People's Democratic Republic of Algeria
Ministry of Higher Education and Scientific Research

University of Ghardaïa

Faculty of Science and Technology

Department of Hydraulics and Civil Engineering

Dissertation

submitted in partial fulfillment of the requirements for the degree of MASTER

Field: *Science and Technology*
Branch: *Civil Engineering*
Specialty: *Structures*

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Thesis Title

Study of Mechanical and Thermal Characteristics of Different Formulations of Lightweight Polystyrene Mortar

Defended publicly on: 18/09/2025

Before the jury :

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Academic Year: 2024 / 2025

Acknowledgements

When I completed my Master's thesis, I owed a great debt of gratitude to all those who supported me and offered their help and advice. I would like to express my deepest appreciation through sincere and heartfelt words:

First and foremost, I wish to thank Almighty God for granting me the strength and patience to accomplish this achievement.

I would like to extend my infinite gratitude to my distinguished professors, who never hesitated to provide me with their valuable guidance and profound knowledge. You have been an invaluable support throughout my academic journey, and your advice and directions have had a significant impact on the development of my thinking and skills.

A special acknowledgment goes to my thesis supervisor, **Mr. LAROUI Abdelbasset**, for his constant support and great patience in guiding me and helping me overcome obstacles. Your valuable advice and constructive remarks have been the cornerstone of the completion of this work.

My sincere thanks also go to the **L.T.P.S** laboratory team for their essential support and professional collaboration, which greatly facilitated the experiments and the success of this project.

Finally, I would like to express my gratitude to everyone who contributed, even with a kind word or an encouraging smile. Every helping hand has been a source of inspiration and support throughout my academic path.

Thank you all, for this success is the fruit of your efforts and immeasurable generosity.

May God bless you and reward you abundantly.

Dedication

To the children and women of **Gaza**, a symbol of resilience and pain, who face suffering every day with faithful hearts and patient souls. I pray to God to ease their hardship and bring their victory closer.

To my beloved **Mother**, who has always been my first source of support, through her efforts and sacrifices since my childhood until this day. Every achievement is but a fruit of her endless giving.

To my two great sources of inspiration, the role model of perseverance and of turning passion into achievement, , the beacon of inspiration in my daily life **Lionel Messi** and **Yacine DOUJA**.

I dedicate these pages as a token of gratitude and appreciation.

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Abstract:

In this thesis, we aimed to recycle both used polystyrene from packaging and crushed bricks from demolition waste, by using them as partial replacements for sand and cement in the preparation of lightweight mortar mixes used for manufacturing thermally insulating panels .Three substitution rates were adopted: (20%, 25%, and 30%) of the total sand volume replaced with polystyrene,and (05%,10%,15%) of the total cement mass replaced with brick waste.

Various tests carried out on the samples showed that the recycled materials contributed to reducing the weight of the mortar and improving its thermal properties, while maintaining acceptable mechanical strength — confirming the relevance of this approach from both environmental and technical perspectives.

Keywords: Lightweight mortar, red brick, expanded polystyrene, thermal insulation, mechanical strength.

Résumé:

À travers ce mémoire, nous avons cherché à recycler à la fois le polystyrène usagé provenant d'emballages et les débris de briques issus de travaux de démolition, en les utilisant comme substituts partiels au sable et au ciment pour la préparation de mélanges de mortier léger destinés à la fabrication de plaques isolantes thermiquement. Trois taux de substitution ont été retenus : (20%, 25% et 30%) du volume total du sable par du polystyrène .et (05 %,10 % ,15%) du masse total du ciment par des déchets de briques. Les différents essais effectués sur les échantillons ont montré que les matériaux recyclés ont contribué à l'allègement du mortier et à l'amélioration de ses propriétés thermiques, tout en conservant une résistance mécanique acceptable, ce qui confirme la pertinence de cette approche d'un point de vue à la fois environnemental et technique.

Mots-clés : Mortier léger, brique rouge, polystyrène expansé, isolation thermique, résistance mécanique

الملخص :

سعينا من خلال هذه المذكرة إلى إعادة تدوير كل من البوليسترين المستخدم سابقا في التغليف، والطوب المكسّر الناتج عن بقايا التكسير، وذلك باستعمالها كبدائل جزئية للرمل و الإسمنت في تحضير خلائط من الملاط خفيف الوزن تستعمل في صناعة صفائح عازلة حراريا.

تم اعتماد ثلاث نسب لتعويض حجم كل من البوليسترين والطوب، وهي:

20%، 25%، و30% من الحجم الكلي للرمل بدل البوليسترين، و 05%، 10%، و15% من الكتلة الكلية للإسمنت بدل الطوب. وقد أظهرت الإختبارات العديدة على مختلف العينات أن المواد المعاد تدويرها ساهمت في تخفيف وزن الملاط وتحسين خواصه الحرارية، مع الحفاظ على مقاومة ميكانيكية مقبولة، مما يُؤكد جدوى هذا التوجه من الناحيتين البيئية والتقنية.

الكلمات المفتاحية: ملاط خفيف، طوب أحمر،بوليسترين موسع، عزل حراري، المقاومة الميكانيكية.

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General introduction

In light of current environmental challenges, it has become essential to reconsider how resources are utilized, especially in the construction sector—one of the most resource-intensive and waste-generating industries. Within this context, there is a growing global trend toward waste valorization and recycling, aiming to produce new construction materials in a way that aligns with the principles of sustainable development and reduces the environmental footprint of industrial activities.

Among the waste products that pose a significant environmental threat is recycled expanded polystyrene (EPS)—a material widely used in lightweight and insulating packaging, yet non-biodegradable, making its disposal a real environmental challenge. Likewise, crushed brick waste, resulting from demolition or manufacturing processes, also holds great potential for reuse due to its mineralogical properties, which are comparable to traditional construction materials.

In civil engineering numerous studies have been dealing with topics related to the use of recycled EPS Anjaneya Dixit, and Sze Dai Pang [43] and Tek Raj Gyawali [41] and Layada, and Khelaifia [46] other works were interested to the use of brick wastes Qian Huang , Xiaohong Zhu [45] and BARKAT [47].

This study aims to evaluate the feasibility of incorporating two recycled materials, polystyrene previously used for packaging, and crushed brick waste from construction debris into lightweight mortar mixtures, specifically intended for use as thermally insulating panels. First we use each material separately with different percentages based on the previous works on the field and second, we use both wastes in the same mixture.

In this experimental work, three different volume substitution ratios were adopted for the recycled polystyrene: 20%, 25%, and 30%, as partial replacements for sand. Similarly, equivalent ratios of crushed brick (05%, 10%, 15%) were used in a parallel set of mixtures. The goal was to compare the influence of each material on the physical, mechanical, and thermal properties of the resulting mortar. All mixtures were prepared with the same water-to-cement ratio, using precise manual mixing techniques.

General introduction

The experimental phase was conducted at the Public Works Laboratory – South Unit, Ghardaïa, in addition to thermal conductivity tests in the University Laboratory, where transient heat conduction was measured using the WL 372 apparatus on cylindrical specimens (4 cm in diameter and 3 cm in height). For accuracy, the average of two samples was taken for each percentage.

To achieve the study's objectives, the work was structured into three main chapters:

Chapter One presents the theoretical background, including a literature review on recycled materials in construction, the properties of both polystyrene and brick waste, and key concepts related to thermal insulation and conductivity.

Chapter Two details the materials used, experimental methods, and procedures adopted in the preparation and characterization of the mixtures.

Chapter Three focuses on analyzing and discussing the experimental results related to density, mechanical strength, and thermal performance of the mortar containing either polystyrene or brick waste.

Finally, based on the obtained results, a general conclusion and a set of perspectives and recommendations are provided, with the aim of encouraging the integration of recycled materials in the production of lightweight, efficient, and eco-friendly construction components

CHAPTER I : Literature Review

I.1. Introduction:

In recent years, mortars and concretes have undergone significant development in Algeria across various sectors, including buildings, civil engineering structures, and special constructions.

Primarily composed of hydraulic binders, these materials form complex systems due to the incorporation of various additives, industrial by-products, and waste materials from the construction industry.

The beneficial — and sometimes contradictory — effects of these components are still not fully understood.

I.2. Mortars:

I.2.1. Definition:

The use of mortar dates back to antiquity and is closely linked to the development of lime-based materials. Roman mortars typically consisted of lime mixed with fine sand. Thanks to the presence of lime and the carbonation process, these mortars hardened over time, which contributed to their remarkable durability. The Romans also developed pozzolanic mortars, made from lime combined with crushed bricks or tiles and occasionally sand. In these mixtures, the fired clay fragments acted as catalysts, accelerating the setting and enhancing the mechanical properties of the mortar **[1]** .

Mortar is a construction material primarily used to bond masonry units, ensure structural cohesion, and fill the joints between building elements. It typically consists of a mixture of sand, a binder (such as cement or lime), and water, combined in specific proportions. These proportions may vary depending on the desired properties of the mortar and the type of additives or admixtures incorporated **[2]**.

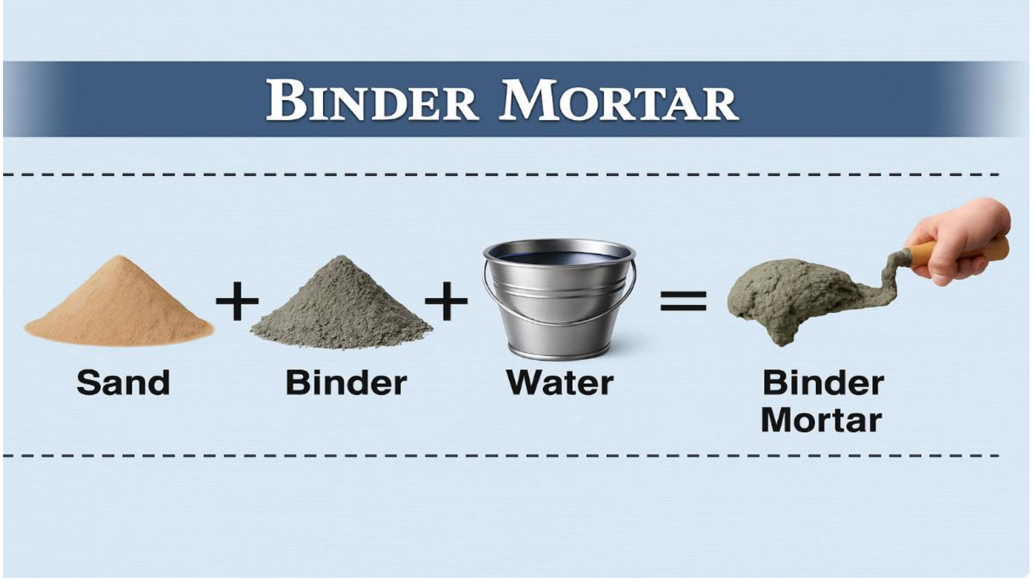
Figure.I.1. Mortar.
Ref: [1].

I.2.2. Components of Mortars :

Mortars are composed of a homogeneous mixture of three main components:

Binder + Sand + Water = Mortar

Figure.I.2. Components of Mortars.
Ref: [2].



I.2.3. Binder :

Hydraulic binders are commonly used in the formulation of mortars. These are materials that set and harden through a chemical reaction with water (hydration), and are capable of doing so even under water. The most widely used hydraulic binder is cement, a fine powder composed mainly of silicates and aluminates. Another traditional binder is lime, obtained by the calcination of limestone.

The most commonly used types of binders include: **[3]**

- **Standardized cements (e.g., Portland cement).**
- **Special cements (e.g., high-alumina cement, quick-setting cement).**
- **Masonry binders, specifically formulated for mortar applications.**
- **Natural hydraulic limes, which harden through both hydration and carbonation.**
- **Slaked limes.**

I.2.4. The role of mortar:

Mortar plays several essential roles in construction applications, contributing to both the mechanical performance and durability of structures. These roles include: **[4]**

- ➢ Ensuring the bonding and cohesion of masonry units, thereby contributing to the strength and monolithic behavior of the overall structure.
- ➢ Protecting buildings against moisture, whether from atmospheric exposure (rain, wind) or capillary rise from the ground.
- ➢ Serving as aerial coatings, applied to external or internal surfaces for protection and aesthetics.
- ➢ Acting as waterproof barriers, limiting water penetration in specific construction elements.
- ➢ Forming wear surfaces, such as the topping layer of concrete slabs, where resistance to abrasion is needed.
- ➢ Serving as a raw material in the production of prefabricated elements, such as blocks, tiles, pipes, and molded components.
- ➢ Being a fundamental component of concrete, by combining with coarse aggregates.
- ➢ Being used in soil consolidation, particularly in foundation works through injection techniques to improve ground stability.

I.2.5. Characteristics of mortars:

Mortars must exhibit several technical and functional characteristics to ensure their effectiveness and durability in construction applications. The most important of these characteristics include: **[5]**

- **Compressive strength:** The ability to withstand crushing forces by evenly distributing loads applied to masonry units.
- **Compactness:** A dense structure minimizes porosity, thereby limiting water infiltration and enhancing mechanical strength.
- **Water tightness:** Essential for achieving effective waterproofing in masonry joints and exterior renders.
- **Adhesion:** The capacity to bond effectively with different construction materials, ensuring structural integrity and resistance to environmental factors.
- **Dimensional stability:** The mortar should maintain a constant volume during setting and curing to prevent settlement, cracking, or dislocation of masonry elements.
- **Chemical resistance:** The ability to resist aggressive agents present in contaminated soils or harsh environmental conditions.
- **Workability:** The mortar must be sufficiently workable to allow for easy application and proper placement by construction workers under site conditions.
- **Durability:** It must retain its mechanical and physical properties over time, especially long-term strength.

All these characteristics depend on:

- The nature of the constituent materials.
- Their proportions (mix design and dosage).

I.2.6. Physicomechanical properties of mortars:

I.2.6.1. Density:

The dry density of hardened mortar is a key parameter for classifying and assessing the material's quality and structural efficiency. It is determined by the ratio of the mass of the oven-dried specimen to the volume it occupies when fully saturated, typically measured via water immersion.

This property reflects the compactness and internal porosity of the mortar. **[6]**

I.2.6.2. Water absorption Capacity (WAC):

The water absorption capacity of a mortar reflects its ability to absorb and retain water through its porous structure. It is defined as the percentage of water absorbed by a dry material when fully immersed in water for a specified period.

The WAC is calculated using the following equation:

$$WAC=(msat-msec/msec)*100\%$$

Where :

msat : the mass of the dry water-saturated material.

msec : the mass of the dry material.

For mortars based on quartz sand aggregates, the WAC should not exceed 08%.

For mortars with natural rock aggregates, the WAC should not exceed 12%. **[7]**

I.2.6.3. Mechanical resistance:

The mechanical strength of mortar is one of its most critical performance indicators, particularly in structural applications. Standard tests are typically performed on prismatic specimens measuring (04x04x16) cm^3, which are cured in water at 20°C until the time of testing. **[8]**

The test procedure involves:

- First, subjecting the specimens to a three-point bending test to determine their flexural tensile strength.
- Then, using the two resulting halves to perform a compressive strength test.

Both flexural and compressive strengths increase over time, generally following a logarithmic trend from day 01 to day 28. This reflects the ongoing hydration and hardening process of the binder (typically cement or lime), which contributes to the gradual improvement in the mortar's structural capacity.

Figure I.3. Mold for casting mortar specimens.

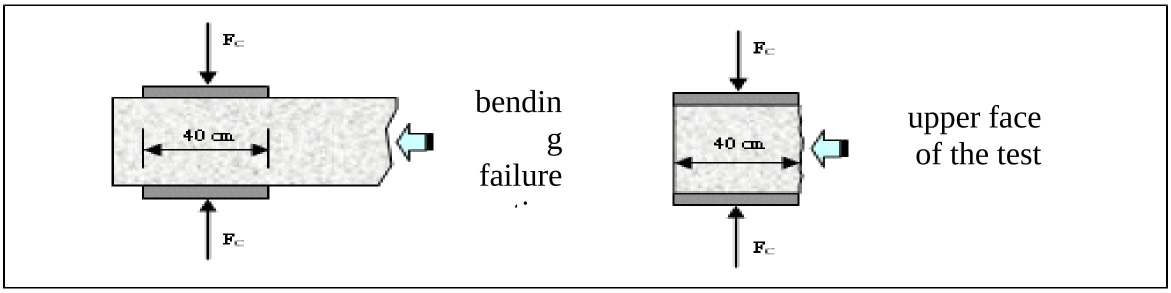


Figure I.4. Compression rupture device.
Ref : [3]

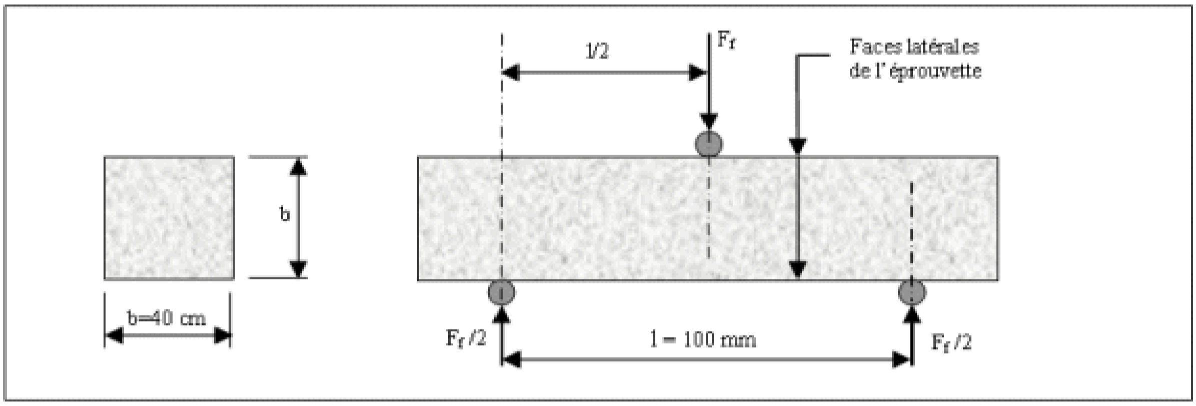


Figure I.5. Device for the bending strength test.
Ref: [4]

I.2.7. Preparation of mortars:

The preparation of mortar requires precise dosages of its constituents based on the type of work to be carried out .A commonly used mix ratio is illustrated in the following table: **[9]**

Sand	Cement	Water
Unit(g)	Unit(g)	Unit(ml)
1350	450	225

Table I.1: Mortar dosages.
Ref:LTPS Lab

- Clear the area of all dust, debris, and especially any plant material, using a broom or brush.
- Place the cement mixer or mortar pan near the materials. Ensure a water source with a shut-off valve is available nearby.
- Spread the required quantity of sand on the mixing surface.
- Add the measured cement (or lime) on top of the sand.
- Mix the sand and cement thoroughly using a shovel. Move the mixture two to three times to achieve a homogeneous dry blend with uniform color.
- Shape the mixed pile into a crater or well in the center.
- Pour approximately two-thirds of the total required water into the crater.
- Fold the edges of the crater inward to allow the dry mix to absorb the water gradually.
- Stir the mixture thoroughly to ensure uniform hydration. Move the pile two to three times again, similar to the dry mixing phase.
- Cut across the top of the mortar pile using a shovel.
- If the mortar is too dry or shows clumping, add water incrementally and re-mix.
- The mortar is ready for use when smoothing the surface with the flat side of a shovel produces a smooth finish and a light sheen of water appears on the surface.

I.2.8. Uses of mortars [10]:

I.2.8.1 Masonry cladding:

In constructions made of masonry elements such as concrete blocks, natural stone, or bricks, mortar plays a vital structural and protective role.

The mortar used must possess sufficient mechanical strength to ensure proper load transfer between the assembled units, and enough compactness to provide watertightness, thus preventing water infiltration.

Figure I.6: Laying of mortar for mortaring.
Ref: [5].

I.2.8.2. Coatings:

This application domain represents one of the most widespread uses of mortars.

In addition to the traditional three-coat rendering systems defined by the NF P 15-201-1 and 2 (DTU 26.1) standards, new forms of coatings have emerged, including:

- Thick single-coat renders, which simplify application and reduce labor time.
- Insulating renders, designed to improve the building's thermal performance by combining mechanical protection with thermal insulation.

These innovations reflect the growing demand for multi-functional mortars that not only provide surface finishing but also contribute to the energy efficiency and durability of buildings.

Figure I.7. Insulating coatings and facade coatings.
Ref: [6].

I.2.8.3. The screeds:

Screeds are applied to ensure the leveling of floor surfaces and to provide a uniform and regular finish. Depending on the intended use, screeds may serve as:

- A finishing layer, often incorporating specific additives or products to enhance certain properties.
- A base layer for the installation of flooring materials (tiles, wood, etc.).

Screeds must possess adequate mechanical strength to:

- Transfer loads efficiently to the underlying substrate.
- Resist abrasion, impact, or puncture, particularly in the case of industrial floors.

Whether bonded, unbonded, or floating, the design and composition of the screed must be adapted to the functional requirements of the structure.

Figure I.8. Fluid screeds and cement screeds.
Ref: [7].

I.2.8.4. Stele sealing wedges:

The wide variety of sealing and wedging requirements in construction has driven industrial mortar manufacturers to develop specialized formulations tailored to each application.

These mortars are designed for precise and durable installation of:

- Roofing components.
- Architectural finishing elements.
- Urban furniture.
- Manhole frames and inspection chambers.

Such mortars must offer strong adhesion, dimensional stability, and resistance to environmental factors, ensuring the long-term functionality and integrity of the installed elements.

II. Recovery and reuse of waste in civil engineering:

Before engaging in the recovery of waste materials, it is essential to first identify their origin, analyze their composition, and characterize their current condition as well as their behavior over time. Additionally, an evaluation of their treatability is required. This process is guided by the principle:

"Measure to understand, and understand to act." **[11]**

CHAPTER I : Literature Review

In general terms, waste is defined as any residual product resulting from a process of production, transformation, or consumption, which the owner or holder is legally or practically obligated to eliminate or dispose of.

Waste valorization refers to any process that enables the utilization of waste for a purpose with positive economic, environmental, or technical value. This broad concept encompasses several strategies, including:

- Reuse (reutilisation).
- Recycling (recyclage).
- Repurposing or recovery for alternative use (valorisation matière ou énergétique). **[12]**

II.1. Recycling :

Recycling refers to the process by which waste is converted into new materials or reintroduced into the production cycle. More specifically, material recovery aims to extract the same substance for reuse, thus minimizing the consumption of raw resources. **[13]**

II.2. Recovery:

Recovery is the process of reclaiming or extracting materials or energy from waste, instead of disposing of it, for use as inputs in other processes. **[13]**

II.3. General information on waste:

II.3.1. Definition of Waste:

Waste refers to any object or substance that has reached the end of its useful life, or has undergone a physical or chemical transformation rendering it unsuitable for its original intended use, and is therefore designated for disposal.

The term originates from the Old French words déchet or cassé, meaning "the portion lost during the use of a product" or "what remains after its consumption."

In recent years, traditional waste disposal method -such as landfilling or incineration-have increasingly revealed their environmental and economic limitations. Consequently, greater emphasis is now placed on reuse, recycling, and the valorization of waste.

In this context, the term "recyclate" is often used to describe secondary raw materials recovered from waste, which are reintroduced into the production cycle, reducing the dependence on virgin raw materials and contributing to circular economy practices. **[14]**

II.3.2. Origins of waste Generation:

The generation of waste is an inevitable consequence of various natural and human activities, and can be attributed to multiple interrelated factors: **[15]**

- **Biological Origins:** Every biological life cycle produces metabolic by-products, which must be eliminated by the organism or the environment.
- **Chemical Origins:** According to the law of conservation of matter, most chemical reactions result in residual by-products in addition to the intended compounds.
- **Technological Origins:** All industrial and manufacturing processes generate waste in the form of excess materials, rejected products, or energy loss.
- **Economic Origins:** Most products and materials have a limited useful lifespan, beyond which they become obsolete or non-functional, thereby generating waste.
- **Ecological Origins:** Environmental protection activities—such as the treatment of polluted water, air purification, or soil remediation—often generate secondary waste that requires dedicated management.
- **Accidental Origins:** Operational failures, equipment malfunctions, or unexpected incidents in production and consumption systems can lead to unplanned waste generation.

II.3.3. Different types of waste: [16]

Waste can be classified into several categories based on its nature, origin, and environmental impact. The main types include:

❖ **Ultimate waste (UW):**

This refers to residual household and similar waste that remains after selective collection and sorting operations. It is considered non-recoverable by current recycling or treatment methods and is typically destined for final disposal (landfill or incineration without energy recovery e.g.,).

❖ **Inert waste (IW):**

Inert waste is chemically and biologically stable. It does not undergo significant physical, chemical, or biological transformations over time. It is non-combustible, non-biodegradable, and does not interact with other substances in a way that could lead to environmental contamination or pose health risks to humans.

Inert waste is generally acceptable in long-term storage facilities and mainly originates from the construction and public works sectors. Examples include:

- Concrete debris.
- Tiles and ceramics.
- Bricks.
- Glass fragments.
- Excavated soil.

❖ **Similar waste (SW):**

Also known as household and similar waste, this category includes domestic waste generated by households, as well as waste produced by small businesses, artisans, and traders that is managed under the same conditions by local authorities.

❖ **Green waste (GW):**

This type refers to plant-based waste originating from parks, gardens, and green spaces, including materials such as grass clippings, branches, hedge trimmings, and dead leaves.

❖ **Organic waste (OW):**

Also referred to as biowaste, fermentable waste, or FFHW (Fermentable Fraction of Household Waste), this category encompasses all biodegradable organic materials, such as:

➢ Green waste (as defined above).

➢ Kitchen and food waste, including food scraps, fruit and vegetable peelings, and spoiled food.

➢ Miscellaneous organic materials, such as newspaper, cut flowers, coffee grounds, coffee filters, tea bags, eggshells, and similar items.

➢ Sewage sludge, generated from wastewater treatment processes.

❖ **Hazardous waste (HW):**

1. **Special industrial waste (SIW):**

These are wastes classified as hazardous due to their physicochemical properties. Examples include waste containing toxic elements such as arsenic and lead, as well as residues like paint sludge, hydrocarbons, and by-products from the petroleum industry.

2. Special household waste (SHW):

This refers to hazardous substances found within domestic waste, including aerosols, adhesives, detergents, insecticide-based cleaners, paints, batteries, fluorescent tubes, and household cleaning agents. These are often referred to as TWDQ (Toxic Waste in Dispersed Quantities), due to their presence in small yet hazardous amounts in households.

3. Packaging waste (PW):

This category includes waste from paper, plastic, cardboard, and similar packaging materials. Waste from building or road demolition may include a combination of all the aforementioned waste categories, with the following approximate composition:

- Concrete (40%).
- Brick (30%).
- Wood (10%).
- Plastics (05%).
- Metals (05%).
- Other materials (10%).

Processing and recycling of this waste involves the removal of unsuitable elements (such as metals or contaminants) to produce recycled aggregates, especially for road construction.

Figure.I.9. Different types of waste.
Ref: [8].

II.3.4. Waste recovery:

Waste recovery refers to any process that treats or utilizes waste in a way that generates a product with positive economic value. It is a broad term that encompasses reuse, recycling, and repurposing.

There are several types of waste recovery methods: **[17]**

- Energy recovery.
- Recovery of organic and mineral raw materials.
- Materials science-based recovery.
- Agricultural recovery.
- Environmental technology recovery.

Recovery processes treat both industrial and household waste, allowing the reintegration of materials into their production cycles. Recycling, in particular, has two major ecological benefits:

1) Reduction of waste volume.
2) Conservation of natural resources.

These recovery practices are integral to the economic systems of modern consumer societies. While some recycling processes are simple and cost-effective, others may be technically complex, expensive, and economically unviable. In such cases, legislation often plays a role in aligning ecological objectives with consumer behaviors.

Since the 1970s, recycling has grown into a significant sector within the economies of developed countries, improving both economic performance and living conditions.

Waste recovery aligns with the "Three Rs" waste management strategy:

Reduce: Efforts aimed at minimizing waste generation at the source.

Reuse: Giving products or materials a second life through alternative uses.

Recycle: Transforming waste into raw materials for new production cycles.

In France, the volume of waste doubled between 1980 and 2005, reaching 360 kg/year per person. Consequently, recycling must be embedded within a broader, integrated waste management approach in order to effectively combat the rise in waste production. **[16]**

II.3.5. The Importance of Waste Recovery:

The growing focus on the recovery of industrial waste and by-products stems from several interconnected factors, including the global energy crisis, the depletion of raw material resources, and the tightening of environmental protection legislation.

The key reasons for promoting waste recovery can be summarized as follows: **[18]**

- Increased industrial production, which generates more waste.
- Rising costs of waste storage and treatment, making recovery a more economical alternative.
- Stricter environmental regulations, encouraging companies to adopt more sustainable waste management practices.
- Improved research and innovation in waste management, leading to more efficient and effective recovery methods.

II.3.6. Use of waste and by-products in the field of civil engineering:

The utilization of waste and industrial by-products in civil engineering is not a recent innovation. In fact, the incorporation of residues from coal and steel industries—such as granulated blast furnace slag—into aggregates or cementitious binders dates back as early as 1880, when their use in cement manufacturing was already being studied.

The development of waste reuse in civil engineering has historically paralleled the expansion of heavy industry, as it offered both economic and environmental advantages by reducing raw material consumption and limiting waste accumulation.

The needs of civil engineering, in terms of materials, can be categorized into four main sequential groups: **[18]**

- **Materials**: Characterized by low technical requirements but consumed in very large quantities.
- **Aggregates**: Must satisfy specific mechanical and physical standards depending on their application.
- **Binders**: Require precise composition, stable properties, and long-term durability.
- **Activators**: Used in small quantities, but their collection, storage, and uniformity may present logistical challenges.

III. Polystyrene:

Polystyrene is a synthetic polymer obtained through the polymerization of styrene monomers. At room temperature (20°C), it is a solid material, becoming pasty at around 120°C, and melting between 150°C and 170°C. It is both flammable and combustible, with an auto-ignition temperature of approximately 490°C. Moreover, polystyrene is soluble in chlorinated and aromatic hydrocarbons.

Characterized by its hardness, brittleness, and transparency, polystyrene exists in several forms and is used in a wide variety of applications. It is a widely produced polymer, commonly employed in the manufacturing of packaging materials, toys, and architectural or industrial models. **[19]**

III.1. Definition:

Polystyrene (PS) is a thermoplastic polymer obtained through the polymerization of styrene monomers. Styrene itself is derived from petroleum refining and is chemically composed of a benzene ring bonded to a vinyl group (CH=CH2).

The polymerization process is typically carried out in an autoclave, producing a solid and rigid plastic material. When mixed with a gas during manufacturing, polystyrene can be expanded into a lightweight cellular material, widely known for its low density and insulating properties.

Polystyrene is characterized by its transparency, brittleness, and ease of molding, and it exists in several forms, each adapted to specific applications. The most common types include:

- General-purpose polystyrene (GPPS): a homopolymer known for its rigidity and clarity.
- High-impact polystyrene (HIPS): a copolymer that incorporates rubber particles, making it more resistant to impact.
- Expanded polystyrene (EPS): a lightweight foam form, often used in thermal insulation and packaging.

Due to its versatility, PS is widely used in packaging, disposable containers, household items, and various industrial and construction applications. **[25][26]**

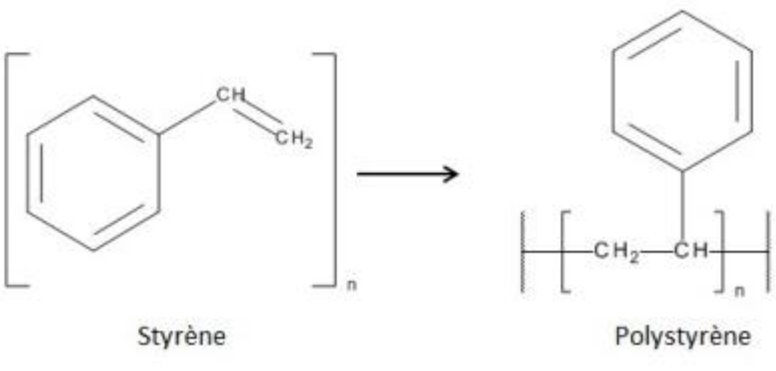


Figure.I.10. Diagram of polystyrene production.
Ref: [9].

III.2. Origin of polystyrene:

Polystyrene (PS) is synthesized through the polymerization of styrene, a petrochemical compound derived primarily from ethylbenzene. Over 90% of global styrene production is obtained via the dehydrogenation of ethylbenzene in the presence of ethylene, making it heavily dependent on petroleum resources.

The chemical formula of polystyrene is $(C_8H_8)_n$ indicating a polymer composed solely of carbon and hydrogen atoms.

Figure.I.11.Polymerization of styrene monomer into polystyrene.
Ref: [10].

Two main polymerization techniques are currently employed in the industrial production of polystyrene:

- Suspension radical polymerization: a process in which the monomer is dispersed in water with the help of stabilizers and initiators, allowing for good thermal control and bead-shaped polymer formation.
- Bulk radical polymerization: a process conducted in the absence of solvents, typically used for the production of transparent and high-purity polystyrene.

To prevent premature polymerization of liquid styrene during storage and transport, stabilizing agents—such as 4-tert-butylcatechol (TBC)—are added as inhibitors. These substances help maintain the monomer in a stable state at low temperatures until it is ready for polymerization. **[20]**

III.3. Forms of Polystyrene:

a) Standard polystyrene

Standard polystyrene, also known as general-purpose polystyrene (GPPS) or rigid polystyrene (RPS), is synthesized in aqueous suspension to achieve high molar masses. The process is carried out in an aqueous medium under a nitrogen atmosphere, with the presence of a plasticizer, a fluidizer, and a radical initiator—typically benzoyl peroxide or tert-butyl hydroperoxide.

The styrene monomer is dispersed in the form of fine droplets within the aqueous suspension, a dispersion made possible by surfactants such as polyvinyl alcohol and tricalcium phosphate.

This form of polystyrene is:

- Amorphous (non-crystalline)
- Transparent, with a glossy appearance
- Rigid and brittle
- Easily colorable

Due to its clarity, it is sometimes referred to as "crystal polystyrene". It represents the base form of polystyrene obtained directly after polymerization. All other types of polystyrene (e.g., high-impact, expanded, or extruded) are derived through modifications of this standard form. **[20][21]**

Figure.I.12. Crystal polystyrene.
Ref: [11].

b) High-impact polystyrene (HIPS)

High-impact polystyrene (HIPS) is produced by polymerizing styrene in the presence of a reinforcing elastomer, typically polybutadiene. The result is an amorphous, two-phase polymer system:

- The continuous phase (matrix) is composed of standard polystyrene (PS).
- The dispersed phase consists of polybutadiene rubber particles embedded within the matrix.

This two-phase morphology leads to enhanced impact resistance, as the rubber nodules absorb and dissipate energy from impacts. Due to the difference in refractive indices between the two phases, HIPS appears translucent to opaque rather than fully transparent.

Compared to standard PS, HIPS demonstrates superior toughness and durability, making it more suitable for applications that require resistance to mechanical shock or deformation.

Figure.I.13. High-impact polystyrene.
Ref: [12].

c) Expanded polystyrene (EPS)

Expanded polystyrene (EPS) exists in two main forms:

- Molded expanded polystyrene (MEPS): This type is produced from expandable polystyrene beads, which are typically standard (crystal) PS spheres containing a blowing agent (a solvent with high vapor pressure) introduced during polymerization. Upon exposure to heat and steam, these beads expand—potentially up to 60 times their original volume. After pre-expansion, they are stabilized and molded into desired shapes using steam heating, which causes them to fuse together.

- Extruded expanded polystyrene (XEPS): This variety is manufactured through an extrusion process, most commonly by physical expansion (direct lazing). The process begins with melting crystal PS granules under pressure in an extruder. Then, one or more nucleating agents and a blowing agent (in liquid or gas form) are added to the molten polymer. The mixture is kept under pressure and forced through a die, resulting in a continuous sheet or plate of expanded material. The extrudate is subsequently cooled and solidified.Both forms of EPS are lightweight, thermally insulating, and widely used in packaging, construction, and thermal insulation systems. **[22]**

Figure.I.14. EPS.
Ref: [13].

III.4. Properties of polystyrene:

1) Electrical and thermal properties

Polystyrene is an excellent electrical insulator, making it suitable for many electrical applications. It can be modified with additives to impart antistatic or conductive properties when required. However, it remains a poor thermal conductor, which contributes to its effectiveness as a thermal insulator.

2) Fire behavior

Polystyrene is a combustible polymer that emits a characteristic sweet odor when burned. It begins to decompose at approximately 300°C, releasing carbon dioxide (CO_2) and water vapor. In conditions of incomplete combustion, carbon monoxide (CO) may also be produced. Additionally, due to the presence of nitrogen (78%) in atmospheric air, nitrogen oxides are often generated during combustion. **[23]**

3) Aging and Weathering

When exposed to outdoor conditions over extended periods, polystyrene undergoes oxidation, leading to surface yellowing and brittleness. The incorporation of UV stabilizers or coloring agents can significantly improve its resistance to aging and environmental degradation. **[24]**

4) Chemical Resistance and Corrosion

Polystyrene is generally resistant to many inorganic substances, including aqueous solutions and food-grade chemicals. It exhibits good resistance to acids, bases, oxidizing agents, and some reagents. However, it is vulnerable to many organic solvents, such as aromatic hydrocarbons, and may swell or dissolve upon contact with concentrated acids or certain solvents. It possesses excellent dimensional stability, maintaining its shape and structure under varying thermal and mechanical stresses. **[24]**

III.5. Technical characteristics of polystyrene (PS):

Polystyrene (PS) exhibits a set of distinctive physical, thermal, and mechanical properties that make it suitable for a variety of industrial applications. These characteristics include: **[24][25]**

- **Material Type:** Amorphous thermoplastic with semi-rigid behavior.
- **Transparency:** PS is naturally transparent; newer formulations can achieve both transparency and improved impact resistance.
- **Rigidity:** High rigidity, with a Young's modulus of approximately 3 GPa.
- **Impact Resistance:** Generally brittle within the temperature range of 0°C to +80°C, but shows improved resistance when expanded.
- **Density:** Approximately 1.015 kg/dm^3 in solid form; expands to one-tenth of this value when foamed (EPS).
- **Surface Feel:** Dry texture with a metallic sound when dropped.
- **Operating temperature range:** 0°C to +100°C.

- **Glass transition temperature (Tg):** ~120°C.
- **Melting range:** Between 150°C and 170°C.
- **Softens:** Becomes paste-like at 120°C.
- **Processing temperature:** 190°C to 250°C.
- **Auto-ignition temperature:** ~490°C.
- **Combustibility:** Highly flammable and combustible.
- **Permeability:** Poor resistance to gas and moisture penetration.
- **Weldability:** Compatible with heat welding techniques and bonds effectively.
- **Sensory Properties:** Odorless and tasteless.

III.6. Applications of Polystyrene:

Polystyrene is widely used in a variety of everyday products due to its versatility, processability, and cost-effectiveness. Its main applications include:

- **Optical media:** Used in the production of CD and DVD cases, particularly employing "crystal" PS for its transparency and rigidity.
- **Disposable items:** High-impact polystyrene (HIPS) is commonly used to manufacture plastic cutlery, cups, and glasses due to its improved impact resistance.
- **Food packaging:** Frequently utilized for containers such as yogurt pots, benefiting from PS's food safety and moldability.
- **Protective packaging:** Expanded polystyrene (EPS) is employed for cushioning and protecting fragile appliances (electronics and home devices e.g.,) during transportation and storage.
- **Building insulation:** Both expanded (EPS) and extruded (XPS) forms of polystyrene are widely used for thermal insulation in construction due to their low thermal conductivity and lightweight nature. **[26]**

Figure I.15. CD cases, crystal PS and food packaging.
Ref: [14].

III.7. Expanded polystyrene:

III.7.1. Introduction:

Expanded Polystyrene (EPS) is a low-density, cellular plastic material primarily used for thermal insulation in buildings. In such applications, detailed understanding of its mechanical behavior is generally not required.

In addition to insulation, EPS is widely employed in the packaging industry, where its performance under impact and shock absorption is particularly valued. **[27]**

Figure I.16. Polystyrene sheets.
Ref: [15].

III.7.2. Expanded polystyrene and the environment

Expanded polystyrene (EPS) is covered by Environmental and Health Declaration Sheets (FDE&S), as detailed in this chapter, and by certifications issued by ACERMI and CSTB. Moreover, thermal studies and environmental impact assessments clearly identify EPS as an insulation material well-suited for environmentally responsible construction projects.

Preserving a natural resource:

EPS is manufactured from naphtha, a by-product of crude oil refining. When compared to the total volume of crude oil extracted annually, EPS production accounts for less than 0.1% of the resource. Therefore, EPS requires only a minimal amount of raw material for its production. Through its insulating properties, it helps conserve this non-renewable resource—oil. Furthermore, naphtha, which serves as the raw material for EPS, is not suitable for use as fuel and would otherwise become waste. Its utilization in the EPS production chain thus prevents additional pollution. **[28]**

III.7.3. Performances:

III.7.3.1. Thermal performance:

The primary characteristic of an insulating material lies in its excellent thermal performance. A well-insulated and energy-efficient home contributes to occupant comfort and improved living conditions. Properly insulating a building—whether new or undergoing renovation—involves minimizing heat loss by placing insulation between the exterior and interior envelopes. This significantly reduces the amount of energy required for heating or cooling. The thermal performance of expanded polystyrene (EPS) is expressed in terms of thermal conductivity and thermal resistance.

- Thermal conductivity

Thermal conductivity, denoted by lambda (λ) and expressed in W/m·K, indicates a material's ability to transmit heat. The lower the lambda value, the better the insulating performance of the product. **[29]**

III.7.3.2. Acoustic performance:

Home comfort also relies on effective sound insulation to prevent noise transmission between rooms and from external sources into the interior.

There are two primary sources of noise:

- **Airborne noise:** Generated by a source that does not come into contact with the structure of the building, such as speech, television, music, or road traffic.
- **Impact noise:** Resulting from the direct vibration of structural elements, such as footsteps on a floor or impacts on a wall. **[28]**

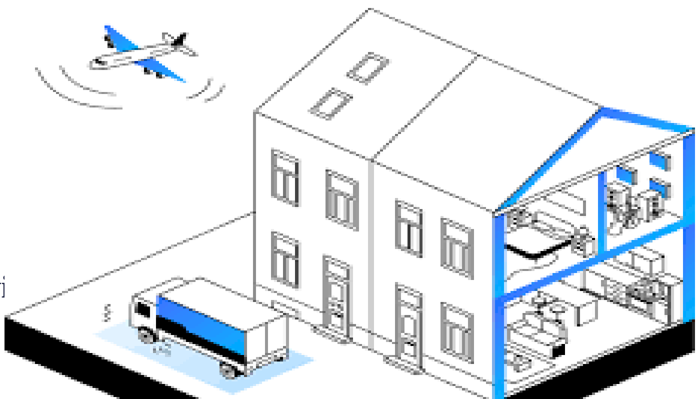


Figure I.17. Image of the sound insulation of a house.
Ref: [16].

IV. Brick Waste:

This section aims to provide relevant information on brick waste, commonly referred to as "briquaillons," "chamotte," or "crushed brick." Despite the widespread use of bricks as a raw material in construction—and, consequently, the large quantities of brick waste generated—there is limited data available on the use of these materials as aggregates, as will be further discussed in Chapter II. In Algeria, according to available sources, research concerning these materials remains scarce. “Briquaillons” refers to fragmented bricks, typically resulting from demolition activities or defective firing processes (such as overfired bricks). On the other hand, “chamotte” refers to crushed or ground fired bricks. **[30]**

IV.1. Definition of brick waste:

Bricks are ceramic products manufactured from clay, with or without the inclusion of additives. They are usually shaped in the form of rectangular parallelepipeds and are widely used in the construction of buildings and civil engineering works. Compared to other construction materials, bricks are among the oldest known building materials. Bricks are increasingly featured in marketing materials from suppliers and manufacturers of fireplaces, barbecues, and ovens. Often considered a “magical” material due to its heat performance capabilities, brick is specifically designed to withstand high temperatures. Depending on the intended application, its composition may include vermiculite, molten cement, and refractory grout in varying proportions. In addition to their thermal resistance, bricks possess the ability to release stored heat—a property known as convection—which significantly contributes to their popularity and effectiveness in thermal applications. **[31]**

IV.2. Types of brick:

There are various types of solid bricks that differ in surface appearance and physical characteristics. These types include: **[32]**

- **Raw earth brick:** May also contain natural fibers such as straw, flax, or horsehair.

- **Compressed earth brick:** A sustainable alternative made by compressing moistened earth under high pressure.
- **Solid fired brick:** A traditional construction material, with a variant known as perforated solid brick, where the perforations are oriented perpendicular to the laying plane.
- **Lightweight and insulating brick:** Manufactured using silico-magnesium clay of low consistency mixed with approximately one-twentieth part of plastic clay. These bricks are as strong as conventional bricks but significantly more porous, have low thermal conductivity, and are light enough to float on water.
- **Hollow fired bricks:** Lighter in weight (and thus less costly to transport) and more insulating. Their perforations are parallel to the laying plane to preserve compressive strength. These have become the most commonly used type.
- **Hemp bricks:** Known for their excellent thermal insulation properties.
- **Frost-resistant bricks:** Designed to withstand repeated freeze–thaw cycles without degradation.
- **Refractory bricks:** Used in high-temperature applications such as furnaces, boilers, fireplaces, and chimneys.

Depending on the type, bricks serve different purposes:

- **Facing bricks:** Intended to remain visible; used primarily for decorative purposes.
- **Solid bricks:** Designed for constructing exterior and load-bearing walls.
- **Plaster bricks:** Utilized for interior partitions and non-load-bearing dividing walls.

IV.3. Physicochemical Characteristics of Brick:

The physicochemical properties of fired bricks vary depending on the type of clay used. Common types include:

- **Illitic clay:** Produces bricks with a gray-brown to reddish coloration.
- **Kaolinitic clay.**
- **Bravastic clay:** Yields orange to pink-colored bricks.

In addition to clay minerals, metallic elements are often present in the clay matrix. These are referred to as refractory elements, due to their high fusion temperatures—significantly higher than the firing temperatures of brick kilns (typically between 800°C and 1000°C). The primary refractory oxides found in bricks are:

- **Silica (SiO_2)**
- **Alumina (Al_2O_3)**

The basic color-determining oxides in brick include: **[33]**

- **Iron oxide.**
- **Titanium oxide.**
- **Manganese oxide.**

Furthermore, fluxing agents, which influence the vitrification process during firing, are categorized into two groups:

1. Alkaline oxides: Such as sodium oxide (Na_2O) and potassium oxide (K_2O).
2. Alkaline earth oxides: Such as calcium oxide (CaO, or lime) and magnesium oxide (MgO, or magnesia).

Accordingly, the mineralogical composition of red brick waste can be determined using X-ray fluorescence (XRF) analysis.

IV.4. Recovery of brick waste:

There is limited information available regarding the fate of brick waste, despite it constituting a significant portion of demolition and construction debris. From a technical standpoint, brick waste is often recycled as a component of masonry-type materials. However, there is an almost total absence of regulatory frameworks governing the manufacture and utilization of recycled brick waste. **[34]**

IV.5. Reuse:

During demolition operations, salvaged bricks can be cleaned and reused either on the same site or at different locations. Moreover, certain old bricks possess high architectural value and are especially sought after for historical restoration projects. **[34]**

IV.6. Recycling:

Recycling is the process of reintroducing waste into the production cycle as a total or partial substitute for natural raw materials. Unlike reuse, recycling requires further processing of the material.

Crushed brick can be used as:

- Aggregates in road subgrades

- Backfill materials
- Landscaping applications
- And other uses within the construction industry.

Nevertheless, regulations governing the manufacture and use of recycled brick materials remain scarce. **[34]**

V. The use of polystyrene additives in lightweight mortars and lightweight concrete:

V.1. Lightweight concrete:

The use of polystyrene in the construction sector remains limited in our country. Currently, it is primarily available in the form of acoustic and thermal insulation panels. However, this innovative material can also be incorporated into concrete formulations to produce “plasterboards” that are ten times lighter, thirty times more insulating, and equally as strong as traditional concrete.

Given Algeria’s hot climate, buildings require effective thermal insulation materials, particularly during the summer. Expanded polystyrene functions as a cooling material that absorbs excess heat during the day, thereby contributing to thermal comfort. Moreover, it creates a dry and comfortable environment by eliminating moisture that could otherwise condense on wall surfaces. Despite not being biodegradable, polystyrene is considered environmentally friendly due to its recyclability. It does not pose a direct threat to the environment if managed correctly. In Algeria, a manufacturer has introduced an innovative German-origin technique in the construction industry. This technique involves using polystyrene panels reinforced with metal for slabs, partition walls, and roofs. The resulting products are insulating, lightweight, and durable, and have been certified by the CTC (Centre Technique des Matériaux de Construction). These reinforced polystyrene panels offer mechanical strength comparable to that of conventional concrete.

Polystyrene beads were selected for producing lightweight concrete due to their low density, widespread availability, and ease of incorporation. Since 1978, such concretes have been employed in both renovation and new construction projects (e.g., slope correction, terraces, lightweight panels, backfilling), as well as in the production of lightweight plasters based on expanded polystyrene beads.

When applied correctly, this type of concrete provides optimized solutions across various construction domains—structurally, economically, and thermally. It opens new avenues for innovation in the construction industry. Expanded polystyrene lightweight concrete is particularly characterized by:

- Its low density,
- Excellent strength-to-weight ratio,
- High thermal insulation capacity,
- Resistance to heat and frost,

And general resistance to physical and chemical degradation common in construction environments. **[35]**

V.2. Composition of lightweight expanded polystyrene concrete:

Lightweight expanded polystyrene concretes are produced by fully or partially replacing traditional aggregates with expanded polystyrene beads, until a suitable mix of granular classes is achieved. This substitution results in a wide range of lightweight construction concretes with varying densities and mechanical strengths.

The components used in the production of polystyrene lightweight concrete are essentially the same as those used in conventional concrete. However, the primary focus in this case shifts from mechanical strength to density optimization.

Given that aggregates constitute a substantial portion of concrete volume, it becomes necessary to replace part of the granular mass with lightweight, or even ultra-lightweight, aggregates. This approach allows for significant reduction in overall weight while maintaining acceptable performance for specific applications. **[36]**

V.3. The properties of Polystyrene in Concrete:

The technical performance of expanded polystyrene (EPS) enables it to play a crucial role in modern construction. The cellular structure of EPS offers a range of advantageous properties that make it suitable for incorporation into lightweight concrete. These properties include:

1- Intrinsic lightness, significantly reducing the overall weight of concrete.
2- Excellent thermal insulation capacity, contributing to energy efficiency in buildings.
3- Customized protection against impacts and falls, enhancing safety and durability.

4- High strength-to-weight ratio: composed of approximately 98% air and 2% material.
5- Stability under various weather conditions and environmentally neutral behavior.
6- Suitability for food contact, meeting hygiene and safety standards in specific applications.
7- Flame-retardant characteristics, improving fire resistance.
8- Resistance to high temperatures, maintaining structural performance under thermal stress.

Polystyrenes are polymeric materials from the styrene family. They exist in numerous types and grades, each offering specific physical and mechanical properties that can be tailored to construction needs. **[36]**

V.4. lightweight mortar: (Example of a Ready-to-Use Lightweight, Insulating, and Fiber-Reinforced Mortar – 500 kg/m^3)

V.4.1. Definition:

XX is a lightweight, ready-to-use mortar delivered in bagged form. It is lightened with virgin expanded polystyrene (EPS) beads of controlled particle size, coated with an E.I.A. admixture, and typically measuring between 2 and 3 mm in diameter.

This mortar is fiber-reinforced and offers excellent thermal insulation properties, making it suitable for applications where both weight reduction and insulation are desired. **[37]**

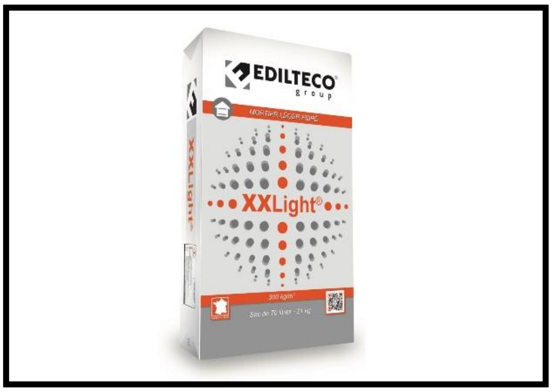


Figure I.18. Lightweight mortar in bag.
Ref: [17].

V.4.2. Applications:

XX lightweight mortar is specifically formulated to reduce structural loads—achieving a weight reduction of approximately 78% compared to traditional concrete.

It is used for: **[38]**

- Thermal and acoustic insulation of various existing substrates in both apartment buildings and single-family homes, whether in new construction or renovation projects.
- Creation of substrates for all types of floor coverings.
- Insulating screeds and underlays.
- Leveling corrections and slope formations.

Figure I.19. Lightweight mortar.
Ref: [18].

V.4.3. Benefits [39]

- Direct tile application possible after 48 hours, with no need for additional leveling.
- Lightweight formulation: 500 kg/m^3.
- Ready-to-use 70-liter bag.
- Fiber-reinforced: prevents cracking and eliminates the need for reinforcement mesh.
- Pumpable over long distances and at significant heights.
- Provides effective thermal insulation.

- Simple and easy to apply.
- Compatible with all types of floor coverings (see compatibility table).
- Dimensionally stable over time.
- Consistent mix quality maintained throughout the entire project.

VI. Previous Studies — Use of EPS and Brick in Mortar:

The following is a summary of key experimental studies and published reviews that have addressed the incorporation of Expanded Polystyrene (EPS) beads — whether new or recycled —and brick waste as a partial replacement for sand in cementitious mixtures. The studies typically focused on the effect of EPS content on: dry density, thermal conductivity, compressive and flexural strength.

VI.1. Use of EPS:

VI.1.1. "Andrea Petrella, Rosa Di Mundo, Michele Notarnicola "2020 (Recycled Expanded Polystyrene as Lightweight Aggregate): [40]

- **Content:** Evaluation of recycled EPS use as an aggregate in mortar/concrete (25%,50%).
- **Main Findings:** EPS mixtures showed a clear reduction in density and a significant improvement in thermal insulation compared to the reference. However, compressive strength decreased with higher EPS content, although acceptable strengths could still be achieved at moderate replacement levels.

VI.1.2. "Tek Raj Gyawali "2022 (Assessment of Different Properties of Lightweight Concrete using Expanded Polystyrene Beads Extracted from Thermocol Wastage): [41]

- **Content:** The study examined the effect of replacing sand/aggregate with EPS beads at progressive volumetric ratios (00%, 20%, 30%, 40%, 50%, 60%).
- **Findings:** Reported a substantial reduction in compressive strength with increasing EPS (up to 60%–90% loss at higher ratios). Significant decreases in density and notable improvements in thermal insulation were also observed. Researchers emphasized that around ~20% EPS content can sometimes yield practically acceptable properties for non-structural applications.

VI.1.3. "Lais Sousa Leão, Gabriel Pandolfi Spini, Marylinda Santos de França, Eliane Betânia Carvalho Costa " 2024 (Recycled expanded polystyrene (EPS) as an eco-friendly alternative for sand in rendering mortars): [42]

- **Content:** One study tested recycled EPS from packaging waste in mortar mixes another examined the influence of bead size and treatment on mortar properties(20%-40%).
- **Findings:** Both confirmed the feasibility of using recycled EPS for improved thermal insulation and reduced density. Mechanical properties, however, decline with higher EPS ratios. Suggested solutions include: reducing bead size, surface treatments (coating), or adding polymeric adhesives.

VI.1.4. "Anjaneya Dixit, Sze Dai Pang "2019 (Lightweight structural cement composites with expanded polystyrene for enhanced thermal insulation): [43]

- **Content & Notes:** Recent research shows that coating EPS beads with a thin layer of fly ash or adhesive/latex enhances the bond between EPS and mortar, reducing strength loss at medium replacement ratios. These approaches represent ongoing innovations to balance insulation benefits with load-bearing capacity (20%,30%,40%).

VI.1.5. "Layada Samir, Khelaifia Khadidja "2020 (Etude et caractérisation d’un béton à base de recyclats): [46]

- **Content:** One study tested recycled waste in mortar mixes another examined the influence of bead size and treatment on mortar properties.
- **Findings:** Both confirmed the feasibility of using recycled EPS for improved thermal insulation and reduced density. Mechanical properties.

VI.1.6. Critical Commentary and Comparison:

- **Most studies show a consistent trend:** a decrease in density and thermal conductivity with increasing EPS content, accompanied by a reduction in compressive and flexural strength. This aligns with our results at 20–40%

substitution levels, where the 20% mix provided the “optimal” density, and the overall properties remained “comparable” across the tested ratios.

- **EPS bead size:** Smaller beads generally yield better homogeneity and a larger contact interface with the mortar matrix, which enhances mechanical performance compared to larger beads.
- **EPS source (beads/recycled):** Recycled EPS may contain impurities or irregularities in shape, which can affect adhesion and porosity. However, recent studies confirm that good results can be obtained when recycled EPS is treated or surface-coated.
- **Mixing and curing methods:** Variations in mixing techniques (manual, mechanical, or with additives such as plasticizers or latex) influence particle distribution and overall performance. Certain mixing approaches enable higher EPS contents (up to ~30%) without a drastic drop in strength.
- **Measurement approach (volume/ weight ratios):** Differences in expressing replacement ratios by volume (%) versus mass (%) may cause apparent discrepancies in comparisons across studies.

VI.1.7. Consistency of our results with the literature:

Since our work used recycled EPS from packaging and tested volumetric replacement ratios of 20%, 25%, and 30%, our finding that 25% provided the best balance between density, strength, and insulation is consistent with many published studies. These often recommend maintaining EPS content within the 20–30% range to achieve acceptable mechanical performance while benefiting from improved thermal and mass properties.

VI.2. Use of brick:

VI.2.1. "Viviana Letelier, José Ortega, Pedro Muñoz, Ester Tarela, Giacomo Moriconi "20 18(Influence of Waste Brick Powder in the Mechanical Properties of Recycled Aggregate Concrete): [44]

This study examined the replacement of a portion of cement with brick powder in the range of 05-15%. Compressive strength is generally maintained or slightly improved at 05-10%, mainly due to limited pozzolanic activity and enhanced particle size distribution. However, at replacement levels of 15% or more, compressive strength tends to decrease as a result of reduced binder content (cement) and increased water absorption.

VI.2.2. "Qian Huang , Xiaohong Zhu "2021 (Recycling of crushed waste clay brick as aggregates in cement mortars: An approach from macro- and micro-scale investigation): [45]

In medium-strength mortar or concrete, replacing 05-10% of cement with brick powder generally keeps compressive strength within ±05% of the reference mix. At a 15% replacement level, compressive strength typically decreases by about 05-15%, accompanied by a noticeable increase in water absorption.

VI.2.3. "Tahar BENTEBBA, BARKAT, ABDEREZZAK "2006 (Valorisation des déchets de brique dans la réalisation des ouvrages en béton): [47]

Several previous studies have shown that the use of brick waste in concrete and mortar production can improve certain physical and mechanical properties of the mixtures. Research conducted at the University of Oran demonstrated that replacing 10% to 15% of cement with finely ground brick powder resulted in an increase in compressive strength by approximately 8% compared to the reference sample, while also reducing the density by about 5%, making the material lighter and more economical. Other studies have indicated that incorporating brick waste enhances internal adhesion and reduces water absorption at lower substitution levels, thereby improving the material's durability and long-term performance under various environmental conditions.

VI.2.4. Critical Commentary and Comparison:

- Our overall trend (a decrease in density with increasing brick powder content) is consistent with the literature, since recycled brick is more porous and lighter than cement or natural aggregates. The slight improvement observed at the 10% replacement level can be explained by better particle packing locally (brick powder filling voids between sand and cement grains), a behavior implicitly described when good granulometric compatibility is achieved. At 15%, however, porosity and the lack of sufficient binding paste dominate, resulting in a clear strength reduction — in line with the general conclusions reported in previous studies.
- For 5–10% replacement: the literature generally anticipates stable or slightly improved strength if the powder is sufficiently pozzolanic and granulometrically compatible. If a slight decrease was observed instead of improvement, it is likely due to:

- insufficient fineness of the brick powder (coarser particles limiting pozzolanic reactivity),
- higher effective water-to-cement ratio caused by water absorption of the powder,
- porous surfaces reducing paste bonding.
- At 15% replacement: the significant drop in compressive strength is fully consistent with reported findings (reduced amount of active binder + higher absorption).
- Any increase in water absorption observed aligns with the expected rise in porosity when the brick powder content increases, which has been explained in previous laboratory studies on mortars containing brick powder.

VI.2.5. Consistency of our results with the literature:

- **The overall trends of our results are consistent with the literature:** a reduction in density and an increase in absorption with higher brick powder content, with stable or slightly improved strength at 05–10% replacement, followed by a marked decline at 15%.
- **Scientific commentary by replacement level:**
  - **05%:** Our outcome is close to the reference; the slight reduction observed may be related to a higher effective W/B ratio or insufficient fineness of the brick powder.
  - **10%:** A local optimum appears (slight increase or stability in density/strength), attributable to improved particle packing; with finer powder, a clearer pozzolanic effect could likely be observed, as suggested in several studies.
  - **15%:** A clear drop, as expected; the literature generally advises against exceeding this threshold in conventional cementitious systems.
- Our comparison with the literature shows that replacing cement with brick powder up to 10% can maintain mechanical properties, provided that adequate particle size distribution and fineness are ensured. In contrast, replacement levels ⩾15% lead to a significant reduction in strength and an increase in absorption, with a decrease in density observed in almost all cases , findings that were experimentally confirmed in this study.

Conclusion:

In conclusion, waste represents a major challenge for all forms of biological life and human activity. Therefore, it is essential for humans, plants, animals, and other living organisms to seek effective solutions to mitigate its impact. In the field of civil engineering in particular, waste can be valorized and reused in meaningful ways, turning a problem into an opportunity. This approach not only helps to reduce environmental pollution but also offers an alternative in regions where natural aggregates are scarce, thereby contributing to more sustainable construction practices

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CHAPTER II : Characterization of materials and experimental techniques

CHAPTER I : Literature Review

II. Introduction :

In this chapter, we present the characteristics of the materials used for mortar production. Material characterization was carried out experimentally at the South Ghardaïa Public works Laboratories (LTP SUD). The method for formulating mortars based on alluvial sand, brick waste, and polystyrene waste was also discussed, as well as the results obtained.

II.1. Materials used:

- ⇨ alluvial sand.
- ⇨ Cement.
- ⇨ Water.
- ⇨ Brick waste.
- ⇨ Expanded polystyrene waste.

II.1.1. Sand:

The sand used in this experimental research is alluvial sand, with a particle size range of 0/5 mm from the **Oued M'zi** River in **Laghouat**.

Figure II.1. The sand uses.
Ref:Author 2025

II.1.1.1. Apparent density:

Apparent density refers to the mass of the material per unit volume, including both the solid particles and the voids between them. It is expressed in kg/m^3, denoted by γ_{ap} and given by:

$$\gamma_{ap} = \frac{M}{V}$$

With : M: Mass of the material (g).

V: Total volume of the sample (cm^3).

This involves filling a volume of 2000 cm^3 and determining the total mass M_T, the mass of the sample will be:

$$M = M_T - M_c$$

Where M_c is the mass of the container (g).

The results of this test are summarized:

Apparent density in g/cm^3				
Container method				
Test N°	M_c (g)	V (cm^3)	Sand	
			M_T(g)	γ_{ap}
01	1810	2000	4936	1.563
02			4930	1.560
03			4922	1.556

Table II.1: Apparent density of sand.
Ref:Author 2025

γ_{ap}= 1.559 g/cm^3

II.1.1.2. Absolute density:

Absolute density refers to the mass per unit volume of the solid material that constitutes the aggregate, excluding any voids that may exist within or between the grains. It is expressed in kg/m3, denoted by γ_{ab} and given by:

$$\gamma_{ab} = \frac{Ms}{Vs} = \frac{Ms}{V2-V1}$$

Where: Ms: Mass of solid grains (g).

Vs: Volume of solid grains (cm^3).

V_1: Initial volume of water (cm^3).

V_2: Total volume (water + solid grains) (cm^3).

Absolute density in g/cm^3				
Container method				
Test N°	M_s (g)	V_1 (cm^3)	Sand	
			V_2 (cm^3)	γ_{ab}
01	400	300	451	2.649
02			456	2.564
03			446	2.740

Table II.2: Absolute density of sand.
Ref:Author 2025

γ_{ab}= 2.651 g/cm^3

II.1.1.3 Sand equivalent:

This test is designed to separate fine particles present in the soil from coarser sand particles. The standard procedure allows for the specification of the sand equivalent value, which reflects the cleanliness and quality of the sand.

Operating Procedure:

- Sieve a quantity of sand (with a mass greater than 500 g).
- Weigh exactly 120 g of the sieved sand.
- Fill the test cylinder with the prepared solution up to the first mark (10 cm)
- Using a funnel, carefully pour the 120 g test sample into the cylinder. Shake the tube vigorously several times using the palm of your hand to eliminate air bubbles and ensure proper wetting of the sample.
- Allow the mixture to stand for 10 minutes.
- Seal the test cylinder with the rubber stopper and manually agitate it using a mechanical shaker, performing 90 strokes of 20 cm horizontal movement within 30 seconds.
- Remove the stopper, rinse it with the solution, and pour the rinse into the cylinder. Also, rinse the inner walls of the cylinder.

- Insert the irrigation tube into the test cylinder, rolling it between your thumb and forefinger while slowly rotating both the irrigation and test cylinders. Simultaneously, apply gentle pressure to stir the contents.
- Continue this operation until the washing solution reaches the second mark.
- Let the sample stand undisturbed for 20 minutes.

❖ **Visual Sand Equivalent (VSE):**

- After 20 minutes of sedimentation, measure the height (H_1) from the top surface of the flocculated suspension to the bottom of the test tube using a ruler.
- Also measure with the ruler the height (H_2) between the upper level of the sediment layer (settled sand) and the bottom of the test tube.

$$\text{VSE} = \frac{H2}{H1} \times 100$$

❖ **Piston Sand Equivalent (PSE):**

- Insert the piston into the test cylinder and allow it to descend gently until it rests on top of the sediment layer. Once in position, lock the piston sleeve and carefully remove the piston from the cylinder.
- Insert a ruler into the notch located on the piston head, ensuring that the zero mark is flush against the inner face of the piston.
- Record the reading H_2', which corresponds to the height of the sedimented layer.

$$\text{PSE} = \frac{H_2'}{H1} \times 100$$

Test N°	H_1 (cm)	H_2 (cm)	VSE (%)
01	12	11.4	95
02	10.6	10	94.33

Table II.3: The results of the equivalent of the sand used (visual).
Ref:Author 2025

<u>VSE</u> = 94.33%

II.1.1.4 Granulometric analysis:

Particle size analysis by sieving is a set of procedures aimed at separating the components of a granular sample based on their particle size. This is achieved using a series of standard sieves in order to obtain a representation of the dry mass distribution of the particles as a function of their size.

Granulometric analysis allows for the determination of particle dimensions and the proportion (by weight) of particles corresponding to each size range.

Sieve (mm)	Partial refusals (g)	Cumulative refusals (g)	Cumulative refusals (%)	Sieves (%)
5	00	00	00	100
4	2	2	0.02	99.8
2	15.5	17.5	0.17	99.83
1	25.5	43	0.43	99.57
0.5	106	149	1.49	98.51
0.25	293	442	4.42	95.58
0.125	52	494	4.94	95.06
0.08	3	497	4.97	95.03
Bottom	2	499	4.99	95.01

Table II.4: Granulometric analysis of used sand.
Ref:Author 2025

The results obtained are summarized in the following table:

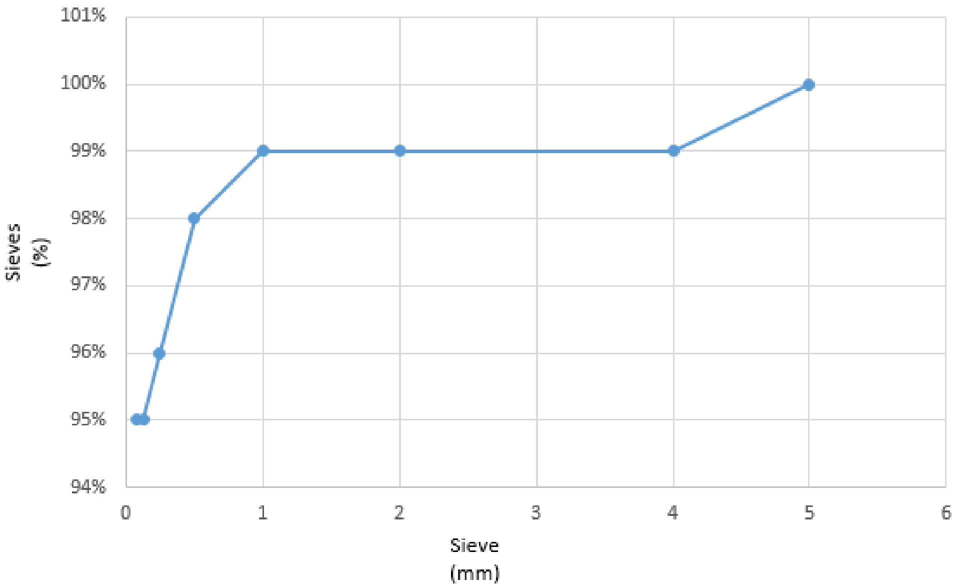

Figure II.2. The granulometric curve of the sand used.
Ref:Author 2025

II.1.2. Cement:

The cement used is CEM II/B-L 32.5 N produced by the LAFARGE cement plant in Algiers (CHAMIL), a gray cement suitable for standard concrete and general masonry applications. It is certified and complies with both the Algerian standard [NA 442-2013] and the European standard [EN 197-1].

Figure II.3. Cement bag used.
Ref: https://www.lafarge.dz/ciment-chamiltm

Chemical analyses	Value
Loss on ignition (%)	13.0±2
Sulfate content (SO3) (%)	2.5±0.5
Magnesium oxide content (MgO) (%)	Max 5%
Chloride content (NA5042) (%)	<0.1

Setting time at 20°	Value
Start of setting (min)	150±30
End of setting (min)	250±50

Mineralogical composition of clinker	Value
C3S (%)	60±3
C3A (%)	8±3

Compressive strength	Value
02 days (MPa)	≥ 16.0
28 days (MPa)	≥ 32.5

Physical properties	Value
Normal consistency (%)	27±2.0
Fineness according to the Blaine method (cm2 /g)	4300-5500
28-day shrinkage (µm/m)	< 1000
Expansion (mm)	≤ 3.0

Tables II.5: Technical characteristics of the cement used.
Ref: https://www.lafarge.dz/ciment-chamiltm

II.1.3. Mixing water:

The water used for mortar mixing is potable water sourced from the public water supply of Ghardaïa. Potable water is suitable for use in the formulation of both concrete and mortar, as long as it meets the relevant quality standards.

II.1.4. Brick Waste:

The first additive used is red brick waste, which consists of crushed brick fragments. The crushing was carried out at the South Ghardaïa Public Works Laboratory (LTP SUD) using a mechanical crusher.

II.1.4.1. Brick crushing process:

The brick waste was first fed into a stone crushing machine (crusher) to produce small brick granules.

After the initial crushing, the resulting heterogeneous mixture of brick powder and granules was sieved using Sieve No. 1, in order to separate finer particles and obtain granules of a more uniform and smaller size.

Figure II.4. Brick powder used.
Ref:Author 2025

II.1.4.2. Brick crushing process by micro-Deval machine:

The final stage of the brick crushing process was carried out using a Micro-Deval machine. In this step, the brick particles previously passed through Sieve No. 1 were further refined. A total of 800 grams of brick fragments were mixed with 5000 grams of iron balls, and the drum was rotated 12,000 cycles. As a result, we obtained a heterogeneous mixture composed of brick powder and very fine granules, derived from crushed clay bricks.

Note:

The Micro-Deval machine is typically used to evaluate the wear resistance of aggregates. It consists of stainless steel cylinders that rotate at a constant speed, allowing the aggregate sample to undergo a controlled abrasion cycle. The test is mainly used to assess the hardness and durability of aggregates by measuring the percentage of material lost during the process. Although this is the primary function of the device, it was used in this study as an alternative method to crush brick waste, due to the limited availability of specialized crushing equipment.

Figure II.5. Brick pellets in the mold of the Micro Deval machine with iron pellets.
Ref:Author 2025

Figure II.6. The Micro Deval Machine.
Ref: https://www.matest.com/fr/granulats/machines-abrasion/micro-deval-machines

II.1.4.3. The density of brick waste:

Brick waste characterization tests are carried out at the Ghardaïa LTPS .

Absolute density ρ_{ab}	Apparent density ρ_{ap}
2.47 g/cm3	1.05 g/cm3

Table II.6: Density of the brick used.
Ref:Author 2025

II.1.4.4. Granulometric analysis of brick waste:

Sieve (mm)	Partial refusals (g)	Cumulative refusals (g)	Cumulative refusals (%)	Sieves (%)
5	00	00	00	100
2	00	00	00	100
1	00	00	00	100
0.4	1.03	1.03	0.01	100
0.2	0.54	1.57	0.015	100
0.1	6.93	8.5	0.085	99.92
0.08	32.60	41.1	0.411	96.59

Table II.7: Granulometric analysis of brick wast used.
Ref:Author 2025

II.1.5. Polystyrene Waste:

The expanded polystyrene (EPS) used in this experiment was collected from packaging waste of household appliances, obtained from local appliance stores. The collected material was then manually shredded using a domestic blender, in the absence of specialized equipment.

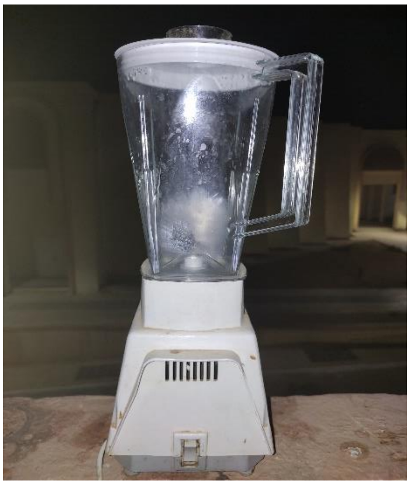

Figure II.7. Home Blender used to cut the polystyrene.
Ref:Author 2025

II.1.5.1. Technical characteristics of Expanded Polystyrene Waste:

- Dimensional Stability: Expanded polystyrene (EPS) exhibits excellent dimensional stability, remaining virtually unaffected by a wide range of environmental conditions. The maximum dimensional variation of EPS foam is typically less than 2%.
- Dielectric Properties: EPS possesses a dielectric strength of approximately 2 kV/mm. Its dielectric constant, measured within the frequency range of 100–400 MHz, ranges between 1.02 and 1.04 at bulk densities from 0.02 to 0.04 g/cm³. Molded EPS can be treated with antistatic agents to meet the requirements of the electronics industry.
- Thermal Insulation: Due to its closed-cell structure composed of approximately 98% air, EPS exhibits very low thermal conductivity, which provides excellent thermal insulation performance. For EPS foam with a density of 0.02 g/cm³, the thermal conductivity is typically in the range of 0.035–0.037 W/(m·K) at 10°C.
- Surface Properties: The manufacturing process of EPS allows for smooth and low-porosity surface finishes, which are beneficial for construction applications.

To evaluate the suitability of the expanded polystyrene waste for use in mortar formulation, a series of experimental tests were conducted, including:

- Density determination

II.1.5.2. The density of EPS waste:

The characterization tests for determining the density of expanded polystyrene (EPS) waste were conducted at the Laboratoire des Travaux Publics du Sud (LTPS) in Ghardaïa. These tests aimed to assess the material's physical properties and ensure its suitability for incorporation into lightweight mortar formulations.

Apparent density ρ_{ap}
0.015 g/cm3

Table II.8: Density of EPS used.
Ref:Author 2025

II.2. Composition of mortars:

In the initial stage, each component of the mortar was individually weighed for every formulation described in the table. This step ensures accurate proportioning of materials in order to achieve consistent and reliable results across all test specimens.

II.2.1. Composition of the control mortar:

Sand	Cement	Water
1350 g	450 g	225 ml

Table II.9: The optimal composition of the witness mortar.
Ref:Author,LTPS 2025

II.2.2. Composition of mortar with EPS waste:

To determine the required weight of expanded polystyrene (EPS) in the mortar formulation, the rule of three (proportional method) was applied. This method enables the calculation of the corresponding EPS mass based on its replacement percentage relative to the reference sand mass.

Example :

-Volume of a single test tube: (4×4×16) = 256 cm^3.

-Volume of 03 test tube: 3×256=768 cm^3.

We have: ρ_{ps}=0.015 g/cm^3.

And as the dosage of polystyrene is relative to the total volume:

768 cm^3 ⟶ 100%

V_{ps} 20% ⟶ So V_{ps}=153.6 cm^3.

$M_{ps} = \rho_{ps} . V_{ps} = 0.015 \times 153.6 = 2.304$ g.

EPS%	Sand (g)	Cement (g)	EPS (g)	Water (ml)
20%	1347.69	450	2.304	250
25%	1347.12	450	2.88	245
30%	1346.54	450	3.456	240

Table II.10: Compositions of mortars for percentages of EPS waste.
Ref:Author 2025

II.2.3. Composition of mortar with EPS and Brick waste:

Note: <u>All samples contain 25% polystyrene.</u>

Brick%	Sand (g)	Cement (g)	Brick (g)	Water (ml)
5%	1347.12	427.5	22.5	250
10%	1347.12	405	45	250
15%	1347.12	382.5	67.5	250

Table II.11: Compositions of mortars for percentages of EPS and Brick waste. Ref:Author 2025

II.3. Preparation of the mortar:

II.3.1. Mixing the mortar components:

The mortar components were mixed using a 5-liter capacity standard mortar mixer, following the sequence below:

- First, cement, water, and brick waste were introduced into the mixer and blended for 30 seconds at low speed.
- Next, the pre-mixed sand and EPS were gradually added over a period of 10 seconds.
- The mixing continued for 30 seconds at high speed, followed by a 15-second pause to scrape down the sides and bottom of the mixing bowl.
- The process was resumed with 30 seconds at low speed, then 1 minute at high speed, ensuring proper homogenization of the mortar.

The prepared mortar was immediately poured into molds following the workability test, using standard molds in our case.

Figure II.8. Electric mixer used in mortar manufacturing [LTPS-Gardaia]. Ref:Author 2025

II.3.2. Casting the specimens:

In this study, a total of 42 mortar specimens were cast using standard molds with dimensions of (04x04x16) cm.

Figure II.9. Mold (04x04x16) cm.
Ref:Author 2025

Steps of specimen molding

The molding of the test specimens was carried out in the following three stages:

- **First step:**

The molds were assembled and lubricated using 40-gauge motor oil to prevent the mortar from adhering to the mold walls.

- **Second step:**

The freshly prepared mortar was poured into the molds, which were then placed onto the vibration (or impact) device.

Figure II.10. Fill the mold and place it in the shock device.
Ref:Author 2025

- **Third and final step:**

The vibration device was activated, allowing the mold to vibrate for 60 seconds. The device automatically stopped after this duration.

II.3.3. Demolding and curing of test specimens:

After 24 hours, the specimens were demolded and transferred to a curing room maintained at a temperature of 20 ± 5 C° and a relative humidity of 97 ± 5%, where they were kept for a period of 28 days.

Figure II.11. Demolding and Naming the test pieces to store in the humid chamber. Ref:Author 2025

II.4. Tests Performed:

II.4.1. Physical test:

- **Dry density test:**

The dry density of lightweight mortar is considered one of its most critical physical properties. This parameter allows for the classification of the mortar and the identification of its suitable range of applications. It is defined as the ratio of the mass of the sample to its apparent volume in a completely dry state. The dry mass of the hardened mortar specimens is determined after a curing period of 28 days.

The dry density is measured immediately before conducting the mechanical tests, using the following formula:

$$\rho=(M/V)$$

- ✓ M: mass of the test specimen (g).
- ✓ V: volume of the test specimen (cm^3).

II.4.2. Mechanical tests:

- ❖ **Flexural tensile Strength test:**

Specimens with dimensions of (04x04x16) cm were used to determine the flexural tensile strength of the mortar. The test was carried out using a flexural strength testing machine equipped with a three-point bending apparatus, compliant with current standards. This method is commonly used to evaluate the tensile strength of mortars and involves applying a load until failure occurs through bending.

The flexural tensile strength of the hardened mortar was assessed after 28 days. The machine used can apply loads of up to 20 kN. The tensile strength value recorded is the average of the failure stresses of three tested specimens.

The bending strength is calculated according to the following equation:

$$\mathbf{R_t=(1.5.F_f.L)/b^3}$$

R_t: Tensile strength in MPA.

F_t: Breaking load in N.

L: Distance between axes of the support rollers of the test piece 40x40x160 mm (L= 100 mm).

b: Width of the square section of the prism in mm (b = 40 mm).

Figure II.12. Flexural failure mechanical test setup. Ref:Author 2025

Figure II.13. composition of a mortar found in our mortar. Ref:Author 2025

- **Compression Strength test:**

The compressive strength of the mortar is evaluated using the two halves obtained from the specimens previously subjected to the flexural test. The objective of this test is to determine the compressive strength by applying an increasing load to the specimen until failure. The failure load corresponds to the maximum load recorded during the test.

Compressive strength measurements were carried out at 28 days using a hydraulic compression testing machine with a capacity of up to 200 kN, equipped with a compression device specifically designed for mortar specimens. The compressive strength value considered is the average crushing stress obtained from three test specimens.

Compressive strength is calculated using the following equation:

$$\mathbf{R_c = F_c/b^2}$$

R_c: compression strength in (MPA).

F_c: Breaking load in (N).

b: The side of the test piece is equal to 40 mm.

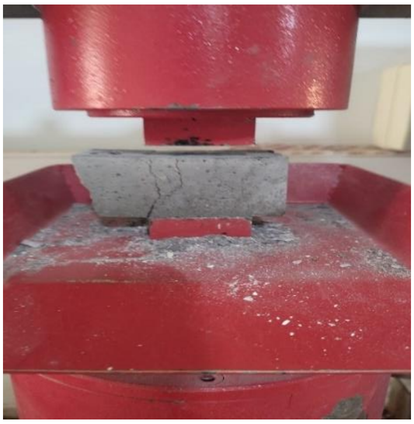

Figure II.15. Device for the mechanical compression test. Ref:Author 2025

Figure II.14. Compression test carried out on the specimens (04x04x16) cm. Ref:Author 2025

II.4.3. Thermal test:

We conducted this experiment at the Process Engineering Laboratory of the University of Ghardaïa.

II.4.3.1. The samples used:

We fabricated mortar panels with dimensions of (40×25×03) cm at the LTPS Ghardaia. Using a drill with a circular bit of 4 cm in diameter, we created circular openings in the panels, resulting in cylindrical samples with a diameter of 04 cm and a height of 03 cm.

II.4.3.2. The device used: WL 372 – Heat Conduction Apparatus:

In our experiments, the WL 372 – Heat Conduction Apparatus is used as an alternative to conventional devices that are specifically designed for construction materials, and employed to determine various thermal properties of construction materials, including thermal diffusivity, thermal conductivity, and volumetric heat capacity. The objective of using this alternative apparatus is to analyze and compare the variation in thermal conductivity (λ) values, rather than focusing solely on the absolute values themselves.

The WL 372 experimental unit enables the investigation of the fundamental laws and thermal properties of solid materials through hands-on experimentation. The apparatus includes two separate setups: one for linear conduction and another for radial conduction, each equipped with dedicated heating and cooling elements. Various samples with differing thermal conductivities can be installed in the linear conduction section for comparative analysis. The unit is also equipped with a display and control module, along with a set of thermocouples that measure temperature at specific locations. The temperature data can be observed in real-time on the digital display and simultaneously transferred to a computer via USB connection for further processing and analysis using the accompanying software.

Figure II.16. WL 372 Machine
.Ref:Author 2025

II.4.3.3. Working Method:

We conducted this experiment at the Process Engineering Laboratory of the University of Ghardaïa.

- Five cylindrical specimens of mortar containing different proportions of EPS were prepared, each with a diameter of 04 cm and a height of 03 cm.

- The five specimens included:
  1. Control specimen (00% polystyrene).
  2. Specimen with 20% polystyrene.
  3. Specimen with 25% polystyrene.
  4. Specimen with 30% polystyrene.
  5. Specimen with 25% polystyrene + 10% crushed brick (as a percentage of cement mass).
- The linear conduction setup of the WL 372 device was used to carry out the experiment.
- The selected specimen was mounted securely on the device, ensuring full surface contact with the central heating element.
- The peripheral cooling system was activated to simulate a temperature gradient between the center and the edge of the sample.
- The heating element was turned on to initiate transient heat conduction through the specimen.
- Temperature sensors embedded in the radial direction recorded the temperature distribution over time.
- The temperature evolution was monitored and recorded continuously via the digital interface and computer software connected via USB.
- The experiment was stopped once a near-steady temperature distribution was observed.
- The specimen was removed, and the procedure was repeated for the remaining samples under the same conditions.
- All collected temperature-time data were stored for further analysis and comparison.

Conclusion:

In this chapter, we have presented the different materials used in our study, along with the detailed compositions of the mortar formulations. Furthermore, we outlined the experimental procedures employed to assess the physical, mechanical, and thermal properties of the developed mortar specimens.

CHAPTER III :Results and discussions

CHAPTER III :Results and discussions

III. Introduction:

In this chapter, we present the results of the experimental work conducted at the LTPS laboratory in Ghardaïa and University of Ghardaïa .The objective of this study is to evaluate the physical and mechanical properties of mortars incorporating brick and polystyrene waste. To assess the influence of these additives on mortar performance, the obtained results are compared with those of a reference mortar without any additives.

III.1. Physical properties:

III.1.1. Dry Density Results:

- **Polystyrene waste variation:**

The dry density was measured after removing the specimens from the molds and leaving them exposed to ambient air for 20 minutes to reach their nominal moisture content prior to drying.

The results of the physical tests for the different mortar variants incorporating varying proportions of polystyrene waste are presented in the following table and corresponding histograms. These results reflect the density values of the specimens after 28 days of curing.

Age	The Types	Average mass (g)	Average volumes (cm^3)	Density (g/cm^3)
28 day	Control (00% EPS)	546.3	256	2.13
	20% EPS	440.8		1.72
	25% EPS	422.82		1.65
	30% EPS	413.8		1.61

Table III.1: Densities of the different variants of EPS in the hardened state. Ref:Author 2025

The Types	Density (g/cm^3)
Control (00% EPS)	2.13
20% EPS	1.72
25% EPS	1.65
30% EPS	1.61

Table III.2: The average density of the different variants of EPS. Ref:Author 2025

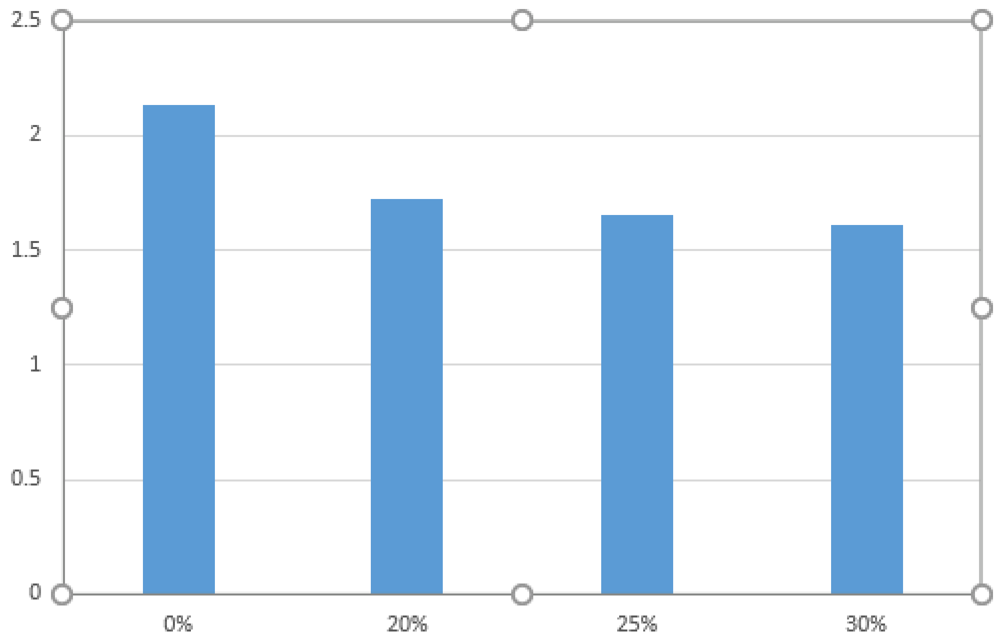

Figure III.1. Density in the cured state as a function of polystyrene content at 28 days. Ref:Author 2025

From the use of EPS as a partial replacement for sand, it was observed that the optimal density was achieved at a 20% EPS substitution rate. However, the difference in density between the different substitution rates remained relatively small.

Interpretation of results:

The figure illustrates that the dry density of the mortar decreases slightly as the proportion of expanded polystyrene (EPS) replacing quarry sand increases. The density progressively declines with increasing EPS content (20%, 25%, 30%). Although the reduction is relatively small, it becomes noticeable due to the lightweight nature of EPS particles. As the amount of EPS increases, the overall density of the mixture decreases accordingly.

- **EPS and brick waste variation:**

Note: All samples contain 25% polystyrene.

Age	The Types	Average mass (g)	Average volumes (cm^3)	Density (g/cm^3)
28 day	Control (00% brick)	422.82	256	1.65
	05% brick	409.45		1.59
	10% brick	412.51		1.61
	15% brick	401.4		1.56

Table III.3: Densities of the different variants of brick and 25% of EPS. Ref:Author 2025

The Types	Density (g/cm^3)
Control (00% brick)	1.65
05% brick	1.59
10% brick	1.61
15% brick	1.56

Table III.4: The average density of the different variants of brick and 25% of EPS. Ref:Author 2025

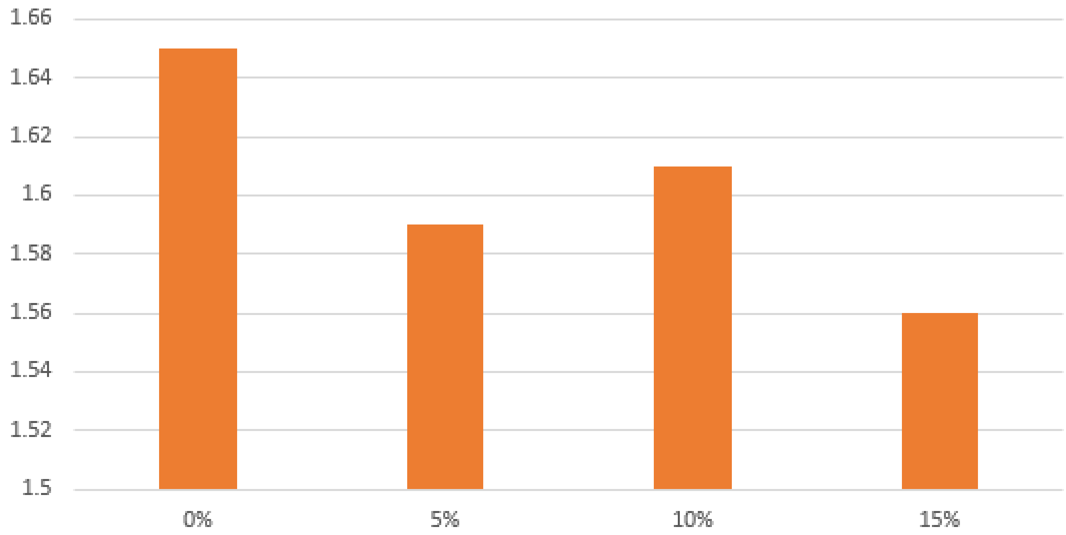

Figure III.2. Density in the cured state as a function of brick and 25% of EPS content at 28 days. Ref:Author 2025

Interpretation of results:

The analysis of the recorded results reveals the following trends:

- The addition of crushed bricks leads to a noticeable decrease in dry density compared to the control mortar. Specifically, the inclusion of 05% brick waste results in an approximate 07% reduction in density.
- Increasing the brick content to 10% leads to a slight increase in density by around 2% compared to the previous 05% mixture.
- At 15% brick content, the mortar exhibits the lowest recorded dry density among all formulations in both series of experiments.

From the use of crushed bricks as a partial replacement for cement and expanded polystyrene (EPS) as a substitute for sand, it can be concluded that the optimal dry density is achieved when the mixture contains 10% brick waste and 25% EPS.

III.2. Mechanical properties:

III.2.1. The results of Tensile strengths by flexion:

To evaluate the effect of varying percentages of expanded polystyrene (EPS) and brick waste on the mechanical properties of the mortar, we present and analyze the results of flexural and compressive strength tests. The measurements were conducted on different specimens prepared for each formulation. It is important to note that the values provided in the following table and histograms represent the average results obtained from each test configuration.

- **Polystyrene waste variation:**

The Types	Age	Flexural strength (MPa)
Control	28 day	8.56
20% EPS		5.33
25% EPS		5
30% EPS		4.6

Table III.5: Effect of polystyrene on flexural strength. Ref:Author 2025

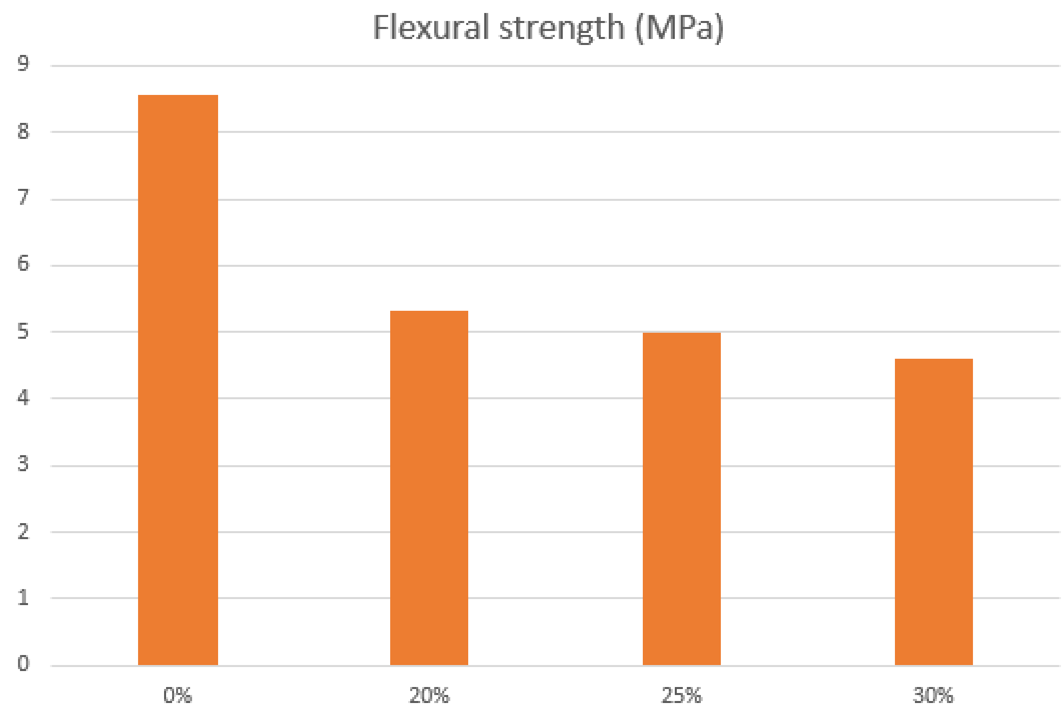

Figure III.3. Effect of polystyrene on flexural strength at 28 days. Ref:Author 2025

Interpretation of results:

The results illustrated in the graph show the variation in flexural strength as a function of the percentage of expanded polystyrene (EPS) after 28 days of curing. A general decrease in flexural strength is observed with increasing EPS content. This reduction is primarily attributed to the progressive substitution of sand with lightweight EPS particles, which weakens the cohesion and load-bearing capacity of the mortar.

- **EPS and brick waste variation:**

Note: All samples contain 25% polystyrene.

The Types	Age	Flexural strength (MPa)
Control	28 day	5
05% brick		4.45
10% brick		5.12
15% brick		4.88

Table III.6: Effect of brick waste and 25% of EPS on flexural strength. Ref:Author 2025

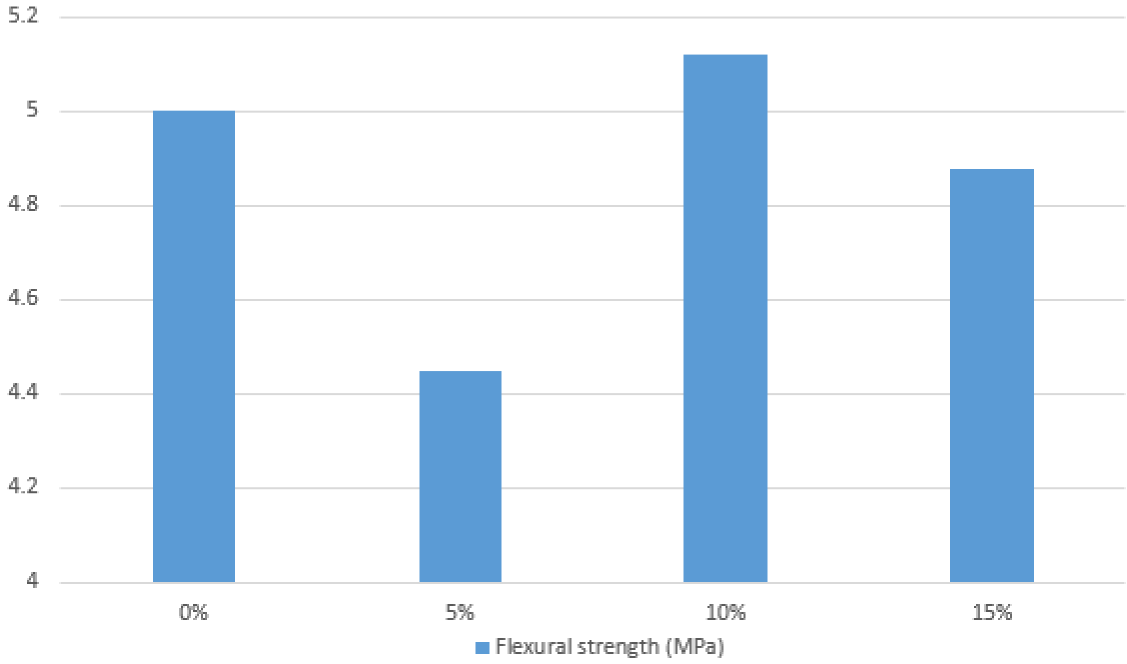

Figure III.4. Change in flexural strength after 28 days and percentage of brick and EPS waste. Ref:Author 2025

Interpretation of results:

The results presented in the graph illustrate the evolution of flexural strength across different mixtures. We observe that, in general, the flexural strength values remain relatively stable with the addition of PET and brick waste compared to the control mix. However, a noticeable decrease in flexural strength is recorded in the sample containing 05% brick waste, indicating a potential negative effect at this substitution level.

III.2.2. The results of Compressive Strengths:

- **Polystyrene waste variation:**

The Types	Age	Compressive Strength (MPa)
Control	28 day	33
20% EPS		27.66
25% EPS		26.26
30% EPS		25.83

Table III.7: Effect of polystyrene on Compressive Strength. Ref:Author 2025

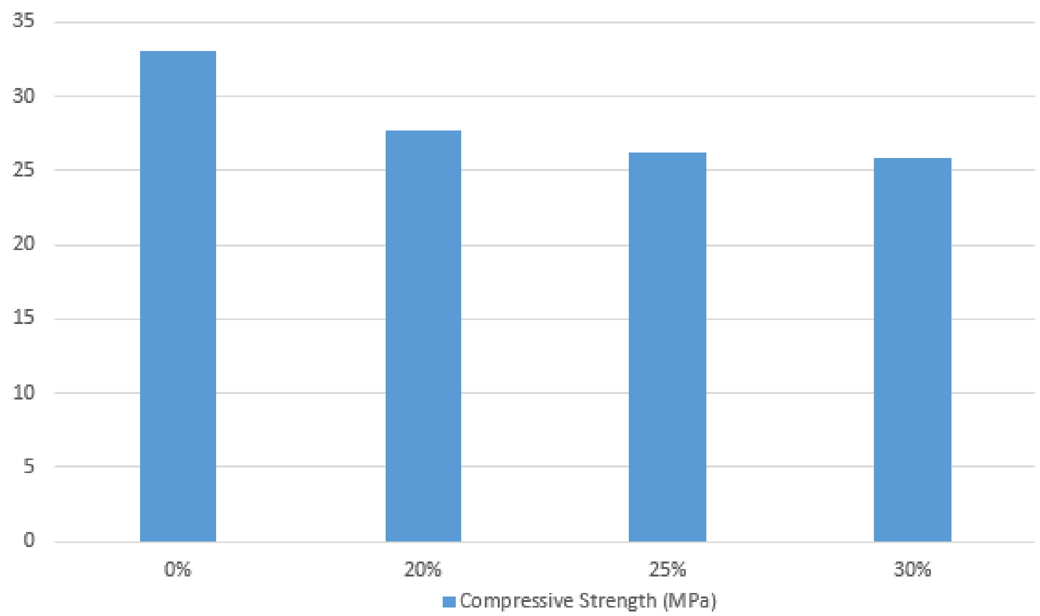

Figure III.5. Effect of polystyrene on Compressive Strength at 28 days. Ref:Author 2025

Interpretation of results:

The graph illustrates the variation in compressive strength as a function of EPS content after 28 days of curing. A clear decrease in compressive strength is observed with increasing EPS percentage. This reduction can be attributed to the presence of additional voids introduced by the EPS particles, leading to increased air content within the matrix after hardening. Consequently, the overall compactness and strength of the mortar are diminished.

❖ **EPS and brick waste variation:**

Note: All samples contain 25% polystyrene.

The Types	Age	Compressive Strength (MPa)
Control	28 day	26.26
05% brick		24.5
10% brick		26.2
15% brick		22.3

Table III.8: Effect of brick waste and 25% of EPS on Compressive strength. Ref:Author 2025

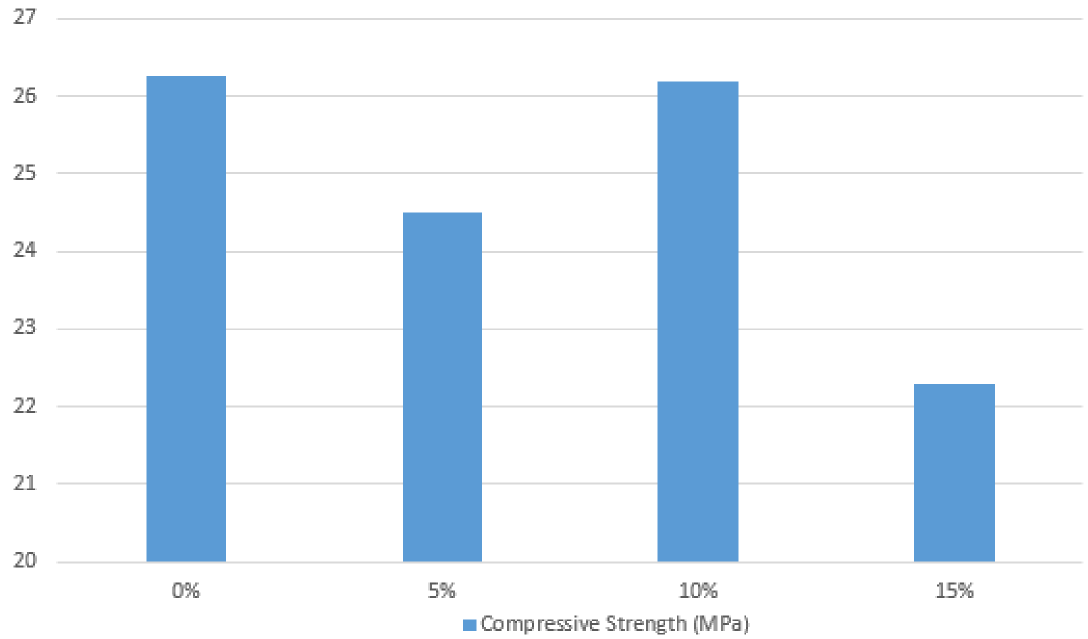

Figure III.6. Variation of compressive strength after 28 days as a function of brick and EPS waste percentage. Ref:Author 2025

Interpretation of results:

The graph indicates that the compressive strength values are slightly lower than those recorded for the flexural strength. This discrepancy may be attributed to the presence of polystyrene particles within the mortar matrix. The type of expanded polystyrene used in this study is irregular in shape and possesses a smooth surface, which limits its bonding capacity with the surrounding sand particles. Consequently, the cohesion within the mixture is weakened. Additionally, the partial substitution of cement with brick waste may contribute to a reduced chemical reaction between the cement and water. The lower cement content may not be sufficient to sustain a complete hydration process, thereby affecting the overall mechanical performance of the mortar.

III.2.3. The results of Thermal test :

Power (W)	Per (%)	T1 (C°)	T2 (C°)	T3 (C°)	Contact point 01 (C°)	Contact point 02 (C°)	T7 (C°)	T8 (C°)	T9 (C°)	λ (W/m·K)
6W	00% Poly	119.5	119	118.4	118	31.1	30.6	30.2	29.8	2
4.5W	20% Poly	99.8	99.4	99	98.8	27.6	27.4	27	26.7	1.85
4.5W	25% Poly	104.9	104.4	103.8	103.5	29.5	29.2	28.7	28.2	1.77
4.5W	30% Poly	120.5	120.1	119.7	119.5	28.1	27.9	27.5	27.1	1.42
4.5W	25% Poly+10% Brik	107.7	107.5	107.3	107.2	26.4	26.3	26.1	25.9	1.6

Table III.9: Effect of EPS and brick waste on Heat transfer. Ref:Author 2025

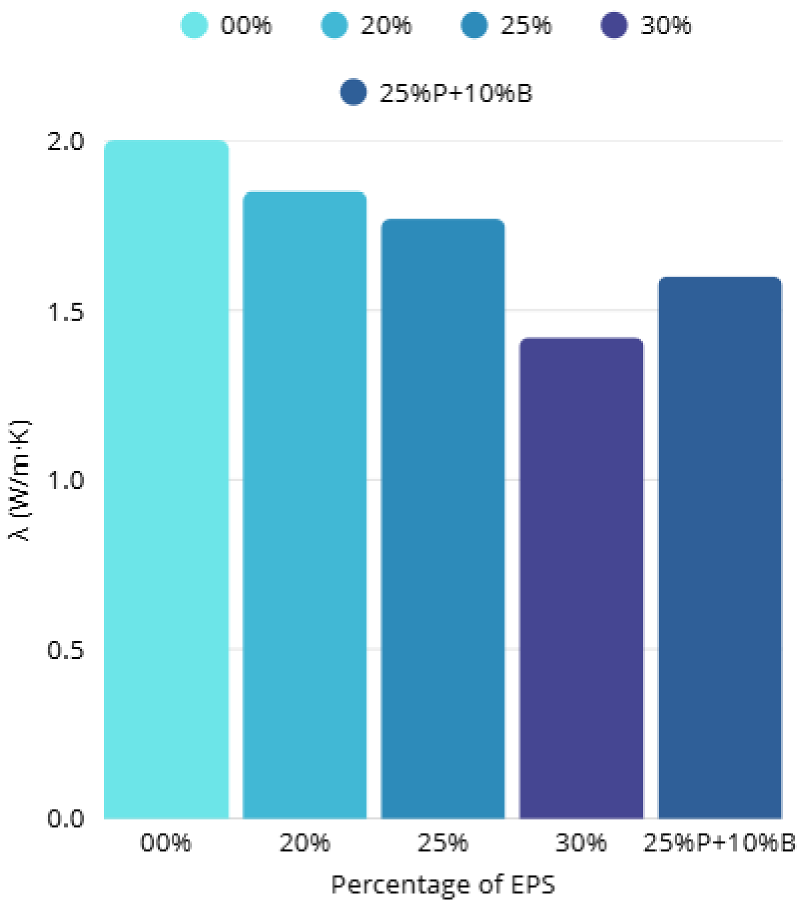

Figure III.7. Variation of Heat transfer as a function of brick and EPS waste percentage. Ref:Author 2025

Interpretation of results:

The graph indicates that the incorporation of polystyrene and brick aggregates into the mix clearly contributes to improving the insulating properties of the materials.

- In the reference sample (00% EPS), the λ value was about 2.0 W/m·K.
- With the addition of 20% EPS, the value decreased to approximately 1.85 W/m·K, representing a reduction of around 10% compared to the reference.
- At 25% EPS, the value continued to decrease to about 1.77 W/m·K, corresponding to a 15% reduction.
- At 30% EPS, the lowest thermal conductivity coefficient was recorded at around 1.42 W/m·K, which represents a reduction of nearly 30% compared to the reference sample. This highlights the direct effect of polystyrene in enhancing thermal insulation due to its porous nature and light weight.
- For the mix containing 25% EPS + 10% brick, the λ value decreased to about 1.6 W/m·K, which is about 20% lower than the reference, slightly lower than the 25% EPS mix without brick, but still higher than the 30% EPS mix. This indicates that the inclusion of brick, as a recycled material, further enhances the thermal benefit of polystyrene thanks to its insulating nature.

Overall, the results confirm that increasing the proportion of recycled polystyrene leads to a gradual and significant improvement in thermal insulation, with maximum efficiency achieved at 30%. Meanwhile, combining brick with polystyrene provided an intermediate thermal performance between the reference and the 30% EPS mix, underlining the importance of controlling additive proportions to achieve a balance between mechanical and thermal properties.

Conclusion:

In light of the previous results concerning mechanical strength and thermal insulation, it is evident that the use of recycled polystyrene and brick can effectively contribute to improving certain thermal properties of concrete while maintaining acceptable physical properties, particularly when added in moderate proportions not exceeding 25% for polystyrene and 10% for brick. Samples containing low proportions of polystyrene and brick demonstrated acceptable performance in terms of compressive strength, reflecting better compactness and internal stability of the material. However, when the substitution rate is excessively increased, it may lead to performance degradation, which highlights the need to adhere to an optimal replacement ratio in order to ensure a balance between technical quality and positive environmental impact.

General Conclusion

Mortar is considered one of the most essential materials used in the construction sector. The accumulation of various types of waste represents an increasing challenge, while their optimal utilization constitutes a practical solution for achieving sustainability. In this work, a study was conducted on the valorization of brick waste and expanded polystyrene (EPS) in mortar production. The main objective was to evaluate the combined effect of these two types of waste on the physical and mechanical properties of mortar. The study was based on comparing the behavior of a reference (ordinary) mortar with that of mortar containing brick powder as a partial replacement of cement ranging from 5% to 15% by weight, and EPS waste as a partial replacement of sand ranging from 20% to 30% by weight. The performance in the hardened state was evaluated, taking the reference sample as the basis for comparison.

Previous studies have shown the following results:

- The addition of brick powder increases density and reduces water absorption. However, increasing the percentage of brick powder gradually decreases density and increases absorption.
- The use of EPS results in a lightweight mortar with higher porosity, where increasing EPS content leads to greater internal voids.
- When combining brick powder and EPS in the mixture, results showed that replacing 10% of cement with brick powder provided the best mechanical resistance, while compressive and flexural strengths slightly decreased compared to the reference sample.
- Mortar containing EPS exhibited lower density and improved thermal properties, especially at 25%, where thermal performance was enhanced compared to the reference mortar.

Accordingly, it can be concluded that incorporating brick and EPS waste into mortar production yields acceptable results in terms of both mechanical and thermal properties, making it suitable for certain construction applications, particularly those not subjected to significant mechanical loads.

General Conclusion

The primary aim of this research is to reduce excessive consumption of sand and cement, and to minimize costs, within the framework of contributing to environmental goals related to lowering carbon dioxide emissions.

Recommendations and future perspectives:

- Broaden the study of the durability of mortars containing such additions.
- Evaluate the thermal conductivity of these mixtures using specialized devices and work on enhancing their performance.
- Investigate additional substitution rates of brick and EPS to obtain more comprehensive results

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Appendix :


ALGÉRIE
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• Un ingrédient idéal pour la composition des mortiers de finition.
MEMBRE DE
HOLCIM

APPLICATIONS RECOMMANDÉES

- Construction de maisons individuelles.
- Tous travaux de maçonnerie.

FORMULATION CONSEILLÉE

	Ciment 50 kg	Sable (sec) 0/5	Gravillons (sec) 8/15mm	Gravillons (sec) 15/25mm	Eau (litres)
Dosage pour béton	X 1	+ X7	+ X5	+ X4	+ 25 L

	Ciment 50 kg	Sable Correcteur 0/1mm	Sable (sec) 0/4mm	Eau (litres)
Mortier de briquetage	X 1	+ X6	+ X9	+ 35 L
Mortier de finission	X 1	+ X9	+ X6	+ 35 L

Remaque: un bidon = 10 Litres

CARACTÉRISTIQUES TECHNIQUES

- Analyses chimiques

	Valeur
Perte au feu (%) (NA5042)	13.0±2
Teneur en sulfates (SO3) (%)	2.5±0.5
Teneur en oxyde de magnésium MgO (%)	Max 5%
Teneur en Chlorures(NA5042) (%)	< 0,1

- Temps de prise à 20° (NA 230)

	Valeur
Début de prise (min)	150±30
Fin de prise (min)	250±50

- Composition minéralogique du Clinker (Bogue)

	Valeur
C3S (%)	60±3
C3A (%)	8±2

- Résistance à la compression

	Valeur
7 jours (MPa)	≥ 16.0
28 jours (MPa)	≥ 32.5

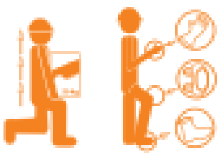
- Propriétés physiques

	Valeur
Consistance Normale (%)	27±2.0
Finesse suivant la méthode de Blaine (cm²/g) (NA231)	4 300 - 5 500
Retrait à 28 jours (µm/m)	< 1 000
Expansion (mm)	≤ 3.0

CONSIGNES DE SÉCURITÉ

1- **PROTÉGEZ VOTRE PEAU** : Portez les équipements adaptés dans vos chantiers: casques, lunettes, gants, genouillères, chaussures et vêtements de sécurité.

2- **MANUTENTION** : levez le sac en pliant les genoux et en gardant le dos droit.



MEMBRE DE HOLCIM

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Tél: 021 98 55 55

LAFARGE لافارج

Appendix

الجمهورية الجزائرية الديمقراطية الشعبية

République Algérienne Démocratique et Populaire

وزارة التعليم العالي والبحث العلمي

Ministère de l'Enseignement Supérieur et de la Recherche Scientifique

جامعة غرداية

Faculté des Sciences et de la Technologie
Département Hydraulique et Génie Civil

كلية العلوم و التكنولوجيا
قسم العلوم والتكنولوجيا

Université de Ghardaïa

Filière : Génie Civil
Spécialité : Structures

Autorisation d'impression d'un mémoire du Master

Les membres du jury	Nom et prénom	Signature
Le président de jury	Nessil Hamid	
Examinateur 1	Aziez Mohammed Nadjib	
Encadrant	LAROUI Abdelbasset	

Je soussigné Mr : Nessil Hamid

Président de jury des étudiants :

1. Boulghiti Ziad

Thème

Study of thermal and mechanical characteristics of different formulation of lightweight polystyrene mortar

J'autorise les étudiants mentionnés ci-dessus d'imprimer et déposer leur manuscrit final au niveau du département.

Président de jury :

Le chef de département :

بولعزيز الطيب
رئيس قسم الري
و الهندسة المدنية

I am Sorry !!!!!