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College of Engineering

**Department of Civil
Engineering**



Effect of Wastepaper Fibers on the Mechanical Properties of Concrete

A Thesis Submitted in Partial Fulfilment of the Requirements for the
M.Sc.Degree in Civil Engineering

Submitted by

Safa Nader Zalaikh

ID: 20145186

Supervised by

Dr. Muhammad Ajmal

Assistant Professor

University of Bahrain

Kingdom of Bahrain

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Defense committee's approval

UNIVERSITY OF BAHRAIN
Deanship of Graduate Studies & Scientific Research



جامعة البحرين
عمادة الدراسات العليا والبحث العلمي

Thesis Discussion Committee Decision

Form Code: UDNGS013

Student Name:	Safa Nader Yusuf Zalaikh
Student ID. No.	20145186
Department:	Civil Engineering
College:	Engineering
Program:	Masters in Civil Engineering
Student GPA:	3.63
Thesis Title:	Effect of Wastepaper Fibers on the Mechanical Properties of Concrete

The Discussion Committee met on 25-November-2024 in Building S41, Room 0113 upon discussing the student whose details are stated above in public. The discussion committee recommends the following:

The student is awarded the grade PASS in the thesis course CENG599.

☐ Without making any changes to the thesis.

☒ After making the modifications attached with this decision.

Discussion Committee Members Approval:

1.	Supervisor Name:	Dr. Muhammad Ajmal	Sign.:	
2.	Internal Examiner:	Dr. MD Shah Alam	Sign.:	
3.	External Examiner:	Dr. M. Kaimur Rahman	Sign.:	

Abstract

As per the Bahrain vision for 2030 that the new construction must follow the green building requirements which can be achieved by utilizing the green concrete in construction industry. From that perspective, this study has been made to produce green concrete by utilizing the money waste available in Bahrain. The use of wastepaper in concrete conserves natural resources, resulting in less pollution of the environment and energy savings.

The study was done by creating four mixes which are the control mix and three other mixes which had waste paper fibers in it which is collected from the Central Bank of Bahrain and the percentages added to the concrete mix were 0.25%, 0.5% and 1% from the total weight of concrete.

A total of 120 specimens were made and tested to check the mechanical properties. The tests made included the compressive strength test, the flexural strength, the tensile strength, the water absorption test, the rapid chloride permeability test and lastly the ultrasonic pulse velocity test.

The main findings of this study was that the addition of waste money fibers did have a positive effect on the mechanical properties of concrete as the compressive strength, flexural strength and tensile strength have been increased. Also the concrete became lighter and the cracks and voids became less. The optimum value to be added was the 0.5% of waste money fibers.

Dedication

To my parents, family, friends and everyone who continuously supports me.

Acknowledgment

I would like to thank my supervisor in this thesis Dr. Muhammad Ajmal for his continuous support in order to make this thesis.

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Abbreviations

Al	Aluminum
Au	Gold
Ba	Barium
BFs	Basalt Fibers
BS	Britain's National Standards
C	Carbon
Ca	Calcium
CFs	Carbon Fibers
EDX	Energy Dispersive X-Ray
EN	European Standards
EPMA	Electron Probe Microanalyzer Analysis
Fe	Iron
GPa	Giga Pascal
K	Potassium
Mg	Magnesium
MPa	Mega Pascal
Na	Sodium
O	Oxygen
PSFs	Plastic Steel Fibers
RCPT	Rapid Chloride Permeability Test
S	Sulfur
SCC	Self-Compacting Concrete
SEM	Scanning Electron Microscope
SF	Silica Fume
SFR	Steel Fibers Reinforced
Si	Silica
SP	Superplasticizer
TEM	Transmission Electron Microscopy
Ti	Titanium
UPV	Ultrasonic Pulse Velocity
WMF	Waste Money Fibers
WRF	Waste Rope Fibers
Zn	Zinc

Chapter 1: Introduction

1.1 Introduction

Concrete is a commonly used material all over the world. It comes in second place in terms of utilization closely behind water. Cement, sand, water, and aggregates as well as additional additives are all used to make concrete. Utilization of the widely spread industrial wastes in the civil construction practice may cause a real possibility of significant decrease in the environment pollution and perceptibly economize the price of civil construction (Mymrin et al., 2009). Apart from the industrial waste, concrete can be produced using waste fiber of paper which also known as Papercrete. Around 50 million tons of wastepaper are created globally per year (Ali et al., 2013). Papercrete is a material originally developed 80 years ago but it is recently rediscovered. Papercrete is a mixture of cement, sand, and paper. When combined and cured, these materials produce a product similar to concrete; however, it is very lightweight. Furthermore, the cost efficiency gained by utilizing the ample supply of recycled paper reinforces the need for research on this alternative. Papercrete is an experimental material which replaces an amount of cement with paper in the normal concrete mix (Bukhari et al., 2016). The use of wastepaper has a role in getting rid of their huge quantities, which constitute a fundamental, environmental problem because of the difficulty of its degradation. Various attempts have been therefore made, in building material manufactures to use waste material products. Paper is fundamentally wood cellulose, which is considered a fibrous' material. Cellulose is the second most generous material on earth after rock (Zaki

et al., 2018).

Bahrain is moving towards the eco-friendly environment by 2030. As per the 2030 vision of Bahrain, the new construction must follow the green building requirements which can be achieved by utilizing the green concrete in construction industry. In this study we are going to produce green concrete by utilizing the paper waste available in Bahrain. The use of wastepaper in concrete conserves natural resources, resulting in less pollution of the environment and energy savings. The following are the main objectives of this study.

1.2 Research Objectives

The main objectives of this thesis are:

1. To produce eco-friendly concrete which can be utilized in local construction to fulfill the Kingdom of Bahrain 2030 vision of Green Buildings.
2. To investigate the effect of the fibers of wastepaper on the mechanical properties of concrete such as the compressive strength, tensile strength, flexural strength, water absorption, rapid chloride permeability and ultrasonic velocity.
3. To check how different percentages of wastepaper fibers affect the mechanical properties of concrete
4. To get the optimum wastepaper fiber percentage that can be used in producing green concrete.

1.3 Thesis Organization

This thesis is organized in a total of 5 chapters. The content of the chapters is as below:

Chapter 1: This chapter consists of the background of the thesis work, and a brief description for the need of this research and the objectives of it.

Chapter 2: In this chapter, the literature review is discussed based on previous studies on the same subject. Also, the mechanical properties of concrete will be discussed in detail as these same properties will be monitored during the experiment of adding wastepaper fibers on the concrete.

Chapter 3: This chapter discusses the methodology used in this experiment including the materials used and the mix designs prepared and the process of preparation of the specimens which are going to be tested.

Chapter 4: In this chapter, the results are shared with the analysis of the findings.

Chapter 5: This chapter is for the final conclusions and recommendations based on the discussion from the previous chapters.

Chapter 2: Literature Review

2. Theoretical Overview

In this section the theoretical background of adding fibers to the concrete mix will be discussed in detail.

Papercrete, as a sustainable construction material consisting of recycled or re-pulped wastepaper mixed with other materials which make the concrete like aggregates, sand and water. The wastepaper generated in quantity yearly is the potential construction resource, and disposal of waste paper is a noticeable issue with the increase of paper consumption. Therefore, the concept of papercrete was proposed to solve these problems by introducing wastepaper fiber into concrete. Typically, the raw materials of papercrete mainly included cementitious materials, aggregates, and wastepaper pulp.

There are no uniform and systematic methods for the mixed design of papercrete in existing studies, and most research involved two common methods to design the papercrete recipe. One method is a wastepaper pulp is used as the substitute of cement; another method is a waste paper pulp is added as extra composition.

There were several advantages to use natural cellulose fiber or wastepaper fiber in concrete. The wastepaper used as an alternative to the raw materials of the concrete was sustainable, renewable, and recyclable. Typically, incineration, landfill, and recycling are the most used technologies for the disposal of wastepaper. Landfill and incineration indeed have a negative effect on the environment, even though wastepaper

recycling is a developed scheme, and the recycling rate is increasing continuously. Processes of paper recycling are regarded as potentially environmentally harmful by using multiple chemicals and energy consumption. The concept of papercrete provides a new treatment, which avoids a set of pollution from wastepaper disposal. On the other hand, due to the introduction of cellulose fiber, the density of the concrete decreases according to the amount of usage of wastepaper. Furthermore, as a result of both low thermal conductivity of paper fiber and pores in papercrete, which was considered to have favorable thermal insulation. However, the influence of cellulose fiber on the mechanical properties of concrete was not explicit, and the research on papercrete only focused on the influence of a single factor.

Overall, adding fibers to concrete is a common practice to improve its properties and performance, and it offers several benefits. These fibers can be made from various materials, such as steel, glass, synthetic polymers, and natural fibers. Some primary benefits of incorporating fibers into concrete is Increased Flexural Strength as fibers help in enhancing the flexural strength (bending resistance) of concrete. When the concrete bends under load, the fibers bridge the cracks that form, preventing further cracking and improving the overall load-bearing capacity. This is particularly useful in applications like pavements, bridges, and slabs. Second benefit is improved durability as fibers help reduce the permeability of concrete, making it more resistant to water and chemical infiltration. This contributes to the overall durability, reducing the likelihood of deterioration due to freeze-thaw cycles, chemical attack, or corrosion of embedded reinforcement (steel bars). The third benefit is

reduced cracks as concrete is inherently brittle and prone to cracking due to shrinkage, thermal changes, or tensile stresses. Fibers help control cracking by distributing stress more evenly and bridging small cracks, leading to a more crack-resistant material. This can result in longer-lasting structures with fewer maintenance needs. Fourth benefit is enhanced impact and abrasion resistance as adding fibers, particularly steel or synthetic fibers, improves concrete's resistance to impact and abrasion. This is beneficial in high-traffic areas or industrial floors, where the surface may be subject to heavy wear and tear. Fifth benefit is increased post-cracking strength as concrete with fibers generally exhibits better post-cracking behavior. After the formation of cracks, fibers can help hold the cracked pieces together, preventing the structure from failing immediately. This is important for applications where structural integrity must be maintained even after cracking. Sixth benefit is improved workability as some fiber-reinforced concretes (especially those with synthetic fibers) can improve the workability of the mix, making it easier to handle and place without compromising strength. This can lead to better quality control during construction. The seventh benefit is faster construction as fiber-reinforced concrete can be easier to place and finish, reducing construction time. In some cases, it can even eliminate the need for traditional steel reinforcement (rebar), speeding up the construction process, particularly in applications like precast panels or pavements. Eighth benefit is reduced shrinkage as fibers can help reduce drying shrinkage in concrete, which is a common cause of cracking. They help control the development of shrinkage cracks, improving the long-term stability of the material. The ninth benefit is cost-effectiveness as although fiber-reinforced concrete can sometimes have a higher initial cost

compared to traditional concrete, the reduced need for steel reinforcement and the longer lifespan of the structure often results in cost savings over time. Enhanced durability and reduced maintenance also contribute to long-term cost savings. The last benefit is sustainability as some types of fibers, particularly natural fibers, can be more environmentally friendly compared to traditional steel reinforcement. Fiber-reinforced concrete can also potentially reduce the amount of cement needed in some mixes, lowering the carbon footprint of the material.

2.1 Previous Studies

This section contains a comprehensive review of previous related studies and discusses the benefits gained from each.

2.1.1 Studies related to the addition of paper fibers to the concrete mix

First, a study the title of “Papercrete towards Building Sustainable & Resilient Infrastructure” (Bukhari et al., 2016) and the main objectives of it were to study the properties of papercrete to determine its potential as a sustainable building material. Also, to determine the ideal papercrete mix. And lastly, to do comparative analysis of Concrete, Wood & Papercrete.

The research focuses on Papercrete, an experimental composite integrating paper fibers into a concrete matrix to reduce weight, cost, and carbon emissions compared to conventional concrete. Papercrete shows potential as a sustainable building material and a substitute for wood, offering strengths akin to traditional lumber while being about one-tenth the weight

of standard concrete. It provides notable thermal and acoustic insulation and can be molded into diverse forms like blocks, panels, and sheets for flexible construction.

A formulation of 60% paper, 20% cement, and 20% additives demonstrated significant weight reduction and ease of handling. Its textured surface enhances interlocking capabilities for structural applications. While challenges in construction remain, further innovation in material science and building techniques could address these issues, advancing Papercrete toward mainstream adoption.

The methodology included experiments with varying Papercrete ratios to assess its properties. Key materials used were cement, sand, paper pulp, boric acid (for fire resistance), and lime plaster (for waterproofing). Compression tests revealed that while Papercrete lacks the strength of concrete, it is suitable for non-load-bearing applications like infill walls and road medians. It also offers advantages like lower cost, reduced weight, and enhanced shock absorption. (Bukhari et al., 2016)

Second study with the title of “Study of Papercrete as A Sustainable Building Material” (Agrawal et al., 2021)

The study aimed to investigate Papercrete's properties as an eco-friendly construction material, identify its optimal mixture, and compare it with concrete and wood. Papercrete combines materials like cement, ground granulated blast furnace slag, quarry dust, paper, and water to create lightweight, cost-effective, and sustainable building blocks. Key processes involve preparing paper pulp, mixing, curing, and testing for structural performance.

Findings:

1. **Lightweight & Strong:** Papercrete is less than one-third the weight of adobe bricks but can support modest structural loads.
2. **Cost-Effective:** Most components are inexpensive, making it suitable for low-cost housing.
3. **Ease of Production:** Simple processes and accessible materials make it user-friendly.
4. **Sustainability:** Recycled paper reduces waste and carbon emissions, promoting eco-friendly construction.
5. **Insulation:** Excellent thermal and acoustic insulation compared to concrete.
6. **Versatile Applications:** Suitable for interior walls, earthquake-prone areas, and low-weight structures.

Challenges:

1. **Water Absorption:** Papercrete readily absorbs water, requiring protective coatings.
2. **Durability:** Degradation due to environmental factors limits longevity.
3. **Structural Limitations:** Additional supports are needed for load-bearing applications.
4. **Material Costs:** Growing popularity may increase raw paper costs.

Recommendations for Improvement:

- Optimize ingredient proportions for specific applications.
- Reinforce with additives like coconut fiber or fly ash.
- Introduce waterproofing agents and admixtures for durability.
- Use higher-grade cement for better strength.
- Enhance aesthetic appeal with pigments and textures.

The research highlights Papercrete's potential for affordable, sustainable construction, particularly for non-load-bearing walls, temporary shelters, and earthquake-prone areas. Further development is needed to address its limitations and standardize its use in construction. (Agrawal et al., 2021)

Third study with the title of "Mechanical properties of papercrete" (Zaki et al., 2018), investigating the characteristics of Papercrete to ascertain its viability as a sustainable construction material. Secondly, determining the optimal Papercrete blend. Thirdly, creating samples using locally available materials. Fourthly, assessing the strengths of different Papercrete formulations. Fifthly, conducting comparative analyses between Concrete and Papercrete.

The study utilized a mix containing Ordinary Portland Cement (Type I), Al-Ekhaider natural sand as fine aggregate, Al-Soddor crushed gravel as coarse aggregate, and waste paper prepared through cutting, soaking, and grinding into sludge. Potable water with a pH of 6-7 and a constant water-to-cement ratio of 0.35, along with a superplasticizer (Sika), ensured mix consistency. The base mix ratio was 1:1.9:2.5 (cement, fine aggregate, coarse aggregate), with variations incorporating 5%, 10%, 15%, and 20% paper sludge to analyze performance.

Findings:

1. Low Density: Papercrete is a viable material for lightweight concrete production.
2. Recycling Benefits: Incorporating wastepaper conserves natural resources, reduces pollution, and minimizes landfill challenges.

3. Workability & Water Absorption: Higher paper content reduces workability and increases water absorption, necessitating adjustments in water or chemical admixtures.
4. Density & Strength: Increased paper content decreases dry density and compressive strength, except for the 5% mix, which showed strength improvement due to aluminosiliceous materials activating hydraulic and pozzolanic reactions.
5. Fire Resistance: Papercrete with 20% paper content offers lightweight bricks with good thermal insulation and fire resistance.
6. Limitations: High water absorption makes Papercrete unsuitable for external or near-ground walls without waterproofing.
7. Flexural Strength: Lower than reference mixes, regardless of paper content.

The study concluded that Papercrete, particularly with 20% paper content, is suitable for lightweight, fire-resistant construction, but requires further refinement to address water absorption and flexural strength limitations. (Zaki et al., 2018)

Fourth study with the title "Mechanical and Physical Characterization of Papercrete as New Eco-Friendly Construction Material" (Cardinale et al., 2021)

The preparation and testing of materials for papercrete specimens involved meticulous processes to ensure uniformity and quality. Waste paper was sourced, shredded, soaked, dried at 50°C, and ground into fine particles. Pulp, obtained during paper manufacturing, was dried, homogenized, and further

refined using a ball mill. Both components were prepared for use in papercrete mixtures alongside Portland cement, natural aggregates (0–4 mm), and tap water with a 0.5 water-to-cement ratio.

Specimen Preparation:

- Types and Volumes: Specimens included "REF" (cement-only), "PAPER" (waste paper at 2%, 5%, and 10%), and "PULP" (pulp at 2%, 5%, and 10%). A total of 21 prismatic specimens ($160 \times 40 \times 40$ mm) and seven thermal conductivity specimens ($300 \times 300 \times 20$ mm) were prepared.
- Curing: Specimens aged for 28 days under controlled humidity and a temperature of 20 ± 2 °C.
- Testing: Mechanical tests (flexural and compressive strength), capillary water absorption, and thermal conductivity assessments were conducted.

Key Findings:

1. Mechanical Strength: Flexural and compressive strengths declined as the volumetric ratio of wastepaper or pulp increased.
2. Density and Thermal Conductivity: Increased recycled paper content reduced bulk density and thermal conductivity.
3. Water Absorption: Water absorption rose with higher wastepaper content but decreased with higher pulp content.
4. Applications: Papercrete showed potential as a sustainable building material, suitable for improving masonry panel strength but requiring waterproofing for durability.

Future Directions:

- Investigating papercrete behavior under varying humidity and temperature conditions.
- Developing designs that balance energy efficiency and structural stability, considering thickness and waterproof treatments.
- Expanding statistical analysis to evaluate long-term performance and durability of papercrete in diverse applications.

These findings highlight papercrete's viability as an eco-friendly material, offering opportunities for sustainable construction with proper enhancements to its properties. (Cardinale et al., 2021).

Fifth study with the title of “Mechanical and structural properties of waste rope fibers-based concrete” (Abdulridha, 2022).

The study investigated the impact of Waste Rope Fibers (WRF) on the properties of concrete by incorporating varying proportions (0%, 0.25%, 0.5%, and 1%) into a standard concrete mix. Locally sourced materials, including cement, sand, gravel, and tap water, were used. WRF was prepared by cutting nylon ropes into 15 mm fibers, exhibiting a tensile strength of 600 MPa and an elastic modulus of 2.66 GPa.

Key Procedures:

1. Concrete Mix Design: Proportions were 1:1.81:2.62 (cement:sand:gravel) with a 0.5 water-to-cement ratio and a superplasticizer to enhance workability.
2. Mixing Process: A precise sequence ensured uniform dispersion of fibers within the mix.

3. Specimen Preparation and Curing: Concrete was cast into molds, demolded after 24 hours, and cured in water tanks until testing.

Tests Conducted:

- Mechanical Strength: Compressive and flexural tests.
- Ultrasonic Pulse Velocity (UPV) and Bulk Density: Assessed homogeneity and material compactness.
- Structural Behavior: Load-deflection, crack propagation, and ductility index tests.

Findings:

1. Workability: Fresh concrete workability decreased with higher WRF content.
2. Mechanical Strength: Compressive strength improved by up to 22%, and flexural strength increased by 4.3% at optimal WRF levels.
3. UPV and Density: Comparable to or slightly lower than control mix, with 1% WRF showing a 3% reduction.
4. Crack Control: WRF significantly reduced crack width and propagation, especially at 0.25% and 1% content.
5. Ductility: Beams with WRF demonstrated higher ductility indices (3.07–3.24) compared to 1.45 for beams without fibers.
6. Energy Absorption: Enhanced at 0.25% and 1% WRF, with service deflection exceeding 87% of maximum load.
7. Optimal Content: A 0.5% WRF addition provided the best balance of strength and ductility.

The study concludes that WRF can enhance concrete's mechanical and structural properties, particularly in crack control and energy absorption, while reducing workability, suggesting its potential as a reinforcement material in sustainable construction. (Abdulridha, 2022)

2.1.2 Studies related to the other fibers addition to the concrete mix

First study with the title of “Mechanical properties of hybrid fiber reinforced concrete” (Liu, B. et al, 2022)

This study investigated the impact of microfibers (carbon fibers and basalt fibers) and macro fibers (plastic steel fibers) on the mechanical properties of coral concrete. A total of 192 specimens were tested, with variations in fiber types and dosages, to assess their influence on compressive strength, splitting tensile strength, axial compressive strength, and elastic modulus.

Materials and Methods:

- **Concrete Composition:** Coral aggregates (5–20 mm coarse, 0–5 mm fine) sourced from the South China Sea, seawater from the Guangxi Beibu Gulf, and ordinary Portland cement were used. Fiber reinforcements included carbon fibers (CFs), basalt fibers (BFs), and plastic steel fibers (PSFs).
- **Mixing and Casting:** Coral aggregates were prewetted in seawater for 1 hour, drained for 2 hours, and incorporated into concrete mixes with precise fiber dosages. Specimens underwent vibration for compaction and were cured in a marine environment cabinet for 28 days.

- Testing: Cube compression, splitting tensile, axial compression, and elastic modulus tests were conducted after curing.

Findings:

1. Fiber Effects:

- Microfibers: Improved pre-macrocrack behavior by delaying failure.
- Macro Fibers: Enhanced post-macrocrack behavior, improving cohesion and appearance post-failure.
- Hybrid Fibers: Combined micro and macro fibers led to superior mechanical property improvements compared to individual fiber types.

2. Optimal Dosage: CFs: 0.15%, BFs: 0.15%, PSFs: 4 kg/m³

At these dosages, improvements were observed as follows:

- Cube compressive strength: +11.2%
- Splitting tensile strength: +25.5%
- Axial compressive strength: +14.1%
- Elastic modulus: +8.5%

3. Sustainability:

- Utilizing seawater and coral aggregates demonstrates potential for environmentally conscious construction in coastal regions.

This research highlights the effectiveness of multiscale hybrid fiber reinforcement in enhancing the mechanical properties and durability of coral

concrete, offering valuable insights for its application in engineering and sustainable construction. (Liu, B. et al, 2022)

Second study with the title of “Mechanical and physical characterization of steel fiber reinforced self-compacting concrete: Different aspect ratios and volume fractions of fibers”. (Alrawashdeh. et al, 2022)

This research examined the impact of steel fibers on the physical and mechanical properties of Self-Compacting Concrete (SCC). Seven mixes were developed, including one control (no steel fibers) and six Steel Fiber Reinforced SCC (SFR-SCC) formulations with varying steel fiber aspect ratios (60 and 80) and volume fractions (0.35%, 0.45%, and 0.55%). A water-to-binder ratio of 0.34 and 2% silica fume (SF) were consistent across mixes.

Key Findings:

1. Workability: Adding steel fibers reduced SCC workability and rheology but still met criteria for flowability, filling, and passing ability.
2. Strength:
 - Compressive strength was optimal with a steel fiber aspect ratio of 80 and a volume fraction of 0.45%.
 - Flexural and splitting tensile strength increased due to crack-bridging by hooked-end fibers.
3. Toughness and Impact Resistance:
 - Toughness peaked with 0.55% steel fiber and an aspect ratio of 80, as longer fibers absorbed more energy.
 - Impact resistance and ductility improved significantly, with fiber length playing a key role in distributing loads.
4. Durability:

- Permeability decreased with higher fiber aspect ratios but increased slightly in SFR-SCC compared to control.
 - Pulse velocity readings (over 4.5 km/s) indicated high-quality concrete.
5. Silica Fume: Enhanced mix consistency, filled voids, and improved bonding, resulting in better tensile strength and overall quality.

Materials and Mix Adjustments:

- Cement and Aggregates: Portland-slag cement, fine and coarse limestone aggregates.
- Additives: Silica fume (2%), limestone powder (152 kg/m³), and Viscocrete superplasticizer (0.45% of binder mass) ensured stability and workability.
- Steel Fibers: Two aspect ratios (60, 80) at three volume fractions optimized toughness, strength, and durability.

The study highlighted the different benefits of steel fibers in enhancing SCC properties, particularly in flexural strength, toughness, impact resistance, and ductility, while maintaining satisfactory workability and durability. These findings provide insights into optimizing steel fiber content for advanced concrete applications.

2.2 Mechanical Properties of Concrete

2.2.1 Compressive Strength:

Compressive strength stands as the prevalent and widely acknowledged indicator of concrete's strength. It serves as the primary benchmark for

assessing whether a particular concrete blend possesses the resilience necessary to withstand applied structural forces. (Abdulridha et al., 2022)

Compressive strength refers to a material or structure's capacity to sustain surface loads without experiencing cracks or deflection. When subjected to compression, material tends to decrease in size, whereas tension causes elongation. For cube test two types of specimens either cubes of 15cm X 15cm X 15cm or 10cm X 10cm x 10cm depending upon the size of aggregate are used. For most of the works cubical molds of size 15cm x 15cm x 15cm are commonly used. (Compressive Strength of Concrete, 2020)

Almost all studies demonstrate compressive strength had a remarkable reduction due to adding paper content, and compressive strength decreases continuously with the increase of paper content

2.2.2 Flexural Strength

Flexural strength, also referred to as the Modulus of Rupture in concrete, provides an indirect assessment of its tensile strength without reinforcement. It quantifies the extreme fiber stresses experienced when a member undergoes bending. Apart from external loads, factors such as warping, steel corrosion, drying shrinkage, and temperature gradients can induce tensile stresses.

The Modulus of Rupture measures the extreme fiber stresses within a member subjected to flexural loading, achievable through either One-point or symmetrical Two-point loading. In a simply supported beam under bending, tensile stresses develop at its underside. Once these stresses surpass the flexural strength threshold, cracks initiate at the location of maximum bending moment. Analyzing the load causing the crack and the crack pattern enables the determination of the concrete member's flexural strength.(B, 2022)

Experimental results indicate that the variation of flexural strength was not monotonous.

2.2.3 Tensile Strength

Concrete's tensile strength denotes its ability to withstand tension-induced cracking or fracture. While concrete structures typically experience complex loading conditions, assessing tensile strength remains crucial for gauging potential damage. Cracks and fractures occur when tensile forces exceed the material's tensile strength.

In contrast to ultra-high-performance concrete, traditional concrete exhibits a notable discrepancy between its high compressive strength and relatively lower tensile strength. Consequently, any concrete structure subject to tensile stress necessitates reinforcement with high-tensile-strength materials like steel. The expanding knowledge base concerning concrete's tensile strength underscores its importance in mitigating potential cracking issues.

The splitting strength decreased when the replacement ratio increased as noticed from the previous studies.

2.2.4 Water Absorption

The water absorption test for concrete evaluates the volume of water absorbed by a concrete specimen. This assessment holds significance in gauging the concrete's durability and water resistance, ensuring its performance aligns with expectations in its designated surroundings.

The concrete water absorption increased with increasing WP percentages as noticed from the previous studies.

2.2.5 Rapid Chloride Permeability

The Rapid Chloride Permeability Test (RCPT) is an essential evaluation technique within civil engineering, specifically designed to ascertain the permeability of concrete and similar construction materials. This test offers valuable information regarding the durability and standard of concrete structures. (Ltd, 2023)

2.2.6 Ultrasonic Velocity

Ultrasonic Pulse Velocity (UPV) testing is utilized for assessing the integrity and excellence of structural concrete or stone, with a capability to penetrate up to 6 feet in thickness. This method involves gauging the velocity and attenuation of an ultrasonic wave as it traverses through the tested material. Regions exhibiting lower velocities generally correspond to lower density and strength compared to those with higher velocities.

Chapter 3: Materials and Methodology

3.1 Materials

The materials used in this experiment include concrete which contains of cement, water, aggregates of 5mm, 10mm and 20mm, marine sand, two admixtures which are ISOLA BT and ISOLA PSM. In addition to the concrete, the waste money fibers were added.

3.2 Methodology

The study aims to find out the most optimum percentage of waste money fibers that shall be added to the concrete mix in order to make it gain more strength and have better properties based on the previous studies that were done in regards to the same matter.

The procedure that was followed to perform this thesis is the following:

3.2.1 Mix Design

The reference mix design for the concrete used for this thesis was obtained from Haji Hassan Ready Mix Concrete Factory which is located in Salmabad, Bahrain.

The mix design is approved by the Ministry of Works in Bahrain is already being used for the current construction projects in the Kingdom of Bahrain.

This mix design has been taken as the reference control mix, and it has a strength of 35 MPa.

The other mixes of designs which has the waste money fibers in them were determined based on the study of previous experiments done on this matter.

The percentage of the waste money fibers was determined based on a previous study as they used the percentages of 0.25%, 0.5% and 1% to see the effect of this addition on the concrete.

As the paper takes large area in the mix, it couldn't be possible to increase the percentage by more than 1% as the bonding of the concrete mix would not be properly done.

Table (3. 1): Concrete Mix Design

Mix Designation	Cement (Kg)	Water (Kg)	Aggregate 20mm (kg)	Aggregate 10mm (kg)	Aggregate 5mm (kg)	Marine Sand (kg)	Admixture 1 - ISOLA BT (kg)	Admixture 2 - ISOLA PSM (kg)	WMF (Kg)
Control Mix	12.25	4.54	25.55	10.97	4.17	26.42	0.123	0.105	0
1% WMF	12.25	4.54	25.55	10.97	4.17	26.42	0.123	0.105	0.841
0.5% WMF	12.25	4.54	25.55	10.97	4.17	26.42	0.123	0.105	0.420
0.25% WMF	12.25	4.54	25.55	10.97	4.17	26.42	0.123	0.105	0.210



Figure (3. 1): Aggregate, Cement and Sand



Figure (3. 2) Admixtures: ISOLA BT and ISOLA PSM

The control mix design contains Ordinary Portland cement, water, aggregate of the size of 20mm, aggregate of the size of 10mm, aggregate of the size of 5mm, marine sand (see Figure 3.1), two admixtures, which are ISOLA BT and ISOLA PSM (see Figure 3.2)

The other mixes were prepared with the exact same quantities of the control mix and in addition to it the waste money fibers (see Figure 3.3) were added as a percentage of the control mix weight.

The exact quantity for each material and for each mix can be seen in Table 3.1 as shown above.



Figure (3. 3): Waste Money Fibers

3.2.2 Preparation of Specimen

The mix design shown in Table 1 is for 0.035 m³ volume of concrete as per the mixer size used in Haji Hassan Ready-mix Concrete factory as shown in Figure 4 below.



Figure (3. 4): Concrete Mixer with 0.035 m³ volume

The cubes mold size used were 100x100x100mm and the beams mold size used were 100x100x500mm as shown in Figure 3.5.



Figure (3. 5): Concrete Molds

Each mix requires 24 cubes and 6 beams to make the planned tests on them in addition to 3 extra cubes in case needed. Therefore, 2 batches were done in the mixer for each mix.

There were 4 mixes in this study, therefore the total cubes made were 108 and total beams were 24 with a total of 132 specimen.

The mix was done using the mixer shown in Figure 3.4. The first batch was created for the cubes molds and the second batch was created for the beams molds.

The metal molds were prepared initially by applying a special oil on the surface to ease the process of the removal of the sample. After preparing the surface of the mold concrete was poured in them and kept for 24 hours. Later, molds were taken to the testing laboratory (Internation Laboratories) located in Hidd in the Kingdom of Bahrain.

All the specimens were cured there for 28 days in a water tank. The curing for all the cubes was done in water temperature between 18 to 22 degrees Celsius. The mechanical properties of concrete were obtained in 3 days, 7 days and 28 days.

3.2.3 Testing of Specimens

The testing of the specimens was done in the laboratory. Each test was done according to a specific standard as follows:

3.2.3.1 Compressive Strength Test

The compressive strength test was done in according to BS standard of BS EN 12390-3 which states that specimens are loaded to failure in a compression testing machine conforming to EN 12390-4. The maximum load sustained by

the specimen is recorded and the compressive strength of the concrete is calculated. (Testing Hardened Concrete - C, 2019)

For each mix, 9 cubes were tested. 3 cubes for 3 days, 3 cubes for 7 days and 3 cubes for 28 days (Figure 3.6). The testing has been done in a special compression machine as shown in Figure 3.7.



Figure (3. 6): Concrete Cubes for testing



Figure (3. 7): Compression Strength Testing Machine

3.2.3.2 Flexural Strength Test

For the flexural strength test, it was performed in according to the BS standard BS EN 12390-5 which states that Flexural strength is the one that measures the tensile strength of concrete. It is a measure of an unreinforced concrete beam or slab to resist failure in bending.

BS EN 12390-5 provides with the process where specimens are subjected to a bending moment by the application of load through upper and lower rollers. The maximum load sustained is recorded and the flexural strength is calculated. (Testing Hardened Concrete - F, 2019)

The distance between upper rollers was 100mm.

For each mix, 6 beams were tested. 3 beams for 7 days and 3 beams for 28 days.

The testing has been done using the machine shown in Figure 3.8.



Figure (3. 8): Flexural Strength Testing Machine

3.2.3.3 Tensile Strength Test

For the tensile strength test, it has been done in accordance with BS EN 12390-5.

For each mix, 6 cubes have been used. These cubes were cored into cylinders of size 64mm in length and 64mm in diameter.

Three cylinders were used for 7 days testing and the other three were used for 28 days testing.

The testing was done using the same machine as the for the compressive strength which is shown in Figure 6.

3.2.3.4 Water Absorption Test

This test has been done in accordance to BS 1881-122:2011. For this test 3 cubes were used for each mix and each was cored first. All the three cubes

were tested at the age of 28 days and the average values have been taken. The samples were put in the oven for 72 hours in a degree of 105 degrees Celsius. The mass of the oven dried specimens has been taken and then the specimens were immersed in water in order to obtain the water absorption percentage. The density of all the specimens have been checked as well.

3.2.3.5 Ultrasonic Pulse Velocity Test

This test has been done in accordance with BS EN 12504-4. For this test, three cubes have been used for each mix and all the three specimens were tested after 28 days and the average value has been taken. The test was performed using the machine/ equipment shown in Figure 3.9.



Figure (3. 9): Ultrasonic Pulse Velocity Testing Machine

3.2.3.6 Resistance to Chloride Ion Penetration Test

This test has been performed in accordance with ASTM C1202-10. Three cubes have been used for each mix, and they were cored first. All specimens were tested on the 28th day and the average values have been taken.

3.2.4 Scanning Electron Microscopy (SEM)

The scanning electron microscope (SEM) employs a concentrated beam of high-energy electrons to produce various signals at the surface of solid specimens. These signals, resulting from interactions between the electrons and the sample, provide details about the sample's external morphology (texture), chemical composition, and crystalline structure and orientation. Typically, data is collected from a selected area of the sample's surface, creating a 2D image that shows spatial variations in these properties. SEM can image areas from around 1 cm to 5 microns in width using conventional techniques, with magnifications from 20X to about 30,000X and a spatial resolution of 50 to 100 nm. Additionally, SEM can analyze specific points on the sample, which are particularly useful for qualitatively or semi-quantitatively determining chemical compositions (via EDS), crystalline structure, and crystal orientations (via EBSD). The SEM's design and

functionality are quite similar to the EPMA, and there is a significant overlap in their capabilities. (Scanning Electron Microscopy, 2024)

For this thesis, SEM analysis has been done for 5 samples which are the control sample with no money fibers, the samples with money fibers with 1%, 0.5% and 0.25%. In addition to these, the money fibers sample has been analyzed as well to know the chemistry of the fibers.

Before the analysis, the samples were first broken then semi-polished and then coated with gold. (See Figure 3.10, 3.11, 3.12 and 3.13)

The SEM scanning has been done in ExpressMed Diagnostics and Research Laboratory in Zinj in Bahrain.



Figure (3. 11): Concrete Samples Preparation for SEM



Figure (3. 10): SEM Machine



Figure (3. 13): Semi-Polished Concrete Sample



Figure (3. 12): Semi-Polished Concrete Sample with WMF

3.2.5 Energy Dispersive X-Ray (EDX)

Energy Dispersive X-Ray Analysis is an X-Ray technique used to determine the elemental composition of materials. It is commonly used in materials and product research, troubleshooting, and deformation, among other applications. The EDX analysis has been performed in King Fahad University of Petroleum and Minerals.

EDX systems are attachments to Electron Microscopy instruments, such as Scanning Electron Microscopy (SEM) or Transmission Electron Microscopy (TEM). These microscopes help identify the specimen of interest with their imaging capabilities. EDX analysis generates spectra with peaks that correspond to the elements present in the sample. Additionally, elemental mapping and image analysis of the sample are also achievable. (Energy dispersive X-ray analysis, 2020)

SEM specializes in producing detailed images of a sample's surface morphology, revealing its texture and topography. On the other hand, EDX focuses on determining the elemental composition of the sample, identifying and quantifying the various elements present. When these two techniques are combined, they create a powerful tool that provides both high-resolution imaging and precise chemical analysis. This combination allows researchers to not only observe the fine structural details of materials but also gain insights into their chemical makeup, leading to a comprehensive understanding of the sample's properties and behavior. (Difference between SEM and EDX Analysis, 2023)

3.3 Summary

Overall, six tests have been performed for 120 concrete specimens ranging from cubes to beams to cylinders which include the control mix and the mixes with different percentages of waste money fibers.

The tests include compressive strength, flexural strength, tensile strength, water absorption, rapid chloride penetration and ultrasonic pulse velocity.

And SEM analysis has been done for the concrete samples and the money fibers to understand the elements and the chemistry composition of the samples as well as the bonding type between the money fibers with the concrete elements.

The results of the specimens for the above tests and SEM/ EDX analysis will be shown and discussed in the next chapter.

Chapter 4: Results and Discussion

4.1 General

Two types of testing have been done in this experiment. The first is the scanning electron microscope (SEM) which is done for the waste money fibers to know the exact elements of this material by microscopy analysis. It has been also done for the control mix to see the bonding of elements without any addition. And it has been done for the other three mixes with waste money fibers with 1%, 0.5% and 0.25% addition to see the bonding of the fibers with the concrete elements.

The second test was for the mechanical properties of concrete which is done by conducting six types of tests which are, the compressive strength test, the flexural strength test, the tensile strength test, the water absorption test, the ultra-pulse velocity test and the rapid chloride penetration test.

The results of all tests will be shown in detail in the following sections.

4.2 Scanning Electron Microscope (SEM)

All the concrete samples were taken from the cubes that were done during the experiment. These cubes have been broken manually, and samples were semi polished by hand.

All the samples have been coated with Gold (Au) as it is part of the analysis by the SEM machine.

4.2.1 SEM for the Waste Money Fibers

The analysis for the money fibers has been done for so many points which are shown in more details in the Appendix.

However, the overall analysis for the money fibers contained the following elements as shown in Table 4.1, 4.2, 4.3, 4.4 and 4.5 as per Figure 4.1 for 6 points.

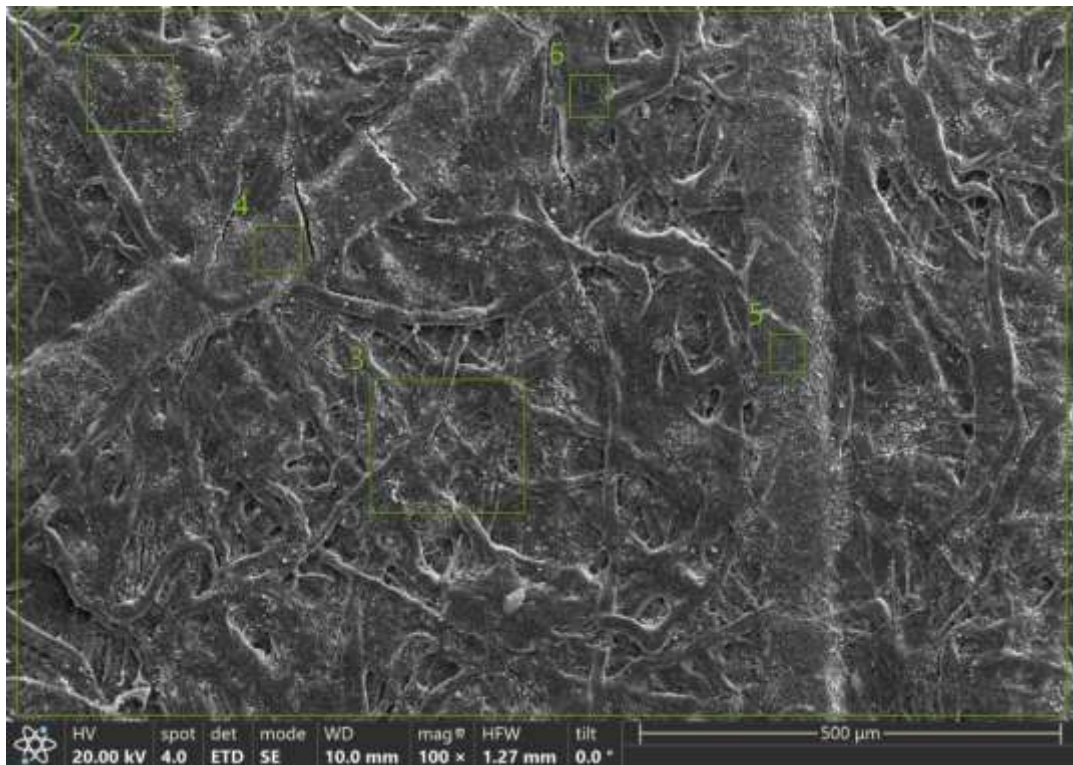


Figure (4. 1): SEM Image for the waste money fibers

The following tables show the chemistry composition of the waste money fibers which are taken from the SEM machine.

Table (4. 1): Point 1 of WMF Chemistry Composition through SEM

Element	Atomic %	Atomic % Error	Weight %	Weight % Error
C	50.7	0.2	36.7	0.1
O	42.9	0.3	41.4	0.3
Mg	0.2	0.0	0.3	0.0
Al	0.2	0.0	0.3	0.0
Si	0.7	0.0	1.1	0.0
S	1.2	0.0	2.4	0.1
Cl	0.2	0.0	0.4	0.0
K	0.1	0.0	0.2	0.0
Ca	1.2	0.0	2.9	0.0
Ti	0.8	0.0	2.2	0.1
Zn	1.3	0.0	5.0	0.1
Au	0.6	0.0	7.2	0.2

Table (4. 2): Point 2 of WMF Chemistry Composition through SEM

Element	Atomic %	Atomic % Error	Weight %	Weight % Error
C	57.7	0.4	40.4	0.2
O	35.0	0.5	32.6	0.4
Al	0.2	0.0	0.4	0.0
Si	0.8	0.0	1.3	0.0
S	2.0	0.1	3.7	0.1
Cl	0.3	0.0	0.6	0.0
Ca	0.3	0.0	0.8	0.0
Ti	0.4	0.0	1.2	0.1
Zn	2.4	0.0	9.2	0.2
Au	0.9	0.0	9.8	0.5

Table (4. 3): Point 3 of WMF Chemistry Composition through SEM

Element	Atomic %	Atomic % Error	Weight %	Weight % Error
C	53.6	0.3	38.0	0.2
O	39.9	0.4	37.7	0.4
Al	0.2	0.0	0.3	0.0
Si	0.7	0.0	1.2	0.0
S	1.6	0.1	3.0	0.1
Cl	0.2	0.0	0.3	0.0
Ca	0.2	0.0	0.5	0.0
Ti	0.9	0.1	2.6	0.2
Zn	1.9	0.0	7.4	0.1
Au	0.8	0.0	8.9	0.4

Table (4. 4): Point 4 of WMF Chemistry Composition through SEM

Element	Atomic %	Atomic % Error	Weight %	Weight % Error
C	49.0	0.4	30.4	0.2
O	33.1	0.6	27.3	0.5
Na	2.3	0.1	2.8	0.1
Mg	0.9	0.0	1.1	0.1
Al	0.4	0.0	0.5	0.0
Si	1.7	0.1	2.5	0.1
S	1.8	0.0	3.0	0.0
Ca	7.6	0.1	15.7	0.2
Ti	0.2	0.0	0.4	0.1
Zn	1.8	0.1	6.1	0.3
Ba	0.6	0.0	4.1	0.2
Au	0.6	0.0	6.1	0.5

Table (4. 5): Point 5 of WMF Chemistry Composition through SEM

Element	Atomic %	Atomic % Error	Weight %	Weight % Error
C	43.0	0.4	28.4	0.3
O	39.1	0.8	34.5	0.7
Na	1.9	0.1	2.4	0.1
Mg	1.6	0.1	2.2	0.1
Al	0.4	0.0	0.6	0.1
Si	2.4	0.1	3.8	0.1
S	0.9	0.0	1.6	0.0
Ca	10.4	0.1	22.9	0.2
Au	0.3	0.0	3.7	0.3

It can be seen from the above tables that the major elements of the money were the Carbon (C) and the Oxygen (O) along with Sodium (Na), Magnesium (Mg), Silica (Si), Sulfur (S), Calcium (Ca), Titanium (Ti) and Zinc (Zn).



Figure (4. 2): SEM Image showing the elements of WMF

4.2.2 SEM for the Control Sample

For the control sample, 10 points have been analyzed to see the chemistry of it by SEM as shown in Figure 4.3 and Table 4.6, 4.7, 4.8, 4.9, 4.10, 4.11, 4.12, 4.13, 4.14 and 4.15.

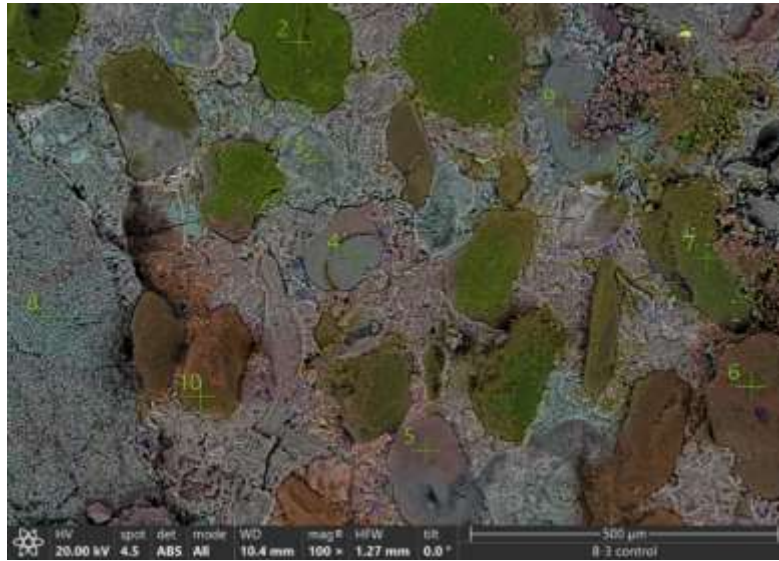


Figure (4. 3): SEM Image for the Concrete Control Sample

Table (4. 6): Point 1 of Control Sample Chemistry Composition through SEM

Element	Atomic %	Atomic % Error	Weight %	Weight % Error
C	5.5	0.1	2.8	0.1
O	66.5	0.6	44.8	0.4
Na	0.4	0.0	0.4	0.0
Mg	0.3	0.0	0.3	0.0
Al	0.3	0.0	0.3	0.0
Si	3.3	0.0	3.9	0.0
K	0.2	0.0	0.3	0.0
Ca	21.9	0.1	37.0	0.2
Fe	0.6	0.0	1.3	0.1
Au	1.1	0.1	9.0	0.6

Table (4. 7): Point 2 of Control Sample Chemistry Composition through SEM

Element	Atomic %	Atomic % Error	Weight %	Weight % Error
C	2.6	0.1	1.6	0.1
O	71.1	0.2	58.3	0.2
Na	0.0	0.0	0.0	0.0
Mg	0.3	0.0	0.4	0.0
Al	0.2	0.0	0.3	0.0
Si	25.2	0.1	36.3	0.1
K	0.0	---	0.0	---
Ca	0.3	0.0	0.7	0.0
Fe	0.0	0.0	0.1	0.0
Au	0.2	0.0	2.3	0.1

Table (4. 8): Point 3 of Control Sample Chemistry Composition through SEM

Element	Atomic %	Atomic % Error	Weight %	Weight % Error
C	5.1	0.1	2.5	0.0
O	60.6	0.4	40.3	0.2
Na	0.3	0.0	0.3	0.0
Mg	1.2	0.0	1.3	0.0
Al	1.7	0.0	1.9	0.0
Si	8.0	0.0	9.4	0.1
K	0.3	0.0	0.5	0.0
Ca	21.2	0.1	35.2	0.1
Fe	0.8	0.0	1.8	0.0
Au	0.8	0.1	6.9	0.4

Table (4. 9): Point 4 of Control Sample Chemistry Composition through SEM

Element	Atomic %	Atomic % Error	Weight %	Weight % Error
C	9.5	0.1	4.9	0.0
O	59.9	0.5	41.2	0.3
Na	0.4	0.0	0.4	0.0
Mg	0.0	0.0	0.0	0.0
Al	0.1	0.0	0.1	0.0
Si	0.4	0.0	0.5	0.0
K	0.1	0.0	0.1	0.0
Ca	29.3	0.1	50.5	0.1
Fe	0.0	0.0	0.1	0.0
Au	0.3	0.0	2.3	0.2

Table (4. 10): Point 5 of Control Sample Chemistry Composition through SEM

Element	Atomic %	Atomic % Error	Weight %	Weight % Error
C	11.8	0.1	7.1	0.0
O	69.4	0.3	55.5	0.2
Na	0.2	0.0	0.2	0.0
Mg	2.7	0.0	3.3	0.0
Al	1.0	0.0	1.3	0.0
Si	2.1	0.0	3.0	0.0
K	0.1	0.0	0.2	0.0
Ca	12.0	0.0	24.1	0.1
Fe	0.3	0.0	0.8	0.0
Au	0.5	0.0	4.6	0.2

Table (4. 11): Point 6 of Control Sample Chemistry Composition through SEM

Element	Atomic %	Atomic % Error	Weight %	Weight % Error
C	14.8	0.2	9.1	0.1
O	54.6	0.2	44.6	0.2
Na	0.5	0.0	0.5	0.0
Mg	1.1	0.0	1.4	0.0
Al	0.8	0.0	1.2	0.0
Si	27.1	0.1	38.9	0.1
K	0.1	0.0	0.2	0.0
Ca	0.6	0.0	1.2	0.0
Fe	0.1	0.0	0.3	0.0
Au	0.3	0.0	2.6	0.1

Table (4. 12): Point 7 of Control Sample Chemistry Composition through SEM

Element	Atomic %	Atomic % Error	Weight %	Weight % Error
C	7.4	0.1	4.5	0.1
O	62.7	0.2	50.5	0.2
Na	0.1	0.0	0.1	0.0
Mg	2.3	0.0	2.8	0.0
Al	1.0	0.0	1.4	0.0
Si	25.3	0.1	35.7	0.1
K	0.2	0.0	0.4	0.0
Ca	0.2	0.0	0.5	0.0
Fe	0.5	0.0	1.3	0.0
Au	0.3	0.0	3.0	0.2

Table (4. 13): Point 8 of Control Sample Chemistry Composition through SEM

Element	Atomic %	Atomic % Error	Weight %	Weight % Error
C	12.1	0.1	6.9	0.0
O	66.7	0.3	50.5	0.3
Na	0.0	0.0	0.0	0.0
Mg	0.1	0.0	0.1	0.0
Al	0.1	0.0	0.2	0.0
Si	0.1	0.0	0.2	0.0
K	0.0	0.0	0.1	0.0
Ca	20.3	0.1	38.5	0.1
Fe	0.0	0.0	0.1	0.0
Au	0.4	0.0	3.5	0.2

Table (4. 14): Point 9 of Control Sample Chemistry Composition through SEM

Element	Atomic %	Atomic % Error	Weight %	Weight % Error
C	10.8	0.1	5.6	0.0
O	59.4	0.4	41.3	0.3
Na	0.0	---	0.0	---
Mg	1.1	0.0	1.2	0.0
Al	0.6	0.0	0.7	0.0
Si	0.7	0.0	0.9	0.0
K	0.0	0.0	0.1	0.0
Ca	26.7	0.1	46.6	0.1
Fe	0.3	0.0	0.8	0.0
Au	0.3	0.0	2.9	0.3

Table (4. 15): Point 10 of Control Sample Chemistry Composition through SEM

Element	Atomic %	Atomic % Error	Weight %	Weight % Error
C	4.3	0.1	2.5	0.1
O	56.4	0.2	42.9	0.2
Na	6.5	0.0	7.1	0.0
Mg	0.2	0.0	0.2	0.0
Al	7.5	0.0	9.7	0.0
Si	23.9	0.1	31.9	0.1
K	0.1	0.0	0.1	0.0
Ca	0.6	0.0	1.2	0.0
Fe	0.0	0.0	0.0	0.0
Au	0.5	0.0	4.4	0.2

It can be seen from the tables that the chemistry of concrete is mainly having Oxygen (O), Carbon (C), Silica (Si) in aggregates and Calcium (Ca) in the cement paste.

4.2.3 SEM for the sample with waste money fibers

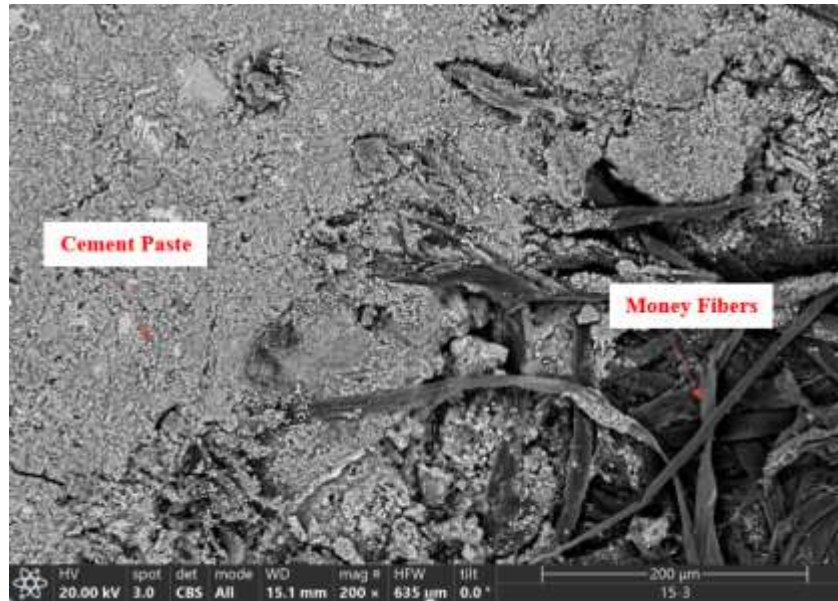


Figure (4. 4): SEM Image of Interface of WMF with Cement Paste

It can be seen from the above figure 4.4 the SEM image of the sample of concrete with waste money fibers.

It can be seen clearly from Figure 4.4 the physical bonding between the cement paste and the fibers and therefore leading to more strength of the concrete as well as the bonding means it is less likely to crack compared to the sample with no fibers and this can be seen through the flexural strength test which is done and shown in the next section.

4.3 Energy Dispersive X-Ray Analysis (EDX)

Two points have been analyzed for the waste money fibers to examine the chemistry of it. And the results can be seen from the tables below (refer to Table 4.16 and 4.17)

Table (4. 16): Point 1 of Chemistry Composition through EDX for the WMF

Element	Atomic %
C	54.2
O	41.1
Cu	1.7
Ca	1.3
Ti	0.9
Cl	0.4
Si	0.4

Table (4. 17): Point 2 of Chemistry Composition through EDX for the WMF

Element	Atomic %
C	53.1
O	42.9
Ti	1.9
Cu	1.6
Cl	0.5

It can be seen from the above tables that the major elements for the chemistry of the waste money fibers are Carbon (C) and Oxygen (O) along with other elements with a much lesser percentage such as Titanium (Ti), Silica (Si) and Calcium (Ca).

4.4 Mechanical Properties Testing

4.4.1 Compressive strength

Table (4. 18): Compressive Strength for 3 Days for the Control Mix

Control Mix							
Age (days)	Dimensions (mm)			Mass (g)	Density (kg/m ³)	Compressive Strength (MPa)	Average Compressive Strength (MPa)
	L	W	H				
3	100.45	100.43	100.42	2420	2388	32.8	32.93
3	100.45	100.25	100.45	2450	2422	32.6	
3	100.56	100.5	100.55	2430	2391	33.4	

Table (4. 19): Compressive Strength for 7 Days for the Control Mix

Control Mix							
Age (days)	Dimensions (mm)			Mass (g)	Density (kg/m ³)	Compressive Strength (MPa)	Average Compressive Strength (MPa)
	L	W	H				
7	100.25	100.33	100.42	2420	2395	36.4	37.30
7	100.25	100.42	100.36	2440	2415	37.6	
7	100.45	100.35	100.42	2430	2400	37.9	

Table (4. 20): Compressive Strength for 28 Days for the Control Mix

Control Mix							
Age (days)	Dimensions (mm)			Mass (g)	Density (kg/m ³)	Compressive Strength (MPa)	Average Compressive Strength (MPa)
	L	W	H				
28	101.09	100.68	100.43	2441	2388	46.4	43.80
28	101.2	100.76	100.85	2477	2408	42.8	
28	101.26	100.66	100.68	2545	2479	42.2	

As it can be seen for the above tables 4.18, 4.19 and 4.20, the compressive strength for the control mix in 3 days was measured for 3 cubes and the average was taken which is 32.93 MPa, and for the 7 days it achieved 37.3 MPa and lastly for the 28 days it reached up to 43.8 MPa which is already passing the design mix anticipated strength which is 35 MPa.

Table (4. 21): Compressive Strength for 3 Days for the 1% WMF

1% of Waste Money Fibers (1% WMF)							
Age (days)	Dimensions (mm)			Mass (g)	Density (kg/m ³)	Compressive Strength (MPa)	Average Compressive Strength (MPa)
	L	W	H				
28	100.51	100.46	100.36	2351	2320	38.8	40.33
28	100.54	100.36	100.42	2343	2312	42.3	
28	100.54	100.68	100.65	2359	2315	39.9	

Table (4. 22): Compressive Strength for 7 Days for the 1% WMF

1% of Waste Money Fibers (1% WMF)							
Age (days)	Dimensions (mm)			Mass (g)	Density (kg/m ³)	Compressive Strength (MPa)	Average Compressive Strength (MPa)
	L	W	H				
3	100.55	100.62	100.42	2393	2355	19.7	20.23
3	100.55	100.36	100.55	2304	2271	20.8	
3	100.52	100.36	100.42	2312	2282	20.2	

Table (4. 23): Compressive Strength for 28 Days for the 1% WMF

1% of Waste Money Fibers (1% WMF)							
Age (days)	Dimensions (mm)			Mass (g)	Density (kg/m ³)	Compressive Strength (MPa)	Average Compressive Strength (MPa)
	L	W	H				
7	100.19	100.25	100.42	2312	2292	21.1	21.33
7	100.36	100.42	100.33	2345	2319	22	
7	100.25	100.42	100.36	2346	2322	20.9	

When adding 1% of waste money fiber into the mix, it can be seen from the above tables 4.21, 4.22 and 4.23 that for 3 days the average compressive strength for 3 cubes is 20.23 MPa, for 7 days the average strength reached to 21.33 MPa and for the 28 days the strength is 40.33 MPa.

Table (4. 24): Compressive Strength for 3 Days for the 0.5% WMF

0.5% of Waste Money Fibers (0.5% WMF)							
Age (days)	Dimensions (mm)			Mass (g)	Density (kg/m ³)	Compressive Strength (MPa)	Average Compressive Strength (MPa)
	L	W	H				
3	100.55	100.36	100.45	2332	2301	26.6	27.27
3	100.24	100.42	100.63	2324	2294	27.2	
3	100.42	100.42	100.38	2372	2343	28	

Table (4. 25): Compressive Strength for 7 Days for 0.5% WMF

0.5% of Waste Money Fibers (0.5% WMF)							
Age (days)	Dimensions (mm)			Mass (g)	Density (kg/m ³)	Compressive Strength (MPa)	Average Compressive Strength (MPa)
	L	W	H				
7	100.46	100.36	100.42	2390	2361	38.6	38.23
7	100.38	100.45	100.42	2398	2368	39.3	
7	100.42	100.45	100.36	2364	2335	36.8	

Table (4. 26): Compressive Strength for 28 Days for 0.5% WMF

0.5% of Waste Money Fibers (0.5% WMF)							
Age (days)	Dimensions (mm)			Mass (g)	Density (kg/m ³)	Compressive Strength (MPa)	Average Compressive Strength (MPa)
	L	W	H				
28	100.45	100.36	100.52	2381	2350	45.8	46.97
28	100.53	100.42	100.36	2407	2376	48.2	
28	100.48	100.33	100.52	2395	2363	46.9	

Once 0.5% of waste money fibres added into the mix, it can be noticed in the above tables 4.24, 4.25 and 4.26 that the average compressive strength for 3 days is 27.27 MPa, for the 7 days it reached to 38.23 MPa which is already passing the design mix strength of 35 MPa and for the 28 days it reached to 46.97 Mpa.

Table (4. 27): Compressive Strength for 3 Days for the 0.25% WMF

0.25% of Waste Money Fibers (0.25% WMF)							
Age (days)	Dimensions (mm)			Mass (g)	Density (kg/m ³)	Compressive Strength (MPa)	Average Compressive Strength (MPa)
	L	W	H				
3	100.52	100.33	100.42	2375	2345	26.7	27.40
3	100.45	100.36	100.42	2400	2371	28.4	
3	100.55	100.25	100.28	2403	2377	27.1	

Table (4. 28) Compressive Strength for 7 Days for the 0.25% WMF

0.25% of Waste Money Fibers (0.25% WMF)							
Age (days)	Dimensions (mm)			Mass (g)	Density (kg/m ³)	Compressive Strength (MPa)	Average Compressive Strength (MPa)
	L	W	H				
7	101.45	100.67	100.66	2404	2338	32.5	31.53
7	100.48	100.36	100.45	2408	2377	31.3	
7	100.56	100.45	100.33	2356	2325	30.8	

Table (4. 29): Compressive Strength for 28 Days for the 0.25% WMF

0.25% of Waste Money Fibers (0.25% WMF)							
Age (days)	Dimensions (mm)			Mass (g)	Density (kg/m ³)	Compressive Strength (MPa)	Average Compressive Strength (MPa)
	L	W	H				
28	100.32	100.42	100.36	2411	2385	46.2	44.57
28	100.4	100.35	100.25	2363	2340	42.8	
28	100.33	100.54	100.36	2390	2361	44.7	

For the 0.25% waste money fibres added to the mix, it can be seen in the above tables 4.27, 4.28 and 4.29

that the average compressive strength for 3 days is 27.4 MPa, for the 7 days it is 31.53 MPa and for the 28 days it reached up to the 44.57 MPa.

Table (4. 30): Compressive Strength for all mixes @ 3 days

Mix Type	Compressive Strength (MPa) @ 3 Days
Control Mix	32.93
1% WMF	20.23
0.5% WMF	27.27
0.25% WMF	27.4

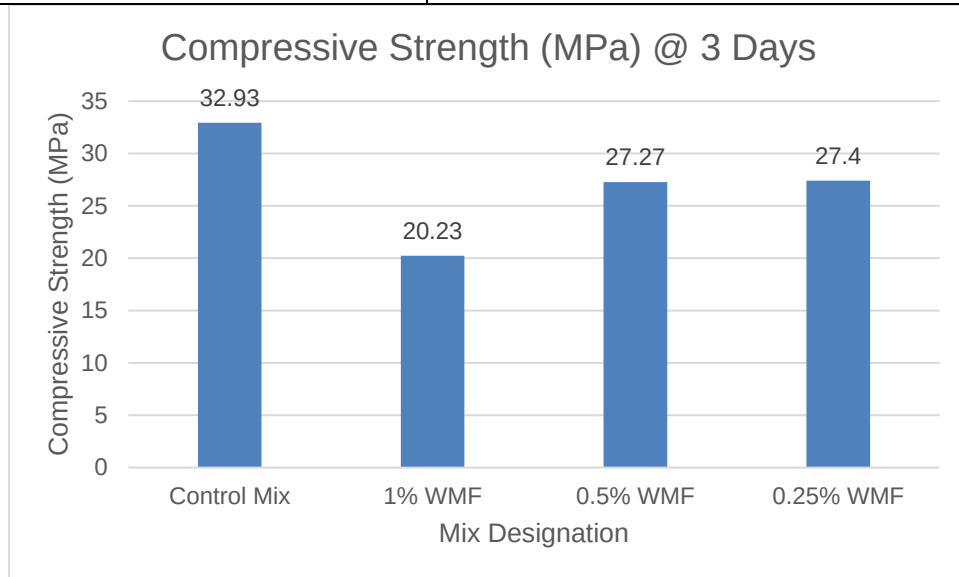


Figure (4. 5): Compressive Strength for all mixes @ 3 days

From Table 4.30 and Figure 4.5, we can see the comparison between the 4 mixes which are the control mix, 1% of waste money fibres mix, 0.5% of waste money fibres mix and 0.25% of waste money fibres mix in regards to the compressive strength in 3 days which is 32.93 MPa, 20.23 MPa, 27.27 MPa and 27.4 MPa respectively.

This shows that the maximum compressive strength in 3 days was achieved for the control mix.

Table (4. 31): Compressive Strength for all mixes @ 7 days

Mix Type	Compressive Strength (MPa) @ 7 Days
Control Mix	37.3
1% WMF	21.33
0.5% WMF	38.23
0.25% WMF	31.53

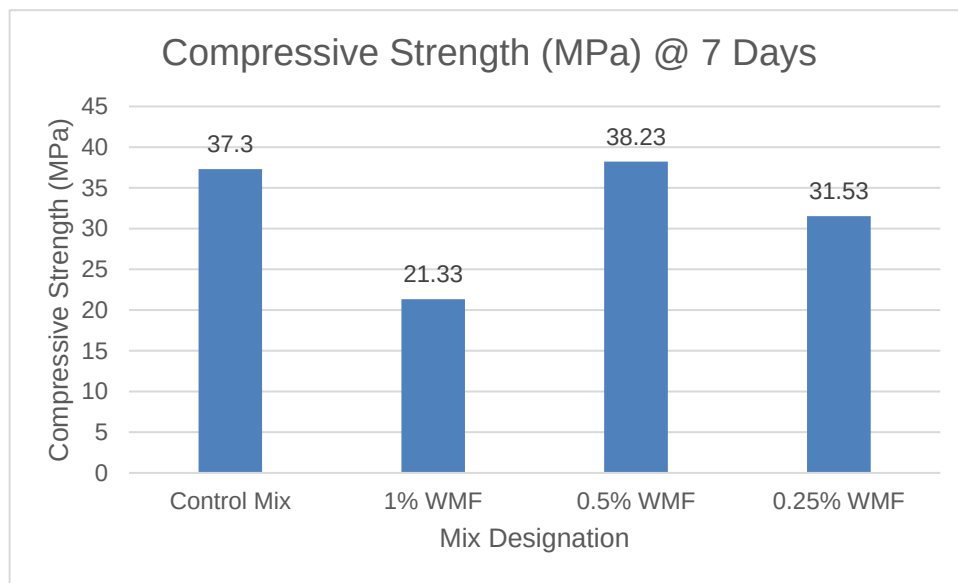


Figure (4. 6): Compressive Strength for all mixes @ 7 days

From Table 4.31 and Figure 4.6, we can see the comparison between the 4 mixes which are the control mix, 1% of waste money fibre mix, 0.5% of waste money fibres mix and 0.25% of waste money fibres mix in regards to the compressive strength in 7 days which is 37.3 MPa, 21.33 MPa, 38.23 MPa and 31.53 MPa respectively.

This shows that the maximum compressive strength in 7 days was achieved for the mix with 0.5% of waste money fibres.

Table (4. 32): Compressive Strength for all mixes @ 28 days

Mix Type	Compressive Strength (MPa) @ 28 Days
Control Mix	43.8
1% WMF	40.33
0.5% WMF	46.97
0.25% WMF	44.57

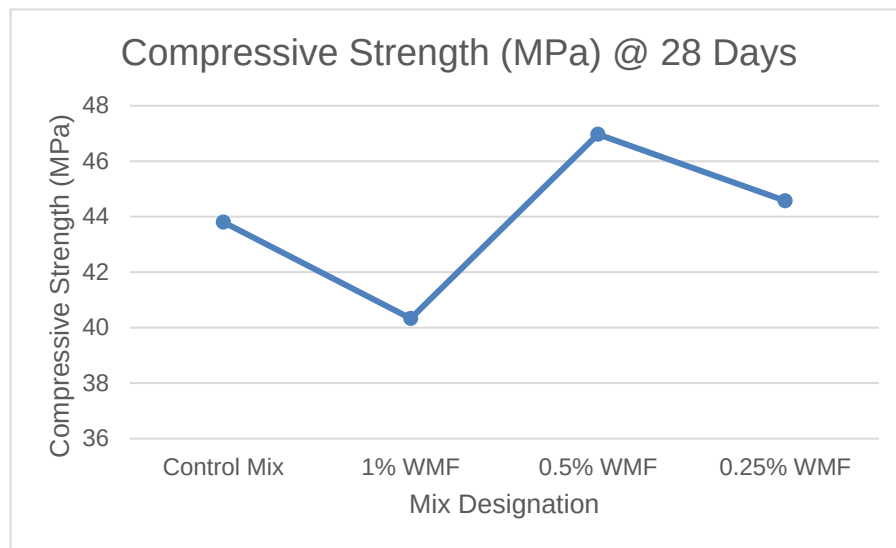


Figure (4. 7): Compressive Strength Curve for all the mixes @ 28 days

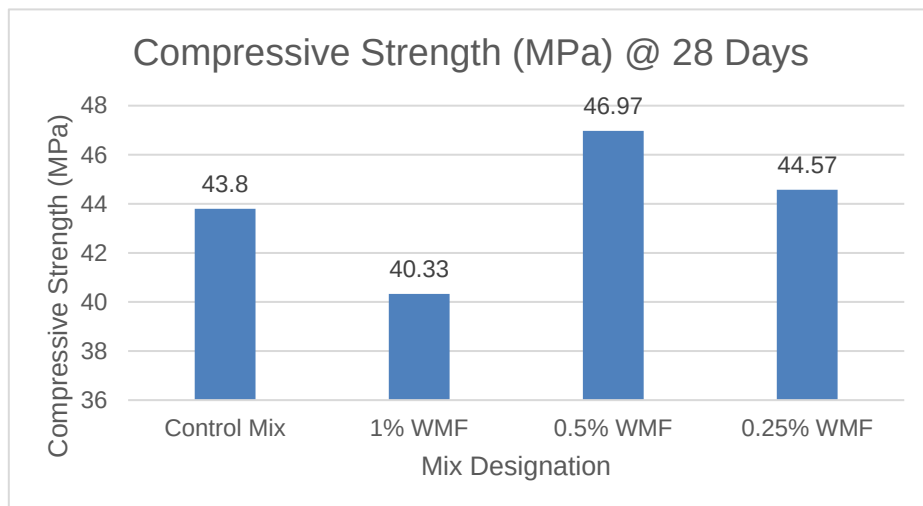


Figure (4. 8): Compressive Strength for all mixes @ 28 days

From Table 4.32 and Figure 4.7 and 4.8, we can see the comparison between the 4 mixes which are the control mix, 1% of waste money fibre mix, 0.5% of waste money fibres mix and 0.25% of waste money fibres mix in regards to the compressive strength in 28 days which is 43.8 MPa, 40.33 MPa, 46.97 MPa and 44.57 MPa respectively.

This shows that the maximum compressive strength in 28 days was achieved for the mix with 0.5% of waste money fibres and this is the most important one even though that all mixes already surpassed the mix design compressive strength which should be 35 MPa.

The percentage of increase in the compressive strength for the 0.5% WMF mix is 7.23% more than the control mix.

From Figure 20, it can be seen clearly that drop of the compressive strength when the 1% of waste money fibers is added. And It can be seen that the maximum strength is at 0.5% waste money fibers.

Figure 4.9 shows the overall results for the compressive strength for all the mixes for the 3, 7 and 28 days.

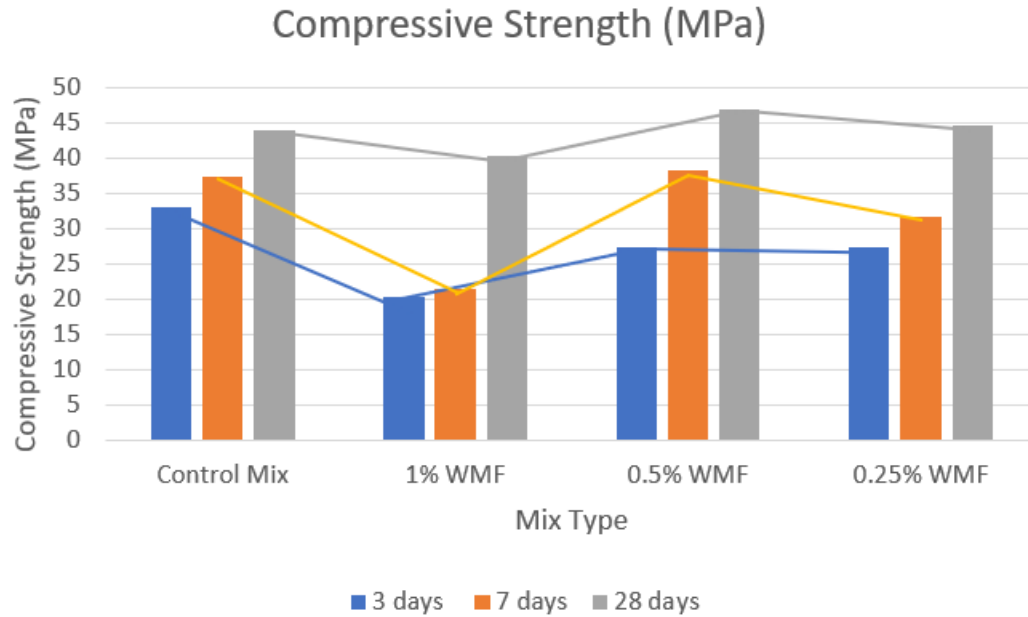


Figure (4. 9): Compressive strength for all samples

4.4.2 Flexural Strength

Table (4. 33): Tensile Strength for 7 days for the Control Mix

Control Mix							
Age (days)	Dimensions (mm)			Mass (g)	Density (kg/m ³)	Flexural Strength (MPa)	Average Flexural Strength (MPa)
	L	W	H				
7	501	100.68	100.61	12610	2485	3.5	3.70
7	501	100	100.77	12500	2476	3.6	
7	500	99.98	100.71	12510	2485	4	

Table (4. 34): Tensile Strength for 28 days for the Control Mix

Control Mix							
Age (days)	Dimensions (mm)			Mass (g)	Density (kg/m ³)	Flexural Strength (MPa)	Average Flexural Strength (MPa)
	L	W	H				
28	501	101.54	101.75	12906	2493	7.1	6.60
28	500	101.61	101.48	12454	2416	6.2	
28	501	101.56	100.55	12381	2420	6.5	

For the control mix, it can be seen in the above tables 4.33 and 4.34 that the average flexural strength for 7 days is 3.7 MPa and for the 28 days it reached up the 6.6 MPa.

Table (4. 35): Tensile Strength for 7 days for the 1% WMF

1% of Waste Money Fibers (1% WMF)							
Age (days)	Dimensions (mm)			Mass (g)	Density (kg/m ³)	Flexural Strength (MPa)	Average Flexural Strength (MPa)
	L	W	H				
7	507	101.49	101.14	12247	2353	4.1	4.20
7	501	101.33	101.54	11983	2325	4.4	
7	501	102.74	101.64	12190	2330	4.1	

Table (4. 36): Tensile Strength for 28 days for the 1% WMF

1% of Waste Money Fibers (1% WMF)							
Age (days)	Dimensions (mm)			Mass (g)	Density (kg/m ³)	Flexural Strength (MPa)	Average Flexural Strength (MPa)
	L	W	H				
28	501	101.28	100.54	12320	2415	6.5	6.70
28	501	101.14	101.33	12110	2359	7	
28	505	101.85	101.23	12146	2333	6.6	

For the 1% waste money fibres added to the mix, it can be seen in the above tables 4.35 and 4.36 that the average flexural strength for 7 days is 4.2 MPa and for the 28 days it reached up the 6.7 MPa.

Table (4. 37): Tensile Strength for 7 days for the 0.5% WMF

0.5% of Waste Money Fibers (0.5% WMF)							
Age (days)	Dimensions (mm)			Mass (g)	Density (kg/m ³)	Flexural Strength (MPa)	Average Flexural Strength (MPa)
	L	W	H				
7	501	100.84	101.1	12210	2391	3.5	3.80
7	500	100.64	100.69	12233	2414	4.4	
7	501	100.54	100.55	12202	2409	3.5	

Table (4. 38): Tensile Strength for 28 days for the 0.5% WMF

0.5% of Waste Money Fibers (0.5% WMF)							
Age (days)	Dimensions (mm)			Mass (g)	Density (kg/m ³)	Flexural Strength (MPa)	Average Flexural Strength (MPa)
	L	W	H				
28	500	101.04	101.33	12243	2392	6.5	6.80
28	500	100.57	101.14	12254	2409	6.8	
28	500	100.54	100.75	12231	2415	7.1	

For the 0.5% waste money fibres added to the mix, it can be seen in the above tables 4.37 and 4.38 that the average flexural strength for 7 days is 3.8 MPa and for the 28 days it reached up the 6.8 MPa.

Table (4. 39): Tensile Strength for 7 days for the 0.25% WMF

0.25% of Waste Money Fibers (0.25% WMF)							
Age (days)	Dimensions (mm)			Mass (g)	Density (kg/m ³)	Flexural Strength (MPa)	Average Flexural Strength (MPa)
	L	W	H				
7	500	101.47	101.74	12271	2377	5	4.17
7	500	101.64	101.75	12399	2398	3.5	
7	500	101.54	101.24	12273	2388	4	

Table (4. 40): Tensile Strength for 28 days for the 0.25% WMF

0.25% of Waste Money Fibers (0.25% WMF)							
Age (days)	Dimensions (mm)			Mass (g)	Density (kg/m ³)	Flexural Strength (MPa)	Average Flexural Strength (MPa)
	L	W	H				
28	500	101.14	101.36	12363	2412	8	7.60
28	501	101.06	101.06	12290	2402	7.3	
28	500	100.94	100.7	12286	2417	7.5	

For the 0.25% waste money fibres added to the mix, it can be seen in the above tables 4.39 and 4.40 that the average flexural strength for 7 days is 4.17 MPa and for the 28 days it reached up the 7.6MPa.

Table (4. 41): Flexural Strength for all Mixes for 7 days

Mix Type	Flexural Strength (MPa) @ 7 Days
Control Mix	3.7
1% WMF	4.2
0.5% WMF	3.8
0.25% WMF	4.17

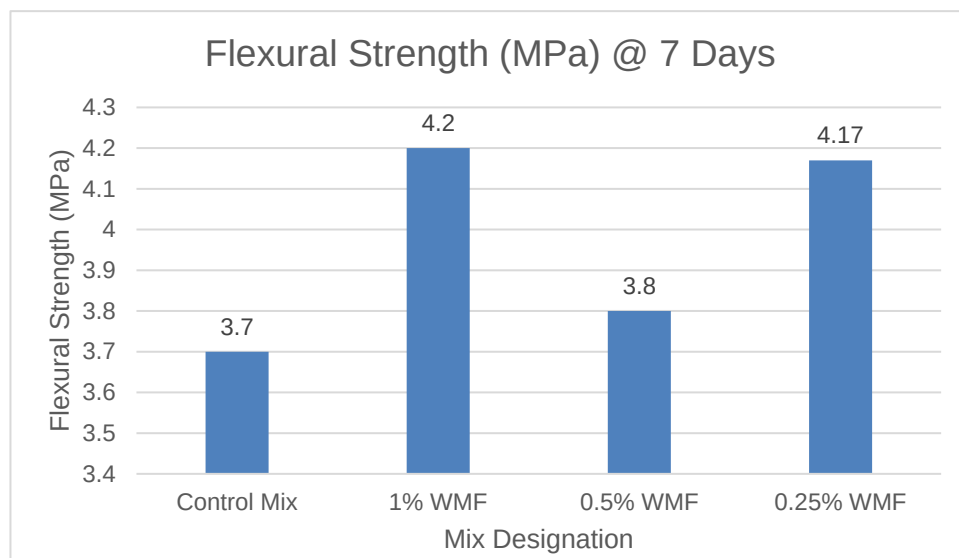


Figure (4. 10): Flexural Strength for all Mixes for 7 days

From Table 4.41 and Figure 4.10, we can see the comparison between the 4 mixes which are the control mix, 1% of waste money fibre mix, 0.5% of waste money fibres mix and 0.25% of waste money fibres mix in regards to the flexural strength in 7 days which is 3.7 MPa, 4.2 MPa, 3.8 MPa and 4.17 MPa respectively.

This shows that the maximum flexural strength in 7 days was achieved for the mix with 1% of waste money fibres.

Table (4. 42): Flexural Strength for all Mixes for 28 days

Mix Type	Flexural Strength (MPa) @ 28 Days
Control Mix	6.6
1% WMF	6.7
0.5% WMF	6.8
0.25% WMF	7.6

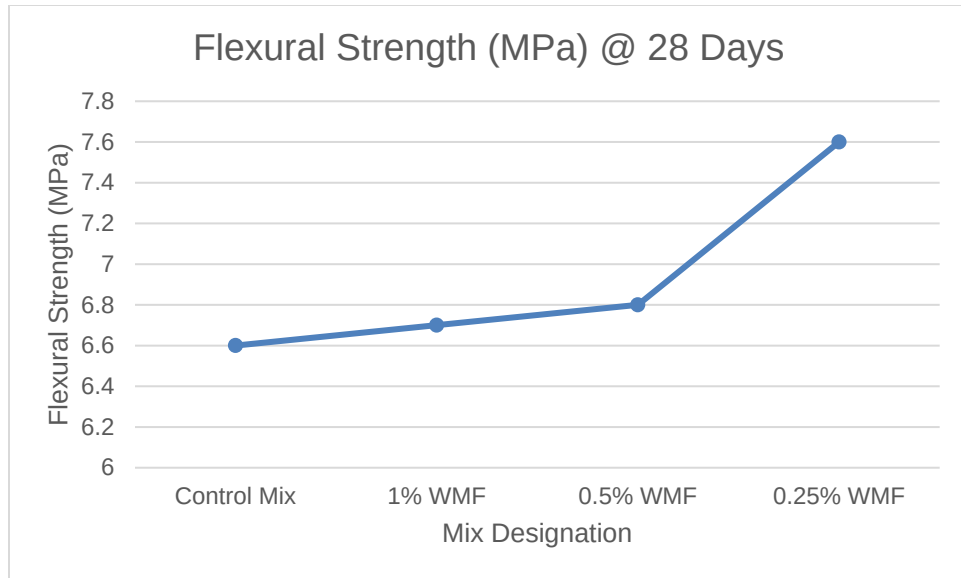


Figure (4. 11): Flexural Strength Curve for all the Mixes @ 28 Days

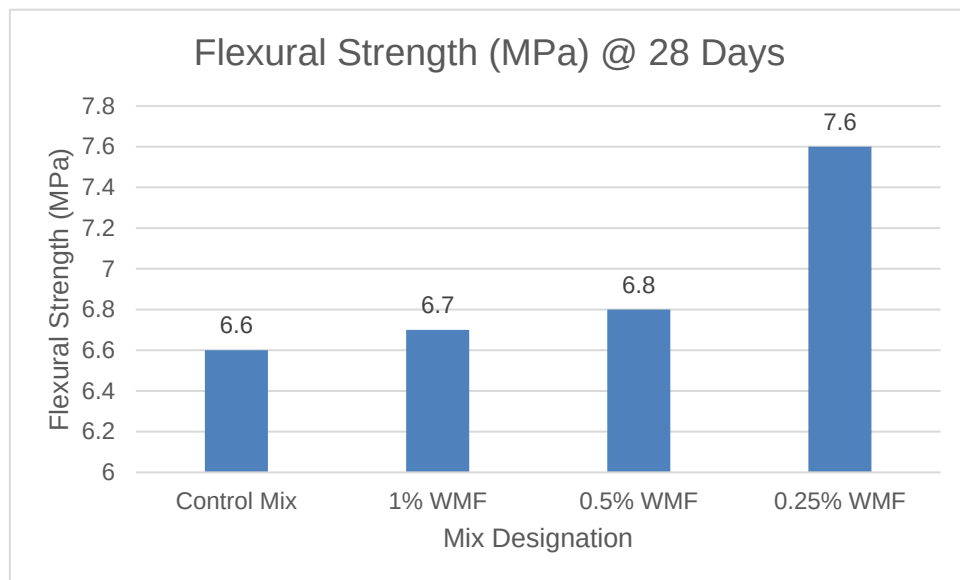


Figure (4. 12): Flexural Strength for all Mixes for 28 days

From Table 4.42 and Figure 4.11 and Figure 4.12, we can see the comparison between the 4 mixes which are the control mix, 1% of waste money fibre mix, 0.5% of waste money fibres mix and 0.25% of waste money fibres mix in regards to the flexural strength in 7 days which is 6.6 MPa, 6.7 MPa, 6.8 MPa and 7.6 MPa respectively.

This shows that the maximum flexural strength in 28 days was achieved for the mix with 0.25% of waste money fibres which is 15.15% more than the flexural strength of the control mix.

And the control mix can be seen as the least one with the flexural strength.



Figure (4. 13): Flexural Strength for the sample with waste money fibers



Figure (4. 14): Flexural Strength for the Control Mix

From Figure 4.13 and Figure 4.14, it can be seen the difference between the control mix and any mix with waste money fibers when the flexural strength has been performed.

It can be clearly seen that the mix with waste money fibers when it reached to the maximum load it did not break fully as it got held by the fibers making the two pieces still connected together.

Whereas the control mix when it reached to the maximum load it broke fully.

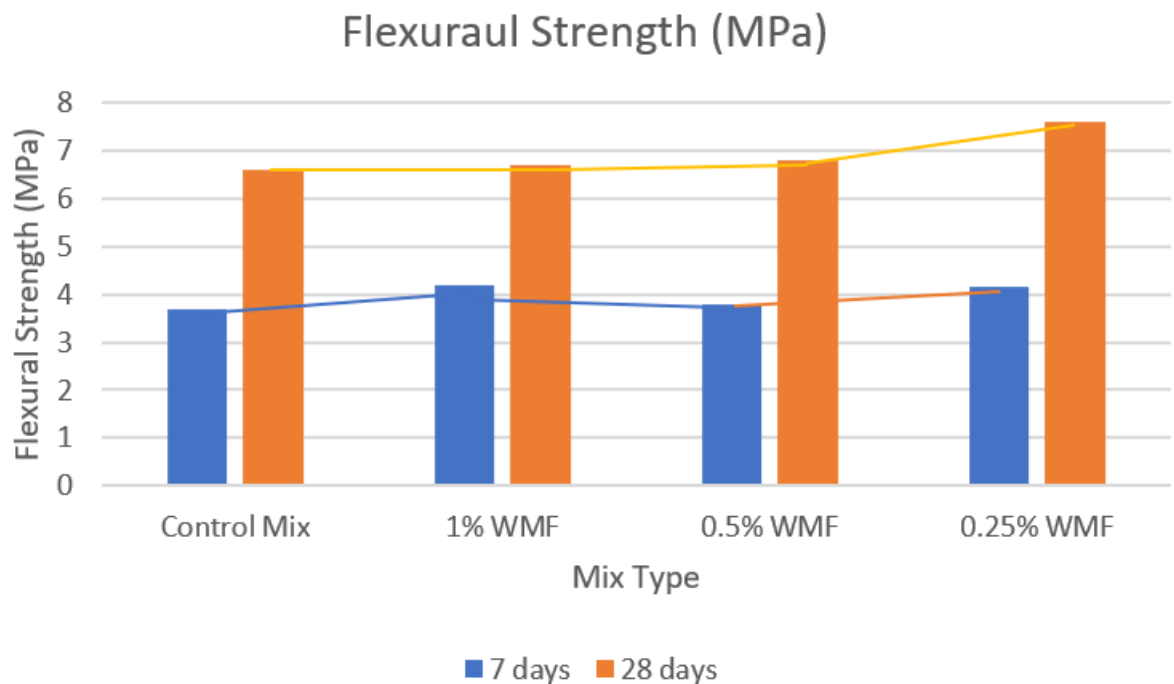


Figure (4. 15): Flexural Strength for all mixes

Figure 4.15 shows the overall results for the flexural strength for all mixes in 7 and 28 days.

4.4.3 Tensile Strength

Table (4. 43): Tensile Strength for 7 days for the Control Mix

Control Mix						
Age (days)	Dimensions (mm)		Mass (g)	Density (kg/m ³)	Tensile Strength (MPa)	Average Tensile Strength (MPa)
	L	D				
7	63.74	63.44	456	2263	2.91	2.97
7	63.38	63.84	458	2258	3.15	
7	63.18	63.57	464	2314	2.84	

Table (4. 44): Tensile Strength for 28 days for the Control Mix

Control Mix						
Age (days)	Dimensions (mm)		Mass (g)	Density (kg/m ³)	Tensile Strength (MPa)	Average Tensile Strength (MPa)
	L	W				
28	63.84	63.74	458	2248	3.85	4.29
28	63.16	63.63	460	2290	4.82	
28	63.53	63.64	459	2271	4.19	

For the control mix, it can be seen in the above tables 4.43 and 4.44 that the average tensile strength for 7 days is 2.97 MPa and for the 28 days it reached up the 4.29 MPa.

Table (4. 45): Tensile Strength for 7 days for the 1% WMF

1% of Waste Money Fibers (1% WMF)						
Age (days)	Dimensions (mm)		Mass (g)	Density (kg/m ³)	Tensile Strength (MPa)	Average Tensile Strength (MPa)
	L	W				
7	63.44	63.86	463	2279	3.41	3.17
7	63.74	63.93	459	2243	3.08	
7	63.66	63.88	460	2255	3.02	

Table (4. 46): Tensile Strength for 28 days for the 1% WMF

1% of Waste Money Fibers (1% WMF)						
Age (days)	Dimensions (mm)		Mass (g)	Density (kg/m ³)	Tensile Strength (MPa)	Average Tensile Strength (MPa)
	L	W				
28	63.75	63.3	465	2318	4.64	4.93
28	63.45	63.31	462	2313	4.96	
28	63.5	63.28	463	2318	5.2	

For the 1% waste money fibres added to the mix, it can be seen in the above tables 4.45 and 4.46 that the average tensile strength for 7 days is 3.17 MPa and for the 28 days it reached up the 4.93 MPa.

Table (4. 47): Tensile Strength for 7 days for the 0.5% WMF

0.5% of Waste Money Fibers (0.5% WMF)						
Age (days)	Dimensions (mm)		Mass (g)	Density (kg/m ³)	Tensile Strength (MPa)	Average Tensile Strength (MPa)
	L	W				
7	63.28	63.55	460	2292	3.72	3.47
7	63.54	63.48	458	2277	3.39	
7	63.33	63.51	454	2263	3.29	

Table (4. 48): Tensile Strength for 28 days for the 0.5% WMF

0.5% of Waste Money Fibers (0.5% WMF)						
Age (days)	Dimensions (mm)		Mass (g)	Density (kg/m ³)	Tensile Strength (MPa)	Average Tensile Strength (MPa)
	L	W				
28	63.5	63.6	462	2290	4.67	5.06
28	63.58	63.39	466	2322	5.45	
28	63.19	63.65	459	2283	5.05	

For the 0.5% waste money fibres added to the mix, it can be seen in the above tables 4.47 and 4.48 that the average tensile strength for 7 days is 3.47 MPa and for the 28 days it reached up the 5.06 MPa.

Table (4. 49): Tensile Strength for 7 days for the 0.25% WMF

0.25% of Waste Money Fibers (0.25% WMF)						
Age (days)	Dimensions (mm)		Mass (g)	Density (kg/m ³)	Tensile Strength (MPa)	Average Tensile Strength (MPa)
	L	W				
7	63.53	63.65	459	2271	3.21	3.21
7	63.41	63.61	456	2263	3.38	
7	63.5	63.54	458	2275	3.05	

Table (4. 50): Tensile Strength for 28 days for the 0.25% WMF

0.25% of Waste Money Fibers (0.25% WMF)						
Age (days)	Dimensions (mm)		Mass (g)	Density (kg/m ³)	Tensile Strength (MPa)	Average Tensile Strength (MPa)
	L	W				
28	63.49	63.58	462	2292	4.48	4.87
28	63.36	63.8	463	2286	5.28	
28	63.45	63.54	460	2286	4.86	

For the 0.25% waste money fibres added to the mix, it can be seen in the above tables 4.49 and 4.50 that the average tensile strength for 7 days is 3.21 MPa and for the 28 days it reached up the 4.87 MPa.

Table (4. 51): Tensile Strength for all Mixes for 7 days

Mix Type	Tensile Strength (MPa) @ 7 Days
Control Mix	2.97
1% WMF	3.17
0.5% WMF	3.47
0.25% WMF	3.21

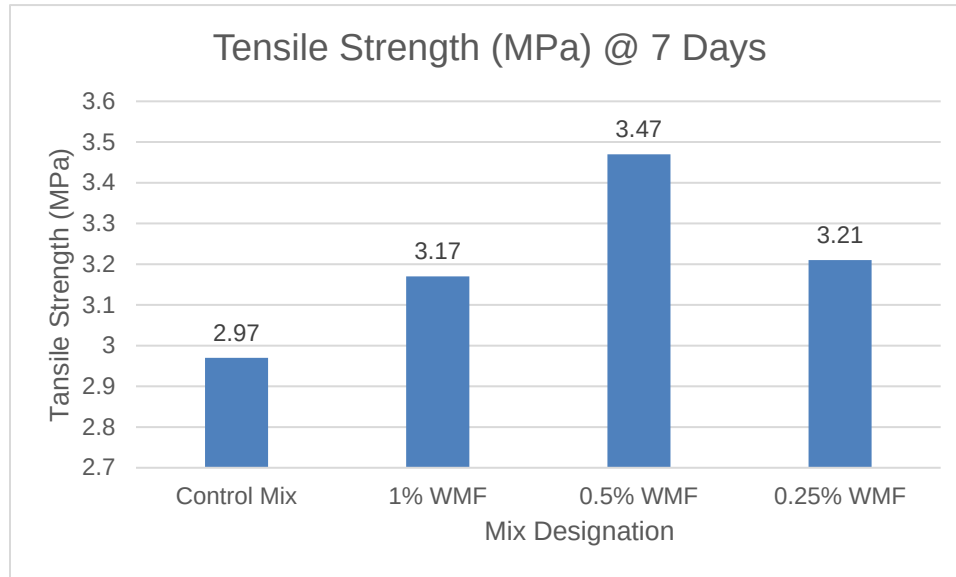


Figure (4. 16): Tensile Strength for all Mixes for 7 days

From Table 4.51 and Figure 4.16, it can see the comparison between the 4 mixes which are the control mix, 1% of waste money fibre mix, 0.5% of waste money fibres mix and 0.25% of waste money fibres mix in regards to the tensile strength in 7 days which is 2.97 MPa, 3.17 MPa, 3.47 MPa and 3.21 MPa respectively.

This shows that the maximum flexural strength in 7 days was achieved for the mix with 0.5% of waste money fibres.

Table (4. 52): Tensile Strength for all Mixes for 28 days

Mix Type	Tensile Strength (MPa) @ 28 Days
Control Mix	4.29
1% WMF	4.93
0.5% WMF	5.06
0.25% WMF	4.87

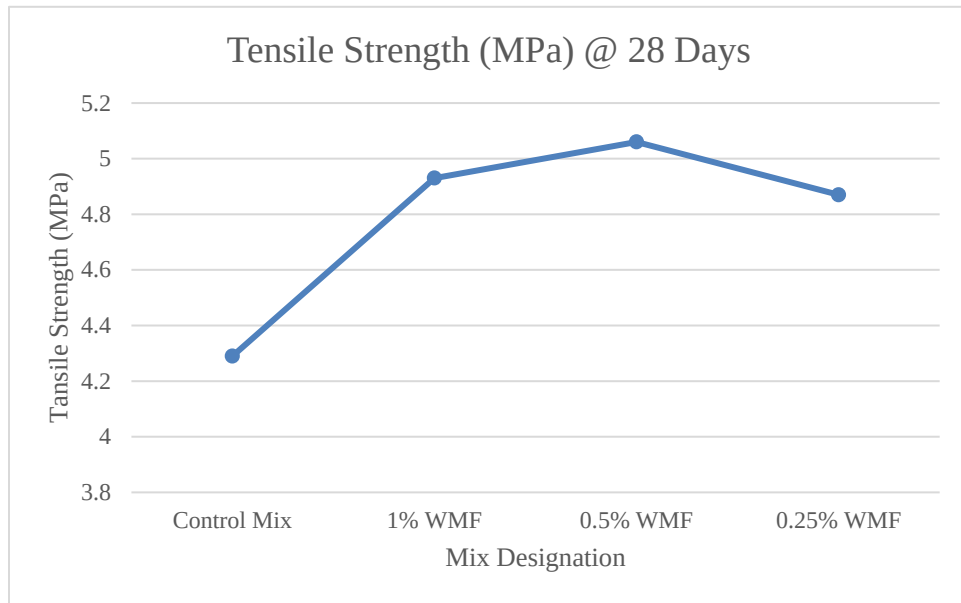


Figure (4. 17): Tensile Strength Curve for all Mixes @ 28 Days

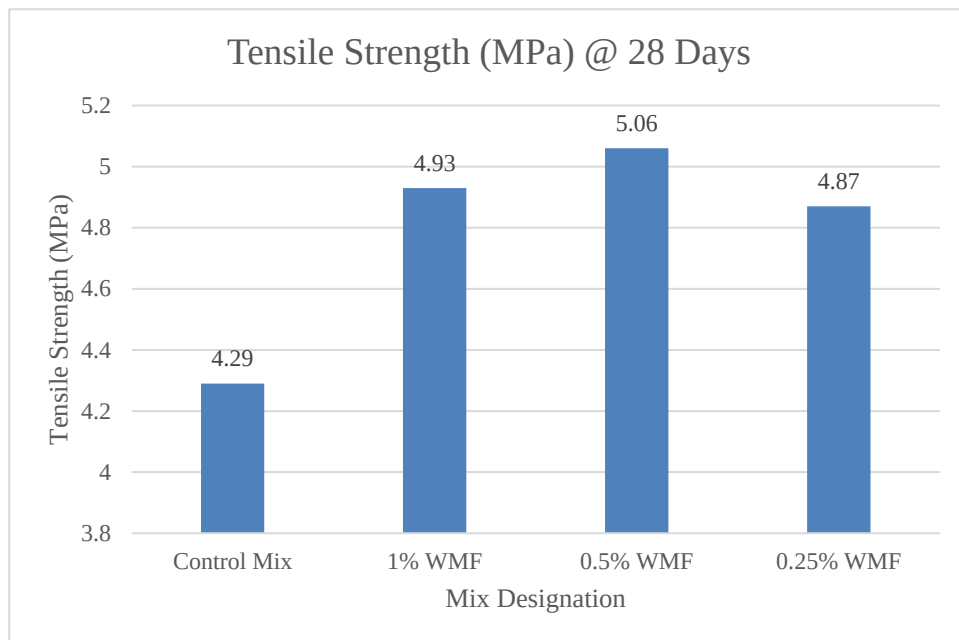


Figure (4. 18): Tensile Strength for all Mixes for 28 days

From Table 4.52 and Figure 4.17 and Figure 4.18, it can see the comparison between the 4 mixes which are the control mix, 1% of waste money fibre mix, 0.5% of waste money fibres mix and 0.25% of waste money fibres mix in regards to the tensile strength in 28 days which is 4.29 MPa, 4.93 MPa, 5.06

MPa and 4.87 MPa respectively.

This shows that the maximum tensile strength in 28 days was also achieved for the mix with 0.5% of waste money fibres with an increase of 17.94% from the control mix value.



Figure (4. 19): Samples prior to Tensile Strength Test



Figure (4. 20): Sample after Tensile Strength Test

Figure 4.21 shows the results of the tensile strength test for all samples for 7 and 28 days.

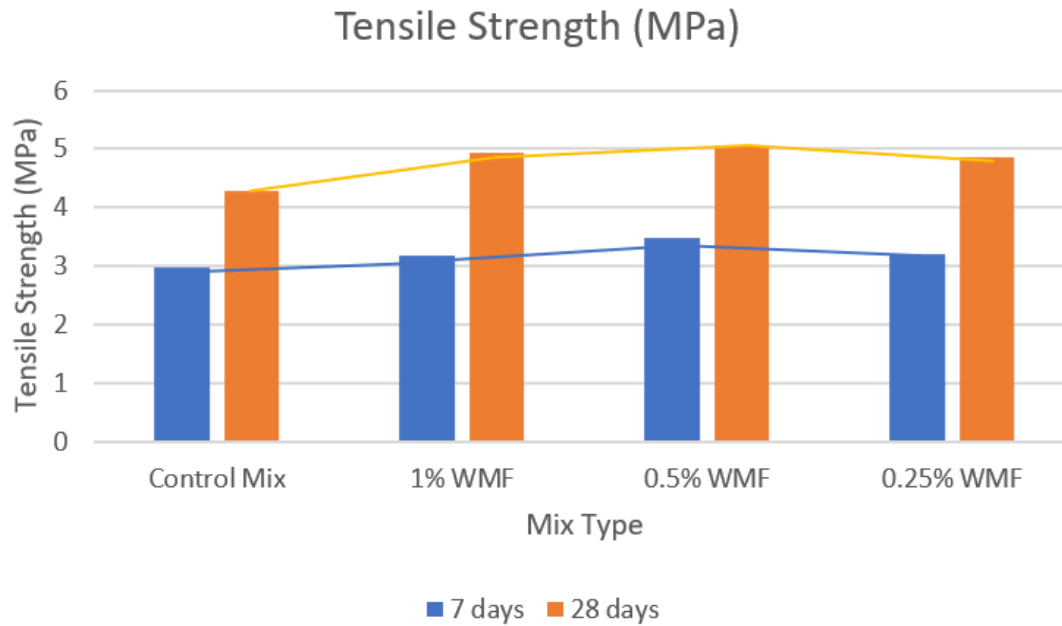


Figure (4. 21) Tensile Strength for all samples

4.4.4 Water Absorption

Table (4. 53): Water Absorption Results for the Control Mix

Control Mix										
Age (days)	Dimensions (mm)		Mass of Oven Dried Specimen (g)	Mass After Immersion in Water (g)	Measured Water Absorption %	Correction Factor	Corrected Water Absorption %	Average Water Absorption %	Density of Specimen (Kg/m³)	Average Density (Kg/m³)
	L	D								
28	63.6	63.47	471.81	483.9	2.56	0.85	2.17	2.26	2430	2413.33
28	63.2	63.44	471.83	483.6	2.49	0.85	2.11		2440	
28	63.4	63.43	458.95	472.6	2.97	0.85	2.51		2370	

Table (4. 54): Water Absorption Results for the 1% WMF

1% of Waste Money Fibers (1% WMF)										
Age (days)	Dimensions (mm)		Mass of Oven Dried Specimen (g)	Mass After Immersion in Water (g)	Measured Water Absorption %	Correction Factor	Corrected Water Absorption %	Average Water Absorption %	Density of Specimen (Kg/m³)	Average Density (Kg/m³)
	L	D								
28	63	63.47	438.84	449.5	2.43	0.84	2.05	2.07	2270	2253.33
28	63.4	63.53	430.62	441.6	2.55	0.85	2.16		2220	
28	63.3	63.48	439.47	449.9	2.37	0.85	2.01		2270	

Table (4. 55): Water Absorption Results for the 0.5% WMF

0.5% of Waste Money Fibers (0.5% WMF)										
Age (days)	Dimensions (mm)		Mass of Oven Dried Specimen (g)	Mass After Immersion in Water (g)	Measured Water Absorption %	Correction Factor	Corrected Water Absorption %	Average Water Absorption %	Density of Specimen (Kg/m³)	Average Density (Kg/m³)
	L	D								
28	63.1	63.49	452.8	460.8	1.77	0.85	1.49	1.51	2330	2313.33
28	62.1	63.53	441.2	449.2	1.81	0.84	1.52		2300	
28	62.9	63.62	447.7	455.7	1.79	0.85	1.51		2310	

Table (4. 56): Water Absorption Results for the 0.25% WMF

0.25% of Waste Money Fibers (0.25% WMF)										
Age (days)	Dimensions (mm)		Mass of Oven Dried Specimen (g)	Mass After Immersion in Water (g)	Measured Water Absorption %	Correction Factor	Corrected Water Absorption %	Average Water Absorption %	Density of Specimen (Kg/m³)	Average Density (Kg/m³)
	L	D								
28	60.7	63.54	438.5	448.1	2.19	0.83	1.83	1.84	2340	2356.67
28	62.1	63.57	451.6	461.2	2.13	0.84	1.79		2360	
28	60.2	63.5	436.3	446.2	2.27	0.83	1.89		2370	

From Tables 4.53, 4.54, 4.55 and 4.56, it can see the comparison between the 4 mixes which are the control mix, 1% of waste money fibre mix, 0.5% of waste money fibres mix and 0.25% of waste money fibres mix in regards to the average water absorption percentatge in 28 days which is 2.26%, 2.07%, 1.51% and 1.84% respectively.

And the average density is 2413.33 Kg/m³, 2253.33 Kg/m³, 2313.33 Kg/m³ and 2356.67 Kg/m³.

Table (4. 57): Average Water Absorption

Mix Type	Average Water Absorption %
Control Mix	2.26
1% WMF	2.07
0.5% WMF	1.51
0.25% WMF	1.84

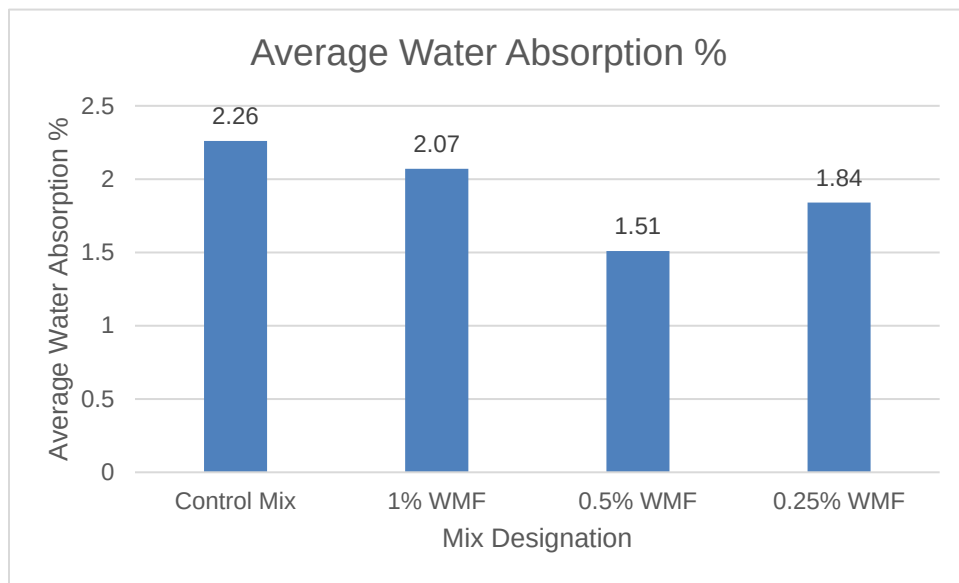


Figure (4. 22): Average Water Absorption for all the mixes

From the table 4.57 and figure 4.22, it can be seen that the control mix has the highest water absorption percentage of 2.26% whereas all the other mixes with waste money fibers have lower water absorption percentages with the lowest of 1.51% for the mix with 0.5% of waste money fibers with a percentage of 33.18% less.

4.4.5 Ultrasonic Pulse Velocity of Concrete

Table (4. 58): Ultrasonic Pulse Velocity Results for the Control Mix

Control Mix			
Age (days)	UPV (Km/s)		Average UPV (Km/s)
	Length Wise	Width Wise	
28	3.330	3.320	3.315
28	3.070	3.360	
28	3.400	3.410	

Table (4. 59): Ultrasonic Pulse Velocity Results for the 1% WMF

1% of Waste Money Fibers (1% WMF)			
Age (days)	UPV (Km/s)		Average UPV (Km/s)
	Length Wise	Width Wise	
28	3.360	3.310	3.373
28	3.410	3.370	
28	3.390	3.400	

Table (4. 60) Ultrasonic Pulse Velocity Results for the 0.5% WMF

0.5% of Waste Money Fibers (0.5% WMF)			
Age (days)	UPV (Km/s)		Average UPV (Km/s)
	Length Wise	Width Wise	
28	3.610	3.590	3.605
28	3.610	3.630	
28	3.580	3.610	

Table (4. 61): Ultrasonic Pulse Velocity Results for the 0.25% WMF

0.25% of Waste Money Fibers (0.25% WMF)			
Age (days)	UPV (Km/s)		Average UPV (Km/s)
	Length Wise	Width Wise	
28	3.910	3.930	3.910
28	3.930	3.890	
28	3.890	3.910	

From tables 4.58, 4.59, 4.60 and 4.61, it can see the comparison between the 4 mixes which are the control mix, 1% of waste money fibre mix, 0.5% of waste money fibres mix and 0.25% of waste money fibres mix in regards to

the average ultrasonic pulse velocity in 28 days which is 3.315 Km/s, 3.373 Km/s, 3.605 Km/s and 3.910 Km/s respectively.

Table (4. 62): Ultrasonic Pulse Velocity Results for all the mixes

Mix Type	Average UPV (Km/s)
Control Mix	3.315
1% WMF	3.373
0.5% WMF	3.605
0.25% WMF	3.910

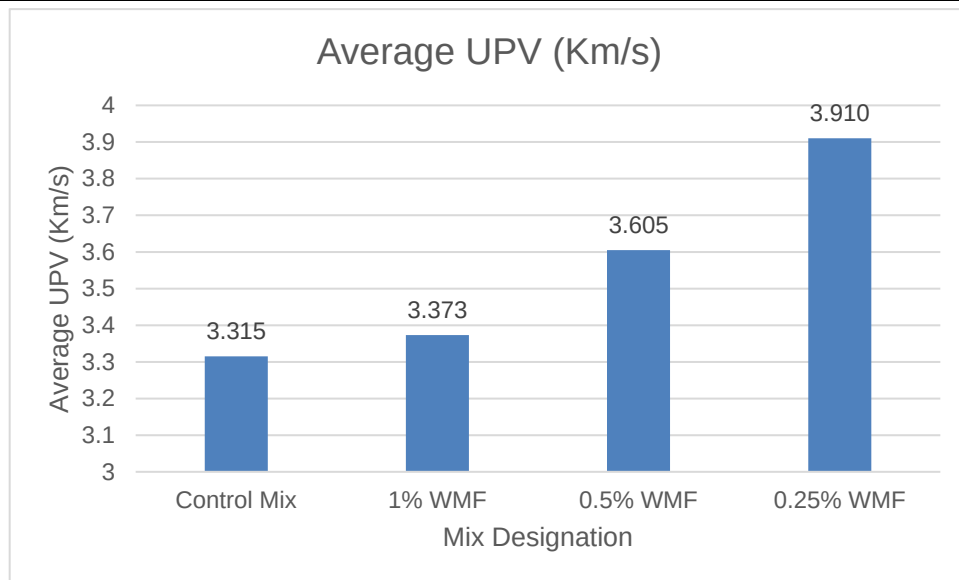


Figure (4. 23): Ultrasonic Pulse Velocity Results for all the mixes

From the table 4.62 and figure 4.23, it can be seen that the mix with the highest ultrasonic pulse velocity is the mix with 0.25% of waste money fibers and the one with the lowest is the control mix with a percentage of 15.217%.

4.4.6 Rapid Chloride Penetration Test

Table (4. 63): Charges Passed in the Control Mix

Control Mix		
Age (days)	Diameter (mm)	Charge Passed (Coulombs)
28	93.260	1549.000
28	93.290	1548.000
28	93.300	1570.000

Table (4. 64): Charges Passed in the 1% WFM Mix

1% of Waste Money Fibers (1% WMF)		
Age (days)	Diameter (mm)	Charge Passed (Coulombs)
28	93.320	1367.000
28	93.250	1347.000
28	93.270	1353.000

Table (4. 65): Charges Passed in the 0.5% WFM Mix

0.5% of Waste Money Fibers (0.5% WMF)		
Age (days)	Diameter (mm)	Charge Passed (Coulombs)
28	93.230	1234.000
28	93.380	1275.000
28	93.220	1257.000

Table (4. 66): Charges Passed in the 0.25% WFM Mix

0.25% of Waste Money Fibers (0.25% WMF)		
Age (days)	Diameter (mm)	Charge Passed (Coulombs)
28	93.410	1185.000
28	93.520	1137.000
28	93.290	1165.000

As it can be seen from table s 4.63, 4.64, 4.65 and 4.66 that the values of the charges passed through the specimens for all the mixes (The control mix, the

1% WFM, 0.5% WFM and the 0.25% WFM) are all below 2000 which as per the ASTM C1202-10 standard is considered as a low value.

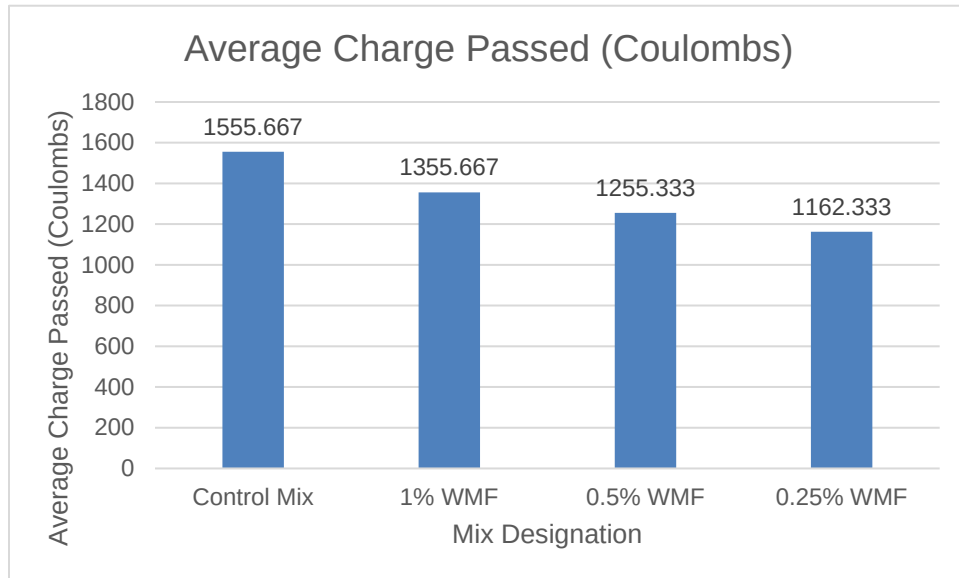


Figure (4. 24): Average Charge Passed for all the mixes in 28 days

From Figure 4.24, which shows the average values of 3 specimens for each mix for the charges passed which is representing the penetration of the chloride, it can be seen that the control mix with no additions has the highest rate of 1555.67, then comes the mix with 1% of waste money fibers then the 0.5% mix and last with the least penetration rate is the 0.25% mix with 1162.33 value.

The Percentage difference between the 0.25% mix and the control mix is 25.28% .

Overall, all the values are considered low as per the ASTM C1202-10 standard which falls under the category of chrages between 1000 to 2000 are considered low.

Chapter 5: Conclusion and Recommendations

5.1 Main Findings

The main findings of this study are summarized through answering the research questions and meeting the objectives set in the introduction chapter. Both are described below:

1. For the compressive strength in 28 days, it can be seen that the mix with higher strength is the one with 0.5% of waste money fibers with a value of 46.97 MPa, then the mix with the 0.25% of waste money fibers with a strength of 44.57 MPa then the control mix with a value of 43.8 MPa and lastly was the mix with the 1% of waste money fibers with a value of 40.33 MPa.

This concludes that the waste money fibers do have an effect in the increment of the compressive strength and the optimum value was obtained when 0.5% of the waste money fibers was added with an increment of 7.23% from the control mix.

2. For the flexural strength. It has been noticed that the mix with 0.25% of waste money fibers had the highest value with an increment of 15.15% from the control mix. Then it comes the mix with 0.5% of waste money fibers with an increment of 3.03%

This also concludes that the waste money fibers do have an effect in the increment of the flexural strength and the optimum value was obtained when

0.5% of the waste money fibers was added with an increment of 7.23% from the control mix.

And it could be clearly seen that the sample with waste money fibers when reach to maximum load it did break but the two pieces were still connected to each other because of the fibers while the opposite with the control sample as it broke completely into two pieces.

3. For the tensile strength, it can be seen from the results that the mix with 0.5% of waste money fibers has the highest strength with a value of 5.06 MPa with an increment percentage of 17.94% from the control mix which has a value of 4.29 MPa.

4. For the water absorption results, it can be seen that the mixtures with the waste money fibers absorb lesser water the control mix.

And from the results, it can be seen that the control mix has the highest water absorption percentage of 2.26% whereas all the other mixes with waste money fibers have lower water absorption percentages with the lowest of 1.51% for the mix with 0.5% of waste money fibers with a percentage of 33.18% less.

And this means that adding waste money fibers is an advantage in this matter and it can be used in the ground structures.

5. For the ultrasonic pulse velocity results, it can be seen that the mix with the 0.25% of waste money fibers has the higher value then the 0.5% mix then the 1% mix and lastly is the control mix.

This concludes the waste money fibers is better for the concrete in terms of the presence of cracks, voids and other types of deterioration.

6. From the SEM images of the sample with waste money fibers, it could be clearly seen the physical bonding between the fibers and the cement paste which resulted to greater strength overall in compression, tension and flexural.

5.2 Recommendations For Further Work

After performing this study, a recommendation is proposed to further improve the study which is as below.

- The study was performed by adding the waste money fibers as addition to the concrete mix. A new study can be done by replacing an amount of the cement with the waste money fibers in order to make a comparison for the results.

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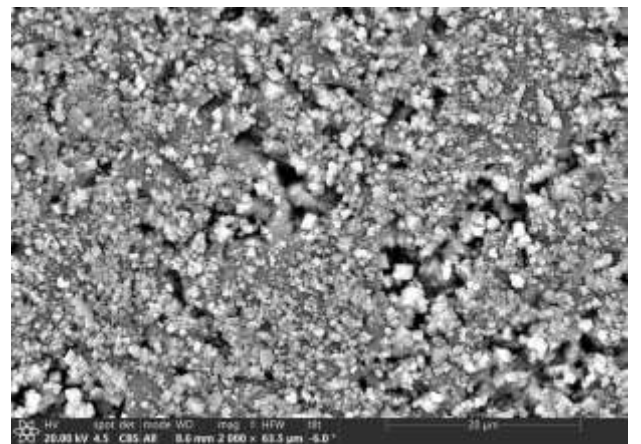
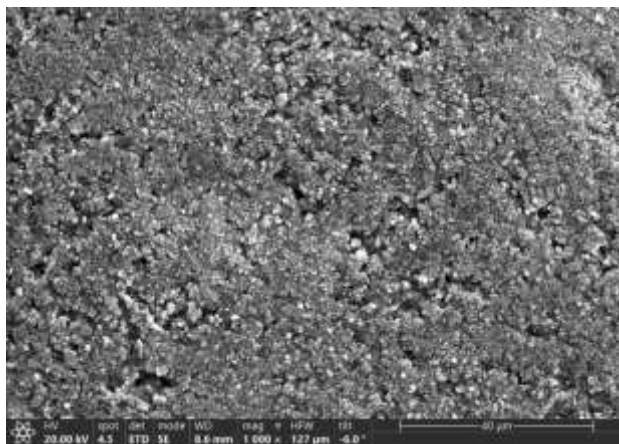
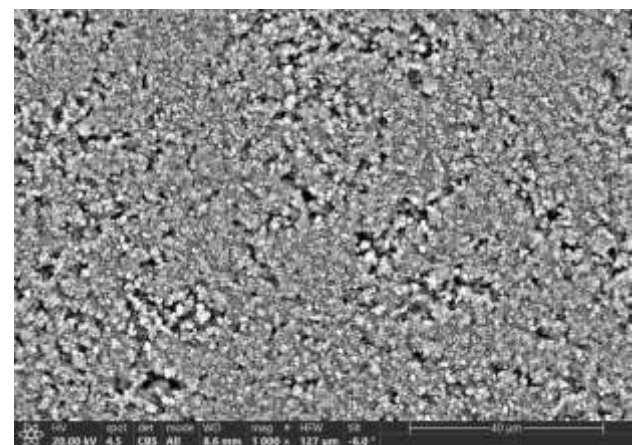
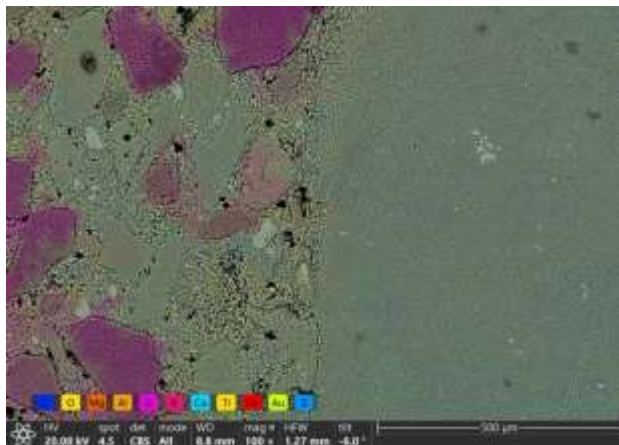
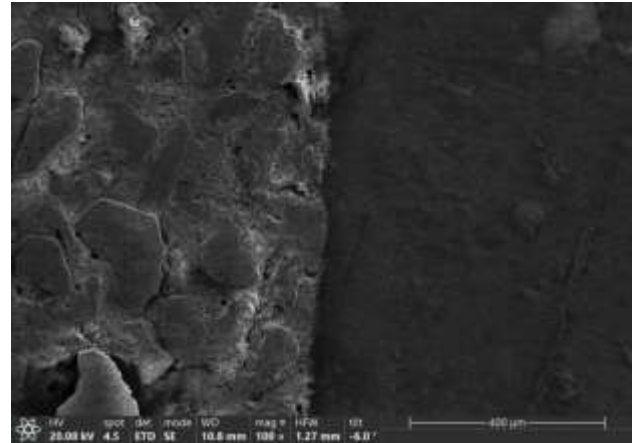
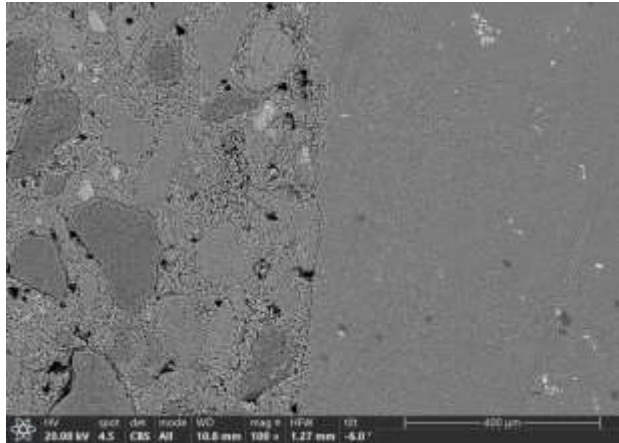
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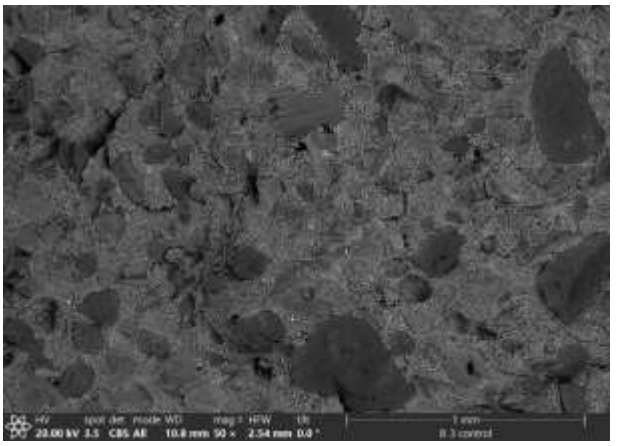
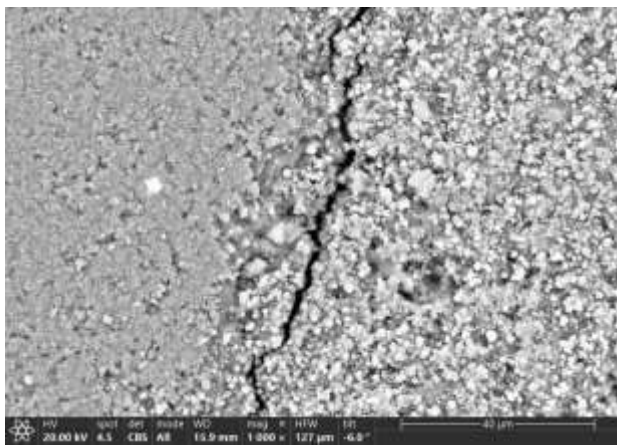
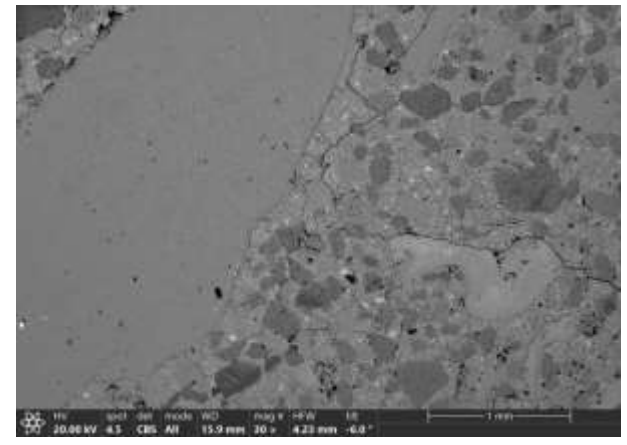
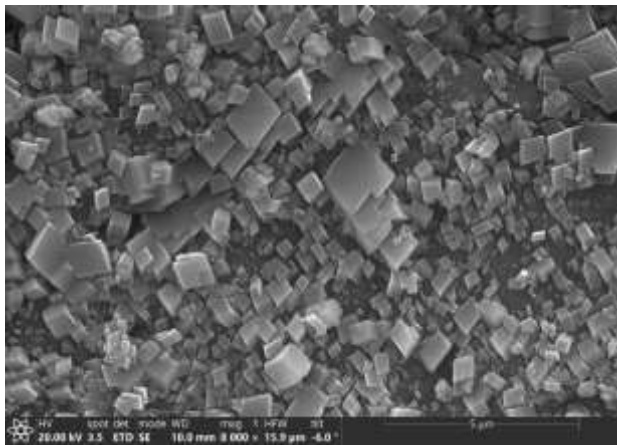
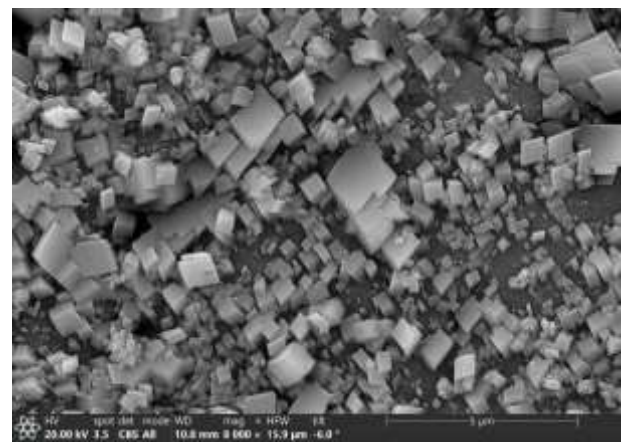
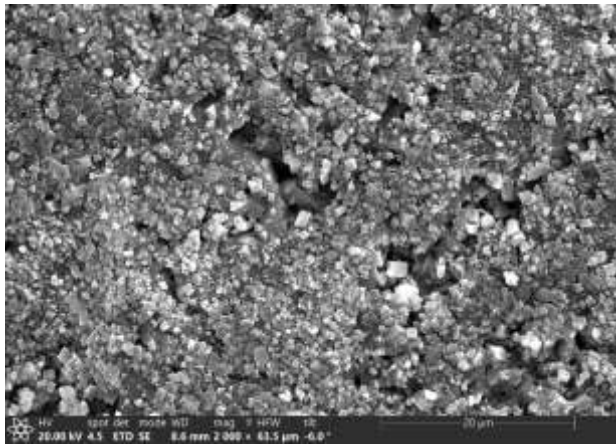
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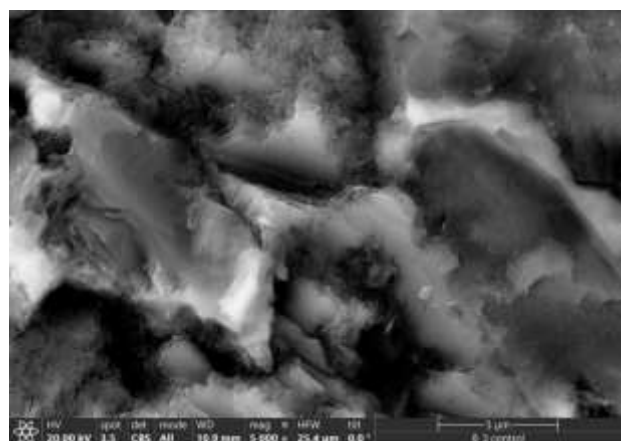
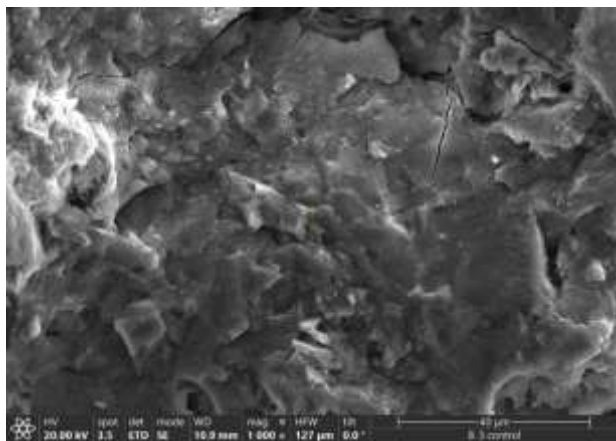
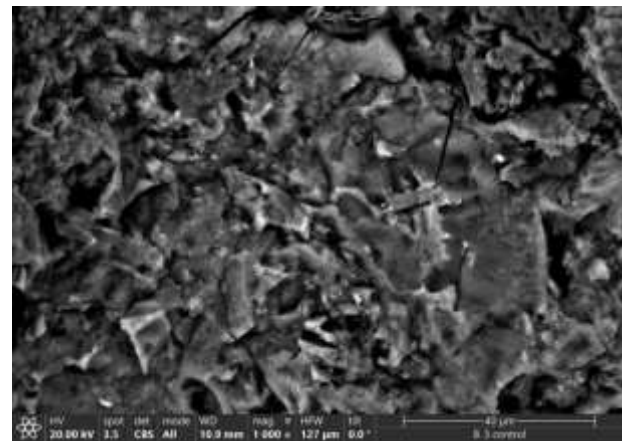
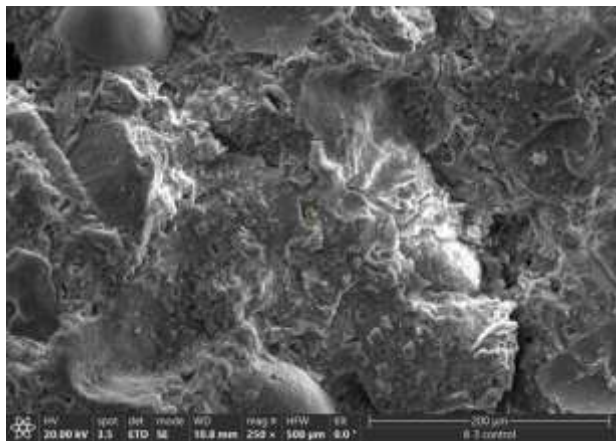
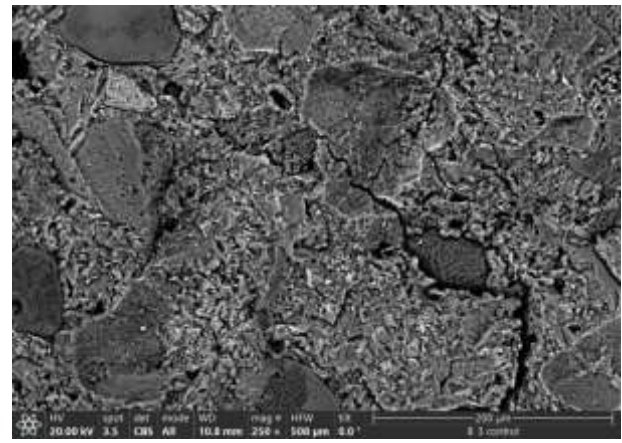
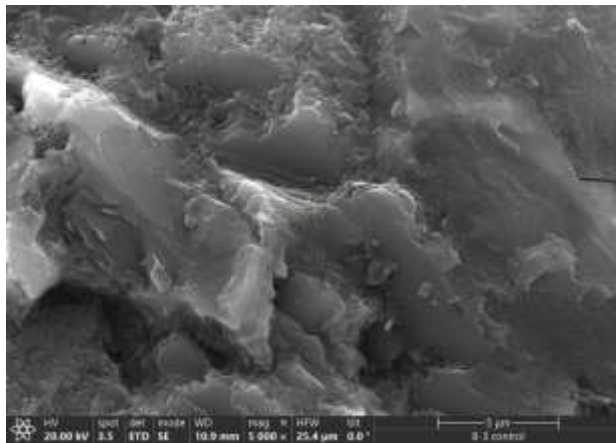
Zaki, H., Gorgis, I. and Salih, S. (2018) *Mechanical properties of Papercrete*. Available at: https://www.matec-conferences.org/articles/mateconf/pdf/2018/21/mateconf_bcee32018_02016.pdf (Accessed: 11 May 2024).

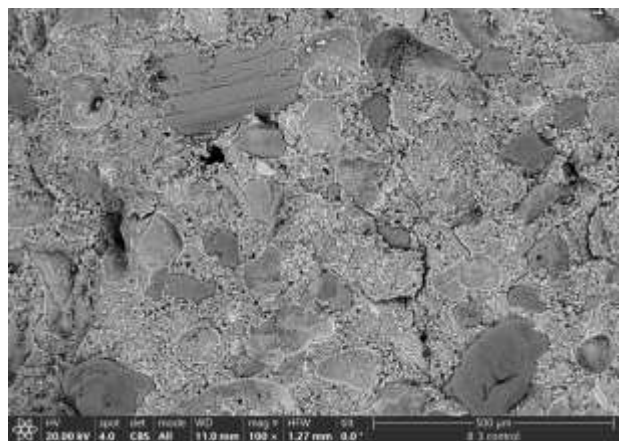
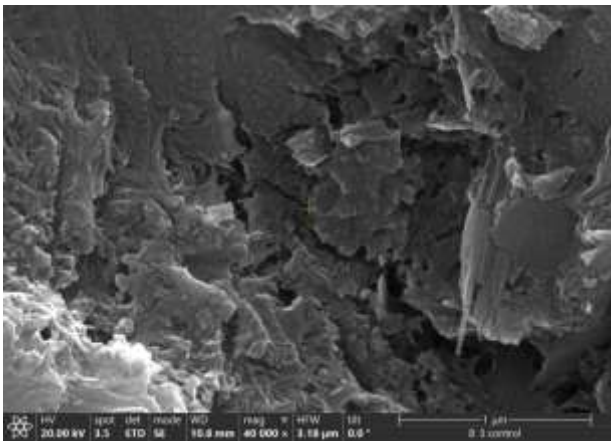
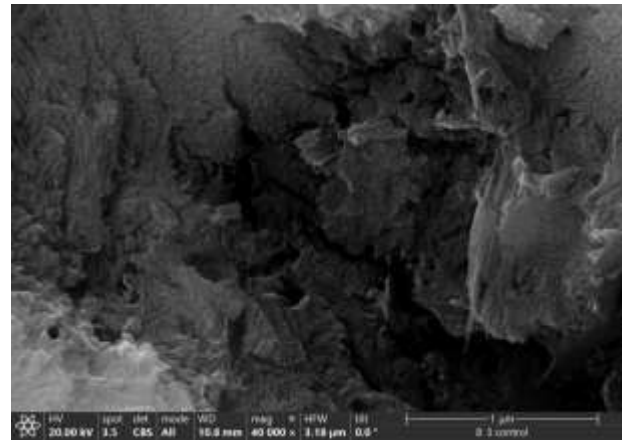
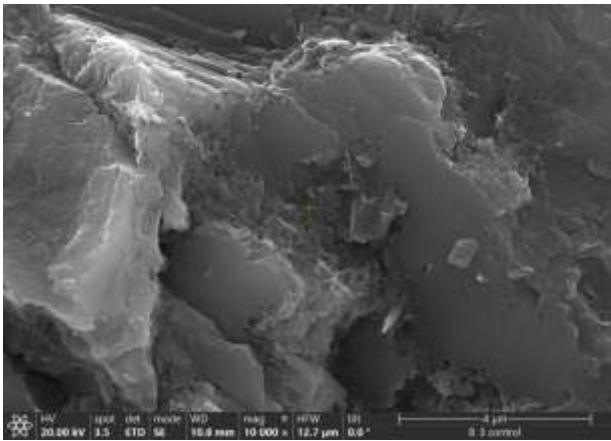
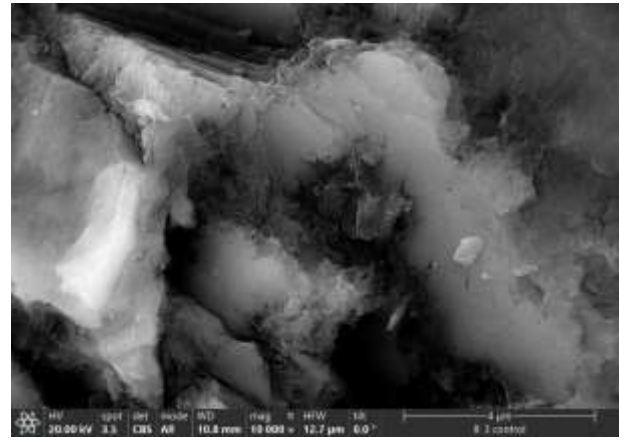
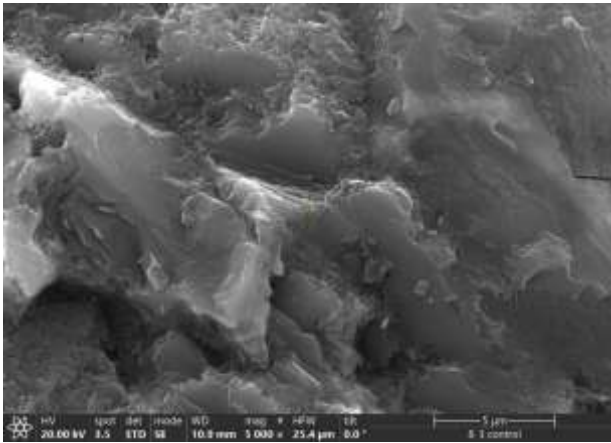
Appendix

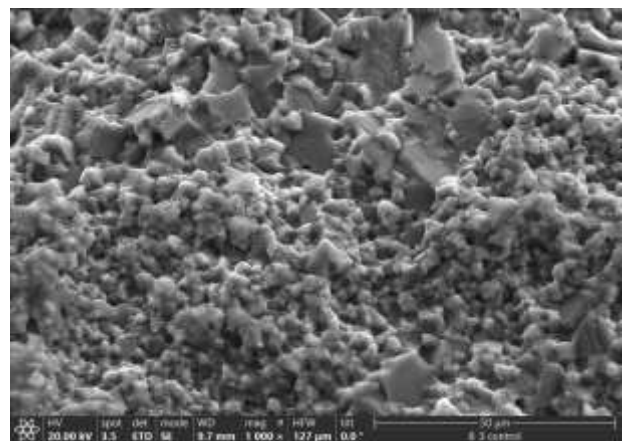
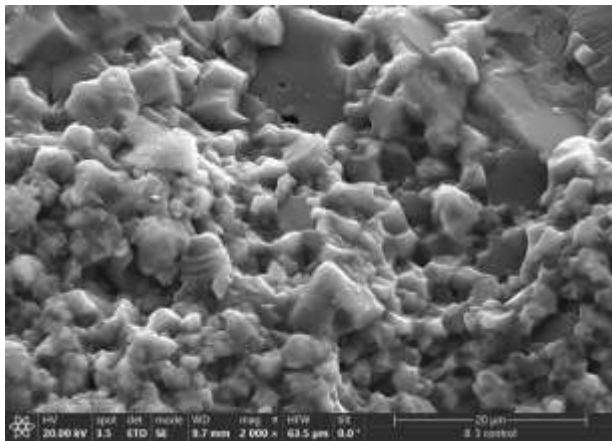
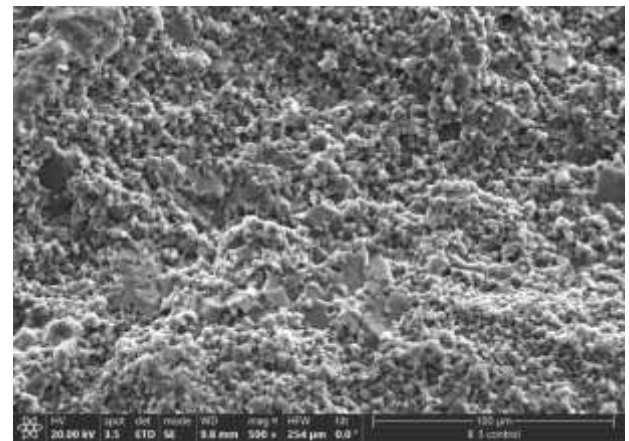
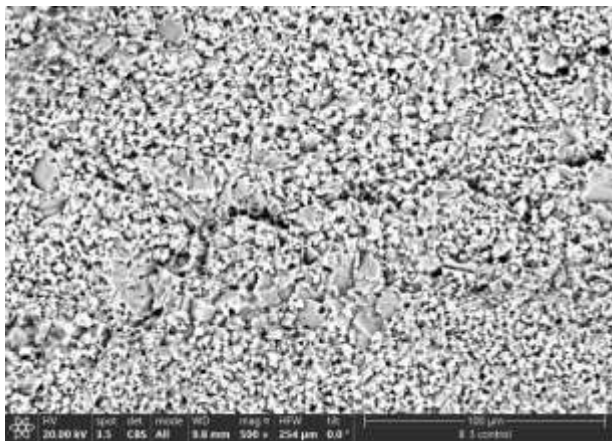
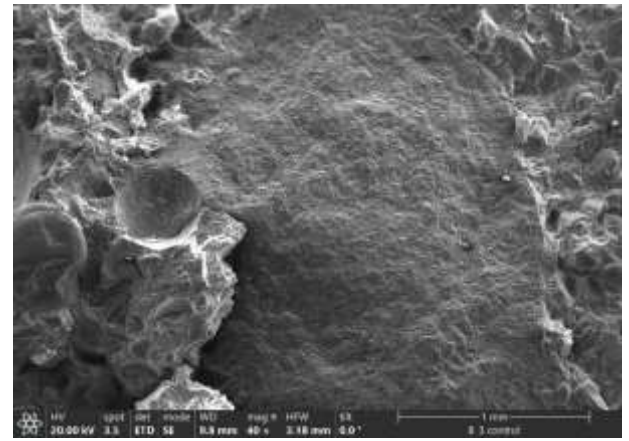
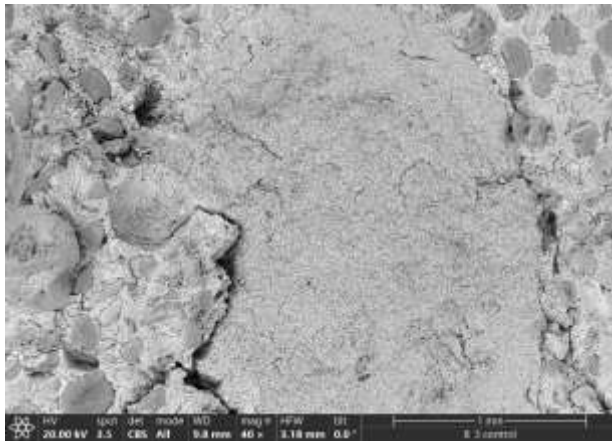
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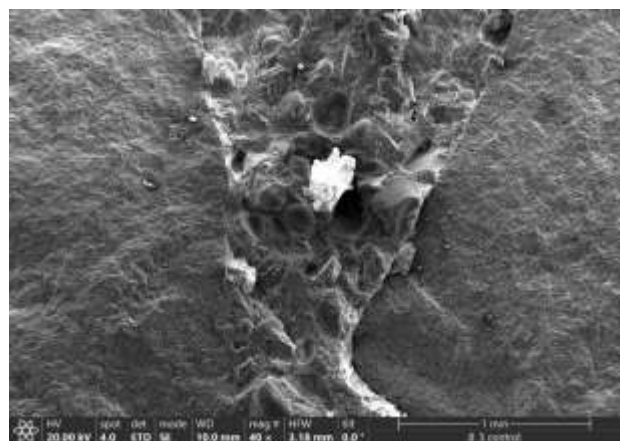
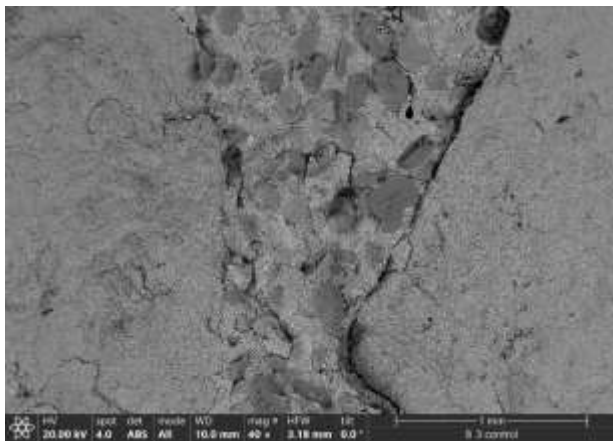
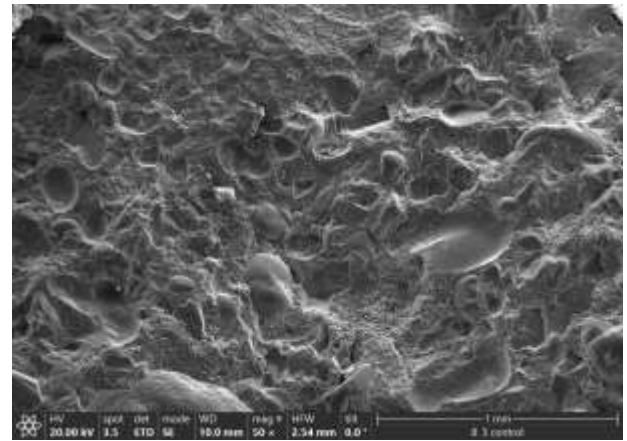
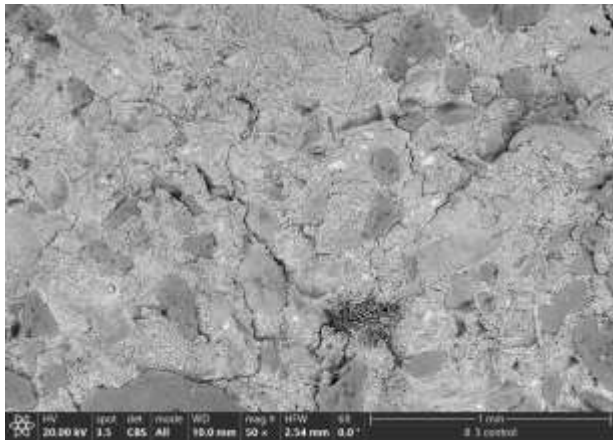
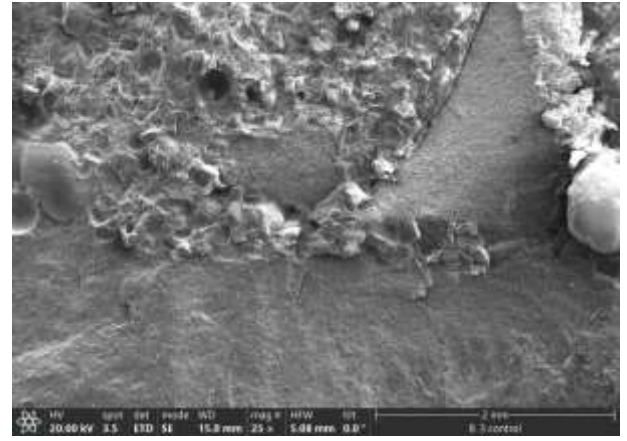
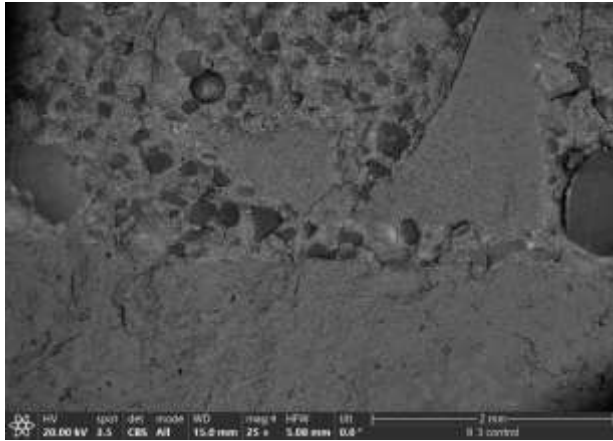


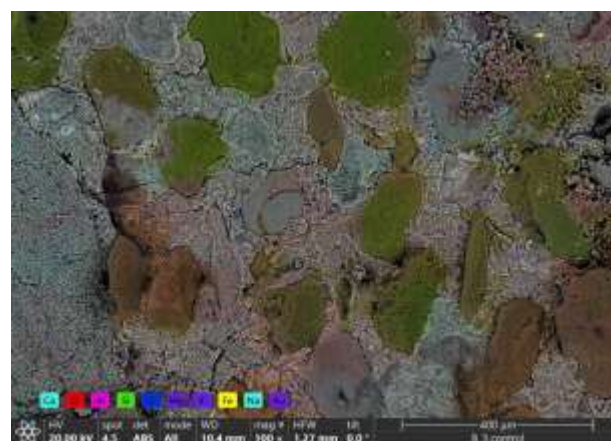
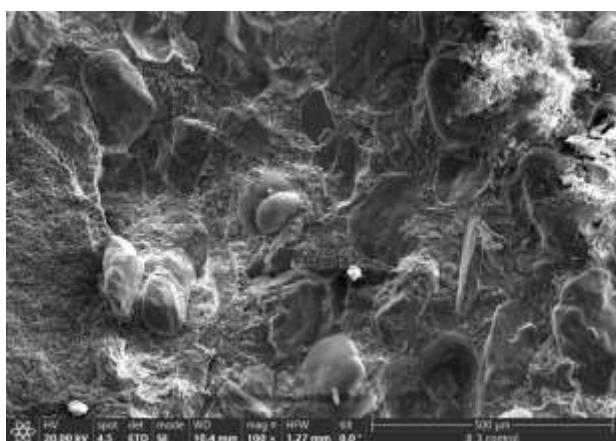
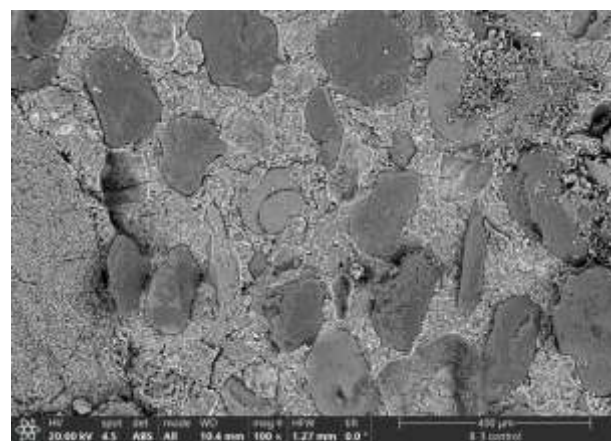
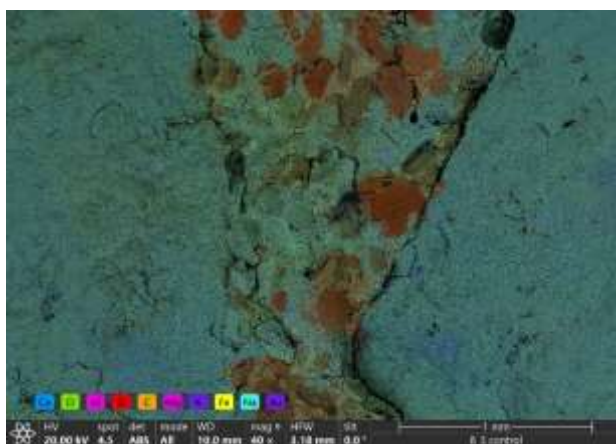




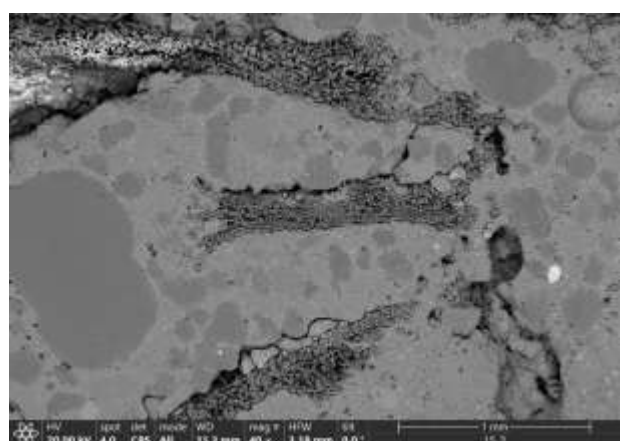
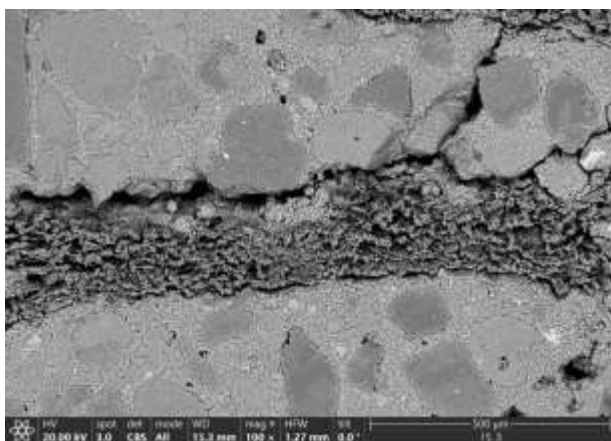
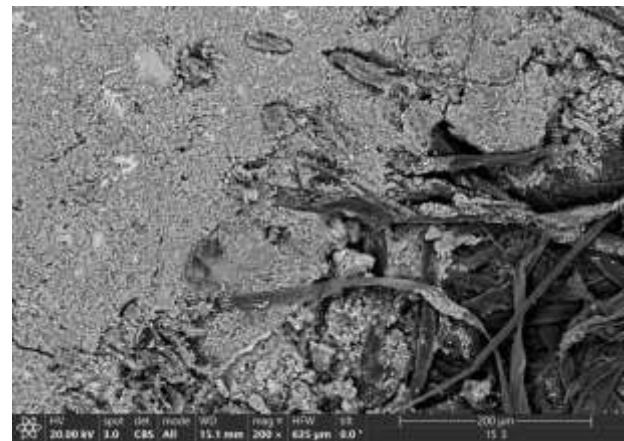
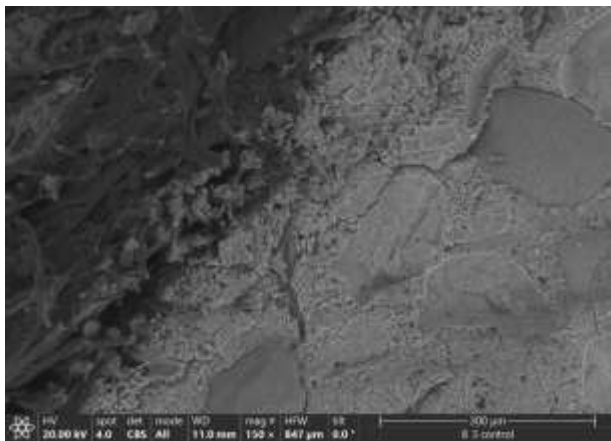
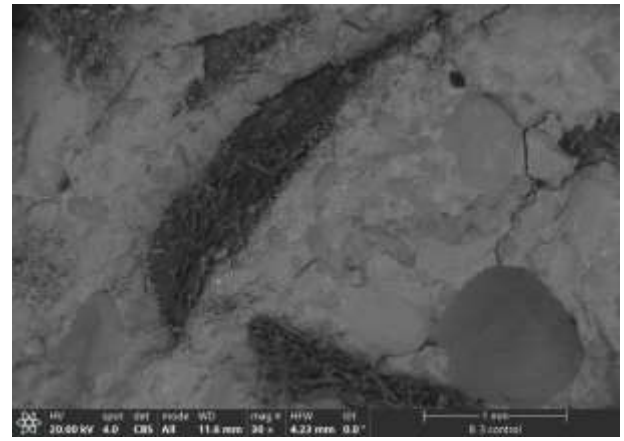
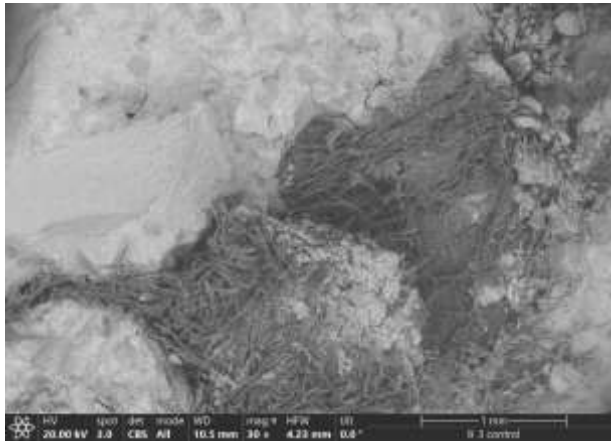


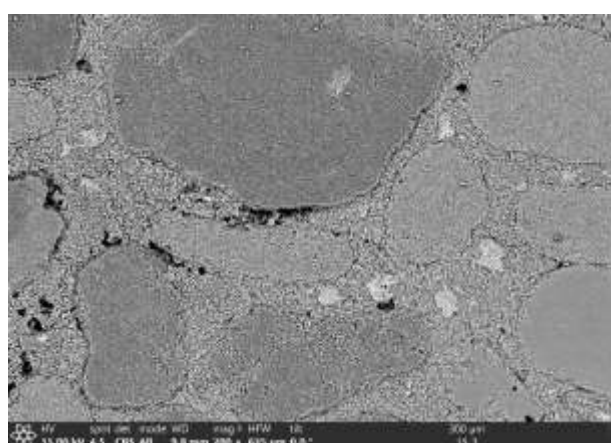
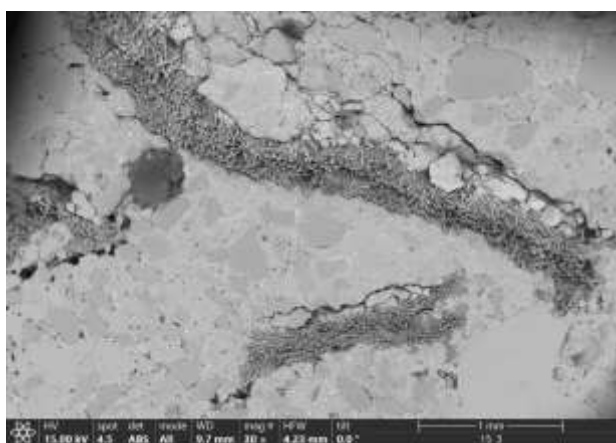
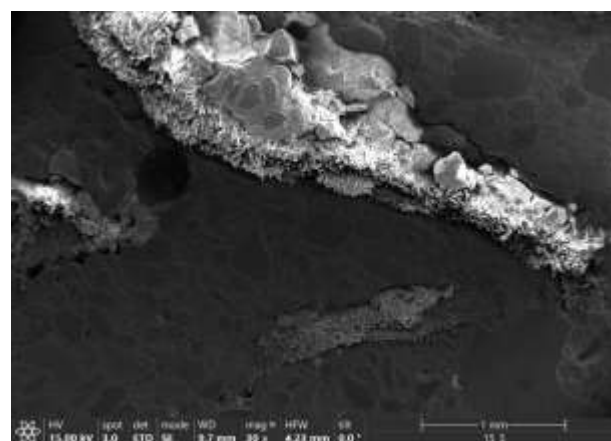
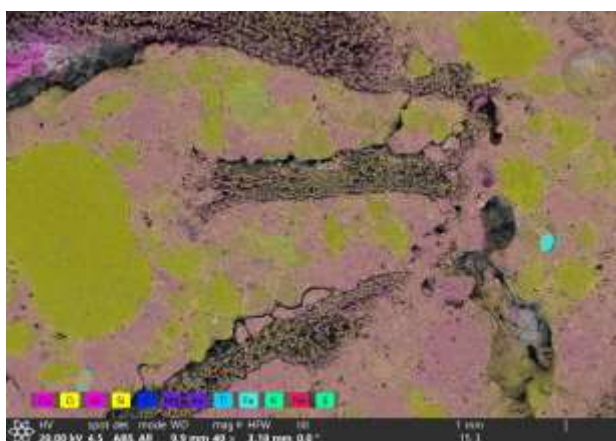
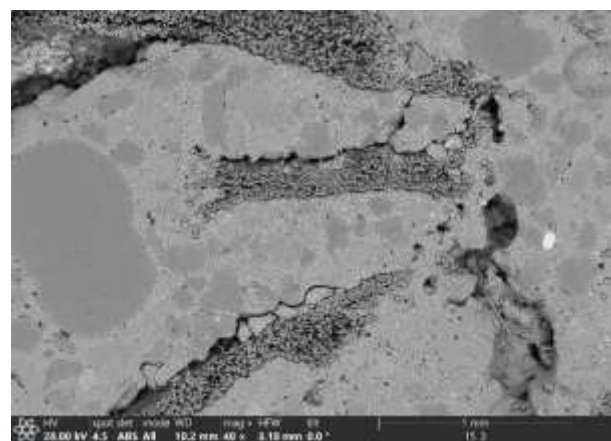
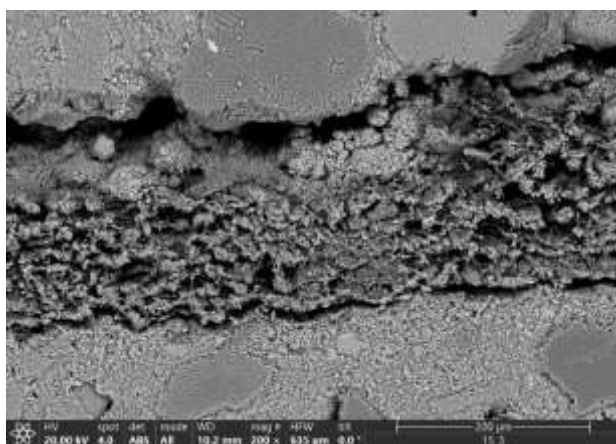


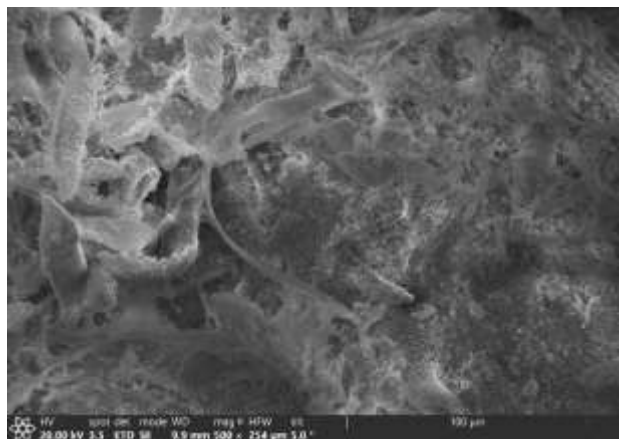
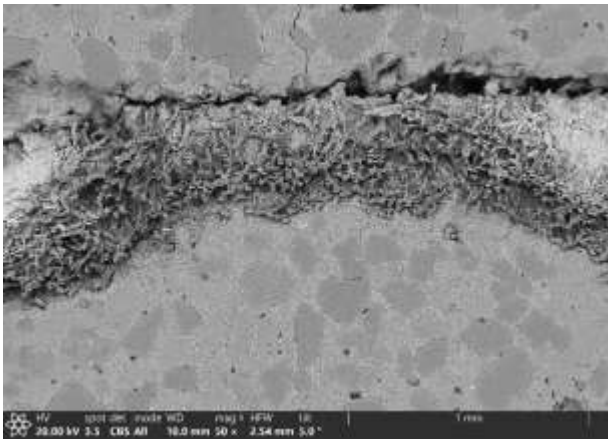
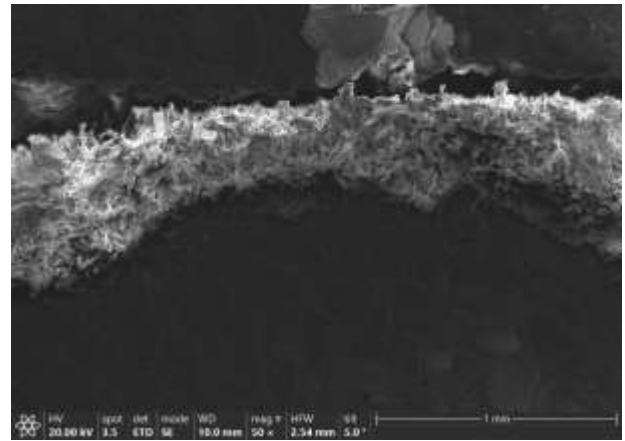
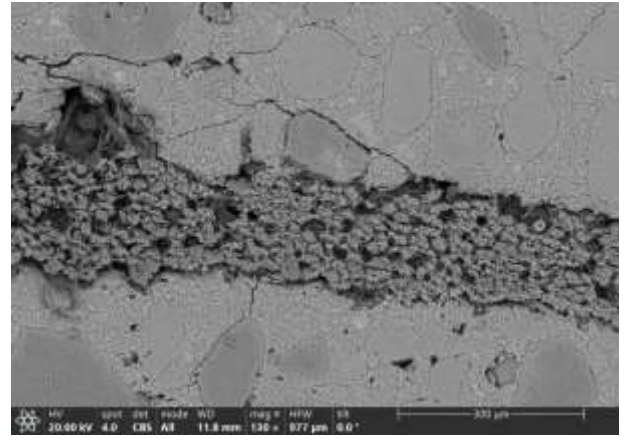
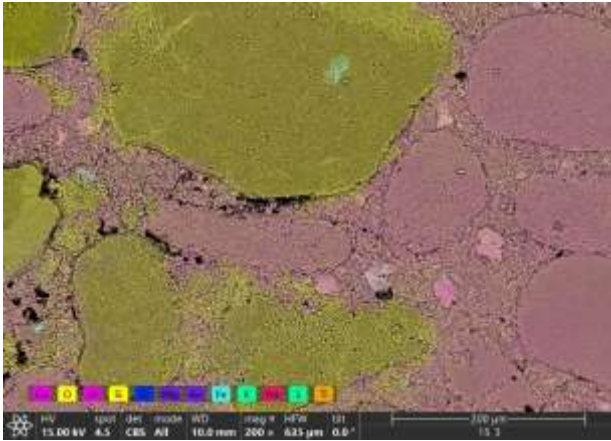


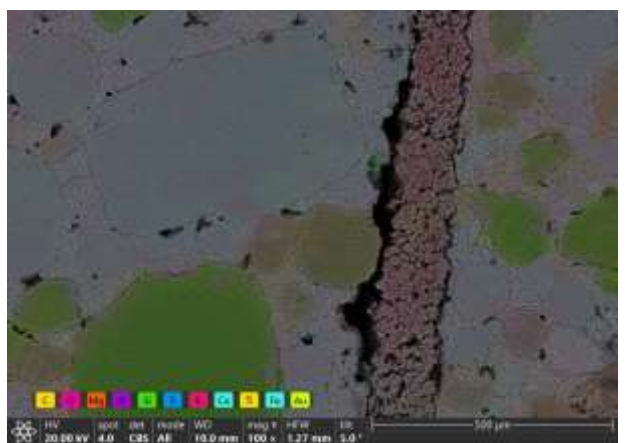
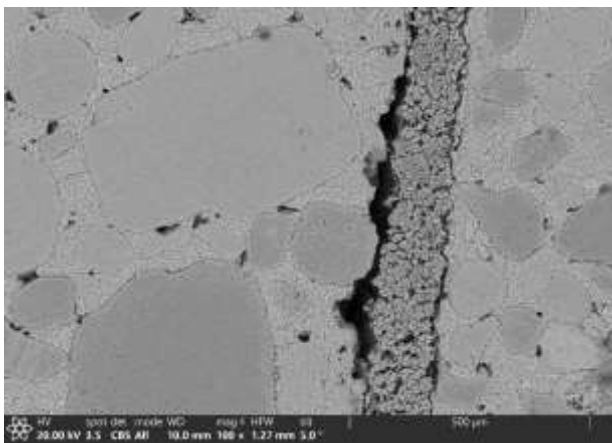
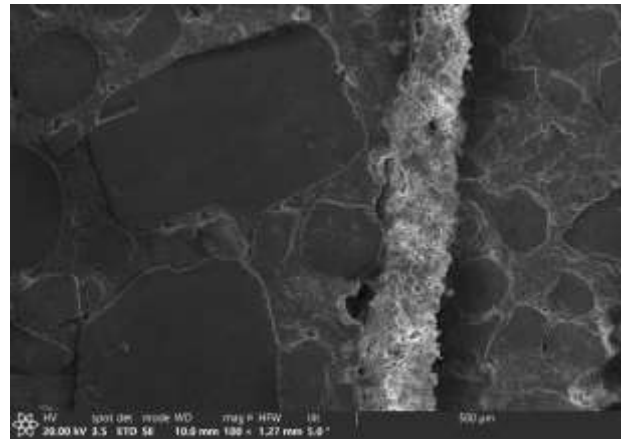
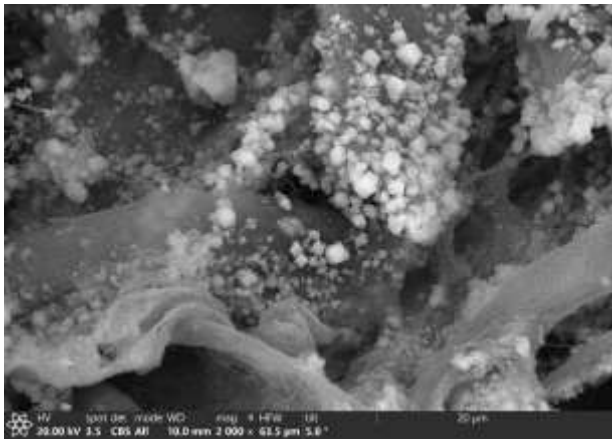
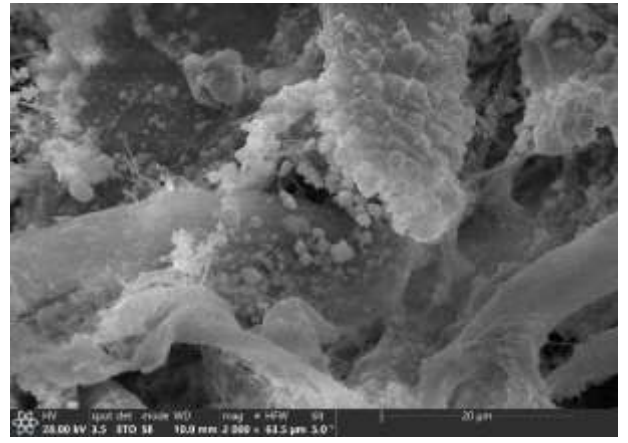
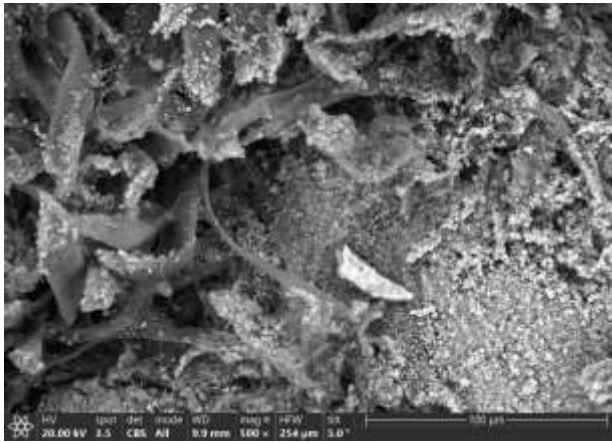


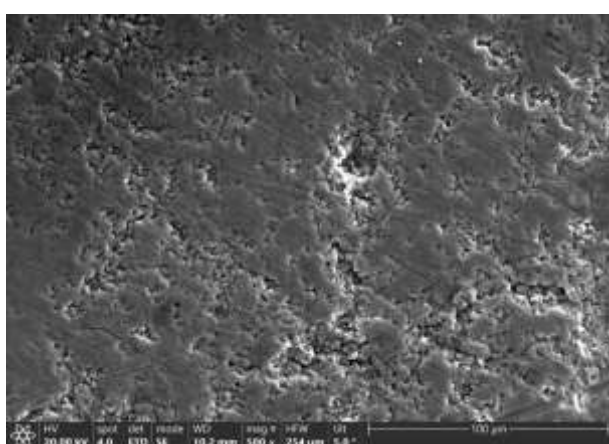
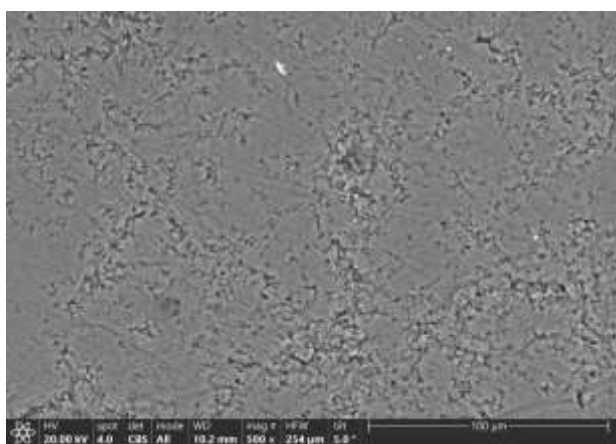
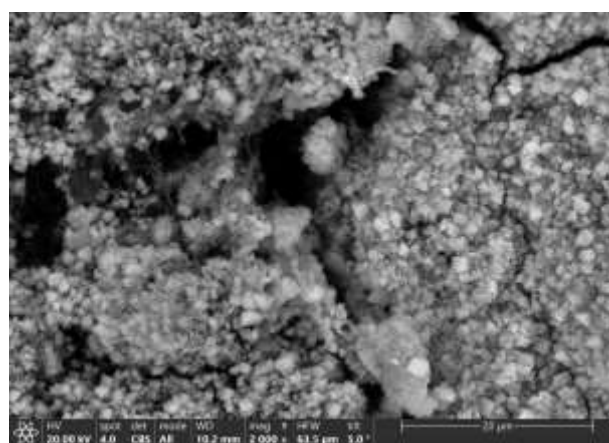
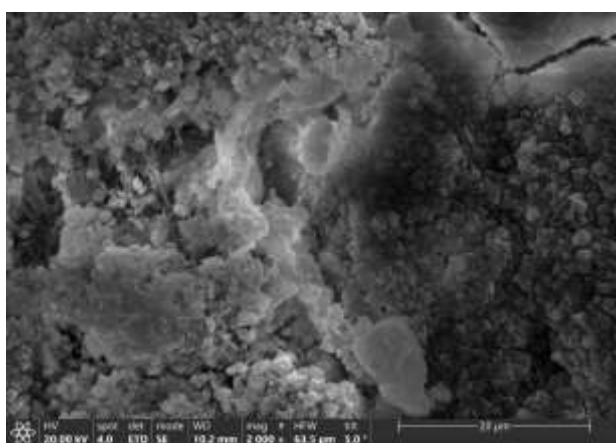
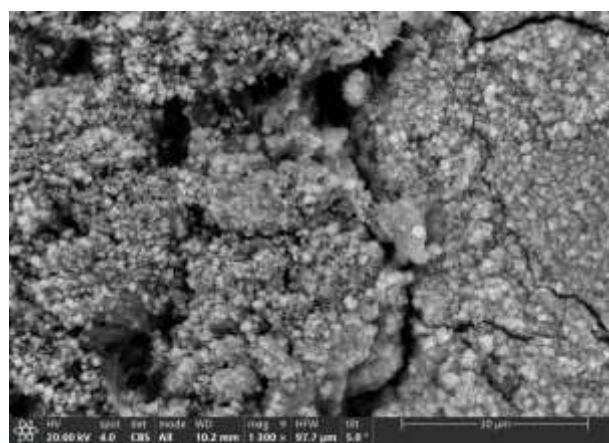
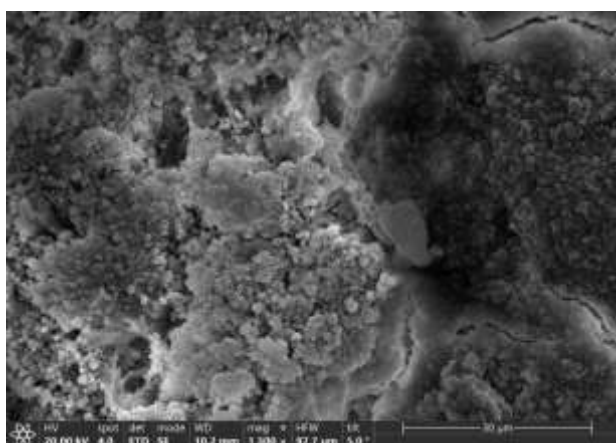
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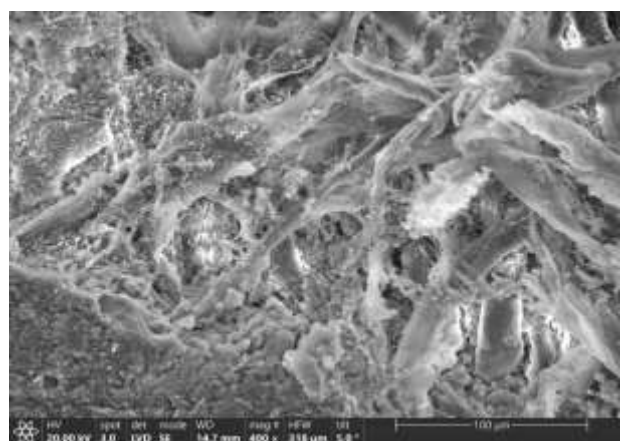
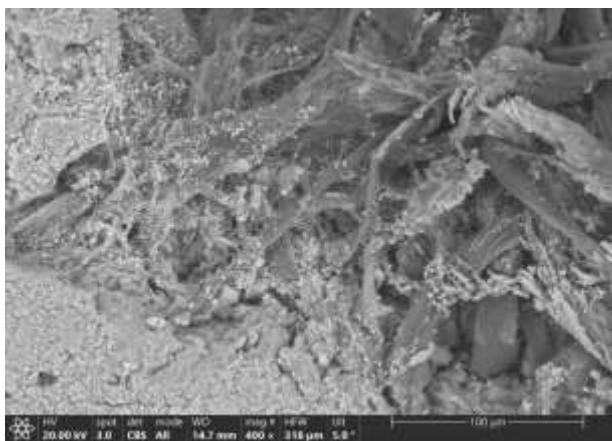
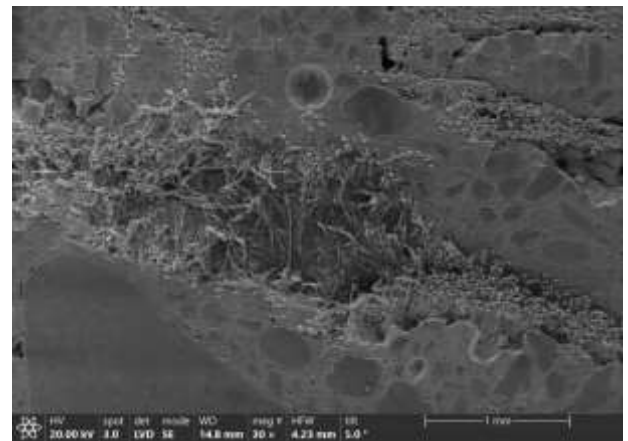
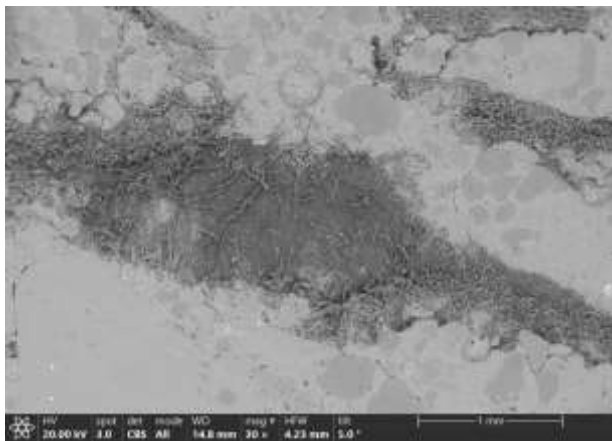
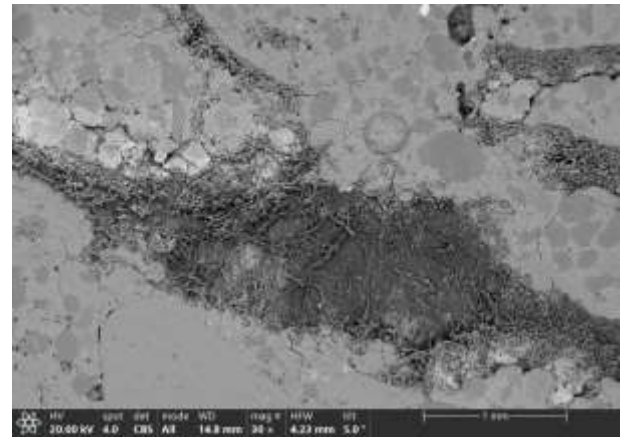
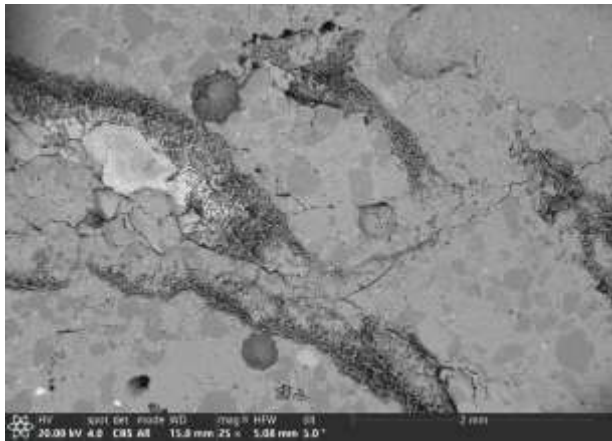


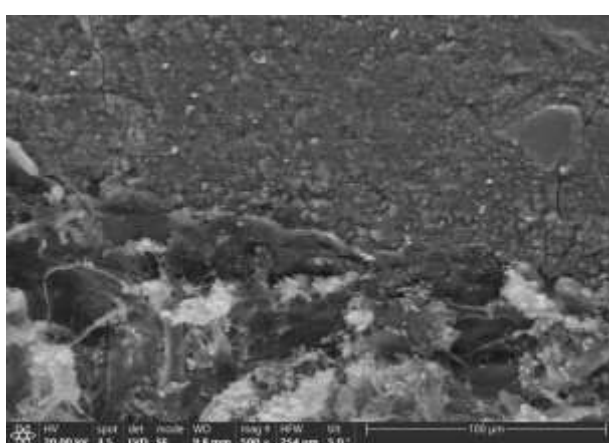
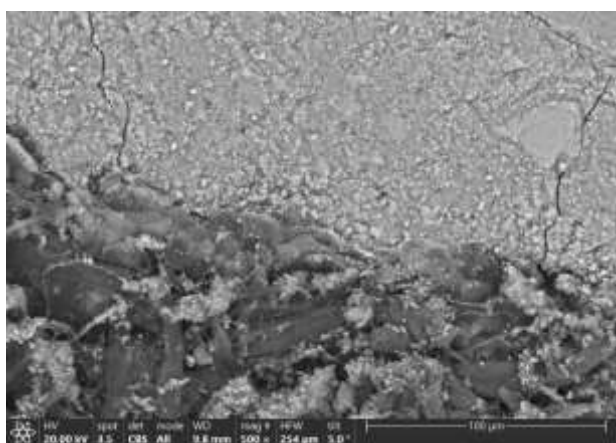
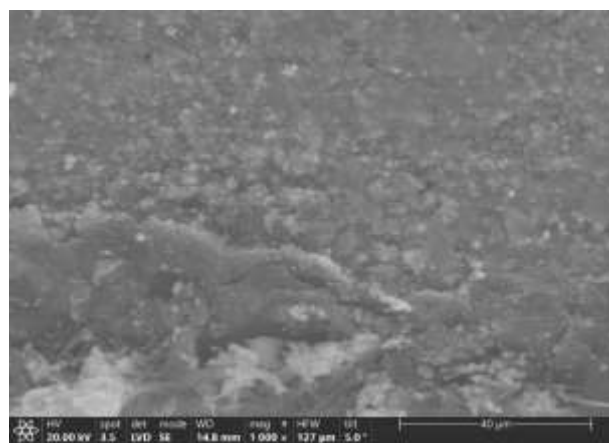
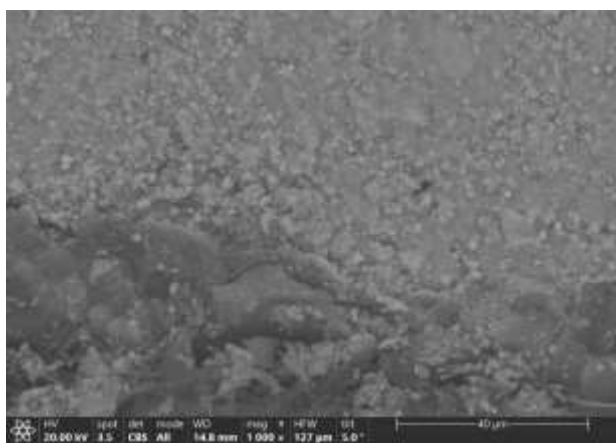
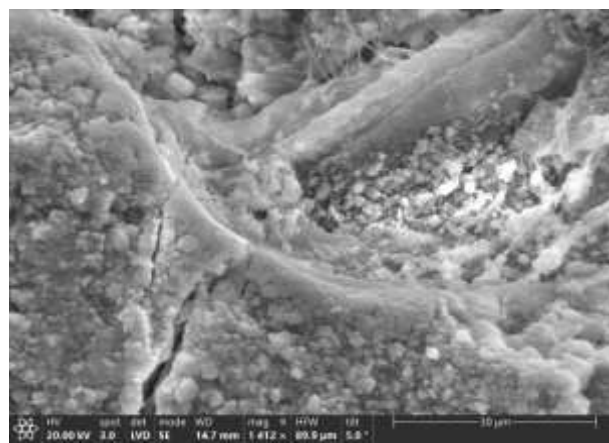
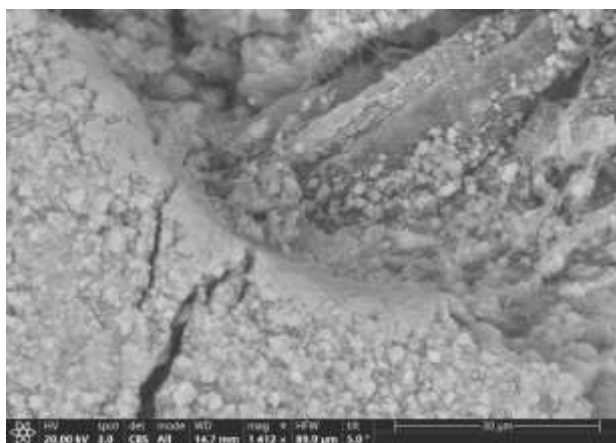


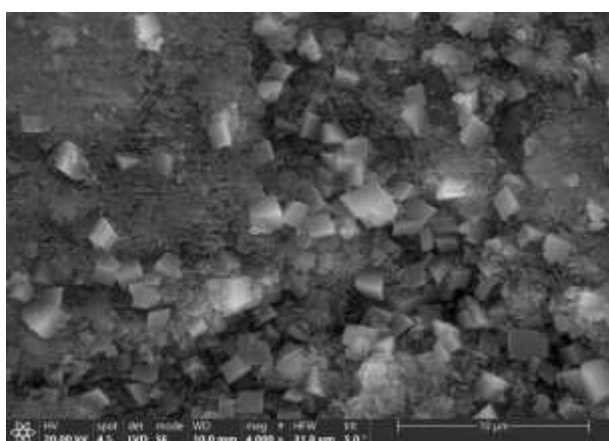
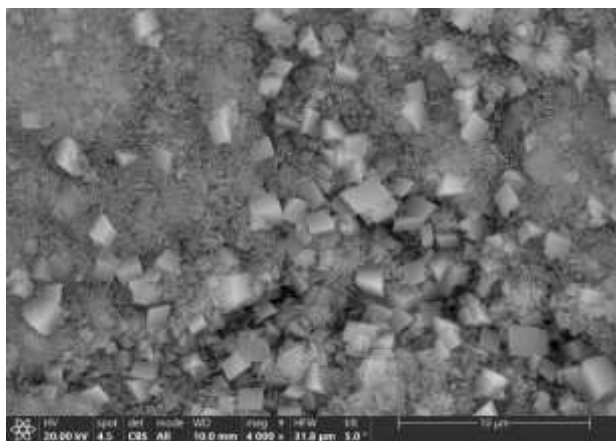
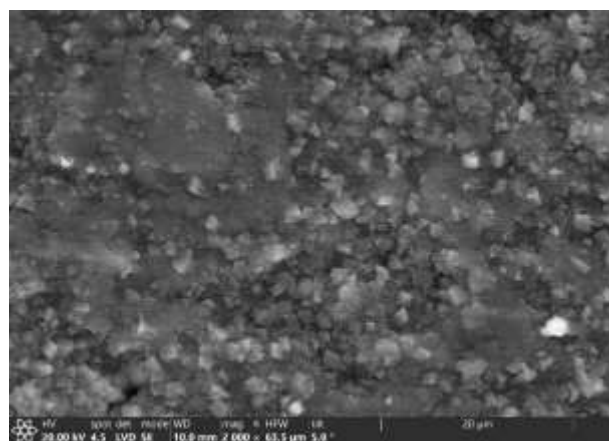
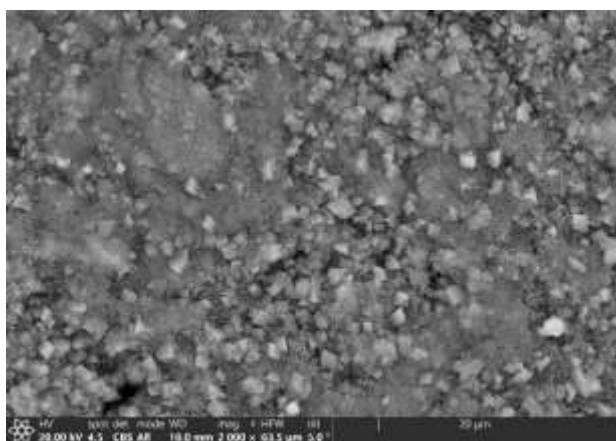
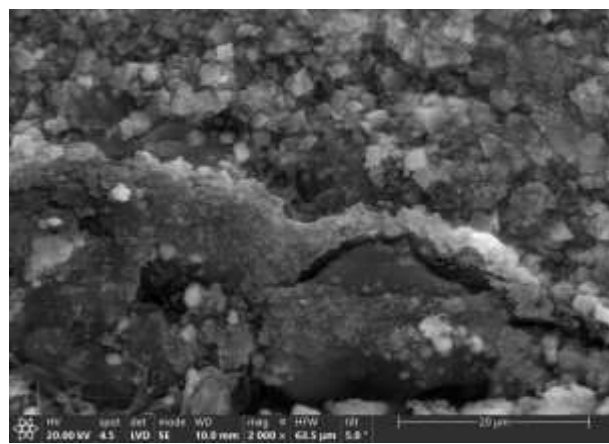
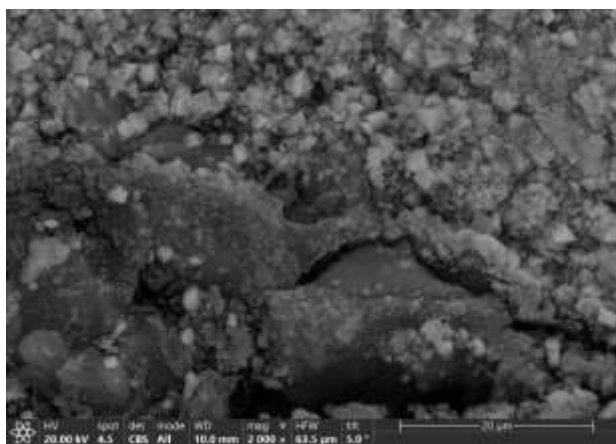




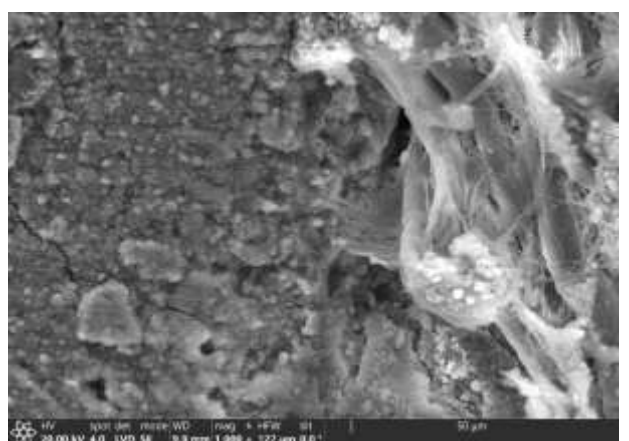
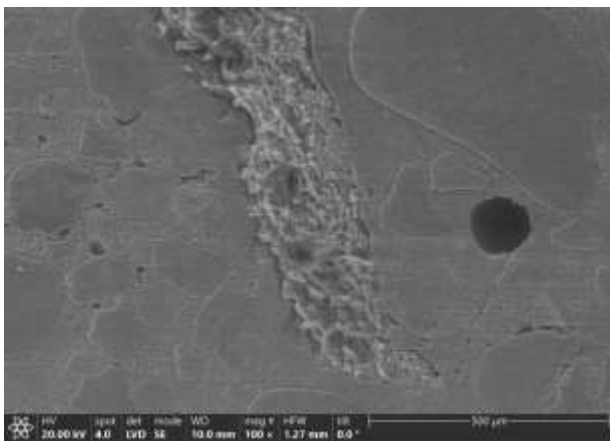
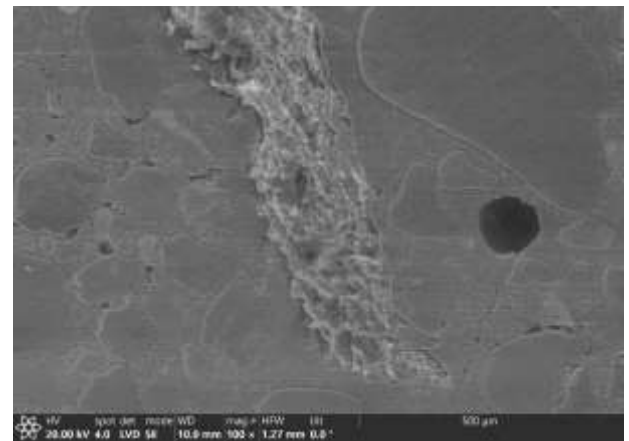
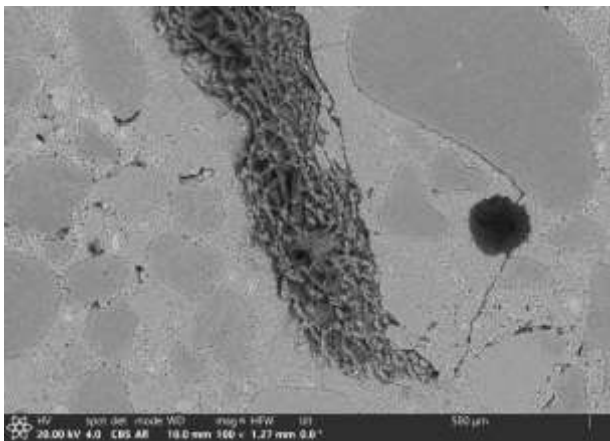
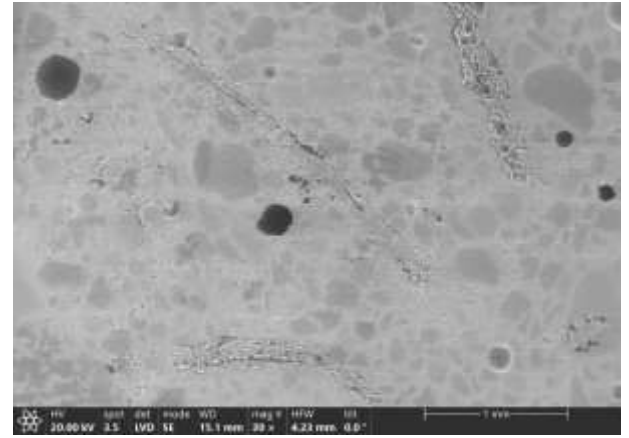
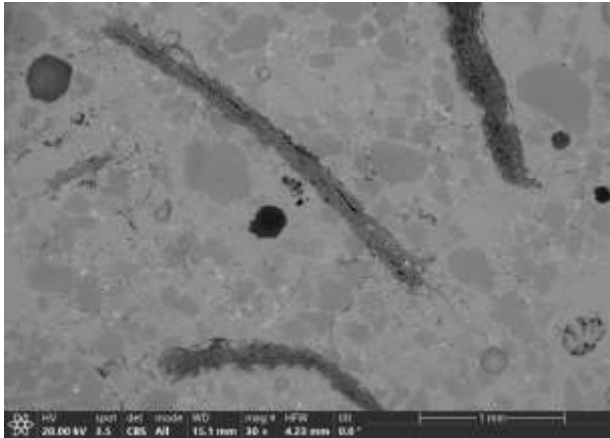


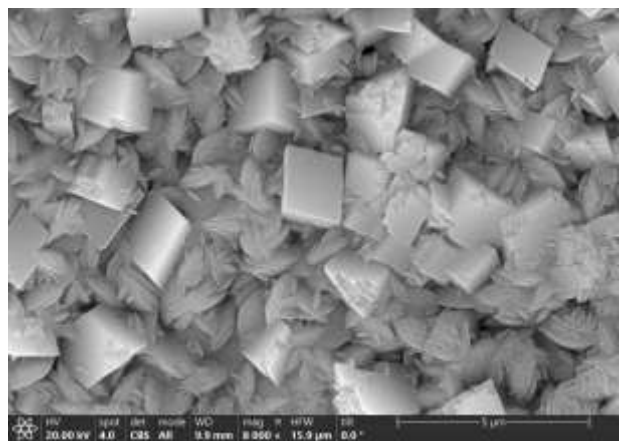
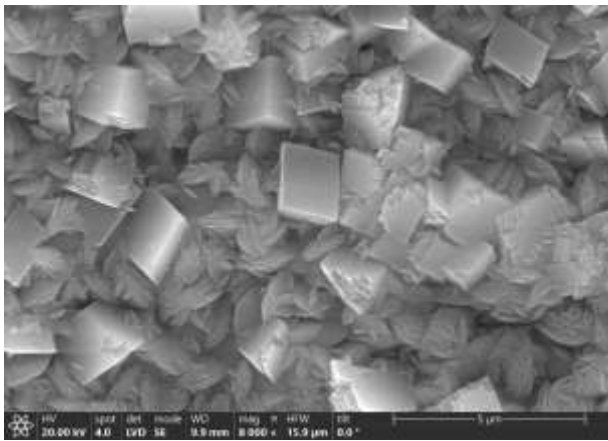
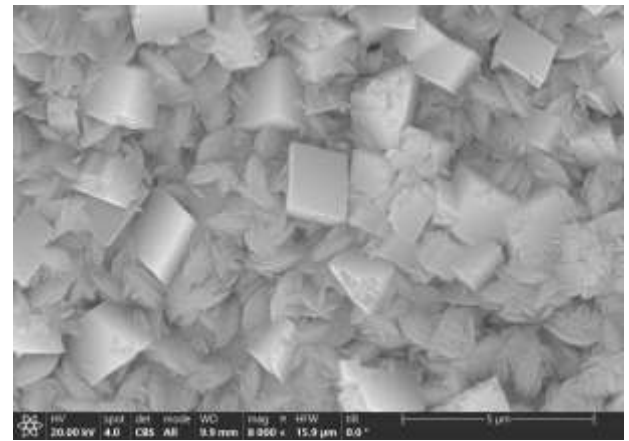
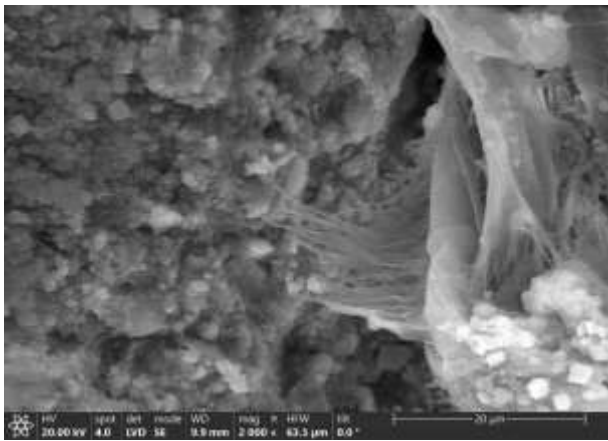
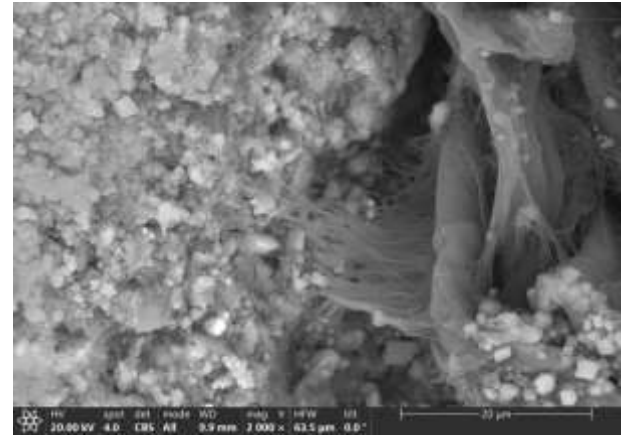
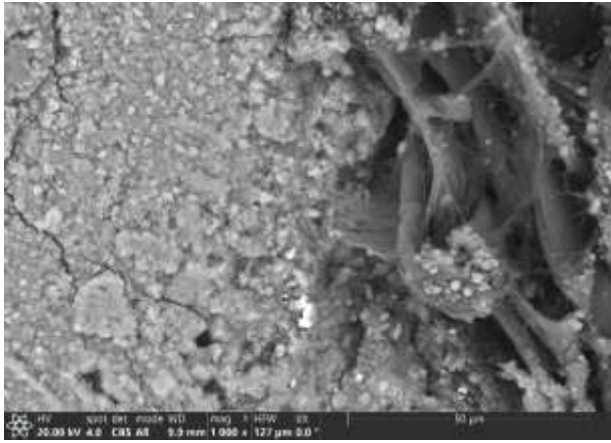


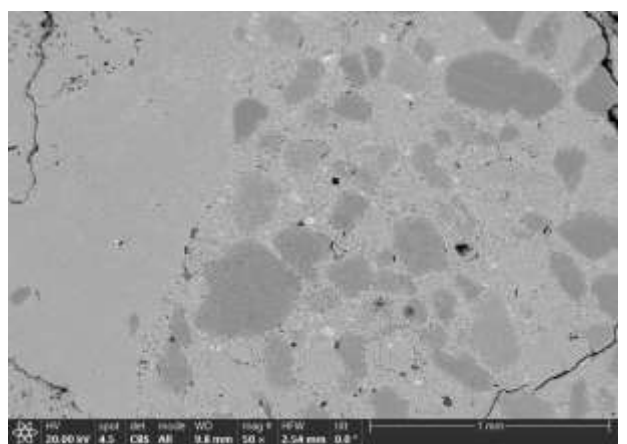
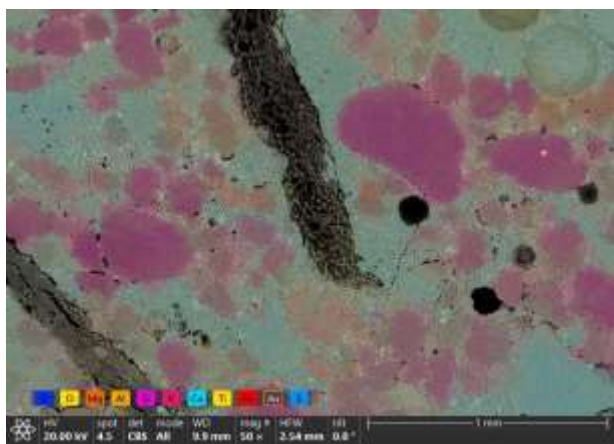
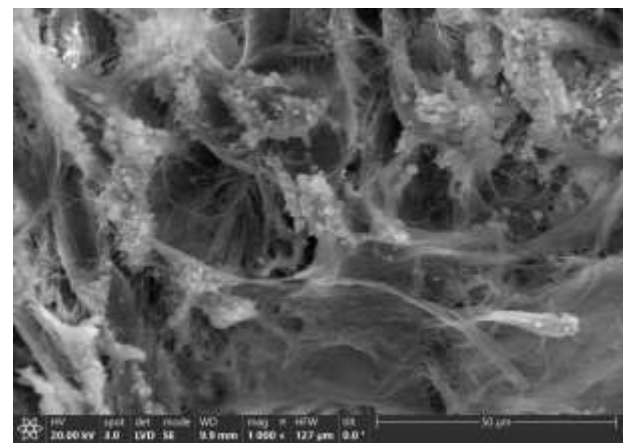
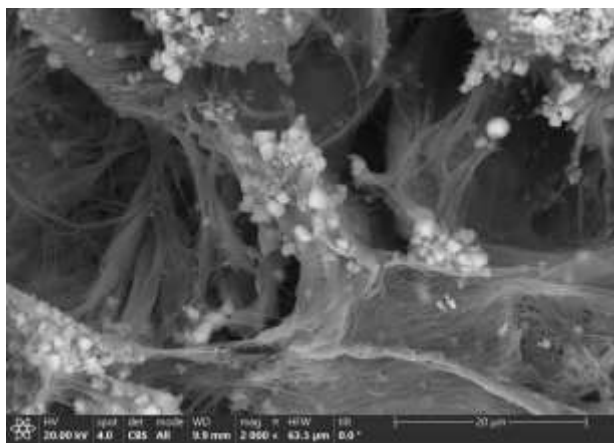
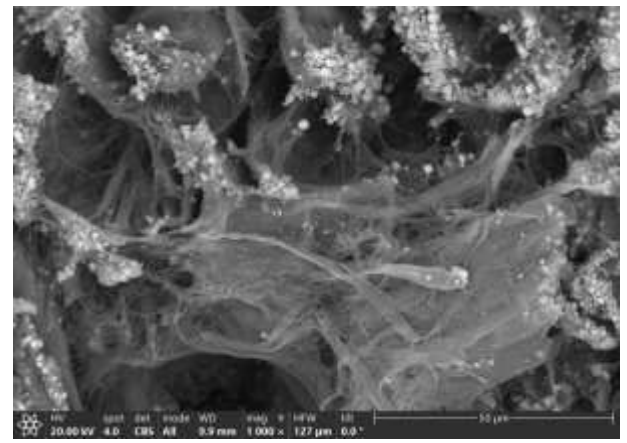
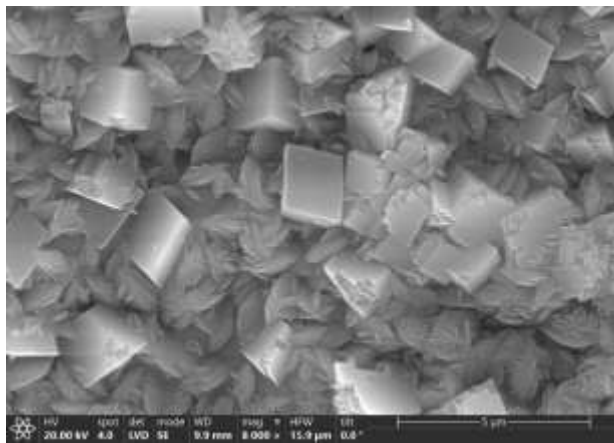


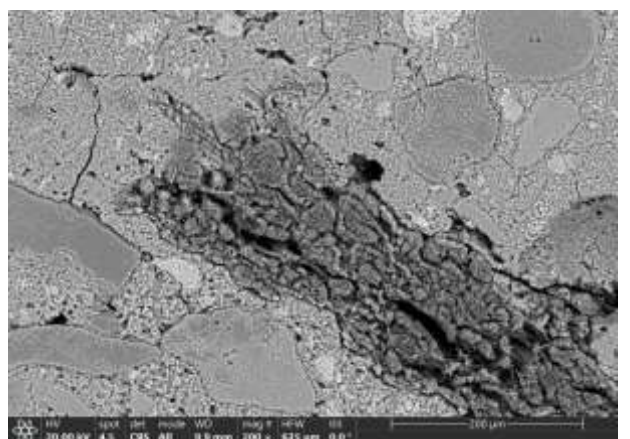
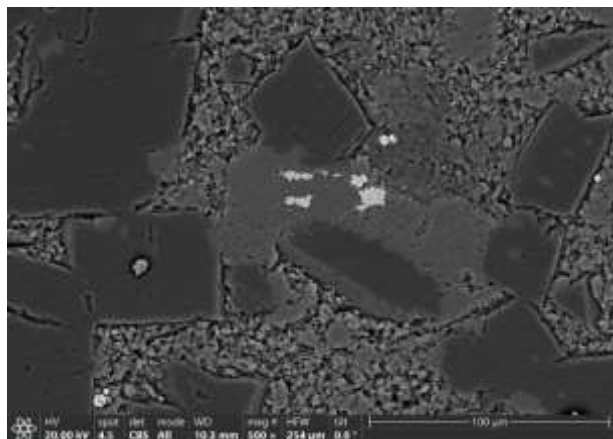
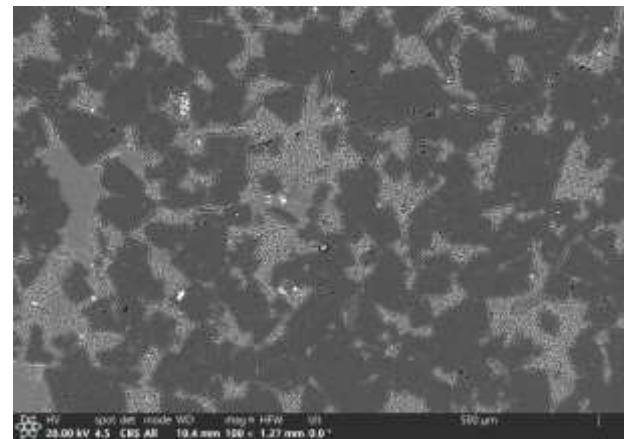
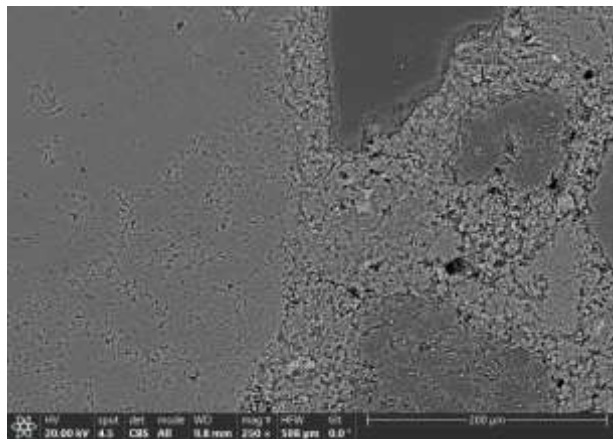
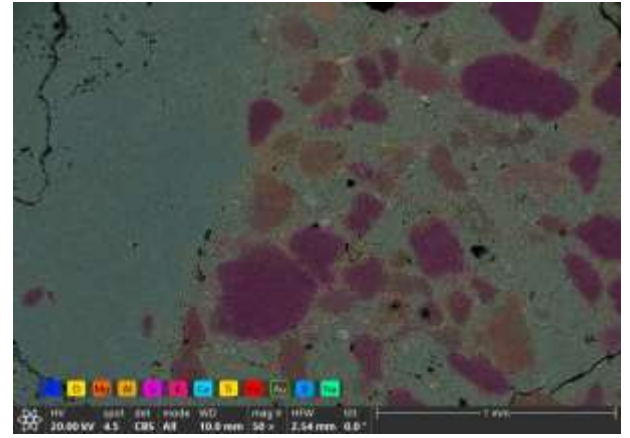
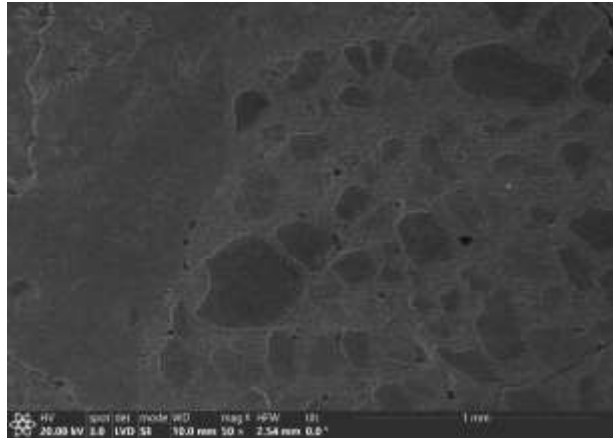


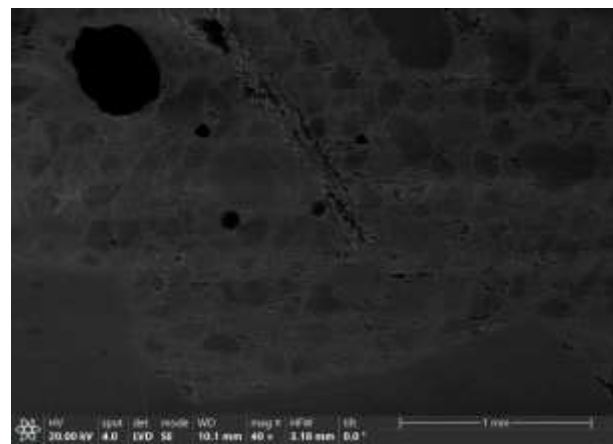
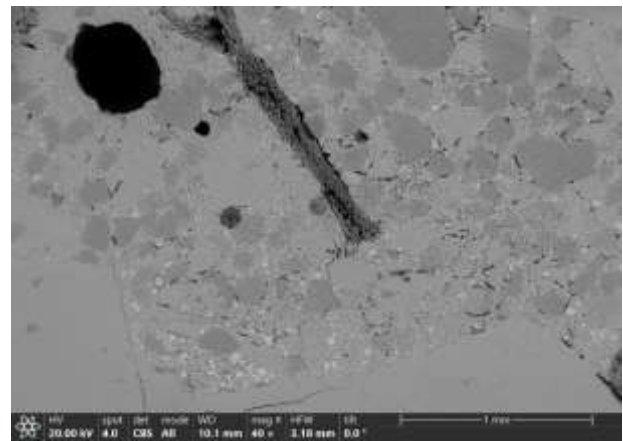
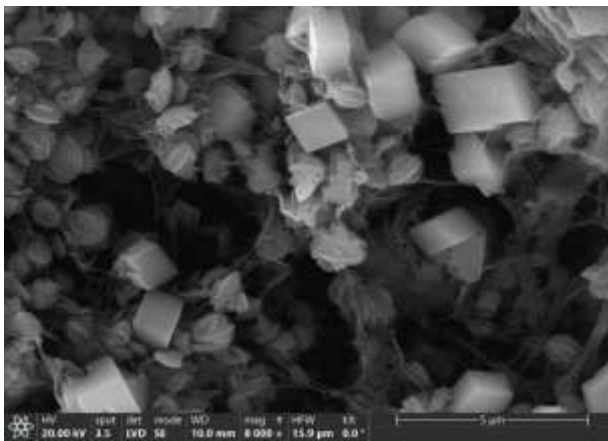
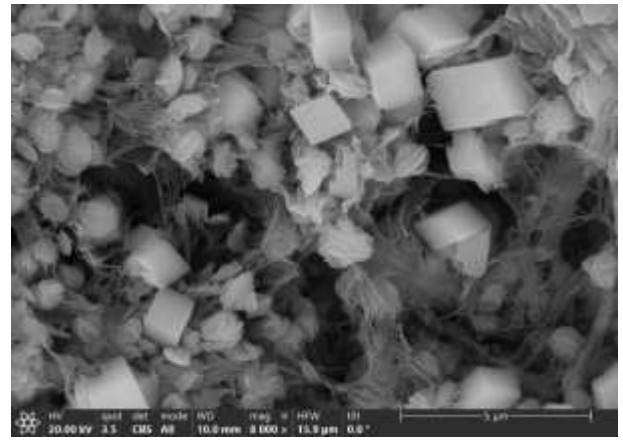
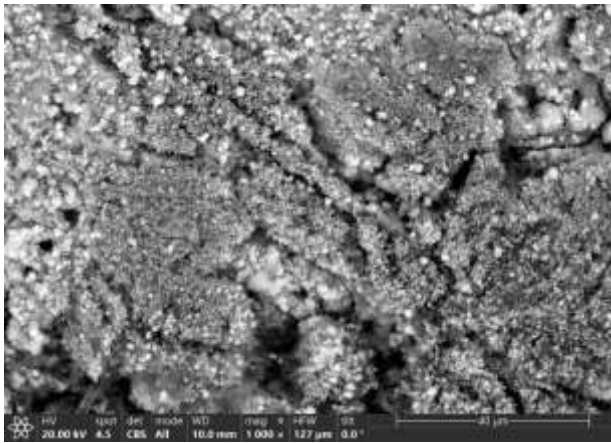
Control Mix with 0.5% of Waste Money Fibers SEM Images:



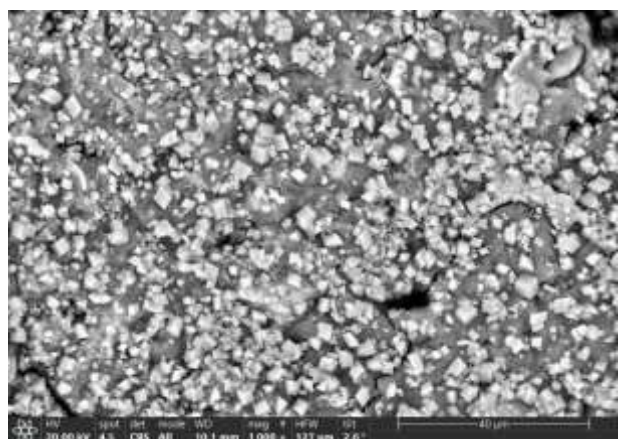
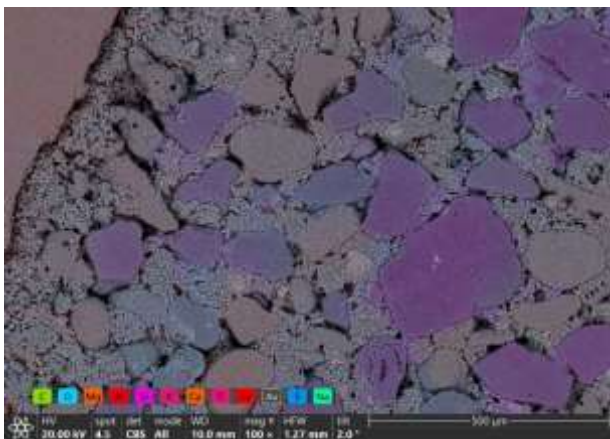
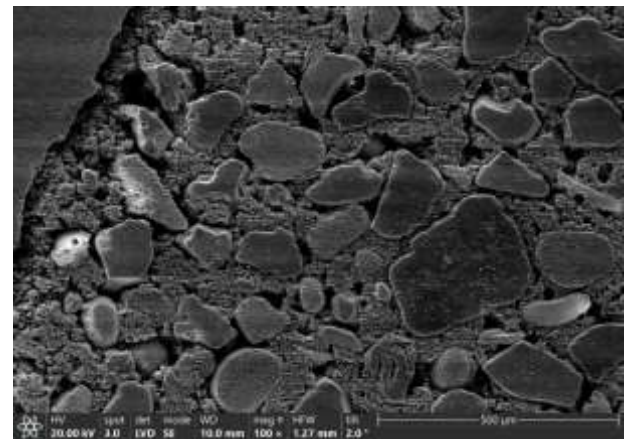
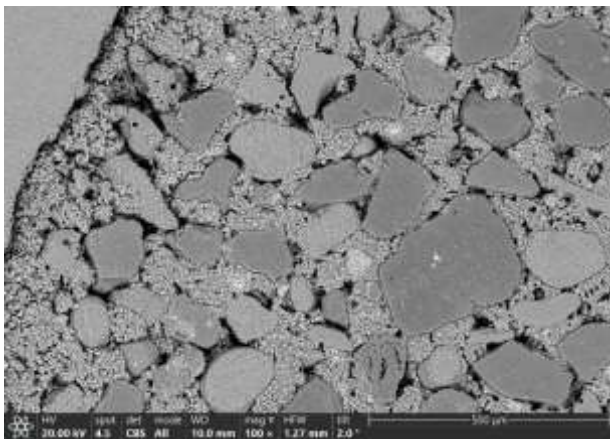
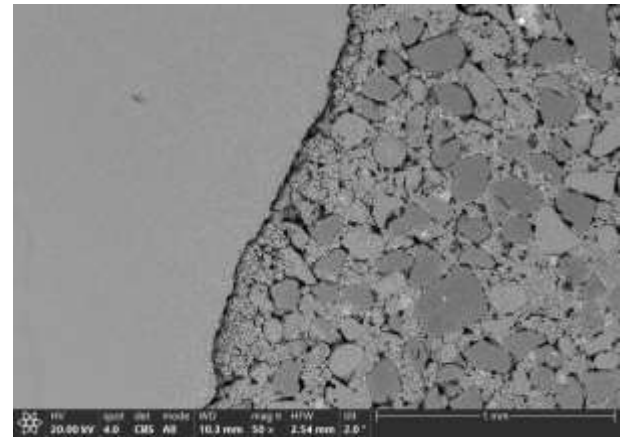
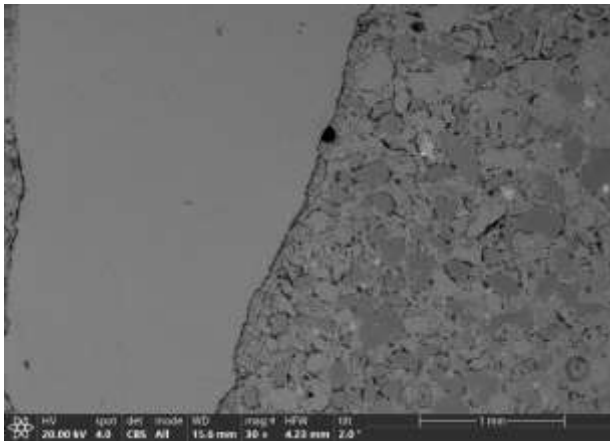


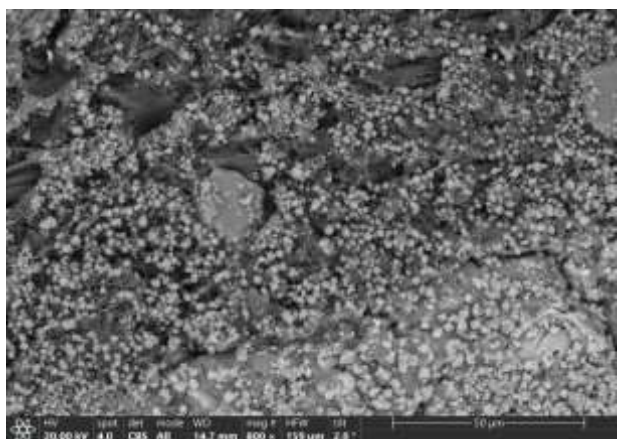
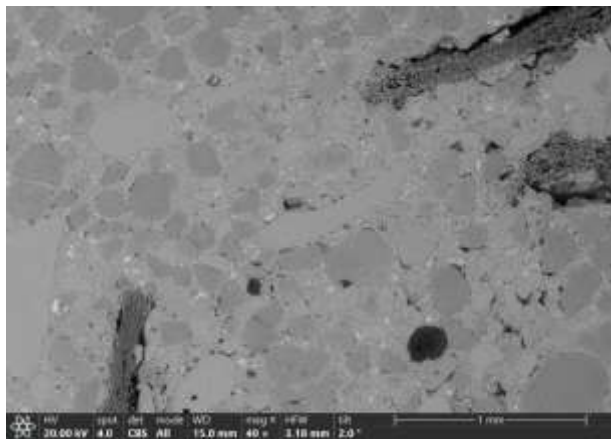
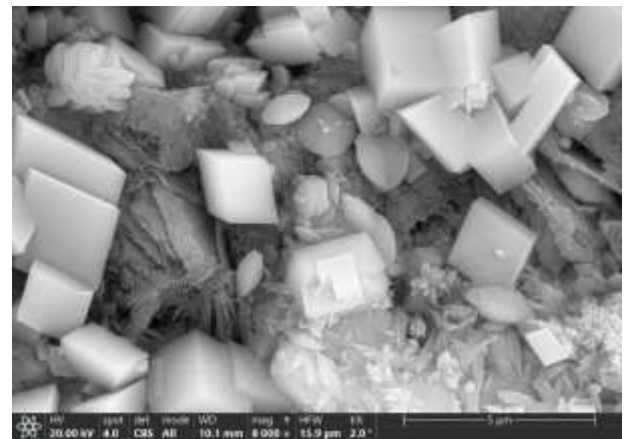
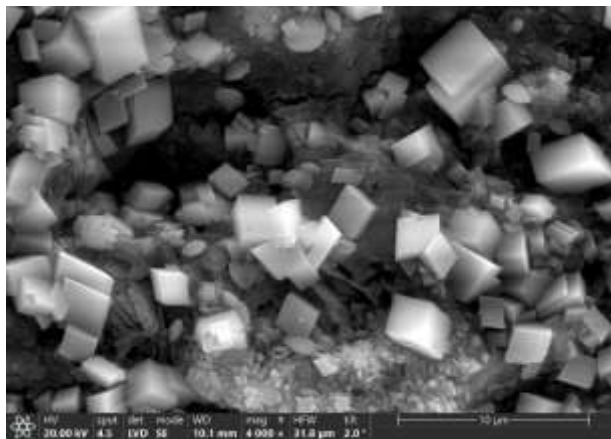
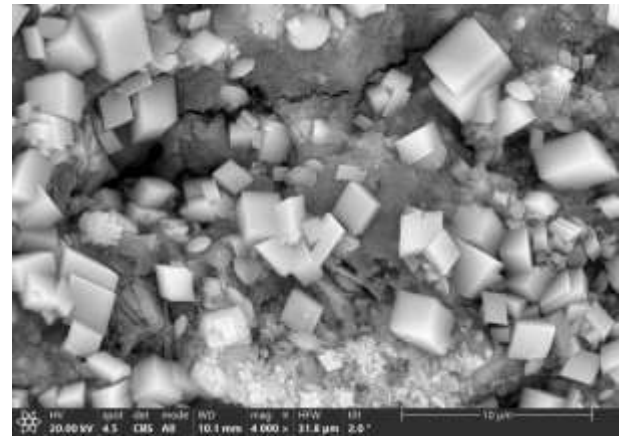
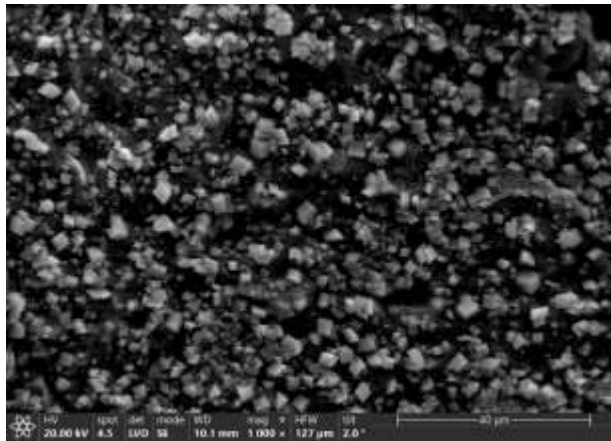


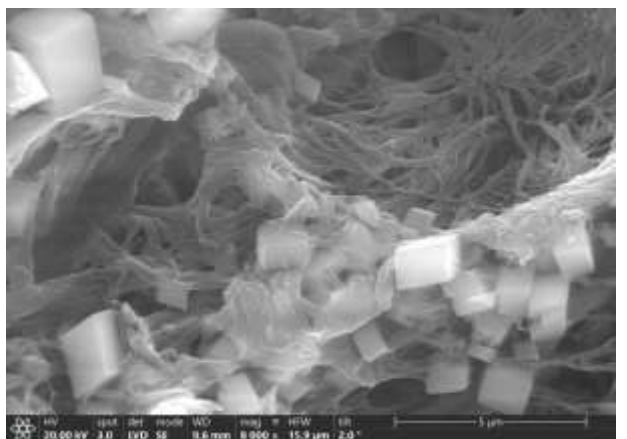
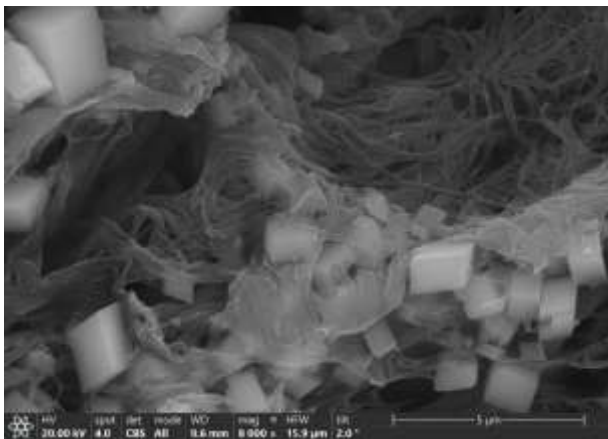
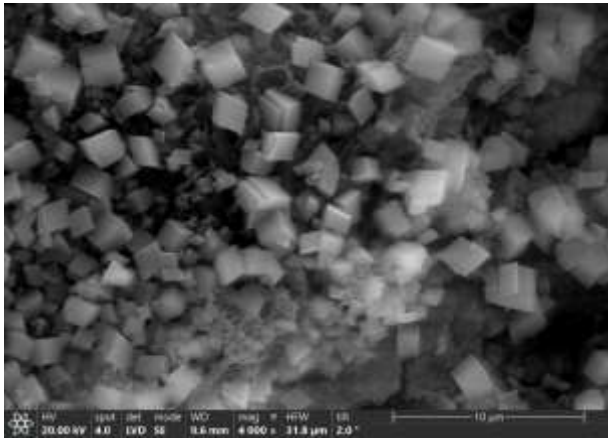
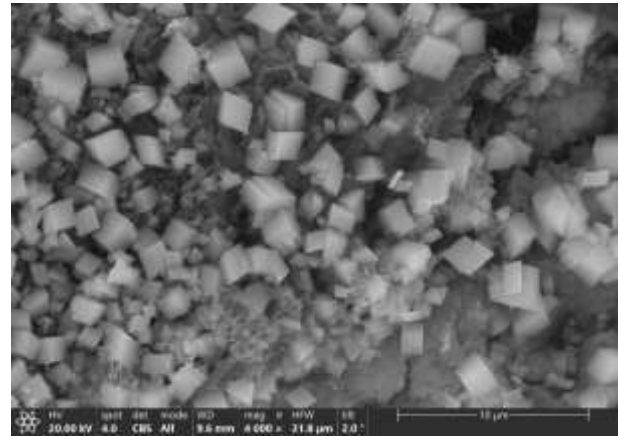
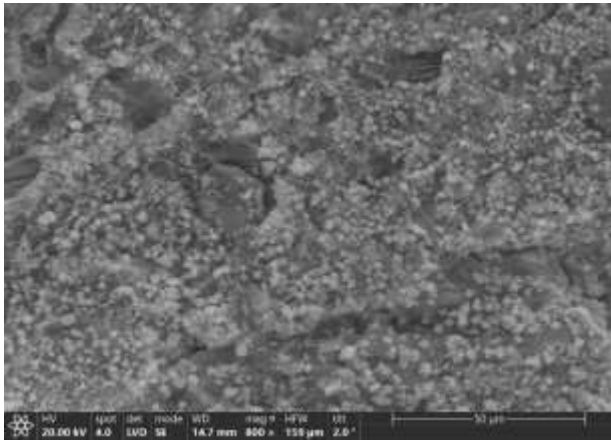


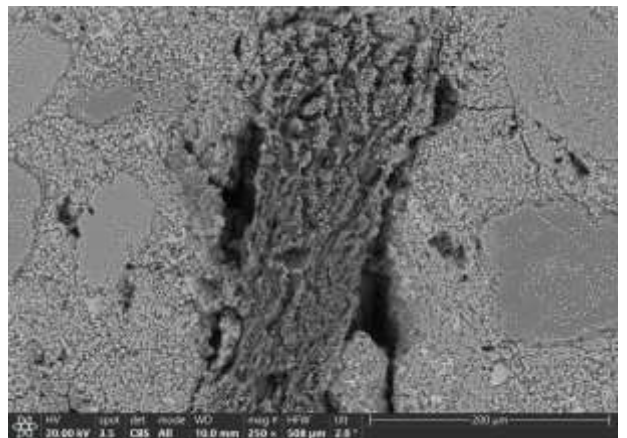
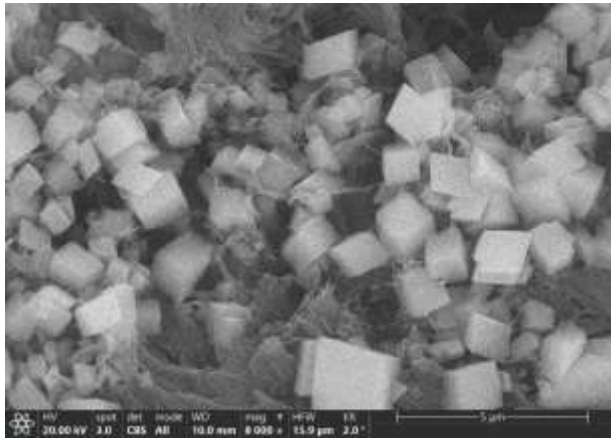
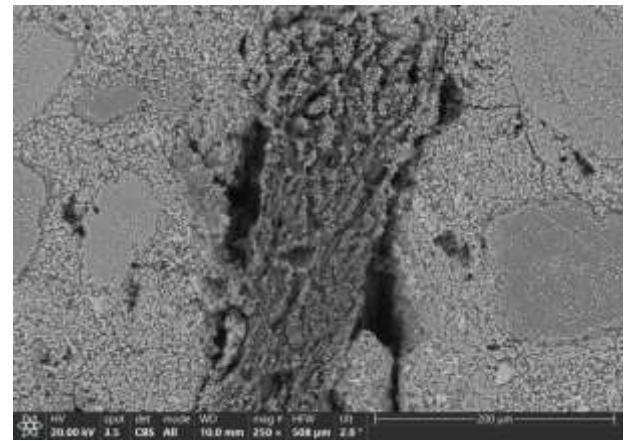
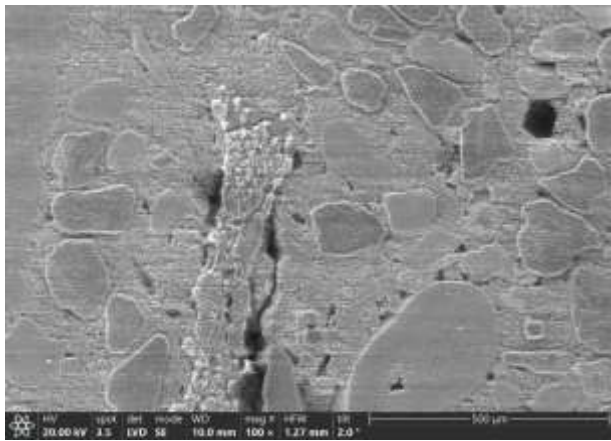
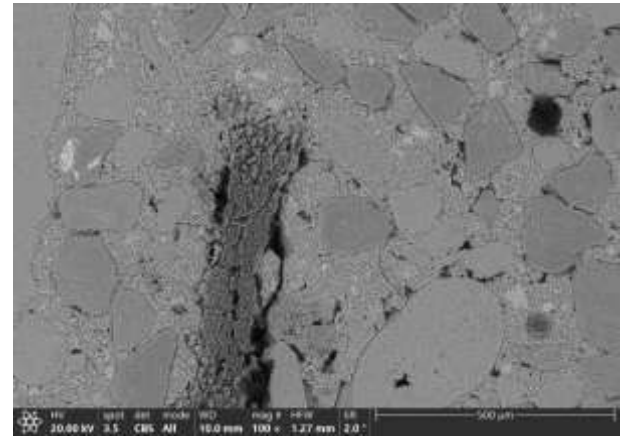
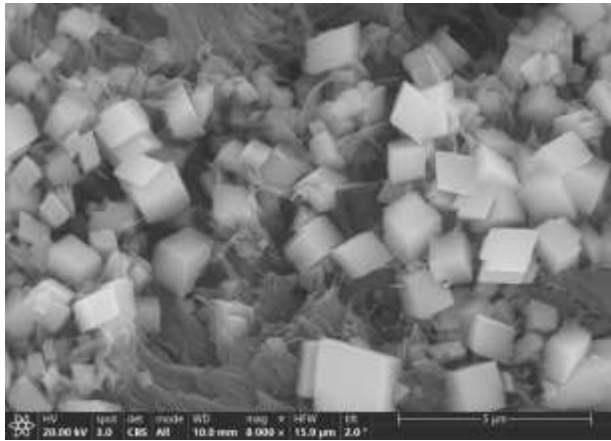


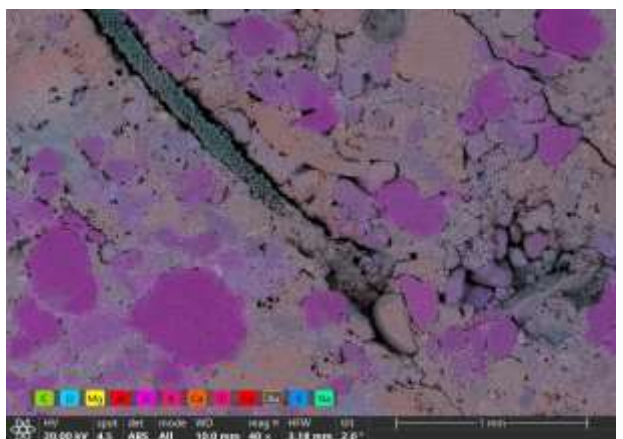
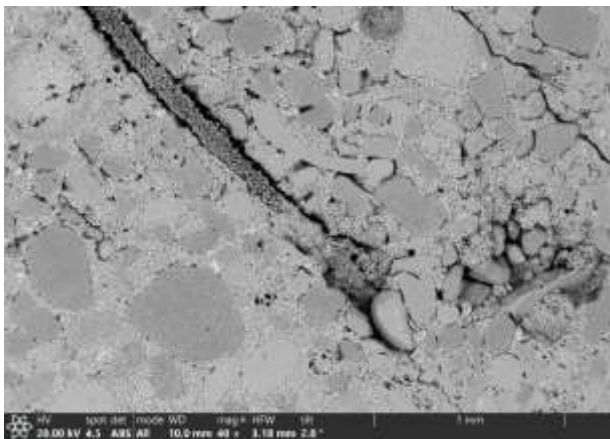
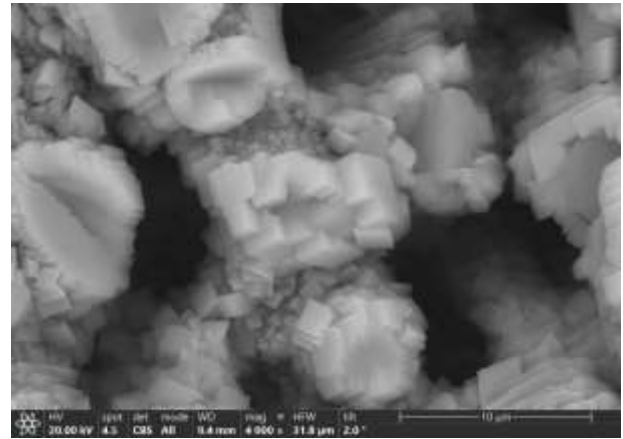
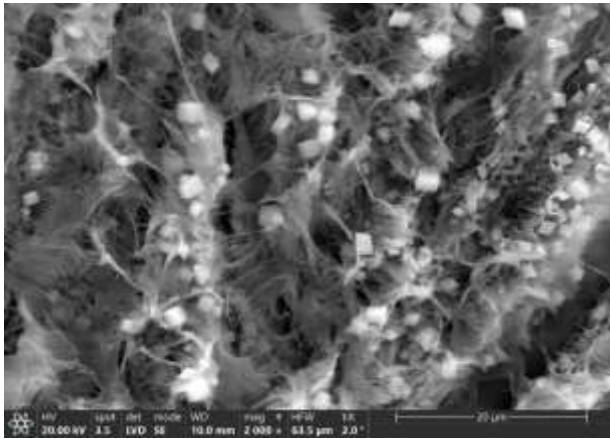
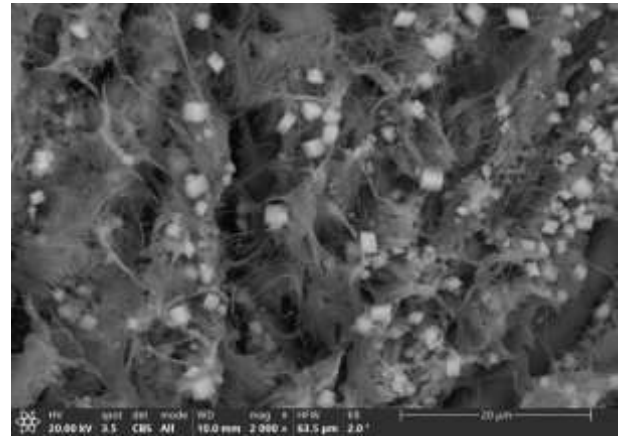
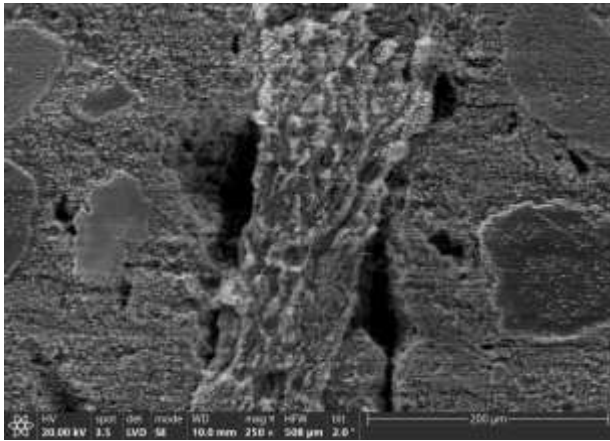
Control Mix with 0.25% of Waste Money Fibers SEM Images:



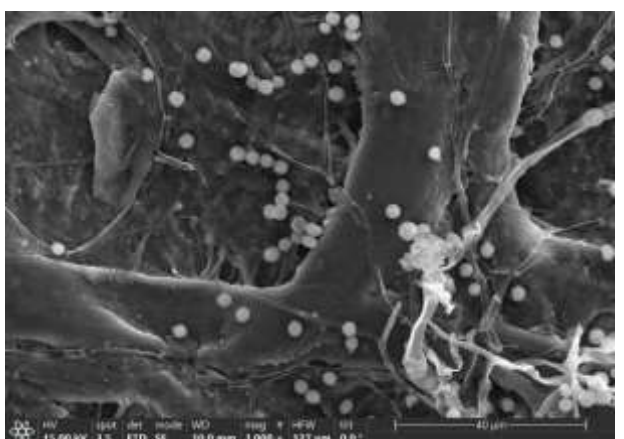
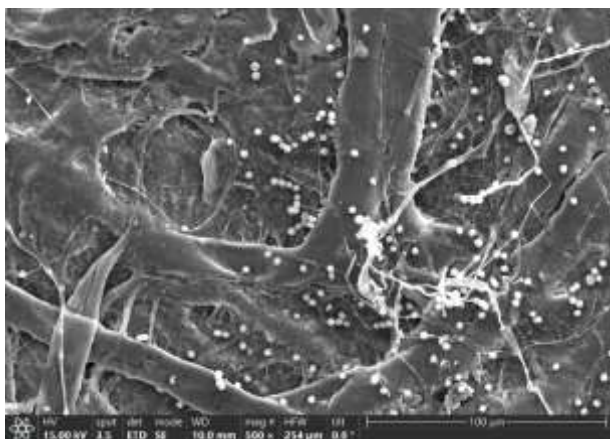
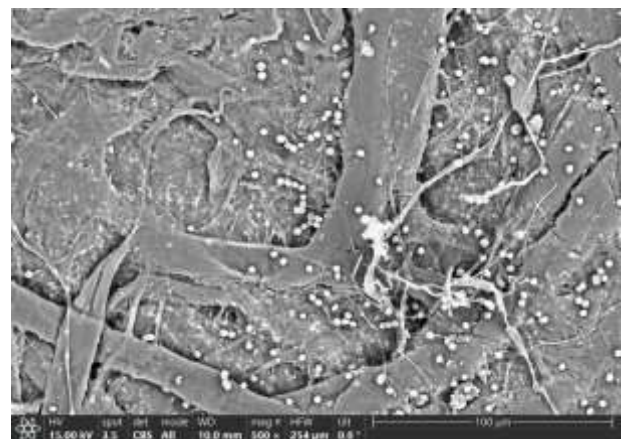
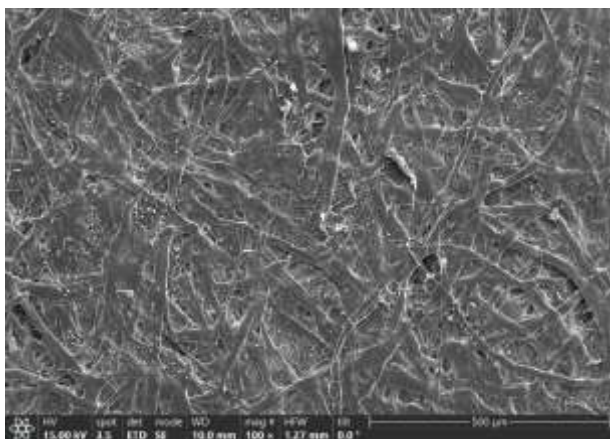
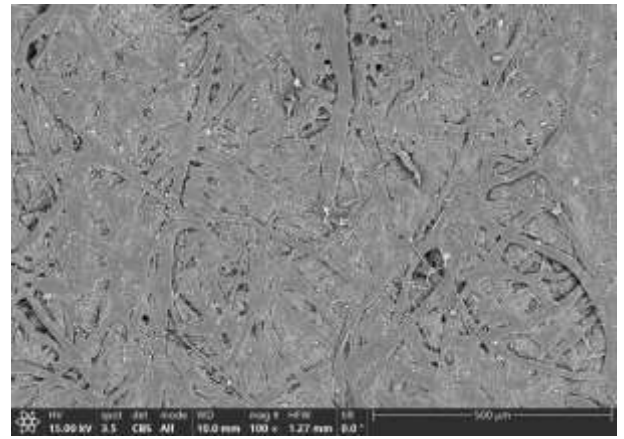
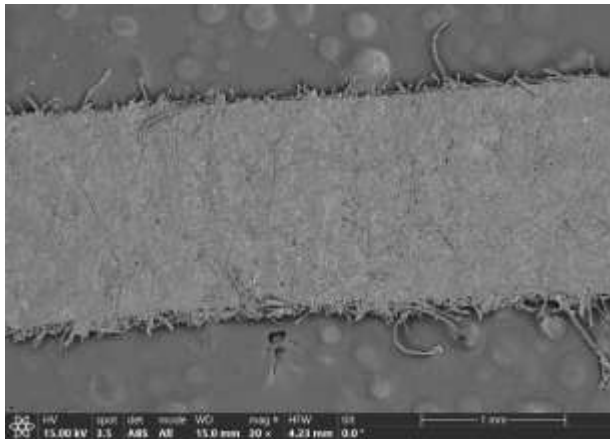


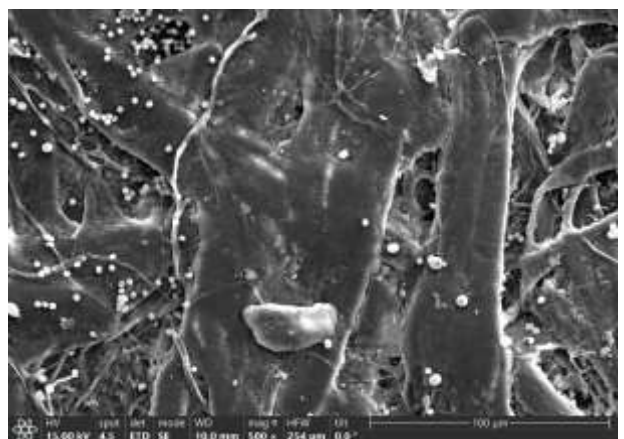
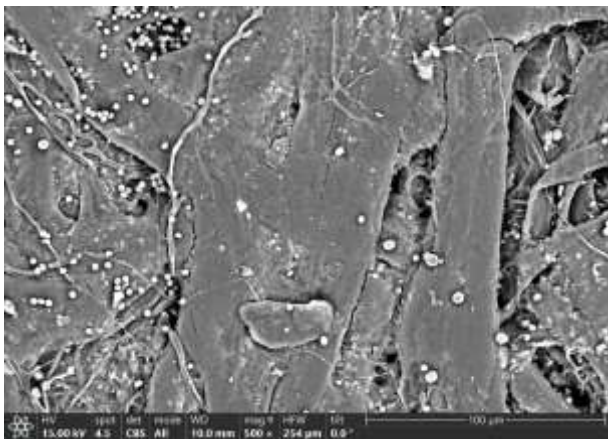
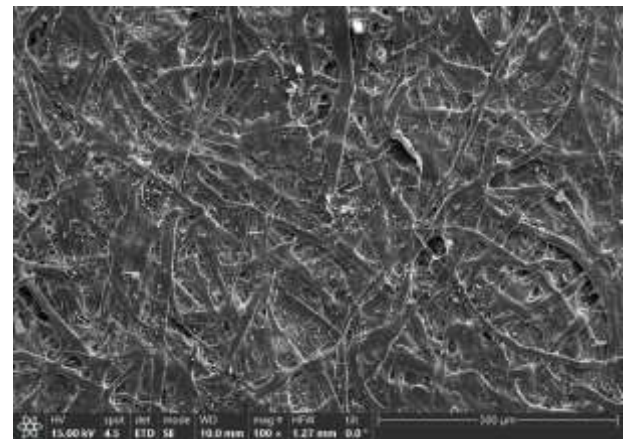
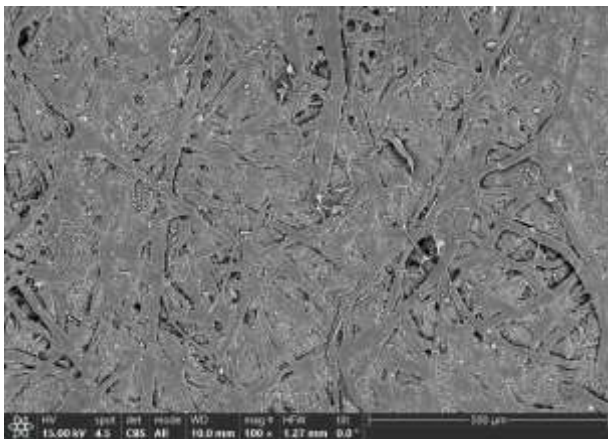
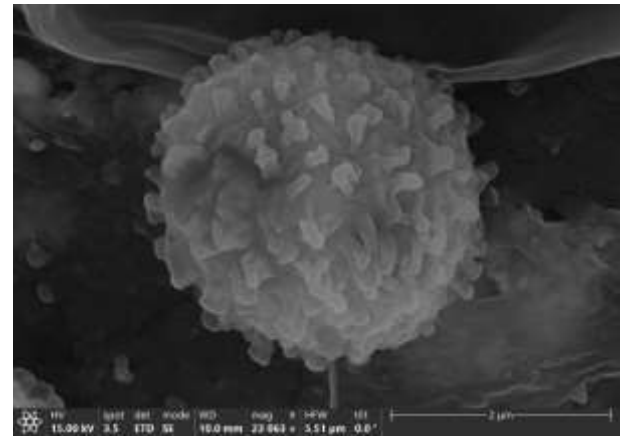
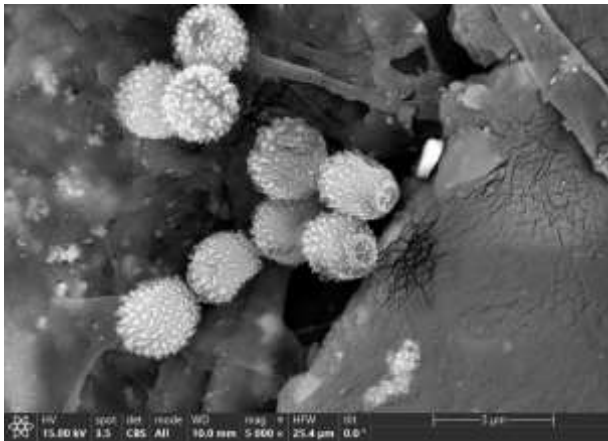


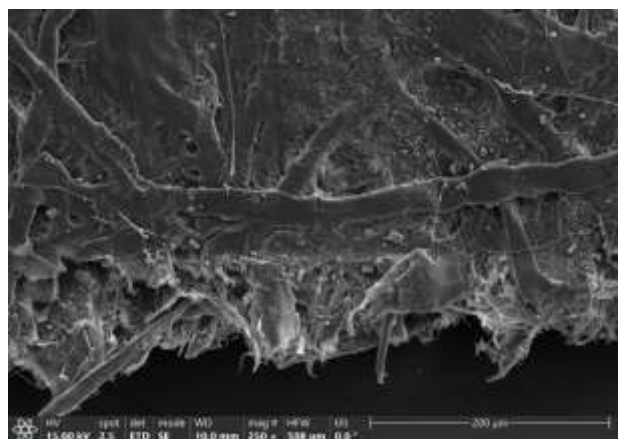
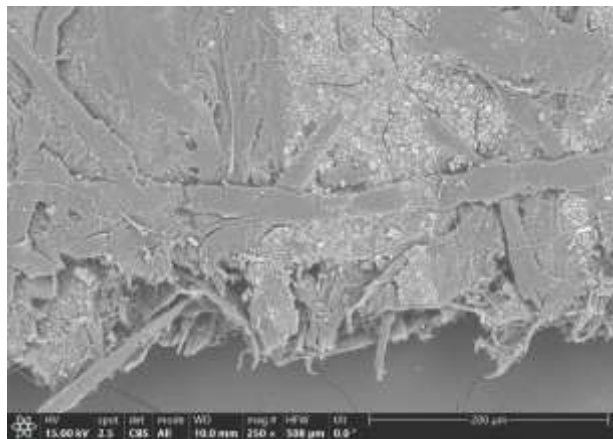
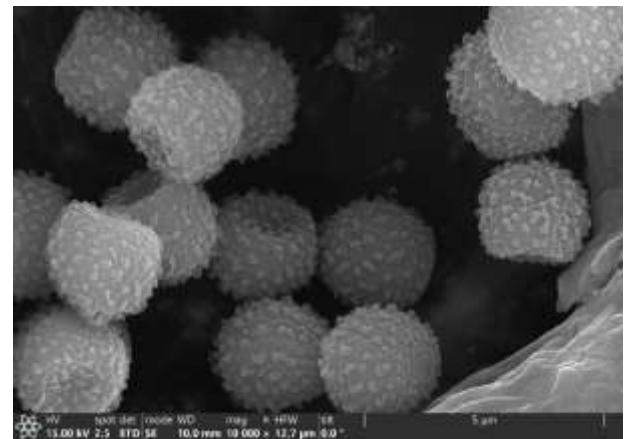
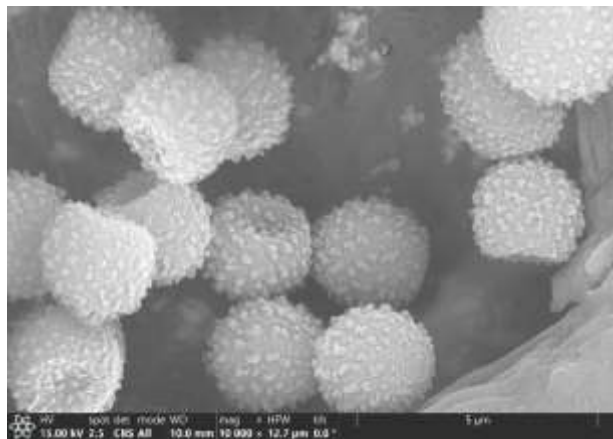
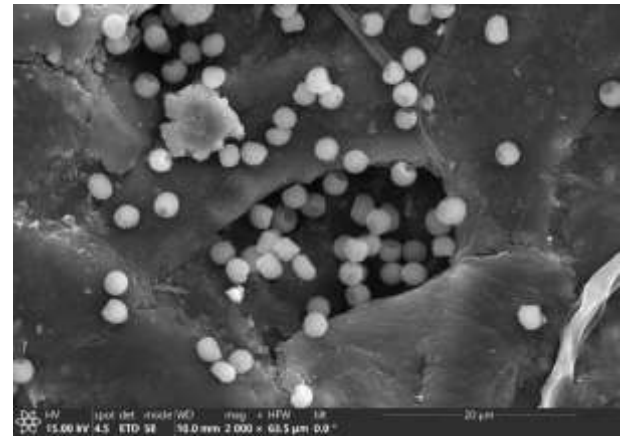
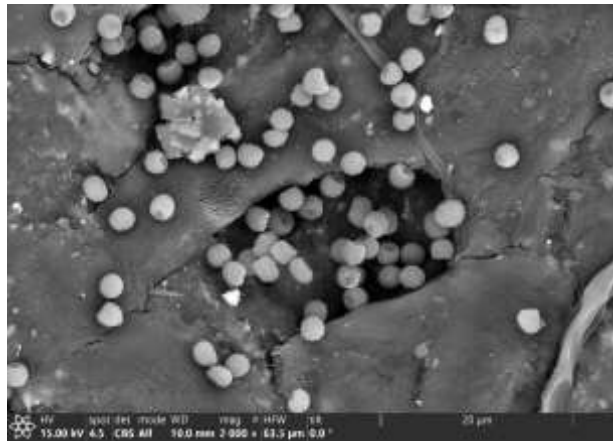


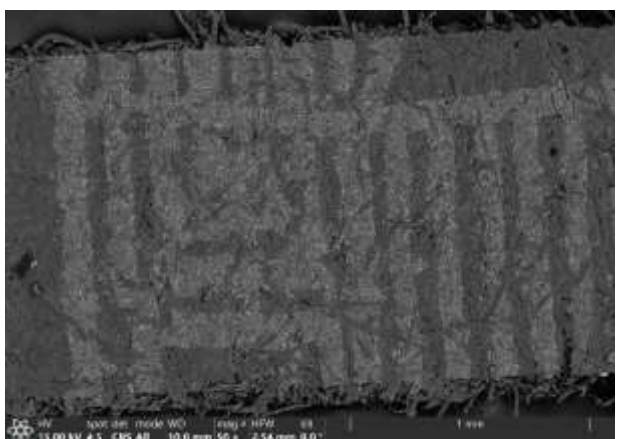
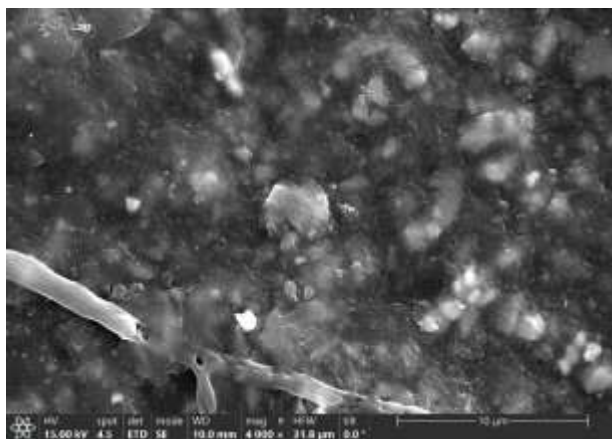
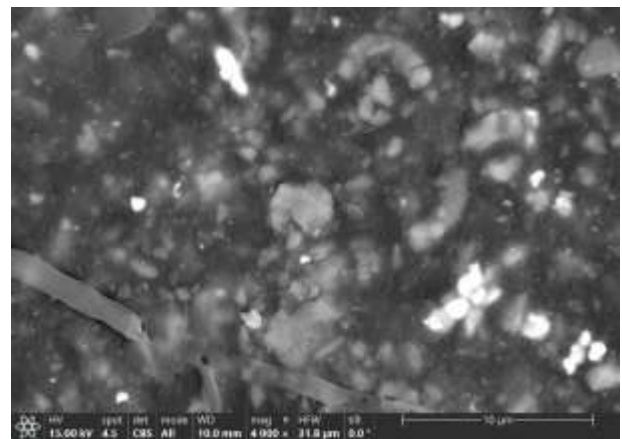
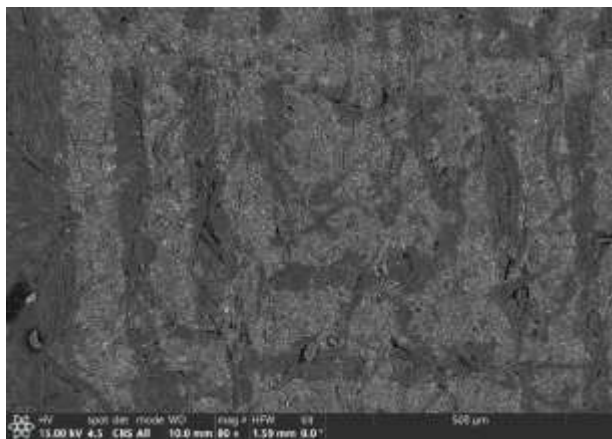
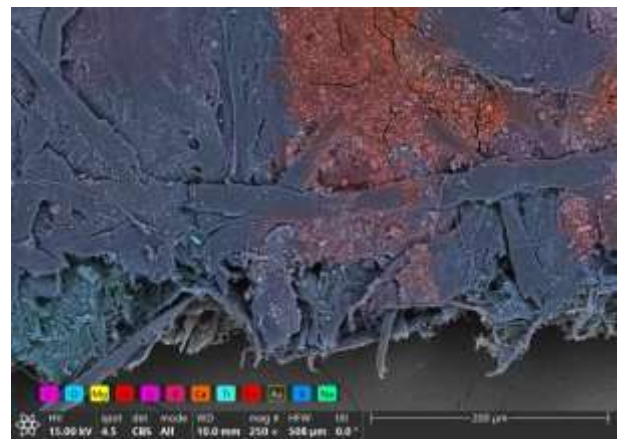
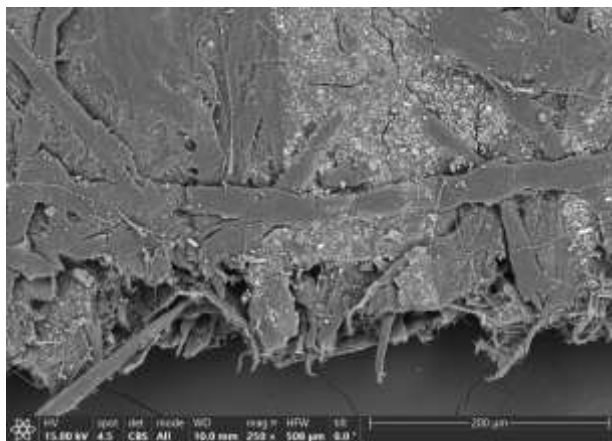


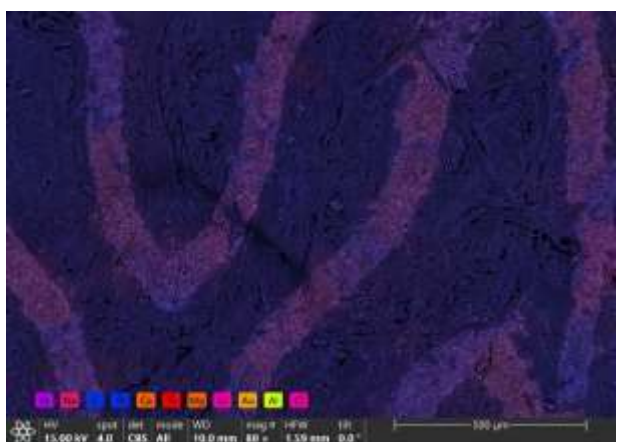
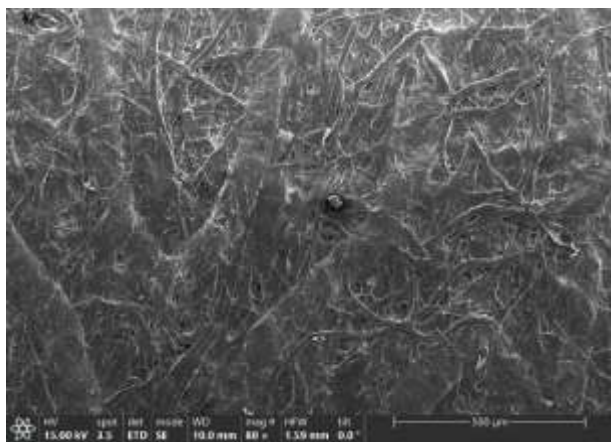
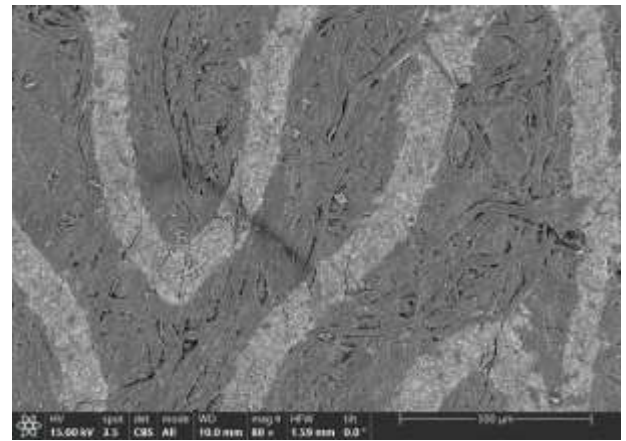
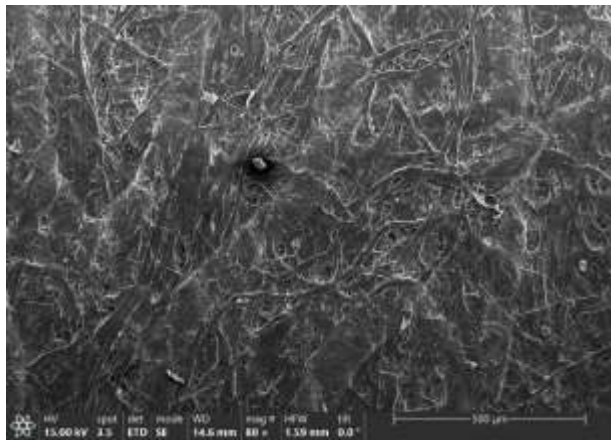
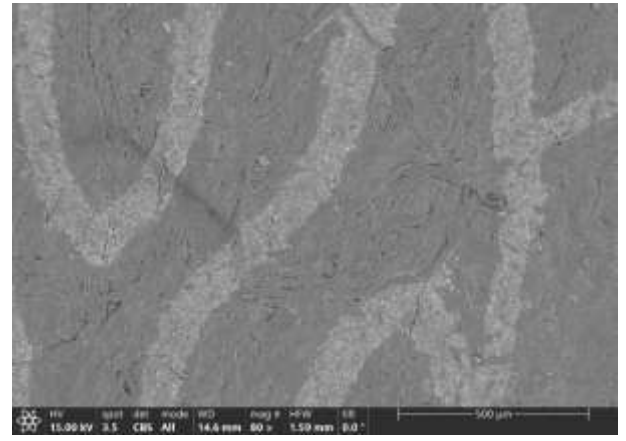
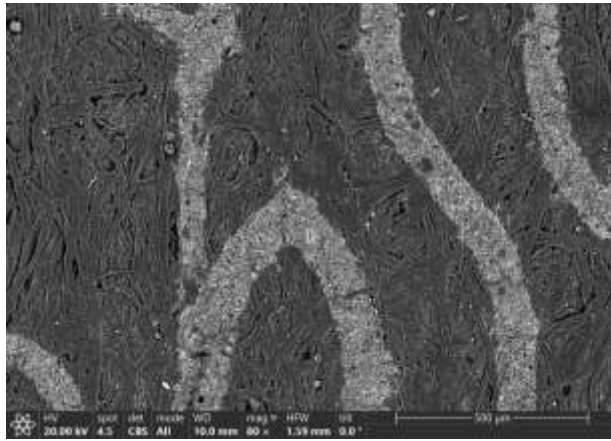
Waste Money Fibers SEM Images:

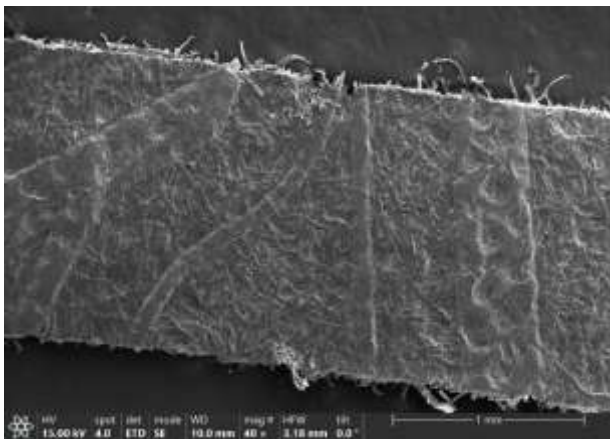
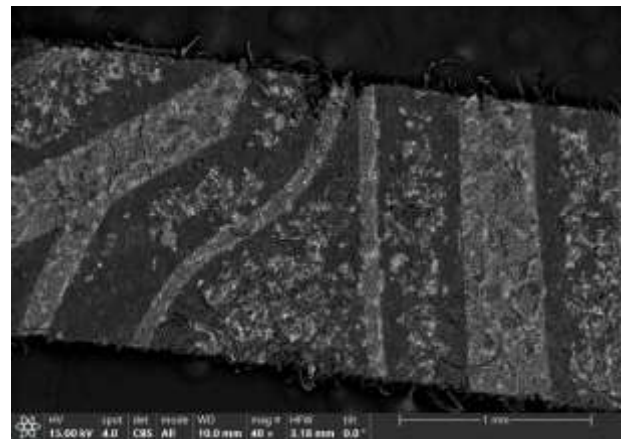
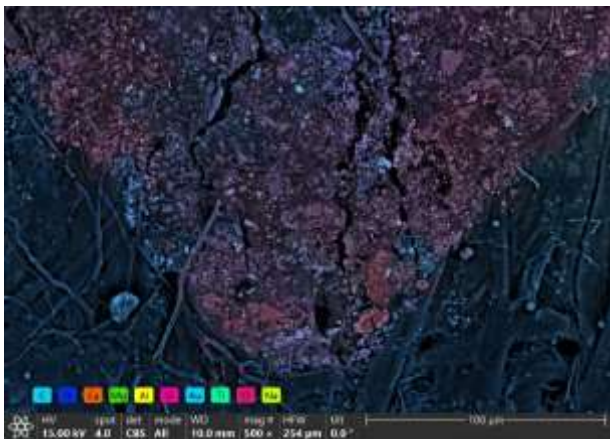
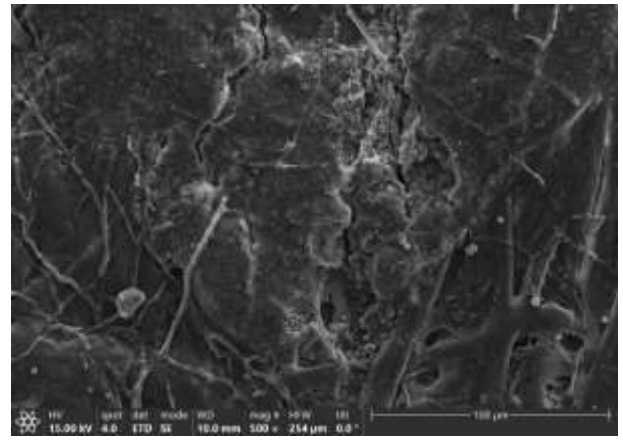
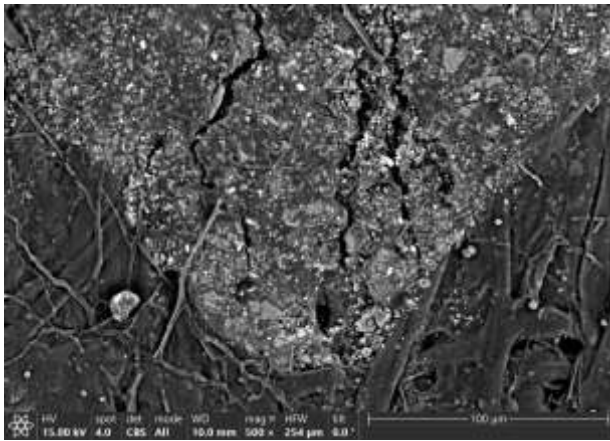


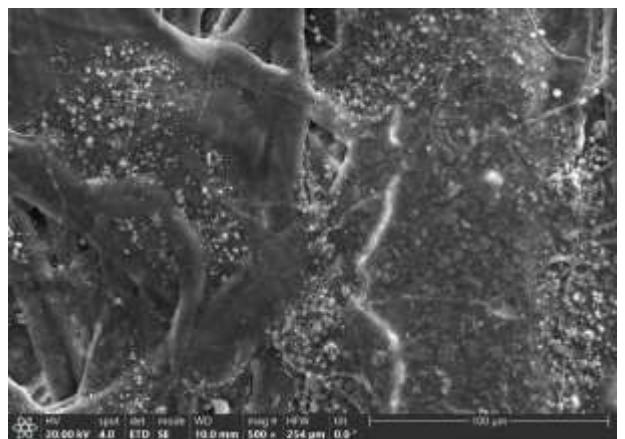
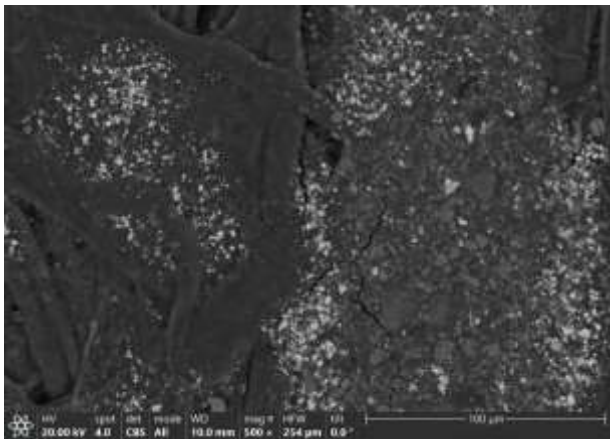
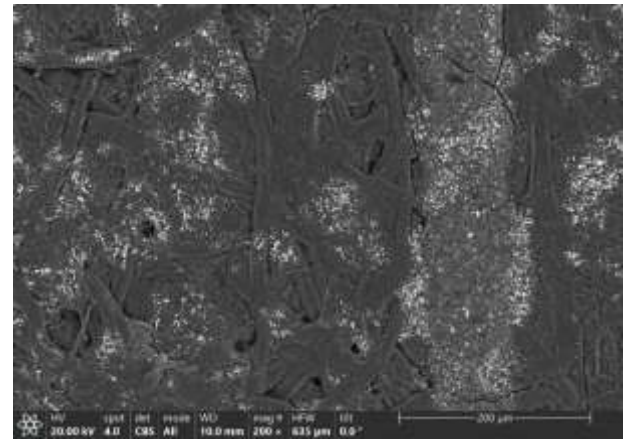
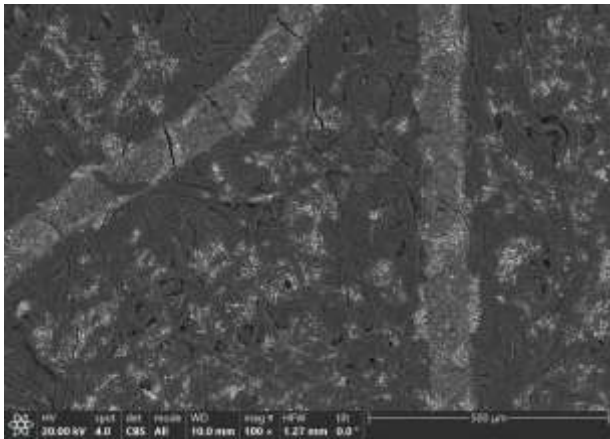
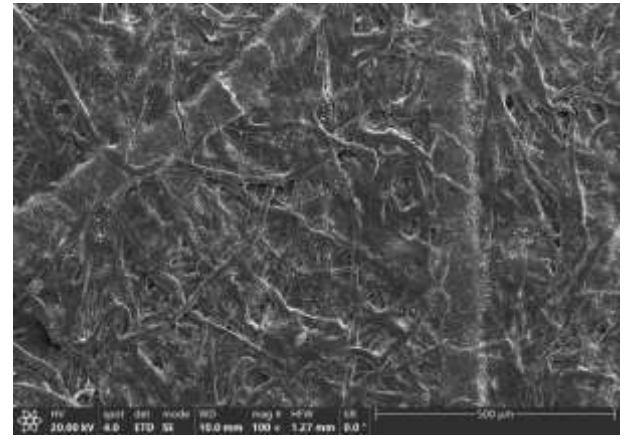
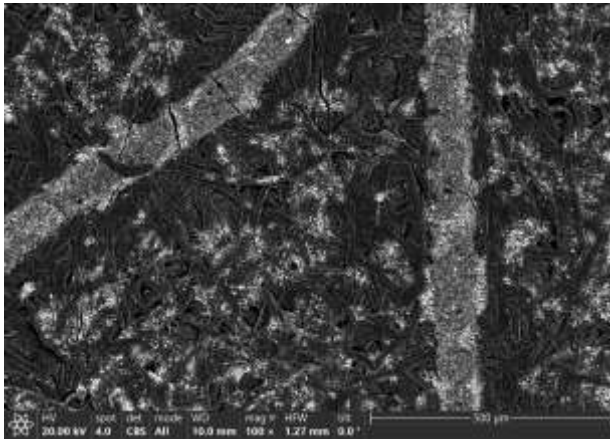


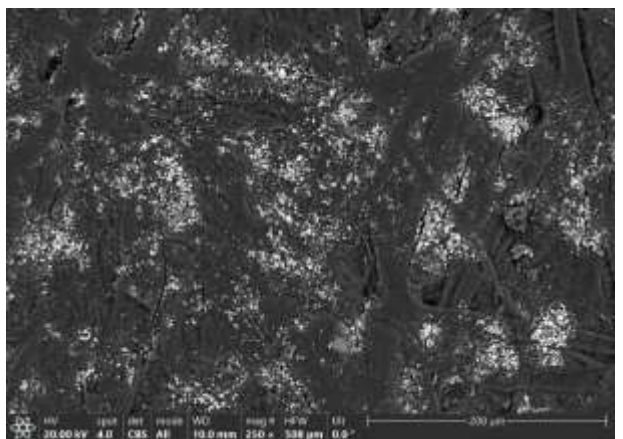
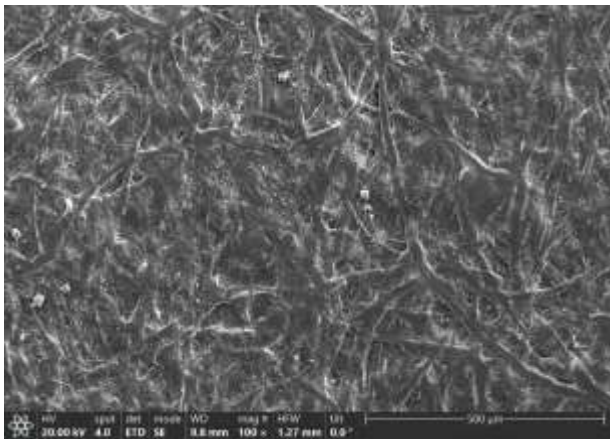
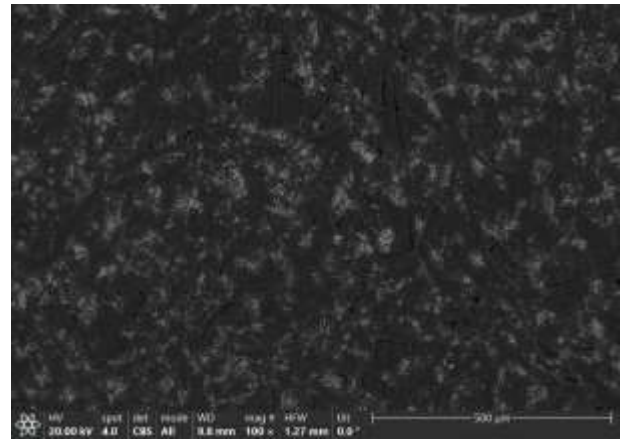
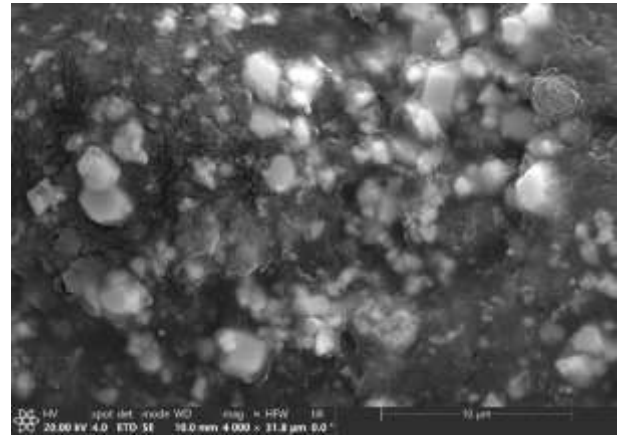
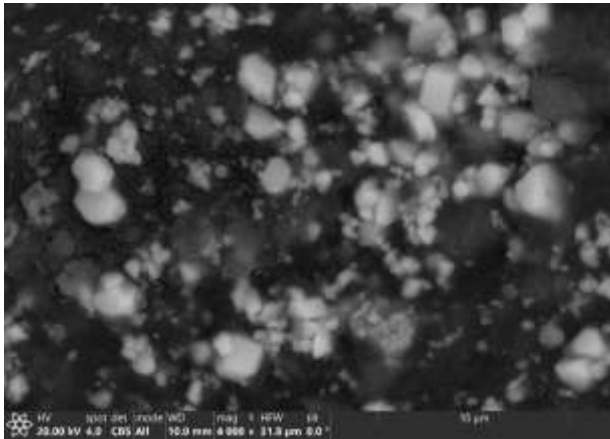


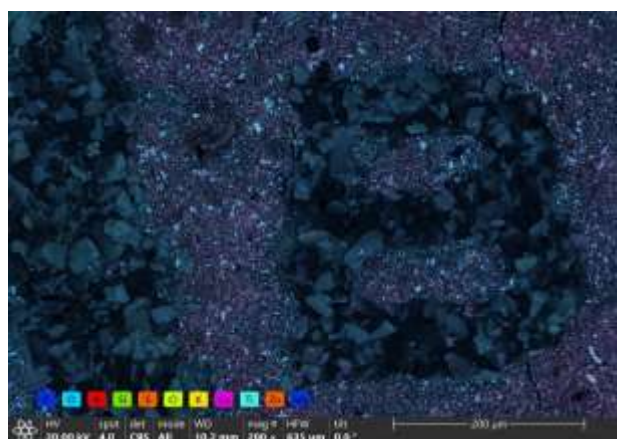
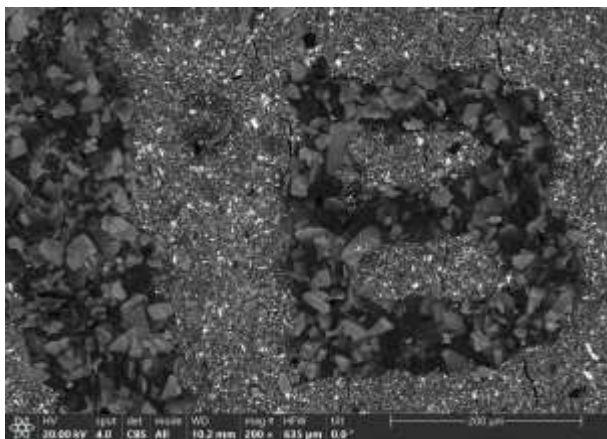
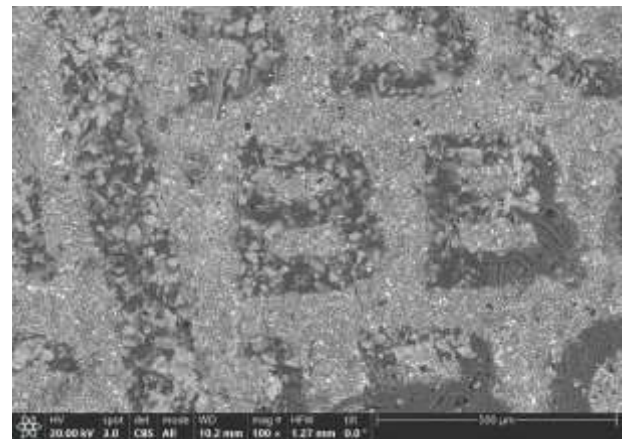
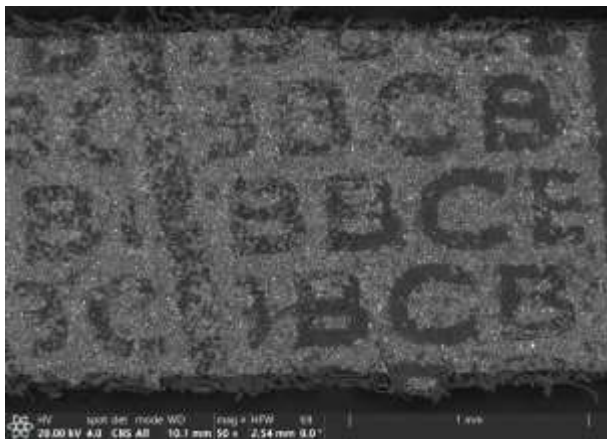
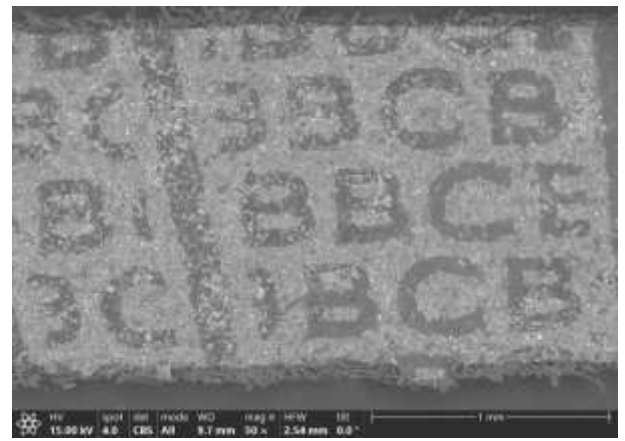




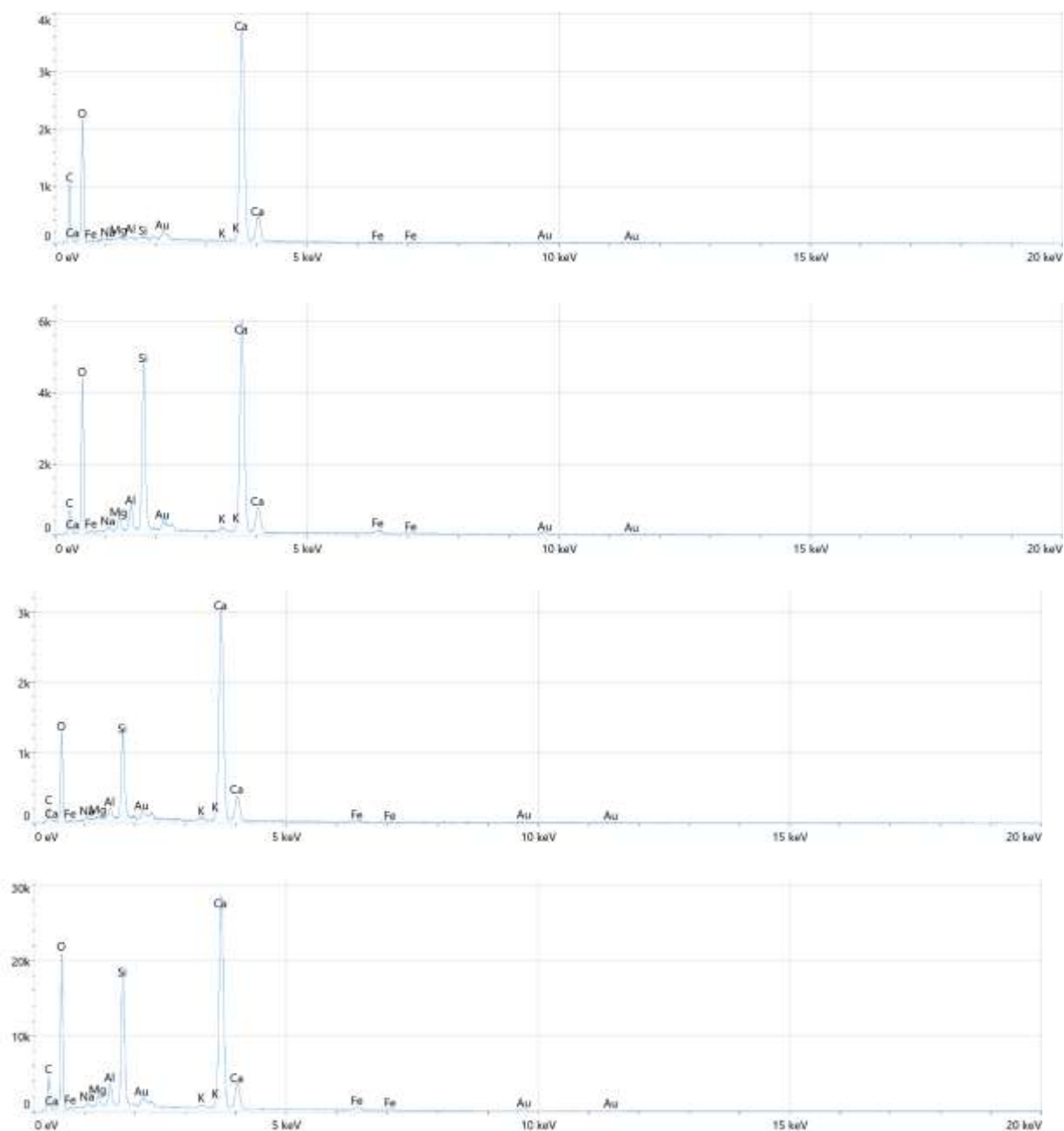








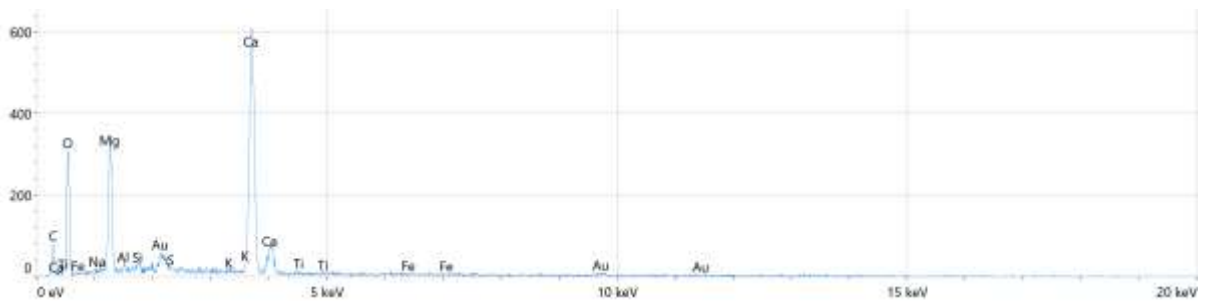
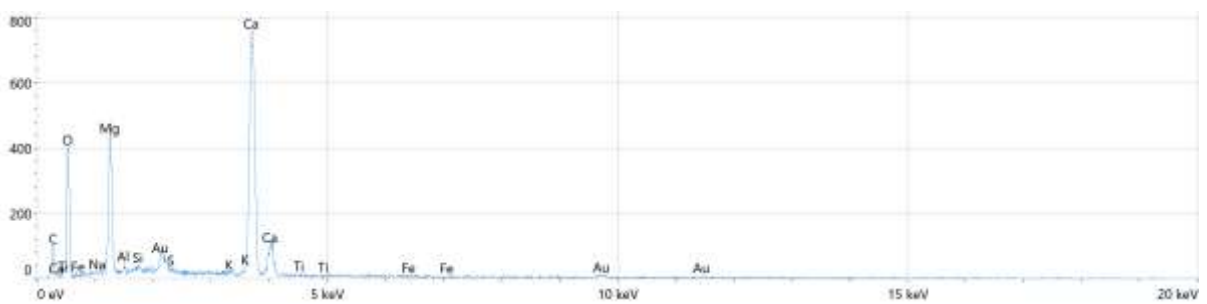
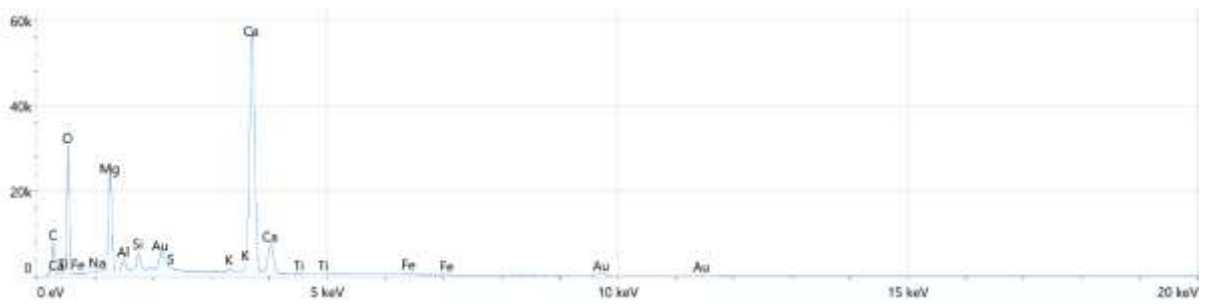
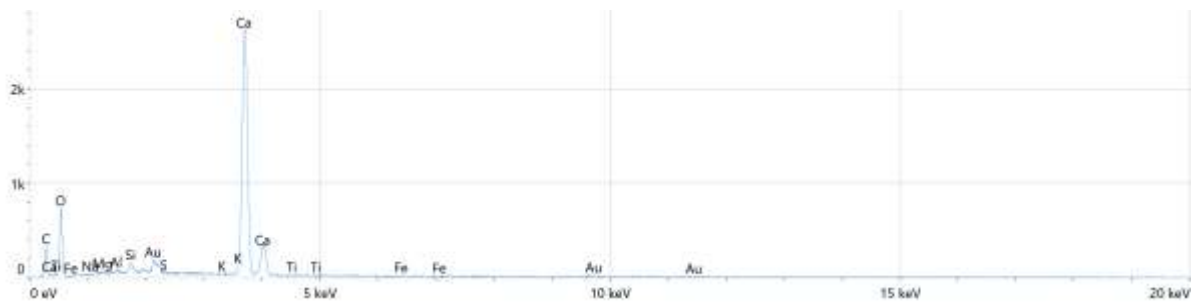
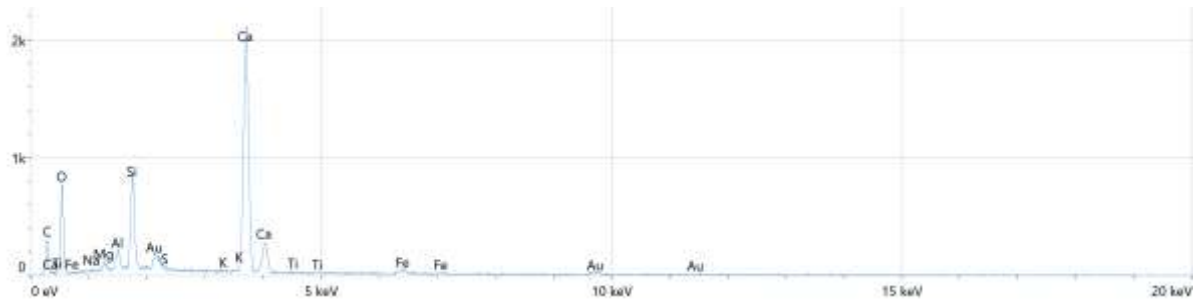
Control Mix EDS Images:



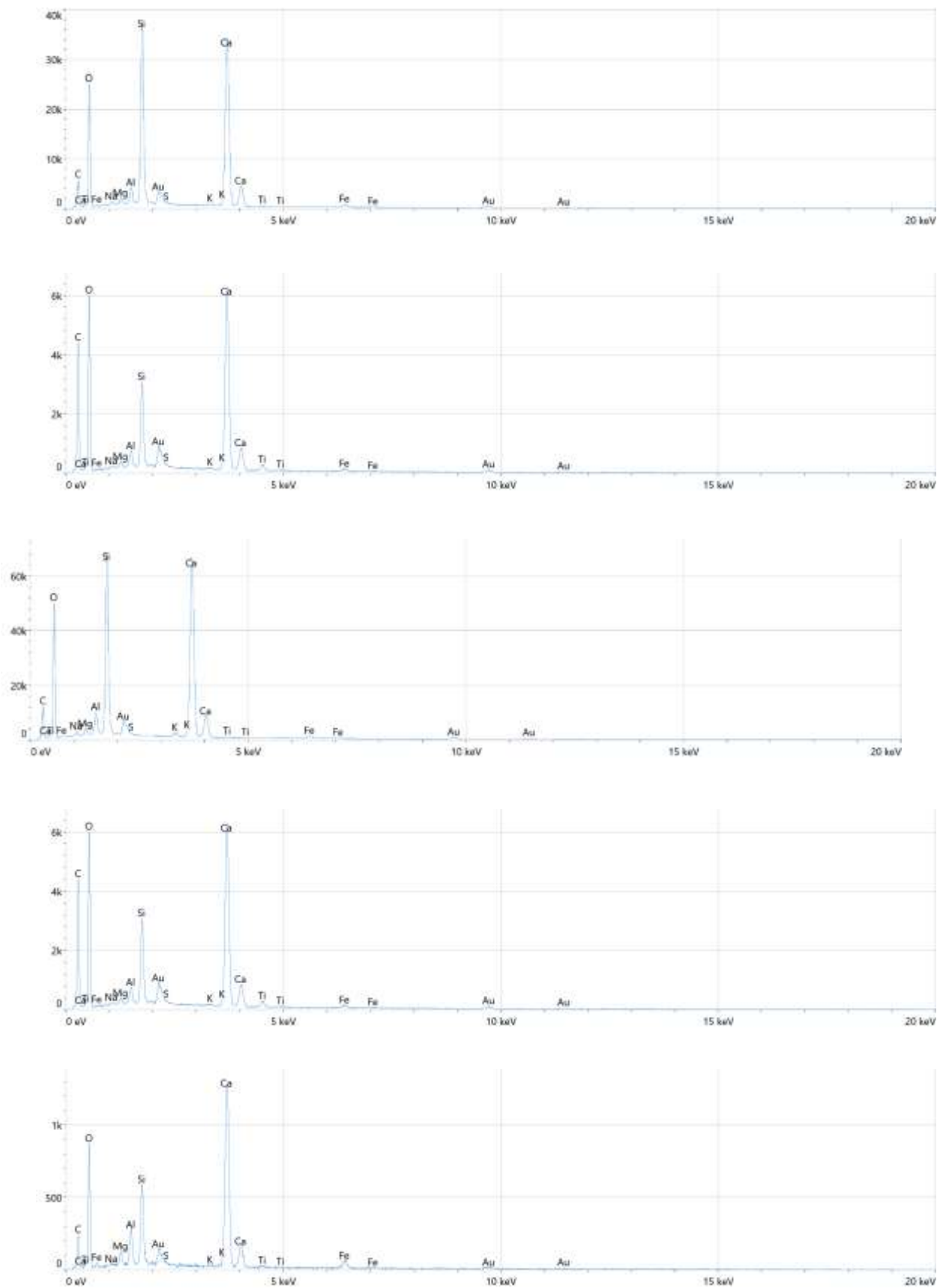
Control Mix with 1% of Waste Money Fibers EDS Images:



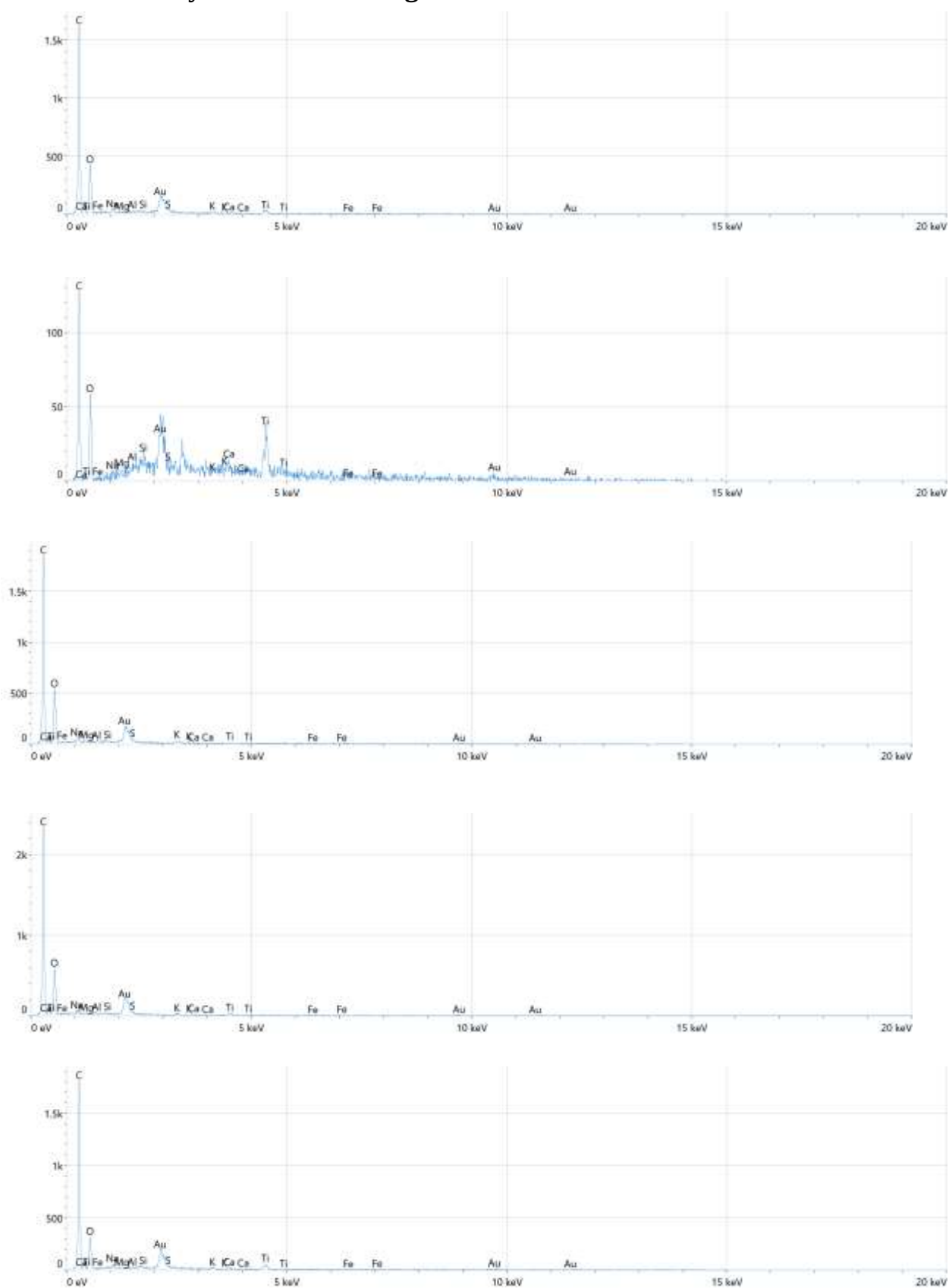
Control Mix with 0.5% of Waste Money Fibers EDS Images:



Control Mix with 0.25% of Waste Money Fibers EDS Images:



Waste Money Fibers EDS Images:



الملخص

وفقاً لرؤية البحرين لعام 2030، فإن البناء الجديد يجب أن يتبع متطلبات المباني الخضراء التي يمكن تحقيقها من خلال استخدام الخرسانة الخضراء في صناعة البناء والتشييد. ومن هذا المنطلق، تم إجراء هذه الدراسة لإنتاج الخرسانة الخضراء من خلال الاستفادة من المخلفات الورقية المتوفرة في البحرين. إن استخدام ورق النفايات في الخرسانة يحافظ على الموارد الطبيعية، مما يؤدي إلى تقليل تلوث البيئة وتوفير الطاقة.

تم إجراء الدراسة من خلال إنشاء أربعة خلطات هي الخلطة الأساسية وثلاث خلطات أخرى تحتوي على ألياف الأموال والتي يتم جمعها من مصرف البحرين المركزي وكانت النسب المضافة إلى الخلطة الخرسانية 0.25%، 0.5%، 1% من الوزن الكلي للخرسانة.

تم تصنيع واختبار 120 عينة للتحقق من الخواص الميكانيكية. وتضمنت الاختبارات التي تم إجراؤها اختبار قوة الضغط، وقوة الانثناء، ومقاومة الشد، واختبار امتصاص الماء، واختبار نفاذية الكلوريد السريعة، وأخيراً اختبار سرعة النبض بالموجات فوق الصوتية.

أهم النتائج التي توصلت إليها هذه الدراسة هي أن إضافة ألياف النفايات كان لها تأثير إيجابي على الخواص الميكانيكية للخرسانة حيث تم زيادة مقاومة الضغط وقوة الانثناء ومقاومة الشد. كما أصبحت الخرسانة أخف وزناً وأصبحت الشقوق والفراغات أقل. وكانت القيمة المثلى التي يجب إضافتها هي 0.5% من ألياف النفايات الورقية.

جامعة البحرين

قسم الهندسة المدنية

كلية الهندسة



تأثير ألياف النفايات الورقية على الخواص الميكانيكية للخرسانة

إطروحة مقدمة كجزء من متطلبات الحصول على درجة الماجستير في الهندسية

إعداد

صفا نادر زليخ

الرقم الأكاديمي: 20145186

إشراف

د. محمد أجمل

أستاذ مساعد

جامعة البحرين

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