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Thesis Topic

Exploitation of industrial by-products to optimize the properties of ecological concrete for sustainable construction

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ATTA ZINE EDDINE

YAHIAOUI IKRAM



Dedication

To my beloved parents, ***Nassira*** *and* ***Mohamed****,*
your love, strength, and endless sacrifices have made this journey possible. Your unwavering support has been the foundation of every success I achieve.

To my dear brothers: ***Kamel****,* ***Sofiane****, and* ***Redouane****,*
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This work is dedicated to you — with all my heart.



Dedication

With all my love and gratitude,

I dedicate this modest work to those who have been a source of strength and support throughout my academic journey:

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*And to my colleague **ATTA Zineddine***

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ملخص

تهدف هذه الدراسة إلى تطوير خرسانة رملية سائلة صديقة للبيئة (FSC) من خلال الاستبدال الجزئي للإسمنت بمسحوق السيراميك (كنفايات صناعية) ومسحوق أصداف البحر (كنفايات طبيعية)، وذلك بنسبة 5% و10% و15%. كما تم استبدال 25% من الرمل الطبيعي بنفايات الغرانيت، وهي نفايات صناعية أخرى.تم إجراء سلسلة من الاختبارات على الخرسانة في حالتيها الطازجة والمتصلبة لتقييم تأثير هذه المواد البديلة على خصائص الخرسانة، بما في ذلك مقاومة الضغط، ومقاومة الانحناء، وامتصاص الماء، والمسامية.وقد أظهرت النتائج أن استخدام هذه النفايات بنسب استبدال مدروسة يمكن أن يُحسّن أو يحافظ على أداء الخرسانة دون التأثير على متانتها، مما يساهم في دعم التوجه نحو البناء المستدام والصديق للبيئة.

الكلمات المفتاحية: خرسانة رملية، منتجات ثانوية، أصداف بحرية، رخام، سيراميك، غرانيت، الاستبدال الجزئي، الخواص الميكانيكية، الاستدامة.

Abstract

This study aims to develop an eco-friendly Flowable Sand Concrete (FSC) by partially replacing cement with **ceramic waste** (an industrial by-product) and **seashell powder** (a natural waste material) at replacement levels of 5%, 10%, and 15%. Additionally, 25% of natural sand was replaced with **granite waste**, another industrial by-product. A series of tests were conducted on both fresh and hardened concrete to evaluate the effects of these substitutions on properties such as compressive strength, flexural strength, water absorption, and porosity. The results showed that, with optimized replacement ratios, the incorporation of these waste materials can improve or maintain concrete performance without compromising durability, thereby supporting the goal of sustainable and environmentally responsible construction.

Keywords: Fluid Sand Concrete, industrial by-products, seashells, marble, ceramics, granite, partial replacement, mechanical properties, sustainability.

Résumé

Cette étude vise à développer un béton fluide écologique (beton sable fluide- BSF) en remplaçant partiellement le ciment par des déchets de céramique (sous-produit industriel) et de la poudre de coquilles marines (déchet naturel), à des taux de substitution de 5 %, 10 % et 15 %. De plus, 25 % du sable naturel ont été remplacés par des déchets de granite, un autre sous-produit industriel. Une série d'essais ont été réalisés sur le béton à l'état frais et durci afin d'évaluer l'effet de ces substitutions sur les propriétés telles que la résistance à la compression, la résistance à la flexion, l'absorption d'eau et la porosité. Substitutions ont montré qu'avec des taux de remplacement optimisés, l'incorporation de ces matériaux de déchets peut améliorer ou maintenir les performances du béton sans compromettre sa durabilité, contribuant ainsi à une construction durable et respectueuse de l'environnement.

Mots-clés : béton FSC, sous-produits industriels, coquillages, marbre, céramique, granit, substitution partielle, propriétés mécaniques, durabilité.

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Notations and Abbreviations

Notations and Abbreviations

- **FSC** : Fluid Sand Concrete
- **OPC** : Ordinary Portland Cement
- **SEM** : Scanning Electron Microscope
- **XRD** : X-ray Diffraction
- **TGA** : Thermogravimetric Analysis
- **UPV** : Ultrasonic Pulse Velocity
- **W/C** : Water-to-Cement Ratio
- **CA** : Coarse Aggregate
- **FA** : Fine Aggregate
- **SP** : Superplasticizer
- **ρ** : Density (kg/m^3)
- **fc** : Compressive strength (MPa)
- **ft** : Tensile strength (MPa)
- **E** : Modulus of Elasticity (GPa)
- **λ** : Thermal conductivity ($W/m \cdot K$)
- **Φ** : Porosity (%)
- **WA** : Water absorption (%)
- **SiO2:** Silicon dioxide
- **CaO:** Calcium oxide
- **Al2O3:** Aluminium oxide
- **Fe2O3**: Iron oxide
- **MgO:** Magnesium oxide
- **TiO2:** Titanium dioxide
- **K2O:** Potassium oxide
- **Na2O**: Sodium oxide
- **CPJ-CEM II/A (Mâtine):** Artificial Portland cement produced by LAFARGE

- **FSC:** Fluid Sand Concrete.
- **FSCC:** Fluid Sand Concrete control
- **$FSCC_{1.....12}$:** Fluid sand concrete made from ceramic, granite and shell waste.
- **NF P18-459**: Standard for water-accessible porosity
- **[EN 1015-18, CEN, 2002]. s**pecifies the method for measuring the capillary absorption
- **M air**: Mass of the sample saturated in air.
- **Msec:** Dry mass of the sample after oven drying.
- **Meau:** Mass of the sample measured under water.

General Introduction

General introduction



The growing accumulation of industrial and organic waste has become a critical environmental issue, contributing to pollution, resource depletion, and the overuse of landfills. At the same time, the construction industry particularly through cement production is a major contributor to greenhouse gas emissions, with cement manufacturing alone accounting for a significant share of global carbon dioxide (CO_2) emissions due to its energy-intensive nature.

In this context, the main objective of this research is to develop eco-efficient concrete by incorporating industrial by-products and bio-based materials such as **seashells**, **granite** waste, **ceramics**, and **marble** as partial replacements for cement and natural sand. This approach aims to simultaneously address two major environmental challenges: waste management and CO_2 emissions. By enhancing the sustainability of concrete without compromising its mechanical and durability properties, this study contributes to the advancement of greener, more resource-efficient construction practices.

To effectively address the research objectives, this study is structured into three main chapters, each focusing on a key aspect of the investigation. The organization of the work is as follows:

Structure of the study

Chapter 1: Bibliographical review on the recovery of waste and its application in concrete. focusing on seashells, granite, ceramics, and marble powder, as well as on the Flowable Sand Concrete (FSC) concept.

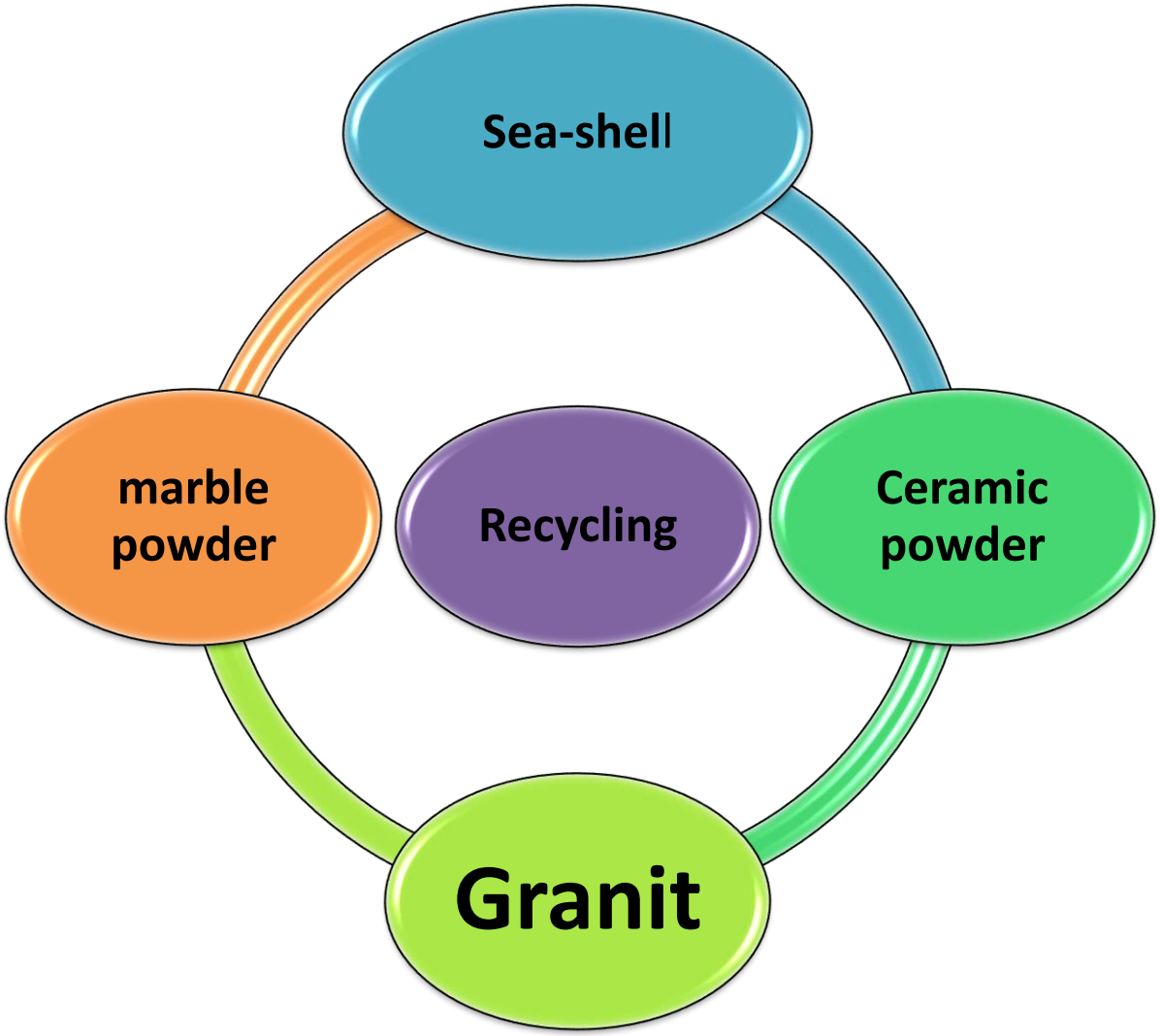
Chapter 2: Presentation of the materials used, and the experimental protocols adopted. This section describes the various tests conducted to assess the properties of modified concrete.

Chapter 3: Analysis and discussion of the results obtained, highlighting the effect of recycled waste on concrete performance, in particular in terms of rheology, density, compressive strength, porosity and water absorption.

This structured approach provides a comprehensive understanding of how recycled industrial and bio-based waste can influence concrete properties.

Chapter I :

Bibliographic research



Chapter I : Bibliographic research

I.1. Introduction

The world's natural resources are facing unprecedented pressure due to the accelerating demands of economic development. This intense and often unsustainable consumption is causing a rapid depletion of these essential resources. Simultaneously, the large-scale generation of industrial and municipal waste has emerged as a critical environmental challenge, with increasingly harmful consequences for ecosystems and human quality of life[1].

Among the sectors most responsible for resource consumption and environmental degradation is the construction industry, particularly through the production of cement. It is estimated that cement manufacturing accounts for approximately 5% of global anthropogenic CO_2 emissions. On average, the production of one ton of cement releases about 0.87 tons of CO_2 into the atmosphere. With cement production continuing to rise globally, the cement industry remains a major contributor to greenhouse gas emissions[2]. In this context, the use of industrial by-products such as waste granite, ceramics, marble, and bio-sourced materials such as seashells presents a promising approach for producing high-performance, environmentally friendly concrete.

This chapter aims to provide a comprehensive review of the recycling of industrial waste into concrete, focusing on the impact of alternative materials on the mechanical and environmental properties of sustainable concrete. The recent scientific literature in this field is reviewed, in addition to highlighting previous research on the impact of these materials on improving concrete performance, contributing to the development of more sustainable and efficient construction solutions.[3]

Concrete is a composite material primarily composed of aggregates (sand and gravel) bound together by a cementitious matrix consisting of cement, water, and various admixtures. Its properties depend largely on its composition and can be classified according to parameters such as density, strength, and workability.

In this thesis, the type of concrete under investigation is:

- **Fluid sand concrete**.[3]

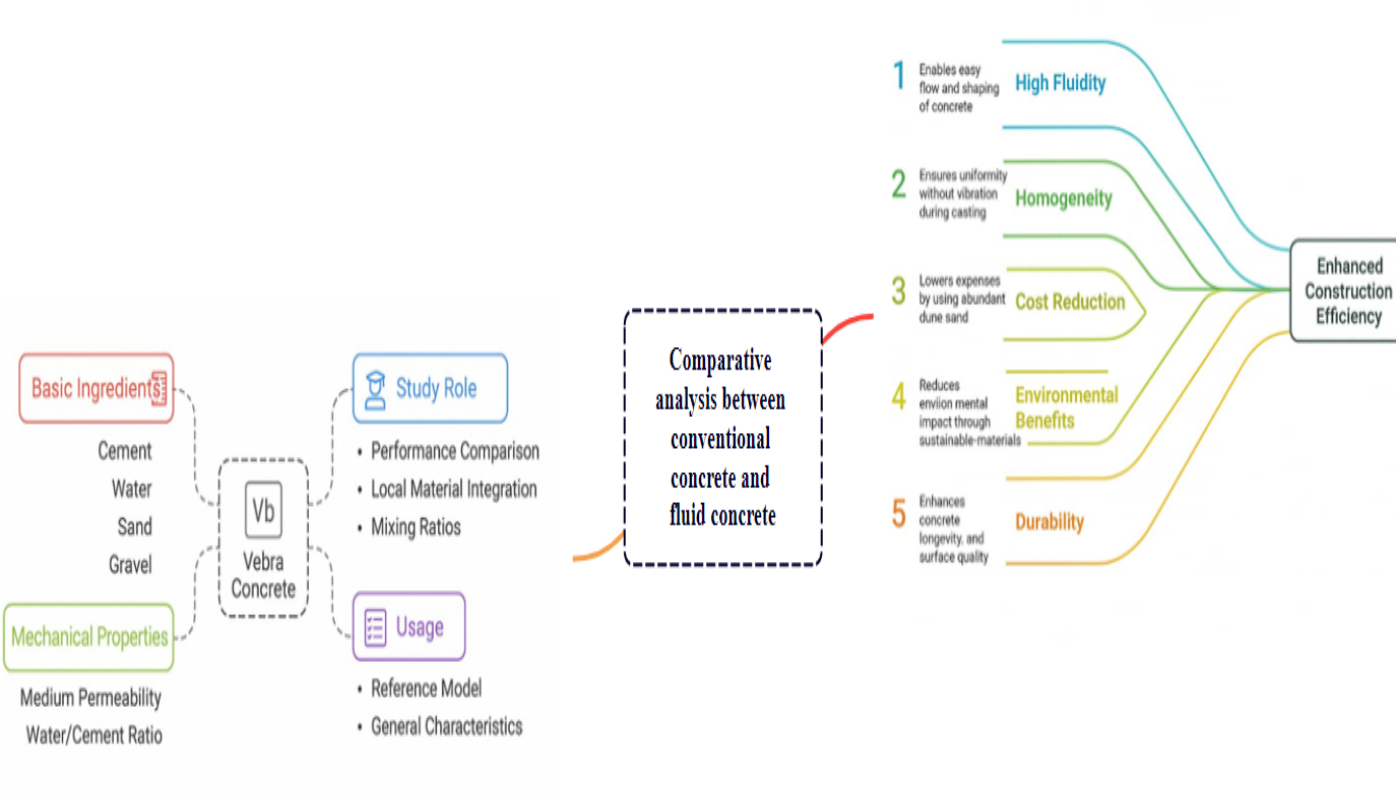


Fig.I.1. Comparative analysis between conventional concrete and Flowable concrete.[3] & [4]

I.2. Flowable Sand Concrete (FSC)

The use of fluid sand concrete promising alternative to deal with the lack of coarse gravel in some regions, especially in southern Algeria. Recent research has focused on the exploitation of local materials such as dune sand, which is widely available, to develop alternatives to traditional building materials. This type of concrete is developed to increase the sand content while keeping the basic characteristics of concrete such as strength and ease of use. This technology improves fluidity during mixing, making it easier to use on construction sites and improving environmental and economic performance.[4] ,[5].

I.2.1. Definition and installation

Fluid sand concrete combines the conventional properties of concrete with a high fluidity and homogeneity ability, allowing it to be easily used in construction applications without the need for external vibrations. It is characterized by non-granular separation, stable ingredients and homogeneous concrete propagation, making it suitable for casting in complex molds or narrow spaces. Their properties are often enhanced by the addition of chemical additives to adjust workability and improve surface strength and quality.[3]

I.2.2. Fields of application in civil engineering

Possible applications of this type of concrete include

Concrete repair: Thanks to its high fluidity, it can fill cracks and gaps with precision, which improves their adhesion to old surfaces and ensures the quality of the repair.

Casting in hard-to-reach locations: High fluidity allows use in narrow spaces, reduces the effort and costs associated with casting work, and also helps improve the stability of the soil under the foundation.

Deep foundations: They are used to pour deep foundations where casting conditions require high surface quality, easy pumping, and homogenization in the composition.

These applications demonstrate the flexibility of fluid sand concrete and its ability to adapt to different project requirements, especially in harsh environments or when conventional materials are scarce.[4]

I.3. Review of alternative materials in concrete

I.3.1. By-Products in Concrete

By-products show varying chemical compositions and physical properties that influence their performance in concrete mixtures. Their selection is based on their availability, compatibility with cementitious matrices, and potential to enhance mechanical behavior.[6]

I.4. Seashells as a Cement Replacement

Shellfish waste, such as oyster and mussel shells, is an abundant waste product. Despite some secondary uses such as fertilizer and handicrafts, most of it is buried. Quantity constraints, hardening soils and economic costs hamper the expansion of reuse. Illegal dumping of this waste into the environment is a growing problem.[7]

Seashells are rich in calcium carbonate ($CaCO_3$), which can be exploited in the manufacture of sustainable concrete. By grinding the shells and turning them into fine powder, they help to improve the pozzolanic activity in the cement matrix, thus improving the microstructure of concrete and increasing its long-term mechanical strength.[8]



Fig.I.2. Types of seashells: (**a**) Scallops; (**b**) Oysters; (**c**) Clam; (**d**) Mussel.[9]



Fig.I.3. (**a**) Scallops; (**b**) Oysters; (**c**) Clam; (**d**) Mussel (before crushing). [10] [11] [12] [13]

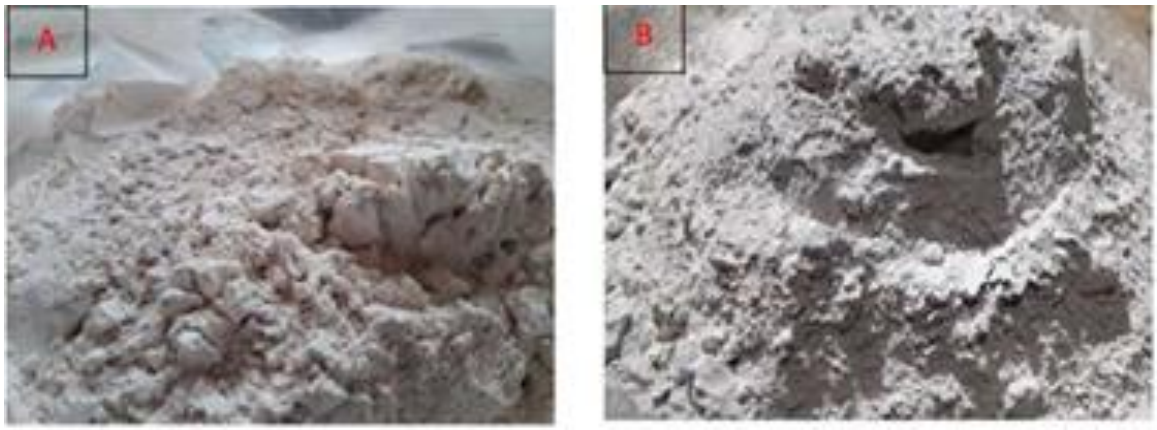


Fig.I.4. (A) Shell powder before calcination, (B) Shell after calcination. [14]

I.4.1. Geometric and mineralogical properties of marine shellfish and their effect on concrete

Marine shellfish, such as Bitunkel and Saint-Jacques, belong to the Pectinidae family and are characterized by their biconvex oval shape, with the right valve more bulbous than the left. The length and height of an adult shell is around 7 cm, while its thickness varies between 1 and 4 mm, according to Minchin (2003) [6],the shape of shells is a critical factor when they are used as additives in concrete, as flat or concave shells can interfere with the uniformity of aggregate distribution in the mix. They also prevent the release of air trapped during the mixing process, leading to the formation of internal voids which have a negative effect on the density and mechanical strength of concrete [6].

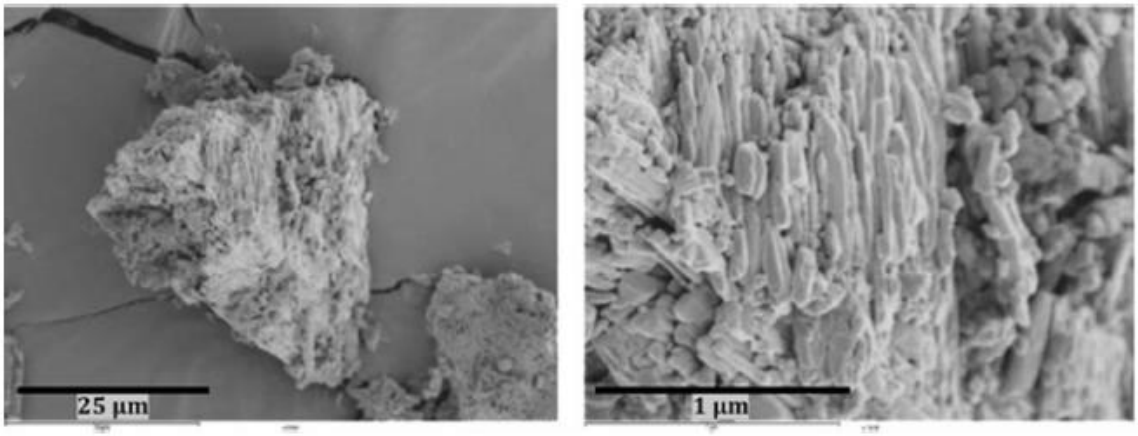


Fig.I.5. Morphology of ground seashell observed by Lertwattanaruk et al. at different magnifications.[15]

I.4.2. Shape effect on concrete

Flat or concave shells have a negative impact on concrete due to their impact on aggregate arrangement in the concrete mix. The presence of these shells can obstruct the outlet of trapped air during mixing, which has a negative impact on the strength and density of the concrete.[8] Juenger, Snellings, Bernal et al [8] have shown that accurate characterization of cementitious additives by appropriate tests is essential to understand the relationship between the properties of these materials and the properties of the resulting composites, and to develop accurate explanatory models. Further characterization tests are therefore needed to better understand the effect of incorporating seashells into concrete.[8]

X-ray diffraction (XRD) analyses have shown that the mineral composition of the majority of marine snails corresponds to the aragonite phase, a crystalline form of calcium carbonate, whose composition is similar to that of calcite, the main component of limestone. However, aragonite is an unstable (metamorphic) form, lying between amorphous and crystalline, whereas calcite is the more stable form. [8]

Scanning electron microscope (SEM) images showed that the surface of powdered marine shells exhibits fine, irregular protuberances, unlike the surfaces of cement or limestone. Wang and colleagues suggested that this irregular surface morphology increases the surface area of shell powder compared to cement and limestone filler, which improved rheological properties, contributes to the development of the aqueous reaction and increases the mechanical strength of the cement paste. [8]

Several studies have shown that replacing part of the cement with seashell powder reduces the amount of heat generated during the aqueous reaction. This reduction is mainly due to the lower proportion of cement in the mix, as snail powder is less reactive than cement and therefore does not release the same amount of heat as in reference mixes. In addition,reducing the amount of cement increases the effective water/cement ratio, resulting in a further reduction in the heat generated by the reaction. On the other hand, mixes containing roasted seashell powder showed higher heat flux rates during the early stages of the reaction, compared to mixes containing only cement. This is due to the reaction of calcium oxide (CaO) from the roasting process with water, which accelerates the formation of calcium hydroxide ($Ca(OH)_2$) and increases the maximum reaction temperature at this stage,clear effects were also observed during the acceleration phase of the aqueous reaction, where the reaction of C_3S (one of the main components of clinker) behaved differently in samples containing snail powder, The incorporation of seashell powder into the mix also affects concrete curing time. Based on data from the studies analyzed, **Figure7** showed the effect of

marine shell powder on curing time.[16]

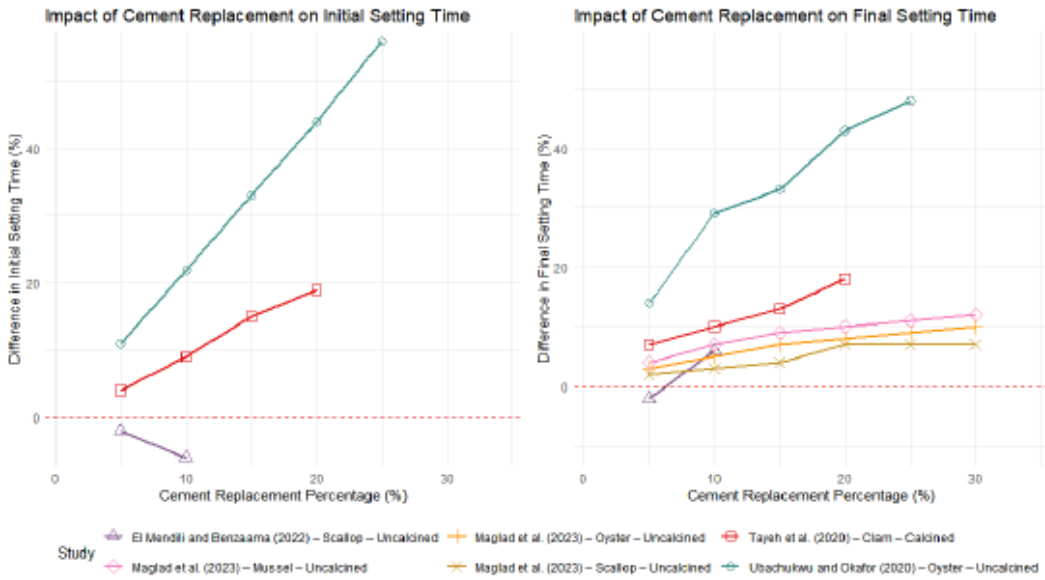


Fig.I.6. The effect of marine shell powder on curing time.[16]

I.4.3. Impact of shell shape on cracking and merging processes in concrete

I.4.3.1. Importance of form and fracking (Shape & Crushing)

Flat particles possess a higher specific surface area, which hinders their optimal packing within the concrete matrix. As a result, a larger quantity of cement paste is required to achieve comparable workability to that of rounded particles, as noted by León and Ramírez (2010) [17]. Nevertheless, the presence of angular particles can enhance the mechanical performance of concrete, particularly in terms of compressive and flexural strength, as demonstrated by Dewar and Anderson (1992) [18] and further supported by Acosta et al. (2007) [19].

I.4.3.2 Criterial and restrictions on the use of flat particles

To ensure good concrete performance, engineering standards determine the maximum allowable ratios of flat and long shells or particles✓ NF standard EN 933-3.[20] Determines that flat particles should not exceed 50% of the total aggregate.

✓ British standard BS 812-105.[21]

The use of flat molecules is prohibited if they exceed 40% of the total mass of the aggregate.

✓ Spanish standard EHE-08.[22]

The coefficient of flatness shall be less than 35% and the coefficient of form CF9 greater than 0.20.

Additional recommendations:

Mehta and Monteiro (2006) [23] recommend not exceeding 15% of flat particles in concrete to maintain their structural quality.

I.4.4. Study of microstructures using scanner electron microscope (SEM)

The exact structure of marine shells was studied using a scanning electron microscope (JEOL JSM-5400), and X-ray scattered energy analysis (EDXS) was performed to detect chemical composition. [5], the researchers studied the microstructure of marine shells using a scanning electron microscope (JEOL JSM-5400) and analyzed their chemical constituents using energy dispersive X-ray analysis (EDXS). The results showed that the outer layer of the shell has a regular crystalline arrangement, which is characteristic of shells of the Pectinidae family. The inner layer consisted of calcite crystals arranged in solid blocks, which helped to enhance the mechanical strength of the shell. To prevent the buildup of electrical charges during electron microscope imaging, the specimens were coated with a thin layer of carbon[6].

I.4.5. Possible synthesis and applications

Dr Héctor Cuadrado Rica et al [8] has analyzed the recycling possibilities of shells in the concrete industry, as they are rich in calcium carbonate ($CaCO_3$), making them promise as an additive in cement mixes. Exposed to temperatures between 820 and 850°C, the shells decompose, producing calcium oxide (CaO) and carbon dioxide (CO_2), a process similar to that involved in the manufacture of clinker. The shells had a solid microstructure that improved the properties of cementitious materials in terms of durability and mechanical performance.[8]

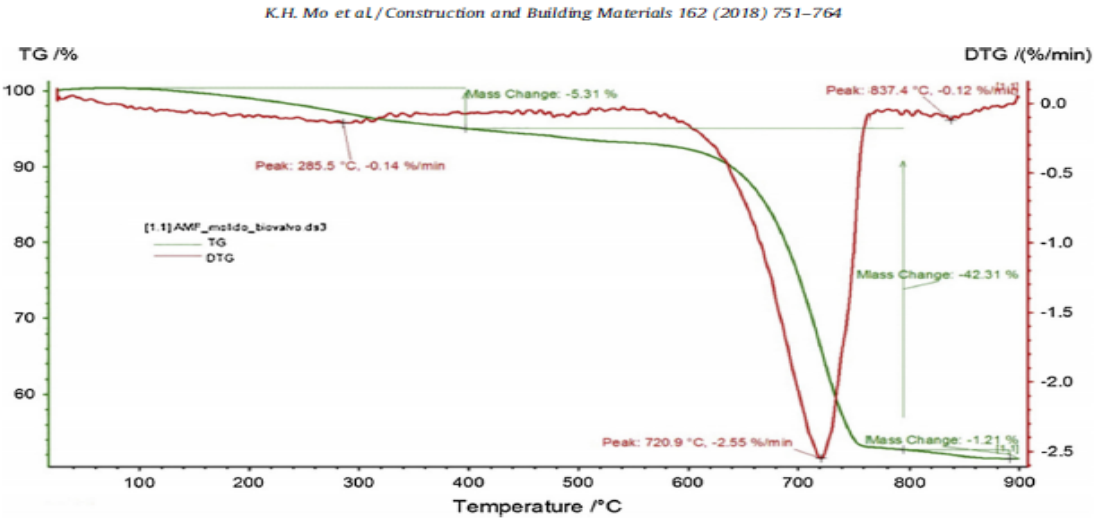


Fig.I.7. TGA curve of mussel shells.[15]

Chemical analysis showed that shell powder contains a high percentage of calcium oxide (51.56%), as well as low percentages of other oxides such as silicon oxide (1, 60%), aluminum oxide (0.92%), magnesium oxide (1.43%), traces of sodium oxide (0.08%) and potassium oxide (0.06%). The chemical composition of the sample is characterized by the presence of sodium oxide (0.92%), magnesium oxide (1.43%), traces of sodium oxide (0.08%) and potassium oxide (0.06%), 0.31% water and a significant loss on ignition of 41.84%, indicating the presence of hydrolysable organic or carbonaceous materials. This chemical composition helped to understand the behavior of the powder when incorporated into the cement mix, and enables it to be compared with other similar additives during the shell cleaning phase.[16]

In addition, chemical composition analysis can detect elements that may adversely affect cement paste properties, such as high potassium and sodium content. Some researchers have suggested that the sodium oxide (Na_2O) content found in snails should be taken into account, requiring additional precautions during the cleaning phase.[24]

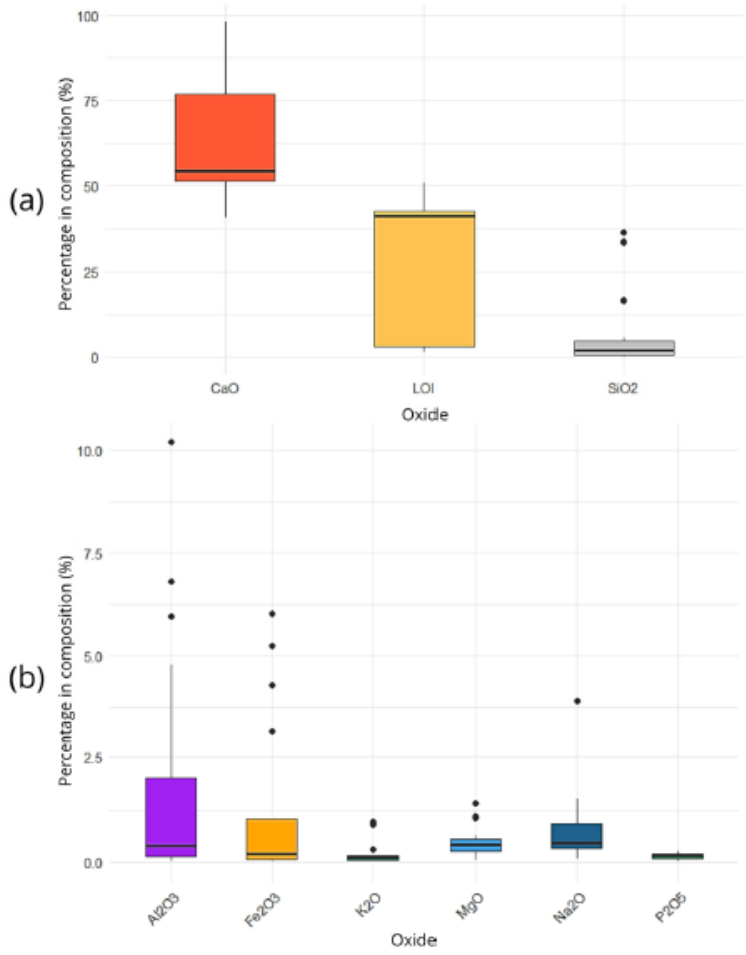


Fig.I.8. Statistical overview of chemical components and loss on ignition of shells. [24]

The shells also show a slightly basic behavior when soaked in water, increasing the pH to values between 9.1 and 9.6, without adversely affecting the properties of the concrete, as reported by Neville (2000) [24]. On the other hand, traces of chloride ions have been observed in certain species such as Pectinidae (approx. 0.07±0.01%) and scallops (approx. 0.05±0.01%), making it necessary to take account of EN 206-1 standards, which specify maximum limits for chloride content in reinforced concrete depending on the nature of its use.

I.4.6. Chemical impact of organic constituents in seashell on concrete properties and treatment methods to improve performance

These organic components can be classified according to their solubility in water:

The soluble fraction contains amino acids and sulfated sugars such as sulfated polysaccharides, which can exhibit amphoteric properties, while the insoluble fraction is made up of amino acids such as glycine and alanine. Studies show that four amino acids

account for around 80% of organic content: aspartic acid and glutamic acid (acidic amino acids), serine and glycine (neutral amino acids). The importance lies in the effect of these organic components, particularly dissolved ones, on concrete properties, as they can introduce air during mixing and affect the interaction of water with cement during rehydration. It is therefore advisable to heat-treat the shells before using them in the concrete mix to optimize their compatibility with the cement components and ensure better performance of the composite material.[6]

I.4.7. Influence of Seashell Adsorption and Absorption Properties on Cement-Based Materials

Researchers have found that the incorporation of seashells into cementitious materials, whether in the form of a powder used as a partial replacement for cement or as a fine aggregate to replace sand, significantly affects the physical and mechanical properties of concrete. The results of using shell powder in the cement mixture showed that it causes a change in the rehydration products, as besides the formation of calcium silicate hydrate (C-S-H), an increase in the formation of ettringite (AFt) and calcium aluminate carbonate compounds was observed, especially in the areas surrounding the shell particles. This phenomenon is attributed to the high calcium carbonate content in the shells, which may contribute to the improvement of the microstructure over time and enhance the concrete's resistance to chemical attacks, Furthermore, studies have shown that the use of shells, either as a powder or as fine aggregate, leads to increased water absorption and higher porosity. If mussel or oyster shells are used as a partial substitute for fine aggregate, the stratified shape and natural porosity of the shells were found to decrease their cohesion with the cement paste and increase voids within the concrete matrix. Similarly, the use of shell powder as a partial replacement for cement led to similar results in terms of increased permeability of the concrete. Despite this negative effect, the chemical reactions resulting from the presence of calcium carbonate may contribute to improved long-term durability under certain environmental conditions [9] ,[25]shells are visualized in **Fig.9.**[9]

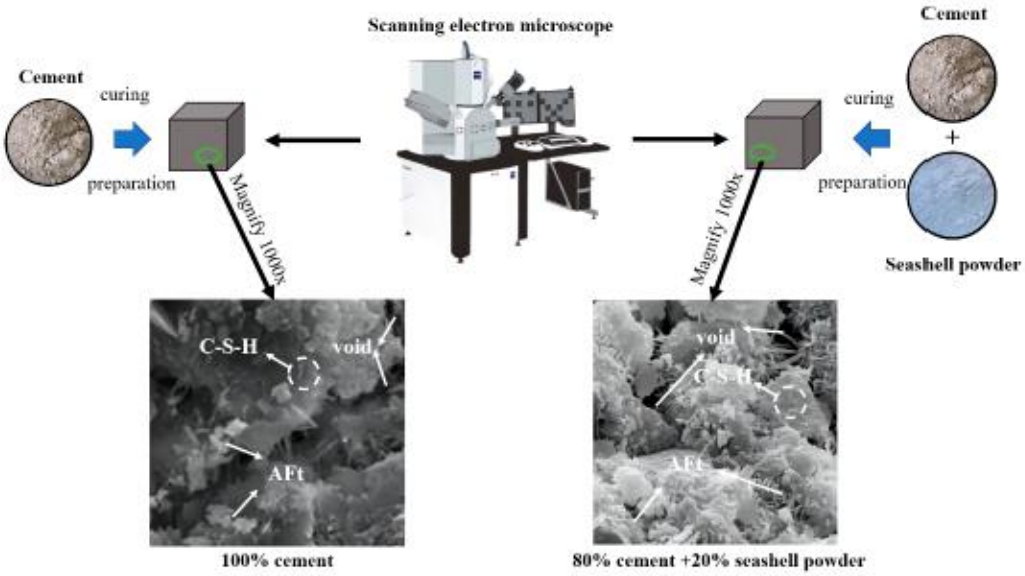


Fig.I.9. Scanning electron microscope images of the cement mixtures with different contents of seashell powders.[9]

I.4.8. Workability

Several studies have investigated the effect of partially replacing cement with calcined seashells on the workability of mortar mixtures. It has been consistently observed that the incorporation of calcined clam shells leads to a reduction in workability, in one comparative study, the reference mortar without substitution (MRC-00) exhibited a slump of 3.5 cm, indicating relatively high workability. When 5% of the cement was replaced by calcined clam shell (MRC-05), the slump decreased to 2.5 cm, a value that remained unchanged even when the replacement level increased to 10% (MRC-10).

These results suggest that while calcined clam shells reduce the workability compared to conventional mortar, increasing the replacement percentage from 5% to 10% does not lead to a further significant decrease. It was also observed that the workability of MRC specimens was higher than that of MR specimens, possibly due to a higher content of binder in the MRC mixes. The decline in workability in mortars incorporating calcined clam shells can be attributed to their physical and chemical characteristics. The calcined shells typically have a high specific surface area and significant porosity, which increase their water absorption capacity. This reduces the amount of free water available to lubricate the particles in the mix, thereby decreasing its fluidity. Furthermore, the high calcium carbonate ($CaCO_3$) content in the

shells can affect the interaction of water with other components in the mixture, potentially increasing the water demand and further reducing workability.[26]

I.4.9. Some experiments applied to seashells

I.4.9.1. Compressive strength

M. Olivia, A. A. Mifshella. et al. [16] used compressive strength as the main criterion to evaluate the performance of the experimental mixes. **Figure 10** showed the compressive strength values for mixes in which cement was replaced by 2%, 4%, 6%, and 8% cement by weight. The results showed that the mix containing 4% crushed shells was the most suitable, achieving the highest compressive strength of 32.24 MPa after 28 days of curing. Based on these results, this mix was selected for further studies on the mechanical properties of veneer concrete.. [16]

Hamid Reza Bahadori, Amir Ahmad Hedaya et al have confirmed that the use of 5% shell powders leads to an improvement in the compressive strength of concrete. [27]

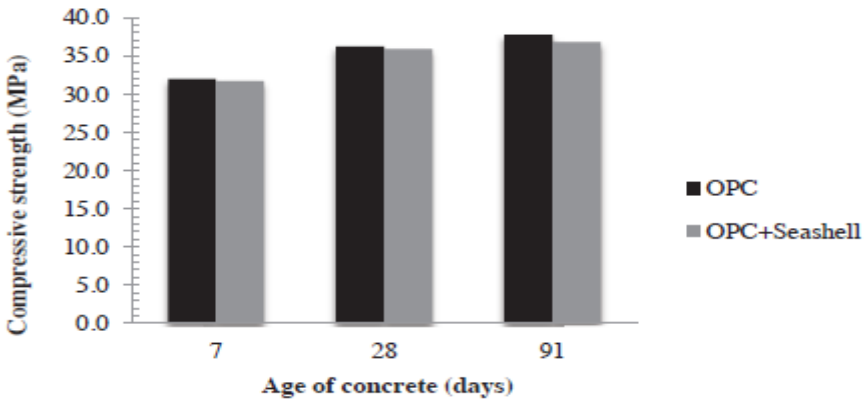


Fig.I.10. Compressive strength of OPC and seashell concrete at 7, 28, and 91 days.[16]

I.4.9.2. Tensile strength

Both OPC and shell cement showed a progressive improvement in tensile strength, as shown in Figure 12. However, the improvement in tensile strength of OPC was greater than that of shell cement after 28 days. One study indicates that the introduction of 5% seashell resulted

in a significant improvement in tensile strength, and this improvement is often attributed to better bonding between cement paste and aggregate at the transition interface.[9]

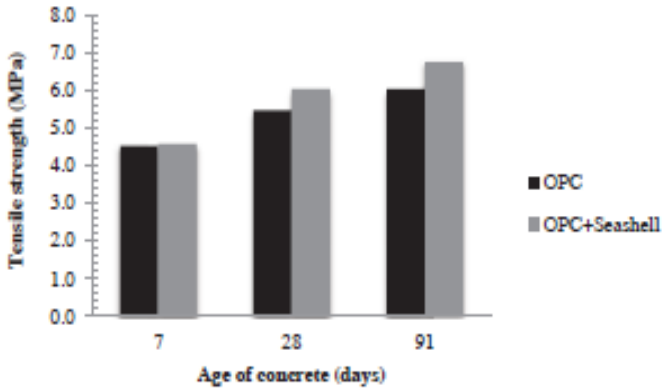


Fig.I.11. Tensile strength of OPC and seashell concrete at 7, 28, and 91 days.[16]

I.4.9.3. Flexural tensile strength

The results of flexural tensile strength tests carried out by Meylí Valin Fernández, Benjamín Sebastián Muñoz Toro et al [26]after 28 days of treatment showed a slight increase in strength of 0.04% and 0.03% for non-calcified shell specimens (MR-05 and MR-10), respectively, compared with the reference specimen MR-00. An increase in resistance of 0.05% was also observed for calcified shell specimens (MRC-05 and MRC-10).

However, these small increases do not allow us to optimize the strength of specimens where part of the cement has been replaced by shells, due to certain inconsistencies in the results.[26]

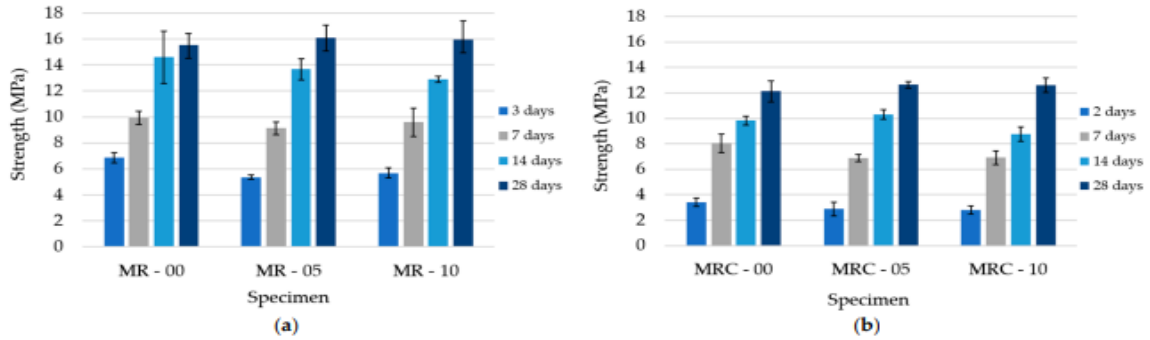


Fig.I.12. Summary of flexural tensile strength results: (a) specimens with uncalcined shell and (b) specimens with calcined shell.[26]

I.4.9.4. Density

Research has illuminated that substituting conventional aggregates with marine shell waste such as brinckel, oyster, or mussel shells leads to a slight reduction in the density of hardened concrete. This subtle decline is not merely a matter of composition, but rather the consequence of the shells' unique physical nature. Though their specific gravity closely mirrors that of natural aggregates, their irregular forms and residual organic content introduce greater air voids into the concrete matrix, thereby tempering its compactness and altering its structural essence..[28] Safi, Nguyen et al [29] reached the same conclusion, observing that density decreases as the snail content of the mix increases. This decrease is attributed to the difference in density between the snails and the sand, the snails having a lower density, which makes the concrete lighter as its percentage increases.[29]

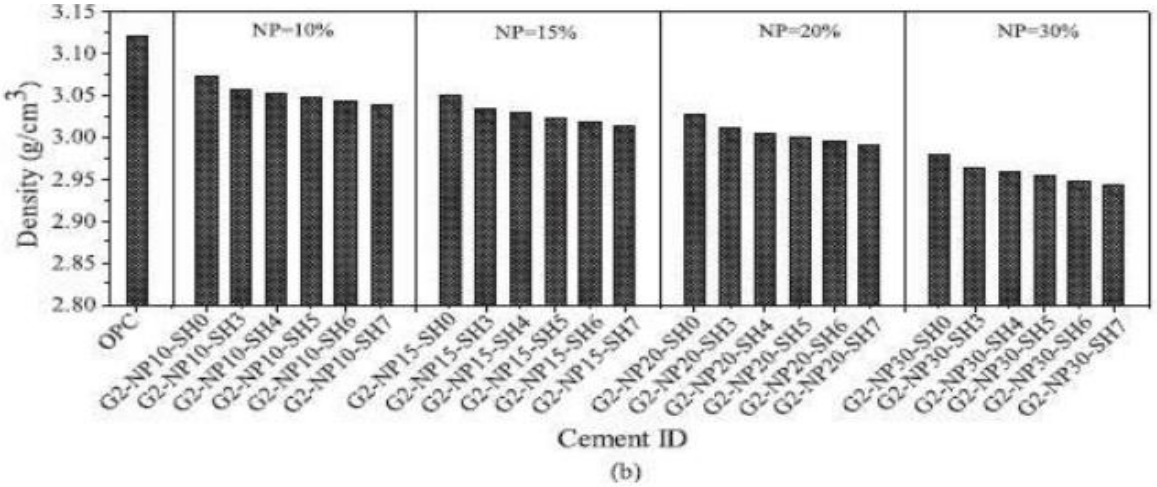


Fig.I.13. Influence of cement substitution by shellfish on cement density. [29]

Hasan et al (2023) graph presents the relationship between sand replacement ratios with shell waste powder and several basic concrete properties. The results showed that compressive strength and dry density reached their highest values for replacement ratios between 10 and 15%, indicating the effectiveness of shell powder in improving internal cohesion between mixed components.

On the other hand, increasing the proportion of shell powder beyond 20-25% resulted in a significant increase in porosity and water absorption, indicating a progressive deterioration of the concrete microstructure. The compressive strength index also showed a clear decrease as the proportion increased, reflecting a reduction in the granular efficiency of the mix and, consequently, a decrease in compressibility and cohesion.

This analysis suggests that the optimum ratio for replacing sand with shell powder lies between 10 and 15%, where mechanical performance and physical properties can be balanced without compromising structural strength.[30]

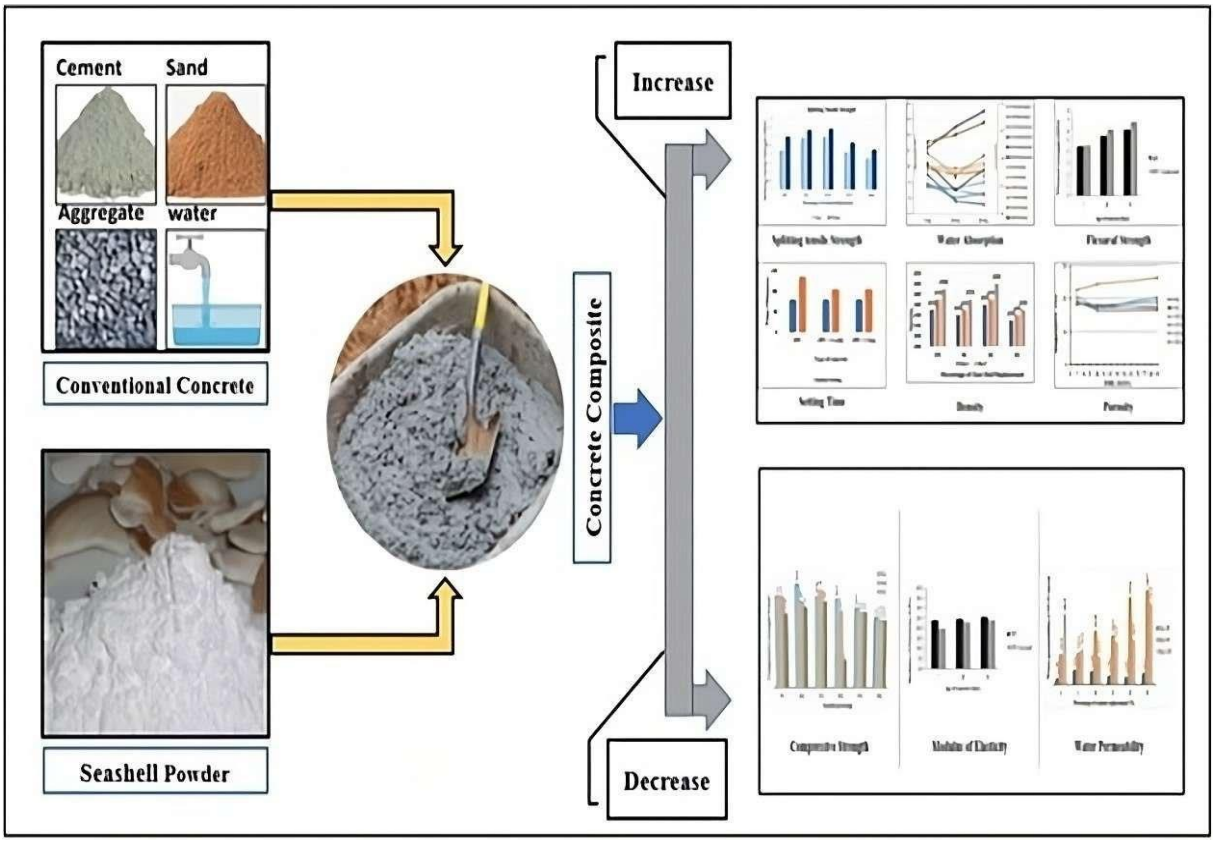


Fig.I.14. Experimental study on the effect of adding snail powder to conventional concrete.[30]

I.4.10. Environmental benefits of recycling seashells in concrete

The integration of sea-shells into concrete components is an important step to promote environmental sustainability in the construction sector. The main environmental benefits of this trend are:

●Reducing the accumulation of marine waste

Seashells, especially those from fishing and aquaculture activities, constitute a large proportion of coastal waste that can contribute to the degradation of marine ecosystems as they accumulate. Recycling these residues into construction materials is an effective way to

reduce pollution and reduce pressure on landfills, helping to protect the coastal environment and promote marine hygiene.

●Reduced dependence on primary resources

The use of shells as a partial alternative to natural aggregates in concrete mixtures reduces the need for quarrying gravel and sand. This in turn limits the environmental impact of extractive activities such as habitat degradation, soil erosion and increased carbon emissions associated with transport and sanitation.

● Promoting the concept of sustainable concrete

This initiative is part of the green concrete development framework, known as Green Concrete, which aims to reduce the carbon footprint by adopting recycled components and achieving resource efficiency. The integration of broken shells contributes to the achievement of these objectives by allowing the use of locally available resources rather than the use of new resources, thus improving the efficiency of the sustainable construction ecosystem.[8]

I.5. Ceramic

Ceramic powder waste, resulting from the cutting and polishing of ceramic materials, is a promising material that can be used as a partial substitute for cement in the manufacture of concrete. In 2018, over 22 billion tonnes of this waste was produced and is often landfilled, leading to pollution of air, soil and groundwater. Containing compounds such as silicon dioxide and aluminum oxide, this waste can pose a risk to ecosystems. However, their reuse in concrete production can minimize environmental impact by reducing their accumulation in the environment. [14]

El-Dieb and Kanaan[31] investigated the feasibility of substituting Portland cement with ceramic waste powder (CWP) at 0, 10, 20, 30 and 40 % by mass. Their program assessed both fresh-state workability and hardened-state performance, with particular emphasis on long-term durability. A detailed characterization of the physical and chemical attributes of CWP was first carried out to gauge its pozzolanic potential and suitability as a cement replacement. Microstructural observations traced how increasing CWP content alters hydration products and pore structure, while a performance-index approach balancing strength, durability and workability was applied to identify the optimum replacement level. The authors conclude that, when dosage is optimized, ceramic waste powder can enhance

selected durability parameters and reduce clinker consumption, offering a viable pathway for diverting solid waste from landfill and advancing the sustainability of concrete construction.[31]

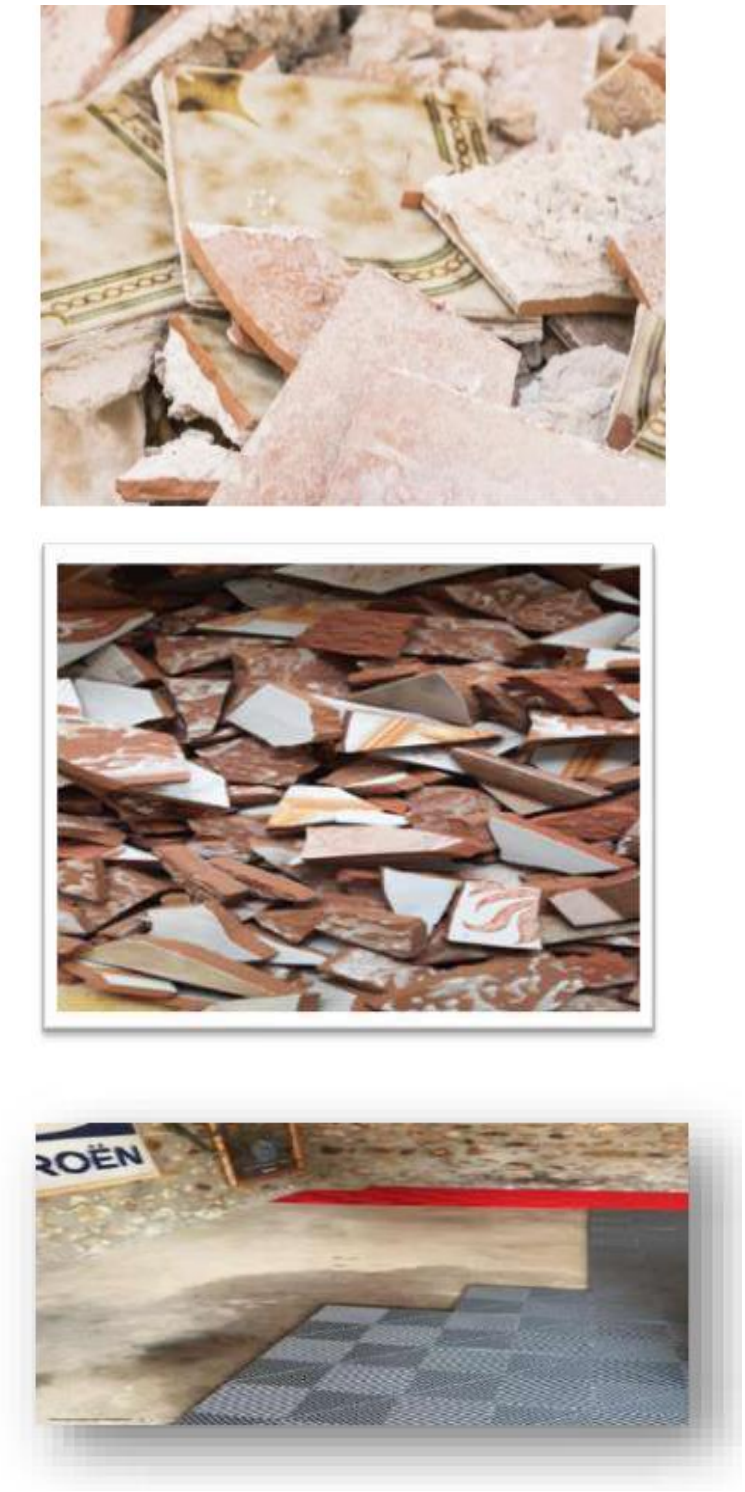


Fig.I.15. Ceramic scrap.[32]&[33]

Fig.I.16. Floor slab.[34]

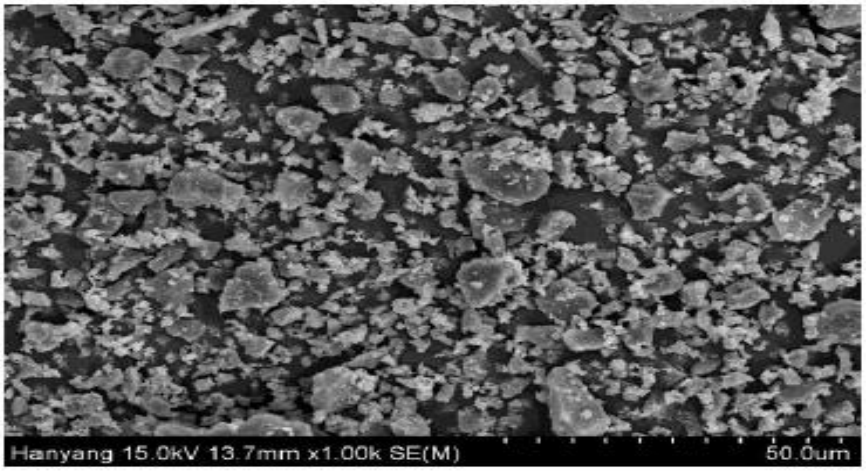


Fig.I.17. Field Emission Scanning Electron Micrograph of ceramic powder.[35]

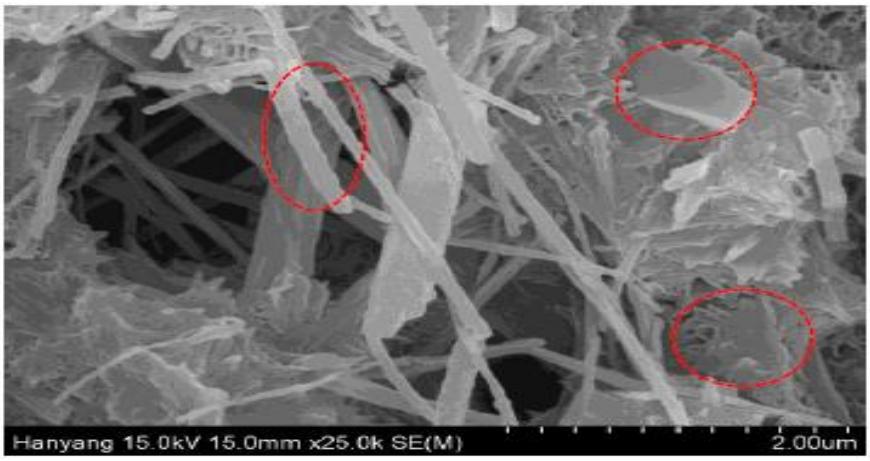


Fig.I.18. Field emission scanning electron micrograph of sample with 40% ceramic as cement replacement.[35]

Scanning Electron Microscopy (SEM) has been widely used to examine the microstructural characteristics of cementitious materials with and without pozzolanic additives [35].In the context of ceramic waste powder, SEM analyses have confirmed that the particles typically have a size below 50 µm, which is favorable for pozzolanic reactivity. However, despite the growing interest in ceramic waste as a supplementary cementitious material, studies specifically addressing its influence on the microstructure of mortar remain relatively scarce. In one investigation, a field emission SEM image of a mortar sample containing 40% ceramic powder as a cement substitute revealed the presence of three main crystalline phases: calcium silicate hydrate (C-S-H), calcium hydroxide (CH), and ettringite. These phases contribute to the mechanical integrity of the cement matrix at various stages of hydration.

While calcium hydroxide typically forms during the early stages, C-S-H the primary strength-giving phase develops progressively, particularly through the pozzolanic reaction between ceramic powder and portlandite. Ettringite, often formed from the reaction of aluminates and sulfates, also plays a role in early strength development and pore structure refinement. These findings highlight the complex interactions between ceramic powder and cement hydration products, reinforcing the material's potential as a viable alternative in sustainable mortar formulations[35].

I.5.1. Chemical properties

Tab.I.1. Chemical properties of ceramic waste.[36]

Materials	Ceramic Powder (%)
SiO2	63.29
Al2O3	18.29
Fe2O3	4.32
CaO	4.46
MgO	0.72
P2O5	0.16
K2O	2.18
Na2O	0.75
SO3	0.10
CL-	0.005
TiO2	0.61
SrO2	0.02
Mn2O3	0.05
L.O.I	1.61

I.5.2. Mineralogical composition of ceramic powder

Tab.I.2. Mineralogical composition of ceramic powder.[37]

Mineral	Amount, mass %
Quartz	44.8
Hematite	3.0
Albite	11.9
Muscovite	4.0
Microcline	7.8
Σ	71.5

I.5.3. Surface Treatments of Technical Ceramics and Implications for Concretes Incorporating Industrial Ceramic Waste

Complementarily, Özcan,et al (2003) [31] evaluated the effect of three surface preparation techniques on the bond strength of a Bis-GMA-based adhesive cement applied to six types of ceramics, including glass ceramics, alumina- or zirconia-reinforced ceramics, and glass-coated compositions. Their study confirmed the effectiveness of hydrofluoric acid etching for glass-based ceramics, while ceramics lacking a silica phase (such as alumina or zirconia) required alternative methods such as sandblasting or tribochemical silica coating followed by salinization to significantly improve chemical bonding. The authors also highlighted a considerable decrease in bond strength after thermal aging, emphasizing the importance of long-term durability testing, these findings align with those of Papia et al. (2013)[31] , proving that treatments combining mechanical activation (via sandblasting) with chemical modification (using MDP-based primers or silanes) are the most effective. By extension, these principles can be applied to the field of environmentally friendly concrete reinforced with ceramic waste (such as zirconia dust or alumina). Given the similar surface properties of these industrial wastes to technical ceramics, targeted chemical treatments could enhance

adhesion between fine particles and the cement paste, thereby improving the internal cohesion of the concrete and stress distribution at the interface zones. [31]

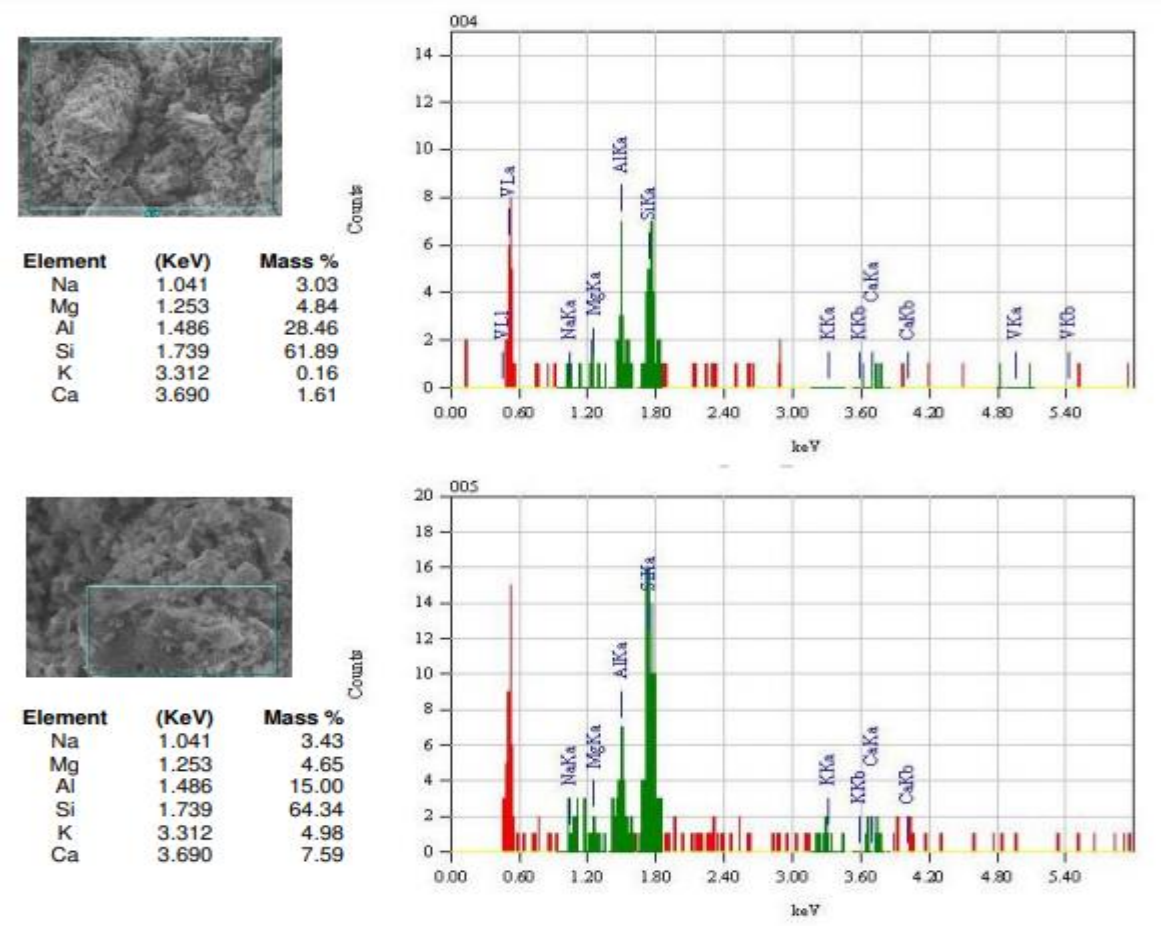


Fig.I.19. EDS analysis of two CWP samples used in the study.[31]

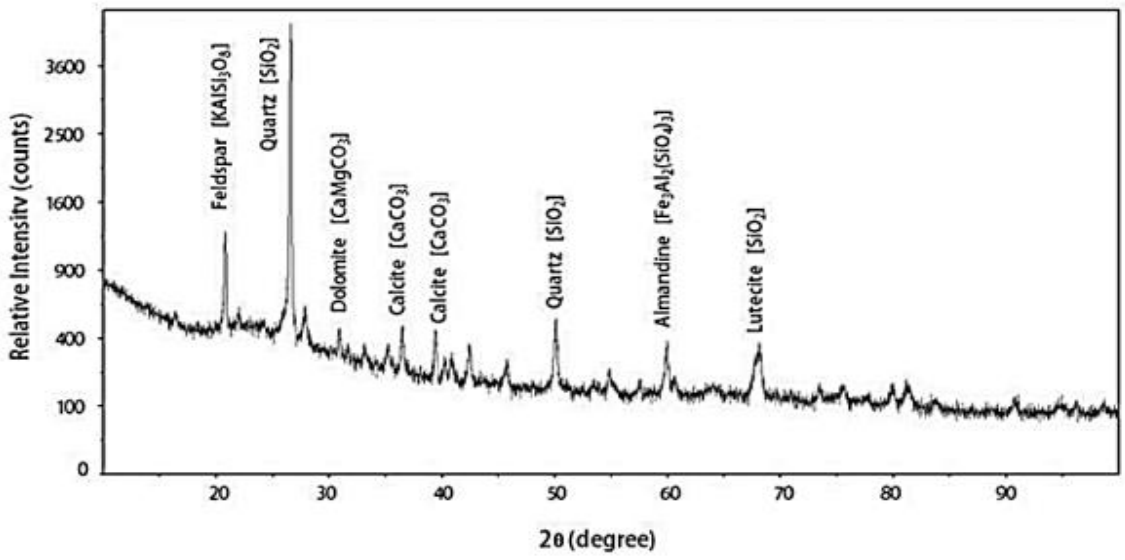


Fig.I.20. XRD pattern of CWP.[31]

Throughout this research.[13]; Amr S. El Dieb, Dima M. Kanaan et al found:

Ceramic waste powder (CWP) can be used as an alternative ingredient to partially replace cement.

Ceramic waste powder improved the workability retention of concrete mixes.

Ceramic waste powder minimizes the development of compressive strength and requires a longer curing time.

Ceramic waste powder significantly improved durability properties.

The Performance Index (PI) methodology is a useful tool for evaluating and selecting the mix best suited to the required performance criteria [31].



Fig.I.21. Ceramic waste powder in concrete.[13]

I.5.4. Slump tests

L. Li, P. Joseph, X. Zhang et al[38]. developed a predictive model designed to capture small variations in concrete compressive strength (ΔS), expressed as a percentage - with positive values indicating an increase and negative values indicating a decrease. The researchers concluded that this model is a combination of parameters that work together: The intrinsic quality of the concrete (M), the water-cement ratio (W/C), and the proportion of cement replaced by ceramic waste powder (CPW), expressed as a percentage. Through careful statistical analysis, the model revealed a convincing interaction between these variables and the resulting strength, confirmed by a strong coefficient of determination (R^2 = 0.68) and a remarkably low standard deviation. These distinctive statistical features attest to the reliable predictive power of the model, providing a reliable lens through which to clearly and accurately predict the effects of concrete composition and material substitution on compressive strength..[38]

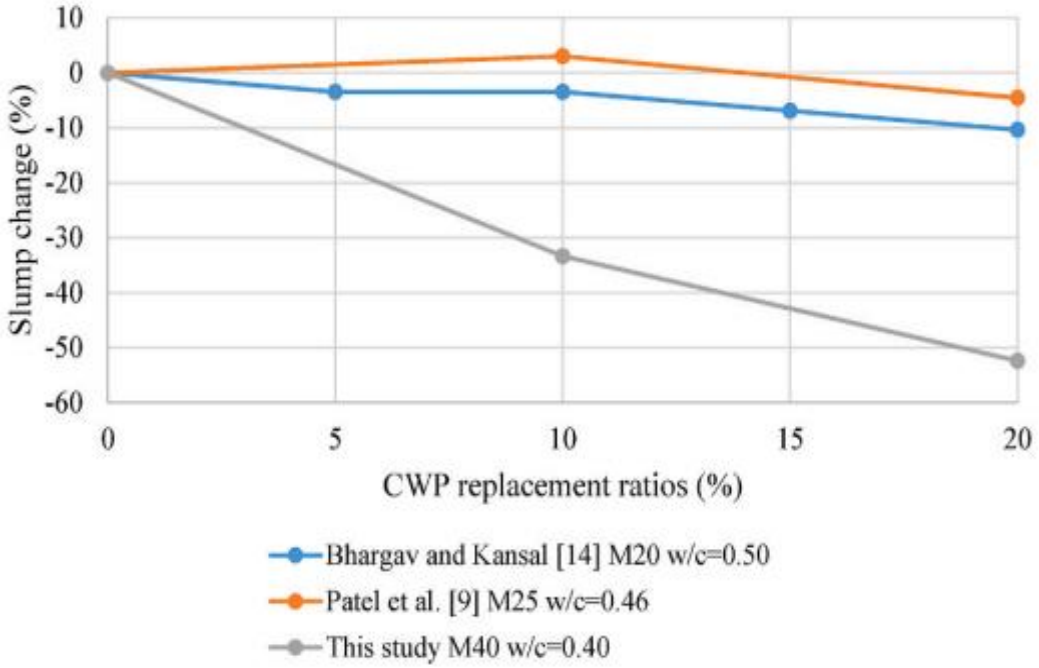


Fig.I.22. Changes in the slump value for different concrete mix designs.[38]

I.5.5. The mechanical properties

I.5.5.1. Compressive test results

L. Li, P. Joseph, X. Zhang et al.[38] found that replacing 10% of cement with ceramic waste powder (CWP) increases the compressive strength, due to the pozzolanic reaction that occurs

between reactive silica or alumina in CWP and calcium hydroxide produced by cement hydration, and CWP contains ferric oxide and titanium dioxide, which may help improve concrete performance, and a decrease in compressive strength occurs when 20% of cement is replaced with ceramic waste powder. CWP has an alkali content that can lead to an alkali-silica reaction (ASR), although this effect is limited when only 10% of the cement is replaced.[38]

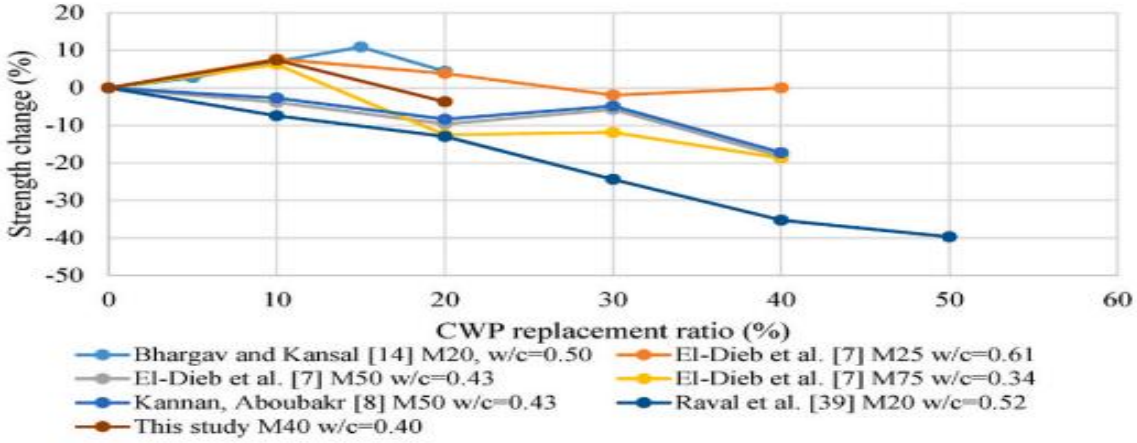


Fig.23. Changes in compressive strength for different concrete mix designs.[38]

I.5.5.2. Water absorption

When L. Li, P. Joseph, X. Zhang et al[38] replaced 10% and 20% of cement with CWP, a slight increase in water absorption was observed after 24 hours of immersion, as well as after 72 hours of immersion, CWP has an alkali content that can cause the concrete to expand and crack through the alkali-silica reaction (ASR), thus increased water absorption, however, CWP particles can fill the voids between concrete components and increase the density of its microstructure, and CWP also contains ferric oxide, which can compress the cement and increase the density of the concrete microstructure.

In general, the increase in water absorption was not significant when replacing 0-20% of cement with CWP, as the voids filling effect and density increase caused by CWP compensates for the increase in water absorption caused by the increased porosity.[38]

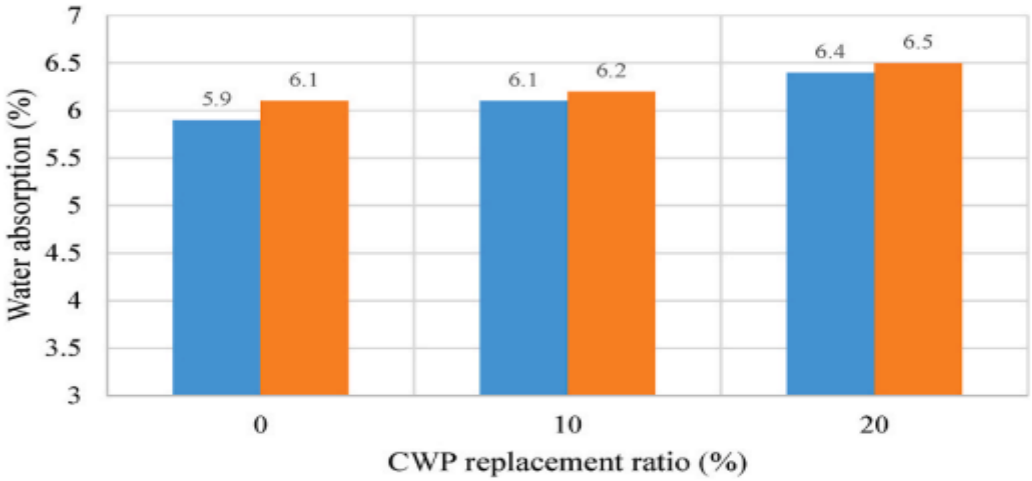


Fig.I.24. Water absorption of concrete specimens at different CWP replacement ratios of cement. [38]

I.5.5.3. Thermal conductivity analysis

The researchers found that replacing cement with CWP reduces the thermal conductivity of concrete and thermal diffusivity, thereby increasing the thermal insulation of concrete.

Specifically, an 11.2% decrease in thermal conductivity and a 13.6% decrease in thermal diffusivity were observed when the replacement rate was increased from 0 to 20%.

Adding CWP to concrete increases its silicon dioxide content and reduces thermal conductivity. In addition, CWP particles reduce the size of air voids in concrete, turning large air voids into multiple small voids.

Increasing the number of small air voids increases the thickness of the cement paste scales surrounding the air voids and improves the thermal insulation of the concrete.

Increasing the number of small voids can also increase the total area of the air voids and prevent heat transfer to the concrete, thereby increasing the thermal resistance.[38]

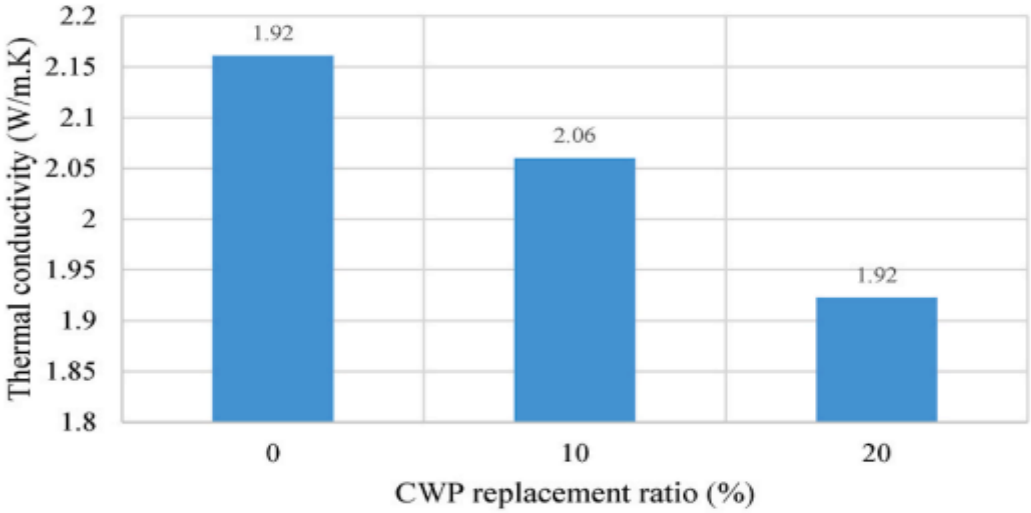


Fig.I.25. Thermal conductivity.[38]

I.5.5.4. Flexure strength

Researchers L. Li, P. Joseph, X. Zhang, et al. [38]did not directly test the flexural strength in this study. However, many studies have developed empirical equations to predict flexural strength based on compressive strength.

Previous studies have collected data on the compressive strength and flexural strength of concrete in which cement was replaced by different levels of CWP.

This data was used to investigate the reliability of different equations for predicting the flexural strength of concrete containing CWP.

The results indicate that one particular equation provided a more accurate prediction of the flexural strength of CWP-containing concrete.

On this basis, the flexural strength of concrete in this study can be predicted using this equation and the obtained compressive strength[38]

I.5.5.5. Modulus of elasticity

Abadou et al[32] reported that the use of ceramic waste in the manufacture of cement mortar resulted in a significant increase in modulus of elasticity compared with conventional mortar, which is in line with the findings of other researchers in previous studies .[32]

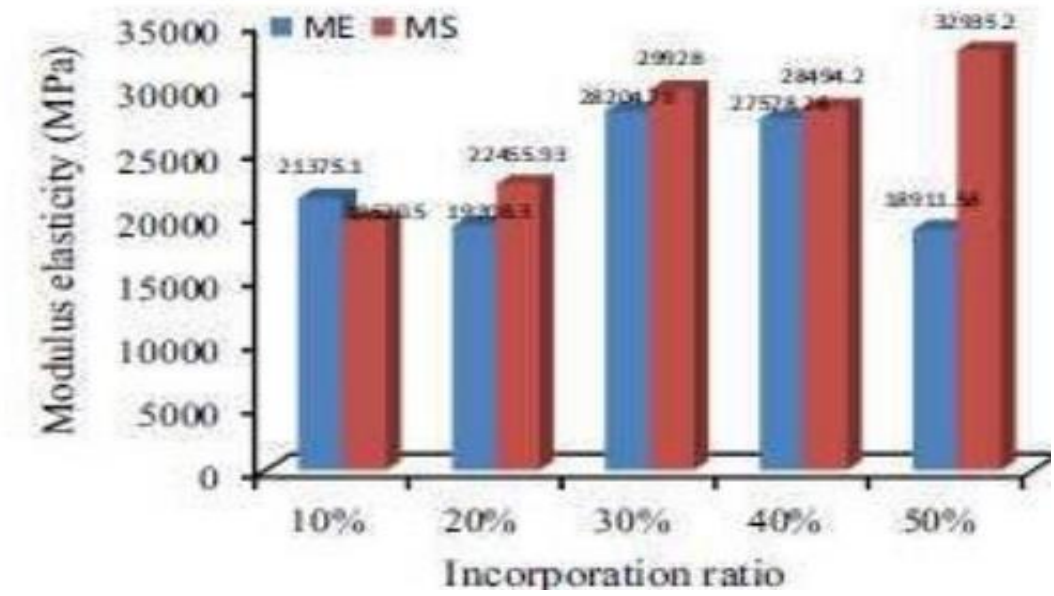


Fig.I.26. The effect of red ceramic waste on the modulus of elasticity of mortar. [32]

I.5.6. Technical and environmental drivers for using ceramic waste in mortar

The incorporation of fine ceramic waste - mainly from the residues of the red brick industry - in the production of cement mortar aims to achieve a set of complementary objectives, including reducing environmental impact, improving the mortar's technical properties and reducing economic cost. the main objective is to partially replace cement, a material with a high impact in terms of energy consumption and CO2 emissions during manufacture, with alternative materials derived from waste and featuring favorable physical properties, such as fine ceramic powder.[39],this type of waste is rich in mineral oxides, such as silica and aluminum oxide, which give it partial pozzolanic activity, enabling it to react with calcium hydroxide produced by cement hydration to form secondary cementitious compounds that improve mortar cohesion and durability. In addition, the microceramic acts as a “microfiller”, improving mix density and reducing porosity, thus improving the mortar's resistance to water penetration and minimizing shrinkage cracks.[39] From an environmental point of view, the use of these wastes minimizes the accumulation of industrial waste and provided a practical and sustainable recycling solution for the construction sector. From an economic point of view, reducing the proportion of cement used reduces production costs without adversely affecting the mortar's basic properties. On the contrary, studies indicate that properties such as water retention, surface adhesion and water vapour permeability can be enhanced by the use of these additives,making them an attractive option for exterior cladding and rendering applications.[39]

I.6. Granite

Granite waste has attracted the attention of many researchers, prompting them to investigate the possibility of using it as an alternative to traditional concrete ingredients such as cement and natural sand. The work carried out by Beretika and Taylor in 1991 was one of the seminal studies examining the use of granite as an alternative to natural sand. Later, the study by Saboya et al (2007) [40] showed that granite's properties enable it to replace natural sand in concrete mixes.[40] This is due to its multiple properties of:



Fig.I.27. Granite waste. [41]

Tab.I.3. Physical Properties of granite powder.[40]

Ingredient	Specific Gravity	Water Absorption	Fineness Modulus
Granite Cutting Waste	2.622	4.36%	2.573

Tab.I.4. Chemical composition of granite powder.[42]

	Weight%
SiO_2	64.5%
TiO_2	0.67%
Al_2O_3	12.01%
Fe_2O_3	5.77%
MgO	0.57%
MnO	0.39%
CaO	4.80%
Na_2O	5.92%

Several studies have already explored this topic, Corinaldesi et al (2010) and Habhoub et al [43] found that partial replacement of sand with stone powder does not significantly affect concrete strength. Bahuria et al (2013) suggested that incorporating stone powder as a substitute for sand can improve the bond between paste and aggregate. Kala (2013) also showed an improvement in mechanical properties thanks to this substitution. Similarly, Singh et al (2016b, 2016c) observed that partial replacement of sand with granite powder improved strength and durability. Medina et al (2017) reported favorable results when cement was partially replaced by granite powder.[43]

I.6.1. Scanning electron microscopy

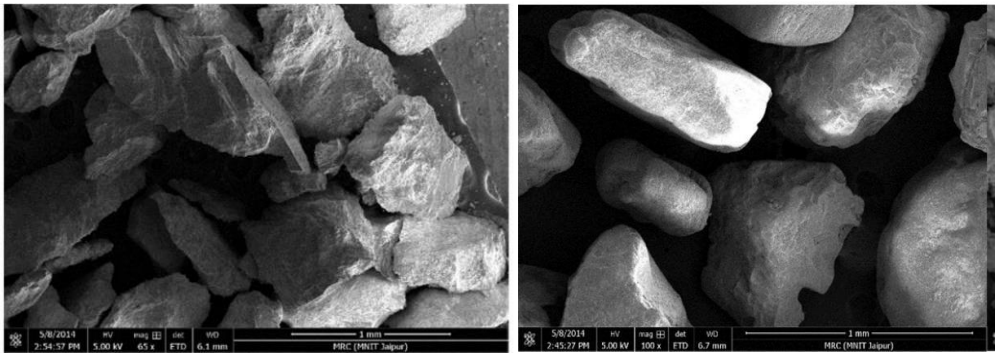


Fig.I.28. SEM images of fine Aggregate particles(Granite & Sand).[40]

Scanning electron microscopy (SEM) analysis involves close examination of the physical properties of aggregate particles at different magnifications. Morphological properties and surface texture, as they appear in SEM images, help to explain the behavior of fresh concrete in terms of workability, as well as its mechanical properties and durability after hardening. The images show that sand particles have a rounder shape and smoother texture than granite particles, which are characterized by sharp angles, a rough surface and a rectangular cross-section. Flat granite waste (GCW) particles exhibit relatively more rounded and elongated morphological characteristics than river sand particles, which are predominantly spherical in shape.[40]

The results of the previous studies suggest that the use of GCW in concrete manufacture is a promising option for addressing the environmental challenges associated with the accumulation of stone waste worldwide. The results showed that the quality of concrete containing GCW is affected by several factors, including: The compaction factor value

progressively decreases as the proportion of GCW in the mix increases, which is attributed to the increased roughness and angularity of the particles.[40]

I.6.2. Assessing the effect of using recycled aggregates from granite waste on concrete properties

Experiments were carried out on low (20 MPa) and high (50 MPa) strength concrete, where sand was partially replaced by granite particles up to 50% by weight. Test results showed that the compressive strength of concrete was unaffected by the introduction of granite waste, compared with conventional concrete. On the other hand, a reduction in tensile strength was observed when 50% granite waste was used, the effect being more pronounced in low-strength concretes. The presence of these particles also reduced the workability of fresh concrete. The study indicates that there is a weakness in the transition zone between cement paste and aggregate in concrete containing granite waste, which can affect the material's performance at the microscopic level.[43]

I.6.3. Curves showing the behavior of concrete when replacing sand with granite

I.6.3.1 Workability

Compressive strength test results showed a progressive decrease in concrete workability with increasing replacement rates for granite waste (GCW). This decrease is due to the roughness and angularity of the particles, which increase their internal friction and reduce the fluidity of the mix.[40]

I.6.3.2. Density

Tab.I.5. Density of Different Mixes.[40]

Replacement (%)	Density (Kg/m³) for GCW series
Control mix (0)	**2440**
10	**2439**
15	**2396**
20	**2370**
25	**2315**
30	**2313**
40	2310

●Explanation

In mixes where granite cuttings (GCW) were used to partially replace natural sand, a progressive decrease in overall concrete density was observed as replacement rates increased. This decrease is attributed to the fact that the specific density of GCW is lower than that of sand, resulting in a reduction in the overall weight of the concrete mix. For example, the density was 2440 kg/m³ in the reference mix (0% replacement), falling to 2310 kg/m³ when 40% of the sand is replaced by GCW.[40]

I.6.3.3. Compressive Strength

Researchers S. Ghannam, H. Najm,et al Vasconez, [42] found the results compressive strength was obtained with 10% of the sand replaced by granite powder, reaching 48.9 MPa versus 35.8 MPa for the reference mix. This improvement is attributed to the ability of the fine granite powder particles to fill the spaces between the fine aggregate grains, thus reducing porosity and improving cohesion within the concrete structure. However, above 10%, a progressive decrease in compressive strength was observed, probably due to oversaturation of the fine particles, resulting in increased voids and poor structural bonding of the cement paste.[42]

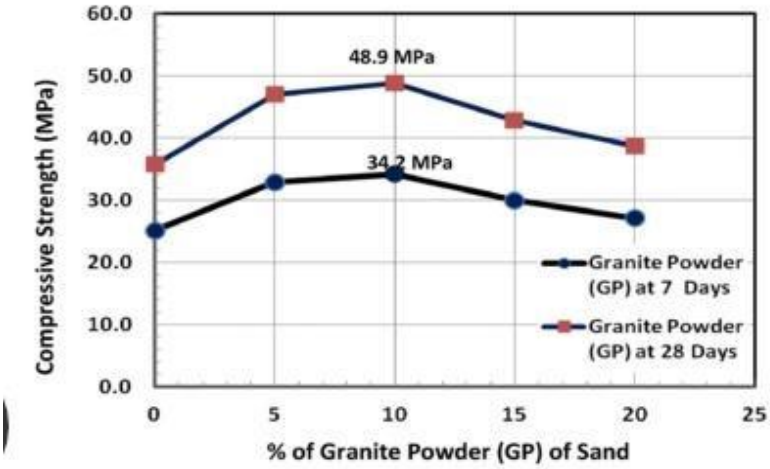


Fig.I.29. Compressive Strength.[42]

I.6.3.4. Flexural Strength

Researchers S. Ghannam, H. Najm,et al[42] Vasconez, found the results showed that the optimum proportion of granite powder to obtain the highest flexural strength was when 10%

sand was substituted, with the highest strength value compared with the other proportions used.[42]

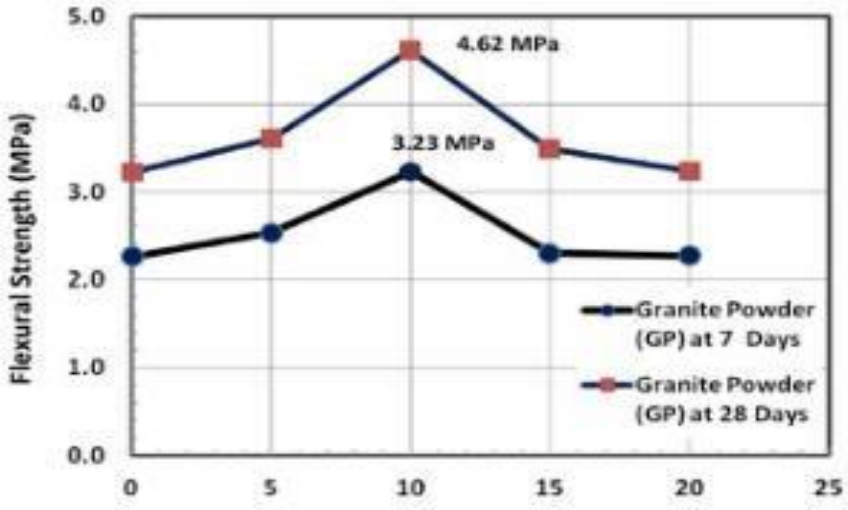


Fig.I.30. Flexural strength of beams with diffrente Proportion of (GP).[42]

I.6.3.5. Split Tensile Strength

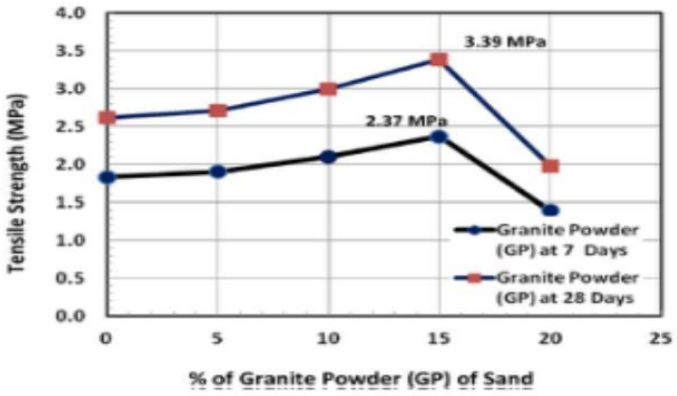


Fig.I.31. Split Tensile Strength.[42]

Researchers have found the results show that replacing sand with granite powder up to 15% improved the friction tensile strength of concrete. The highest strength value was recorded at this ratio, indicating that this is the optimum replacement ratio. On the other hand, exceeding this ratio resulted in a decrease in strength, indicating that excessive use of granite powder can have a negative effect on the mechanical properties of concrete.[42]

I.6.4. The environmental benefits of granite recycling

Granite polishing waste (GPW) has been recognized as a fine waste. Inappropriate disposal of this waste consumes valuable landfill space and poses serious health risks, such as silicosis, if not properly managed (National Institute for Occupational Safety and Health, 1974; Li et al., 2016)[44]. Consequently, the reuse of these wastes in concrete applications has recently received considerable attention (Li et al., 2019a).[44]

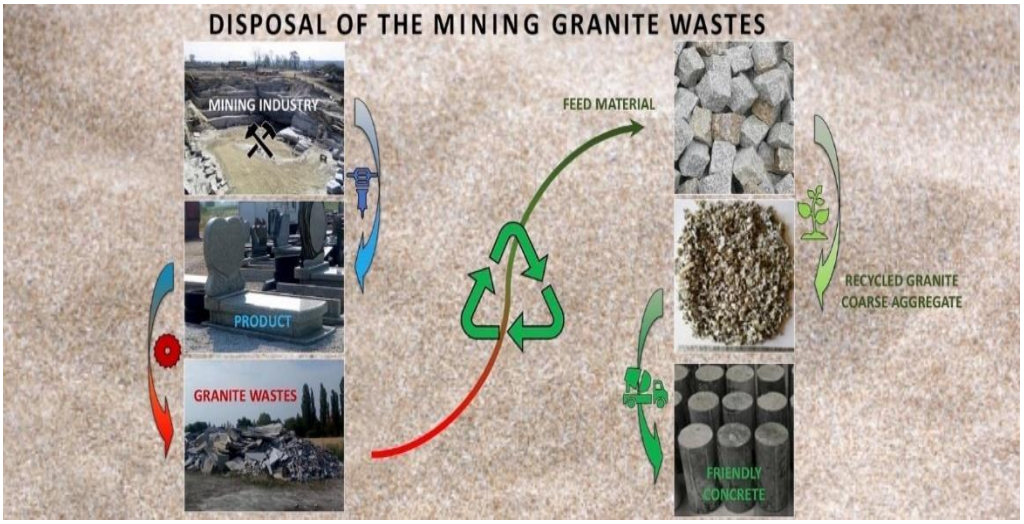


Fig.I.32. Granite wastes.[44]

I.7. Marble

Marble powder is a very fine material produced as a by-product during the sawing and shaping of marble slabs. It is estimated that around a quarter of the weight of marble is turned into powder during the manufacturing process. As this waste accumulates, significant environmental problems arise, unless it is properly used or recycled



Fig.I.33. Marble rock. [45] & [46]

I.7.1. The Filler Effect of Fine Marble Powder in Enhancing Concrete Performance

The use of marble powder in concrete treatments minimizes the environmental problems resulting from the accumulation of marble waste, by making practical use of this waste. It is also an effective way of reducing part of the cost of cement manufacture. In addition, marble powder can improve the strength of concrete or mortar, particularly when used in measured proportions such as 15%,[47] This is a sustainable option, as it minimizes harmful industrial waste and reduces dependence on cement production, which emits large quantities of greenhouse gases. What's more, replacing part of the cement with marble powder improved the internal density of concrete and reduces the total weight of the final product, providing environmental, economic and technical benefits. [48]

Several studies have highlighted the importance of the physical properties of constituent materials in influencing the mechanical performance of cementitious mixtures. In this context, the Alpine white marble powder used in this study has a density of approximately 2.34 g/cm³ and a particle size refined through sieving with a 63-micron mesh, making it a particularly fine material. When compared to Portland cement and standard sand, significant differences in particle size distribution are observed **« see Fig 32 ».** Both marble powder and Portland cement exhibit a finer particle size than standard sand, which enhances the packing density of the mixture by filling voids between coarser particles. This improved particle packing leads to greater cohesion in the cementitious matrix, which can positively influence

the mechanical properties of the resulting concrete. According to several researchers, the incorporation of fine powders contributes to better compaction and microstructural densification, which are critical to improving compressive strength and durability Belachia et al [49]. This phenomenon, often referred to as the "filler effect," emphasizes the role of fine materials like marble powder in reducing porosity and enhancing the overall performance of concrete composites .[49]

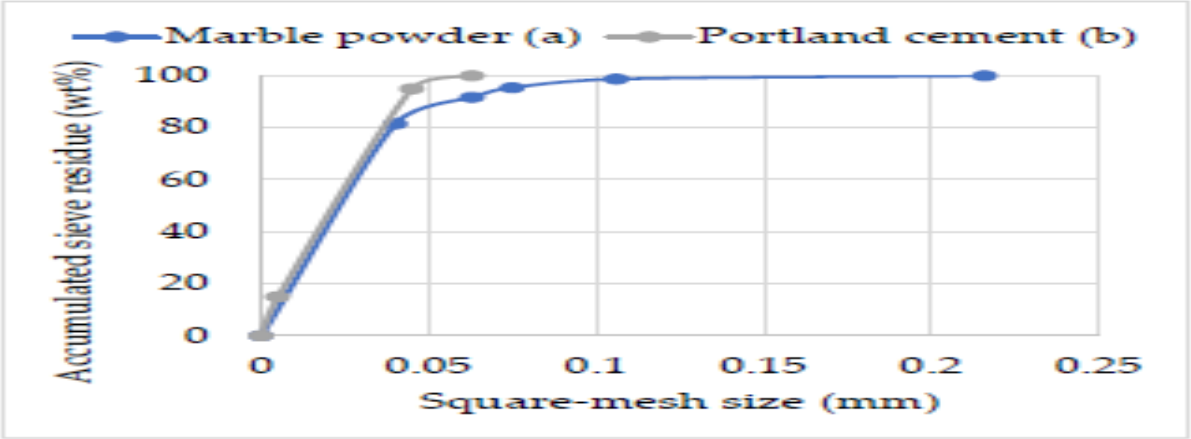


Fig.I.34. Particle-size distribution of (**a**) Marble powder, (**b**) Portland cement.[49]



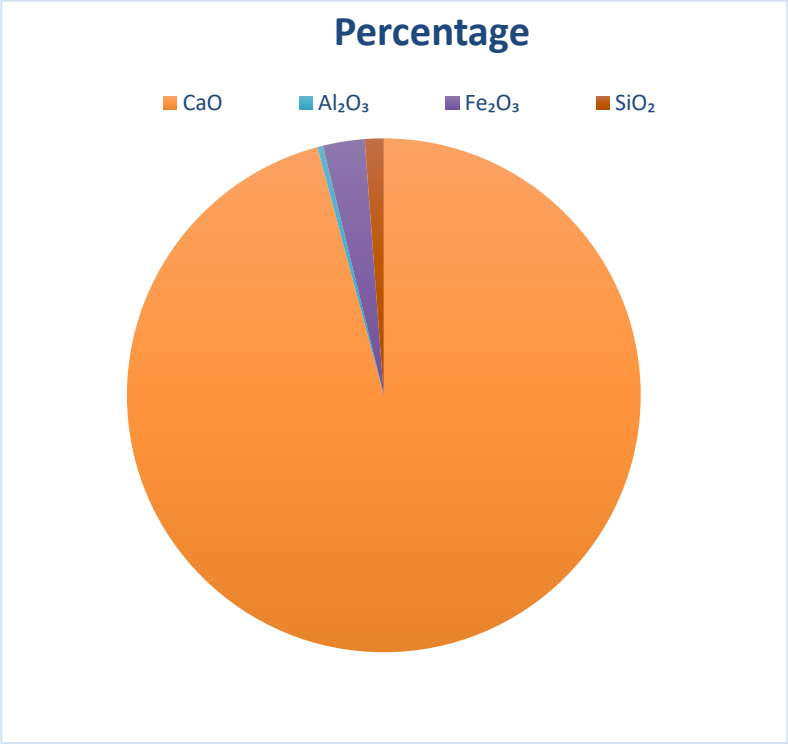
Fig.I.35. Waste Marble Powder (WMP) and its particle shape.[48]

● The oxide contents of marble powders, determined by analyses carried out at the Erciyes University laboratory, are reported in Table.6.

Tab.I.6. The oxide contents of marble powders.[50]

Oxide	Percentage (%)
CaO	53,06
Al_2O_3	0,2
Fe_2O_3	1,45
SiO_2	0,66
MgO	0,45
SO_3	0,24
SrO	0,12
Na_2O	0,09
BaO	0,03
ZnO	0,02

A relativistic circle showing some of the chemical compositions of marble



Tab.I.7. Petrographic, Mineralogical, and Physico-Mechanical Characteristics of Marble Types. [46]

Petrographic Nature	**Micritic limestone**	**Micritic limestone**	**Micritic limestone**
Color	White	Dark grey	Grey with green veins
Appearance	Homogeneous	Non-homogeneous	Non-homogeneous
Texture	Massive	Massive	Massive
Structure	Microcrystalline	Microcrystalline	Microcrystalline
Mineralogical Composition			
Calcite	100%	96%	94%
Quartz	-	3%	3%
Iron oxide	-	0.1%	3%

I.7.2. Experimental Methodology

The curve showed the results of 28-day concrete compression tests with different percentages of replacement of cement with marble dust powder

I.7.2.1. Effect of Marble Dust Powder on Compressive Strength:

Vinodhini Ellappan, V. Amudhan et al [50] determined the compressive strength 28 days after the successful curing process. Due to the low silica oxide content in the marble dust powder, a continuous decrease in compressive strength was observed. This decrease is due to the poor adhesion between the surface of the marble powder and the cement. It was found that the maximum compressive strength is achieved when 20% of the cement is replaced by marble dust powder. When the replacement ratio exceeds this limit, the compressive strength continues to decrease. The results obtained confirm that the optimum replacement ratio of cement with marble dust powder was shown to bethe figure.34

This result was confirmed by SA Abdullah Anwar, S Mohd, A Husain.[50],[51]

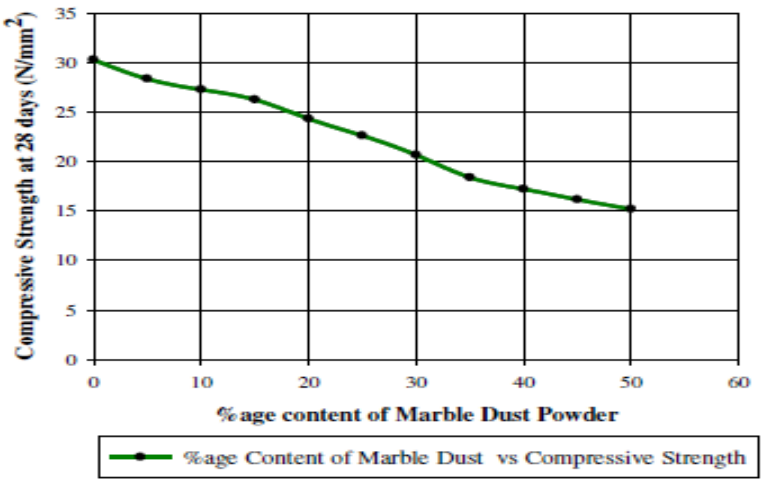


Fig.I.36. Percentage Replacement of Marble Dust Powder vs Compressive Strength (N/mm2) of Concrete for M 20.[50]

I.7.2.2. Ultra-sonic pulse velocity (UPV)

Researchers Esraa M. Auda and Aliabdo et al found the results indicate that the introduction of marble dust had no significant effect on the ultrasonic pulse velocity, which is attributed to the limited relationship between this velocity and compressive strength, since the wave velocity depends on the fourth root of the compressive strength. show the mathematical relationship between compressive strength and wave velocity when marble dust is used as a partial replacement for cement, this relationship being illustrated in Fig **35.** [47]

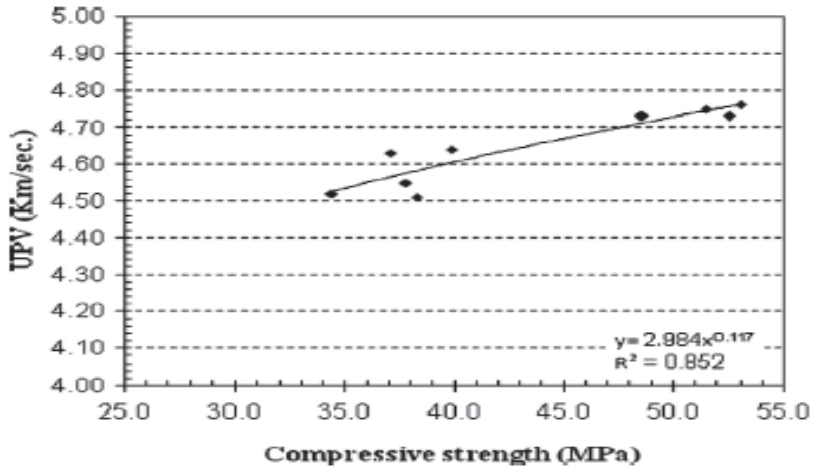


Fig.I.37. Relationship between UPV and cube compressive strength of concrete made with marble dust at 28 days.[47]

I.7.2.3. Porosity:

Researchers Esraa M. Auda and Aliabdo et al found Porosity refers to the voids or pores in concrete, which directly affect its strength and durability. [47]

As shown in figure36, porosity decreases as the proportion of marble dust in the mix increases, particularly at water-cement ratios of 0.50 and 0.40.

This indicates that the use of marble dust can contribute to the reduction of pores in concrete when certain water-cement ratios are respected.[47]

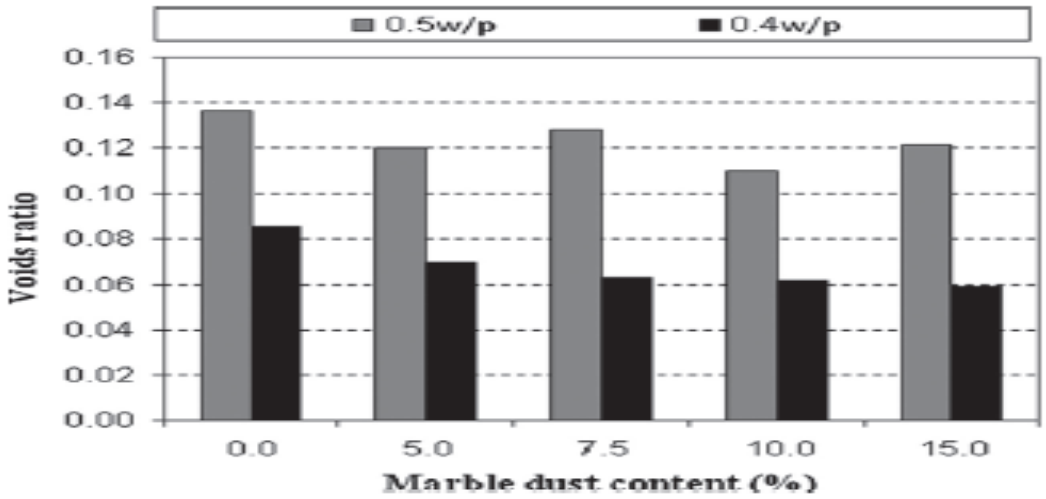


Fig.I.38. Porosity values of concrete made with marble dust.[47]

Improved porosity

The use of marble dust as a partial replacement for sand has improved concrete porosity.

This improvement in porosity is due to the effect of marble dust as a "filler", which fills the voids in the concrete, thus reducing pore size.

This effect has been demonstrated in previous studies by Kristulovic and Demirel Relationship between porosity and compressive strength:

Figure 37 showed the relationship between compressive strength (fc) and porosity (P) of concrete after 56 days.[47] , [49]

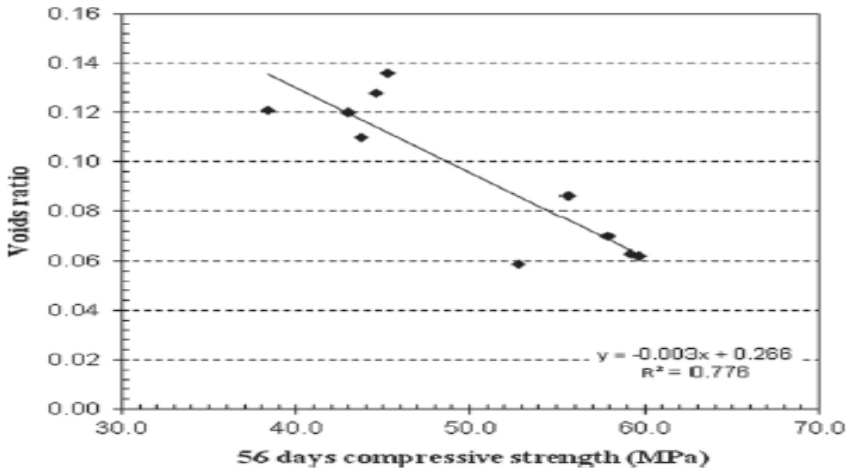


Fig.I.39. Relationship between porosity values and cube compressive strength of concrete made with marble dust at 56 days.[47]

I.7.2.4. Water absorption coefficient

H. Sellaf a. et al[52]. tested the water absorption capacity of mortar according to the type of material used in its composition. Mortar prepared with tuff aggregates and a low percentage of cement (5%), known as mortar mix (MT), showed a higher level of water absorption than mortar in which marble powder was incorporated (MTM). However, the MT samples showed greater susceptibility to the phenomenon of capillary rise, unlike the MTM samples in which the increase in moisture was limited to the lower part of the sample,It is possible that continuous hardening contributed to the reduction in the rate of water absorption, due to the formation of additional moisture-induced wetting products, particularly in the case of marble powder, as these products refill the pores and increase the density of the microstructure, leading to a reduction in the size of voids within the material.[52]

Tab.I.8. The values of the Water absorption coefficient (m^2/s).[52]

Mixture code	**MT**	**MTM 5**	**MTM 10**	**MTM 15**	**MTM 20**
At 28 days $\times 10^{-10}$	12.53	10.15	8.56	6.78	4.46
At 96 days $\times 10^{-10}$	7.23	5.1	3.56	4.28	3.36

I.8. Conclusion

This analysis highlights the need for a deep and comprehensive structural transformation of the Algerian construction sector in light of growing environmental challenges and increasing pressure on limited natural resources. In order to achieve this transformation, an integrated



maximize the efficient use of resources and minimize the environmental impact of construction activities, The efficient management of solid waste from construction and demolition activities is a strategic priority, not only in terms of reducing the environmental and logistical burden caused by the accumulation of this waste, but also by recovering it and transforming it into value-added resources, whether by producing alternative building materials or contributing to the production of renewable energy sources. This approach is an essential pillar in achieving national and international sustainable development objectives, At the same time, the involvement of construction sector organizations is essential to ensure the effectiveness of this transformation. They must adopt sustainable production models, invest in clean technologies and train their human resources in environmental best practices. Establishing a culture of sustainability within these organizations is essential to the success of the transition. In conclusion, adopting a circular economy approach in the construction sector is not an option, but a necessity in view of current and future environmental challenges. This structural change will help preserve natural resources, minimize negative environmental impacts and steer economic growth towards a more sustainable and inclusive path in Algeria.

Chapter II
Materials and methods

Chapter II : Materials and methods

II.1. Introduction

This chapter aims to provide a comprehensive and detailed presentation of the raw materials used in this study, as well as the experimental methodology adopted to prepare and analyses the mixtures. An understanding of the material properties and working techniques is essential to ensure accurate and reliable results. Consequently, this chapter is organized to cover all the necessary aspects of the research.

In the first part, the nature of the main components used in the composition of sandcrete, including the types of cement, sand, aggregates and chemical additives, will be examined. Each of these materials has a specific effect on the physical and mechanical properties of the concrete. Particular attention is paid to the granular distribution of the sand, the nature and shape of the aggregates, and the chemical and physical properties of the different types of cement used. These materials are selected according to strict criteria in order to guarantee the optimum performance of the concrete produced. The second part presents the approach to concrete mix design, which includes determining the appropriate proportions of mix components according to the technical requirements of each application. Mixing steps and sample preparation techniques are explained, with the emphasis on minimizing variations and ensuring repeatability of experiments. The aim is to achieve an optimum balance between the workability of fresh concrete and its mechanical efficiency after hardening. The last part of this chapter presents the experiments carried out to evaluate the properties of mixes in the fresh state and after hardening. For fresh concrete, tests such as the diffusion test were carried out to assess workability and homogeneity. These parameters are essential to ensure ease of pouring and quality of compaction.

II.2. Characterization of the materials used

In this study, raw materials extracted from local sources located in the province of Médéa were used, and these materials were subjected to a rigorous program of characterization tests in the civil engineering laboratory, in accordance with national and international standards adopted in the field of concrete technology.



Fig II.1. Additives to the cement and sand in the mix.

II.2.1. Cement

The cement used is CPJ-CEM II/A (Mâtine), a type of Portland composite cement with a clinker content of between 80% and 94%, with an added mineral component of limestone (Mâline) up to a maximum of 20%. It is produced to approved technical standards such as [NA442] and is known for its good mechanical properties, with a 28-day compressive strength of 42.5 MPa. The introduction of limestone improves the cement's environmental properties by reducing its carbon footprint and the heat generated during the reaction. Its stable chemical composition, summarized in the table, enables it to be used in a variety of conditions requiring reliable, long-lasting performance.

Chemical Analysis of the Cement

Tab.II.1. Chemical analysis of the cement.

Parameter	Values (%)
Loss on ignition (%) (NA 5042)	7.00 – 9.50
Insoluble residues (%) (NA 5042)	1.50 – 3.00
Sulfate content as SO_3 (%) (NA 5042)	2.00 – 2.50
Magnesium oxide content MgO (%)	1.90 – 2.30
Chloride content (%) (NA 5042)	0.01 – 0.03

Hypothetical Composition of Clinker

Tab.II.2. Hypothetical composition of the clinker.

Compound	Values (%)
Tricalcium silicates C_3S	58.00 – 64.00
Tricalcium aluminates C_3A	6.00 – 8.00



Fig.II.2. Cement used (Appendix A).

II.2.2. Aggregate

II.2.2.1. Sand

We used Wad Suf sand because it has a number of characteristics, including:

Tab.II.3. Physical Properties of the Sand Used.

Characteristic	**Sand**
Source	Oued Saouf
Grain size class	0/3
Fineness modulus	1,85
Absolute density (g/cm³)	2.63
Bulk density (g/cm³)	1.18
Sand equivalent (%)	81
Water absorption rate (%)	0.96
Compacity (%)	50
Porosity (%)	50



Fig.II.3. Sand of Oued Sauf.

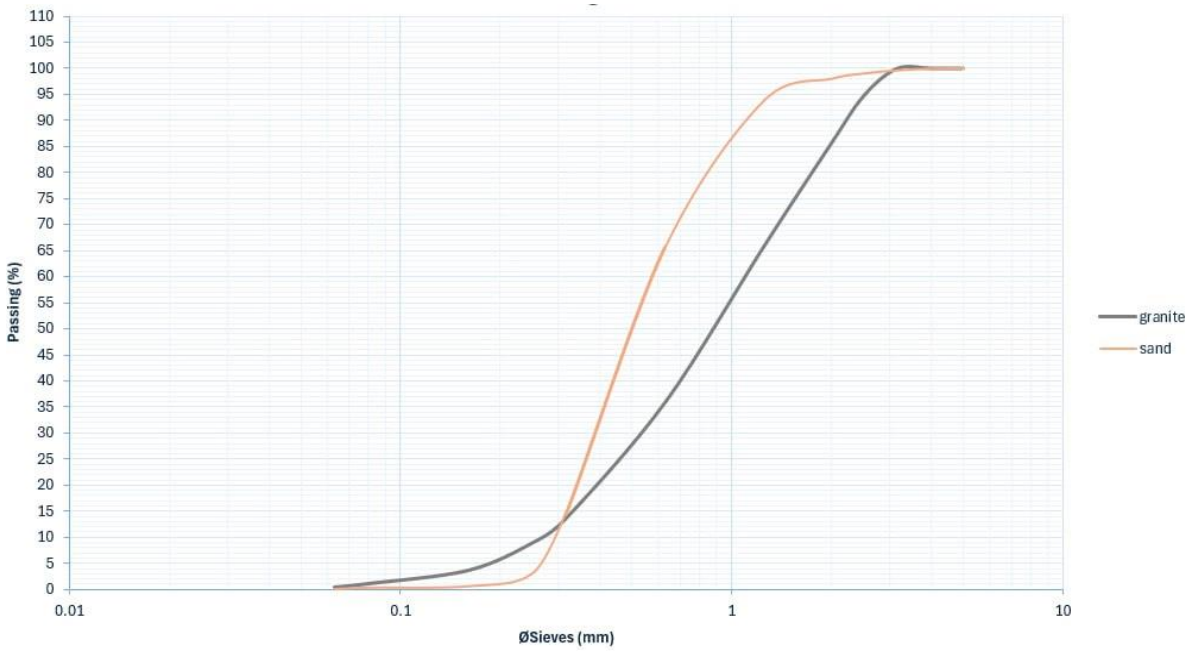


Fig.II.4. Grading curve for sand used.

II.2.2.2. Granite Sand

The granite used in this work comes from granite industry waste, which is collected and crushed for use as an alternative to conventional sand in the production of liquid concrete. The granules obtained are between 0 and 3 mm in size, corresponding to the granularity of sand (0/3).



Fig.II.5. Granite sand preparation.

The granular properties of the granitic waste adopted in this study are presented in Figure 4, which shows the particle size distribution. In addition, Table II.3 provides a summary of the most important physical properties of granitic sand, including density, smoothing modulus and volumetric classification, which are key parameters for assessing the behavior of this material in different applications.

Tab.II.4. Physical Properties of Granite Sand.

Property	Granite Sand
Granular class	0/3
Fineness modulus	2.8
Absolute density (g/cm³)	2.52
Apparent density (g/cm³)	1.8
Water absorption rate (%)	0.9
Compactness (%)	47.01
Porosity (%)	52.99

II.2.2.3. Ceramic Powder

In this research, ceramic waste from the manufacturing processes of a ceramic materials production unit is used as an alternative source to conventional sand. After collection, the waste is subjected to a fine mechanical grinding process using specialized equipment, with the aim of transforming it into a powder that can be incorporated into concrete mixes, particularly in the production of fluid concrete. The resulting material has a specific surface area (fineness) of 3400 cm²/g, which makes it suitable for enhancing the performance of cementitious mixtures. Figure II.6 illustrates the various stages in the preparation of ceramic sand, from raw waste through the grinding stage to the final product.



Fig.II.6. Ceramic sand preparation.

II.2.2.4. Shell Powder

The waste seashells used in this study were collected from local beaches and underwent a thorough cleaning process consisting of several cycles of washing to remove impurities and contaminants. After cleaning, the shells were first dried at a constant temperature of 200 °C in a laboratory oven to eliminate moisture. They were then mechanically ground using a Los Angeles abrasion machine at 3000 rpm to reduce particle size. Subsequently, a heat treatment at 650 °C was applied to modify their physical and chemical properties. Finally, the resulting material was sieved through a 0.65 micrometer mesh, yielding a highly fine powder with a specific surface area (fineness) of 2900 cm^2/g, making it suitable for use as a partial cement replacement in concrete mixtures.

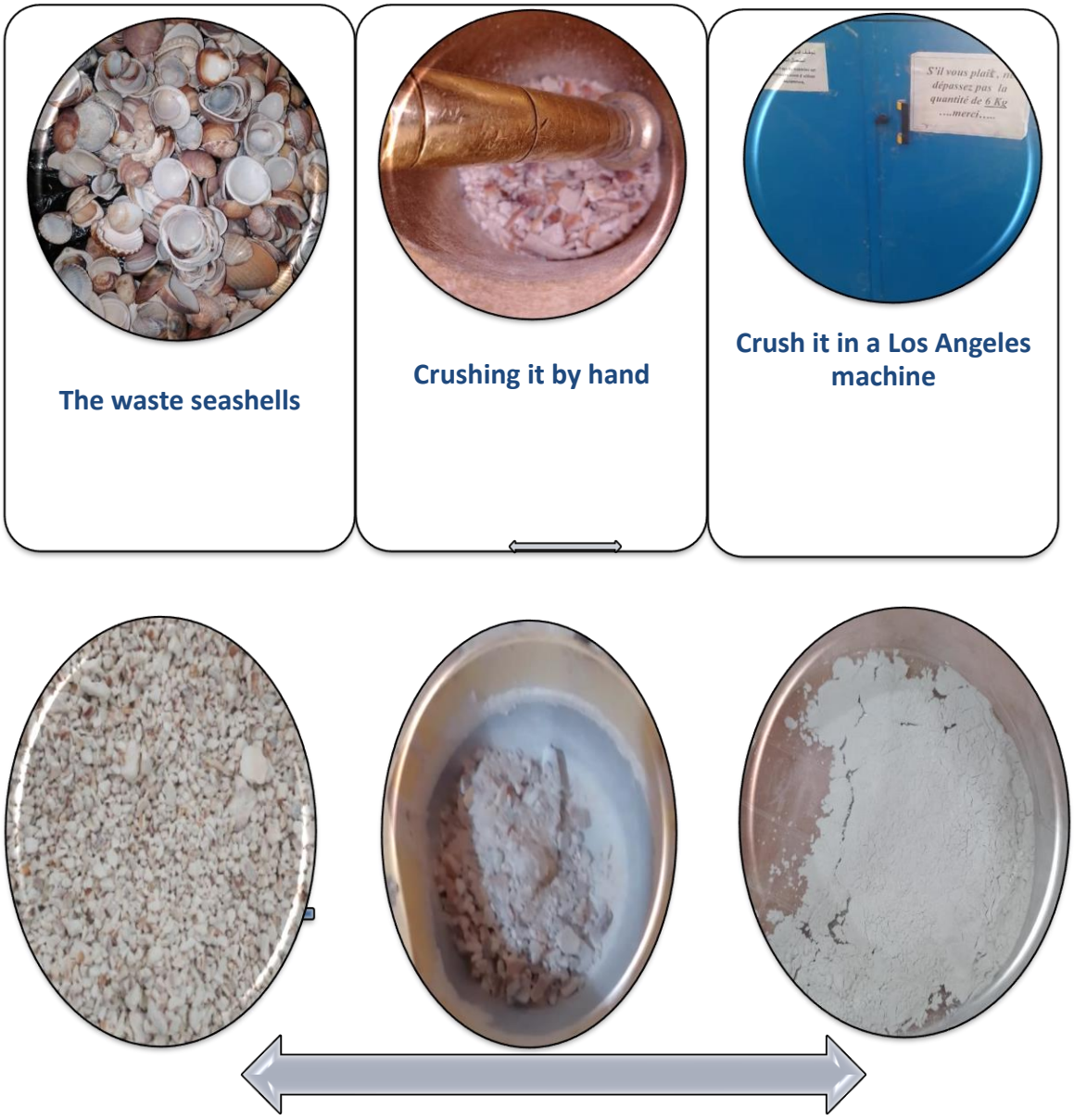




Fig.II.7. Shell Powder preparation.

II.2.3. Marble powder

To obtain marble powder from marble cutting and polishing workshops, the waste is collected, crushed, and ground to a high fineness. The powder is used after it reaches a fineness of approximately 3000 cm^2/g, reflecting the large specific surface area of its fine grains, making it suitable for many applications in construction and composite materials.

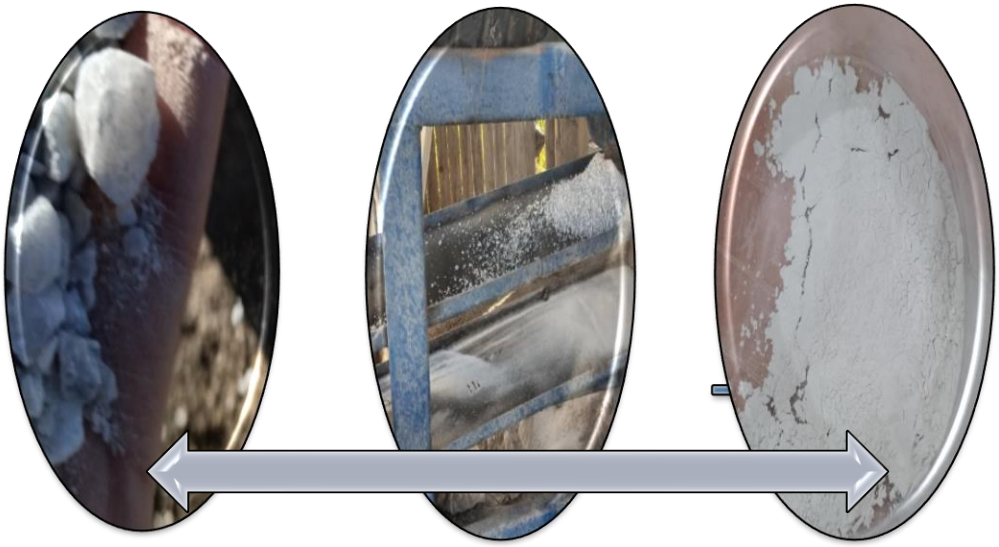


Fig.II.8. Preparation of marble powder.

II.2.4. Mixing water

The mixing water used to make the concrete is tap water, considered to be potable, free of any impurities harmful to concrete and in compliance with standard NF EN 1008. Its temperature is between 18 and 20°C.

II.2.5 Superplasticizer

To ensure satisfactory workability, we used a polyether carboxylate-based Superplasticizer - High Water Reducer formulated on the basis of a combined synthetic polymer marketed by SikaCem under the name "**tempo 10**". See the technical data sheet in < appendix B> for more details on this admixture.



Fig.II.9. Superplasticizer tempo 10.

Tab.II.5. SikaCem®-100 MP - Technical Data Summary.

Item	Description
Product Name	SikaCem®-100 MP
Physical State	Liquid
Color	Brown
Density	Approx. 1.01 kg/L at 25°C
pH Value	Not specified
Chemical Composition	Blend of organic compounds
Chloride-Free	Yes (complies with EN 934-2)
Packaging	20 L and 200 L containers
Shelf Life	12 months from production date
Storage Conditions	+5°C to +45°C, away from direct sunlight and frost
Advantages	Improves workability, reduces shrinkage, increases durability, minimizes bleeding
Standards	Complies with BS EN 934-3
Applications	Mortar additive for performance enhancement

II.3. Composition of Flowable Sand Concrete

The aim of this formulation was to determine the amount needed for each of the mix materials, in order to obtain a liquid sandy concrete (FSC) with desirable properties.

Our study focuses on the effect of adding snail, granite, marble, and ceramic wastes, taken in different forms (SQ, SG, SM, and SC), on the soft and hardened properties of BSF.

To determine the quantities of materials: Sand, cement, filler, water, and admixtures, we relied on the ratio:

The ratio of water to cement + filler (E/C+F) = 0.38

Our study focuses on the effect of partial volumetric replacement of cement (0%, 5%, 10%, 15% and 20%) on the properties of liquid sand concrete (FSC) in its fresh and hardened states

The different compositions are shown in the following table:

Tab.II.6. Components of concretes formulated from waste shells, granite, glass and ceramics.

Mix	Cement (kg/m³)	Sand (kg/m³)	Water (l/m³)	Filler (kg/m³)	SSP	Ceramic powder	SP (%)
FSCC	400	1400	228	200	0	0	0.8
FSC1	381,29	1064,64	228	200	18,71	0	0.8
FSC2	362,58	1064,64	228	200	37,42	0	0.75
FSC3	343,87	1064,64	228	200	56,13	0	0.7
FSC4	383,87	1064,64	228	200	0	16,13	0.8
FSC5	367,74	1064,64	228	200	0	32,26	0.85
FSC6	351,61	1064,64	228	200	0	48,39	0,9
FSC7	365,16	1064,64	228	200	18,71	16,13	0.8
FSC8	330,32	1064,64	228	200	37,42	32,26	0.8
FSC9	295,48	1064,64	228	200	56,13	48,39	0.8
FSC10	365,16	1400	228	200	18,71	16,13	0.8
FSC11	330,32	1400	228	200	37,42	32,26	0,8
FSC12	295,48	1400	228	200	56,13	48,39	0,8

FSCC: Flowable Sand Concrete.

FSCC$_1$: Flowable sand concrete based on 5%sea-shell waste + 25%granite waste.

FSCC$_2$: Flowable sand concrete based on 10%sea-shell waste + 25%granite waste.

FSCC$_3$: Flowable sand concrete based on 15%sea-shell waste + 25%granite waste.

FSCC$_4$: Flowable sand concrete based on 5% ceramics waste+0% sea-shell waste + 25%granite waste.

FSCC$_5$: Flowable sand concrete based on 10% ceramics waste+0% sea-shell waste + 25%granite waste.

$FSCC_6$: Flowable sand concrete based on 15% ceramics waste +0% sea-shell waste +25%granite waste.

$FSCC_7$: Flowable sand concrete based on 5% ceramics waste +5% sea-shell waste +25%granite waste.

$FSCC_8$: Flowable sand concrete based on 10% ceramics waste +10% sea-shell waste +25%granite waste.

$FSCC_9$: Flowable sand concrete based on 15% ceramics waste +15% sea-shell waste +25%granite waste.

$FSCC_{10}$: Flowable sand concrete based on 5% ceramics waste +5% sea-shell waste +0%granite waste.

$FSCC_{11}$: Flowable sand concrete based on 10% ceramics waste +10% sea-shell waste +0%granite waste.

$FSCC_{12}$: Flowable sand concrete based on 15% ceramics waste +15% sea-shell waste +0%granite waste.

SSP: sea-shell powder **CP:** ceramic powder **GS**: granite sand.

II.4. Concrete mixing sequence

The mixing method and the composition of the concrete ingredients are key factors that directly affect the quality of the hydration process, which contributes to a concrete with good performance and a long shelf life.

The concrete mixes were prepared using a 5-liter mixer.

Depending on the desired properties and the ingredients used, different mixing sequences can be followed, as reported in several previous studies.

The following sequence was adopted in the mixing process:

1. Dry mixing: Cement, sand, marble powder, seashell waste, granite, glass, and ceramic are mixed dry for 30 seconds using a mixer.
2. Add initial water: Add the first amount of water (w1 = 70% of total water) and continue mixing for 1 minute.
3. Add the remaining water with the plasticizer: Add the remaining water (w2 = 30%) mixed with the superplasticizer and mix for one minute.
4. Rest period: Allow the mixture to rest for 3 minutes.
5. Final mixing: Re-mix the mixture for an additional 1 minute.

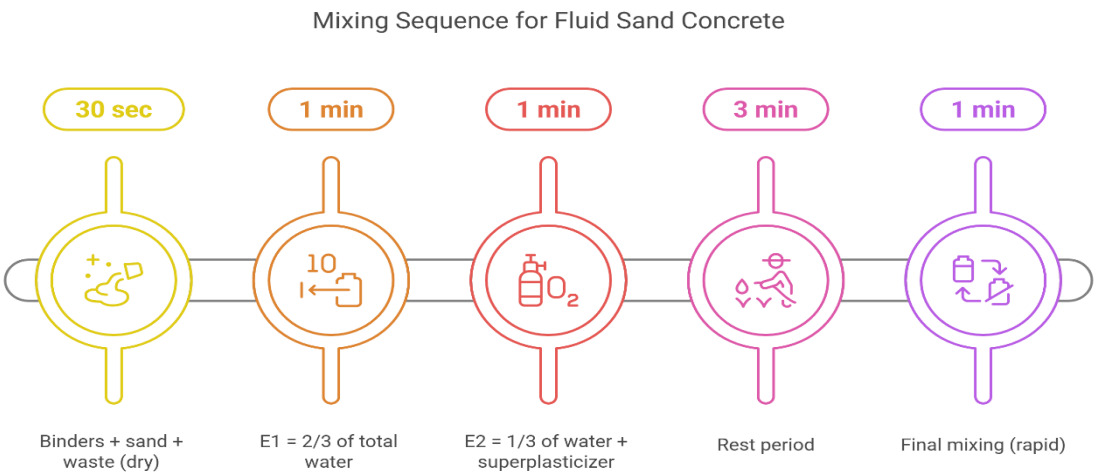


Fig.II.10. Mixing sequence for Flowable sand concrete.

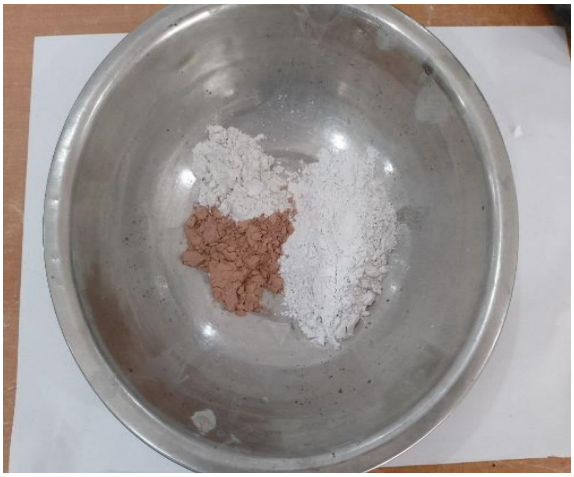












Fig.II.11. Mixing protocol

II.5. Tests carried out on different blends (FSC)

II.5.1 Fresh state

II.5.1.1. Mini cone spreading

The spreading test consists in filling a truncated cone-shaped mold placed on a smooth horizontal surface. Once the mold has been lifted, the spreading diameter of the mortar is measured in two perpendicular directions, and the average is taken. Figure 12 shows the steps involved in the mini cone spread test in accordance with NF EN 12350-8.



Fig.II.12. Stages of the spreading test.

II.5.2. Specimen preparation and storage

The various types of fluid sand concrete are all manufactured in the laboratory environment. The fluid sand concrete was poured into metal molds of prismatic shape 4x4x16cm intended for compression tests in accordance with standard NFEN12390-2.

Keeping the concrete specimens in water, also known as curing, is a crucial step in ensuring optimum development of the concrete's mechanical properties. After demolding, the specimens are immersed in a water bath at a controlled temperature, generally around 20°C. This immersion prevents loss of moisture from the concrete, ensuring continuous hydration of the cement. Curing in water promotes hardening and improves concrete strength, minimizing the risk of cracking and shrinkage. This method is maintained for a specific period, often 28 days, to ensure that the concrete achieves its maximum performance.



Fig.II.13. Preparation and storage of specimens.

II.5.3. Hardened state

II.5.3.1. Compression testing

The compressive strength was determined according to [NF EN 196-1] by axial compression testing on prismatic half-models with dimensions 4x4x4x16 cm. These tests were carried out at 7 and 28 days using a hydraulic press with a maximum capacity of 2000 kN, conforming to [NF P 18-412].

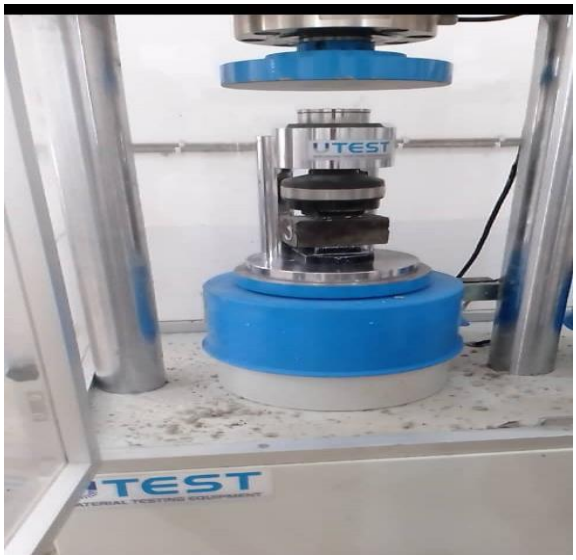




Fig.II.14. Device for measuring compressive strength.

The compressive strength is determined using the following formula:

Rc = $\frac{F_c}{b^2}$**……. (Equation II.1)**

Where:

Rc: Compressive strength (in MPa)

Fc: Failure load (in Newtons, N)

b: Side length of the specimen (in mm), here it is given as 40 mm

II.5.3.2. Bending test

According to [EN 196-1], specimens are subjected to a bending resistance test at the specified age, which is one of the most widely used methods for evaluating material properties. A prismatic specimen with dimensions (4 x 4 x 4 x 16) cm is loaded using a three-point bending technique until it is broken into two parts, allowing the behavior of the material under bending stress to be determined.



Fig.II.15. Device for measuring tensile strength.

II.5.3.3. Ultrasonic test

Before proceeding with the ultrasonic tests, the accuracy of the instrument's performance was confirmed by calibrating it with a customized calibration rod for each sample. These tests were conducted using the direct transmission method, where the wave was directed perpendicular to the direction of sample fabrication. The transducers (transmitter and receiver) were placed on opposite sides of the sample, and a thin layer of Vaseline was used to optimize the contact between the surface and the transducers. The transit time of the wave inside the sample was then recorded in microseconds**. Figure 16** shows the various stages of this test, which was carried out in accordance with the requirements of NF EN 12504-4.



Fig.II.16. Calibration and measurement of ultrasonic wave travel time.

II.5.3.4. Porosity accessible to water

The open porosity of water in concrete is evaluated using the hydrostatic weighing method, according to the procedure approved by AFPC-AFREM [AFPC, 1997]. Concrete specimens are prepared and placed in a vacuum for 4 hours, then immersed under vacuum for 24 hours to be completely saturated with water. The sample is then weighed under water to determine the saturated mass (Meau), then its surface is dried and weighed in air to determine the surface saturated mass (Mair).

Finally, it is dried in an oven until it reaches dry mass (Msec).

The porosity open to water is calculated using the following equation:

$$\varepsilon\,\% = \frac{(M_{air} - M_{sec})}{(M_{air} - M_{eau})} \times 100$$

Where:

- **M air**: Mass of the sample saturated in air (g)

- **Msec:** Dry mass of the sample after oven drying (g)
- **Meau:** Mass of the sample measured under water (g)
- **ε:** Water-accessible porosity in %.



Fig.II.17. Water-accessible porosity test.

II.5.2.5 Capillary Absorption Test

The capillary absorption test aims to evaluate the ability of a hardened mortar to absorb water through the capillary property, which helps determine its porosity and permeability. In this experiment, barrel-shaped samples of mortar are dried to a constant mass, and then one face is immersed in water between 5 and 10 mm deep, under normal atmospheric pressure. The increase in mass is recorded at specific time intervals, and the capillary absorption coefficient, which reflects the speed at which water seeps into the material through its pores, is calculated. A high coefficient indicates high porosity, making the material more susceptible to moisture intrusion and deterioration over time.

This type of test is described in the European standard EN 1015-18, which specifies the method for measuring the capillary absorption coefficient in hardened mortars [EN 1015-18, CEN, 2002].



Fig.II.18. Capillary Absorption Test.

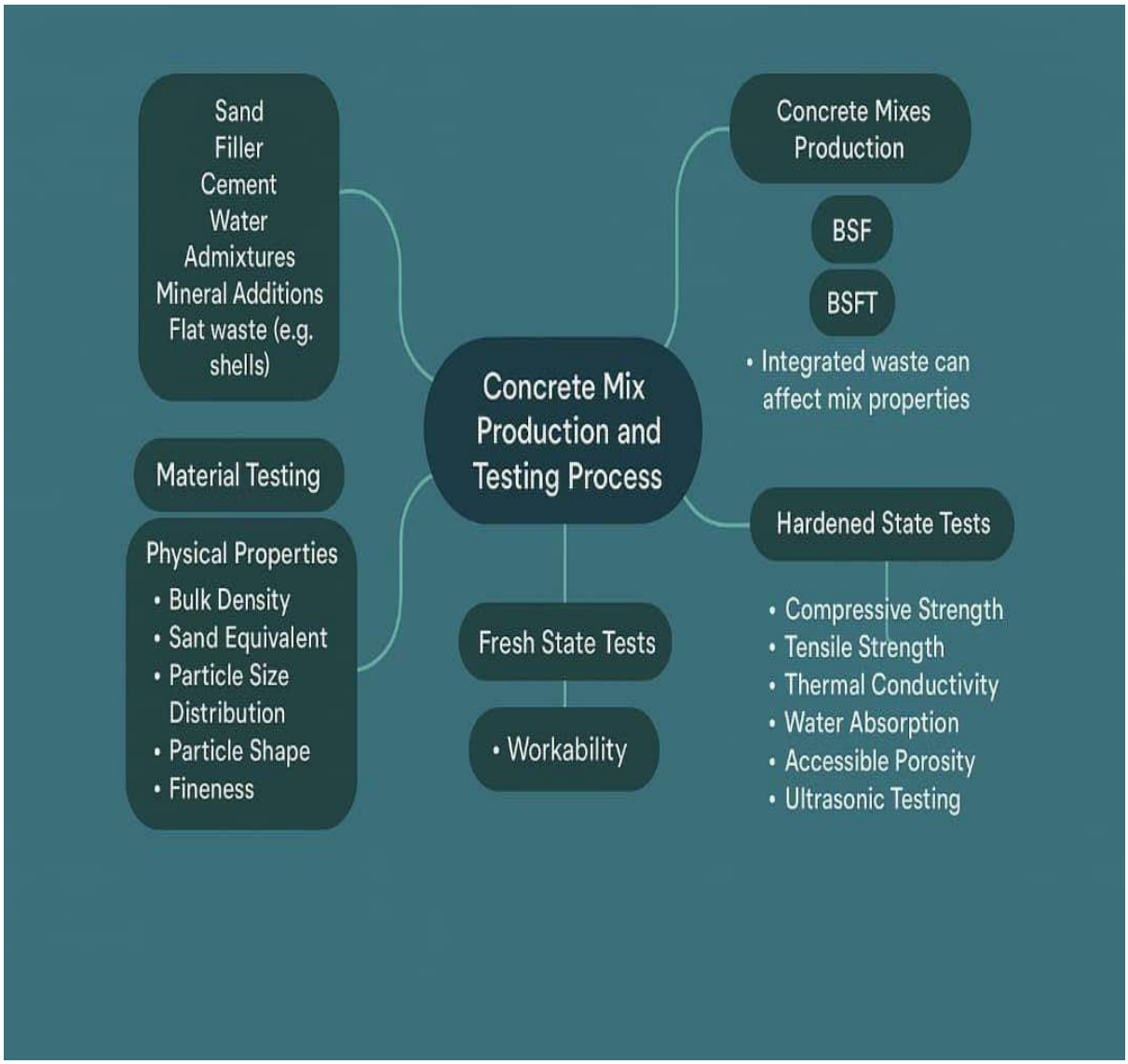


Fig.II.19. Experimental protocol.

II.6. Conclusion

Through this study, we used local materials available in the Algerian market such as cement, natural aggregates, and superplasticizers, with the aim of developing sandy concrete mixtures with good workability. This choice was driven by the need for practical and efficient solutions that take into account local potential and respond to the cost and performance requirements of the construction sector in Algeria.

A series of laboratory experiments were carried out to evaluate the rheological and physicomechanical properties of these mixtures, in order to understand their behavior and suitability for use in different applications. These experiments included measurements of density, permeable porosity, and water absorption rate upon immersion, as well as mechanical strength tests such as compressive and tensile strength.

The results yielded accurate data to analyze the performance of the prepared concrete mixtures, especially in terms of their ability to strike a balance between the fluidity required at the casting stage and the strength required after hardening. The incorporation of waste or alternative materials into these mixtures showed a promising potential to produce concrete with good performance, while minimizing the environmental and economic impact

Based on this information, the use of local and recycled materials in the manufacture of pumpable sand concrete is a viable option and represents an important step towards the development of sustainable and innovative construction solutions adapted to the local context.

Chapter III
Results and Interpretation

Chapter III: Results and interpretation

III.1. introduction

III.1.1. Impact of Solid Waste on the Properties of Concrete

This chapter presents and analyzes the experimental results obtained to assess the effects of incorporating industrial waste (granite, ceramic, and marble) and bio-based materials (seashells) into flowable sand concrete (FSC). The study focuses on evaluating the mechanical and rheological behavior of FSC produced with locally available materials. Results are organized based on concrete age, test type, and the specific mix examined, ensuring clarity and ease of interpretation. The subsequent discussion aims to provide insights into the technical and environmental benefits of using recycled and natural waste materials in concrete production. Beyond evaluating their performance, the chapter explores opportunities for optimizing FSC formulations to enhance both durability and sustainability in construction applications.

III.1.1.1Fresh properties of concrete

a) <u>Slump flow</u>

In this section, we present and analyze the flow spread graph, which highlights the variations in the workability of fluid sand concrete (FSC) depending on the different types of waste materials incorporated into the mix. This graph is essential for assessing how the inclusion of industrial and bio-based waste influences the rheological behavior and ease of placement of the conditions. Concrete, thereby facilitating an evaluation of its suitability for real construction sites.

The analysis of slump flow reveals the distinct influence of the incorporated waste materials on the workability of fluid sand concrete (FSC), with a constant superplasticizer dosage of 0.8%. The reference mix (FSCC) exhibited a flow diameter of 280 mm, serving as a baseline for comparison. The addition of seashell powder (SSP) progressively enhanced the flowability, with an increase of 3.6% at 10% SSP (290 mm), reaching a 7.1% improvement at 15% SSP (300 mm). This enhancement is likely due to the fine particle size and lubricating effect of the seashell powder and also could be due, as Bassam et al [53]. suggest, to the slower hydration kinetics of shellfish, which delays the stiffening of the mixture. In contrast, the inclusion of ceramic powder (CP) reduced the flowability, with a decrease of 3.6% at 10% CP (270 mm) and 7.1% at 15% CP (260 mm), This may be attributed to the rough texture and porous nature of ceramic particles, as well as their lower angularity and larger
particle size, as also suggested by Li et al. [54].

When a balanced mixture of SSP and CP was used (in equal proportions), the effects of the two materials appeared to offset each other, as the slump remained constant at 280 mm regardless of the total substitution level (5%, 10%, or 15%). These results highlight that the type of waste used has a significant impact on the rheological behavior of FSC, and that carefully selected combinations can help maintain good flowability even when incorporating alternative materials.

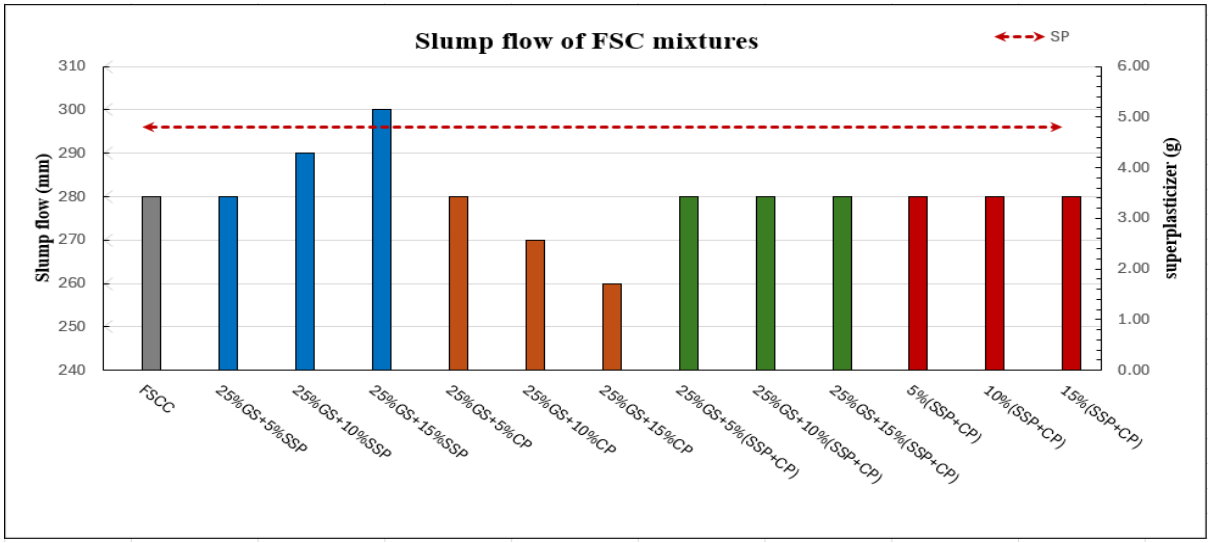


Fig.III.10. Influence of waste materials on the flowability of FSC with a superplasticizer dosage of 0.8%.

- ✓ These variations in flow spread, despite a constant superplasticizer dosage, highlight the importance of understanding the specific influence of waste materials on concrete properties. Optimizing fluid sand concrete formulations for real construction site applications requires careful attention to flowability and ease of placement, which are essential for achieving optimal performance.
- ✓ To achieve a consistent and optimal spread for each type of concrete, it may be necessary to **adjust** the superplasticizer dosage depending on the specific requirements of each mix. The graph below illustrates this need and shows how dosage variations can help maintain constant flowability.

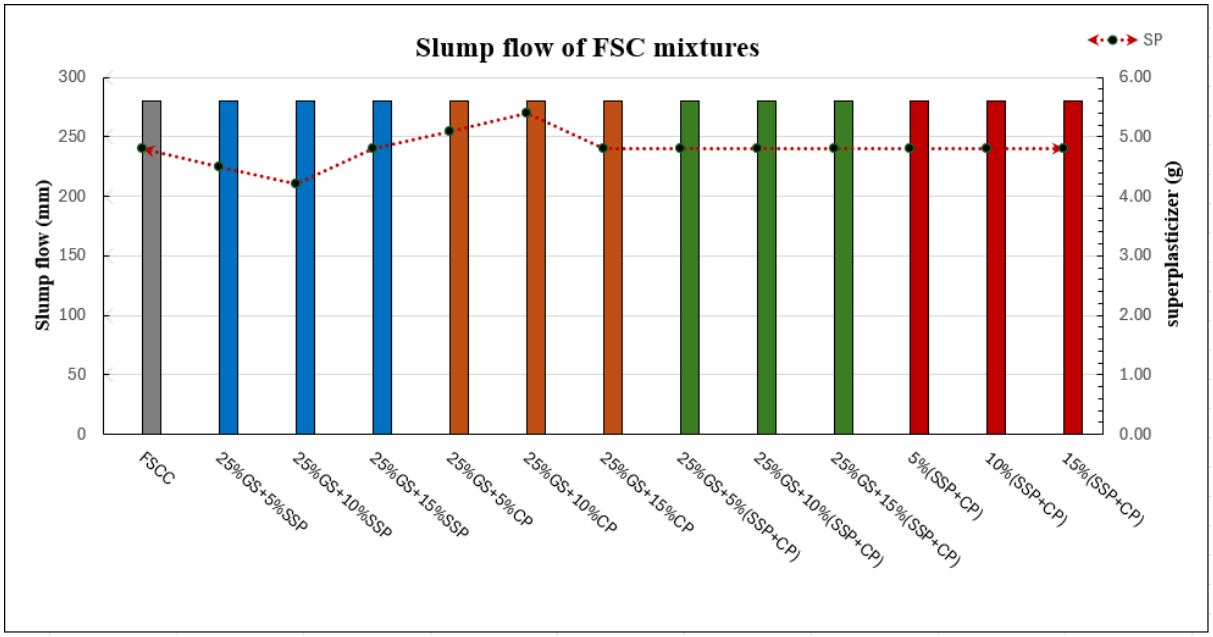


Fig.III.11. Superplasticizer Dosage for Various Concrete Mixes.

III.1.1.2. Hardened State

b) <u>Compressive strength</u>

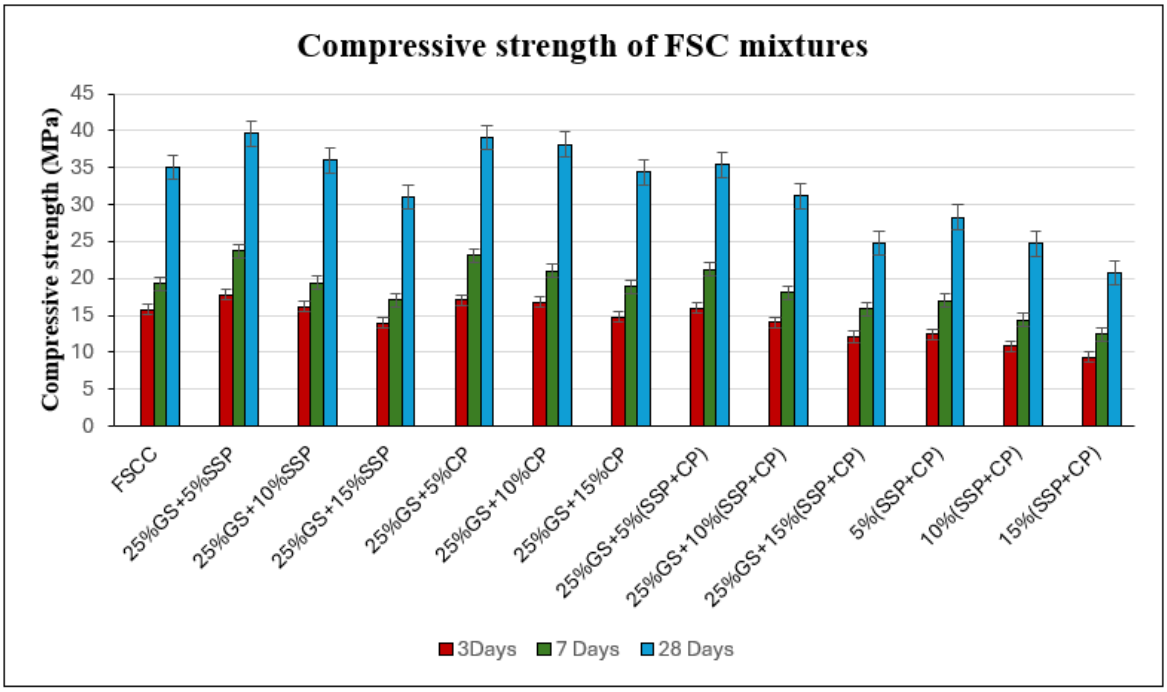


Fig.III.12. Compressive strength of FSC mixtures.

The compressive strength results at 3, 7, and 28 days show distinct trends depending on the type and proportion of waste materials added. At 28 days, replacing part of the mix with 5% seashell powder (SSP) or ceramic powder (CP) led to an increase of approximately 13% and 11%, respectively, compared to the reference mix. Using 10% SSP or CP still

resulted in gains, though more moderate, in the range of 2% to 9%. In contrast, incorporating 15% SSP or CP caused a drop in strength of about 11–12%, indicating a potential threshold beyond which mechanical performance declines. For ternary combinations of SSP and CP with granite sand (GS), the addition of 5% maintained strength at a level similar to the control, but increasing the proportion to 10% or 15% led to decreases of approximately 11% and 29%, respectively. Blends containing only SSP+CP (without GS) showed even sharper reductions, with strength decreasing by 19% at 5% substitution, and up to 41% at 15. These findings indicate that low replacement levels of industrial or biosourced waste can enhance or at least maintain the compressive strength of concrete. In contrast, higher replacement percentages generally lead to a reduction in strength, likely due to increased porosity, dilution of the cementitious matrix, or weakened interfacial bonding. In particular, a 5% replacement with seashells was found to be the most beneficial for improving compressive strength. Similarly [53], Alotaibi et al.[55] reported that the incorporation of 5% ceramic powder led to a 12.5% increase in compressive strength compared to the control mix, while higher dosages caused a gradual decline in performance.

c) Flexural strength

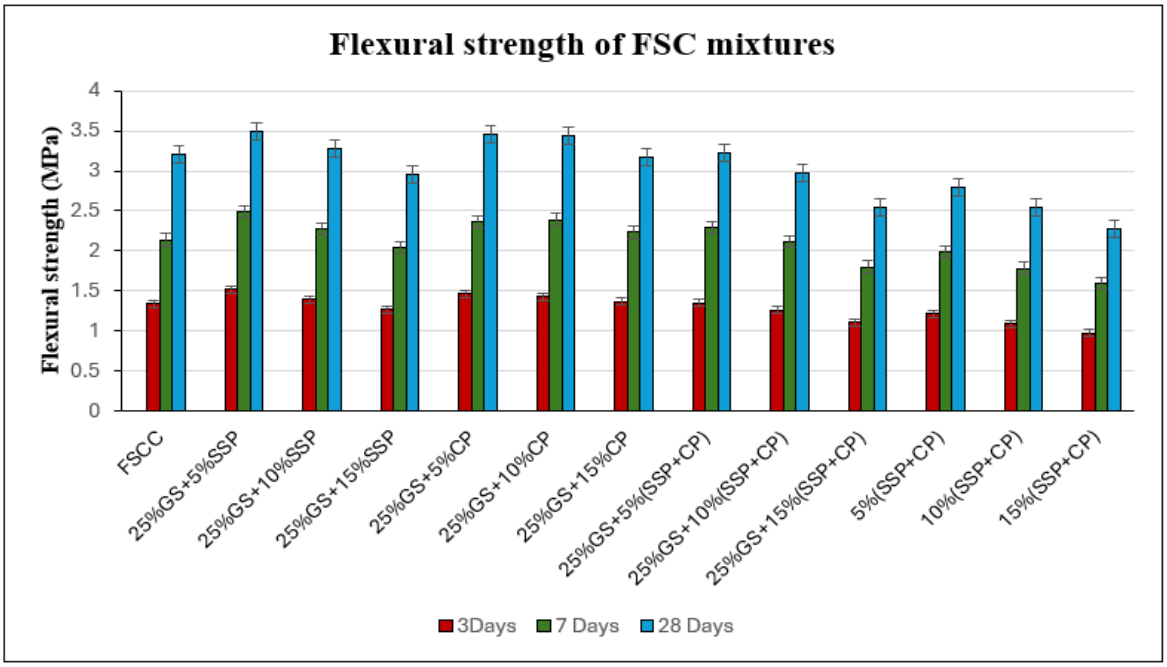


Fig.III.13. Flexural strength of FSC mixtures.

Flexural strength results at 3, 7, and 28 days indicate that incorporating small amounts of SSP or CP enhances performance relative to the control. At 28 days, the addition of 5% SSP or CP led to increases of approximately 9% and 7.5%, respectively. A 10% substitution maintained or slightly improved the performance, with gains up to 1.8%, while 15% additions resulted in

reductions of about 8%.

In ternary blends (GS + SSP + CP), a 5% replacement produced a flexural strength similar to the reference mix, while 10% and 15% substitutions led to decreases of approximately 7% and 21%, respectively. For binary SSP+CP blends (without GS), flexural strength dropped progressively with higher substitution rates around 13% lower at 5%, 21% at 10%, and up to 29% lower at 15%. These results confirm that low waste content can enhance or preserve flexural strength, but excessive amounts impair mechanical performance, likely due to poor particle packing or increased microstructural porosity.

a) <u>Density</u>

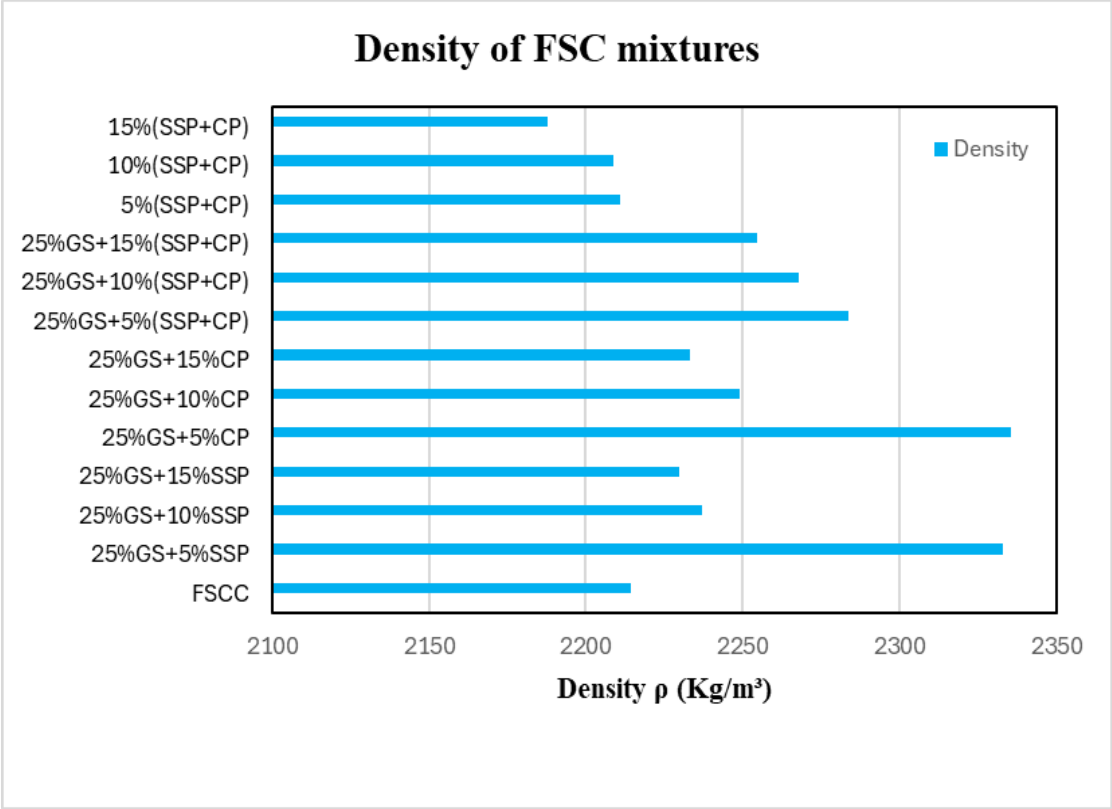


Fig.III.14. Density of FSC mixtures.

The analysis reveals that most concrete mixes incorporating granite sand (GS) in combination with shell powder (SSP) or ceramic powder (CP) exhibit higher densities compared to the reference mix (FSCC). The most notable increases were observed in the mixes with 25%GS+5%SSP and 25%GS+5%CP, which achieved density gains of approximately 5.4% and 5.5%, respectively. Mixes containing higher percentages of SSP or CP (10% and 15%) still demonstrated positive density variations, though more moderate, ranging from 1.0% to 2.9%.In ternary blends that combine GS with both SSP and CP, the density improved by 2.0% to 3.1%, indicating that the interaction between angular GS particles and fine powders enhances particle packing and minimizes voids. Conversely, binary mixes incorporating only SSP and CP, without GS, showed a slight decline in density at higher replacement levels. At 15% (SSP+CP), the density was approximately 1.2% lower than FSCC. This suggests that granite sand plays a key role in densifying the hardened matrix, while an excess of fine powders alone can reduce compaction efficiency due to insufficient granular skeleton support.

e) Modulus of elasticity

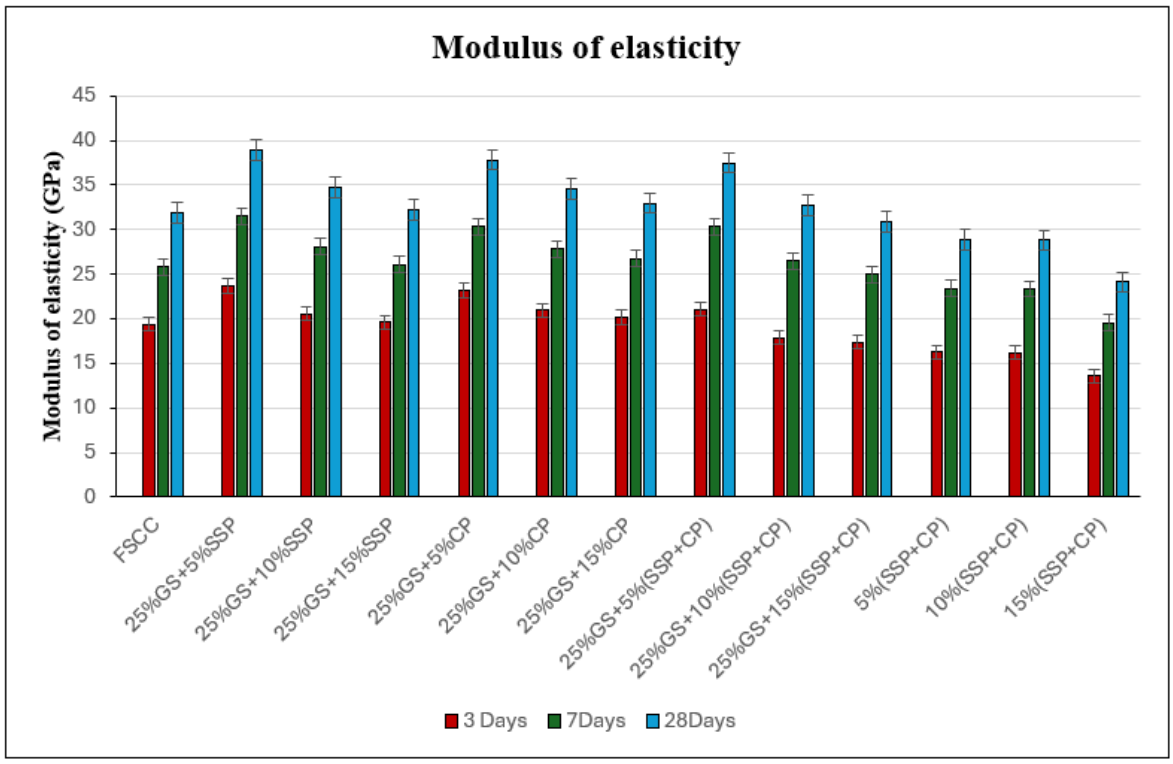


Fig.III.15. Modulus of elasticity of FSC mixtures.

The results indicate that the incorporation of 25% granite sand (GS) with 5% shell powder (SSP) or 5% ceramic powder (CP) leads to a notable enhancement in the modulus of elasticity compared to the FSCC reference mix across all ages. At 3 days, the 25%GS+5%SSP mix

exhibited an increase of approximately +22%, and 25%GS+5%CP showed a gain of +19.4%. At 7 days, these same mixes improved the modulus by +22% and +17.3%, respectively. By 28 days, the 25%GS+5%SSP mix again achieved the highest improvement (+22% over FSCC), followed by 25%GS+5%CP with a gain of about +18.5%. Other mixes containing 10–15% SSP or CP presented moderate improvements, generally ranging from +7% to +13%.

However, when only SSP and CP were used (without granite sand), especially at 15% replacement, the modulus of elasticity decreased significantly: the 15%(SSP+CP) mix dropped by approximately −24% compared to FSCC at 28 days. These findings suggest that the angularity of GS, combined with a limited amount of fine waste material, contributes to a denser microstructure and stronger interfacial transition zone (ITZ), leading to a higher elastic modulus. Excessive use of only fine powders appears to reduce stiffness due to increased porosity and weaker matrix connectivity.

f)Ultrasonic pulse velocity (UPV)

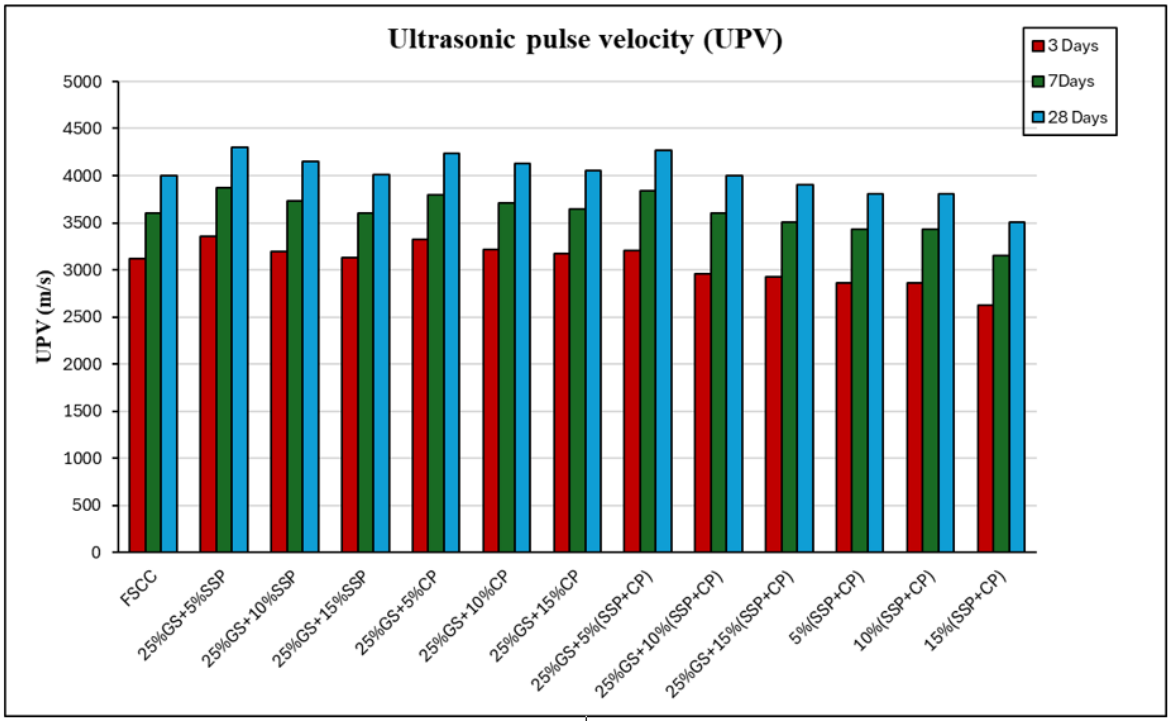


Fig III.16: UPV of FSC mixtures.

The UPV results showed a consistent trend across all mixes. Mixes incorporating 25% granite sand (GS) with 5% SSP or CP demonstrated the highest pulse velocities, with improvements of up to +6% compared to the FSCC reference at 28 days. These enhancements indicate better material compactness and connectivity in the microstructure. Conversely, mixes with high percentages of (SSP+CP) without GS substitution showed significant declines in UPV

especially the 15%(SSP+CP) mix, which recorded a decrease of approximately −12.5% relative to FSCC. This suggests increased porosity and a more discontinuous internal matrix in high-powder-content mixtures.The correlation between UPV and modulus of elasticity is evident, as higher UPV values typically align with greater stiffness and reduced internal defects, confirming the beneficial role of moderate GS and powder substitution in improving concrete quality.

g)Porosity

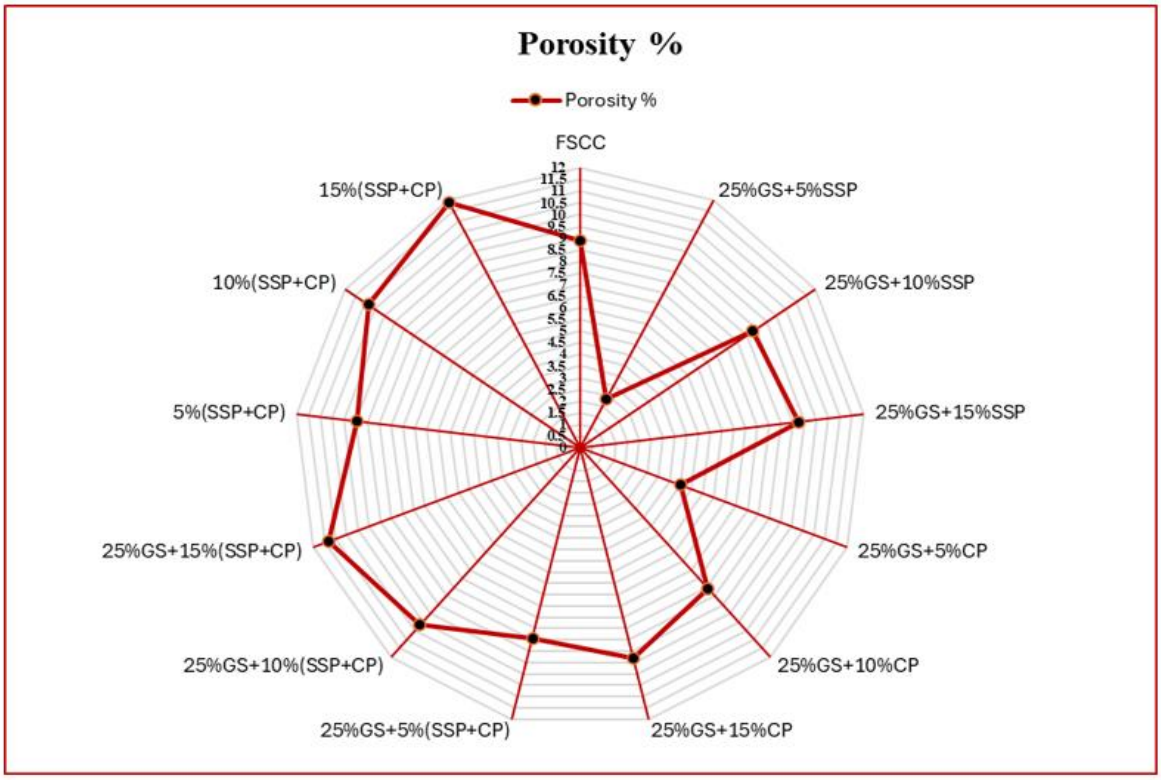


Fig.III.17. Porosity of FSC mixtures.

Compared to the reference mix (FSCC), which exhibited a porosity of 8.90%, the mix containing 25%GS+5%SSP achieved the most significant reduction, lowering porosity by approximately –73%. Similarly, the 25%GS+5%CP mix showed a notable decrease of around –49%. These results suggest that a 5% incorporation of ceramic or shell powder with granite sand improves compactness. As the replacement level increased, porosity approached or exceeded that of the control. The 25%GS+10%SSP and 25%GS+10%CP mixes had porosity values only slightly lower (around –1% to –9%) than FSCC. At 15%, both SSP and CP mixtures surpassed the reference, with porosity increases of approximately +4% to +5%.

Mixtures containing only combined SSP and CP (without granite sand) showed even higher porosity values. For example, the 15%(SSP+CP) mix displayed an increase of

+33.4% compared to the FSCC, while 10%(SSP+CP) and 5%(SSP+CP) showed increases of approximately +21% and +6%, respectively. Overall, these results demonstrate that a 5% dosage of ceramic or shell powder in combination with granite sand optimally reduces porosity, while higher dosages or absence of granite sand lead to increased porosity and reduced compactness.

h)Water absorption by capillarity

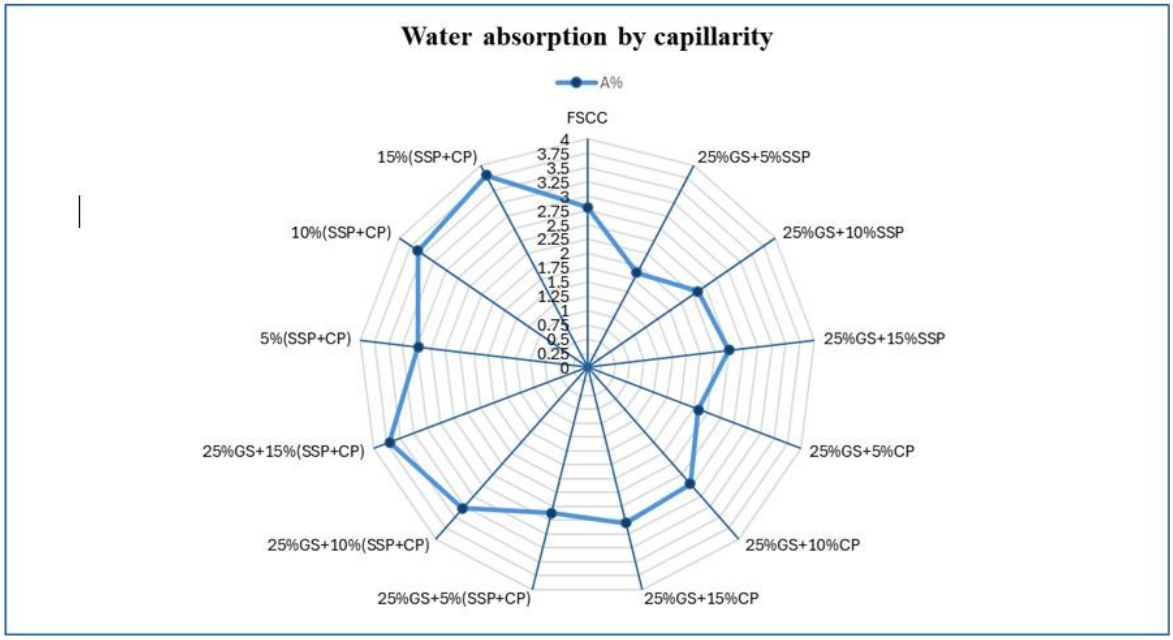


Fig.III.18. Absorption d'eau des BSF à base de déchets solides.

The reference mix (FSCC) exhibited a capillary water absorption of 2.8%, serving as the baseline for comparison. Most modified mixes incorporating granite sand (GS) with either shell powder (SSP) or ceramic powder (CP) showed notable reductions. The 25%GS+5%SSP mix achieved the greatest improvement, with a 33.2% decrease compared to FSCC, followed by 25%GS+5%CP and 25%GS+10%SSP, with reductions of 25.7% and 16.1%, respectively. However, mixes with higher additions (10–15%) of CP or SSP, particularly in binary combinations without GS, generally exhibited increased absorption. For instance, 25%GS+15%(SSP+CP) showed a 32.1% increase, while the 15%(SSP+CP) mix recorded a 35.7% rise relative to the reference. These results indicate that moderate additions of SSP or CP in combination with GS enhance resistance to water absorption, whereas excessive use or the absence of GS tends to worsen the capillary absorption behavior.

III.2. Conclusion

This study investigated the influence of incorporating granite sand (GS), shell powder (SSP), and ceramic powder (CP) on the fresh and hardened properties of fluid sand concrete (FSC). The results show that the inclusion of these industrial and biosourced waste significantly affected workability, density, mechanical performance, and durability indicators.

- In the fresh state, all mixes maintained sufficient flowability with 0.8% superplasticizer, though higher CP content tended to slightly reduce slump flow, likely due to the angularity and higher water demand of ceramic particles. In terms of density, all mixtures remained within the range of normal-weight concrete, with slight variations attributed to the type and proportion of waste added.
- Regarding mechanical performance, both compressive and flexural strengths improved with low additions (5%) of SSP or CP. At 28 days, the best results were obtained with 25%GS+5%SSP and 25%GS+5%CP.
- Dynamic modulus of elasticity and UPV results also confirmed this trend, with the best values corresponding to the mixes containing 5–10% of SSP or CP. In contrast, higher replacement levels (15%) led to slight performance reductions. Porosity and capillary absorption followed a similar pattern, with minimum values observed for 5% SSP or CP blends, while higher levels or combinations increased these indicators due to microstructural discontinuities.
- Overall, the optimal substitution rate was found to be **around 5%** for both SSP and CP, providing a balance between mechanical performance, durability, and sustainability. These findings highlight the potential of combining granite sand with low dosages of shell and ceramic powders to produce eco-efficient concrete suitable for structural applications, especially where improved durability and long-term performance are required.
- this concrete is suitable for various applications, including structural elements, precast components, marine works, pavements, and sustainable construction projects especially where long-term performance and eco-efficiency are required.

General conclusion

General conclusion

Faced with growing environmental challenges and the demand for more sustainable building materials, this study aims to contribute to the development of environmentally friendly sandcrete (ESC) using a range of industrial and biological by-products, such as shell powder, ceramic waste, marble and granite, as partial substitutes for cement and natural sand. The research involved a series of bibliographical studies and laboratory analyses on the properties of these materials and their effect on the behavior of concrete in the fresh and hardened states. Results showed that incorporating these materials in controlled proportions (5%, 10% and 15%) can improve compressive strength, reduce bulk density and improve diffusion behavior and internal cohesion, with varying effects on absorption and porosity. Certain wastes, such as roasted shells, have also been shown to play a role in improving concrete microstructure and long-term durability.

These results underline the technical and environmental potential of this approach, as it helps to reduce dependence on natural raw materials and provides an innovative solution for recycling industrial waste, thus supporting circular economy concepts in the construction sector. However, further studies on the behavior of this concrete in various service environments are needed to assess its long-term performance and suitability for structural applications.

This work represents an effective step towards the development of ecologically and economically sustainable concrete, and is helping to open up new horizons in the use of alternative materials in the construction industry, in line with national and global sustainable development objectives.

Recommendations

Recommendations

General Recommendations Based on the Study Findings:

- **Encourage the use of local waste materials in concrete**

It is recommended to utilize locally available organic or industrial waste, such as seashells, as partial replacements in concrete mixtures. This contributes to reducing environmental impact and promotes material sustainability.

- **Conduct additional tests on setting time using the Vicat apparatus:**

The study recommends performing Vicat tests to assess the effect of incorporating waste materials (such as seashells) on the initial and final setting times of cement paste. This is crucial to evaluate the practical applicability of such mixtures under various field conditions.

- **Extend experiments to determine the optimal replacement ratios:**

Further research is advised to identify the most effective proportions of waste additives that achieve a balance between mechanical performance and environmental efficiency.

- **Investigate the long-term behavior of modified concrete:**

It is important to carry out long-term monitoring and testing on concrete containing waste to assess how its properties evolve over time, especially under harsh environmental conditions.

- **Encourage adoption of sustainable materials in local construction projects:**

The integration of these results into local building codes is recommended to promote the use of recycled materials, especially in non-structural applications such as pavements, blocks, and eco-friendly elements.

Appendix

Appendix(A)

MATINE cement technical data



ALGERIA

Matine
Cement



PORTLAND LIMESTONE CEMENT

NA442 CEM II/B-L 42,5 N

Matine Grey cement for high-performance concrete intended for the construction of Civil Engineering Structures, and superstructure for bulldings.

Matine
NA442 CEM II/B-L 42,5 N

Matine is certified, in conformity with Algerlan NA442 – 2013 and European Standard.

PRODUCT ADVANAGES

- A high initial strength for prestressed concrete work
- Faster demouding rate
- Better workability and rheology
- It creates a True White Cement which provides high performance

A member of LefOrgeHolcim

TECHNICAL DATA SHEET – MATINE CEMENT

PRODUCT NAME: Matine Portland Limestene Cement
STANDARD REFERENCE: NA442 CEM II/B-L 42.5 N
PACKAGING: 50 kg bag
MANUFACTURER: Lafarge Algeria (a member of LafargeHolcim)

PRODUCT DESCRIPTION

MATINE is a high-performance grey Portlánd limenstone cement specificily engineered for the construction:

- Civil engineering structures
- Infrastructure and superstriuctures
- Prestressed and reinforcel concrete aplications

KEY TECHNICAL CHARACTERISTICS

Complles with	CEM II/B-L (Portland limestone cement)
Compressive Strengesн)	≥ 42.5 MPa
Initial Setting Time	≥ 60 minutes
Fineness (Blaine)	Approx, 3200 4000 cm²/g
Chioride Content	≤ 0.1%
Color	Grey
Form	Powder

PRODUCT ADVANTAGES

- High initial strength– ideal for fast demoulling
- Improved workability and flow chaŕacteristics
- Enhanced durability for concrete exposed to aggressive environments
- Better performance in hot climate
- True strength class 42.5N for demanding construction needs

RECOMMENDED APPLICATIONS

- Structural concrete
- Prestressed beams
- Prefabricated elements
- Foundations and slabs
- Bridges and industrial infrastructure

HEALTH & SAFETY

- Use personal protective equipment (PPE) when handling
- Avoid inhalation of cenet duet
- In case of contact with eyes or skin

Appendix(B)

BUILDING TRUST

PRODUCT NOTICE

Sika® ViscoCrete® TEMPO-10

High Range Water Reducer / Superplasticizer of New Geneation– Versatile

INFORMATION ABOUT THE PRODUCT

Sika® ViscoCrete® TEMPO-10 is a versatile new generation high-fange water reducer non-chloride, based-chloride, based on actylic copolymer.

FIELDS OF APPLICATION

Sika® ViscoCrete® TEMPO-10 sunble for the praduction of precast concrete, job site concrete, and Leady-mixed concrete. iso for concrete with long transport or placement times:

- Fluid to highly fluid concretes
- Low water/cement ratio concretes, with or without silica fume
- High early strength concreetes (up to 30 MPa in 24 hours)
- Air-entrained concretes

FEATURES / ADVANTAGES

Sika® ViscoCrete® TEMPO-10 conbines several mechanisms of action. By adapting to the surface and lonic charge of cement grains, it helps tose cement particles and improve hydration.

Main advantages:

- High water redduction capacity for improved strength and durability
- Extended workability without segregation
- Excellent compatibility with various types of cement and additions
- Improved surface finlshes
- Maintains consistency in hot veather
- Reduced admixture dosage for similar performance compares ted traditional superplasticizers

STANDARDS / APPROVALS

Packaging

- 200 kg drum
- 1100 kg IBC

PRODUCT DESCRIPTION

Packaging

- 200 kg drum
- 1100 kg IBC

STANDARDS / APPROVALS

Sika® ViscoCrete® TEMPO-10 corplies:

- Standard NF EN 934-2 Tables 1, 3.1 & 3.2.
- French Certification: PV CNERIB: DTEM 25'2016.

Sika ViscoCrete® TEMPO-10

High-performance water-reducing and plasticizing additive

Description Sika ViscoCrete® TEMPO-10 is a high-performance water-reducing and plasticizing additive. It is designed for the production of ready-mixed and precast concrete, improving the workability and mechamical strength of concrete.

Uses
- Ready-mixed concrete
- Precast concrete
- Self-compacting concrete (SCC)
- Concrete with improved surface finish
- Concrete requiring long workability retention

Characteristics/Advantages Strong plasticizing effect
- Extended workability retention
- Increases mechanical strength
- Compatible with most cement types
- Reduces water content
- Improves surface finish

Packaging Available in 1000-liter containers and 200-liter drums.

Storage conditions 12 months in original, sealed packaging, protected from direct sunlight and frost.

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