PEOPLE'S DEMOCRATIC REPUBLIC OF ALGERIA
MINISTRY OF HIGHER EDUCATION AND SCIENTIFIC RESEARCH
ABDELHAMID IBN BADIS UNIVERSITY OF MOSTAGANEM
FACULTY OF SCIENCES AND TECHNOLOGY
DEPARTMENT OF CIVIL ENGINEERING

N° of order: M …………/GC /2025

Final year project

Sector: Civil Engineering

Specialty: Materials in Civil Engineering

Physico-mechanical behavior of clay bricks made from plastic waste

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2024-2025


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Abstract

This study aims to propose an innovative solution to two major challenges: the accumulation of plastic waste and the overreliance on traditional construction materials. The project involves reusing 1% of plastic waste in the production of dredged sediment bricks (DSB), with the goal of creating an alternative, economical, and eco-friendly building material.

The methodology consisted of producing brick samples with and without plastic waste including clay (dredged sediments) and lime, followed by a series of physical and mechanical tests, including compressive and flexural strength, dry density, total and capillary water absorption. The properties of the soil used were evaluated through Atterberg limits, methylene blue value, and grain size analysis.

The results showed that adding plastic significantly reduced water absorption, with a slight decrease in mechanical strength, making the bricks suitable for non-load-bearing walls. The study also highlights important environmental and economic benefits, such as reduced clay consumption, plastic waste valorization, and lower production costs.

Key-words: Brick, Plastic waste, Clay, Lime, Mechanical strength, Total water absorption, Capillary absorption.

Résumé

Cette étude vise à proposer une solution innovante à deux problèmes majeurs : l'accumulation des déchets plastiques et la dépendance excessive aux matériaux de construction traditionnels. Le projet consiste à réutiliser des déchets plastiques, à hauteur de 1 %, dans la fabrication de briques à base de sédiments de dragage (BSD), dans le but de produire un matériau de construction alternatif, économique et respectueux de l’environnement.

La méthodologie adoptée repose sur la fabrication d’échantillons de briques avec et sans déchets plastiques incorporant l’argile (sédiments de dragage) et la chaux, suivie d’une série d’essais physiques et mécaniques, incluant la résistance à la compression et à la flexion, la densité, l’absorption d’eau totale et capillaire. Les propriétés du sol utilisé ont été caractérisées par des tests tels que les limites d’Atterberg, la valeur au bleu de méthylène et l’analyse granulométrique.

Les résultats ont montré que l’ajout de plastique réduit significativement l’absorption d’eau, avec une légère baisse de la résistance mécanique, ce qui rend ces briques adaptées pour des murs non porteurs. L’étude met également en évidence des avantages environnementaux et économiques importants, notamment la réduction de l’utilisation de l’argile, la valorisation des déchets plastiques et la diminution des coûts.

Mots clés : Brique, Déchets plastiques, Argile, Chaux, Résistance mécanique, Absorption d’eau totale, Absorption capillaire.

ملخص

تهدف هذه الدراسة إلى إيجاد حل مبتكر لمشكلتين أساسيتين تواجهان البيئة وقطاع البناء، وهما :تراكم النفايات البلاستيكية والاعتماد المفرط على المواد التقليدية في البناء. تمثلت فكرة المشروع في إعادة استخدام النفايات البلاستيكية بنسبة 1% في صناعة الطوب رواسب المجروفة (DSB)، بهدف إنتاج مواد بناء بديلة، اقتصادية، وصديقة للبيئة.

اعتمدت المنهجية على تحضير عينات من الطوب الطيني مع وبدون نفايات بلاستيكية تحتوي على الطين(رواسب التجريف)والكلس .ثم إجراء سلسلة من الاختبارات الفيزيائية والميكانيكية، شملت :مقاومة الضغط والانحناء، الكثافة، والامتصاص الكلي والشعري للماء .كما تم تحليل خصائص التربة المستعملة من خلال اختبارات حدود أتربرغ، وقيمة الميثيلين الأزرق، والتحليل الحبيبي.

أظهرت النتائج أن دمج النفايات البلاستيكية قلل من امتصاص الماء بشكل ملحوظ، مع انخفاض طفيف في المقاومة الميكانيكية، مما يجعل هذه الطوب ملائمًا للاستعمال في الجدران غير الحاملة. كما تبرز الدراسة فوائد بيئية واقتصادية هامة، تتمثل في تقليل استخدام الطين، وخفض التلوث البلاستيكي، وتقليل التكاليف.

الكلمات المفتاحية: الطوب، النفايات البلاستيكية، الطين،الكلس، المقاومة الميكانيكية، الامتصاص الكلي للماء، الامتصاص الشعري.

Dedication

*We dedicate this humble work, which is the result of years of effort and sacrifice, To **our dear parents**, who have supported and encouraged us throughout our academic journey, and who have always provided us with both moral and material support since the day we opened our eyes to this world.*

*And to the **one** who gave us the desire and strength to live and carry on.*

*We also dedicate it to **our brothers and sisters**,*

*To all our **friends**,*

*To all our **colleagues**,*

*And to our dear primary school teacher, **Mrs. BouhalaS.**, who was the first to plant in us the love of learning and knowledge. She has all our respect and gratitude.*

Thanks

Praise be to ***Allah****, by whose grace good deeds are completed, and through whose mercy we are granted strength and success. we thank Him for granting us the patience and perseverance to accomplish this humble work, and we pray that it will be beneficial and accepted.*

We would like to express our sincere gratitude to everyone who contributed to the success of this work, especially the respected professors who generously shared their knowledge and guidance throughout our academic journey.

Special thanks go to our supervisor, ***Mrs. BELAS Nadia****, for her continuous support and insightful advice, which had a significant impact on the completion of this research. We would also like to express our sincere gratitude to the President of the jury,* ***Mr. BELARIBI Omar****, and the Examiner, Mrs.* ***GUERZOU Torkia****, for their time, constructive remarks, and their valuable evaluation of my work, Our heartfelt thanks also go to the invited member,* ***Mr. CHACHOUR Majid****, for his interest in our research and his insightful contributions.*

We would also like to express our deep and sincere thanks to ***Mr. KHALIFA****, the laboratory assistant, for his valuable help and his dedication in providing the necessary conditions for the experimental work. He has our full respect and appreciation.*

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GENERAL INTRODUCTION

GENERAL INTRODUCTION

The current environmental issue, particularly the management of plastic waste, has led to innovative research aimed at reusing this waste in construction materials. Among the proposed solutions, the use of earthen bricks incorporating plastic waste represents a promising approach to address both waste management challenges and the growing demand for sustainable building materials.

Earthen bricks have traditionally been used in construction due to their low cost, availability, and good properties. However, they have certain limitations in terms of mechanical strength and durability, integrating plastic waste into these bricks could offer a solution to improve their performance while reducing the amount of plastic polluting natural environments.

Earthen bricks made with plastic waste exhibit physical-mechanical behavior that largely depends on the type and proportion of plastic used. The addition of plastic may influence compressive strength, durability and other key properties needed for construction use. Furthermore, these materials offer an ecological alternative by helping to reduce plastic waste and the carbon footprint of traditional construction materials.

This research aims to study the physical-mechanical properties of earthen bricks made from plastic waste, with the goal of evaluating their potential as construction materials. By exploring the interactions between soil and recycled plastics, we aim to determine the best formulation practices for producing bricks that are both high-performing, durable, and environmentally friendly.

This study is divided into **two main parts**. The **first part** covers the theoretical background. Chapter one addresses the issue of plastic waste, its types, environmental impacts, and recycling methods, with a focus on the current state of recycling in Algeria. Chapter two discusses clay bricks, their properties, types, and manufacturing process, while also exploring the potential of incorporating waste materials. The study's main objective—integrating plastic waste into clay bricks—and outlines the adopted methodology and experimental setups presented in Chapter three.

The **second part** is dedicated to the experimental work. Chapter one describes the materials used and the preparation of the brick samples. Chapter two presents the results of mechanical and physical tests, such as compressive strength and water absorption. Finally, chapter three provides a detailed analysis of the results, comparing the plastic-modified bricks to conventional ones, in order to evaluate their effectiveness and suitability for construction use.

This study is closed with a general conclusion and research perspectives.

PART 1

BIBLIOGRAPHIC SYNTHESIS

CHAPTER I
PLASTIC WASTE

CHAPTER I: PLASTIC WASTE

I.1.INTRODUCTIONTO PLASTIC

To say that a material is plastic means that it possesses plasticity — in other words, it can be molded or shaped at will into specific forms using an external force. Plastics are organic materials made up of macromolecules obtained through the polymerization of monomers. They are produced either by transforming natural substances or by direct synthesis from substances extracted from petroleum, natural gas, coal, or other mineral sources. (Adjoudj, 2017)

I.1.1. Definition of plastic

Plastic refers to a wide range of synthetic or semi-synthetic materials made from polymers. These materials are characterized by their plasticity—that is, the ability to be shaped or molded under heat and pressure, then harden into that shape. Plastics are primarily derived from petrochemical sources such as crude oil and natural gas. In recent years, however, bio-based plastics derived from renewable resources like corn starch and sugarcane have also been developed (Andrady& Neal, 2009).

Plastics are generally divided into two main categories:

- **Thermoplastics**, which can be melted and reshaped multiple times (e.g., PET, HDPE).
- **Thermosetting plastics**, which harden permanently after being molded once and cannot be remelted (e.g., bakelite, epoxy resin) (Thompson et al., 2009).

I.1.2. Historical Background

The journey of plastic began in the 19th century:

- **1839** – *Charles Goodyear* discovers vulcanization of rubber, laying the foundation for modern plastic development.
- **1862** – *Alexander Parkes* introduces Parkesine at the London International Exhibition. This cellulose-based plastic is considered the first semi-synthetic plastic (Science History Institute, 2020).
- **1907** – *Leo Baekeland* invents Bakelite, the first fully synthetic plastic, which was non-conductive and heat-resistant—widely used in electronics (Mossman, 2008).
- **1920s–1930s** – Mass production of new types of polymers such as PVC,polystyrene, and nylon.

- **Post–World War II** – The plastic boom accelerates with the use of inexpensive synthetic materials in packaging, consumer goods, construction, and more.

I.1.3. Importance of Plastics

Plastics transformed various sectors:

- **Medical:** Syringes, IV bags, prosthetics.
- **Construction:** Pipes, insulation, roofing.
- **Automotive & Aerospace:** Lightweight parts that improve fuel efficiency.
- **Electronics:** Casing, circuit boards, insulation.
- **Consumer goods:** Packaging, textiles, household items.

However, due to their resistance to degradation, plastics also contribute heavily to global pollution, especially single-use plastics (Thompson et al., 2009).

I.1.4. Plastic Types

Plastic is one of the most widely used synthetic materials in the world due to its versatile properties such as light weight, durability, and moldability. Plastics are classified into various types based on their chemical structure and physical properties. The main types include:

- ***Polyethylene (PE):*** Used in bags and packaging.
- ***Polypropylene (PP):*** Used in containers and automotive parts.
- ***Polyvinyl Chloride (PVC):*** Used in pipes and windows.
- ***Polyethylene Terephthalate (PET):*** Used in water and beverage bottles.
- ***Polystyrene (PS):*** Used in disposable utensils and insulation.
- ***Engineering plastics such as ABS and PC:*** Used in industrial and electronic applications.

Understanding plastic types is essential for determining their applications and efficient recycling strategies, as can be seen in the Fig.I.1 and the Tab.I.1.

Fig.I.1. Plastic types. (medium)

Tab.I.1. Plastic Types and Their Uses (Virgin and Recycled).

Plastic Name	Description	Common Uses of Virgin Plastic	Uses of Recycled Plastic Waste
Polyethylene Terephthalate (PET)	Hard and clear plastic, suitable for making fibers	Soft drink and water bottles, padding for sleeping bags and pillows	Soft drink bottles, detergent bottles (multi-layer), clear wrapping film, textile fibers, rugs, jackets
High-Density Polyethylene (HDPE)	Very common plastic, usually white or colored	Grocery bags, freezer bags, milk and cream bottles, shampoo and cleaning bottles	Compost bins, detergent bottles, moving crates, garbage bins, agricultural pipes, recycling containers
Unplasticized Polyvinyl Chloride (uPVC)	Hard and rigid plastic, can be transparent	Juice bottles, lightbulb sockets, plumbing fittings	Detergent bottles, pipes, and plumbing connections
Plasticized Polyvinyl Chloride (PVC)	Soft, transparent, and elastic plastic	Garden hoses, shoe soles, blood collection bags and tubes	Flexible indoor pipes, industrial flooring

Low-Density Polyethylene (LDPE)	Soft and flexible plastic	Ice cream tub lids, garbage bags, black plastic sheets	Construction film, nursery uses, packaging industry, plastic bags
Polypropylene (PP)	Hard but flexible plastic, has many uses	Ice cream containers, chip bags, drinking straws, food boxes and packaging	Compost bins, curbside recycling bins, endless machinable uses
Polystyrene (PS)	Rigid and brittle plastic, can be clear and glass-like	Yogurt pots, plastic lids, crystal imitation ware	Clothespins, hangers, office supplies, spools, cassette/CD cases
Expanded Polystyrene (EPS)	Lightweight, energy-absorbing foam, thermal insulator	Hot drink cups, takeaway food containers, deli trays	Packaging

I.1.5. Plastic pollution in world

To date, 75% of all plastic ever produced has become waste, and volumes are rising quickly (SilpaKaza et al., 2018). The World Bank reports that by 2050, the world is expected to generate 3.40 billion tons of waste annually, increasing drastically from today’s 2.01 billion tons (World Bank, 2018).

The largest use market for plastics is packaging; in 2018, approximately 36% of all primary production of plastic was used for packaging (Sheldon and Norton, 2020). In addition, plastic packaging typically has a very short “in-use” lifetime (often around six months or less). Some items are even used and disposed of within a few hours (e.g., single-use plastic cups, plates, carrier bags…) (Geyer, 2020). Packaging is therefore the dominant generator of plastic waste, responsible for 46% of the global total in 2018 (Ibid). As much as 32% of this waste is “mismanaged”- meaning that it is either uncollected, dumped, littered or disposed of in uncontrolled landfills- and thus likely to become pollution (Jambeck et al. (2015). In a business-as-usual scenario, global mismanaged plastic waste is forecast to triple by 2060. (Lebreton and Andrady, 2019).

High production rates and a lack of consumer awareness have led to uncontrolled plastic waste generation. Globally, around 150 million tons are released every year (Singh et al., 2017). In the USA, 34.56 million tons of post-consumer plastic waste (including residential, commercial, and institutional sources) was generated in 2015. Recycling rates remain low (slightly higher than 9%), while almost 76% of PSW is disposed in landfills the remaining fraction is used as an energy source (EPA, 2018). In 2016, the European Union countries plus Norway and Switzerland generated 27.1 million tons of post-consumer plastic waste. Of this, 31.1% was recycled, 41.6% was recovered as energy, and 27.3% ended up in landfills. It was the first time that recycling overtook landfilling (Plastic the facts, 2018). In developing countries, the percentage of plastics in MSW streams is on the increase, mainly due to changes in people's lifestyle. The summary of annual PSW generation in some Asian cities (from Indonesia, India, Thailand, Malaysia, Iran, and Bangladesh) can be estimated around 1 million tons (Dhokhikah and Trihadiningrum, 2012).

Researchers estimated that in 2015, the Asian continent was the largest contributor to global plastic waste, generating 82 million tons. Recent statistics on plastics waste generation shows that many countries have made efforts to reduce their waste, but others are continuing along the same path. For example, China's overall plastic waste production had fallen to 21.60 17 million tons in 2016 compared to 59.08 million tons produced in 2010, a reduction of nearly 28 million tons (for comparison, U.S. production fell less than 4 tons during the same time period). At 34.02 million tons, the United States was the largest producer of plastic waste in the world in 2016. Germany produced 14.48 million tons of plastic waste in 2010, in 2016 the production has fallen to 6.68 million tons. Pakistan generated about 6.41 million tons of plastic waste in 2010, making it the sixth-largest producer of plastic waste, but fell to 16th in 2016 with a total of 2.73 million tons. Russia's production rose from about 5.84 million tons of plastic waste in 2010 to nearly 8.47 million tons in 2016, making it one of the few countries whose production of plastic waste is increasing rather than decreasing. (Plastics waste by countries, 2022).

I.2. PLASTIC WASTE

Plastic waste has become one of the most pressing environmental challenges of our time. Since the mid-20th century, plastic production has increased exponentially due to its versatility, durability, and low production cost. However, these same properties that make plastic useful have also led to significant environmental consequences. According to the United Nations Environment Programme (UNEP), the world has produced over 9 billion tons of plastic since the 1950s, with a large portion of it ending up as waste in landfills, oceans, and natural ecosystems (UNEP, 2021).

One of the major concerns regarding plastic waste is its **non**-biodegradable nature, which means it can persist in the environment for hundreds of years. Studies indicate that approximately 8 million tons of plastic waste enter the oceans annually, contributing to marine pollution and harming aquatic life (Jambeck et al., 2015). Additionally, microplastics—tiny plastic particles resulting from the breakdown of larger plastics—have been found in water bodies, soil, and even the human food chain, raising health and environmental concerns (Rochman et al., 2019).

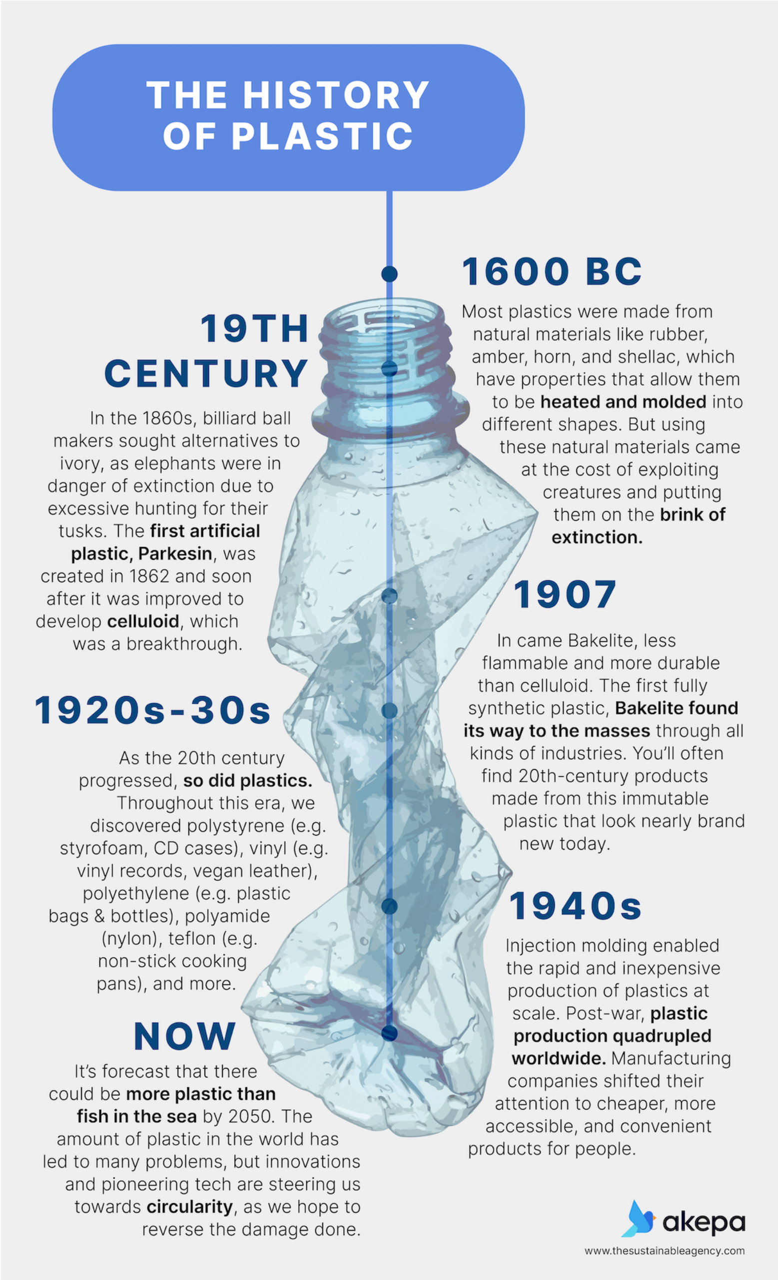
Efforts to manage plastic waste have included recycling, bans on single-use plastics, and international agreements**.** In 2022, the United Nations Environment Assembly (UNEA) took a significant step by mandating the development of a global treaty to combat plastic pollution (UNEA, 2022). However, challenges such as low recycling rates, improper waste management, and continued plastic production growth hinder progress in tackling plastic pollution effectively.

The need for sustainable solutions is more urgent than ever, with scientists and policymakers emphasizing the importance of reducing plastic consumption, improving waste management systems, and developing biodegradable alternatives to address the growing crisis of plastic waste, as depicted in the Fig.I.2.

Fig.I.2. Plastic waste. (eurekapub)

I.3. HISTORY OF PLASTIC WASTE

The history of plastic waste is closely tied to the rapid growth of plastic production and consumption. Plastic was first mass-produced in the early 20th century, but it was in the **1950s** that its use became widespread due to its low cost, durability, and versatility (Geyer et al., 2017). Since then, plastic production has increased exponentially, leading to a corresponding rise in plastic waste, this is illustrated in the Fig.I.3 and Fig.I.4.



THE HISTORY OF PLASTIC

1600 BC

Most plastics were made from natural materials like rubber, amber, horn, and shellac, which have properties that allow them to be **heated and molded** into different shapes. But using these natural materials came at the cost of exploiting creatures and putting them on the **brink of extinction.**

19TH CENTURY

In the 1860s, billiard ball makers sought alternatives to ivory, as elephants were in danger of extinction due to excessive hunting for their tusks. The **first artificial plastic, Parkesin**, was created in 1862 and soon after it was improved to develop **celluloid**, which was a breakthrough.

1907

In came Bakelite, less flammable and more durable than celluloid. The first fully synthetic plastic, **Bakelite found its way to the masses** through all kinds of industries. You'll often find 20th-century products made from this immutable plastic that look nearly brand new today.

1920s-30s

As the 20th century progressed, **so did plastics.** Throughout this era, we discovered polystyrene (e.g. styrofoam, CD cases), vinyl (e.g. vinyl records, vegan leather), polyethylene (e.g. plastic bags & bottles), polyamide (nylon), teflon (e.g. non-stick cooking pans), and more.

1940s

Injection molding enabled the rapid and inexpensive production of plastics at scale. Post-war, **plastic production quadrupled worldwide.** Manufacturing companies shifted their attention to cheaper, more accessible, and convenient products for people.

NOW

It's forecast that there could be **more plastic than fish in the sea** by 2050. The amount of plastic in the world has led to many problems, but innovations and pioneering tech are steering us towards **circularity**, as we hope to reverse the damage done.

akepa

www.thesustainableagency.com

Fig.I.3. The History of plastic. (thesustainableagency)

I.3.1. Early Stages (1950s - 1970s)

In the 1950s, global plastic production was about 1.5 million tons per year, and plastic waste was not yet considered a major issue. Most plastic was used in industrial and military applications, with limited single-use consumer products (Geyer et al., 2017). However, by the 1970s**,** the rise of disposable plastics—such as plastic bags and packaging—began to significantly contribute to waste accumulation.

I.3.2. Growth and Environmental Awareness (1980s - 1990s)

Between the 1980s and 1990s, plastic production and waste increased dramatically, with over 100 million tons of plastic being produced annually (UNEP, 2021). During this period, concerns about plastic pollution grew, especially regarding its impact on marine life. The discovery of large amounts of plastic waste in the oceans led to calls for better waste management and recycling. In 1988, the American Society of Plastics Manufacturers introduced plastic identification codes to facilitate recycling (Bashar Ramadan, 2022).

I.3.3. The Global Plastic Waste Crisis (2000s - Present)

By the 2000s, global plastic production had surpassed 200 million tons per year, with plastic waste becoming a global environmental crisis. Studies showed that only 9% of plastic waste was being recycled, while the rest ended up in landfills, incinerators, or the natural environment (Geyer et al., 2017).

In 2018, China—one of the world's largest importers of plastic waste—banned plastic waste imports to protect its environment. This disrupted the global recycling industry, forcing many countries to reconsider their waste management strategies (No-Burn.org, 2019).

In 2022**,** the United Nations Environment Assembly (UNEA) adopted a historic resolution to develop a legally binding international treaty to combat plastic pollution, aiming to address plastic waste across its entire life cycle (UNEA, 2022).

Today, plastic waste remains one of the biggest environmental challenges, with an estimated **8** million tons of plastic entering the oceans annually (Jambeck et al., 2015). Efforts to reduce plastic pollution include bans on single-use plastics, advancements in biodegradable materials, and improved recycling technologies.

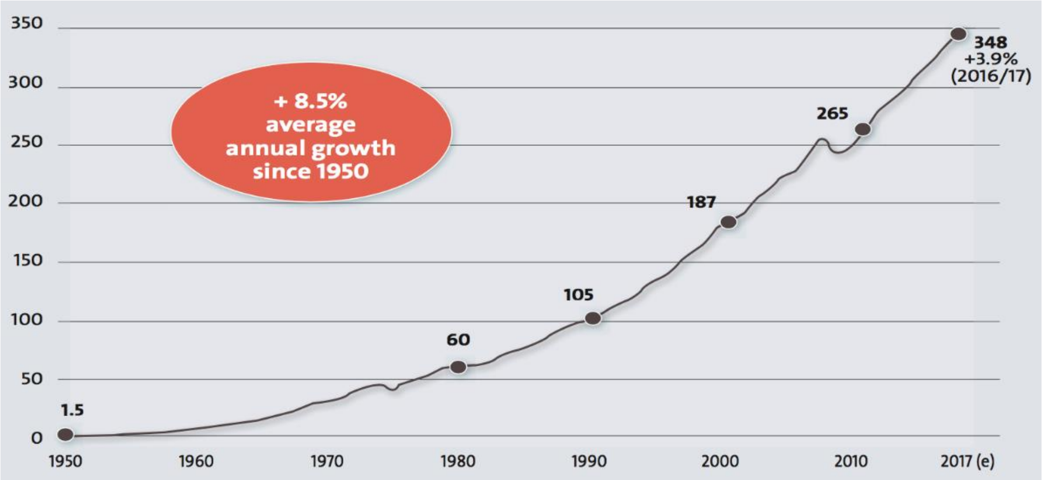


Fig.I.4. The evolution of plastic waste. (nap.nationalacademies)

I.4.THE USE OF PLASTIC WASTE IN CIVIL ENGINEERING

Plastic waste has emerged as a significant environmental issue due to its non-biodegradable nature and widespread accumulation. However, recent research and engineering innovations have explored the potential of incorporating plastic waste into civil engineering applications. The utilization of plastic waste in construction helps reduce environmental pollution while

The applications and uses of plastics are extensive. Some plastic items, such as food packaging, become waste immediately after purchase. Other plastic items can be reused multiple times. Reusing plastics is preferable to recycling because it consumes less energy and resources. It can offer several benefits:

- Reduction in energy consumption
- Reduction in solid waste sent to landfills
- Reduction in carbon dioxide (CO_2), nitrogen oxides (NO), and sulfur dioxide (SO_2) emissions

I.4.1. Plastic Waste in Road Construction

One of the most promising applications of plastic waste in civil engineering is in road construction. Waste plastics such as polyethylene (PE), polypropylene (PP), and polystyrene (PS) are used as modifiers in bitumen for asphalt roads. This technique improves road durability, flexibility, and resistance to water damage (Vasudevan et al., 2011). Countries such as India, the UK, and the Netherlands have successfully constructed roads using waste plastic, resulting in stronger and more wear-resistant pavements (Sharma et al., 2020).

I.4.2. Plastic Waste in Concrete and Bricks

Plastic waste has been integrated into concrete and bricks as an alternative to conventional materials:

I.4.2.1. *Plastic in concrete*

Waste plastic (e.g., PET bottles) can replace coarse or fine aggregates, leading to lightweight concrete with improved thermal insulation properties (Al-Manaseer&Dalal, 1997), this is evident from the Fig.I.5 presented.

Fig.I.5. Plastic in concrete. (geo.fr)

I.4.2.2. *Plastic bricks*

Melted plastic is molded into bricks that are stronger, lighter, and more water-resistant than conventional clay bricks. These bricks offer a sustainable alternative by reducing reliance on natural resources (Rahman et al., 2019), as highlighted in the accompanying Fig.I.6.

Fig.I.6. Plastic waste in bricks

I.4.3. Geotechnical Applications (Soil Reinforcement & Stabilization)

Plastic waste materials such as shredded plastic fibers are used in geotechnical applications to enhance soil properties. This technique:

- Improves soil strength and stability
- Enhances resistance to erosion and cracking
- Is used in embankments, retaining walls, and slope stabilization (Choudhary et al., 2010).

I.4.4. Plastic Waste in Structural Applications

Innovative uses of plastic waste in structural applications include:

I.4.4.1. ***Plastic lumber*** Made from recycled plastic, this material serves as a substitute for wood in decking, fencing, and formwork, offering water resistance and durability (Badur et al., 2007), as shown in the Fig.I.7.

Fig.I.7. Plastic waste in bricks (tangentamaterials.com)

I.4.4.2. *Modular plastic housing*

Some companies have developed prefabricated houses using plastic waste, providing affordable and eco-friendly housing solutions (Banerjee et al., 2019), as shown in theFig.I.8.

Fig.I.8. House made with plastic. (architecturelab.net)

I.5.PLASTIC RECYCLING

We must consider plastic recycling in any plastic waste management program. In addition to reducing the amount of plastic waste in landfills, it can also significantly contribute to preserving petrochemical raw materials and saving energy. However, there are currently certain technological and economic limitations that prevent the complete and efficient recycling of plastic waste into useful products, as depicted in the Fig.I.9.

Fig.I.9. Recycling of plastic. (pinterest)

1.6. POLYETHYLENE TEREPHTHALATE

I.6.1. Definition of PET

As illustrated in the Fig.I.10 below PET stands for polyethylene terephthalate, which is also referred to as PETE, and it is a type of plastic. Chemically, it is a polymer obtained through the polycondensation of terephthalic aceanthrylene glycol. The molecules are composed exclusively of hydrogen, carbon, and oxygen atoms.

PET exists in many forms: injection-molded parts, tubes, packaging films, fibers, fabrics, etc. It is commonly used in the manufacturing of plastic bottles (BENMEKEDECH-GOUISEM, 2015).

Fig.I.10.PET plastic. (fr.vecteezy)

I.6.2. PET Manufacturing

This can be clearly seen in the Fig.I.11PET can be produced in the industry through two main synthesis processes:

- **Esterification** of terephthalic acid and ethylene glycol
- **Transesterification** of dimethyl terephthalate and ethylene glycol

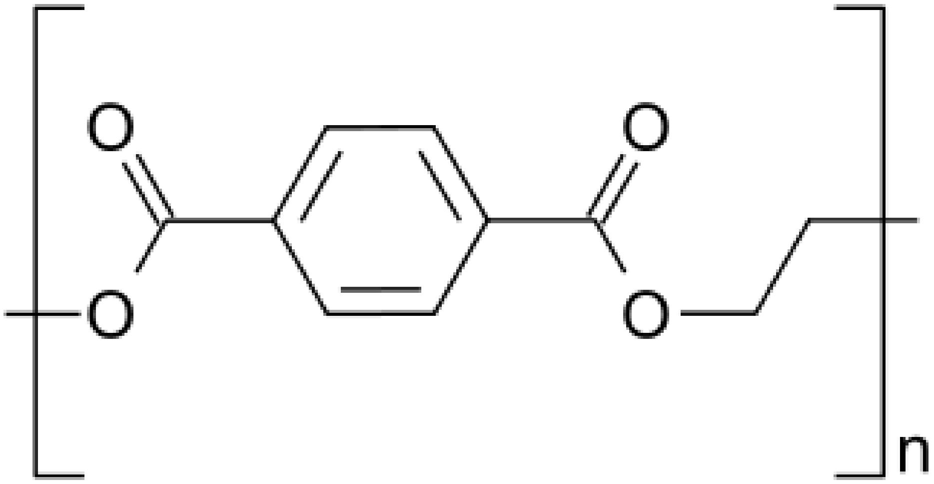


Fig.I.11. Chemical composition of polyethylene terephthalate. (Wikipedia)

I.6.2.1. *Esterification& Transesterification*

The Fig.I.12 below demonstrates the pre-polycondensation of terephthalic acid (TA)and ethylene glycol (EG) does not require a catalyst since the carboxylic acid groups of TA are reactive and catalytic on their own. However, the reaction takes place at high temperatures (230–260°C) and under vacuum (0.3–0.5 MPa) until the [EG]/[TA] ratio reaches between 1.3 and 1.5. Water and excess EG are then removed at the end of this reaction, which lasts between 3 and 4 hours. The reaction does not require the use of a metal catalyst. (SALHI & SALHI, 2012).

When the reactants (**DMT** and **EG**) are combined, the mixture is heated to a temperature between 160 and 180°C under vacuum. The addition of a catalyst (metal salt) is necessary. When the [EG]/[DMT] (dimethyl terephthalate) ratio is between 1.7 and 2, the catalyst is deactivated to avoid an increase in the thermal degradation rate of the polymer. At the end of the reaction, excess EG and methanol are distilled off. (SALHI & SALHI, 2012)

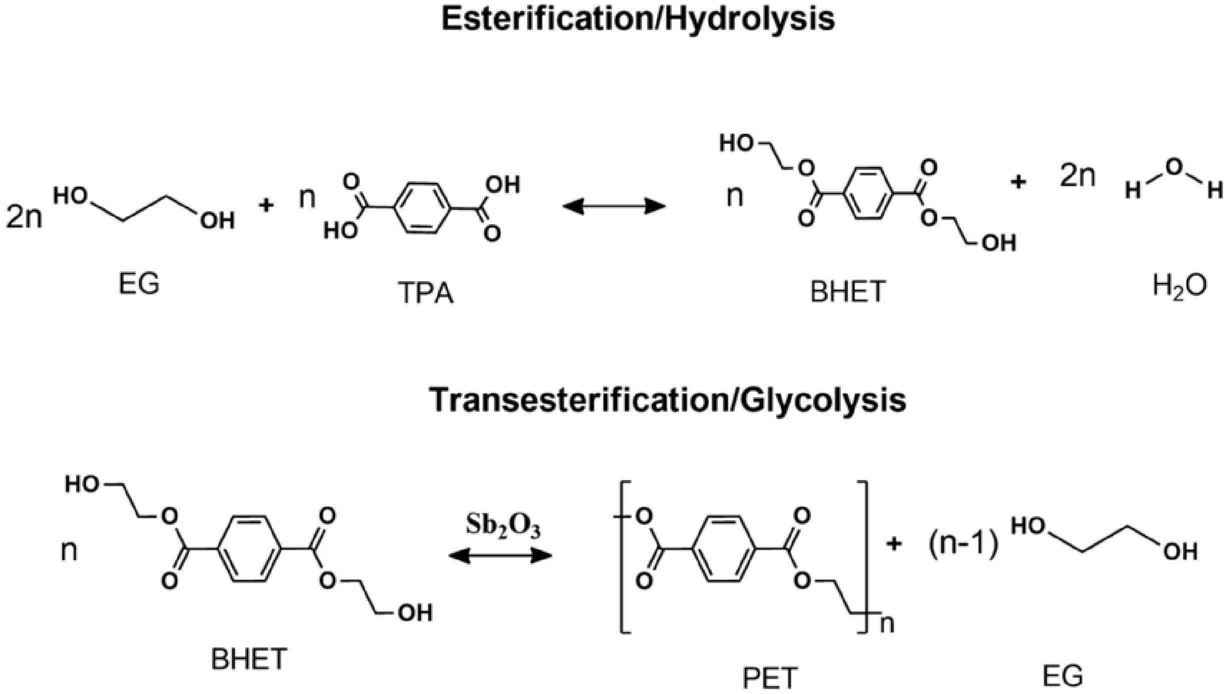


Fig.I.12. Esterification Transesterification. (Wikipedia)

I.6.2.2. *Processing*

PET is semi-crystalline. Forced cooling preserves the amorphous state of the polymer, making it transparent. This results in films, photographic and audio/video recording substrates, thin sheets, etc.

To achieve the semi-crystalline state, PET requires nucleating additives (e.g., talc, barium sulfate) to meet industrial production speeds. It has high stretchability, allowing molecular orientation, which gives it excellent mechanical properties (tensile strength, tear resistance, fatigue resistance).

PET bottles for mineral water are transparent, biaxially oriented, and partially crystalline.

PET is suitable for food use (bottles, microwave-safe containers).

The processing of linear polyesters is easy and allows for very short molding cycles. It is carried out using well-dried pellets, which have been in a heated dryer at 90–120°C for several hours, as linear polyesters are sensitive to hydrolysis. (INRS)

I.6.3. General Properties of PET

PET has become one of the most widely industrialized polymers due to its excellent electrical, chemical, and physical properties, which make it heavily used in the film, fiber, and packaging industries.

PET is a rigid material with good dimensional stability. It offers good barrier properties and chemical resistance. Its crystallinity ranges from amorphous to relatively crystalline. It can be very transparent and colorless, though thick parts are often opaque and whitish. (BENYACHE, 2016)

I.6.3.1. *Main Properties*

The main properties of PET are (Benmekideche&Gouissem, 2015):

- Break resistance
- Barrier to oxygen and carbon dioxide
- Chemical stability
- Flexibility
- Transparency
- Heat resistance
- Light weight
- Durability

- Melting temperature: 245°C
- Glass transition temperature: 61–77°C

I.6.4. Applications of PET

PET is used in various sectors depending heavily on its molecular properties. Thus, the choice of the appropriate grade for a specific application is based on its intrinsic viscosity, which is directly related to the material's molecular weight. Common application areas include:

- **Textiles** : textile yarns, fibers, etc.
- **Films**: packaging, photographic film supports, etc.
- **Hollow bodies**: bottles for carbonated beverages, etc.
- **Automotive**: fan blades, alternators, ignition circuit handles, etc.
- **Medical applications**: tubular knit prostheses for vascular grafts, larynx and esophagus prostheses, etc.
- **High-tech applications**: magnetic media, IT tools such as floppy disks, audio/video tapes, computer data tapes, etc.

The main non-fiber application of PET is the manufacturing of bottles for beverages and food packaging. The first PET bottle application dates back to 1984, and since then, it has become the material of choice for bottle manufacturing and packaging. (Benayache, 2016)

I.6.5. Recycling Methods of PET

As shown in Tab.I.2 there are three main methods used for PET recycling:

Tab.I.2. main methods used for PET recycling (Benayache, 2016)

Type of Recycling	Description	Advantages	Disadvantages
Mechanical Recycling	Melting and remolding PET without altering its chemical structure.	Low cost, simple process	Polymer degradation after multiple cycles
Chemical Recycling	Depolymerizing PET into its monomers.	Restores original properties	Requires more energy and complex equipment
Energy Recovery	Incinerating PET to produce energy.	Reduces volume of waste	Releases greenhouse gases

			and potential toxic substances

I.6.5.1. *Mechanical Recycling*

This process involves sorting, cleaning, shredding, and reprocessing post-consumer PET into pellets or flakes. These are reused in textiles, strapping, and non-food packaging. It is the most commonly practiced form of PET recycling worldwide (Awaja& Pavel, 2005).

I.6.5.2. *Chemical Recycling*

PET can undergo hydrolysis, methanolysis, or glycolysis to be chemically broken down into its monomers. These monomers can then be repolymerized into virgin-quality PET. Although expensive, this process is highly effective in maintaining product quality (Al-Sabagh et al., 2016).

I.6.5.3. *Energy Recovery*

PET combustion produces carbon dioxide, water vapor, and energy, similar to burning fossil fuels. Although useful, it is often the last resort due to environmental concerns (Shen et al., 2010).

I.6.6. Valorization of Recycled PET

Valorization refers to giving new economic or functional value to recycled materials. PET waste can be repurposed into:

- Textile fibers (used in jackets, carpets, and insulation)
- Thermoformed packaging
- 3D printing filaments
- Construction materials (e.g., lightweight concrete additives, tiles)
- Food-grade containers (with multilayer technologies to ensure safety)

I.6.7. Applications of Recycled PET (RPET)

This can be seen more clearly in Tab.I.3.

Tab.I.3. Applications of RPET

Application	Form of Recycled PET Used	Example Products
Textiles and Fibers	PET Flakes or Chips	Jackets, carpets, upholstery
Packaging (Non-food and Food)	Re-pelletized PET	Trays, bottles (with multilayer barriers)
Construction	Shredded PET or Modified PET	Lightweight concrete, bricks
3D Printing	PETG Filament	Prototypes, household tools

I.6.8. Benefits of PET Recycling and Valorization

- Environmental Impact: Reduces plastic pollution and landfill pressure.
- Economic Efficiency: Saves raw materials and energy (up to 60% energy savings vs. virgin PET).
- Industrial Applications: Encourages innovation in textiles, construction, and packaging.
- Circular Economy: Supports sustainability by keeping materials in use longer.

I.6.9. Challenges and Future Perspectives

Challenges include ensuring food-grade safety, improving sorting technologies, and increasing public awareness. New research focuses on enzymatic recycling and advanced solvent-based recycling technologies for improved environmental performance and process efficiency (Tournier et al., 2020).

I.7. RECYCLING OF PLASTIC WESTE IN ALGERIA

Algeria generates approximately 13 million tons of household waste annually, with plastic waste constituting a significant portion. Despite the potential for recycling, only about 10% of this waste is currently recycled (Algeria Invest, 2024).

I.7.1. Recent Statistics on Plastic Waste

We can observe this phenomenon in the Tab.I.4 and Fig.I.13

Tab.I.4. Recent Statistics on Plastic Waste (National Waste Agency (AND); Algeria Invest (2024)).

Year	**Total Waste Generated (million tons)**	**Plastic Waste (million tons)**	**Recycling Rate (%)**
2018	13.1	1	6.2
2019	13.5~	1.1	6.4
2020	14~	1.22	6.7
2021	14.5~	2.03	7
2022	15~	2.39	7.1
2023	15.5~	2.55	8.9
2024	16~	2.7	~10

Fig.I.13. Plastic waste in Algeria beach (Algerie360)

I.7.2. Recycling Initiatives and Projects

I.7.2.1. *El Kader Plast Plant in Oggaz*

In September 2022, a recycling plant named El Kader Plast commenced operations in Oggaz, Mascara province. The facility focuses on recycling polypropylene (PP) and high-density polyethylene (HDPE) plastics, with a capacity of 40 tons per day (Afrik 21, 2022).

I.7.2.2. *Sebtex Recycling in ChelghoumLaïd*

Sebtex Recycling processes approximately 1.2 million plastic bottles daily, converting them into 30 tons of wadding material used in textiles. Half of this production is exported, contributing to both environmental sustainability and economic growth (Reuters, 2022).

I.7.2.3. *Delta Recycle in Algiers*

Delta Recycle is a digital platform facilitating the collection and recycling of plastic waste. It connects waste collectors with recycling centers, promoting eco-citizen participation and creating sustainable jobs for Algerian youth (Delta Recycle, 2024).

I.7.3. Government Strategies and Goals

Algeria's National Strategy for the Integrated Management and Recovery of Waste by 2035 (SNGID 2035) aims to:

- Reduce household waste by 10%
- Recover 47% of household and special waste
- Recycle 60% of inert waste

Additionally, the National Waste Agency (AND) has implemented selective waste sorting systems in the wilayas of Algiers, Boumerdès, and Oran to enhance recycling efforts (Afrik 21, 2023).

I.7.4. Challenges in Plastic Waste Management

Despite these initiatives, challenges persist:

- Limited recycling infrastructure
- Low public awareness and participation
- Prevalence of informal waste collection sectors
- Lack of strict regulations and incentives for recycling

These factors contribute to the continued low recycling rates and environmental pollution (Circemed, 2023).

I.8.ADVANTAGES AND LIMITATIONS

I.8.1. Advantages of using plastic waste in civil engineering

- **Environmental benefits** – Reduces plastic pollution.
- **Cost-effectiveness** – Utilizes waste materials efficiently.
- **Durability** – Enhances resistance to water and wear.
- **Sustainability** – Promotes recycling and reduces landfill waste.

I.8.2. Challenges and Limitations

- **Quality control issues** – Variability in plastic waste properties.
- **Processing difficulties** – Requires advanced sorting and recycling technologies.
- **Long-term performance concerns** – Further research is needed.

I.9. CONCLUSION

The use of plastic waste in civil engineering presents an innovative and sustainable solution to environmental pollution. Applications such as plastic roads, plastic-based concrete, and structural components demonstrate the potential of plastic waste in improving infrastructure strength and sustainability. However, further research, standardization, and government support are essential for large-scale adoption.

CHAPTER II

CLAY PROPERTIES, TYPES, AND USES IN CONSTRUCTION

CHAPTER II: CLAY PROPERTIES, TYPES, AND USES IN CONSTRUCTION

II.1. INTRODUCTION

Clay is a fine-grained natural soil material formed primarily through the chemical weathering of silicate rocks, especially feldspar. It is widely recognized for its plasticity when wet and its hardening behavior when dried or fired, which makes it essential in both ancient and modern construction techniques (Mamlouk&Zaniewski, 2011), as can be seen in the Fig.I.14.

Fig.I.14. Clay in nature. (Istockphoto)

II.2. TYPES OF CLAY

Clays are classified based on their mineral composition and behavior. Each type has different characteristics and is suited for specific uses in construction or industry (Grim, 1968; Moore & Reynolds, 1997), as depicted in the Fig.I.15 and presented in the Tab.I.5.

Fig.I.15. Types of Clay(pinterest)

Tab.I.5. Common Types of Clay (Grim, 1968; Moore & Reynolds, 1997)

Clay Type	Main Properties	Common Uses
Kaolinite	Low plasticity, non-swelling, white color	Porcelain, ceramics, bricks
Smectite	High plasticity, swelling, water absorbent (e.g., bentonite)	Sealing layers, liners, geotechnical barriers
Illite	Moderate plasticity, non-swelling	Soils, general construction fill
Ball Clay	High plasticity, fine-grained, grayish color	Pottery, tile bodies, blended with kaolin
Fire Clay	Resistant to high temperatures, low impurities	Refractories, fireplaces, furnaces

II.3. PHYSICAL PROPERTIES

Key characteristics of clay include fine particle size, plasticity, shrinkage upon drying, and porosity. It is excellent at retaining water and acts as a natural binder in earth-based construction (Bell, 2007).

II.4. APPLICATIONS IN CONSTRUCTION

Clay has been used for thousands of years in construction especially in:

- Brick manufacturing (fired and unfired)
- Plastering and coatings
- Rammed earth and cob wall systems
- Floor and roof tiles

Recent innovations also involve recycling plastic waste with clay to produce eco-friendly bricks (Al-Fakih et al., 2020).

II.5. CLAY IN ALGERIA

II.5.1. Types of clay in Algeria

Algeria is rich in clay resources due to its diverse geology, which includes mountainous regions, high plateaus, and semi-arid areas.

II.5.1.1. *Kaolinite (White Clay)*

The Fig.I.14 demonstrates that Kaolinite is mainly found in the northern provinces such as Jijel, Skikda, and TiziOuzou. It is used in ceramics, paper, and cosmetics industries. Research has shown that Algerian kaolin possesses high purity and industrial potential (Bouhounand al., 2019).

Fig.I.16. Kaolinite (White Clay) (Famactu.com)

II.5.1.2. *Illite and Smectite* (Plastic Clays)

These clays are widely distributed across the Tell Atlas and High Plateaus. They are essential for the production of bricks and tiles, and serve as a base for construction materials (African Journal of Earth Sciences, 2019), as can be seen in the Fig.I.15.

Fig.I.17. Plastic Clays(insapedia)

II.5.1.3. *Bentonite*

Bentonite is particularly abundant in the Maghnia region (Tlemcen Province). It is utilized in drilling muds, water purification, and pharmaceutical applications. Algerian mining authorities highlight its strategic economic value (ANAM, 2021–2024), this is illustrated in theFig.I.18.

Fig.I.18. Bentonite(pinterest)

II.5.1.4. *Red Clay*

Prevalent in highland and Saharan regions, red clay is used mainly in traditional pottery and adobe structures. Studies on vernacular architecture underscore its cultural and constructional importance (University of Tlemcen, 2018).

II.5.2. Geographic Distribution of Clays in Algeria

This information is tabulated in Tab.I.5 Geological surveys confirm the wide availability of industrial clays throughout the country

Tab.I.6. Region and clay types (Ministry of Energy and Mines, 2020)

Region	Clay Types
Tell Atlas	Kaolinite, Illite
Laghouat	Construction-grade clays
Maghnia (West)	Bentonite
Saharan Fringe	Red clay (for pottery and adobe)

II.5.3. Industrial and Cultural Uses of Clay in Algeria

II.5.3.1. *Construction*

Clay plays a key role in the production of bricks, cement, and tiles in both public and private sectors (African Journal of Earth Sciences, 2019).

II.5.3.2. *Traditional Pottery*

In regions like Tlemcen, Ghardaïa, and Kabylie, clay-based pottery is a longstanding tradition, reflecting local culture and artisanal knowledge (University of Tlemcen, 2018).

II.5.3.3. *Cosmetics and Wellness*

Kaolinite and ghassoul are widely used in traditional skincare, with growing interest in the natural cosmetics market (Journal of Natural Products, 2021).

II.5.3.4. Modern Industrial Use

Processed clay is utilized in cement manufacturing, chemical industries, and even pharmaceuticals. There is a rising trend in exporting refined kaolin and bentonite (World Industrial Minerals Review, 2023).

II.5.4. Reserves and Economic Potential

Algeria holds significant clay reserves, amounting to hundreds of millions of tons. The National Agency for Mining Activities continues to promote investment and value-added transformation for both local consumption and export (ANAM, 2021–2024).

II.5.5. Challenges

Despite its potential, clay exploitation in Algeria faces multiple challenges (Ministry of Energy and Mines, 2020).:

- Outdated extraction and processing technologies.
- Incomplete geological mapping in southern regions.
- Environmental concerns from unregulated mining

II.5.6. Opportunities

There are emerging opportunities in using clay for sustainable construction, especially when mixed with recycled plastic waste. Furthermore, international demand for natural clay in cosmetic and wellness industries is growing, giving Algeria an edge in the global market (World Industrial Minerals Review, 2023).

II.6. ADVANTAGES AND LIMITATIONS

Clay is affordable, abundant, and environmentally sustainable. It provides good insulation and regulates humidity. However, it can be weak in water resistance and prone to cracking during drying (Morton, 2008).

II.7. CLAY BRICKS

Clay bricks are among the oldest and most widely used building materials in the world. Their origin dates back thousands of years, and they have been a fundamental part of traditional and modern construction across various cultures. As the construction industry moves toward more sustainable practices, clay bricks are gaining renewed interest due to their eco-friendly nature, thermal insulation properties, and cost-effectiveness. This document explores the characteristics, composition, types, and applications of clay bricks, with a focus on their relevance in contemporary architecture and sustainable building.

II.7.1. Definition of clay bricks

Clay bricks are construction units made primarily from natural clay mixed with water and sometimes reinforced with straw, sand, or other additives. The bricks are shaped manually or mechanically and then either sun-driedorfired in kilns to gain hardness and mechanical strength. (Minke, 2006), as shown in the Fig.I.19.

Fig.I.19. Clay bricks. (pinterest)

II.7.1.1. *Main Components of Clay Bricks*

The primary constituents used in the production of clay bricks, such as clay minerals, **Sand**, and additives, are listed in Tab.I.7. (Norton, 1997).

Tab.I.7. Main Components of Clay Bricks (Norton, 1997).

Component	**Function**
Clay (Loam)	Primary material; provides plasticity and moldability
Water	Facilitates mixing and shaping
Sand	Reduces shrinkage and prevents cracking
Straw/Fibers	Enhances crack resistance and thermal insulation
Additives (lime, ash, etc.)	Improve final brick performance

II.7.2.*Types of clay bricks*

Various types of bricks in Table I.8 and Fig.I.20.

Tab.I.8. some types of bricks (Adam &Agib, 2001)

Type	Description	Drying Method
Unfired Brick (Adobe)	Sun-dried only, commonly used in traditional buildings	Natural drying
Fired Clay Brick	Kiln-fired for higher strength and durability	Kiln firing
Stabilized Clay Brick	Mixed with cement or lime for better water resistance	Natural or kiln

Fig.I.20. Types of clay bricks. (pinterest)

II.7.3.*Physical and mechanical properties of clay bricks*

The main physical and mechanical characteristics of clay bricks, including density, water absorption, and compressive strength, are summarized in Table I.9 (Walker, 2004).

Tab.I.9. Physical and mechanical properties of clay bricks (Walker, 2004).

Property	**Typical Values (Range)**
Dry Density	1600 – 1900 kg/m³
Compressive Strength	2 – 10 MPa
Water Absorption	10 – 25%
Thermal Conductivity	0.4 – 0.8 W/m·K
Shrinkage upon Drying	2 – 8%

II.7.4. Advantages and disadvantage

II.7.4.1. *Advantages of Clay Bricks*

- **Sustainable and eco-friendly** material.
- **Low cost**, especially in rural or developing areas.
- **Good thermal and acoustic insulation**.
- **Reusable and recyclable** material.
- **Breathable**, contributing to better indoor air quality.

II.7.4.2. *Disadvantages of Clay Bricks*

- **Low water resistance**, especially in unfired bricks.
- **Lower compressive strength** than concrete or cement bricks.
- **Poor frost resistance** in cold climates.
- **Requires controlled drying** to avoid cracks and defects.

II.8. APPLICATIONS OF CLAY BRICKS

As shown in the Tab.I.10and Fig.I.22below

Tab.I.10. Application of bricks

Field	**Usage Examples**
Traditional housing	Walls, partitions in rural and desert areas
Eco-construction	Earth-based housing, green buildings
Historic restoration	Restoration of heritage and mud-brick buildings
Insulated walls	Used for interior or secondary thermal barriers

Fig.I.22. House made with clay bricks. (pinterest)

II.9. ABOUT CLAY BRICKS

Clay bricks continue to serve as a vital building material due to their natural origin, environmental compatibility, and ability to provide comfortable indoor environments. Despite some limitations in water and frost resistance, advances in stabilization techniques have expanded their use beyond traditional settings. Their low cost, reusability, and minimal environmental impact make them a strong candidate for sustainable construction practices. As the construction sector evolves, integrating ancient materials like clay bricks with modern methods may be key to achieving environmentally responsible development.

II.10. RECYCLING IN BRICK-MAKING PRACTICAL EXAMPLES FROM RESEARCH AND INDUSTRY

In recent years, the construction industry has increasingly turned to sustainable practices to address the growing environmental concerns associated with traditional building materials. One of the most promising approaches in this context is the incorporation of recycled materials into brick manufacturing. Various types of waste, including plastic, glass, fly ash, paper sludge, and construction debris, have been successfully integrated into brick production to reduce environmental impact and enhance material performance (Pacheco-Torgal&Jalali, 2011).

Plastic waste, in particular, has attracted attention due to its abundance and long degradation time. Studies have shown that adding shredded plastic into clay bricks can improve insulation properties while simultaneously reducing the weight of the bricks (Aeslina et al., 2013). Similarly, industrial by-products such as fly ash and bottom ash have been used to replace portions of clay, resulting in eco-friendly bricks with acceptable strength and durability (Bhanumathidas&Kalidas, 2003).

Recycling such materials not only diverts waste from landfills but also reduces the extraction of natural resources, thereby promoting a circular economy in the construction sector. As environmental regulations tighten and demand for sustainable infrastructure rises, recycled-content bricks are poised to become a viable alternative in green building projects (Huang et al., 2007).

II.11. EXPERIMENTAL USE OF WASTE IN BRICK PRODUCTION IN ALGERIA

II.11.1. Use of Plastic Waste in Fired Clay Bricks

This experiment was conducted by University of Tlemcen (Zerrouki&Kazi-Tani, 2021).

Appropriate equipment was used in this experiment Shredded polyethylene waste (plastic bags)

Researchers replaced 0%, 5%, and 10% of clay by weight with shredded polyethylene waste in traditional clay brick mixtures. The bricks were then molded, dried, and fired at 950°C. These results were obtained:

- Weight reduction: Up to 17% weight decrease with 10% plastic content.
- Thermal insulation: Improved due to increased porosity caused by the combustion of plastic during firing.
- Compressive strength: Decreased from ~12 MPa (control) to ~8.5 MPa (at 10% plastic).
- Water absorption: Increased slightly with more plastic content.
- Environmental impact: Utilizes abundant plastic waste, reduces landfill use.

In conclusion Plastic waste can be used up to 5% in brick production without significantly compromising structural integrity. It also improves insulation, making it suitable for non-load-bearing walls.

II.11.2. Incorporation of marble waste into bricks

This experiment was conducted by University of Bejaia (Bendoukha&Bensaci, 2020).

Appropriate equipment was used in this experiment Marble sludge/dust from cutting and polishing processes

Clay was partially replaced with marble waste at rates of 5%, 10%, and 15%. The bricks were shaped and fired at 900°C.

These results were obtained:

- **Compressive strength** Improved with 10% marble content, reaching up to 15 MPa, higher than the control sample (~12 MPa).
- **Water absorption** Decreased with more marble content due to denser structure.
- **Density** Slight increase, indicating improved compactness.
- **Surface finish** Smoother bricks, suitable for aesthetic applications.

In conclusion Marble waste can be effectively used to enhance both mechanical and physical properties of bricks, while also addressing waste disposal from the marble industry.

II.11.3.Use of Fly Ash from Thermal Power Plants

This experiment was conducted by SONELGAZ (Hamidouche&Cherif, 2019)

Appropriate equipment was used in this experiment Fly ash from coal combustion. Fly ash was added at 10%, 20%, and 30% by weight to the clay brick mix. The bricks were fired at lower temperatures (800°C–850°C).

These results were obtained:

Firing temperature reduction: Up to 100°C lower due to fly ash fluxing properties. Compressive strength: Comparable to traditional bricks at 10–20% fly ash content (~11–13 MPa).

Cost and energy savings: Reduced fuel consumption due to lower sintering temperature. Environmental benefit: Diverts harmful industrial byproducts from landfills.

In conclusion Fly ash is a promising additive for sustainable brick production in Algeria, with benefits in strength, energy efficiency, and environmental protection.

II.12. CONCLUSION

Clay remains a fundamental natural material in the construction industry due to its abundant availability, plasticity, and versatility. Its diverse types, such as kaolinite, smectite, illite, and bentonite, exhibit distinct physical and chemical properties that determine their suitability for various industrial and traditional applications. In Algeria, rich clay deposits support a wide range of uses, from brick manufacturing and pottery to cosmetics and modern industrial processes, highlighting the material's economic and cultural significance.

Despite challenges such as outdated extraction techniques and environmental concerns, the potential of Algerian clays remains strong. Innovations like incorporating recycled plastic waste, marble residues, and fly ash into brick production demonstrate promising advances toward sustainable and eco-friendly construction practices. These efforts not only reduce environmental impacts by diverting waste from landfills but also improve brick performance in terms of thermal insulation and mechanical strength.

Overall, the integration of traditional knowledge with modern technology in clay utilization offers a path forward for sustainable development in Algeria's construction sector. By optimizing clay resources and embracing recycling methods, Algeria can enhance its construction materials' quality while contributing positively to environmental conservation and economic growth.

CHAPTER III

UTILIZATION OF PLASTIC WASTE IN CLAY BRICKS

CHAPTER III: UTILIZATION OF PLASTIC WASTE IN CLAY BRICKS: A SUSTAINABLE APPROACH

III.1. INTRODUCTION

Plastic waste represents one of the most persistent environmental pollutants due to its long degradation period and widespread accumulation (Jambeck et al., 2015). Meanwhile, conventional clay brick production consumes significant natural resources and energy, contributing to environmental degradation (UNEP, 2018). Incorporating plastic waste into clay bricks offers a sustainable alternative that not only mitigates plastic pollution but also reduces production costs and enhances certain properties such as lightweight and thermal insulation (Rafieizonooz et al., 2017; Ahmad et al., 2020).

III.2. OBJECTIVES OF THE STUDY

- To evaluate the mechanical and thermal properties of clay bricks infused with plastic waste (Rafieizonooz et al., 2017).
- To assess the environmental and economic viability of this recycling approach (Kumar et al., 2019).
- To determine the potential application of these bricks in the construction industry (Siddique & Naik, 2004).

III.3. MATERIALS AND METHODOLOGY

III.3.1. Materials Used

- Clay: Extracted from local deposits and refined to remove impurities (Mamlouk & Zaniewski, 2011).
- Recycled Plastic Waste: Includes polyethylene (PE), polypropylene (PP), and polystyrene (PS) (Al-Salem et al., 2010).
- Additives: Lime and water were added to enhance the bricks' strength and durability (García et al., 2018).

III.3.2. Manufacturing Process

- Plastic Preparation: Collected plastic waste was cleaned, dried, and shredded into fine particles using an industrial shredder (Ahmad et al., 2020).

- Mixing Process: Clay was mixed with plastic waste, sand, and cement in appropriate proportions based on trial-and-error methods (Rafieizonooz et al., 2017).
- Molding and Compaction: The prepared mixture was molded into brick shapes and compacted using mechanical presses to ensure uniform density (Kumar et al., 2019).
- Drying and Curing: The molded bricks were air-dried for several days, followed by water curing to develop adequate strength (Mamlouk & Zaniewski, 2011).
- Testing and Quality Control: Finished bricks underwent tests for compressive strength, water absorption, and thermal conductivity to ensure quality and suitability (Siddique & Naik, 2004).

III.4. TESTING AND QUALITY CONTROL

III.4.1. Compressive Strength

Bricks infused with plastic waste demonstrated acceptable compressive strength for low-load-bearing construction. However, increasing the amount of plastic waste beyond a certain threshold tended to reduce mechanical strength (Rafieizonooz et al., 2017; Kumar et al., 2019).

III.4.2. Water Absorption

Plastic-infused bricks exhibited reduced water absorption compared to traditional clay bricks, indicating improved resistance to moisture and weathering (Ahmad et al., 2020).

III.4.3. Environmental and Economic Benefits

- Plastic Waste Reduction: Contributes to reducing environmental plastic pollution (Jambeck et al., 2015).
- Conservation of Resources: Limits the need for excessive clay extraction (UNEP, 2018).
- Cost-Effective: Utilization of plastic waste reduces reliance on raw materials, thus lowering production costs (Kumar et al., 2019).

III.5. CHALLENGES AND LIMITATIONS

- Emission Concerns: Processing plastic at elevated temperatures may release toxic substances such as dioxins, necessitating adequate filtration and emission control systems (Al-Salem et al., 2010).

- Compliance: Plastic-infused bricks must conform to national building codes and standards before widespread use (García et al., 2018).
- Market Acceptance: Construction professionals and consumers must be made aware of the potential advantages of these alternative bricks (Siddique & Naik, 2004).

III.6. CONCLUSION

This study shows that incorporating plastic waste into clay bricks can be a sustainable solution for reducing both environmental pollution and reliance on non-renewable resources in construction. The resulting bricks show promise in terms of mechanical performance and thermal behavior. Nevertheless, broader research and testing are needed to ensure regulatory compliance and increase public confidence in this emerging material.

PROBLEM STATEMENT AND OBJECTIVES OF THE WORK

PROBLEM STATEMENT AND OBJECTIVES OF THE WORK

Plastic waste is one of the major environmental challenges of our time. Each year, millions of tons are produced, with a significant portion ending up in nature, landfills, or the oceans, contributing to pollution and ecological harm. Simultaneously, the construction sector is a heavy consumer of natural resources and a major emitter of CO_2, particularly through the use of traditional bricks and cement.

In response to these challenges, innovative approaches are essential to recycle plastic waste while enhancing the sustainability of construction materials. One such solution is incorporating plastic waste into earthen bricks, a widely used material known for its acoustic properties. However, this raises questions about the mechanical performance and long-term durability of the resulting bricks.

The incorporation of plastic waste into clay bricks offers a sustainable, cost-effective, and practical solution to modern construction challenges. Actually, to the best of our knowledge, this specific material combination and method have not been tested in Algeria before. Furthermore, research carried out on this kind of bricks seems rare, making this research a novel contribution to sustainable construction in the region.

Main research question:

To what extent does incorporating plastic waste into earthen bricks affect their physical and mechanical properties, and what are the implications for sustainable construction?

To answer this question and with the goal of promoting sustainable and eco-friendly construction practices in Algeria, this study focuses on the impact of plastic additions on mechanical properties (tensile and compressive strengths) and durability factors (capillary absorption and total water absorption).

Following the problem statement, this section presents the experimental phase of the study, including the preparation of samples and testing of clay bricks reinforced with plastic waste to validate the hypotheses and achieve the study’s objectives.

PART 2

EXPERIMENTAL PROCESS

CAHPTER I

MATERIALS

CHAPTERI: MATERIALS

I.1. INTRODUCTION

The choice of materials used in the manufacture of compressed dredged sedimentrequires knowledge of their various physical, chemical, mineralogical and mechanical characteristics that can predict the quality of BTC according to their use.

In this chapter, we first present the characteristics of the clay (dredged sediments), the lime and plastic fibers used for the manufacture of the bricks. Secondly, we describe the various experimental methods used for experiments on the mechanical strengths and absorption of ECB.

I.2. DREDGED SEDIMENTS

Dredged sediments from the Chorfa II dam, located in the western part of Algeria, more precisely in the commune of Chorfa in the wilaya of Mascara (Fig1).The sediments have undergone a process of drying, crushing, grinding and sieving(Achour,2025), as can be seen in the Fig.II.1.

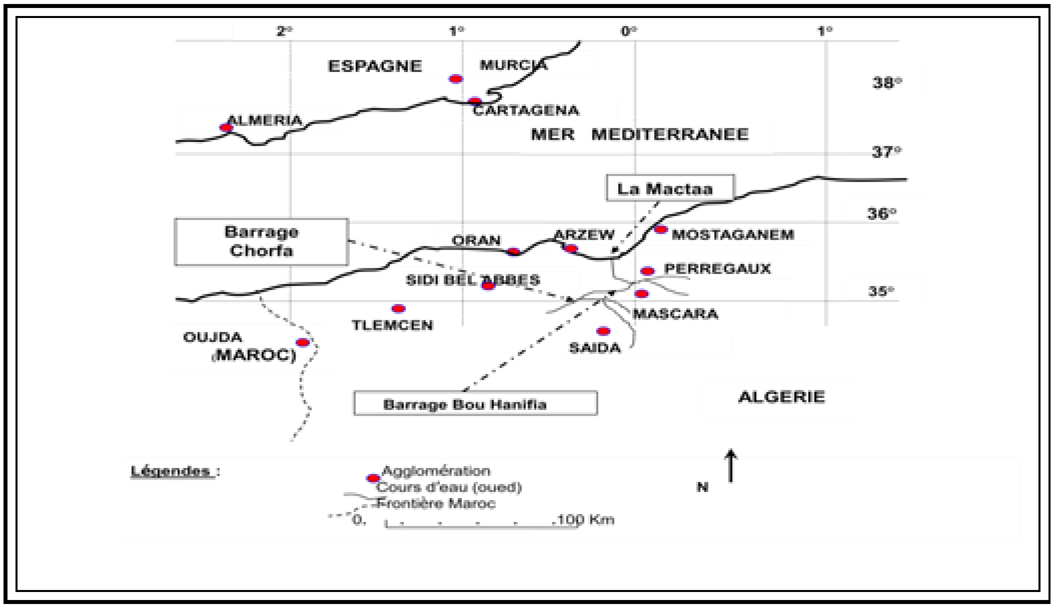


Fig.II.1. Location plan of the “Chorfa II” dam(ANBT 2020**).**

A sediment treatment process was implemented to prepare the dredged sediment sample for partial use as a substitute for lime. This method makes it possible to assess the physicochemical properties and mechanical performance of the sediments. This same process has been applied in several studies to treat dredged sediments, as shown in the works, these processes are illustrated in fig II.2.

Fig.II.2. The processing stages of dredged sediments (Acchour, 2024).

- **Drying:** The raw sediments (silt) sample is first placed in an oven at 105°C to remove moisture, which then facilitates grinding and sieving.
- **Crushing**: After drying, the silt is crushed to make crushing easier.
- **Grinding:** The crushed silt is then finely ground.
- **Sieving:** The crushed silt is passed through an 80 µm sieve in the dry process, and only the elements that pass through the sieve are retained for the following stages.

The sediments (clay) studied was subjected to physicochemical analysis to determine its properties (Tab. II.1 and II.2).

Tab.II.1. Chemical compositions of sediments, using XRF (weight%) (Achour,2024)

Composition of oxides	**Raw Sediments**
SiO_2	**40.04**
Al_2O_3	**10.58**
Fe_2O_3	**4.40**
CaO	**20.11**
MgO	**1.93**
SO_3	**0.30**
K_2O	**0.92**
Na_2O	**0.25**
Cl	**0.06**
PF	**23.08**
$CaCO_3$	**/**

Tab.II.2. Chorfa II dam Sediments densities.

Settings	Raw Sediments
Absolute Density g/cm^3	2.44
Apparent Density g/cm^3	1.51

I.3. LIME

The lime used in this study is quicklime (CaO) produced in the town of Hassasna, Erco Unit, wilaya of Saida. Its main characteristics are presented in Fig.II.3 and Tab.II.3

Fig.II.3. Lime

Tab.II.3. Chemical analysis and physical characteristics of quicklime (Erco Unit, Hassasna, 2025).

Chemical Analysis		**Physical Characteristics**		
Oxides	Mass %	Designation	Unit	Value
CaO	82.77	**Absolute density**	**kg/m³**	**2230**
Al_2O_3	10.63			
Fe_2O_3	3.27			
SiO_2	1.35	**Apparent density**	**kg/m³**	**1490**
MgO	1.88			
SO_3	0.11			
K_2O	0.15			
Na_2O	0.06	**Specific surface area**	**m²/kg**	**300**

I.4. PLASTIC FIBERS (PET)

The plastic fibers used in this study are polyethylene terephthalate, known commercially as PET. It is waste brought back from the Wilaya Public Institution for the Management of Technical Landfill Sites in Mostaganem, which currently oversees the management of five technical landfill sites for household and similar waste Fig.II.4).

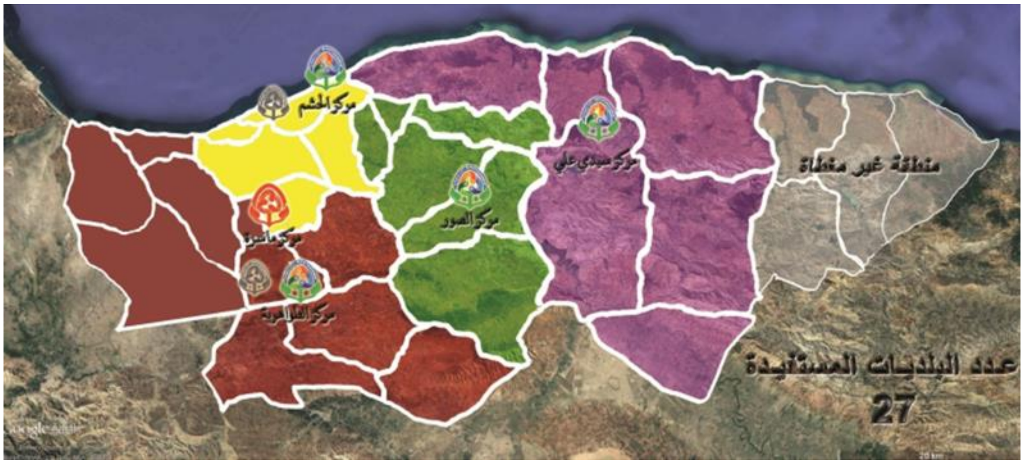


Fig.II.4. Locations of technical landfills in Mostaganem (Achour,2006)

This PET is obtained by finely grinding plastic bottles. Fig6 shows the PET waste used in our research (FigII.5).

FigII.5. PET used

Before being used in brick manufacturing, the crushed polyethylene terephthalate was subjected to laboratory tests, namely: apparent and absolute density. These tests were carried out at the laboratory

- Materials Laboratory for Construction Materials, Department of Civil Engineering, Abdelhamid Ibn Badis University of Mostaganem.
- Laboratory for Construction, Transport and Environmental Protection (LCTPE), Faculty of Sciences, University of Mostaganem.

Tab.II.4. Physicochemical, mechanical and thermal properties of PET reference mass (Achour,2006)

Property	Description
Apparent density	2.564
Absolute density	0.428
Tensile strength	55 - 75 MPa
Elongation at break	50 - 150 %
Hardness	85 - 95 Shore D Good impact resistance, even at low temperature
Impact resistance	Excellent, making it ideal for food and beverage packaging
Transparency	Excellent, ideal for food and drink packaging
Rigidity	High rigidity, offering good structural stability
Glass transition temperature (Tg)	70 - 80 °C
Melting temperature (Tm)	250 - 260 °C
Heat resistance	Withstands moderate temperatures, but may deform above 70 °C
Chemical resistance	Resistant to most oils, fats and alcohols, but sensitive to strong bases
Gas barrier	Good barrier to oxygen and carbon dioxide (CO_2), ideal for carbonated beverages
Water impermeability	Excellent, preserving the quality of liquid products

I.5. CONCLUSION

In this chapter, we have presented the different materials used in this study such as clay or sediments, lime and plastic fibers. These identifications are a crucial step in the experimental study of the bricks made of these components.

CHAPTER II

TESTS

CHAPTERII: TESTS

II.1 INTRODUCTION

As part of the search for innovative environmental solutions, the use of plastic waste in brick manufacturing has emerged as a promising approach to achieving sustainability. To ensure the quality and performance of such bricks, several essential tests must be conducted. These include the Atterberg limits test to determine soil properties, absolute and apparent density tests to assess compactness and porosity, the methylene blue test to evaluate the presence of active clay, as well as mechanical strength tests such as compression and flexural resistance. Additionally, total water absorption and capillary absorption tests are crucial to assess the bricks' water absorption capacity. These tests are fundamental to understanding the behavior of plastic waste bricks and ensuring their suitability for construction applications.

II.2 ATERBERG LIMITS

II.2.1 Operating Procedure

The procedure for determining the liquid limit is as follows (Casagrande apparatus Fig.II.6):

1. Take approximately 200 grams of soil previously sieved with a 0.4 mm sieve by wet and dry method.
2. Knead the entire sample until a homogeneous and nearly fluid paste is obtained.
3. Take a portion of the paste and spread it in the cup of the Casagrande apparatus using the spatula.
4. Create a groove in the paste in such a way as to divide it into two halves. The grooving tool must be held perpendicular to the cup, with its beveled edge facing the direction of movement Fig. (II.7).
5. Subject the cup and the material it contains to repeated shocks at a rate of 2 shocks per second.
6. Stop the shocks when the two lips come together over about 2 cm, and note the number of blows N corresponding to this (Fig.II.8).
7. Take about 5 grams of soil from both sides of the groove where they have just closed, to determine the water content.

8. Re-homogenize the soil and dry it slightly, then repeat steps 3 to 7. At least three tests are required with an increasing number of blows, ideally ranging between 15 and 35.

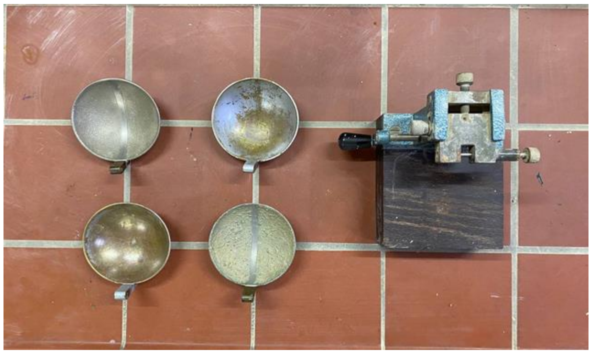


Fig.II.6. Casagrande apparatus

Fig.II.7. The groove

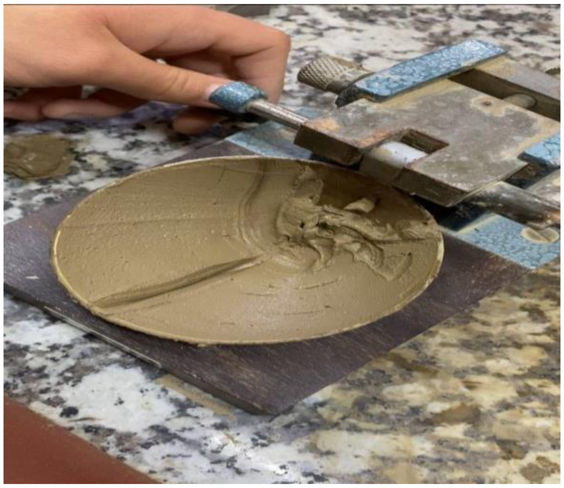


Fig.II.8. Contact between the two lips of the groove

II.2.2. Determination of the Plastic Limit

The procedure for determining the plastic limit is as follows:

- Take a bit of material and form a small ball. (FigII.9)
- Roll the ball by hand on a marble plate in such a way as to obtain a rod (FigII.10).

Three cases may arise:

- The rod begins to crack when it reaches a length of 10 cm and a diameter of 3 mm. In this case, the soil is at the plastic limit and its moisture content must be measured (this is the water content).
- The soil is still too fluid, and you cannot form the rod. The material needs to be dried a bit.

- The rod begins to crack too early; the material is dry. You need to moisten it a bit.

At least two tests must be performed to determine the plastic limit.

FigII.9. The soil ball

FigII.10. Rod

II.2.3 Calculation

To calculate the liquid limit, the following formula is used:

$$W_L = \omega_N \left(\frac{N}{25}\right)^{0.121}$$

Where:

- ω_N is the water content corresponding to the number of blows N.
- The average of the three tests is used.

To calculate the plastic limit, the average of the two tests is used.

II.3. DENSITY

This is the variation in mass relative to volume, and there are two types: apparent and absolute densities

II.3.1. Apparent density (NA EN 1097)

This is the ratio between the mass of a body and the unit of apparent volume (including voids). It is expressed in (g/cm3) and is calculated by filling a container with the desired material without compacting it, then levelling it off and weighing it. (Fig II.11)

II.3.1.1. Equipment used

- A balance with an accuracy of 0.01 g.
- A container with a volume of 5 liters.
- A levelling ruler

II.3.1.2. Procedure

- Weigh the empty, calibrated container.
- Take the material (clay) in both hands, forming a funnel shape.
- Place both hands approximately 10 cm below the container.
- Pour the material into the center of the container until it is full and overflows around the edge.
- Level off with the ruler without compacting the material.
- Weigh the contents and note the mass M.
- Repeat the operation three times to validate the test.

The apparent density is determined by the following formula:

$$\rho app = \frac{M}{V}$$

M: Mass of the material 'g'

V: Volume of the container 'cm^3'.

Fig II.11. Operating procedure – Apparent density.

II.3.2. Absolute density (NF EN 1097)

This is the ratio between the mass and the unit volume of the material (g/cm^3) that constitutes the aggregate, without taking into account any voids that may exist in or between the grains (FigII.12).

II.3.2.1. *Clay*

The equipment used is:

- A pycnometer.
- A balance.

Procedure**:**

1. Fill the pycnometer with water up to the neck.
2. Place the stopper and fill the pycnometer up to the mark.
3. Weigh the pycnometer + stopper + water assembly (M1).
4. Weigh a mass M2 of clay.
5. Empty some of the water from the pycnometer.
6. Place the mass M2 of clay in the pycnometer.
7. Remove any impurities to ensure the stopper is watertight
8. Place the stopper on the pycnometer and fill it with water up to the mark
9. Weigh the pycnometer + stopper + water + material assembly (M3).

FigII.12. Operating procedure – Absolute density

II.3.2.2. *Plastic fibers*

Equipment used:

- Precision balance
- Graduated cylinder (or test tube)
- Water
- Cut-up plastic waste

Procedure

1. Weigh the graduated cylinder empty and note the mass.
2. Add a known quantity of water to the cylinder and note the volume V1.
3. Weigh a precise mass of cut plastic (ms) using the balance. (Fig.II.13)
4. Gently place the pieces of plastic into the water in the cylinder,
5. avoiding the formation of air bubbles.
6. Record the new volume indicated in the cylinder (V2). (Fig.II.14)
7. Calculate the actual volume of the pieces of plastic: **Vs = V2 - V1.**
8. Calculate the absolute density:

$$\boldsymbol{\rho s = ms / Vs.}$$

ρs: absolute density (g/cm³ or kg/m³)

ms: mass of the plastic pieces (g)

Vs: actual volume displaced by the plastic (cm³)

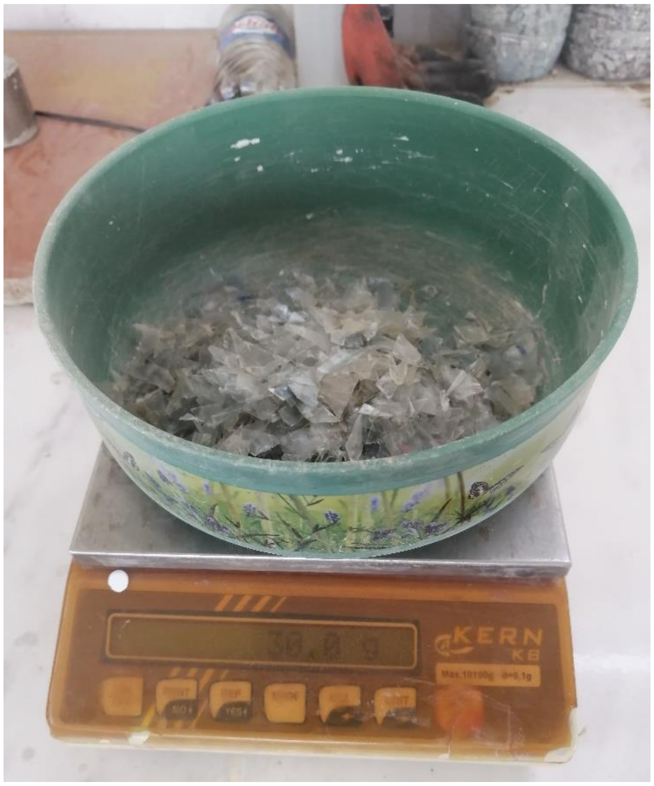


Fig.II.13. plastic weight

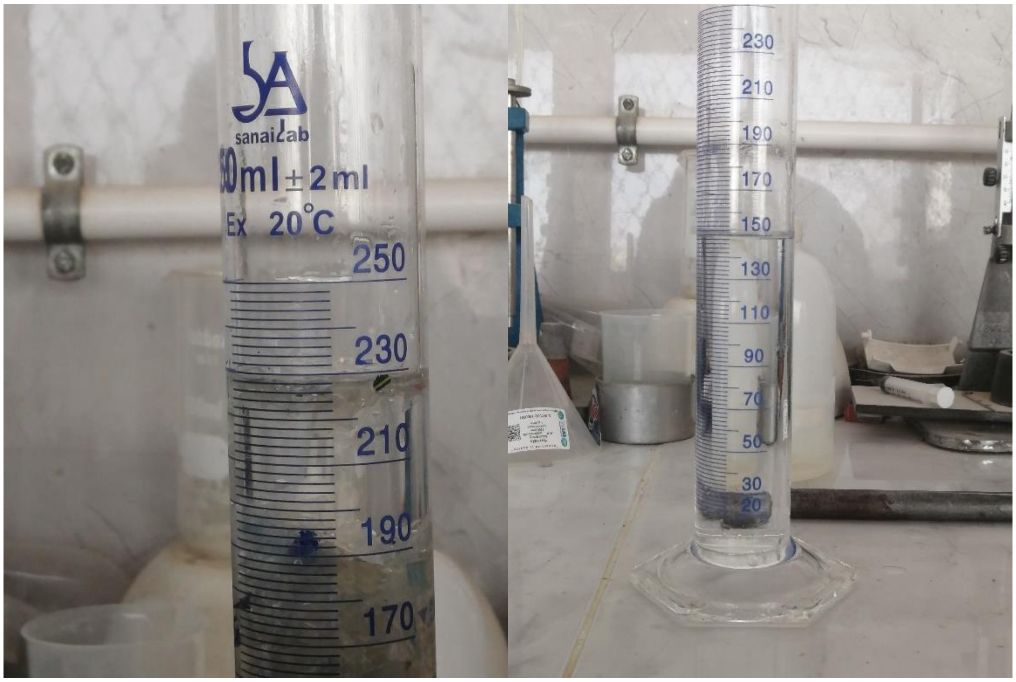


Fig.II.14. Plastic submerged in water

II.4. THE METHYLENE BLUE TEST

II.4.1. Operating Procedure: as showing in Fig.II.15

1. Take 10 grams of dry soil passed through a 5mm sieve.
2. Soak the test sample in a beaker with 100 cm^3 of water.
3. Using the agitator (700 rpm), disperse the suspension for 5 minutes.
4. Using the dosing device, introduce 5 cm^3 of blue dye and stir (400 rpm) for 1 minute.
5. Spot Test:

   Using a rod, place a drop of the suspension on filter paper.

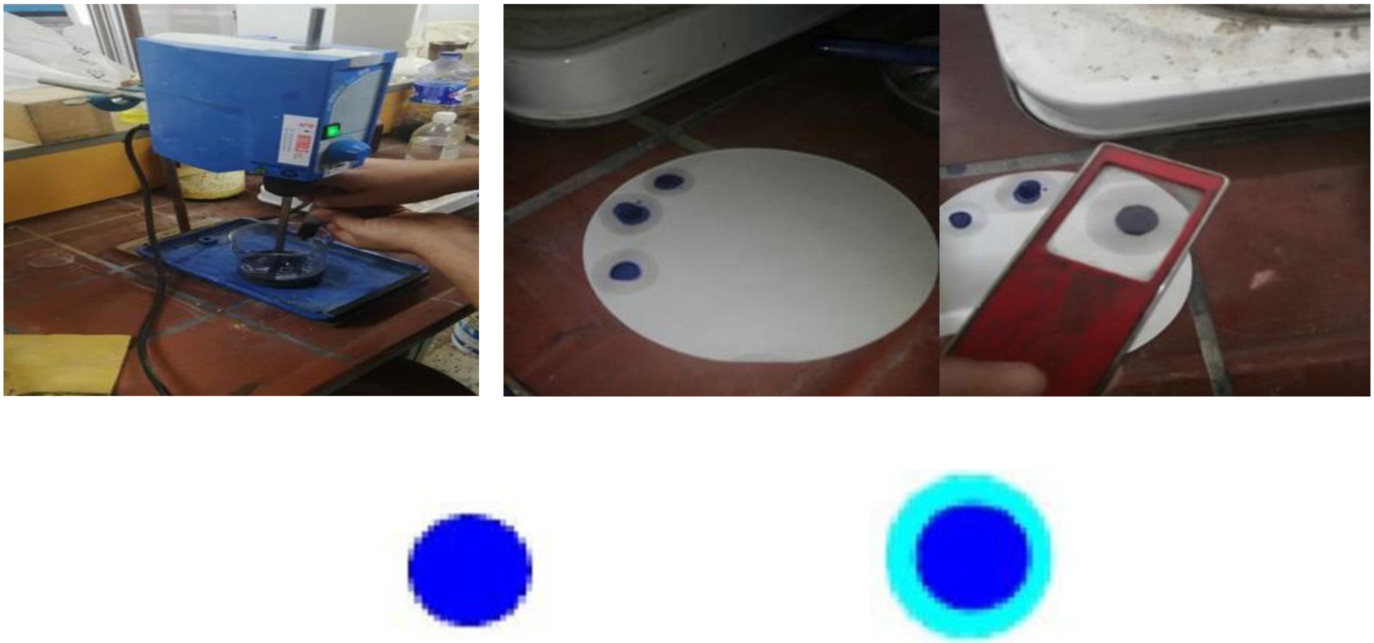
- **Negative Test:**

  The test is considered negative if the spot on the filter paper has no halo. In this case, add another 5 cm^3 of blue dye, stir again for 1 minute, and repeat the spot test (Step 5 is repeated). This operation is repeated as many times as necessary (as long as the test remains negative).

- **Positive Test**:

  The test is considered positive if the spot on the filter paper forms a halo. In this case, carryout 5 successive spot tests (one test per minute) without adding any more blue dye. If all 5tests are positive, the test is complete.

- If the 2nd, 3rd, or 4th spot test becomes negative (the spot loses its halo), add only 2.5 $cm^3$of blue dye and resume the spot tests from the beginning until all 5 spot tests are positive.



Négative test **Positive test**

Fig.II.15. The methylene blue test

II.4.2 Calculation

Methylene Blue Value (VBS) is calculated by:

$$VBS = \frac{B}{m} \times 100$$

- B: Mass of methylene blue solution added (g)
- m: clay mass

$$\boldsymbol{SST\ (m2/g)\ =\ 20.93 \times VBS}$$

The specific surface area is the ratio of the total surface area of the grains to their volumes, sometimes their weights (m^2/m^3 or m^2/Kg). It is of the order of 10 to 20 m^2/g for kaolinite and of the order of 500 m^2/g for montmorillonite.

The methylene blue test helps classify soil types based on their dye absorption, which indicates clay content. The table below shows this classification.

Tab.II.5. The nature of the soil according to the following classification (AFNOR, 1994)

Methylene Blue Value (VBS in g/100g of soil)	Nature of Soil
<0.2	Sandy soils
0.2 – 2.5	Silty soils
2.5 - 6	Silty-clayey soils
6 – 8	Clayey soils
> 8	Very clayey soils

II.5. PREPARATION OF COMPRESSED DREDGED SEDIMENT(DSB)

II.5.1. Specific materials

The prismatic test specimens ($4x4x16cm^3$) used to determine the various tests set out in our experimental program, were made in a mould (Fig.II.16) specially machined for this purpose. The mould consists of 5 hardened steel elements assembled by 8 studs.

Fig.II.16. Mould used for manufacturing DSB

Two types of bricks were manufactured. The first one is a reference compressed earth brick (Fig.II.18RDSB) and the second contains 1% of plastic fibers (Fig.II.19DSB 1%). The Tab.II.6 and Fig.II.17 show the compositions of the bricks.

Tab.II.6. Compositions of the bricks in gram.

Bricks	Clay	Lime	Plastic	Water
RDSB	385.02	24.576	/	112.19
DSB 1%	381.17	24.576	3.85	111.15

Fig.II.17. Components used for the bricks manufacture

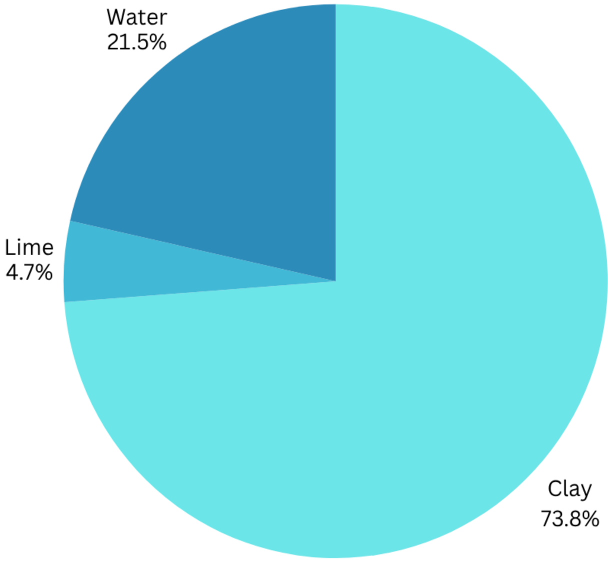


Fig.II.18. RDSB composition

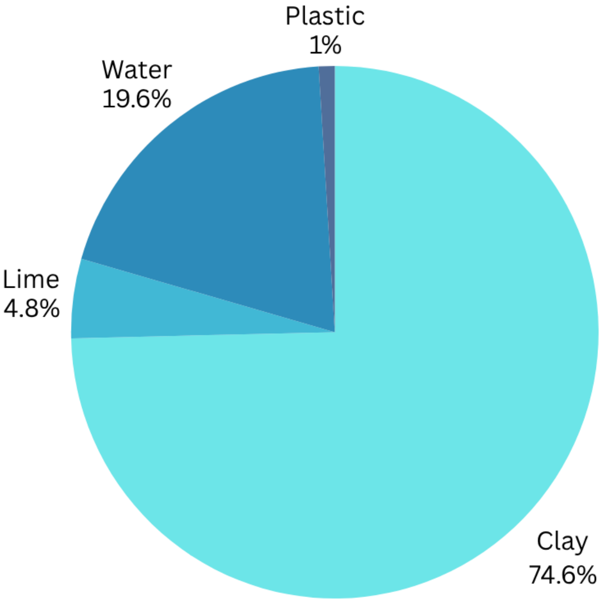


Fig.II.19. 1%DSB composition

II.5.2. Methodology for Preparing and Manufacturing Bricks

As part of this study, clay bricks reinforced with plastic waste were manufactured following a precise methodology to ensure mixture homogeneity and quality results. We began by thoroughly mixing the components of the mixture, which included clay, lime, shredded plastic waste, and water, until a fully homogeneous consistency was achieved. Several samples were produced, some containing a certain percentage of plastic waste and others serving as control samples without plastic, to compare their properties and test results. The mixture was then poured into molds in three stages, carefully leveling and lightly tamping each layer manually with a stone approximately 15 times per layer to achieve partial compaction and air removal. A metal cover was placed over the mold, followed by placing two weights on the sides to balance the press during compression. Subsequently, a simple manual press was used to compress the sample evenly until the desired brick shape was obtained. This approach was adopted to ensure precise reproducibility and uniform manufacturing conditions for all samples. As showing inFig.II.20.

Mixture **Layers** **Leveling**

Appearance **Machine** **Closing**

Pressing **Strength** **Result**

Fig.II.20. Manufacturing Bricks tabs

II.6 MECHANICAL STRENGTH

II.6.1 Flexural strength: EN 12390-4

The test must be carried out using a testing machine that complies with EN 12390-4 (Fig. II.21).

Prismatic test pieces are subjected to a bending moment until failure by applying a load using upper and lower rollers. The maximum load reached during the test is recorded, and the flexural strength is calculated.

The flexural strength is given by the following equation:

$$\boldsymbol{Rf} = \frac{\mathbf{3}(\boldsymbol{F}.\boldsymbol{L})}{(\boldsymbol{d}\mathbf{1}.\boldsymbol{d}\mathbf{2})}$$

Where:

Rf: is the flexural strength, in megapascals (Newtons per square millimeter).

F: is the maximum load, in Newtons;

L: is the distance between the support rollers, in millimeters. d1 and d2: are the lateral dimensions of the sample in millimeters. Express the flexural strength to the nearest 0.05MPa (N/mm^2)

For this test we need a hydraulic press (mould crushing test - flexure).

Fig.II.21. Flexion test

II.6.2. Compressive strength: EN 12390-3

The test consists of breaking the hollow block moulds between the plates of a 3000 kN hydraulic press at a constant speed (0.5 kN/s). These must be well centered between the plates in order to avoid the appearance of moments due to the eccentricity of the compressive load (Fig. II.22). Compressive strength is calculated using the following formula:

$$RC = F/S$$

Rc: Compressive strength (MPa)

F: Breaking load (N)

S: Cross-sectional area of the test piece (mm2)

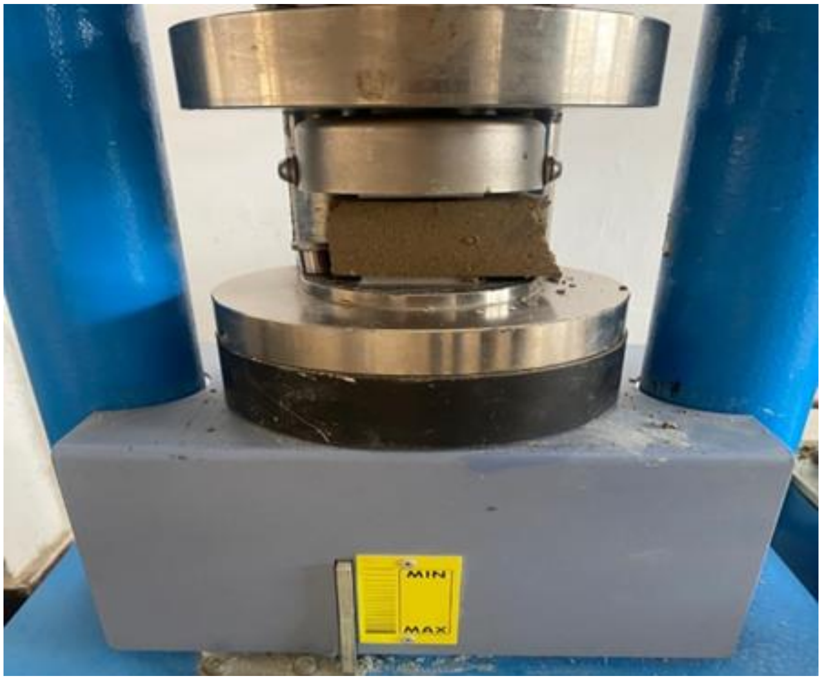


Fig.II.22. Compression test

II.7. DURABILITY TEST

II.7.1 Capillary absorption

Water absorption by capillary action is measured using the test detailed in experimental standard NF XP 13-901. The principle is to partially immerse the brick to a depth of 5 mm The water absorption coefficient Cb corresponds to the absorption rate after a period of 10 minutes.as showing in Fig.II.23, The water absorption coefficient Cb is expressed by the following formula:

$$Cb = \frac{100 \times (Mh - Md)}{S\sqrt{t}}$$

With:

Mh - Md: is the mass of water, in grams, absorbed by the block during the test;

S: surface area of the immersed face, in square centimeters;

t: is the immersion time of the block, in minutes

Fig.II.23. Principle of the capillary absorption test

II.7.2. Total absorption

Various procedures can be used to determine the total absorption capacity of the brick (BS 3921: 1985): Immersion in cold water (24 to 48 hours) after kiln drying to constant mass.

Using the above methods, very different results can still be obtained (Bungey and Millard, 1996). For this study, we used the cold-water immersion test and the boiling test. The first test consists of immersing the brick in a water tank for 24 h, and measuring the increase in weight Ph compared with the weight of the brick in the dry state Ps.

Total absorption (TWA) is determined by the following formula:

$$\boldsymbol{TWA}\% = \frac{\boldsymbol{Ph - Ps}}{\boldsymbol{Ps}}$$

For the boiling test, the dry bricks are placed in a vat of water at room temperature. The water is brought to the boil for a period of1 h, maintained at 100°C for 5 h. The bricks were left to cool at room temperature for between 16 and 19 hours. The wet bricks were then removed and weighed. Water absorption is assessed as shown in equation. As illustrated in the Fig.II.24

Fig.II.24. Total absorption test

II.8. CONCLUSION

To conclude, this chapter represents a fundamental phase in exploring the potential use of plastic waste in brick production. It focused on conducting a series of experimental tests aimed at evaluating the physical, mechanical, and chemical characteristics of the prepared samples. These tests serve as a preliminary step toward understanding the behavior of the plastic-based bricks and assessing their compliance with construction standards. In the following chapters, the results of these tests will be analyzed and compared to established benchmarks, providing insight into the feasibility and practical effectiveness of this innovative

CHAPTER III

TESTS RESULTS

CHAPTER III: TEST RESULTS

III.1. INTRODUCTION

This chapter presents the experimental results obtained from testing brick samples containing plastic waste. The results cover Atterberg limits, bulk density of both clay and plastic, methylene blue test, mechanical strength tests, and finally water absorption tests. For each test, the chapter includes definitions, measurement methods, calculations, results, and stepwise interpretations.

III.2. ATTERBERG LIMITS TEST

Atterberg limits define the critical water contents of fine-grained soils, which indicate their behavior and plasticity. These limits include the Liquid Limit (LL), Plastic Limit (PL), and Plasticity Index (PI). They are essential for understanding the workability and strength of clayey soils used in brick making.

III.2.2 Measurement Methods

- **Liquid Limit (LL):** Determined by the Casagrande cup method, where the soil paste is placed in a cup and the number of blows required to close a groove of 12.7 mm is recorded at different moisture contents.
- **Plastic Limit (PL):** Determined by rolling soil threads of 3 mm diameter until they crumble, indicating the plastic limit moisture content.

III.2.3 Calculation Formulas

$$PI = LL - PL$$

Where:

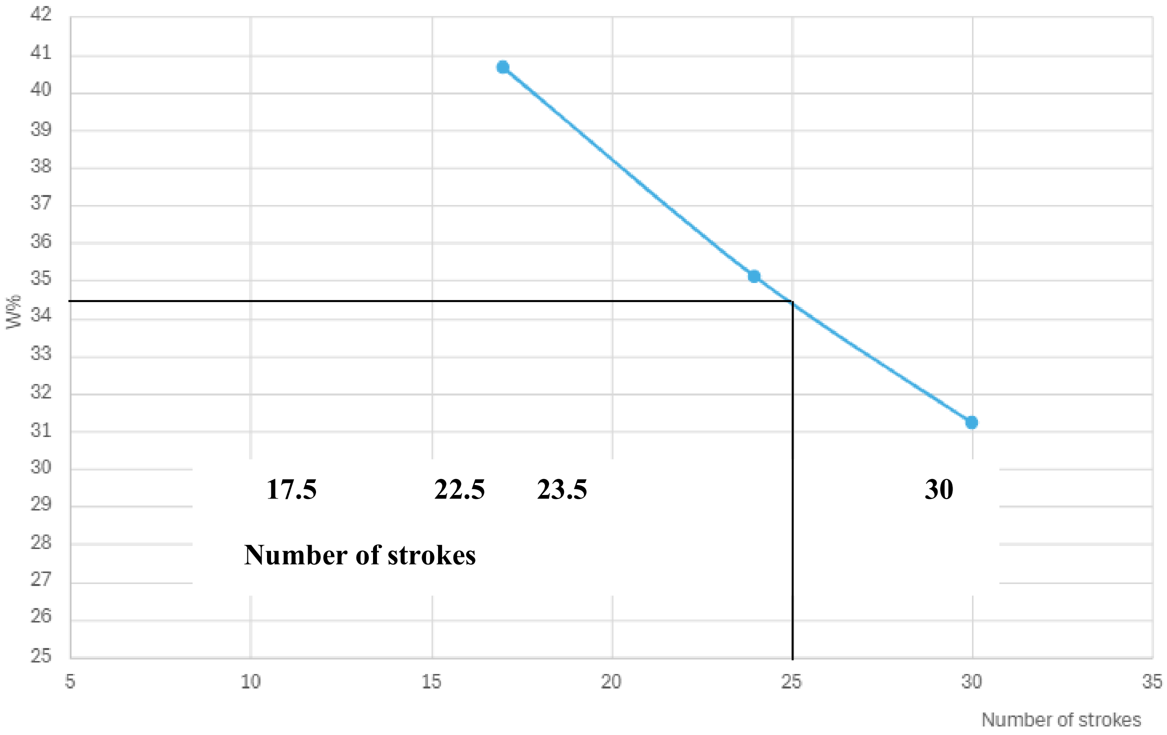
- LL = Liquid Limit (%)
- PL = Plastic Limit (%)
- PI = Plasticity Index (%), which measures soil plasticity range.

III.2.4. Results

The following table (Tab.II.7) and graph (Fig.II.25) presents the results obtained from the Atterberg limits test, which includes both the liquid limit and plastic limit for various soil samples. The liquid limit was determined using different numbers of blows (17, 24, and 30) following standard procedures, and the corresponding water contents were calculated. The plastic limit was also measured for the same samples. These values are essential for classifying the soil and evaluating its plasticity characteristics, which are critical for understanding its behavior in engineering applications

Tab.II.7. Determination of Liquid Limit (WL) and Plastic Limit (WP) of Soil Samples

	Liquidity limit						Plasticity limit	
Number of strokes	17		24		30			
Soil number	1	2	3	4	5	6	7	A
Total wet weight	9.0	11.3	10.5	10.9	11.5	11.9	10.8	9.9
Total dry weight	8.6	10.1	9.8	9.3	10.5	10.8	10	9.5
Soil weight	7.4	7.6	7.7	6.9	7.4	7.2	7.6	7.6
Water weight	0.4	1.2	0.7	0.8	1	1.1	0.8	0.4
Net dry weight	1.2	2.5	1.9	2.4	3.1	3.6	2.4	1.9
Water content	33.33	48	36.84	33.33	32	30.55	33.33	31.05
W_L	40.66		35.09		31.22			



$$W\% \approx 34.4$$

Fig.II.25. Results obtained from the Atterberg limits test

The graph shows approximately three data points plotting the relationship between the number of blows and the moisture content. A downward-sloping curve is drawn, indicating an inverse relationship between the number of blows and moisture content.

In the Liquid Limit (LL) test:

- As the moisture content increases, the number of blows needed to close the groove in the soil sample decreases.
- The Liquid Limit is defined as the moisture content at which the groove closes after exactly 25 blows.

In this graph, the point at which the curve intersects with 25 blows (vertical line) corresponds to a moisture content of W% ≈ 34.4.

This value indicate to :

- If the moisture content is higher than 34.4%, the soil behaves in a liquid state.
- If it's lower, the soil starts to behave in a plastic state.

Importance of This Result

- The Liquid Limit is a key index property used in soil classification systems such as the Unified Soil Classification System (USCS).
- Lower values (< 30%) indicate low plasticity, while values between 30–50% indicate medium plasticity**.**
- The value of 34.4% suggests that the soil has medium plasticity, which affects:

  - Shrink-swell behavior**.**
  - Workability and molding properties**.**
  - Stability of the soil in engineering constructions**.**

The moisture content W% ≈ 34.4determined from the curve represents the Liquid Limit of the soil. This is a moderate value indicating medium plastic behavior. Such information is essential in foundation and pavement design and helps determine whether the soil is suitable for construction or requires stabilization.

III.3. BULK DENSITY AND ABSOLUTE DENSITY TEST

III.3.1 Definition

Bulk density is the mass of material per total volume (including voids). Measuring bulk density of both clay and plastic helps understand their effect on the overall brick density. Absolute density is The mass of a material per unit of its true volume, excluding any pores or voids within or between particles.

III.3.2. Density Calculation for Clay and Plastic

Clay

A sample with mass 30 g

$$\rho clay = \frac{M2}{M1 + M2 + M3} \rho l$$

$$\rho clay = \frac{30}{341.7 + 30 + 360} \times 1 = 2.564$$

Plastic

A sample with mass 0.95 kg and volume 1000 cm³ (0.001 m³):

$$\rho plastic = \frac{m}{V2 - V1}$$

$$\rho plastic = \frac{30}{270 - 200} = 0.428$$

III.3.3. Interpretation

Clay has a higher bulk density than plastic, so adding plastic reduces the overall density of the brick.

III.4. METHYLENE BLUE TEST

III.4.1 Importance

This test measures the amount of active clay minerals, affecting soil plasticity.

III.4.2 Measurement Method

A methylene blue solution is gradually added to the sample until a persistent color change occurs, indicating absorption by clay minerals.

III.4.3 Calculation Formula

Methylene Blue Value (VBS) is calculated by:

$$VBS = \frac{B}{m} \times 100$$

- B: Mass of methylene blue solution added (g)
- m: clay mass

The total specific surface area of the portion is given by

$$SST\left(m^2/g\right) = 20.93\ \times VBS$$

III.4.4. Results

$$VBS = \frac{0.02}{10} \times 100 = 2\%$$

Tab.II.8. Soil Classification Based on Methylene Blue Value (AFNOR. (1994))

Soil blue value	Nature of the soil
<0.2	Sandy soils
0.2-2.5	Loamy soils
2.5-6	Loamy-Clayey Soils
6-8	Clayey Soils
>8	Very Clayey soils

$$SST\left(m^2/g\right) = 20.93\ \times 2$$

$$SST\left(m^2/g\right) = 41.86\,m^2/g$$

The VBS result indicates that the soil is Loamy.

III.5. MASS LOSS

The study of mass loss in brick samples is a crucial indicator for understanding the behavior of construction materials incorporating unconventional additives, such as plastic waste. In this context, brick specimens were prepared using 1% plastic waste, along with a control sample without any additives, and monitored for changes in mass over different curing periods: 3, 7, 14, and 28 days. This investigation aims to assess the stability of the samples over time, particularly in relation to moisture absorption, and to understand the physical interactions that may affect the durability and quality of these alternative materials. Mass loss analysis provides valuable insights into the efficiency of using plastic as a component in bricks, allowing for performance comparisons with conventional bricks.

Tab.II.9. Weight difference between before and after some days in gram

DAYS	Bricks	weight	weight after	percentage difference %
3 days	1%DSB	511.5	508.3	0.63
	RDSB	502.5	499.7	0.56
7 days	1%DSB	433.2	429.3	0.90
	RDSB	490.5	485.6	1.00
14 days	1%DSB	508.8	485.6	4.56
	RDSB	506.5	492.1	2.84
28 days	1%DSB	483.0	454.6	5.88
	RDSB	511.7	493.17	3.62

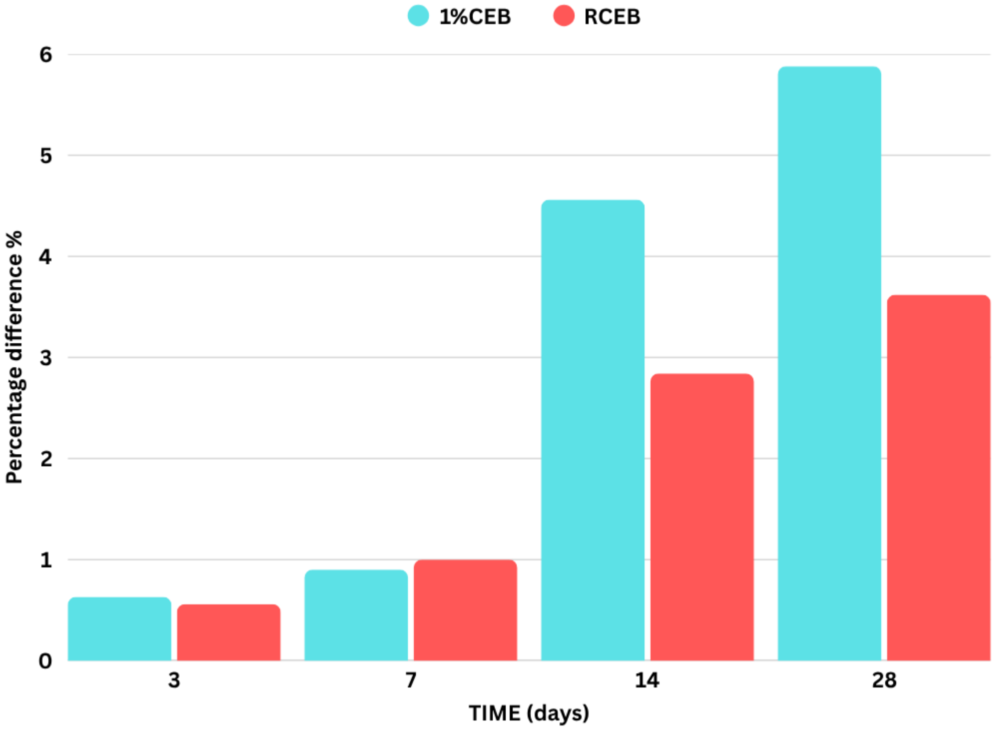


Fig.II.26. Weight difference between before and after some days in gram (1%DSB)

III.5.1. Discussion of the Results

The bar chart illustrates the percentage difference in mass for two types of compressed earth bricks:

- **RDSB** (Reference Compressed Earth Brick)
- **1%DSB** (Compressed Earth Brick containing 1% plastic waste)

Measurements were taken at 3, 7, 14, and 28 days.

Day 3 and Day 7

- The mass loss difference between the control sample (RDSB) and the modified sample (1%DSB) is minimal — less than 1%.
- This indicates that the incorporation of 1% plastic waste has little to no effect on the early-stage mass stability of the bricks.

Day 14

- A noticeable increase in mass loss is observed in the 1%DSB sample (~4.6%) compared to the control (~2.8%).
- This suggests that plastic-containing bricks may begin to show increased susceptibility to drying or internal structural changes after two weeks of curing.

Day 28

- The gap becomes more pronounced: the 1%DSB sample reached about **5.9%** mass loss, while the control brick is at **3.6%**.
- This may imply that plastic waste incorporation results in a more porous structure or weaker particle bonding over time, allowing more moisture to evaporate.

III.5.2. Interpretation

Incorporating 1% plastic waste into compressed dredged sedimentshows comparable performance to the control during the initial curing phase (3 and 7 days). However, as curing time increases, the plastic-containing bricks tend to lose more mass, potentially indicating lower structural stability or increased porosity. Further analysis is needed to assess the long-term durability and mechanical performance of these eco-friendly alternatives

III.6. MECHANICAL STRENGTH TESTS

The results of the flexural and compressive strength tests are shown in Table II.10 and Figures II.27 and II.28.

Tab.II.10. Results of mechanical strength tests in MPa

DAYS	Bricks	Flexion	Compression	
			1	2
14 days	1%DSB	**σ =0.294**	σ =0.678	σ =0.643
			σ_{moy}=0.661	
	RDSB	**σ =0.291**	σ =0.291	σ =0.459
			σ_{moy}=0.375	
28 days	1%DSB	**σ =7.243**	σ =1.205	σ =0.905
			σ_{moy}=1.055	
	RDSB	**σ =6.88**	σ =1.28	σ =1.44
			σ_{moy}=1.360	

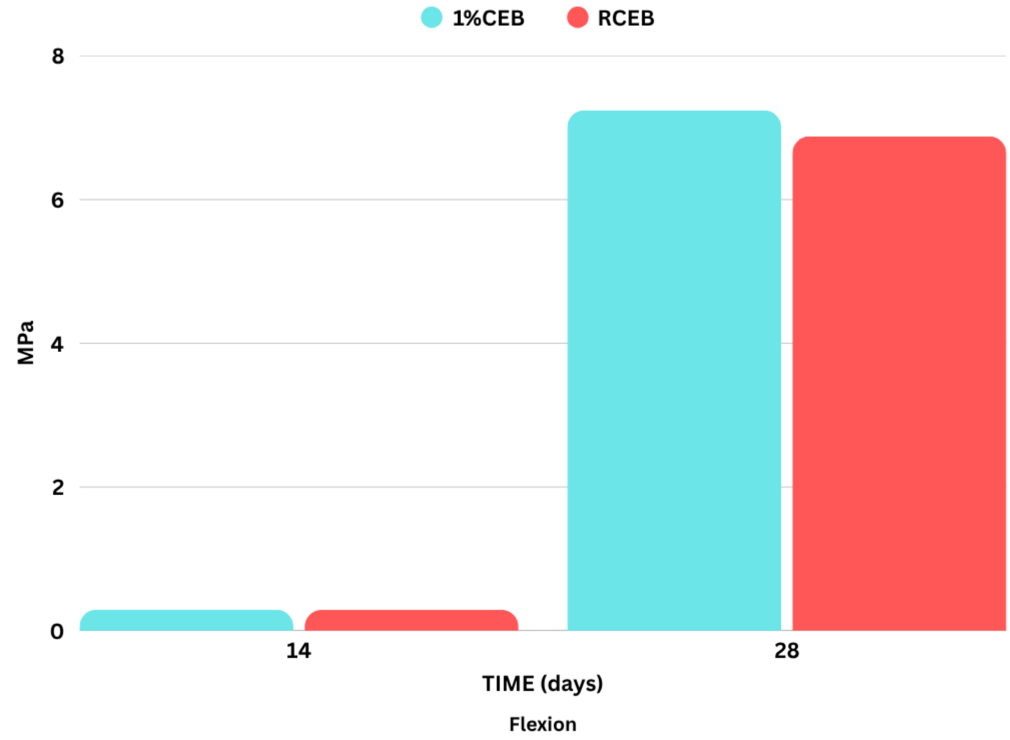


Fig.II.27. result of flexion effort in MPa

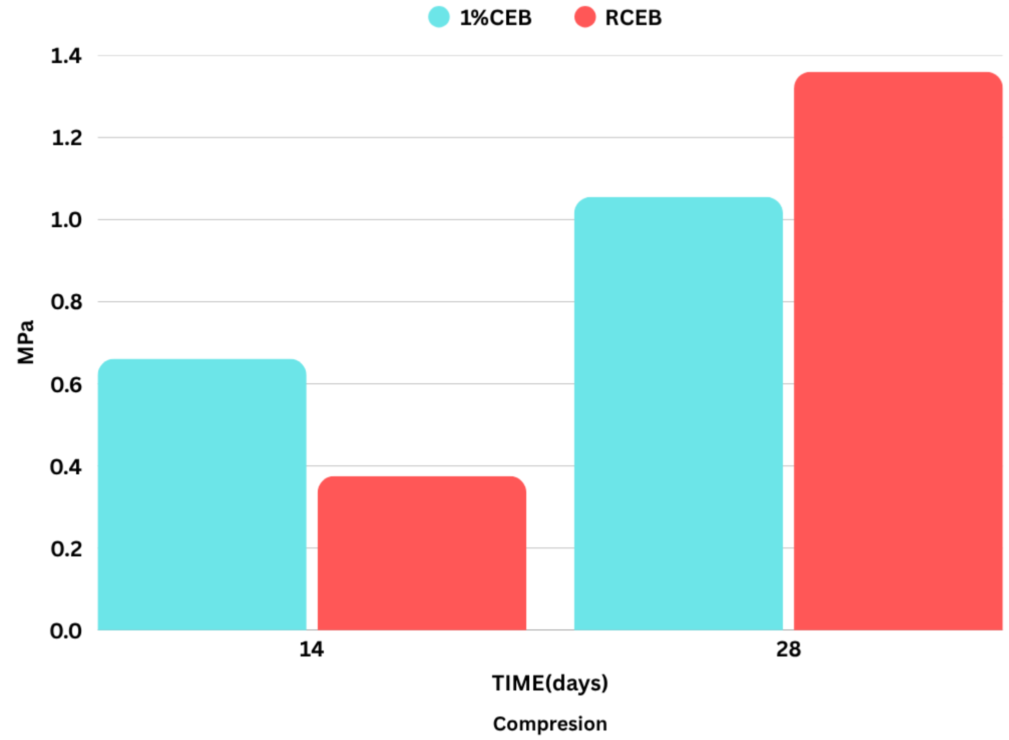


Fig.II.28. result of compression effort in MPa

III.6.1. Interpretation of Flexural and Compressive Strength Results

The mechanical performance results presented in Table II.10 and illustrated in Figures II.29 and II.30 were evaluated against both international and Algerian standards for masonry materials to determine their applicability in construction.

At 14 days, the flexural strength of traditional compressed dredged sediment(1% DSB) and recycled compressed dredged sediment(RDSB) was low, approximately 0.29 MPa for both types. This is below the minimum flexural strength values specified by Algerian standard **NA 442 (Algerian Standard for Clay Bricks)** and comparable international standards (ASTM C67, EN 771-1), which typically require a minimum flexural strength of around 2 to 5 MPa for structural masonry units. However, after 28 days of curing, significant improvement was observed with flexural strengths reaching 7.24 MPa (1% DSB) and 6.88 MPa (RDSB), thus exceeding the minimum benchmarks. The enhancement in RDSB is attributed to the reinforcing effect of plastic fibers that help resist bending stresses and limit crack propagation.

Concerning compressive strength, initial values at 14 days were modest (0.66 MPa for 1% DSB and 0.37 MPa for RDSB), falling short of the minimum requirement set by **NA 442**, which generally demands compressive strengths of at least 3 MPa for non-load-bearing bricks and higher (5 MPa or more) for load-bearing units. After 28 days, compressive strengths increased to 1.05 MPa and 1.36 MPa for 1% DSB and RDSB respectively, showing improved internal cohesion but still below structural standards for load-bearing masonry.

In summary, the inclusion of plastic fibers in RDSB may cause an initial reduction in early-age strength but contributes to enhanced long-term flexural properties, making these bricks suitable for non-structural or insulation purposes within the Algerian construction context. To comply fully with Algerian structural masonry standards, further material optimization is required to increase compressive strength.

III.7. WATER ABSORPTION TEST

III.7.1. Capillary Water Absorption

III.7.1.1. *Definition*

It means the amount of water absorbed by the specimen through capillary action when placed in contact with water.

III.7.1.2. *Measurement Method*

The specimen's lower surface is in contact with water, and weight is recorded before and after absorption.

III.7.1.3. *Calculation Formula*

$$Cb = \frac{100 \times (Mh - Md)}{S\sqrt{t}}$$

Where:

Mh - Md: is the mass of water, in grams, absorbed by the block during the test;

S: surface area of the immersed face, in square centimeters;

t: is the immersion time of the block, in minutes

III.7.1.4. *Results*

After some time, we got the results shown in the table II.11 and figure II.28.

Tab.II.11. Weight difference between before and after capillary absorption in gram

Samples	Moment of manufacture	Weight after 28days	Weight after 10 min of absorption	Coefficient of absorption $g/cm^2.min^{1/2}$
1%DSB	478.6	386.7	394.7	3.952
RDSB	509.4	439.01	447	3.947

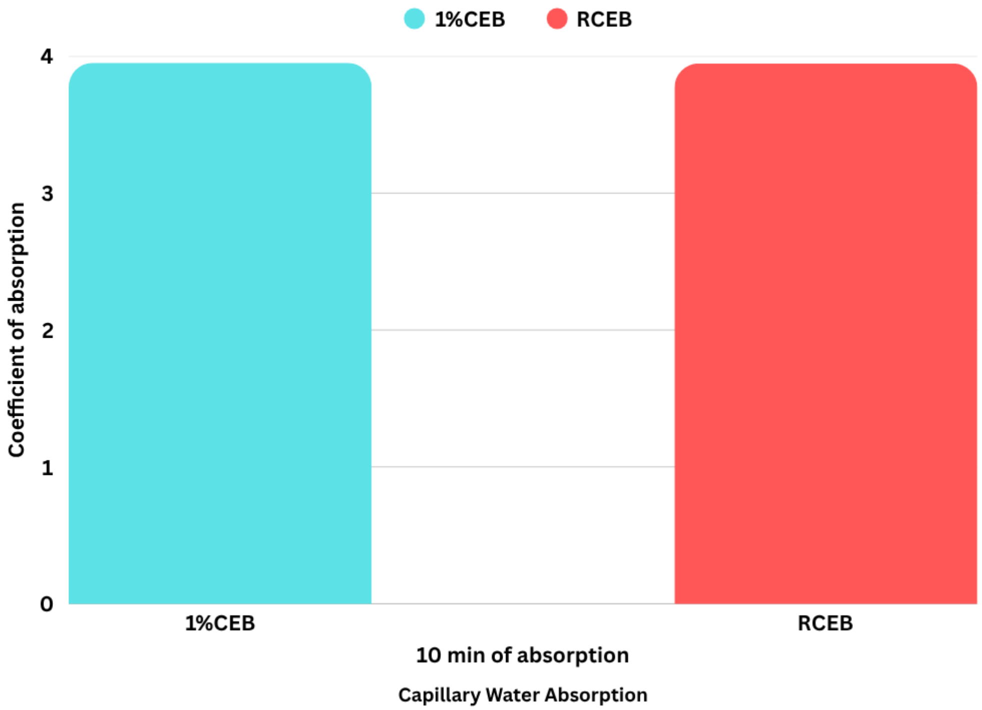


Fig.II.29. Coefficient of Capillary Water Absorption Calculated from the Weight Difference in 1% DSB Samples (g/cm^2.min$^{1/2}$)

III.7.2. Total Water Absorption

III.7.2.1. *Definition*

Amount of water absorbed after full immersion of the specimen for 48 hours.

III.7.2.2. *Measurement Method*

The specimen is submerged in distilled water for 48 hours, weighed, and absorption is calculated using the same formula.

III.7.2.3. *Results*

After some time, we got the results shown in the table II.12 and figure II.30.

Tab.II.12. Weight difference between before and after total absorption in gram

Test tub	Moment of manufacture	Weight after 28days	Weight after 48h of absorption	TWA%
1%DSB	507.8	408.7	487.5	19.28
RDSB	515.2	416.9	500.8	20.12

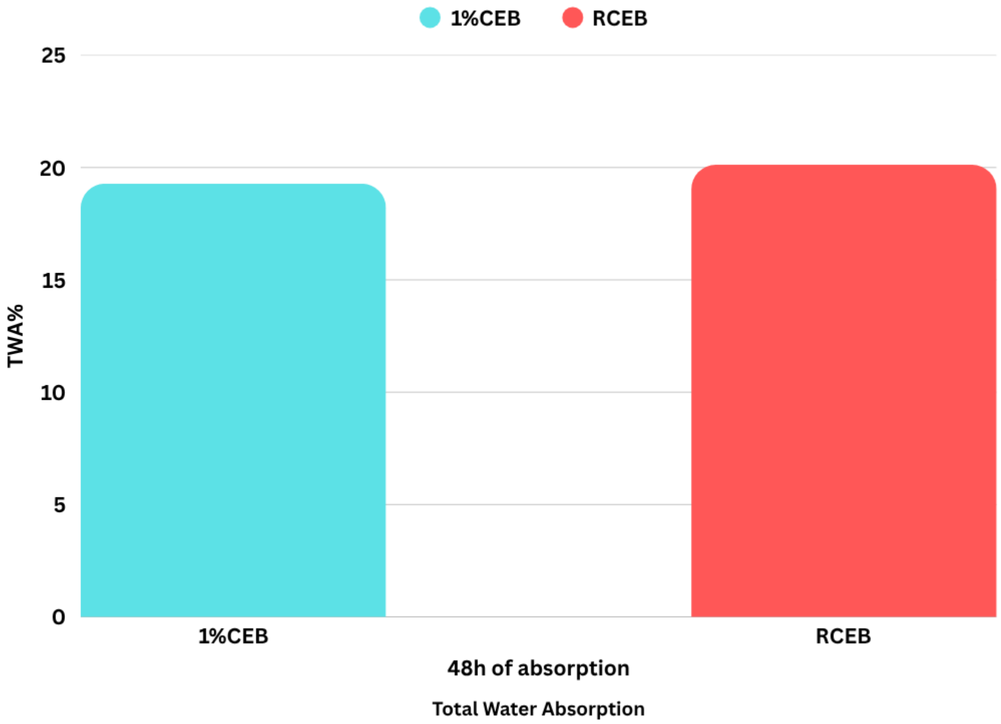


Fig.II.30. Percentage Weight Variation of RDSB Before and After Total Water Absorption

III.7.3. General Notes

- Both tests should be performed on representative samples of the same type of brick.
- High absorption indicates high porosity and lower mechanical resistance.
- Capillary absorption is more critical than total absorption, as it mimics natural water rising from soil.

III.8. CONCLUSION

The incorporation of plastic into the soil leads to a decrease in the Atterberg limits, indicating reduced soil plasticity. Bulk density also decreases as the lighter plastic material replaces the denser clay. Additionally, the methylene blue value declines, reflecting a lower content of effective clay minerals and thus reduced plasticity. Although mechanical strengths, including flexural and compressive strength, decrease with the addition of plastic, they remain within acceptable limits. On the other hand, water absorption increases, suggesting higher porosity, which may negatively affect the long-term durability of the material.

GENERAL CONCLUSION

GENERAL CONCLUSION

The present study has addressed a crucial environmental and engineering challenge: the excessive accumulation of plastic waste and the need for more sustainable building materials in Algeria and beyond. By investigating the integration of plastic waste into compressed dredged sediment(DSBs), this work contributes to the dual objective of environmental preservation and sustainable construction development.

Throughout this research, we explored the physical, chemical, and mechanical properties of clay bricks modified with a 1% plastic waste addition. The experimental program included tests for flexural and compressive strength, capillary and total water absorption, and density. The materials used in the brick mixtures were characterized thoroughly, including Atterberg limits**,** methylene blue value, and grain size distribution, to ensure a comprehensive understanding of the soil behavior before and after the plastic addition.

The results revealed several important findings:

- The addition of plastic waste caused a slight reduction in mechanical resistance, especially compressive strength. While this may seem like a drawback, the remaining strength levels are still acceptable for non-load-bearing structures or secondary construction elements, especially in rural or low-income housing projects.
- Water absorption decreased significantly in bricks containing plastic. This is due to the hydrophobic nature of plastic, which reduces water uptake and enhances durability against moisture-related deterioration.
- From an economic and ecological perspective, incorporating plastic waste in brick production reduces the demand for natural clay and provides a valuable outlet for managing non-biodegradable waste. This supports goals of sustainable material use and waste reduction, essential for a greener construction industry.

Nevertheless, some challenges remain:

- The lower mechanical strength may limit these bricks to non-structural uses unless further stabilized or optimized.
- The processing of plastic waste—collection, sorting, cleaning, and shredding—requires proper organization to ensure safe and effective reuse in construction.

- There is currently a lack of official standards in Algeria for plastic-modified construction materials, which may slow down adoption unless clear technical guidelines and certifications are developed.

In conclusion, this study demonstrates that reusing plastic waste in the production of clay bricks is a feasible, environmentally responsible, and economically viable alternative for sustainable construction. With further research and technical development, such bricks can become a key solution to the dual problems of plastic pollution and resource overexploitation.

Nevertheless, challenges remain, such as plastic waste processing, technical optimization of the material, and the lack of regulatory standards.

The study recommends continuing research to improve formulations, expand possible applications, and develop a legal framework for large-scale use of this alternative material:

- Explore other types and proportions of plastic waste,
- Study long-term performance under environmental stress (e.g., weathering, aging),
- Conduct life-cycle assessments and cost-benefit analyses,
- Scale up production and develop regulatory frameworks for industrial use.

This innovation supports Algeria’s path toward a **circular economy**, where waste is transformed into resources, and construction becomes a tool for ecological balance and sustainable development.

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