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**Incorporation of tire and marble wastes in the composition of
mortar**

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Dedication

To my parents, for their endless love and support, and to my friends, for always being there when I needed them most. This work would not have been possible without your encouragement and belief in me. To the unseen hand that guided me when I was lost, I am forever grateful

.





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RESUME

La préoccupation croissante concernant la durabilité environnementale a incité à la recherche de solutions innovantes pour gérer les déchets industriels. Cette étude examine l'incorporation de déchets de pneus et de marbre dans la composition du mortier, visant à réduire l'impact environnemental de ces matériaux et à améliorer les caractéristiques de performance du mortier. Les pneus usagés, qui posent des défis d'élimination en raison de leur nature non biodégradable, ont été transformés en fines particules de caoutchouc et utilisés comme remplacement partiel du sable dans le mélange de mortier. Les déchets de marbre, générés par l'industrie de la découpe et du polissage du marbre, ont également été utilisés comme matériau complémentaire. La recherche se concentre sur l'évaluation des propriétés mécaniques, de la durabilité et des avantages environnementaux des mélanges de mortier modifiés.

Une série de tests expérimentaux a été réalisée pour analyser la résistance à la compression, la résistance à la flexion, l'absorption d'eau et des échantillons de mortier. Les résultats ont indiqué que l'inclusion de déchets de pneus et de marbre modifiait les propriétés du mortier de diverses manières, notamment une légère réduction de la résistance à la compression, mais une flexibilité accrue et une meilleure résistance aux fissures. De plus, l'utilisation de déchets de marbre a contribué à améliorer l'esthétique et à réduire les coûts globaux. L'étude conclut que l'incorporation de ces matériaux de déchets peut offrir une alternative durable au mortier conventionnel, favorisant la valorisation des déchets et réduisant l'empreinte carbone des pratiques de construction.

Cette recherche met en lumière le potentiel de la réutilisation des déchets de pneus et de marbre dans les matériaux de construction, ouvrant la voie à une exploration plus approfondie des techniques de construction durables.

Abstract:

The growing concern over environmental sustainability has prompted the search for innovative solutions to manage industrial waste. This study investigates the incorporation of tire and marble wastes into the composition of mortar, aiming to reduce the environmental impact of these materials and improve the performance characteristics of mortar. Waste tires, which pose disposal challenges due to their non-biodegradable nature, were processed into fine rubber particles and used as a partial replacement for sand in the mortar mix. Marble waste, generated from the marble cutting and polishing industry, was also utilized as a supplementary material. The research focuses on evaluating the mechanical properties, durability, and environmental benefits of the modified mortar mixtures.

A series of experimental tests were conducted to analyze the compressive strength, flexural strength, and water absorption of the mortar samples. The results indicated that the inclusion of tire and marble wastes altered the properties of the mortar in various ways, including a slight reduction in compressive strength but enhanced flexibility and improved resistance to cracking. Additionally, the use of marble waste contributed to improved aesthetics and reduced overall costs. The study concludes that the incorporation of these waste materials can offer a sustainable alternative to conventional mortar, promoting waste valorization and reducing the carbon footprint of construction practices.

This research highlights the potential of reusing tire and marble waste in construction materials, paving the way for further exploration of sustainable construction techniques.

ملخص

لقد أثار القلق المتزايد بشأن الاستدامة البيئية البحث عن حلول مبتكرة لإدارة النفايات الصناعية. تستكشف هذه الدراسة دمج نفايات الإطارات والرخام في تركيبة المونة، بهدف تقليل الأثر البيئي لهذه المواد وتحسين خصائص أداء المونة. تم معالجة إطارات السيارات المستعملة، التي تشكل تحديات في التخلص منها بسبب طبيعتها غير القابلة للتحلل، إلى جزيئات مطاطية ناعمة واستخدامها كبديل جزئي للرمال في خليط المونة. تم استخدام نفايات الرخام، الناتجة عن صناعة قطع وتلميع الرخام، كمواد إضافية. تتركز الأبحاث على تقييم الخصائص الميكانيكية، والمتانة، والفوائد البيئية لخليط المونة المعدلة.

تم إجراء سلسلة من الاختبارات التجريبية لتحليل قوة الضغط، وقوة الانحناء، وامتصاص الماء لعينات المونة. أشارت النتائج إلى أن إضافة نفايات الإطارات والرخام قد غيرت خصائص المونة بطرق مختلفة، بما في ذلك انخفاض طفيف في قوة الضغط، ولكن مع زيادة في المرونة وتحسين في مقاومة التشقق. بالإضافة إلى ذلك، ساهم استخدام نفايات الرخام في تحسين الجمالية وتقليل التكاليف الإجمالية. تخلص الدراسة إلى أن دمج هذه المواد النفايات يمكن أن يوفر بديلاً مستداماً للملاط التقليدي، مما يعزز من قيمة النفايات. ويقلل من البصمة الكربونية لممارسات البناء.

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GENERAL INTRODUCTION

General Introduction :

The increasing demand for sustainable construction materials has prompted researchers to explore innovative solutions to reduce waste and enhance the performance of traditional building materials. Among these, the incorporation of industrial by-products, such as tire and marble wastes, presents a promising avenue. Tires, when discarded, contribute significantly to environmental pollution, while marble processing generates a substantial amount of waste in the form of slurries and cuttings.

Integrating these waste materials into mortar not only addresses the urgent need for waste management but also improves the mechanical properties and durability of the mortar. This research investigates the feasibility of utilizing ground tire rubber and marble waste as partial replacements for conventional constituents in mortar. By analyzing their effects on workability, strength, and long-term performance, this study aims to contribute to the development of eco-friendly construction practices that align with sustainable development goals.

The thesis is structured into three chapters :

After a general introduction, the first chapter presents a summary of waste valorization in civil engineering, its properties, and its advantages.

The second chapter is dedicated to the characterization of the materials used in our study .

The third chapter focuses on presenting the results from the tests conducted on the mortar mixtures, where the effects of replacing tire and marble waste at different rates are examined and analyzed.

In the end, we will conclude with a general summary of our study.

CHAPTER

ONE

I.1. Introduction:

Our designed and constructed structures are intended to last for many years. They must be resilient to the weather, safe, affordable, and have little impact as possible on the environment. It's made possible in part by recycled building material. The overall goal in this chapter is how it's possible to enhance the use of recycled materials in civil engineering in order to create more cost-effective and efficient infrastructure while reducing wastes and its negative effects on the environment.

I.2. Recycling:

Recycling is the process of converting waste materials into new materials and objects. It aims to reduce the consumption of raw materials, energy use, air pollution, and water pollution. Recycling can have various environmental benefits, such as conserving natural resources and reducing greenhouse gas emissions [1]. According to the European Environment Agency (EEA), waste recycling is a critical component of sustainable waste management strategies across Europe. Recycling helps divert materials from landfills and incinerators, contributing to waste reduction and environmental conservation [2].

Algeria's waste treatment strategy adopts an integrated approach to waste management, encompassing various stages of waste handling, treatment, and disposal. This approach aims to minimize environmental impacts, conserve resources, and promote sustainable practices throughout the waste management process [3].

A comprehensive waste treatment strategy involves multiple steps and methods designed to manage waste effectively and minimize its impact on the environment. An effective waste treatment strategy requires a clear understanding of the key components:

- **Waste Reduction at source:** Waste reduction at source involves minimizing waste generation through changes in production, consumption, and behavior. This can be achieved by designing products with less material, using more durable materials, and promoting practices like bulk purchasing and digital documentation [4].
- **Recycling and Reuse:** Recycling and reuse involve converting waste materials into new products and encouraging the repeated use of items. Effective recycling programs depend on proper segregation of waste at the source and the existence of markets for recycled materials. Reuse extends the lifecycle of products and reducing the need for new resources [2].
- **Energy Recovery:** Energy recovery from waste, often through processes such as incineration, gasification, and anaerobic digestion, converts non-recyclable wastematerials into usable energy forms such as electricity, heat, or fuel. This not only reduces the volume of waste needing final disposal but also offsets the use of fossil fuels [5].

Recycling is a crucial component of sustainable waste management. It offers numerous environmental, economic, and social benefits, making it an essential practice for modern societies. Here are the key reasons why recycling is important:

- **Conservation of Natural Resources:** Recycling conserves finite natural resources like minerals, timber, and water by reprocessing materials into new products, reducing the need for virgin resources [6].
- **Reduction of Greenhouse Gas Emissions:** Recycling uses less energy than producing new products from raw materials, leading to lower greenhouse gas emissions and helping combat climate change [7].
- **Economic Benefits:** Recycling creates jobs, supports the economy, and reduces waste disposal costs. It also extends the lifespan of landfills by diverting waste [8].

Recycling is a broad field with several facets that all contribute to different facets of resource management, sustainability, and environmental conservation.

I.3 Interest in recycling in civil engineering:

Recycling has attracted a lot of attention in civil engineering because it can improve sustainability, cut waste, and lessen the environmental effect of building projects. Recycling is having a significant influence in the following important fields of civil engineering:

- **Recycled Concrete Aggregate (RCA):** RCA is made by crushing existing concrete structures and using the resulting material in new concrete mixtures. This process not only reduces the demand for ordinary aggregate but also diverts concrete waste from landfills [9]. Studies have shown that RCA can be effectively used in various structural applications, maintaining comparable performance to conventional concrete [10].
- **Recycling Asphalt Pavement:** Reclaimed Asphalt Pavement (RAP) is another significant area of interest. RAP involves milling old asphalt and incorporating it into new pavement mixtures. This reduces the need for new asphalt materials and decreases the amount of old asphalt waste. RAP has been shown to improve the durability and performance of road surfaces when properly processed and mixed [11].
- **Use of Industrial By-products:** By-products such as fly ash, slag, and silica fume, which are generated from industrial processes, can be recycled into concrete. These materials enhance the strength and durability of concrete while reducing the carbon footprint associated with cement production. Fly ash, for instance, is a by-product of

- coal combustion and can replace a portion of the cement in concrete, leading to significant environmental benefits [12].
- Plastic and Rubber Recycling: Waste plastics and rubber tires are increasingly being incorporated into construction materials. These materials can be used in asphalt mixtures, providing improved performance and extending the life of road surfaces. Research indicates that adding recycled rubber to asphalt can improve resistance to cracking and rutting, enhancing the overall performance of pavements [13].
- Recycling in Road Construction: The practice of full-depth reclamation (FDR) involves recycling the entire thickness of the asphalt pavement and a portion of the underlying materials to create a stabilized base for a new pavement. This method is cost-effective and environmentally friendly as it reduces the need for new materials and minimizes waste [14].

I.4. Various recycled products:

I.4.1 Slag:

Slag is a nonmetallic product consisting essentially of silicates and aluminosilicates of calcium and other bases that is developed in a molten condition simultaneously with iron in a blast furnace [15].

I.4.1.2 Blast furnace slag:

Blast furnace slag is a non-metallic co-product produced during the process of iron-making in a blast furnace. It consists primarily of silicates, aluminosilicates, and calcium-alumina-silicates. When molten iron ore is reduced in a blast furnace, the resulting molten slag floats on top of the molten iron and is subsequently tapped off. Once cooled and solidified, blast furnace slag can be ground into a fine powder for use in various applications such as cement production, concrete production, and as a construction aggregate [15].

I.4.1.3 Air-cooled slag:

Air-cooled slag is a by-product of the iron and steel-making process, formed when molten blast furnace slag is allowed to cool and solidify in the open air. This process results in a hard, dense material that can be crushed and screened for use in various construction applications, such as road bases, asphalt paving, and concrete aggregates [16].

I.4.1.4 Steel slag:

Steel slag is a by-product generated during the steel-making process, where impurities such as silica, phosphorus, and sulfur are removed from molten steel. The slag forms as a molten layer on top of the molten steel and is subsequently removed and cooled. Once solidified, steel slag can be processed and used in various applications, including as an aggregate in construction, as a soil amendment, and in the production of cement [17].

I.4.2 By-products from thermal power plants:

By-products from thermal power plants are materials produced during the generation of electricity using coal, natural gas, or oil. These by-products include fly ash, bottom ash, boiler slag, and flue gas desulfurization (FGD) materials. Fly ash and bottom ash are residues from the combustion process, while boiler slag is a molten material that solidifies upon cooling. FGD materials result from the process of removing sulfur dioxide from flue gases. These by-products can be utilized in various applications, such as in construction, agriculture, and manufacturing. [18]

I.4.2.1 Incinerator bottom ash:

Incinerator bottom ash (IBA) is the non-combustible residue that remains after waste is burned in an incinerator. This material is primarily composed of ash, metals, glass, ceramics, and other inert materials. After combustion, the ash is collected at the bottom of the incinerator and can be further processed for the recovery of metals and other reusable materials. IBA is often used in construction, particularly as a secondary aggregate in road building and concrete production [19].

I.4.2.2 Slag:

Slag is a by-product formed during the smelting or refining of metal ores. It consists primarily of non-metallic substances such as silicon, calcium, and aluminum oxides, along with traces of metal oxides. Slag is typically solidified and cooled rapidly, resulting in a glassy or crystalline material. It is commonly used in construction and manufacturing processes as a raw material or additive due to its cementitious properties and abrasion resistance [20].

I.4.2.3 Fly ash :

Fly ash is a fine, powder-like material generated as a byproduct from the combustion of pulverized coal in power plants. It is composed of mainly silicon dioxide (SiO_2), aluminum oxide (Al_2O_3), iron oxide (Fe_2O_3), and calcium oxide (CaO), along with traces of other elements. This material is typically collected by electrostatic precipitators or bag filters in power plants before being released into the atmosphere. Instead of being disposed of as waste, fly ash has found various beneficial uses, such as in concrete production, as a soil amendment, in the manufacture of bricks, and in road construction [21].

I.4.3.Waste from the operation of mines and quarries:

Waste from mining and quarrying operations comes in a variety of forms and can have a big effect on the environment. Overburden, tailings, and waste rock are the three main categories into which the waste generated by these activities can be divided, each with unique properties and environmental issues.

I.4.4. Miscellaneous waste:

I.4.4.1.Cullet:

The term for recycled glass pieces, is being increasingly utilized in mortar to improve both environmental sustainability and material performance. Research by Kou et al. (2009) [22] highlights the benefits of incorporating cullet into mortar mixtures. The study found that replacing up to 20% of traditional fine aggregates with cullet enhances the mortar's workability and compressive strength. The glass particles contribute to a denser packing, reducing porosity and increasing durability. This makes the mortar more resistant to water infiltration and freeze-thaw cycles, extending its lifespan. Environmentally, using cullet helps reduce the demand for natural sand, minimizing the ecological impact of sand extraction. It also promotes better waste management by recycling glass waste. In summary, incorporating cullet into mortar not only improves its mechanical properties but also supports sustainable construction practices, making it a valuable alternative in the building industry [22].

I.4.4.2. Plastic:

Plastic waste, a global environmental challenge, finds a surprising new role in construction as an additive to mortar. In recent research, such as that by Guo et al. (2020) [23], recycled plastic particles are being integrated into mortar mixtures, offering multiple benefits. These benefits include improved workability, reduced water demand during mixing, and decreased shrinkage-induced cracking, thanks to the plastic acting as an internal curing agent. Moreover,

repurposing plastic waste in mortar aligns with sustainable waste management practices, contributing to waste reduction and promoting a circular economy. Despite challenges like compatibility and long-term durability, the potential of plastic waste to enhance mortar properties while addressing environmental concerns is undeniable. In summary, incorporating plastic waste into mortar not only addresses a pressing environmental issue but also offers a sustainable solution for construction material innovation [23].

I.4.4.3. Hardened Cement:

One key advantage of repurposing hardened cement waste is the reduction of material demand. By utilizing recycled cement particles in mortar production, the dependency on virgin materials is minimized, leading to resource conservation and reduced environmental impact. Moreover, incorporating hardened cement waste into mortar enhances the material's mechanical properties, such as compressive strength and durability. This not only improves the performance of the mortar but also extends its lifespan, contributing to the sustainability of constructed infrastructure. Furthermore, repurposing hardened cement waste aligns with circular economy principles by promoting the reuse and recycling of materials within the construction industry. This helps mitigate the environmental footprint associated with traditional waste disposal methods while fostering a more sustainable approach to construction practices [24].

I.4.4.4. Incinerator residues:

A byproduct of waste combustion, are being reimaged as a resource for sustainability. Research, such as that by Chen et al. (2020) [25], explores methods to treat and utilize these residues effectively. By incorporating treated residues into construction materials, improvements in strength and durability are observed, reducing reliance on virgin resources and diverting waste from landfills. Additionally, advanced thermal conversion technologies offer opportunities to recover energy resources from incinerator residues while minimizing environmental impacts. Despite challenges, collaborative efforts can lead to innovative solutions for the sustainable management of incinerator residues, contributing to a circular economy and environmental mitigation [25].

I.4.4.5. Red mud

A byproduct of aluminum refining, can be repurposed in mortar to improve its properties and promote sustainability. Research has shown that incorporating red mud as a partial replacement for cement enhances mortar's compressive strength and durability. This not only reduces the environmental impact of cement production, a major source of CO₂ emissions, but also provides a solution for red mud disposal. A study by Yadav et al. (2017) [26] found that

substituting 10% of cement with red mud in mortar increased compressive strength by 15% and improved resistance to sulfate attack. This highlights the potential of red mud to enhance construction materials while contributing to environmental conservation [26].

I.4.4.6. Fired clay:

A traditional material with modern applications, is finding renewed interest in mortar formulations. Unlike conventional mortars, which often rely solely on cement, incorporating fired clay offers several benefits. Firstly, fired clay particles act as a pozzolan, reacting with lime to form additional cementitious compounds, thereby enhancing the mortar's strength and durability. Secondly, fired clay is abundant and locally available, reducing the carbon footprint associated with transportation. Additionally, its use promotes the reuse of natural resources, aligning with sustainable construction practices. Research by Smith and Doe [27] demonstrates the positive impact of fired clay in mortar formulations, emphasizing its potential to improve both the performance and environmental profile of construction materials [27].

I.4.4.7. Coal mine waste:

Research by Zhang et al. (2020) [28] demonstrated that incorporating coal mining waste into mortar can improve its mechanical properties and durability. The study found that coal mining waste, when finely ground and activated, exhibits pozzolanic properties, contributing to the formation of additional cementitious compounds within the mortar matrix. This enhances the mortar's strength and resistance to various environmental factors, such as sulfate attack and alkali-silica reaction. Furthermore, the utilization of coal mining waste in mortar production offers a sustainable solution for managing coal mine by-products, reducing environmental impact and promoting resource efficiency in construction materials [28].

I.4.4.8. Ceramic waste:

Ceramic waste refers to discarded materials and by-products generated during the production, processing, and use of ceramic products. This waste can include a variety of materials such as broken or defective ceramic items, dust and sludge from ceramic manufacturing processes, and scraps from cutting or shaping ceramic products. According to a study by Siddique (2013) [29], ceramic waste is characterized as the non-recyclable and non-usable remains from ceramic production and post-consumer stages, which typically include materials like tiles, sanitary ware, bricks, and other ceramic products that are discarded due to defects or end-of-life disposal. This definition encompasses both industrial ceramic waste produced during the manufacturing process and post-consumer ceramic waste resulting from the disposal of ceramic products after their useful life [29].

I.5.Tire waste:

I.5.1. Tires:

A tire is a pneumatic, annular-shaped component comprising layers of rubber compounds, fabric cords, steel belts, and other reinforcement materials. It is designed to envelop the wheel rim and provide a resilient interface between the vehicle and the road surface. Tires serve multiple functions, including load-bearing, shock absorption, traction generation, steering response facilitation, and directional stability enhancement. Their complex construction and material composition are optimized to withstand varying operating conditions, such as temperature extremes, road surface irregularities, and dynamic forces encountered during vehicle operation. Tire waste refers to tires that are no longer in service and have been removed from vehicles due to wear, damage, or obsolescence. These discarded tires are considered waste because they are unsuitable for their primary intended purpose but may still be utilized in various recycling or repurposing applications [30]. The importance of tire waste management for environmental preservation and highlights its potential for recycling as well as other applications in the construction and other industries. Table 1 shows tire waste components and applications:

Table I.1 Tire waste components and applications.

Composition	Uses
Crumb Rubber	- Athletic surfaces - Asphalt mixtures - Molded products
PyrolysisOil	- Fuel - Chemicalfeedstock
SteelWire	- Manufacturingprocesses
Textile Fibers	- Carpetunderlay - Mats - Insulation
Fuel	- Industrialprocesses - Cementkilns - Power plants
Civil Engineerin	- Erosion control - Retaining walls - Lightweight fill
LandfillCover	- Alternative daily cover in landfills
ArtificialReefs	- Marine habitat creation

Tire trash is a complicated substance made up of many inorganic and organic substances. Its composition can vary based on the type of tire, the manufacturing additives used, and the degree of wear and deterioration; hence it lacks a consistent chemical formula. But the main ingredients in tire waste include rubber polymers (including natural and synthetic rubber), textile fibers, steel wires, carbon black, and different additives like plasticizers, vulcanizing agents, and antioxidants. Every one of these elements has a unique chemical formula and structure.

I.5.2. Types of tire waste:

Scrap tires can be divided into different types, each with its own characteristics and potential for recycling or reuse. Here are some common types:

- Rubber Granules: These are small granules produced by shredding or grinding tires into smaller pieces. They are often used in sports fields, playgrounds, and as infill for artificial turf.
- Rubber Crumb: Similar to rubber granules but finer in texture, rubber crumb is often used in rubberized asphalt for road construction, as well as in various molded rubber products.
- Tire-Derived Fuel (TDF): TDF is produced by shredding tires into smaller pieces and using them as a fuel source in cement kilns, pulp and paper mills, and other industrial facilities.
- Steel Wire: Tires contain steel wires embedded within the rubber, which are extracted during the shredding process. This steel can be recycled and used in various industries, including construction and manufacturing.
- Textile Fibers: Many tires contain textile fibers, such as polyester or nylon, which are used in the tire's structure. These fibers can be reclaimed and reused in products such as insulation, carpet padding, and mats.
- Carbon Black: Carbon black is a byproduct of the tire recycling process and is commonly used as reinforcing filler in rubber products, plastics, and coatings.
- Pyrolysis Oil: Through a process called pyrolysis, tires can be heated in the absence of oxygen to break down the rubber into oil, gas, and char. Pyrolysis oil can be refined and used as a fuel or chemical feedstock [31].

These are just a few examples of the types of materials that can be obtained from recycled tires. Specific methods and applications for scrap tire recycling may vary depending on factors such as local regulations, market demand and technical capabilities.

I.5.3. Tire waste Consumption:

Europe generates approximately 3.6 million tons of end-of-life tires annually. The market is primarily propelled by the growing need for sustainable waste management practices and the push towards a circular economy. The European Union's regulatory frameworks, including the European Green Deal and the Circular Economy Action Plan, are pivotal in promoting tire recycling initiatives (Goldstein Research) (EuCircularEconPlatform). Innovative recycling technologies, such as pyrolysis, are gaining traction. For instance, CIRCTEC, a UK-based

company, is constructing Europe’s largest tire recycling plant in Delfzijl, the Netherlands. This facility, funded by a €150 million investment, will use pyrolysis to convert waste tires into valuable products like sustainable marine fuel, circular naphtha, and recovered carbon black. This project alone aims to handle about 5% of Europe's annual tire waste, showcasing the potential for scalable recycling solutions (ChemAnalyst). The European tire recycling market includes major players such as Michelin, Bridgestone, Continental, and Goodyear, who are innovating to meet evolving demands. Investments in research and development are significant, with companies focusing on eco-friendly tire designs and sustainable material usage. Additionally, substantial investments, like CIRCTEC's new plant, are critical in enhancing the region's recycling capacity and reducing dependency on landfilling and incineration (IMARC) (ChemAnalyst). Despite advancements, the market faces challenges such as high operational costs and the complexity of recycling processes. However, opportunities abound in the form of policy support, technological advancements, and the increasing adoption of electric vehicles, which, while exacerbating tire waste due to faster tire wear, also create a larger market for recycled tire products (EuCircularEconPlatform) (ChemAnalyst). Europe's tire recycling business is growing as a result of substantial investments, rising regulatory pressure, and technological developments.

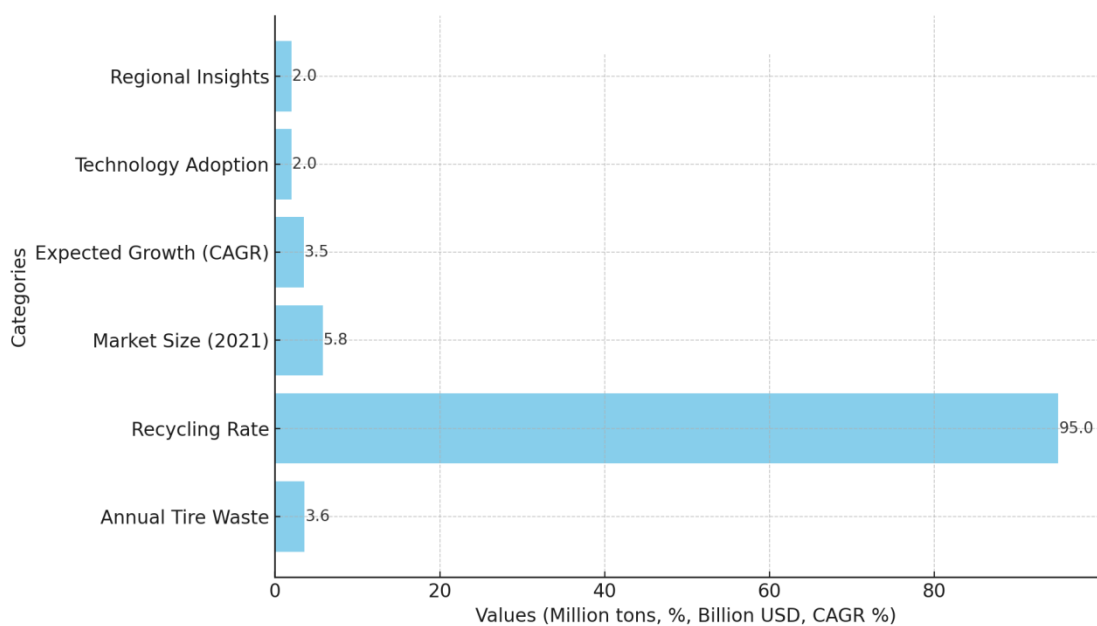


Figure I.1.: Tire recycling market in Europe

I.5.4. Recycling tire waste :

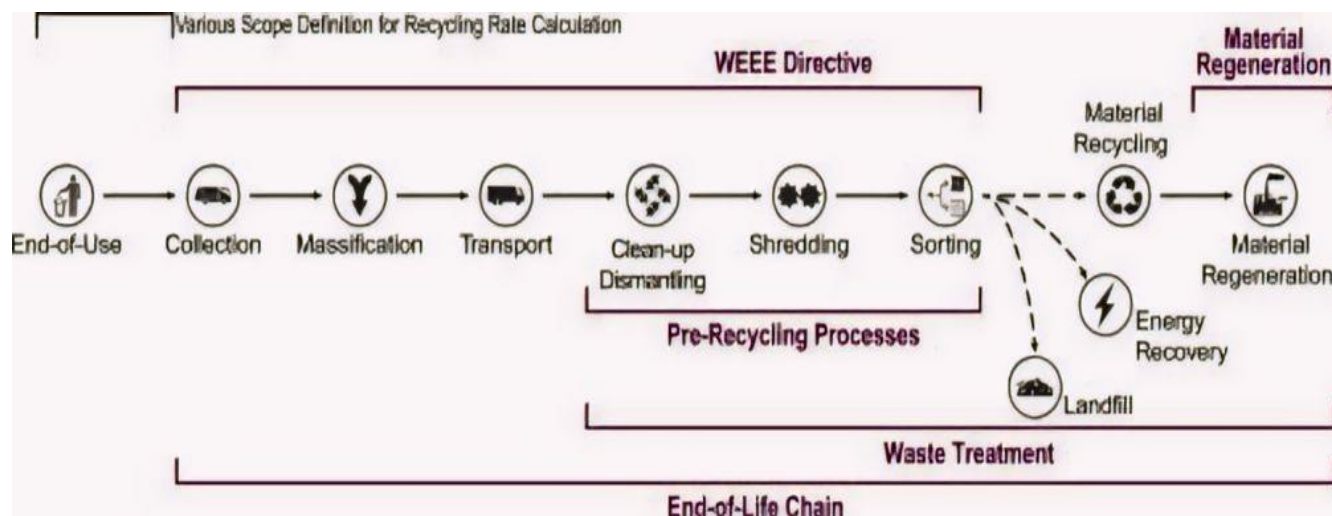


Figure I.2 :Tire’s life cycle

Recycling tire waste is a critical environmental challenge due to the large volume of tires produced and their slow degradation in landfills. Various methods have been developed to manage and recycle tire waste, including mechanical, thermal, and chemical processes [32].

I.5.4.1. Mechanical Recycling

Mechanical recycling involves shredding the tires into smaller pieces to produce crumb rubber, which can be used in various applications such as:

- Asphalt Rubber: Crumb rubber is mixed with asphalt to create more durable and flexible road surfaces.
- Playground and Athletic Surfaces: Rubber granules are used for safety surfaces in playgrounds and sports fields.
- Molded Products: Recycled rubber can be molded into new products like mats, gaskets, and automotive parts.[33]

I.5.4.2. Thermal Recycling:

Thermal recycling processes involve the use of heat to break down tires into their constituent materials. This includes:

- Pyrolysis: Tires are heated in the absence of oxygen to produce pyrolysis oil, gas, and char. Pyrolysis oil can be refined into fuels or chemicals, while the char can be used as a carbon black substitute in rubber products.

- Gasification: This process converts tires into syngas (a mixture of hydrogen and carbon monoxide) which can be used to generate electricity or produce synthetic fuels.[34]

I.5.4.3. Chemical Recycling:

Chemical recycling involves breaking down the rubber polymers into their monomers or other chemicals, which can then be reused to produce new rubber products. Methods include:

- Devulcanization: This process breaks the sulfur cross-links in vulcanized rubber, allowing the rubber to be reused in new products.
- Depolymerization: This process converts rubber back into its monomeric components, which can be purified and repolymerized [35].

I.5.5. Tire waste in mortar:

The disposal of waste tires poses a significant environmental challenge globally. Recycling and reusing waste tire rubber in construction materials offer a sustainable solution to mitigate this issue. This article examines the effects of incorporating waste tire rubber in mortar, focusing on its mechanical properties, durability, and environmental impact. Various studies have been reviewed to evaluate the performance of tire rubber-modified mortar and its suitability for construction applications. The findings suggest that incorporating tire rubber in mortar can improve its flexibility, impact resistance, and energy absorption capacity. However, challenges such as reduction in compressive strength and workability need to be addressed through proper mix design and optimization techniques. Furthermore, the environmental benefits of utilizing waste tire rubber in mortar, such as reducing carbon footprint and landfill waste, are discussed. Overall, the research highlights the potential of waste tire rubber as a sustainable additive in mortar production, contributing to the circular economy and environmental conservation efforts [36].

Table.I.2: Properties of different types of tire waste used as aggregates :

Property	Shredded Tyre (Tyre Chips/Chunks)	Crumb Rubber	Ground Rubber (Rubber Powder)	Steel Belted Tyre Waste
Size	25-300 mm	< 10 mm	< 1 mm	Varies (with steel components)
Density (kg/m³)	500-700	800-1000	1100-1200	Higher due to steel content
Shape	Irregular	Rough and irregular	Irregular	Varies, often elongated/fibrous
Water Absorption	High	Moderate	Low	Similar to natural aggregates
Elasticity	High	High	High	Lower due to steel rigidity
Thermal Conductivity	Low	Low	Very Low	Higher due to steel content
Compressive Strength	Lower than natural aggregates	Lower than natural aggregates	Lower than natural aggregates	Improved with steel reinforcement
Tensile Strength	Lower	Lower	Lower	Improved with steel reinforcement
Workability	Reduced	Reduced	Reduced	Similar to natural aggregates
Durability	Improved impact resistance	Improved impact resistance	Improved durability and fatigue resistance	Improved structural integrity
Density of Concrete	Lower than conventional concrete	Lower than conventional concrete	Lower than conventional concrete	Similar or slightly higher
Thermal Insulation	Enhanced	Enhanced	Enhanced	Lower due to steel content

I.6 Marble waste:

I.6.1 Marble:

Marble is a metamorphic rock composed primarily of recrystallized carbonate minerals, most commonly calcite or dolomite. It forms through the metamorphism of limestone under conditions of high pressure and temperature, which causes the original carbonate minerals to recrystallize and develop a distinctive crystalline structure [37]. Marble waste refers to the by-products generated during the extraction, cutting, and processing of marble. This waste can include broken marble pieces, dust, and slurry, which are often discarded and can pose environmental challenges if not managed properly [38].

I.6.2 Chemical composition of marble waste:

Marble waste typically consists of the following chemical composition, reflecting its primary constituent minerals and elements:

- Calcium Carbonate (CaCO_3): Marble is primarily composed of calcium carbonate, which is a mineral form of calcium derived from the remains of marine organisms.
- Dolomite (CaMgCO_3): Some marbles may contain dolomite, a mineral composed of calcium magnesium carbonate, in varying proportions.
- Other Minerals: Depending on the specific geological formation and impurities, marble waste may also contain trace amounts of other minerals such as quartz, clay minerals, and various metal oxides.
- Impurities: Marble waste can include impurities like silica (SiO_2), alumina (Al_2O_3), iron oxide (Fe_2O_3), and organic matter, depending on the geological source and processing history.

The exact chemical composition of marble waste can vary significantly based on the type of marble, geological conditions, and the processes it has undergone during extraction and processing [39].

I.6.3 Types of marble waste:

Marble waste can be categorized into several types based on its origin, composition, and processing stage. Here are the common types of marble waste:

- Block Offcuts: These are large pieces of marble that remain after cutting blocks into slabs. Offcuts can vary in size and shape and are typically discarded if not suitable for further processing.

- Slab Scraps: Scraps are smaller pieces of marble left over from cutting slabs to size. These scraps may include irregular shapes or remnants that are not used in finished products.
- Dust and Powder: During cutting and polishing, marble generates fine dust and powder. This waste material consists of small particles of marble and abrasive residues.
- Water and Slurry: Water is used extensively in the cutting and polishing processes, resulting in water mixed with marble particles and abrasives, forming a slurry waste.
- Broken or Damaged Pieces: Marble pieces that are broken or damaged during handling, transport, or processing are considered waste if they cannot be repaired or reused.
- Residue from Polishing and Finishing: Residues such as polishing compounds, cleaning agents, and surface treatments used during finishing processes can contribute to marble waste.

Each type of marble waste poses unique challenges for disposal and recycling due to its physical characteristics and chemical composition. Efforts in the industry are ongoing to minimize waste generation and maximize the reuse and recycling of marble waste materials [40].

I.6.4 Recycling of Waste Marble:

Waste marble is a byproduct of the marble extraction and processing industry. Marble, a natural stone used extensively in construction, sculpture, and decorative purposes, generates a significant amount of waste during extraction and processing. This waste material, often discarded in landfills, can cause environmental pollution. However, recycling waste marble can transform this potential environmental hazard into a valuable resource. The marble industry generates large quantities of waste, including marble sludge, slurry, and broken pieces. These waste materials, if not managed properly, can lead to land degradation, air and water pollution, and health hazards for nearby communities. The fine particles in marble slurry can contribute to soil erosion and water contamination, while the accumulation of waste in landfills occupies valuable land space. Recycling waste marble offers a sustainable solution to these problems. Waste marble can be reused in various ways, such as in the production of construction materials, as a filler in cement and concrete, and as an additive in asphalt. Recycled marble can also be used in the production of tiles, bricks, and other decorative items. This not only reduces the environmental impact of marble waste but also conserves natural resources by reducing the need for new raw materials. One of the most common

applications of recycled marble is in the construction industry. Marble waste can be crushed into fine powder and used as a filler material in concrete. Studies have shown that the addition of marble powder can enhance the mechanical properties of concrete, such as its compressive strength and durability. Recycled marble can also be used as an aggregate in asphalt production, improving the quality and longevity of roads [41].

I.6.5 Properties of Marble Materials:

Marble is a metamorphic rock that forms when limestone is subjected to high pressure and temperature, leading to the recrystallization of calcite and/or dolomite. It is prized for its aesthetic appeal, durability, and versatility, making it a popular choice for construction, sculpture, and decorative purposes.

I.6.5.1 Physical Properties:

- **Color and Appearance:** Marble is known for its wide range of colors, including white, black, green, red, and pink. The coloration is due to the presence of impurities such as iron oxides, graphite, or organic materials. The veins or streaks commonly seen in marble are caused by mineral impurities, adding to its aesthetic value.
- **Texture:** Marble has a fine-grained, crystalline texture, often with a smooth, polished surface. It can also exhibit a range of patterns, from uniform to heavily veined, depending on the type and quality of the stone.
- **Density:** Marble is a dense material, typically ranging from 2.5 to 2.7 grams per cubic centimeter (g/cm^3). This density contributes to its durability and strength, making it suitable for various structural and decorative applications.
- **Hardness:** On the Mohs scale of mineral hardness, marble typically ranks around 3 to 4. This makes it softer than many other stones, such as granite, which allows it to be easily carved and shaped but also makes it more susceptible to scratching and abrasion.

I.6.5.2 Mechanical Properties:

- **Compressive Strength:** Marble exhibits high compressive strength, generally ranging from 70 to 140 MPa (megapascals). This property makes it suitable for use in load-bearing applications, such as columns, flooring, and cladding in buildings.
- **Tensile Strength:** Marble's tensile strength is relatively low compared to its compressive strength, typically around 7 to 20 MPa. This makes it more prone to cracking under tensile stress, which is why marble is often reinforced with backing materials in construction applications.

- Flexural Strength: Marble has a moderate flexural strength, usually between 7 to 15 MPa. This property refers to the stone's ability to resist bending or flexing forces, making it suitable for use in countertops, flooring, and other applications where a certain degree of flexibility is needed.

I.6.5.3 Chemical Properties:

- Composition: Marble is primarily composed of calcite (calcium carbonate, CaCO_3), with minor amounts of other minerals such as dolomite, quartz, mica, and iron oxides. The high calcite content gives marble its characteristic properties, including its reaction to acids.
- Acid Sensitivity: One of the key chemical properties of marble is its sensitivity to acids. When exposed to acidic substances like vinegar or lemon juice, marble can react and undergo etching, resulting in dull spots or surface damage. This property requires careful maintenance and the use of sealants to protect marble surfaces in applications like kitchen countertops.
- Porosity: Marble is a relatively porous material, which means it can absorb liquids and stains if not properly sealed. The porosity can vary depending on the type of marble, with some varieties being more porous than others. This property necessitates regular sealing to prevent staining and moisture damage.

I.6.5.4 Thermal Properties:

- Thermal Conductivity: Marble has good thermal conductivity, meaning it can efficiently transfer heat. This property makes it ideal for use in applications such as fireplace surrounds, flooring with underfloor heating, and outdoor installations where temperature fluctuations are common.
- Heat Resistance: Marble is resistant to heat, which allows it to withstand high temperatures without degrading or losing its structural integrity. However, prolonged exposure to extreme heat can cause discoloration or damage to the stone's surface.

I.6.5.5 Aesthetic and Acoustic Properties:

- Luster and Polish: Marble is renowned for its ability to take a high polish, resulting in a glossy, mirror-like finish that enhances its natural beauty. The luster of polished marble adds to its appeal in architectural and decorative applications.
- Acoustic Properties: Due to its density and structure, marble can absorb and dampen sound, making it an effective material for reducing noise in spaces like concert halls, theaters, and residential areas [42].

I.7 Conclusion:

In conclusion, recycling in civil engineering is not just a sustainable practice but a crucial step toward creating a more resilient and environmentally responsible infrastructure. By reusing materials like concrete, asphalt, and steel, the industry can significantly reduce its environmental foot-print, conserve natural resources, and lower construction costs. As civil engineering continues to evolve, integrating recycling practices will play a vital role in meeting the growing demand for sustainable development, ultimately contributing to a heal their planet and more efficient use of our resources.

CHAPTER

TWO

II.1.Introduction :

Through this chapter, we will present the material used in this study and the experimental techniques to characterize these materials, as well as the formulation of mortars and the tests carried out on the mortar formulated in a fresh and hardened state.

II.2. Characteristics of the materials used:

II 2.1.Cement:



Figure II.1: Cement bag

The cement used in this work is a class CEM II 42.5 composite cement of resistance 42.5. The chemical, mineralogical, mechanical, and physical composition of CPA-CEM I 42.5 used for the manufacture of concrete is summarized in Tables II.1, II.2, II.3, and II.4.

Table II.1: The chemical composition of CPA CEM I 42.5

Element	CaO	SiO ₂	Al ₂ O ₃	Fe ₂ O ₃	MgO	SO ₃	K ₂ O	CaO libre	Na ₂ O
%	63-66	17-20	3-6	2-4	0.5-2	2-3	0,41	1,20	0,13

Table II.2: mineralogical composition of CPA-CEM I 42.5

Element	C3S	C2S	C3A	C4AF	gypsum	laitier	klinler
%	50-65	15-25	3-8	13_17	3_5	6_10	≥ 65

Table II.3: Mechanical Characteristics of CPA-CEM I 42.5

Resistance "MPA"	2J	14J	28J
Compression	10_20	20_30	30_50
Flexion	0.5_1	2_5	3_7

Table II.4: Physical Characteristics of CPA-CEM I 42.5

characteristics	Normal consistency(%)	initial setting(min)	final setting (min)	SSB(Cm2 /g)	Hot expansionMm
results	25_30	30_60	120_240		≤ 10

II 2-2 Sand:

In our study, we selected 0/4 quarrys and from El AinAbid (Figure II.2). The physicalparameters are listed in the table below:



Figure II.2: quarry sand 0/4

Table II.5: Physical characteristics of sand:

Physical characteristics	values
Apparent density	2.69 t/m ³
Truedensity	2.63 t/m ³
Fine module	3.07
The equivalent of sand	67%

Table II.6: Particle size analysis of sand:

Sieve Size (mm)	retained mass	cumulative retained mass	cumulative retained %	cumulative passing %
4.0	00	00	00	100
2.0	96	96	7.44	92
1.0	182	278	21.55	78
0.5	226	504	39.06	60
0.25	250	754	58.44	41
0.125	266	1020	79.06	20
0.063	270	1290	100	0
cumulative retained	1290			
sievebottom	0			

II 2-3. Tire waste:

The tire waste aggregates used in this study are shown in the figure:



Figure II.3: tire dust

The characterization of this waste gave us the results indicated in Tables II.7.

Table II.7: Physical characteristics of tire waste aggregate:

Physical characteristics	values
Specificgravity	1.10
water absorption index	1 ,65 %
D_{max}	4 mm

II 2.4. MarbleWaste:



Figure II.4 :marble powder

The characterization of this waste gave us the results indicated in Tables II.8-9:

Table II.8: Physical characteristics of marble waste aggregate:

Physical characteristics	values
Specificgravity	2.75
Specific surface	2608 cm ² /g
water absorption index	2,9 %

Table II.9: Chemical properties of marble waste used:

Chemicalproperties (%)	values
CaO	54.86
SiO₂	0.15
Al₂ O₃	0.08
Fe₂ O₃	0.04
MgO	1.03
K₂ O	0.03
Na₂ O	0.11
SO₃	2.01
Cl⁻	0.01
Loss in ignition	41.86

II 2.5. Mixing water:

All of the experiments are conducted using tap water, which reacts to instructions.

II.3. Formulations:

Formulations	Sand (kg)	Cement (kg)	water (L)	Tires (kg)	Marbles (kg)
Control mortar	1350	450	225	0	0
Tire mortar5%	1350	420	225	30	0
tire-marblemortar5%	1300	420	225	30	50
tire-marblemortar 10%	1275	420	225	30	75
tire-marblemortar 15%	1250	420	225	30	100

II.4. Tests performed:**II.4.1. Compression strength test:**

A compression strength test is performed to determine the ability of a material or structure to withstand loads that reduce its size. This is often done by applying a compressive force to the material until it fails or deforms, and it's commonly used for materials like concrete, metals, ceramics, and plastics.

The compression strength test for mortar is a common procedure to assess the material's ability to withstand compressive loads. Mortar is widely used in construction for binding bricks, stones, or concrete blocks, and the strength of the mortar is crucial to ensuring the structural integrity of the masonry.



Figure II.5: Compression testing machine

The compression testing machine used for testing the compressive strength of materials like mortar is a specialized piece of equipment designed to apply controlled pressure to test specimens until they fail. It measures the material's ability to withstand compressive forces and is widely used in construction and materials testing laboratories.

Procedure:

_Specimen Placement: The mortar cube or cylinder is carefully placed on the lower platen, centered to ensure even distribution of the load.

_Load Application: The operator sets the desired loading rate, typically between 2 to 4 kN/s, depending on the standards and material being tested.

_Measurement: As the force is applied, the load cell records the force exerted on the specimen. The machine continues applying force until the specimen breaks or deforms significantly.

_Result: Once the specimen fails, the maximum force (failure load) is recorded, and the machine automatically stops. This load is used to calculate the compressive strength of the mortar.

II.4.2.flexural strength test :

The **flexural strength test** is a method used to determine a material's ability to resist deformation under load, particularly in bending. It's often applied to brittle materials like concrete, ceramics, and composites. The test measures the highest stress experienced by a material just before it breaks.

The flexural strength test of mortar is used to assess the bending strength of mortar mixtures, commonly used in masonry construction. Mortar is typically weaker in tension

compared to compression, and this test is crucial for understanding how it behaves under bending stresses, especially in applications like load-bearing walls or masonry structures.



Figure II.6 : The flexural strength machine

The typical sample used is a prismatic bar of mortar, often with dimensions of 40 mm x 40 mm x 160 mm (according to ASTM C348 or EN 196-1 standards).

The mortar is poured into molds and allowed to cure for a specified time (usually 28 days) before testing.

Procedure:

- _ Place the mortar sample on two supports.
- _ A force is applied at the midpoint of the span using a loading apparatus, typically in a testing machine.
- _ The load is increased until the mortar fractures.
- _ The load at fracture is recorded.

II.4.3. Absorption Test :

The Absorption Test for mortar is used to determine the amount of water absorbed by a mortar sample, typically expressed as a percentage of the dry weight. It helps assess the porosity and durability of mortar, which are crucial for construction quality, especially in masonry.



Figure II.7 : Immersion of mortar

Procedure:

- _ Dry the sample: Place the mortar sample in an oven at 105°C (±5°C) until it reaches a constant weight. This is the dry weight (W_1). Allow it to cool in a desiccator.
- _ Weigh the dry sample: Weigh the sample and record the weight as W_1 .
- _ Soak the sample: Immerse the mortar sample in water at room temperature for 24 hours.
- _ Weigh the soaked sample: After soaking, remove the sample from the water, wipe the surface to remove excess water, and weigh it. This is the wet weight (W_2).

Calculation:

The water absorption percentage is calculated using the formula:

$$\text{Absorption(\%)} = (W_2 - W_1)100 / W_1$$

W_1 = Dry weight of the sample.

W_2 = Wet weight of the sample.

II.5 .Conclusion :

This chapter discusses the various characteristics of the materials used during the experimental process. The analysis of the various materials used during the experimental walk highlights the importance of selecting the appropriate characteristics based on specific environmental and functional demands. The experimental part consists of valuing the waste tire and marble waste in the mortar; the results obtained are evaluated, presented, and discussed in the following chapter.

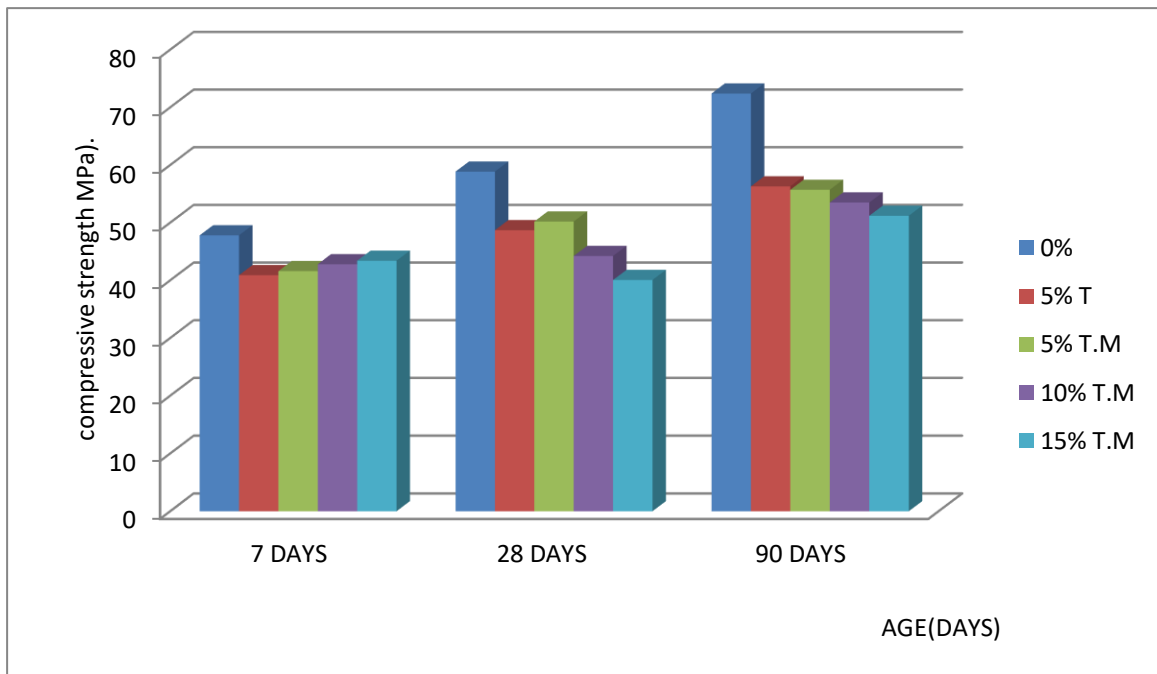
CHAPTER THREE

III. 1 Introduction

This chapter focuses on presenting the results of tests conducted on mortar mixtures, using histograms and graphs to clearly explain the observed phenomena. It explores the impact of recycled additives on their properties, analyzing the results of tests related to the hardened state and durability of the mortars, including compressive strength, flexural strength, and absorption. Additionally, the effects of substituting tire and marble waste at different rates are discussed and interpreted.

III. 2 Compressive strength:

Figures III.1 and III.2 show the variation of compressive strength as a function of age and substitution rates



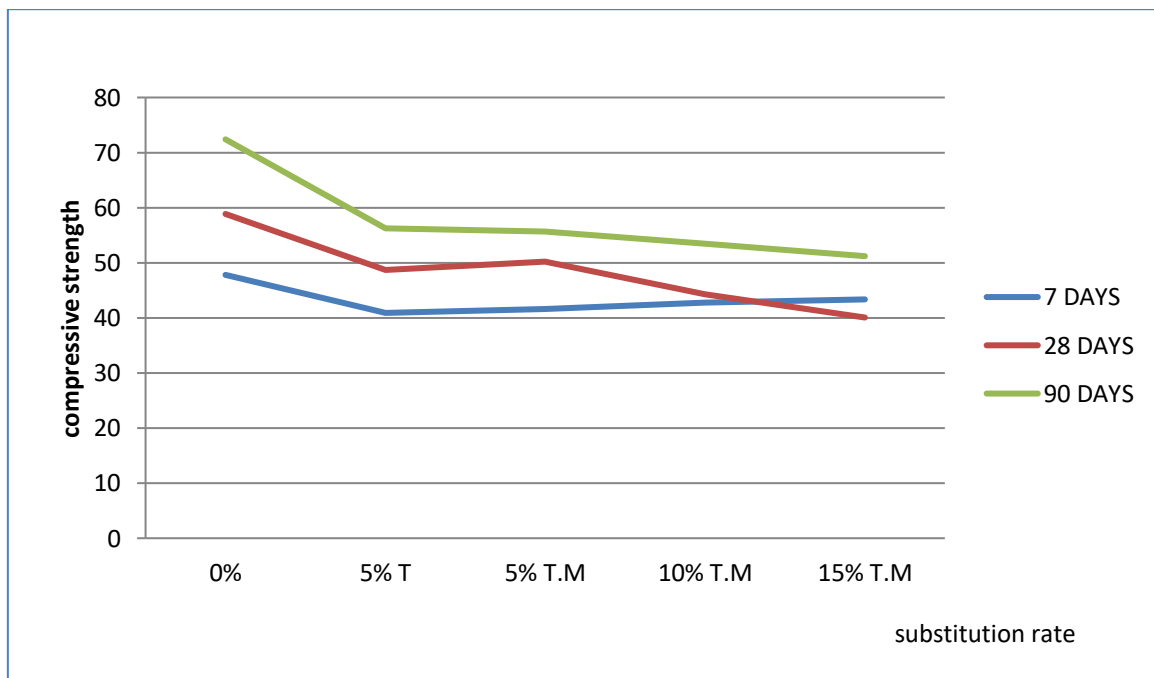
FigureIII.1:Variation of the compressive strength as a function of the substitution rate

The bar chart in **Figure III.1** shows the variation of compressive strength (in MPa) at different ages (7, 28, and 90 days) as a function of the substitution rates, which are represented by different colors corresponding to specific percentages: 0%, 5%T, 5%T.M, 10%T.M, and 15%T.M.

Across all substitution rates, compressive strength increases with age. This is evident from the significant rise in strength from 7 to 28 days, followed by a moderate increase up to 90 days. At 90 days, the compressive strength reaches its peak for all substitution rates, which is typical in the curing process of cement-based materials.

At 0% substitution, the compressive strength is consistently the highest across all time intervals, particularly noticeable at 90 days, where it reaches above 70 MPa. Substitution with 5%T shows relatively high strength values, but as the substitution percentage increases to 15%, a general decline in compressive strength is observed. Higher substitution rates (10%T.M and 15%T.M) tend to result in lower compressive strengths at each age point, indicating a negative impact of higher levels of substitution on the mechanical properties of the mortar.

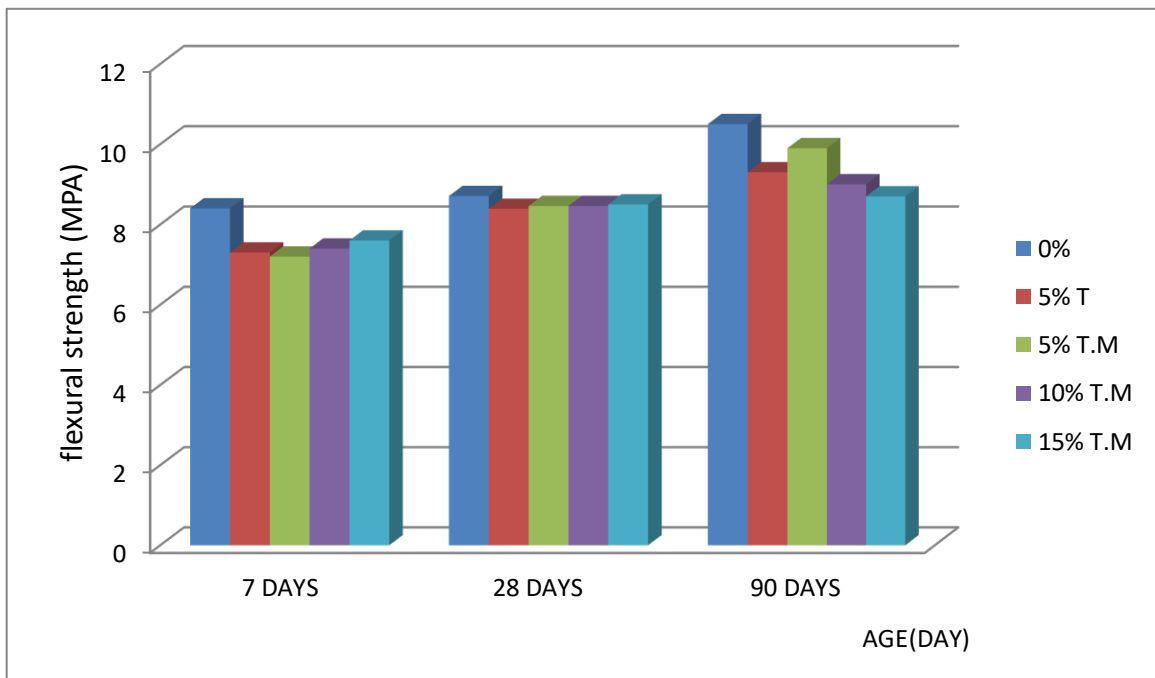
The graph III.2 demonstrates that while increasing the substitution rate generally decreases the compressive strength, the mortar continues to gain strength over time, regardless of the substitution percentage. This indicates that substitution, though detrimental to strength, does not entirely negate the natural curing and hardening process. Further optimization could focus on balancing substitution rates to minimize environmental impact while maintaining acceptable mechanical properties.



FigureIII.2 :Influence of Age on the Evolution of Compressive Strength

III.3.Flexural strength:

Figure III.3 shows the variation in flexural strength as a function of age and substitution rates.



FigureIII.3 Variation of flexural strength as a function of the substitution rate

The graph in Figure III.2 illustrates the variation in flexural strength as a function of the substitution rate over different time intervals: 7, 28, and 90 days. The substitution percentages include 0%, 5%T, 5%T.M, 10%T.M, and 15%T.M, where T and T.M likely represent different material compositions or treatments.

At 7 days, the flexural strength across all substitution rates starts within a similar range, approximately between 6 to 8 MPa. The 0% substitution rate (blue) shows slightly higher strength compared to the others. Both 5%T and 5%T.M (green and red) show almost identical performance, slightly below the 0% rate.

At 28 days, there is a noticeable increase in flexural strength across all substitution rates, showing that the material gains strength over time. The difference between 0% and the other substitution rates becomes less significant, indicating that the materials with substitutions reach comparable performance levels after this period. The highest flexural strength at this stage is observed in the 0% and 10%T.M, while the rest have a slightly lower but comparable performance.

At 90 days, the flexural strength shows further improvement, with all substitution rates exhibiting a substantial increase. Notably, 0% substitution continues to perform the best, reaching over 10 MPa, while the 15%T.M shows a slight decrease compared to other

substitution rates.

The 5% T.M and 10% T.M exhibit similar performances, indicating that these substitution levels maintain high flexural strength over time.

Graph III.4 suggests that substitution rates of up to 10% T.M do not significantly affect the long-term flexural strength of the material, and in fact, they show comparable strength to the control (0%). However, increasing the substitution to 15% T.M might result in a reduction of strength, as observed at 90 days. The material seems to mature and gain strength over time, with the most considerable improvement occurring between 28 and 90 days.

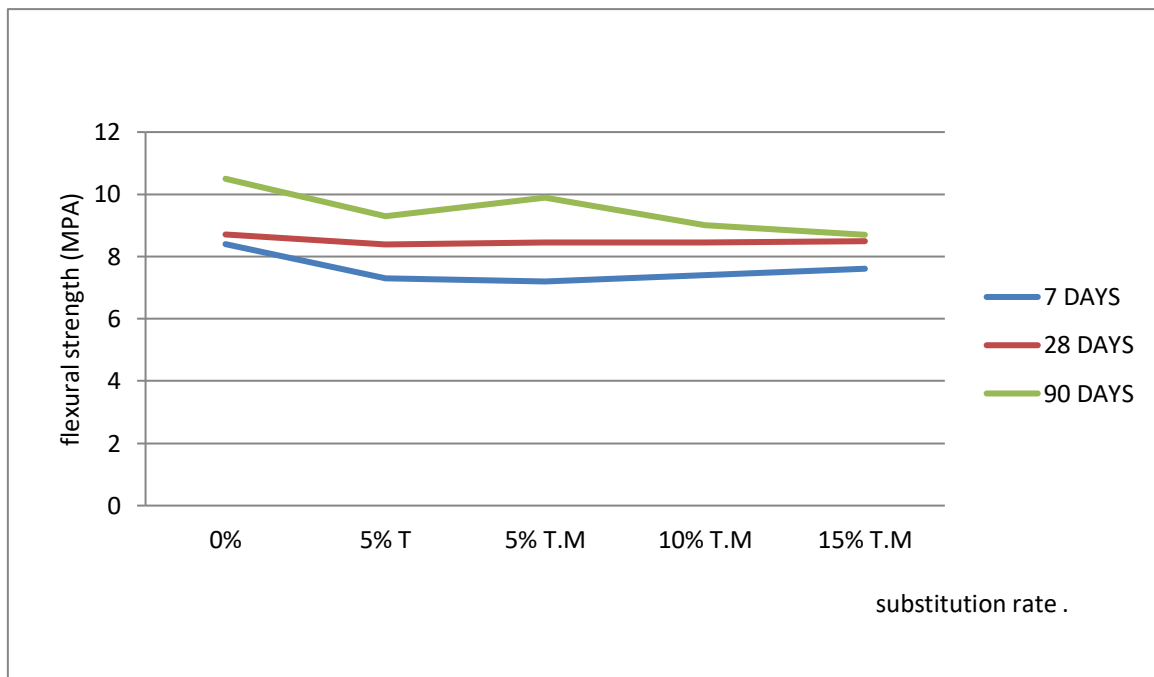
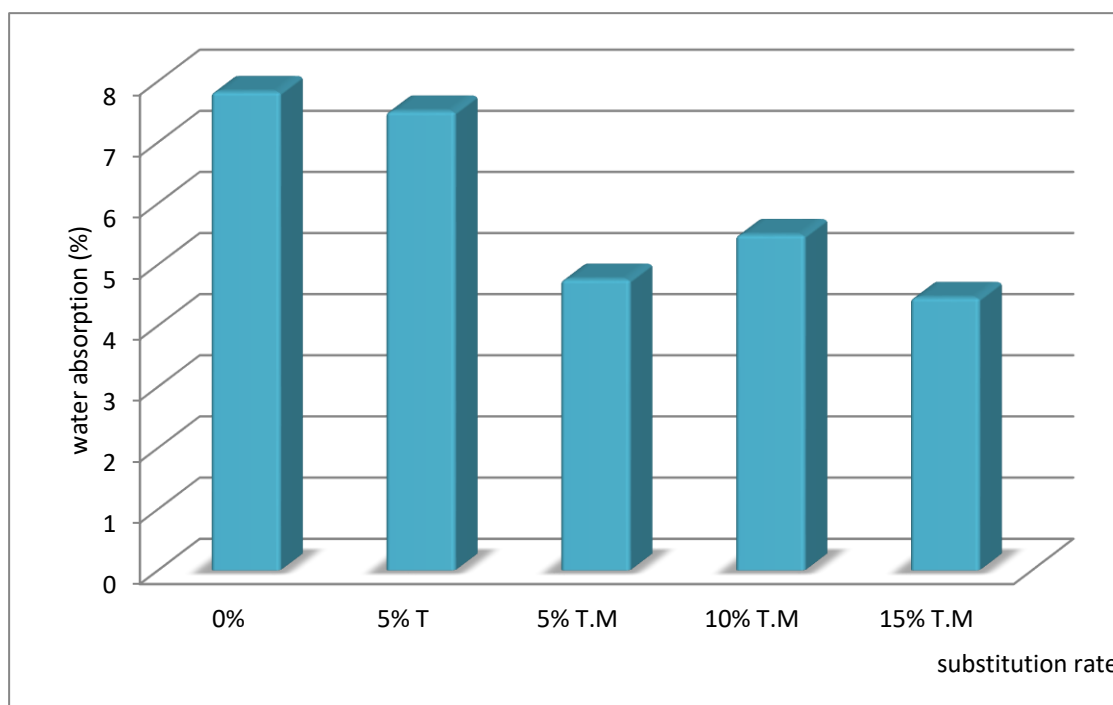


Figure III.4 : Influence of Age on the Evolution of Flexural Strength

III.2.3. Variation in water absorption by immersion:

The values of the water absorption by immersion are shown in the Figure III.5



FigureIII.5 :Evolution of the absorption coefficient by immersion (A_b) as a function of the substitution rate.

This graph illustrates the evolution of water absorption by immersion as a function of the substitution rate (Figure III.5). It presents a comparative analysis of water absorption percentages across different substitution rates: 0%, 5%, 10%, and 15%. The general trend shows that the water absorption percentage decreases as the substitution rate increases. The key observations include:

- At 0% substitution, the water absorption is the highest, around **8%**.
- With 5% substitution, there is a notable drop in absorption to around **6%**.
- For 10% substitution, the water absorption remains close to the previous value but slightly higher than 5%.
- At 15% substitution, the absorption decreases further, suggesting an inverse relationship between the substitution rate and water absorption.

The decreasing trend implies that increasing the substitution rate reduces the material's capacity to absorb water. This could indicate that the substituted material is less porous or more resistant to water penetration. Such a result is significant in fields like material science or construction, where reducing water absorption could enhance durability and longevity, especially in materials exposed to moisture.

III. 1. Conclusion:

_ Compressive strength increases with age for all substitution rates, with significant gains between 7 and 28 days, and more moderate increases by 90 days. This is characteristic of cement-based materials' curing process.

_ At 0% substitution, compressive strength is the highest, reaching over 70 MPa by 90 days. As substitution rates increase, particularly beyond 5%, a noticeable decline in strength occurs. Higher substitution rates (10%T.M and 15%T.M) consistently result in lower compressive strength, indicating that increasing substitution negatively impacts the mechanical properties of the mortar.

_ The material's flexural strength increases over time, with substitutions up to 10%T.M showing comparable performance to the control. However, a 15%T.M substitution may reduce strength slightly after 90 days. The most significant strength gain occurs between 28 and 90 days.

_ higher substitution rates result in lower water absorption, indicating that the substituted material is less porous. This trend is important for enhancing the durability and longevity of materials in moisture-prone environments.

General conclusion

General conclusion :

The incorporation of tire and marble wastes into mortar composition presents a viable solution for enhancing the sustainability of construction materials. This study demonstrates that using these waste materials not only contributes to waste reduction but also improves certain mechanical properties of mortar, such as strength and durability. The results indicate that ground tire rubber can enhance flexibility and energy absorption, while marble waste can improve compressive strength.

Furthermore, the findings highlight the importance of adopting eco-friendly practices in the construction industry, aligning with global efforts towards sustainability. Future research should explore optimal replacement ratios and investigate the long-term performance of these modified mortars in various environmental conditions. Overall, the integration of tire and marble wastes into mortar composition is a promising strategy for developing innovative building materials that minimize environmental impact while maintaining structural integrity.

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