically analyses and discusses the results obtained from the test performed on the development of GECC using MD and CBA as partial replacement of cement to examine the material properties (physical and chemical) of the waste materials like MD and CBA being used as binder, and the mechanical properties of the developed GECC. Specimens were cured in water for 28 days to achieve maximum strength of 99% before conducting the test. The conducted tests along with their procedures are described in detail in the previous chapter. In this chapter, we critically discusses the results of the tests only. The results and discussion have been divided into three parameters stated in the objectives and the optimum mix-design proportions can be concluded based on these parameters. These are:

1. Investigating the material properties (physical and chemical) of MD and CBA.
2. Evaluating the mechanical properties of developed GECC.
3. Proposing the optimum percentage of MD and CBA in the development of GECC.

4.2. Physical and Chemical Properties of Materials

4.2.1. Particle Size Distribution

Sieve analysis method was used to analyze the particle size distribution of sand, MD and CBA as discussed in previous chapter of research methodology. The sand sample of 1000 gm was taken to analyze its particle size distribution. A group of sieves ranging from 3/8-inch sieve having largest openings placed on the top and 75 µm (No. 200) sieve having smallest openings at the bottom along a pan below it was used in accordance with ASTM C136 to perform the test. Result obtained for sand sieve analysis is tabulated in Table 4.1.

Sieve Size	Mass Retained in Grams on each Sieve	Individual Percentage (%) Retained	Total Percentage (%) Retained Cumulative	Total Percentage (%) Passing
3/8	0	0	0	100
4.75 mm (No. 4)	0	0	0	100
2.36 mm (No. 8)	5	0.5	0.5	99.5
1.18 mm (No. 16)	10	1	1.5	98.5
600 µm (No. 30)	85	8.5	10	90
300 µm (No. 50)	403	40.3	50.3	49.7
150 µm (No. 100)	398	39.8	90.1	9.9
75 µm (No. 200)	53	5.3	95.4	4.6
Pan	46	4.6	100	0
Total	1000	100	–	–

Table 4.1 Sieve Analysis of Sand

Table 4.1 showed that 100% of sand was observed to pass through sieve 3/8 and sieve No. 4, 99.5% from sieve No. 8, 98.5% from sieve No. 16, 90% from sieve No. 30, 49.7% from sieve No. 50, 9.9% from sieve No. 100, and 4.6% from sieve No. 200. Grain size distribution curve of sand obtained from the above Table 4.1 is graphed below in Figure 4.1.

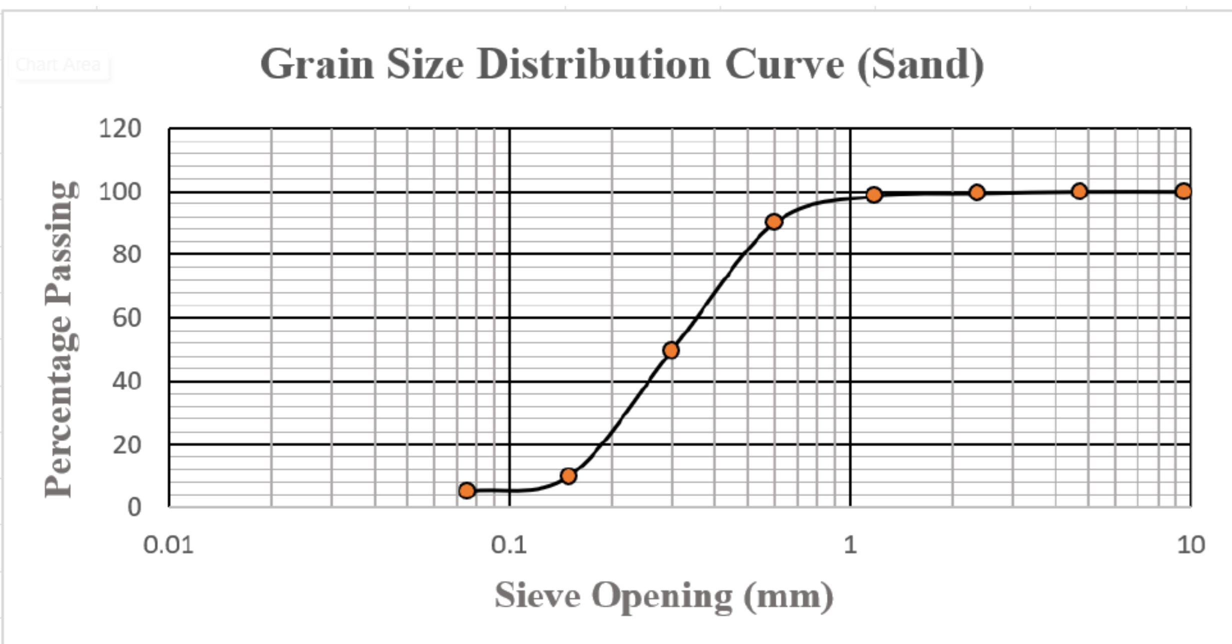


Figure 4.1 Grain Size Distribution Curve (Sand)

The MD sample of 1000 gm was taken to analyze its particle size distribution. A group of sieves ranging from 3/8-inch sieve having largest openings placed on the top and 75 µm (No. 200) sieve having smallest openings at the bottom along a pan below it was used in accordance with ASTM C136 to perform the test. Result obtained for MD sieve analysis is tabulated in Table 4.2.

Sieve Size	Mass Retained in Grams on each Sieve	Individual Percentage (%) Retained	Total Percentage (%) Retained Cumulative	Total Percentage (%) Passing
3/8	0	0	0	100
4.75 mm (No. 4)	0	0	0	100
2.36 mm (No. 8)	0	0	0	100
1.18 mm (No. 16)	0	0	0	100
600 μm (No. 30)	5	0.5	0.5	99.5
300 μm (No. 50)	53	5.3	5.8	94.2
150 μm (No. 100)	653	65.3	71.1	28.9
75 μm (No. 200)	221	22.1	93.2	6.8
Pan	68	6.8	100	0
Total		100		

Table 4.2 Sieve Analysis of Marble Dust

Table 4.1 showed that 100% of MD was observed to pass through sieve 3/8, sieve No. 4, sieve No. 8 and sieve No. 16, 99.5% from sieve No. 30, 94.2% from sieve No. 50, 28.9% from sieve No. 100, and 6.8% from sieve No. 200. Grain size distribution curve of sand obtained from the above Table 4.2 is graphed below in Figure 4.2.

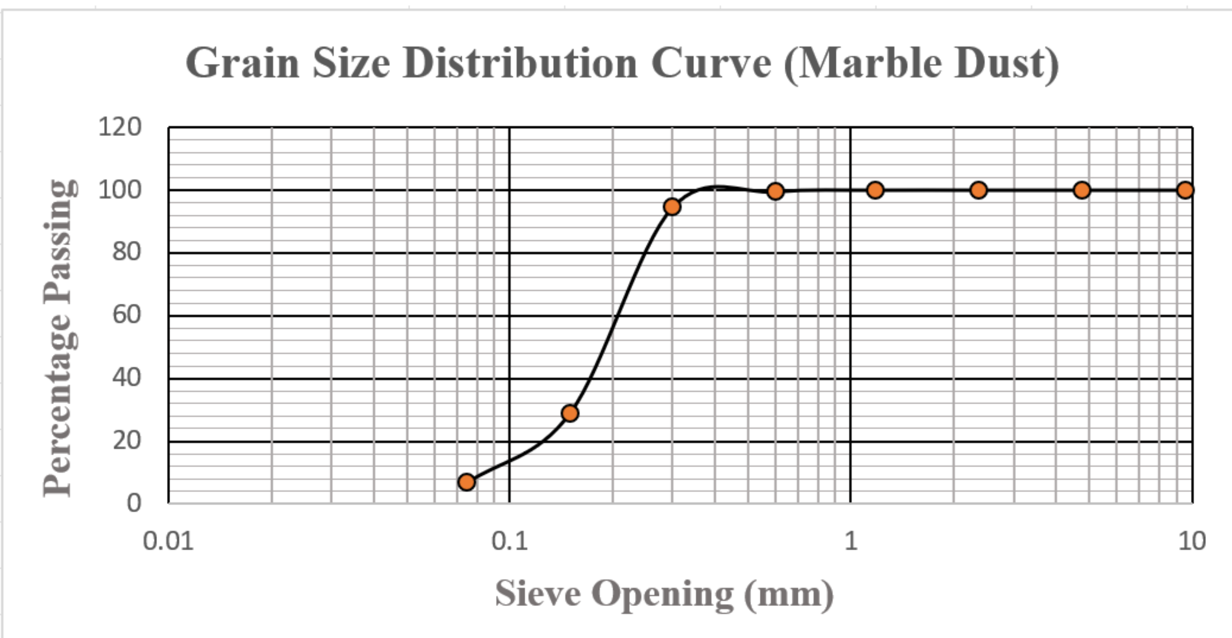


Figure 4.2 Grain Size Distribution Curve (Marble Dust)

Chapter 5

CONCLUSION

Introduction

Conclusion

The aim of the project is to develop Green ECC. The development will lead to the following productive conclusion:

1. Development of Green ECC with minimum emission of CO_2, will pave the way for a more sustainable and eco-friendly construction industry.
2. Green ECC's development will unveil the potential to transform waste materials like MD & CBA into sustainable construction components, aligning with the global sustainability agenda.
3. This project will act as a catalyst for future advancements in sustainable construction materials, contributing to a greener and more sustainable future.

4.1. LIMITATIONS

1. The development of a green engineering cementitious composite using marble dust and coal bottom ash is a valuable research topic, but like any project, it may have certain limitations. Here are some potential limitations:
2. The experimental work and tests are performed with small cubes and prisms in the lab. However, investigating the feasibility of large-scale production and implementation of these green engineering cementitious composites in real-world construction projects is not possible here in this lab.
3. The long-term durability and performance of the green cementitious composite may not be fully evaluated within the scope of the project. Monitoring its behavior over extended periods is essential for comprehensive evaluation.
4. External factors such as weather conditions and regional variations can influence the performance of the composite in real-world applications.

4.2. FUTUTRE WORK

Future work involves:

1. Investigating the feasibility of large-scale production and implementation of these green engineering cementitious composites in real-world construction projects.
2. Investigating and monitoring the long-term durability and performance of the green cementitious composite for comprehensive evaluation.
3. Evaluating the impact of external factors such as weather conditions and regional variations of the composite in real-world applications.

Chapter 6

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