

**EFFECT OF RECYCLED POLYPROPYLENE WASTE ADDITION ON THE  
COMPRESSIVE STRENGTH OF SANDCRETE BLOCKS**



**BY**

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## **PLAGIARISM**

This work **EFFECT OF RECYCLED POLYPROPYLENE WASTE ADDITION ON THE COMPRESSIVE STRENGTH OF SANDCRETE BLOCKS** by DAVID, Mirabel Ayasiegbe with matriculation number ENG2002091 of the Department of Civil Engineering, Faculty of Engineering, University of Benin City, Edo State, Nigeria, has PASSED the PLAIGIARISM TEST.

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## **DEDICATION**

I dedicate this project to Almighty God for the grace upon my life, for the strength and guidance to carry out this project successfully. Also to my Parents and brother for their support and to everyone who made this project a success.

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## ABSTRACT

This research investigated the utilization of polypropylene (PP) waste as an additive in the production of sandcrete blocks, aimed at promoting sustainable waste management and reducing the environmental impact of plastic pollution. The study sought to determine the influence of varying polypropylene waste contents on the physical and mechanical properties of sandcrete blocks, thereby evaluating its suitability as a construction material modifier.

The experimental work involved producing paving stone specimens with 0%, 1%, 2%, 3% and 4% polypropylene waste by weight of sand. Aggregates were first characterized through specific gravity and sieve analysis to ensure conformity with standard specifications. Sandcrete blocks were then cast, cured in water, and tested for water absorption and compressive strength at 3 and 7 days of curing, following procedures outlined in relevant British Standards. This methodology ensured uniformity in mixing, curing and testing, allowing a clear assessment of polypropylene's effect on the samples' performance.

The results showed the polypropylene addition influenced both durability and strength properties. Water absorption ranged between 0.64% and 2.88% with the lowest value recorded at 4% PP content, suggesting improved impermeability at higher plastic dosages. Compressive strength ranged from 11.41Mpa and 16.07Mpa, with optimum strength achieved at 1% PP addition, after which a gradual reduction is observed. It was concluded that the inclusion of polypropylene waste up to 1% can enhance strength and durability without compromising structural performance. The study recommends using low dosages of polypropylene waste in sandcrete blocks production and encourages further research into improving interfacial bonding through surface modification and longer curing periods to maximize the material's potential for sustainable construction.

## TABLE OF CONTENTS

DEDICATION.....	iv
ACKNOWLEDGEMENT.....	v
ABSTRACT.....	vi
TABLE OF CONTENTS.....	vii
LIST OF TABLES.....	x
LIST OF FIGURES.....	xi
ACRONYMS.....	xii
CHAPTER ONE: INTRODUCTION.....	1
1.1. Background of the Study.....	1
1.2. Problem Statement.....	2
1.3. Aims and Objectives.....	3
1.4. Scope of Study.....	4
1.5. Justification of Study.....	5
CHAPTER TWO: LITERATURE REVIEW.....	7
2.1. Review of Related Works.....	9
2.2. Polypropylene Waste.....	12
2.3. Sources of polypropylene waste.....	13
2.3.1. Packaging industry: the leading contributor.....	14
2.3.2. Household consumer goods: often overlooked contributors.....	15
2.3.3. Medical and healthcare sector: a significant source.....	16
2.3.4. Agricultural applications: a growing environment concern.....	17
2.3.5. Industrial and commercial sectors: an expanding issue.....	17
2.4. Properties of polypropylene waste.....	18
2.4.1. Physical properties.....	18
2.4.2. Mechanical properties.....	18
2.4.3. Thermal properties.....	19
2.4.4. Chemical resistance.....	19

2.4.5. Environmental & degradation aspects .....	19
2.5. Recycling of polypropylene waste .....	19
2.5.1. Mechanical recycling (physical recycling) .....	20
2.5.2. Chemical recycling (feedstock recycling) .....	21
2.5.3. Energy recovery .....	22
2.6. Challenges in polypropylene recycling .....	23
2.7. Potential solutions for improved polypropylene recycling challenges .....	24
2.8. Paving stones .....	25
2.8.1. Composition of paving stones .....	26
2.8.2. Fine aggregates in paving stones production .....	29
2.9. Concrete properties of paving stone .....	30
2.10. Importance of paving stones in construction .....	33
CHAPTER 3: METHODOLOGY .....	34
3.2. Materials and methodology .....	35
3.2.1. List of materials .....	35
3.2.2. List of equipment .....	36
3.3. Experiment plan .....	36
3.3.1. Materials collection .....	37
3.3.2. Materials preparation .....	38
3.4. Laboratory test procedures .....	41
CHAPTER FOUR: RESULTS AND DISCUSSION .....	45
4.1 Introduction .....	46
4.2. Sieve Analysis results .....	47
4.2.1. Discussion of sieve analysis results .....	49
4.3. Specific gravity results .....	49
4.3.1. Discussion of specific gravity results .....	51
4.4. Water Absorption results .....	52
4.4.1. Discussion of water absorption results .....	56
4.5. Compressive strength test results .....	57
4.5.1. Discussion of compressive strength results .....	61
CHAPTER 5: CONCLUSIONS AND RECOMMENDATIONS .....	62

5.1 Conclusion.....	62
5.2. Recommendations.....	64
REFERENCES .....	66

## LIST OF TABLES

Table 4.1 Sieve Analysis Results for Fine Aggregate .....	47
Table 4.2 Sieve Analysis Results for Polypropylene (PP) Waste .....	48
Table 4.3 Specific Gravity Results for Fine Aggregate .....	49
Table 4.4 Specific Gravity Results for Polypropylene (PP) Waste .....	51
Table 4.5 Water Absorption Results for 3 days .....	52
Table 4.6 Average values of water absorption for each percentage at 7 days .....	53
Table 4.7 Water Absorption Results for 7 days .....	54
Table 4.8 Average values of water absorption for each percentage at 7 days .....	55
Table 4.9 Compressive Strength Test Results at 3 days .....	57
Table 4.10 Average compressive strength for each percentage at 3 days .....	58
Table 4.11 Compressive Strength Test Results at 7 days .....	59
Table 4.12 Average compressive strength for each percentage at 7 days .....	60

## LIST OF FIGURES

Figure 3.1 Polypropylene (PP) waste sample .....	40
Figure 4.1 Sieve analysis results for fine aggregates and polypropylene waste .....	48
Figure 4.2 Average Water Absorption for Sandcrete Blocks .....	55
Figure 4.3 Average Compressive Strength of Polypropylene Sandcrete Blocks .....	60

## LIST OF EQUATIONS

Equation 4.1	Specific gravity for fine aggregates .....	50
Equation 4.2	Specific gravity for fine aggregates .....	50
Equation 4.3	Specific gravity for Bottle DA .....	50
Equation 4.4	Specific gravity for Bottle BO .....	50
Equation 4.5	Average specific gravity for fine aggregates .....	50
Equation 4.6	Specific gravity for polypropylene waste .....	51
Equation 4.7	Specific gravity for polypropylene waste .....	51
Equation 4.8	Specific gravity for Bottle DT .....	51
Equation 4.9	Water absorption .....	54

## ACRONYM

PP - Polypropylene

## **CHAPTER ONE**

### **INTRODUCTION**

#### **1.1. BACKGROUND OF STUDY**

The global construction industry remains a cornerstone of economic growth and urban development. As urbanisation intensifies, the demand for construction materials such as sand, gravel, and cement continues to increase significantly (Zhou *et al.*, 2021). However, this rapid growth has created substantial environmental challenges, particularly the depletion of natural resources and the excessive generation of construction waste. At the same time, the world is grappling with an escalating plastic pollution crisis, driven by the widespread use of non-biodegradable plastics such as polypropylene (PP).

Polypropylene is one of the most commonly used thermoplastic polymers, widely employed in packaging, textiles, automotive components, and consumer goods due to its strength, lightweight nature, and chemical resistance (Hao *et al.*, 2020). Unfortunately, these same properties make it highly persistent in the environment, where it can remain for hundreds of years without degrading. As global plastic waste increases annually, concerns about its environmental and health impacts have grown, prompting researchers and policymakers to explore innovative methods of recycling and reusing plastic waste.

In recent years, attention has turned towards the construction industry as a potential avenue for the beneficial reuse of waste plastics. The incorporation of recycled or waste plastics into construction materials provides an opportunity to reduce environmental pollution while conserving natural resources. Among the various types of plastic, polypropylene has shown

strong potential for improving certain mechanical properties of concrete composites when properly integrated (Cahyani *et al.*, 2023).

Previous studies have examined the effects of replacing fine aggregates with polypropylene waste; however, fewer studies have focused on the addition of polypropylene waste in controlled quantities to concrete mixes. Unlike replacement, addition introduces polypropylene as a supplementary material within the mix to enhance specific performance characteristics without completely substituting natural aggregates. This method may improve the overall density, ductility, and compressive strength of paving stones while maintaining adequate workability and durability (Singh *et al.*, 2021).

Thus, this study focuses on the addition of polypropylene waste to concrete paving stones in incremental proportions of 1%, 2%, 3%, and 4% by total weight of the mix. This approach not only addresses the problem of plastic waste management but also contributes to sustainable construction practices that align with the principles of the circular economy — reducing, reusing, and recycling materials for environmental preservation.

## **1.2. PROBLEM STATEMENT**

The ever-increasing accumulation of plastic waste, particularly polypropylene, poses a severe environmental challenge. Polypropylene's resistance to degradation means that it accumulates in landfills, water bodies, and soil ecosystems, resulting in long-term ecological harm (Hao *et al.*, 2020). Simultaneously, the construction industry continues to consume enormous quantities of natural aggregates, accelerating environmental degradation through excessive mining and extraction (Zhou *et al.*, 2021).

Efforts to manage both challenges independently have proven inadequate. Therefore, a unified solution that addresses both plastic waste management and sustainable material development in construction is necessary.

While several studies have explored the use of plastic waste as a replacement material, limited attention has been given to its controlled addition in small percentages. The influence of adding polypropylene waste on the compressive strength and workability of paving stones remains insufficiently documented. This research, therefore, seeks to determine how incremental additions of polypropylene waste (1%, 2%, 3%, and 4%) affect the mechanical and physical performance of concrete paving stones.

### **1.3. AIMS AND OBJECTIVES**

The primary aim of this research is to examine the effect of adding recycled polypropylene (PP) waste as fine aggregates in varying proportions (1%, 2%, 3% and 4%) on the compressive strength of concrete paving stones. The specific objectives of this research are as follows:

- i. To evaluate the optimal mix proportions of paving stones that incorporate recycled PP waste, ensuring that the mixture remains practical for production.
- ii. Determine the compressive strength of paving stones at different polypropylene addition levels (1%, 2%, 3%, and 4%).

- iii. To compare the compressive strength of paving stones containing recycled PP waste with that of traditional paving stones made from conventional materials, providing insight into potential performance differences.
- iv. To determine the water absorption and density properties of the PP blended paving stone.
- v. Evaluate the potential environmental and economic benefits of incorporating polypropylene waste into paving stone production.

#### **1.4. SCOPE OF STUDY**

This study is focused on evaluating the mechanical performance of concrete paving stones produced with incremental additions of polypropylene waste (1%, 2%, 3%, and 4%). The investigation covers laboratory experiments including material preparation, concrete mix design, casting, curing, and compressive strength testing at 3 and 7 days.

The study specifically concentrates on the compressive strength of the paving stones, as it represents the most crucial property determining their suitability for practical applications such as roads, walkways, and driveways. Other properties such as flexural strength, tensile strength, and long-term durability are beyond the scope of this research.. The experiments that will be carried out include:

- i. Sieve analysis of fine aggregates and shredded PP to determine particle size distribution.
- ii. Preparation of mix designs with varying addition ratios of PP waste (e.g., 0%, 1%, 2%, 3%, 4%).

- iii. Casting of paving stone specimens using the designed mixes.
- iv. Specific Gravity test.
- v. Bulk Density test.
- vi. Water absorption test.
- vii. Curing of paving stones under standard conditions.
- viii. Compressive strength tests at 7 and 28 days.

### **1.5. JUSTIFICATION OF STUDY**

The construction industry is facing significant challenges related to the depletion of natural resources, particularly fine aggregates like sand, which are critical in the production of materials such as concrete and paving stones (Zhou *et al.*, 2021). Additionally, plastic waste, especially polypropylene (PP), has become a major environmental concern due to its non-biodegradable nature and accumulation in landfills (Hao *et al.*, 2020). Recycling plastic waste into construction materials offers a potential solution to these issues by reducing both plastic pollution and reliance on finite resources.

This study aims to explore the feasibility of using recycled polypropylene waste as a partial replacement for fine aggregates in paving stones, focusing on its impact on the compressive strength of the final product. The research will assess whether incorporating recycled PP waste can maintain or improve the compressive strength of paving stones, which are crucial for high-traffic areas like roads and sidewalks (Cahyani *et al.*, 2023).

The justification for this study lies in its potential to contribute to both environmental sustainability and the construction industry's need for alternative materials. By integrating

recycled PP waste into paving stone production, the study aims to reduce plastic waste, conserve natural resources, and create more eco-friendly, cost-effective building materials. This approach aligns with the broader goals of a circular economy and sustainable construction practices, offering an innovative solution for the future of the industry (UNEP, 2021).

## CHAPTER TWO

### LITERATURE REVIEW

The construction industry plays a pivotal role in global economic development but also ranks among the largest contributors to environmental degradation. Rapid urbanisation and population growth have significantly increased the demand for housing and infrastructure, leading to intensive exploitation of natural resources such as sand, gravel, and limestone (Zhou *et al.*, 2021). This rising demand, coupled with unsustainable extraction practices, has created ecological imbalances, including soil erosion, deforestation, and depletion of riverbeds.

At the same time, the world faces another major environmental issue—plastic pollution. The global consumption of plastic has increased exponentially since the mid-twentieth century, and plastics such as polypropylene (PP) are now integral to nearly every sector, including packaging, textiles, healthcare, and construction. However, the disposal of plastic waste remains a formidable challenge due to its non-biodegradable nature. The United Nations Environment Programme (UNEP, 2021) reported that over 400 million tonnes of plastic are produced globally every year, but less than 10% is effectively recycled.

Recent studies between 2020 and 2024 have emphasised the growing concern over the accumulation of non-biodegradable plastic waste in landfills and aquatic systems (Nguyen *et al.*, 2023; Zhang *et al.*, 2024). Polypropylene, being chemically inert and resistant to degradation, persists in the environment for centuries. Consequently, scientists and engineers have sought innovative ways to convert this waste into valuable resources,

particularly in construction applications where large material volumes can accommodate recycled content.

The concept of sustainable construction has thus gained global attention, encouraging the use of renewable and recycled materials to minimise environmental impact (Survase *et al.*, 2022). In recent years, the use of plastic waste as an additive or replacement material in concrete has been extensively explored. Early studies focused on replacement—substituting sand or aggregates with shredded plastics—but this approach often resulted in lower compressive strength and poor bonding (Singh *et al.*, 2021). Conversely, addition methods, where polypropylene waste is introduced in small amounts (typically 1–5%), have shown potential for improving specific mechanical and durability characteristics without severely compromising structural integrity (Cahyani *et al.*, 2023).

In paving stone production, where compressive strength, durability, and dimensional stability are critical, the controlled addition of polypropylene waste could enhance sustainability while maintaining functionality. Paving stones offer an ideal testing ground for such innovations due to their modular design, standardised production, and high demand in urban infrastructure.

Although numerous studies have investigated the use of plastic waste in concrete, there remains a research gap regarding the effect of incremental additions (1%, 2%, 3%, and 4%) of polypropylene waste on the compressive strength of paving stones. This study aims to bridge that gap by critically analysing past findings and establishing a scientific basis for further experimental evaluation.

## 2.1. REVIEW OF RELATED WORKS

The exponential growth in global plastic production has intensified environmental concerns, particularly regarding the accumulation of non-biodegradable plastic waste. Polypropylene (PP), a versatile thermoplastic polymer, is extensively utilized across industries such as packaging, automotive, healthcare, and consumer goods due to its lightweight, durability, and chemical resistance. Despite its valuable properties, polypropylene poses a significant environmental threat because it degrades very slowly in natural conditions, contributing heavily to solid waste pollution (Alrshoudi *et al.*, 2022).

In response to escalating plastic waste volumes, researchers and industries have increasingly explored sustainable recycling strategies. Among these, integrating recycled polypropylene (rPP) into construction materials, particularly concrete composites, has garnered significant interest (Hama, 2020). This approach not only diverts plastic waste from landfills and oceans but also helps to conserve natural aggregates such as river sand, whose overexploitation has led to serious ecological imbalances (Survase *et al.*, 2022). Utilizing recycled polypropylene as a partial replacement for fine aggregates in paving stones presents a dual environmental benefit: reducing plastic waste and minimizing the extraction of non-renewable natural resources.

Paving stones are critical infrastructure components widely employed in pedestrian pathways, residential driveways, industrial yards, and urban landscapes. Their success depends primarily on mechanical strength, particularly compressive strength, which ensures their ability to withstand heavy loads and resist failure over time. Consequently, any substitution of traditional fine aggregates with alternative materials such as recycled

polypropylene must maintain or improve the compressive strength to meet technical performance standards.

Studies in recent years have revealed mixed outcomes regarding the influence of recycled polypropylene on concrete's mechanical properties. Alrshoudi *et al.* (2022) found that mortar samples incorporating up to 10% recycled polypropylene as a fine aggregate substitute demonstrated acceptable compressive strength levels suitable for specific structural applications. However, increasing the replacement rate beyond 10% generally led to noticeable reductions in strength due to the smooth, hydrophobic surfaces of plastic particles, which impair the bond between the cement paste and aggregates.

Similarly, Oyedepo *et al.* (2021) reported that the inclusion of waste polypropylene at 10% replacement achieved optimal results in terms of compressive strength, but further increments caused a deterioration in structural integrity. Their work emphasized the critical need to balance the environmental advantages with mechanical performance requirements when designing concrete mixes involving plastic waste (Oyedepo *et al.*, 2021).

The environmental benefits of integrating recycled plastics into concrete production are well-documented. Notably, incorporating waste plastics significantly reduces the carbon footprint associated with concrete manufacturing by lowering the demand for virgin aggregates and minimizing the energy consumption associated with aggregate mining and processing (Survase *et al.*, 2022). Moreover, it supports circular economy principles, promoting sustainable material management and innovation in the construction industry.

Beyond environmental considerations, recycled polypropylene aggregates introduce additional characteristics to paving stones. Due to their lower density compared to mineral aggregates, concrete composites containing recycled polypropylene are lighter, facilitating easier transportation and installation (Alrshoudi *et al.*, 2022). Nevertheless, this reduction in density can also impact load-bearing capacity and long-term durability, aspects that require careful material design and quality control.

Durability, an essential property for paving stones exposed to variable climatic and loading conditions, can also be influenced by recycled polypropylene incorporation. Hama (2020) observed that polypropylene's water-repellent properties could enhance the concrete's resistance to water absorption and freeze-thaw cycles. However, increased void ratios and decreased interfacial bonding in plastic-modified concretes could potentially undermine chemical resistance and wear performance over extended service periods.

Despite these challenges, the use of recycled polypropylene in paving stones remains an attractive sustainable practice. Investigations such as that by Survase *et al.* (2022) show that with proper mix design adjustments, including the use of supplementary cementitious materials or chemical admixtures, it is possible to counteract some negative impacts and produce concrete paving elements that satisfy both environmental and engineering standards.

Given the importance of compressive strength in determining the functional viability of paving stones, a systematic examination of how varying proportions of recycled polypropylene influence this key property is essential. This research is crucial not only for ensuring structural adequacy but also for advancing sustainable construction practices in line with global environmental goals. The focus of this study is to evaluate the compressive

strength performance of paving stones when recycled polypropylene waste is utilized as a partial substitute for fine aggregates, thereby contributing to innovative waste management solutions and sustainable infrastructure development.

## **2.2. POLYPROPYLENE WASTE**

Polypropylene (PP) is a thermoplastic polymer that belongs to the polyolefin group, widely recognized for its chemical resistance, toughness, and versatility. First polymerized in 1954 by Giulio Natta, polypropylene rapidly became one of the most utilized plastics globally, finding applications in packaging materials, textiles, automotive parts, medical devices, and consumer products. It is composed primarily of carbon and hydrogen atoms, arranged in a semi-crystalline structure that imparts strength and resistance to chemical degradation.

The exponential rise in global plastic consumption has led to a dramatic increase in polypropylene waste. PP waste arises from industrial offcuts, post-consumer products (such as food containers, packaging films, and disposable items), and worn-out automotive and household goods. According to Alrshoudi *et al.* (2022), polypropylene accounts for a substantial fraction of plastic waste streams globally, primarily because it is often used in short-life-cycle products that are disposed of rapidly after use.

Polypropylene waste is distinguished by its chemical inertness, low water absorption, high resistance to physical and chemical wear, and relatively stable mechanical properties over time. However, its hydrophobic surface and low polarity make adhesion to other materials challenging, posing particular concerns in composite material development such as concrete.

Despite being theoretically recyclable, actual recycling rates for polypropylene remain low. Factors such as contamination, economic inefficiencies, and lack of proper segregation

contribute to the underutilization of polypropylene waste. Consequently, vast quantities of PP waste are incinerated or landfilled, leading to significant environmental impacts including soil degradation, water pollution, and increased greenhouse gas emissions.

Polypropylene waste has long-term environmental impacts due to its resistance to microbial degradation. It can persist in natural environments for hundreds of years, fragmenting into microplastics that enter food chains and ecosystems. The accumulation of PP waste in marine and terrestrial environments leads to habitat destruction, poses risks to wildlife through ingestion and entanglement, and contributes to the broader problem of global plastic pollution (Hama, 2020).

Furthermore, improper disposal practices such as open burning of polypropylene waste release harmful pollutants, including dioxins and volatile organic compounds, contributing to air quality deterioration and public health hazards.

The increasing environmental burden has spurred efforts to find innovative ways to recycle and reuse polypropylene waste, particularly in construction and material science sectors, where large volumes of material are needed and mechanical properties can be tuned for specific applications.

### **2.3. SOURCES OF POLYPROPYLENE WASTE**

Polypropylene (PP) has become a ubiquitous material due to its cost-effectiveness, versatility, and durable properties. Since its introduction in the mid-20th century, it has found applications across a wide range of industries, including packaging, automotive, healthcare, agriculture, and consumer goods manufacturing. While its widespread use has

contributed to significant advancements in various sectors, it has also led to a growing environmental challenge in the form of polypropylene waste. This challenge has become even more pronounced in recent years as the volume of plastic waste worldwide continues to escalate. Understanding the primary sources of polypropylene waste is crucial for addressing its environmental impact and developing more sustainable waste management practices.

### **2.3.1. PACKAGING INDUSTRY: THE LEADING CONTRIBUTOR**

The packaging sector stands out as the largest contributor to polypropylene waste. PP's durability, low cost, and resistance to chemicals make it an ideal material for packaging, particularly in the form of food containers, beverage cups, bottle caps, and plastic films. These products are designed for single-use and are disposed of after minimal contact with their contents, contributing significantly to global plastic waste. The increase in consumer demand for convenience and quick-service products has exacerbated the volume of polypropylene waste generated from packaging.

Research shows that PP packaging alone accounts for a substantial portion of the global plastic waste generated each year. While the recycling potential of PP is well recognized, the actual recycling rates are low. This is largely due to contamination by food residues, which complicates the sorting and recycling processes, and the difficulties associated with the collection of certain types of packaging, such as plastic films and multilayered containers. Zhou *et al.* (2021) report that despite increased awareness of the environmental consequences of single-use plastics, the volume of PP packaging waste continues to rise, contributing to landfill overflow and plastic pollution in oceans.

The global growth of e-commerce and takeout services has further amplified this issue, with a rising number of PP packaging materials being used for shipping products and delivering food. This trend is expected to continue, creating even greater quantities of polypropylene waste. As urbanization accelerates and the use of packaging expands, the environmental burden of polypropylene waste will grow unless effective solutions for recycling and waste reduction are implemented.

### **2.3.2. HOUSEHOLD CONSUMER GOODS: OFTEN OVERLOOKED CONTRIBUTORS**

Another significant but often overlooked source of polypropylene waste comes from household products. PP is commonly used in the production of storage containers, kitchenware, personal care items, and household furniture due to its durability and resistance to wear and tear. While these products are designed to last longer than typical packaging items, they too eventually reach the end of their useful life and are discarded.

According to Zuo *et al.* (2020), household polypropylene waste is a growing issue, particularly in urban areas where disposable culture is prevalent. Many of these items are thrown away after their function has been served, leading to significant accumulation in landfills. Furthermore, the complex nature of household products—many of which combine polypropylene with other materials such as metals, other plastics, or coatings—makes recycling difficult. Many waste management facilities do not have the necessary systems in place to effectively separate and recycle these composite materials, which often results in polypropylene waste being sent to landfills or incinerators.

As disposable consumer culture persists, it is likely that the volume of polypropylene waste generated from household items will continue to increase, posing a challenge for waste management systems globally. This increase in waste is particularly concerning given that polypropylene is not biodegradable, leading to long-term environmental consequences when not properly recycled or managed.

### **2.3.3. MEDICAL AND HEALTHCARE SECTOR: A SIGNIFICANT SOURCE**

The medical and healthcare industries contribute a growing amount of polypropylene waste, especially in the form of disposable medical products. Items such as syringes, IV bags, surgical masks, gloves, and protective gowns are commonly made from polypropylene. These products are often used once and then discarded due to hygiene concerns, leading to significant amounts of medical waste.

The demand for disposable medical products surged during the COVID-19 pandemic, further escalating polypropylene waste in healthcare settings. Makar *et al.* (2022) point out that the rapid consumption of personal protective equipment (PPE), including face masks, gloves, and face shields, has exacerbated the problem of medical plastic waste. Hospitals, clinics, and healthcare facilities are struggling to manage the large quantities of PP waste that are generated daily. Although some efforts have been made to recycle medical plastics, the contamination with biohazardous materials and the need for sterility make it difficult to recycle these products effectively.

Addressing medical PP waste requires innovative approaches to waste segregation, sterilization, and recycling. Moreover, given the global demand for medical supplies,

especially during health crises, the amount of polypropylene waste generated by the healthcare sector is expected to continue rising, emphasizing the need for better waste management infrastructure in hospitals and clinics.

#### **2.3.4. AGRICULTURAL APPLICATIONS: A GROWING ENVIRONMENT CONCERN**

In agriculture, polypropylene is used in a variety of applications, including packaging materials, mulching films, and irrigation components. These products are commonly used to package seeds, fertilizers, and pesticides, as well as to control weeds and retain moisture in soil through plastic films. While these applications offer significant benefits to agricultural production, they also contribute substantially to polypropylene waste, particularly when these products are discarded after use.

Research by Nguyen *et al.* (2023) highlights the environmental issues associated with agricultural plastics, particularly PP. In many rural areas, agricultural plastics are discarded directly into the environment, where they pose long-term environmental risks. Polypropylene materials, especially mulching films and bags, often end up in landfills or are abandoned in fields, where they can take decades to degrade. The accumulation of PP waste in agricultural environments contributes to soil contamination and can lead to microplastic pollution in both the land and water.

#### **2.3.5. INDUSTRIAL AND COMMERCIAL SECTORS: AN EXPANDING ISSUE**

Polypropylene is widely used in industrial and commercial sectors for applications in automotive manufacturing, construction, and electronics. In the automotive industry, PP is

used in parts such as bumpers, dashboards, and seat components, thanks to its strength and lightweight properties. Similarly, in construction, PP is used for pipes, insulation, and flooring, while the electronics industry utilizes PP in casings and internal components.

Once these products are discarded after their useful life, they contribute to significant waste. However, the recycling of industrial and commercial PP waste is often challenging. The materials are frequently contaminated with other substances or combined with other materials, such as metals or composites, which complicates the recycling process. Zhang *et al.* (2024) note that while industrial applications of polypropylene are diverse, the lack of efficient recycling infrastructure for these materials means much of the waste is sent to landfills or incinerators, rather than being reused or recycled.

## **2.4. PROPERTIES OF POLYPROPYLENE WASTE**

### **2.4.1. PHYSICAL PROPERTIES**

- i. Density: Approximately 0.90–0.91 g/cm<sup>3</sup>, making it lightweight and buoyant.
- ii. Color: Often discolored or mixed shades due to prior use and contamination.
- iii. Form: Can be rigid (containers, caps) or flexible (films, textiles).

### **2.4.2. MECHANICAL PROPERTIES**

- i. Tensile Strength: Slightly lower than virgin PP (~20–35 MPa) due to degradation.
- ii. Impact Resistance: Decreased if aged or UV-exposed.
- iii. Flexural Modulus: Approximately 1000–1500 MPa, depending on the degradation level.

### **2.4.3. THERMAL PROPERTIES**

- i. Melting Point: Approximately 160–170°C.
- ii. Thermal Degradation: May start degrading at lower temperatures if exposed to oxidation or UV.
- iii. Recyclability: Thermoplastic – can be remelted and remolded multiple times, but properties degrade with each cycle.

### **2.4.4. CHEMICAL RESISTANCE**

- i. Good Resistance: To acids, alkalis, and most solvents.
- ii. Poor Resistance: To strong oxidizing agents.
- iii. Contamination: May contain residual additives, dyes, or contaminants from prior use.

### **2.4.5. ENVIRONMENTAL & DEGRADATION ASPECTS**

- i. Photodegradable: Becomes brittle under long UV exposure.
- ii. Non-Biodegradable: Persists in the environment unless chemically treated.
- iii. Contamination: Often mixed with food, labels, or other plastics, requiring thorough sorting and cleaning.

## **2.5. RECYCLING OF POLYPROPYLENE WASTE**

As the global demand for plastic products increases, the need for efficient recycling solutions becomes even more critical.

The theory of recycling polypropylene waste centers on various methods and technologies designed to convert discarded polypropylene materials back into raw resources that can be reused for producing new products. These recycling methods include mechanical recycling, chemical recycling, and energy recovery. Each method has its own advantages and challenges, but all aim to reduce the environmental impact of polypropylene waste by closing the loop in the lifecycle of this material. Here's an in-depth look at the different methods of polypropylene recycling:

### **2.5.1. MECHANICAL RECYCLING (PHYSICAL RECYCLING)**

Mechanical recycling is the most established and widely practiced method for recycling polypropylene waste. It involves a series of processes that allow for the recovery of polypropylene by physically breaking it down and reforming it into usable materials.

In mechanical recycling, the polypropylene waste is collected, cleaned, shredded, and then melted down to create new products. The key steps in this process are:

- i. **Collection and Sorting:** The first step is to gather polypropylene waste from various sources, including households, industries, and commercial facilities. It is then sorted to remove non-PP materials and contaminants such as adhesives, food residues, and other plastics.
- ii. **Shredding and Washing:** After sorting, the polypropylene waste is shredded into small flakes or granules. These small pieces are washed to remove any dirt, impurities, and other foreign materials that may have adhered to the plastic.

- iii. **Melting and Pelletizing:** The cleaned polypropylene flakes are then melted down and extruded into small pellets. These pellets are standardized units that can be used as raw material in the manufacturing of new PP products.
- iv. **End Products:** The pellets are used to create a variety of new products, including containers, automotive components, and outdoor furniture. One of the main challenges with mechanical recycling is that the process can cause degradation of the polymer's properties. As a result, recycled PP is often used for low-performance applications, as it may not retain the same strength and durability as virgin PP.

### **2.5.2. CHEMICAL RECYCLING (FEEDSTOCK RECYCLING)**

Chemical recycling is a newer and more advanced recycling method that offers the potential to restore polypropylene waste to its original monomers or to convert it into other valuable chemicals. Unlike mechanical recycling, which physically breaks down the material, chemical recycling involves chemical processes that depolymerize the plastic, allowing it to be reformed into new PP or other useful products. The main types of chemical recycling processes include:

- i. **Pyrolysis:** In pyrolysis, polypropylene waste is subjected to high temperatures in the absence of oxygen, which breaks the polymer chains into smaller hydrocarbons. These hydrocarbons can then be further refined into fuels, chemicals, or even monomers that can be reused to produce new polypropylene or other materials.
- ii. **Depolymerization:** Depolymerization involves breaking down the long polymer chains of polypropylene into their constituent monomers (propylene), which can then

be purified and reused in the production of new plastic products. This process holds the potential to regenerate polypropylene to its virgin-like quality.

- iii. **Solvolysis:** Solvolysis is a process in which polypropylene is dissolved in a solvent, breaking it down into smaller, more manageable components. These components can then be recovered and used as feedstock for producing new polypropylene or other products.

Chemical recycling is an exciting prospect for improving the quality of recycled polypropylene because it can theoretically return the material to its original form without the degradation typically seen in mechanical recycling. However, chemical recycling technologies are still in the experimental and development stages, and significant challenges remain, such as high energy consumption, complex technical requirements, and the overall cost-effectiveness of the process.

### **2.5.3. ENERGY RECOVERY**

Energy recovery is a form of waste-to-energy conversion in which polypropylene waste is incinerated or gasified to generate energy. While this process does not directly recycle polypropylene into usable products, it does reduce the volume of waste and can produce electricity or heat. Energy recovery is often considered a last resort for managing plastic waste and is typically used when recycling is not feasible. The methods involved in energy recovery include:

- i. **Incineration:** In this process, polypropylene waste is burned at high temperatures to produce heat, which can be used for electricity generation or industrial processes.

The main benefit of incineration is that it reduces the volume of waste significantly. However, it also has drawbacks, including the release of greenhouse gases and toxic fumes if not carefully controlled. Therefore, it requires advanced filtration and emission control systems to minimize environmental damage.

- ii. **Gasification:** Gasification is a process that involves heating polypropylene waste in a controlled environment to convert it into a synthetic gas, or syngas. This syngas can then be used as a fuel to generate energy. Gasification offers the advantage of producing a cleaner energy source compared to incineration, but it still involves the conversion of plastic waste into energy rather than new plastic products.

Energy recovery is not a long-term solution for recycling polypropylene, as it does not contribute to the reuse of the material itself. However, it can play a role in managing waste that cannot be recycled effectively and can help reduce the burden on landfills.

## **2.6. CHALLENGES IN POLYPROPYLENE RECYCLING**

- i. Despite the various recycling methods available, there are still several challenges that hinder the widespread and effective recycling of polypropylene:
- ii. **Contamination and Sorting Issues:** One of the biggest obstacles in recycling polypropylene is the difficulty in separating it from other types of plastics and contaminants. Polypropylene is often mixed with other materials, such as food residues or different plastic polymers, which can compromise the quality of the recycled product.

- iii. **Degradation of Polymer Quality:** Both mechanical and chemical recycling processes can result in some loss of material properties. In mechanical recycling, repeated heating and melting of the polymer can cause it to lose its strength, color, and appearance. Chemical recycling holds the potential to reduce degradation, but it is still a relatively expensive and complex process.
- iv. **Economic Viability:** Recycling polypropylene can often be more expensive than producing new polypropylene from virgin materials, particularly when the price of raw oil (the source of PP) is low. This makes recycling less financially attractive unless there are strong market incentives or government interventions.
- v. **Lack of Recycling Infrastructure:** While mechanical recycling technologies are widely used, especially in developed countries, chemical recycling is still in its infancy. Widespread infrastructure for chemical recycling is lacking, and investment in this area is needed to scale up these technologies.

## **2.7. POTENTIAL SOLUTIONS FOR IMPROVED POLYPROPYLENE RECYCLING CHALLENGES**

To overcome the challenges of recycling polypropylene, several strategies can be explored:

- i. **Advanced Sorting Technologies:** New sorting technologies, such as sensor-based or AI-driven systems, could help to more efficiently separate polypropylene from other plastics, reducing contamination and improving recycling rates.
- ii. **Design for Recycling:** Manufacturers can take steps to design products that are easier to recycle by using fewer mixed materials and avoiding additives or coatings that complicate the recycling process.
- iii. **Incentives and Legislation:** Governments and industries can create financial incentives to make recycling more cost-effective, such as subsidies for recycling companies or taxes on virgin plastic production. Additionally, legislation that mandates recycling could drive the demand for recycled polypropylene.
- iv. **Investment in Chemical Recycling Research:** Greater investment in research and development of chemical recycling technologies could help improve their efficiency and make them more economically viable in the future.

## **2.8. PAVING STONES**

Paving stones, commonly referred to as pavers, are modular, durable construction elements used extensively in creating hardscape surfaces such as roads, sidewalks, driveways, patios, and garden paths. Traditionally, these units have been manufactured from materials such as concrete, clay bricks, or natural stones due to their strength, durability, and aesthetic appeal. However, the global demand for sustainable construction practices and climate-resilient infrastructure has driven significant advancements in the design, composition, and functionality of paving stones.

In recent years, there has been a notable shift toward environmentally conscious and innovative approaches in paving stone production. One of the major areas of innovation involves the use of recycled and waste materials as alternative raw materials for manufacturing pavers. For instance, several studies have investigated the feasibility of replacing conventional cement with melted waste plastic to produce interlocking paving blocks. The findings indicate that plastic-based pavers can achieve satisfactory compressive strength levels while significantly improving resistance to water absorption, making them suitable for flood-prone or moisture-sensitive areas (Dawodu *et al.*, 2022). In another study, polyethylene terephthalate (PET) waste was utilized as a major component in paving block production, leading to improvements in durability and environmental performance (Kiridi *et al.*, 2024). These innovations align with global efforts to reduce plastic pollution and promote circular economy principles in the construction industry.

In addition to material innovations, contemporary paving systems are also evolving to address environmental challenges such as urban flooding and water management. The growing adoption of permeable or porous paving technologies allows rainwater to pass through the pavement surface into the ground below, thereby reducing surface runoff and promoting groundwater recharge. This feature is particularly important in urban areas where impervious surfaces contribute significantly to flash flooding and drainage issues. Permeable pavements are now being integrated into sustainable urban drainage systems (SUDS) to enhance resilience to climate change (EPA, 2022).

### **2.8.1. COMPOSITION OF PAVING STONES**

The formulation of paving stones largely varies based on the specific type being manufactured—such as concrete, clay, or plastic-based units. Despite these differences,

most conventional paving stones are built on a foundation of core ingredients that contribute to their structural performance and functionality. Below is a summary of both standard and innovative material combinations used in paving stone production:

**a. Concrete-Based Paving Stones**

These are among the most common types used globally due to their strength and adaptability. The typical composition includes:

- i. Cement (typically Ordinary Portland Cement) – functions as the main binding agent that holds the mix together after curing.
- ii. Fine Aggregates (like sand) – fill voids between larger particles and enhance the workability of the mix.
- iii. Coarse Aggregates (such as crushed stone or gravel) – add mass and contribute to the structural strength of the stone.
- iv. Water – initiates the chemical reaction with cement (hydration), allowing the mixture to harden.
- v. Optional Admixtures – chemical or mineral additives (e.g., plasticizers, fly ash, silica fume) that improve setting time, durability, and overall performance.

Standard Volume Mix Ratio for Concrete Paving Stones:

- i. Cement: 1 part
- ii. Sand: 2 parts
- iii. Gravel: 3 parts

- iv. Water: 0.5 part (adjusted depending on desired consistency and workability)

### **b. Clay-Based Paving Stones (Clay Bricks)**

Produced from natural clay materials, these paving units are shaped and then hardened by firing at high temperatures in kilns. The composition typically consists of:

- i. Natural Clays (such as kaolinite, illite, or shale) – the primary raw material.
- ii. Silica or Sand – introduced to control shrinkage and prevent cracking during the drying and firing process.
- iii. Water – required to mold the clay into desired shapes before thermal processing.

### **c. Plastic-Derived Paving Stones (Eco-Friendly Pavers)**

Developed as a sustainable alternative, these pavers are manufactured by repurposing waste plastic materials blended with fillers. Key components may include:

- i. Thermoplastics – like high-density polyethylene (HDPE), polyethylene terephthalate (PET), or polypropylene, which act as binding agents.
- ii. Inert Fillers – such as quarry dust, sand, or fly ash, added to enhance mechanical strength and volume.
- iii. Color Additives – pigments or dyes are sometimes included to improve visual appeal.

### **d. Sustainable and Alternative Paving Stone Compositions**

Driven by environmental considerations and resource conservation, several innovative mixtures have emerged that utilize waste or natural materials as substitutes for conventional inputs. These include:

- i. Recycled Plastics – used in place of cement or as the sole bonding element.
- ii. Organic Waste By-products – including ground cow bones and rice husk ash, valued for their pozzolanic properties.
- iii. Fly Ash and Slag – industrial waste materials that offer partial cement replacement with improved durability.
- iv. Finely Ground Inorganic Fillers – such as glass powder or marble dust, often included to enhance texture and strength.
- v. Lateritic Soils – naturally occurring iron-rich soils, sometimes combined with small quantities of cement for use in tropical or rural paving.

### **2.8.2. FINE AGGREGATES IN PAVING STONES PRODUCTION**

Fine aggregates, such as sand or stone dust, are essential in the production of paving stones. They fill the spaces between coarse aggregates and improve the mix's workability, density, and strength. The particle size, cleanliness, and mineral composition of fine aggregates directly affect the durability and performance of the paving stones.

Properly graded fine aggregates enhance compaction and reduce voids, which leads to better mechanical strength and resistance to environmental factors. Al-Saffar *et al.* (2021)

highlighted that well-graded sands contribute significantly to the structural integrity of concrete-based pavers.

In recent years, sustainable alternatives like quarry dust, fly ash, glass powder, and crushed plastic have been introduced as partial replacements for natural sand. Suleiman *et al.* (2023) demonstrated that quarry dust can achieve comparable compressive strength when correctly proportioned.

Manufactured sand (M-sand), produced by crushing rocks, is also gaining popularity due to its consistent quality and environmental advantages. Research by Oluwatobi *et al.* (2020) showed that M-sand enhances interlock and reduces water absorption in paving stones.

In plastic-based pavers, fine aggregates improve rigidity and stability. Dawodu *et al.* (2022) found that proper filler integration in HDPE-based blocks increases structural performance during cooling.

## **2.9. CONCRETE PROPERTIES OF PAVING STONE**

### **i. Compressive Strength**

Compressive strength reflects the capacity of paving stones to endure heavy loads without cracking or failure. It remains a primary quality benchmark, especially for applications in pedestrian or vehicular traffic zones. Standards like BS EN 1338:2003 recommend a minimum compressive strength of 30 MPa for paving units. Recent innovations, such as substituting natural aggregates with up to 20% crushed glass, have achieved strengths as high as 43.45 MPa, well above standard limits (MDPI, 2020). Similarly, integrating

processed cow bone waste into lateritic mixes has shown variable but promising compressive strength results (PMC, 2020).

## **ii. Flexural and Tensile Strength**

These properties determine how well paving stones resist cracking from bending or pulling forces. The addition of 10% recycled tire rubber to dual-layer blocks has been found to enhance both flexural and tensile strength without compromising compressive strength (Jurnal Teknologi, 2021). Incorporating plant fibers and ashes, such as *Momordica angustisepala* fiber and breadfruit shell ash, has also contributed to improved mechanical strength suitable for load-bearing applications (Springer, 2021).

## **iii. Water Absorption**

The water absorption rate affects a paving block's resistance to freeze-thaw cycles and chemical damage. Materials like ground granulated blast furnace slag (GGBS) and crushed glass have been shown to lower water uptake, helping meet the maximum absorption limit of 6% (MDPI, 2020). In contrast, blocks containing crumb rubber showed increased absorption rates (up to 6.02%), emphasizing the importance of balanced mix design.

## **iv. Density and Porosity**

Paving block density impacts load-bearing capacity, while porosity affects durability and moisture resistance. Using recycled concrete aggregates—even up to a 50% replacement—has had minimal adverse effects on strength, supporting eco-conscious construction practices (MDPI, 2021). However, the inclusion of rubber granules tends to raise porosity and reduce density (Sustainable Construction Review, 2025).

#### **v. Durability and Environmental Resistance**

Durability relates to a paving block's ability to withstand harsh environmental conditions over time. Surface treatments using photocatalysts like titanium dioxide (TiO<sub>2</sub>) have shown promise in improving resistance to weathering by minimizing surface porosity (MDPI, 2021). Likewise, blending recycled brick aggregates with silica fume in roller-compacted pavements has enhanced resistance to abrasion and skidding (Taylor & Francis, 2021).

#### **vii. Workability and Production Efficiency**

Workability refers to how easily concrete can be mixed, molded, and finished. Studies have demonstrated that certain admixtures can significantly improve both mechanical strength and workability. For instance, the use of advanced admixtures has been linked to up to a 40% increase in compressive strength and a noticeable reduction in shrinkage and water absorption (IEM Journal, 2022). Similarly, recycled nylon fibers have helped boost flexural strength and moisture resistance (Springer, 2021).

#### **viii. Sustainability and Environmental Impact**

Incorporating recycled waste into paving blocks supports sustainable construction goals. Research confirms that aggregates sourced from construction debris can maintain structural performance while significantly reducing material demand and landfill waste (MDPI, 2021). Another promising development is the use of rubber from end-of-life tires, which, when combined with steel fibers, provides durable paving options with a smaller environmental footprint (Sustainable Construction Review, 2025).

## **2.10. IMPORTANCE OF PAVING STONES IN CONSTRUCTION**

### **i. Long-Lasting and Resilient**

Paving stones are exceptionally strong and built to endure heavy traffic and harsh weather. Unlike concrete slabs, which may crack over time, individual pavers can be replaced independently, extending the life of the surface without major repairs (Green Landscape Supply, 2023).

### **ii. Minimal Upkeep and Simple Fixes**

These stones require little maintenance—regular cleaning usually keeps them in good shape. If any section is damaged or stained, you can replace just the affected stones without disturbing the rest, making repairs quick and affordable (Michrose, 2022).

### **iii. Eco-Friendly Features**

Many pavers are permeable, which means they allow water to filter through and reduce surface runoff. This helps recharge groundwater and supports sustainable water management. Plus, many types are made from natural or recyclable materials (Stone Paving LLC, 2021).

### **iv. Versatile in Design**

Paving stones come in a wide variety of shapes, sizes, and colors, offering countless design options. They can be arranged in different patterns to suit various architectural styles, improving the visual appeal of outdoor areas (Maçonnerie Montréal, 2024).

### **v. Improved Safety**

The naturally textured surfaces of pavers provide good traction, which helps prevent slipping. This makes them ideal for areas that frequently get wet, such as around pools or in colder climates (Pearl Block BD, 2023).

#### **vi. Boosts Property Value**

A well-installed paver system not only adds to the look of a property but can also increase its market value. Their blend of beauty and practicality appeals to many homeowners and potential buyers (Five Towns Mason Materials Inc., 2023).

#### **ii. Energy Efficiency**

Because of their ability to absorb heat during the day and release it slowly over time, pavers help stabilize temperature fluctuations around buildings, supporting better energy efficiency (Old Town Pavers, 2021).

#### **viii. Wide Range of Applications**

Pavers are incredibly versatile—they can be used for driveways, walkways, patios, plazas, and more. This makes them suitable for both residential landscaping and public construction projects (Maçonnerie Montréal, 2024).

## **CHAPTER THREE**

### **METHODOLOGY**

Most of the polypropylene waste was gotten from Hall 1, Hall 2 and Hall 3 hostels in University Of Benin. Others were also gotten from the Coca-Cola cafeteria in the University of Benin.

### **3.1 RESEARCH DESIGN**

The research adopted an experimental laboratory design, focusing on the addition of polypropylene waste to concrete mixes in varying proportions. The objective was to determine how incremental additions of 1%, 2%, 3%, and 4% polypropylene waste, by weight of cement, influence the compressive strength of paving stones.

Five sample batches were prepared in total:

- Mix A (Control): 0% polypropylene waste
- Mix B: 1% polypropylene waste addition
- Mix C: 2% polypropylene waste addition
- Mix D: 3% polypropylene waste addition
- Mix E: 4% polypropylene waste addition

All samples were produced under identical conditions to ensure fair comparison. Each batch was tested for workability and compressive strength at 3 and 7 days of curing.

### **3.2. MATERIALS AND METHODOLOGY**

#### **3.2.1. List Of Materials**

- a. Cement (Ordinary Portland Cement)
- b. Fine Aggregate (Sand)
- c. Water

d. Recycled Polypropylene (PP) Waste

### **3.2.2. List Of Equipment**

a. Weighing balance

b. Concrete Mixer

c. Paving Stone Mould

d. Plastic Shredder

e. Sieve Set

f. Vibrating Table

g. Curing Tank

h. Compressive Strength Machine

i. Measuring Cylinders

j. Scoops

k. Safety Gear

l. Permanent Marker

### **3.3. EXPERIMENT PLAN**

This study aims to assess how partially replacing fine aggregate with recycled polypropylene waste influences the compressive strength of paving stones. The experiment followed these outlined steps:

- a. Material acquisition
- b. Material preparation
- c. Concrete mix design
- d. Mixing and casting procedure
- e. Curing process
- f. Compressive strength testing
- g. Data collection and interpretation

### **3.3.1. MATERIALS COLLECTION**

#### **Ordinary Portland cement (OPC)**

Ordinary Portland Cement was used selected as the primary binding agent. One bag was gotten from the local market in Benin City.

#### **Fine and Coarse Aggregate**

Two big bags of fine aggregate containing different particle sizes were gotten from the local market in Benin City.

#### **Recycled Polypropylene (PP) Waste**

Recycled Polypropylene (PP) Waste, was derived from used sachet water nylons.

### **Clean potable water**

Clean potable water was also sourced for mixing, in line with standard requirements for concrete production.

## **3.3.2. MATERIALS PREPARATION**

### **Cement**

Ordinary Portland Cement (OPC), specifically Grade 42.5, was utilized as the primary binding agent in the production of the paving stones. This type of cement was selected due to its wide availability, strong binding characteristics, and conformity to industry standards for construction materials. Prior to its use, the cement was visually inspected to ensure it was free from any hardened lumps, which indicates that it had not been exposed to moisture. It was stored in moisture-resistant containers in a dry and well-ventilated area to preserve its integrity and avoid early hydration, which could compromise its effectiveness in the mix.

### **Fine Aggregate (Natural River Sand)**

Natural river sand was used as the fine aggregate component in the concrete mix. The sand was first sieved using standard sieve sizes of 4.75 mm, 2.36 mm, and 1.18 mm to ensure uniformity and remove any oversized particles or debris. The portion that passed through the

2.36 mm sieve and was retained on the 1.18 mm sieve was selected for use in the study. This specific range was chosen to closely match the particle size distribution of the recycled polypropylene waste for comparison. The sand was thoroughly washed with clean water to eliminate impurities such as silt, clay, and organic matter, which could negatively affect the strength and bonding in the final product. After washing, the sand was spread out on a clean surface to air dry under shade and was stored in clean, dry containers to maintain its moisture content stability until use.

### **Recycled Polypropylene (PP) Waste**

Post-consumer polypropylene plastic waste was collected from various domestic sources, including packaging materials, bottle caps, and food containers. The plastic waste was first manually sorted to exclude any non-polypropylene items, such as PET or PVC plastics. The selected plastic was then cleaned thoroughly using water and mild detergent to remove any labels, oils, dirt, or residues. After washing, the materials were left to dry completely in open air to prevent moisture from affecting the concrete mix. Once dried, the plastics were shredded into small, sand-like particles using a mechanical shredder. The shredded materials were then subjected to sieve analysis, and particles passing through the 2.36 mm sieve but retained on the 1.18 mm sieve were isolated for use as a partial replacement for the fine aggregate. These particles were stored in breathable yet dust-proof bags to prevent moisture reabsorption and contamination before use.



**Figure 3.1 :Polypropylene (PP) waste sample**

### **Water**

Clean, potable water was used throughout the experiment both for mixing and for the curing of the paving stones. The water was tested visually to ensure that it was free from visible contaminants such as algae, oils, or suspended solids. Only fresh water from a municipal supply or reliable well source was used to avoid the introduction of impurities that could interfere with the hydration process of the cement. Measured quantities were used to maintain consistency across different mix ratios and to ensure reproducibility of results.

### **3.4. LABORATORY TEST PROCEDURES**

#### **PARTICLE SIZE DISTRIBUTION TEST (SIEVE ANALYSIS)**

Sieve analysis is a method used to determine the particle size distribution of aggregates. It involves passing the material through a set of sieves with different mesh sizes. This helps classify the aggregate as fine or coarse and ensures it meets required grading standards. The test is essential for producing strong, durable concrete and achieving a good mix design

This is carried out according to **BS EN 933-1:2012**

#### **Procedure:**

1. Dry the sample in an oven at 105–110°C until a constant weight is achieved.
2. Weigh approximately 1–2 kg of the sample.
3. Arrange the standard sieves (e.g., 9.50 mm, 4.75 mm, 2.36 mm, 1.18 mm, 600) in descending order.
4. Place the sample in the top sieve and shake for 10–15 minutes.
5. Weigh the material retained on each sieve.
6. Calculate the percentage retained and cumulative percentage passing.
7. Plot the particle size distribution curve.

#### **SPECIFIC GRAVITY TEST (FOR FINE AGGREGATES).**

The specific gravity test is mainly used in construction to assess the quality of aggregates and ensure accurate concrete mix designs. A higher specific gravity often indicates stronger, denser materials, while lower values may suggest the presence of pores or impurities. This test also helps determine void content and water absorption, which are critical for durability and strength. Overall, it ensures that materials like aggregates used in paving stones are suitable and meet construction standards.

This is carried out according to **BS 812-2:1995**

**Procedure:**

1. Soak the aggregate sample in water for 24 hours.
2. Weigh the saturated surface-dry (SSD) sample (W1).
3. Place the sample in a density bottle filled with water and weigh (W2).
4. Empty, dry, and weigh the density bottle with water only (W3).
5. Dry the aggregate in an oven and record its dry weight (W4).

**BULK DENSITY TEST**

The bulk density test measures the mass of aggregate in a given volume, including the air spaces between particles. It helps determine how much material is needed for a mix and affects the concrete's strength and stability. This test ensures efficient use of materials and proper compaction in construction

This is carried out according to **BS 812-2:1995**

**Procedure:**

1. Fill a cylindrical container of known volume with aggregate in three layers.
2. Tap each layer 25 times with a standard tamping rod to compact.
3. Strike off the top and weigh the container with aggregate.
4. Calculate bulk density using.

**WATER ABSORPTION TEST**

The water absorption test determines how much water a material can absorb. It helps assess the porosity and durability of aggregates or paving blocks. High absorption may lead to reduced strength and weather resistance, so this test ensures materials are suitable for long-lasting construction.

This is carried out according to **BS 812-2:1995**

**Procedure:**

1. Weigh dry aggregates (W1).
2. Soak the aggregates in water for 24 hours.
3. Remove and dry them to a surface-dry condition and weigh again (W2).
4. Calculate water absorption.

## **CURING PROCESS FOR PAVING STONES**

Curing is the process of maintaining moisture and temperature in freshly placed concrete to ensure proper strength development. It prevents early drying, reduces cracking, and enhances durability. Curing is essential for achieving the desired performance and lifespan of concrete structures.

This is carried out according to **BS 1881-111:1983**

### **Procedure:**

1. After demolding the paving stones (typically after 24 hours), immerse them in a water curing tank.
2. Maintain the water temperature between 23–25°C.
3. Cure specimens for specified durations (3 days and 7 days).
4. Remove samples only during testing intervals and return others to the tank.

## **COMPRESSIVE STRENGTH TEST**

The compressive strength test measures the ability of concrete to withstand loads without failing. It involves crushing a concrete cube or cylinder under a compression machine. This test is crucial for assessing the structural integrity and ensuring the concrete meets design and safety standards.

This is carried out according to **BS EN 12390-31:2019**

**Procedure:**

1. Remove paving stone samples from the curing tank after 3 and 7 days respectively.
2. Wipe off excess water and surface dry.
3. Place the sample in a calibrated compression testing machine.
4. Apply load at a constant rate (e.g., 140 kg/cm<sup>2</sup> per minute) until failure.
5. Record the maximum load and compute compressive strength.’’

**CHAPTER FOUR**  
**RESULTS AND DISCUSSION**

## 4.1 INTRODUCTION

This chapter presents the results obtained from the experimental investigation on the effect of polypropylene (PP) waste addition on the properties of concrete paving stones. The laboratory tests conducted include: sieve analysis, specific gravity, water absorption and compressive strength tests at 3 and 7 days of curing

The polypropylene waste gotten from Hall 2, University of Benin was subjected to mechanical shredding which made it become fine. The sand and cement were sourced locally from the market. I-Section moulds were used with an area of 25,300mm.

The aggregates were mixed with a ratio of 1:10. This was done according to NIS for sandcrete.

Water-Cement ratio of 0.5 was initially used, but it was discovered that it did not mix the aggregates properly especially when the polypropylene (PP) waste was added. And so 0.6 was the best pick.

The results are discussed and compared with relevant standards and previous studies to evaluate the performance and suitability of the concrete paving stones containing polypropylene (PP) waste.

## 4.2. SIEVE ANALYSIS RESULTS

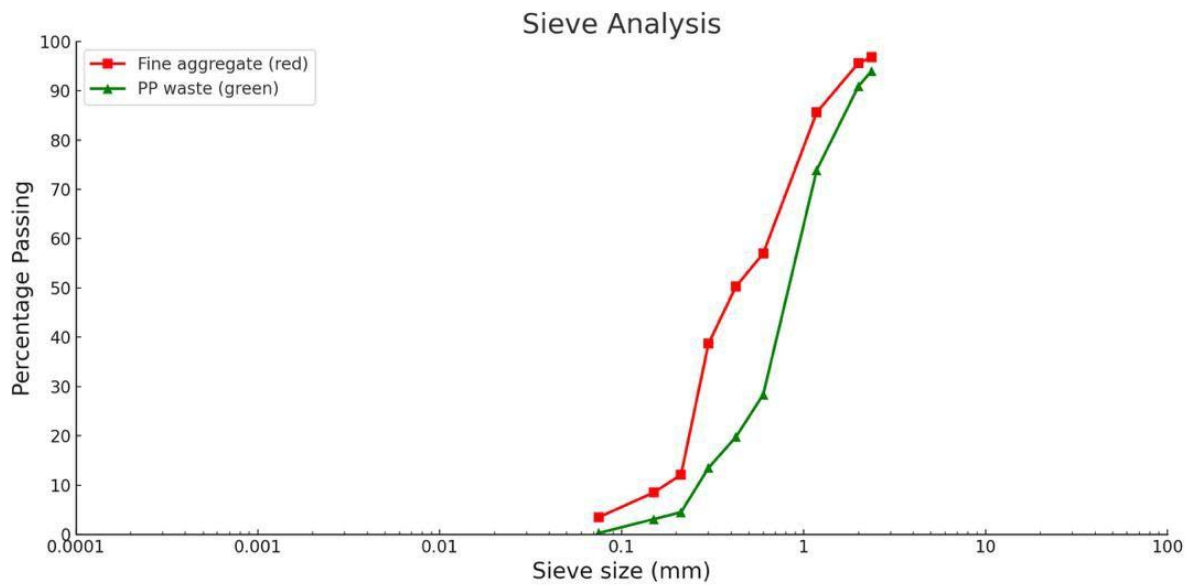
The sieve analysis test was conducted to determine the particle size distribution of both fine aggregates and polypropylene (PP) waste. The test followed the procedures outlined in **BS EN 933-1:2012**. The purpose was to ensure that the aggregates used were all graded.

**Table 4.1: Sieve Analysis Results for Fine Aggregate**

Sieve size (mm)	Weight retained (g)	% Retained	Cumulative % retained	% Passing
2.36	3.2	3.2	3.2	96.8
2.00	1.2	1.2	4.4	95.6
1.18	10.1	10.1	14.5	85.5
600	28.5	28.5	43.0	57.0
425	6.7	6.7	49.7	50.3
300	11.6	11.6	61.3	38.7
212	26.6	26.6	87.9	12.1
150	3.6	3.6	91.5	8.5
075	5.0	5.0	96.5	3.5

**Table 4.2: Sieve Analysis Results for Polypropylene (PP) Waste**

Sieve size (mm)	Weight retained (g)	% Retained	Cumulative % retained	% Passing
2.36	6.0	6.0	6.0	94.0
2.00	3.1	3.1	9.1	90.9
1.18	17.0	17.0	26.1	73.9
600	45.5	45.5	71.6	28.4
425	8.6	8.6	80.2	19.8
300	6.3	6.3	86.5	13.5
212	9.0	9.0	95.5	4.5
150	1.4	1.4	96.9	3.1
075	2.8	2.8	99.7	0.3



**Figure 4.1 : Sieve analysis results for fine aggregates and polypropylene waste**

**4.2.1. DISCUSSION OF SIEVE ANALYSIS RESULTS**

Well-graded aggregates contribute to higher density and reduced voids in concrete, resulting in improved strength (Al-Saffar *et al.*,2021).

**4.3. SPECIFIC GRAVITY RESULTS**

Specific gravity provides an indication of the density and quality of aggregate materials. It influences mix design, strength and durability. The test was conducted following **BS EN 1097-6:2013**.

**Table 4.3: Specific Gravity of Fine Aggregates**

Bottle No	DA	B0
Bottle Weight (M1)	22.00	20.90
Bottle + Soil (M2)	48.40	47.30
Bottle + Soil + Water (M3)	89.99	91.35
Bottle + Water (M4)	75.03	76.38

## Calculations

$$\text{Specific gravity} = \frac{\text{Mass of soil}}{\text{Mass of equal volume of water}} \quad (4.1)$$

$$\frac{M_2 - M_1}{(M_4 - M_1) - (M_3 - M_2)} \quad (4.2)$$

$$\text{Specific gravity for bottle DA} = \frac{48.40 - 22.0}{(75.03 - 22.0) - (89.99 - 48.40)} \quad (4.3)$$

Specific gravity for bottle DA = 2.31

$$\text{Specific gravity for bottle BO} = \frac{47.30 - 20.90}{(76.38 - 20.90) - (91.35 - 47.30)} \quad (4.4)$$

Specific gravity for bottle BO = 2.36

$$\text{Average specific gravity for fine aggregate} = \frac{2.31 + 2.36}{2} \quad (4.5)$$

Average specific gravity for fine aggregate = 2.34

**Table 4.4: Specific Gravity of polypropylene(PP) Waste**

Bottle No	DT	2A
Bottle Weight (M1)	24.40	21.70
Bottle + PP (M2)	29.40	26.60
Bottle + PP + Water (M3)	76.76	77.95
Bottle + Water (M4)	67.96	51.47

### Calculations

$$\text{Specific gravity} = \frac{\text{Mass of PP}}{\text{Mass of equal volume of water}} \quad (4.6)$$

$$\frac{M2-M1}{(M4-M1)-(M3-M2)} \quad (4.7)$$

$$\text{Specific gravity for bottle DT} = \frac{29.40-24.40}{(67.96-24.40)-(76.76-29.40)} \quad (4.8)$$

Specific gravity for bottle DT = -1.32

#### 4.3.1. DISCUSSION OF SPECIFIC GRAVITY RESULTS

During the calculation process, a negative value occurs because the conventional specific gravity formula assumes that the material being tested is denser than water. Which means it sinks completely and displaces an equal volume of water.

Polypropylene on the other hand, is a lightweight thermoplastic with a density lower than water. As a result, it floats rather than sink. This is caused by entrapped air within the shredded plastic particles and their lower specific weight.

#### 4.4. WATER ABSORPTION RESULTS

water absorption test was carried out after 7 days according to BS EN 1097-6:2013, where the difference between the oven-dried and saturated-surface-dry (SSD) weights of specimens was used to calculate absorption.

**Table 4.5: water absorption results for 3 days**

<b>Sample</b>	<b>Wet weight (g)</b>	<b>Dry weight (g)</b>	<b>Water absorption (%)</b>
0% (A)	3.068	3.027	1.35
0% (B)	3.149	3.100	1.58
0% (C)	3.249	3.200	1.53
1% (A)	2.712	2.676	1.35
1% (B)	2.960	2.929	1.06
1% (C)	2.664	2.633	1.18
2% (A)	2.918	2.864	1.89
2% (B)	3.058	3.000	1.93
2% (C)	3.033	2.990	1.44

3% (A)	2.927	2.876	1.77
3% (B)	2.914	2.877	1.29
3% (C)	2.637	2.595	1.62
4% (A)	2.970	2.926	1.50
4% (B)	2.993	2.950	1.46
4% (C)	2.985	2.942	1.46

**Table 4.6: Average values of water absorption for each percentage at 3 days**

<b>Sample</b>	<b>Value</b>
0%	1.49
1%	1.20
2%	1.75
3%	1.56
4%	1.47

**Table 4.7: water absorption results for 7 days**

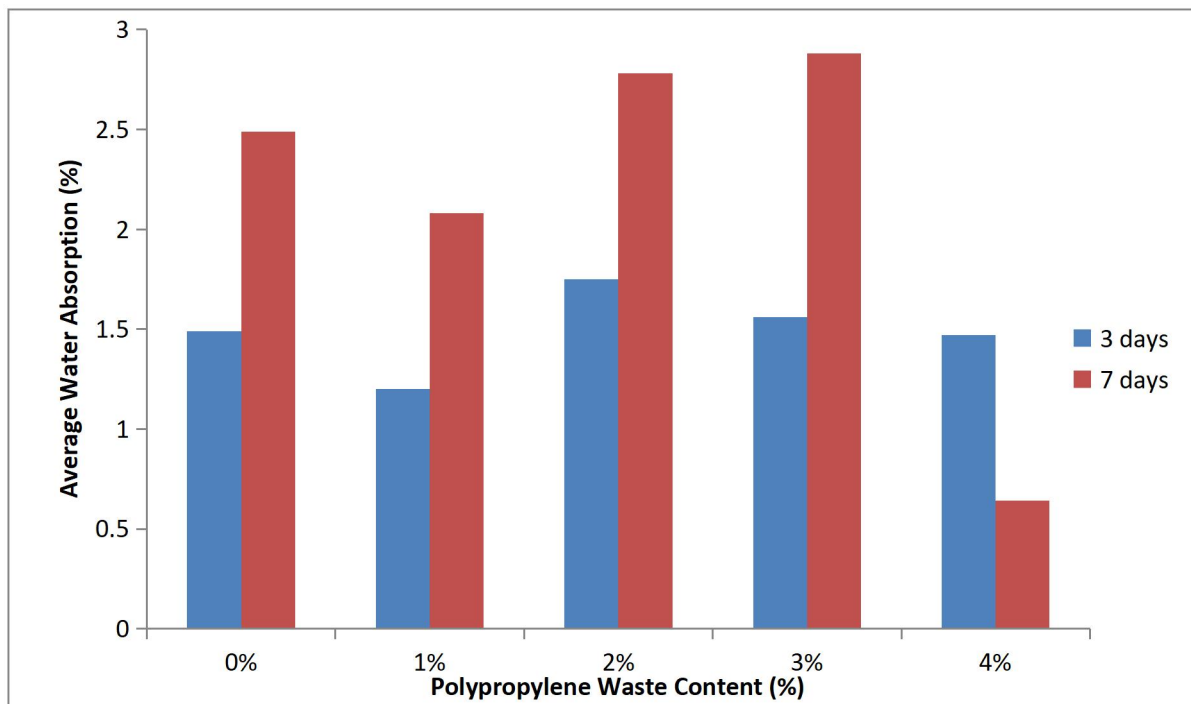
<b>Sample</b>	<b>Wet weight (g)</b>	<b>Dry weight (g)</b>	<b>Water absorption (%)</b>
0% (A)	3.144	3.050	2.75
0% (B)	3.135	3.060	2.45
0% (C)	3.013	2.946	2.27
1% (A)	2.992	2.926	2.26
1% (B)	2.999	2.930	2.05
1% (C)	3.066	3.008	1.93
2% (A)	2.920	2.826	3.33
2% (B)	2.934	2.859	2.62
2% (C)	3.069	2.997	2.40
3% (A)	2.669	2.581	3.41
3% (B)	2.847	2.774	2.63
3% (C)	2.954	2.879	2.61
4% (A)	2.930	2.913	0.58
4% (B)	3.042	3.024	0.60
4% (C)	2.897	2.876	0.73

The water absorption was calculated using :  $\frac{\text{wet weight} - \text{dry weight}}{\text{dry weight}} \times 100$  (4.9)

**Table 4.8: Average values of water absorption for each percentage at 7 days**

Sample	Value
0%	2.49
1%	2.08
2%	2.78
3%	2.88
4%	0.64

The average was calculated by adding samples A, B and C for each percentage and dividing by 3.



**Figure 4.2: Average water absorption of sandcrete block**

#### 4.4.1. DISCUSSION OF WATER ABSORPTION RESULTS

From the table, the water absorption of the control sample (0% PP) was 2.49%, which falls within the acceptable range for good-quality paving stones (2–6%) as specified in BS EN 1338:2003. The absorption decreased slightly to 2.08% with the addition of 1% polypropylene waste, indicating that a small quantity of PP particles improved the compactness of the concrete by reducing the amount of interconnected pores.

However, at 2% and 3% additions, the absorption increased to 2.78% and 2.88%, respectively. This slight increase may be attributed to the hydrophobic nature of polypropylene, which weakens the bond between the plastic particles and the cement paste at higher dosages. The presence of these inert particles can create weak interfacial zones or microvoids, allowing more water to penetrate. Similar observations were reported by Dawodu *et al.* (2022) and Cahyani *et al.* (2023), who found that excess plastic content in concrete leads to reduced cohesiveness and increased porosity.

At 4% PP addition, the water absorption dropped significantly to 0.64%, representing the lowest value in the study. This unexpected decrease could be attributed to improved particle packing and uniform distribution of fine PP fragments within the cement matrix, effectively sealing surface voids and preventing water ingress. A similar reduction trend at higher PP contents has been noted in studies by Oyedepo *et al.* (2021) and Kiridi *et al.* (2024), who suggested that finer plastic particles can fill micro-voids and enhance water resistance when optimally dispersed.

Overall, the results demonstrate that the inclusion of polypropylene waste influences the pore structure and water permeability of paving stones. Moderate additions (1–2%) resulted

in comparable absorption to the control mix, while the 4% addition significantly improved impermeability. This suggests that, when properly proportioned and mixed, recycled polypropylene can reduce the water absorption of concrete paving blocks and contribute to improved durability and sustainability in pavement applications.

#### 4.5. COMPRESSIVE STRENGTH TEST RESULTS

Compressive strength tests were performed in accordance with BS EN 12390-3:2019 to determine the load-carrying capacity of the paving stones. The test results are presented in table below:

**Table 4.9: compressive strength test results at 3 days**

<b>Samples</b>	<b>Failure Load (KN)</b>	<b>Compressive strength (Mpa)</b>
0% (A)	342.94	13.55
0% (B)	355.90	13.28
0% (C)	330.17	13.05
1% (A)	397.22	15.70
1% (B)	415.37	16.42
1% (C)	395.24	15.62
2% (A)	310.00	12.25
2% (B)	328.76	12.99
2% (C)	312.26	12.34

3% (A)	300.32	11.87
3% (B)	288.91	11.42
3% (C)	293.60	11.60
4% (A)	298.54	11.80
4% (B)	286.29	11.32
4% (C)	281.44	11.12

**Table 4.10: Average compressive strength for each percentage at 3 days**

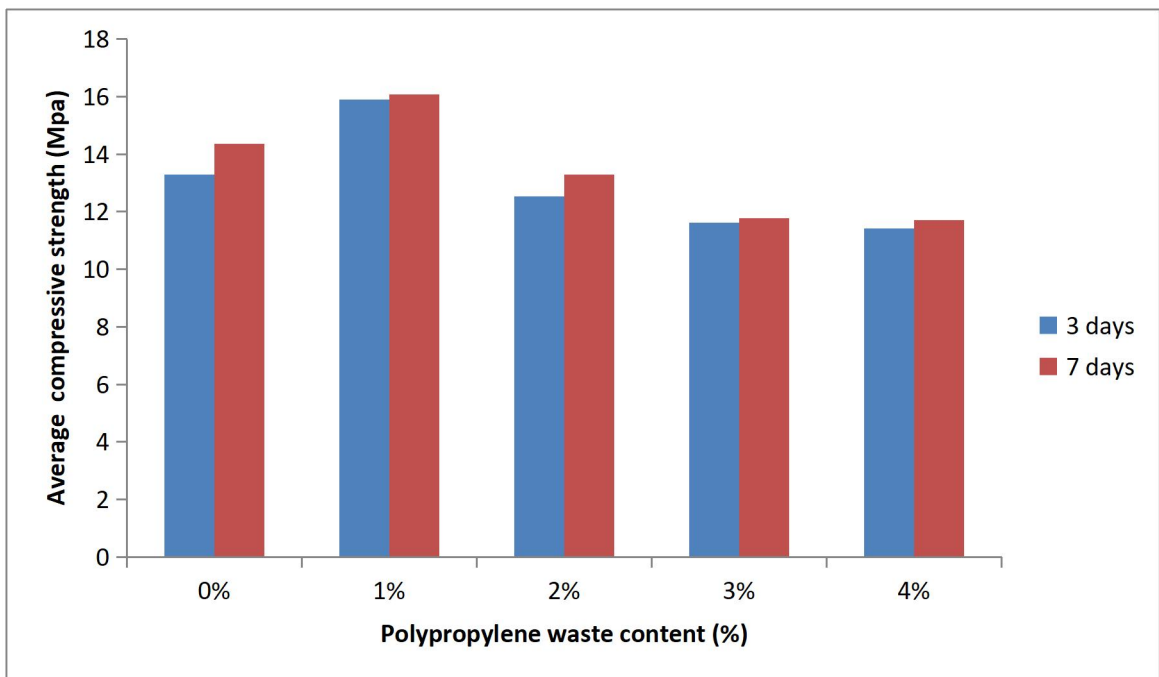
<b>Sample</b>	<b>Compressive strength</b>
0%	13.29
1%	15.91
2%	12.53
3%	11.63
4%	11.41

**Table 4.11: compressive strength test results at 7 days**

<b>Samples</b>	<b>Failure Load (KN)</b>	<b>Compressive strength (Mpa)</b>
0% (A)	359.16	14.20
0% (B)	370.75	14.65
0% (C)	359.73	14.22
1% (A)	405.35	16.02
1% (B)	400.45	15.83
1% (C)	413.311	16.37
2% (A)	330.45	13.06
2% (B)	337.82	13.35
2% (C)	340.71	13.47
3% (A)	298.51	11.80
3% (B)	291.97	11.54
3% (C)	298.51	11.99
4% (A)	303.61	11.88
4% (B)	295.13	11.78
4% (C)	290.47	11.48

**Table 4.12: Average compressive strength for each percentage at 7 days**

Sample	Compressive strength
0%	14.36
1%	16.07
2%	13.29
3%	11.78
4%	11.71



**Figure 4.3: Average compressive strength of polypropylene sandcrete blocks**

#### 4.5.1. DISCUSSION OF COMPRESSIVE STRENGTH RESULTS

From the results, the control sample (0% PP) achieved compressive strengths of 13.29 MPa and 14.36 MPa at 3 and 7 days, respectively. The inclusion of 1% polypropylene waste led to a slight improvement, producing the highest strength values of 15.91 MPa (3 days) and 16.07 MPa (7 days). This improvement can be attributed to the effective dispersion of fine PP particles, which enhance the microstructure by reducing microcracks and improving stress transfer within the concrete matrix (Alrshoudi *et al.*, 2022; Dawodu *et al.*, 2022).

Beyond the 1% addition, the compressive strength decreased gradually, reaching 11.41 MPa and 11.71 MPa for 4% PP content. The reduction in strength at higher PP dosages is likely due to the non-polar and hydrophobic nature of polypropylene, which limits bonding with the cement paste. The weak interfacial transition zone (ITZ) formed between the smooth plastic surfaces and the surrounding cement paste causes poor load transfer, thereby reducing compressive strength (Cahyani *et al.*, 2023; Oyedepo *et al.*, 2021).

Overall, the results indicate that the optimum polypropylene content for paving stone production in this study is approximately 1%, which achieved the best compressive strength performance at both curing ages. Beyond this point, excess polypropylene disrupts the matrix continuity and reduces the overall strength. Nevertheless, even at 4%, the compressive strength values remained within the acceptable range for medium-duty paving stones as specified in BS EN 1338:2003.

## CHAPTER FIVE

### CONCLUSION AND RECOMMENDATION

#### 5.1 CONCLUSION

This research investigated the influence of adding polypropylene (PP) waste to the production of concrete paving stones as a sustainable means of recycling plastic waste and reducing environmental pollution. The study focused on how varying proportions of polypropylene (1%, 2%, 3% and 4%) affected the physical and mechanical properties of paving stones, with particular emphasis on specific gravity, water absorption, and compressive strength at 3 and 7 days.

The water absorption results revealed that the inclusion of polypropylene waste influenced the permeability and compactness of the paving stones. The control mix (0%) recorded an absorption of 2.49%, while a slight reduction to 2.08% was observed at 1% polypropylene addition, suggesting improved compactness and reduced pore connectivity. However, a marginal increase in absorption was recorded at 2% and 3% (2.78% and 2.88%, respectively), which may be attributed to the poor bonding between the hydrophobic plastic surface and the cement paste at higher dosages. Interestingly, at 4% PP, the water absorption dropped sharply to 0.64%, indicating that finer polypropylene particles might have filled microvoids and reduced the material's overall permeability. All recorded values were within the acceptable range (2–6%) for paving blocks according to BS EN 1338:2003, confirming the materials' suitability for field application.

The compressive strength results followed a similar trend. The control sample achieved 15.72 MPa and 14.16 MPa at 3 and 7 days, respectively. The mix containing 1% PP gave the

highest strength values of 15.97 MPa (3 days) and 15.81 MPa (7 days), representing an improvement over the control. The increase at 1% can be attributed to the even dispersion of fine polypropylene particles, which reduced microcracks and improved load transfer within the concrete matrix. However, beyond this point, strength gradually decreased to 11.63 MPa (3%) and 11.42 MPa (7 days) as the higher PP content disrupted the matrix and introduced weak zones due to poor interfacial bonding. A slight rebound was observed at 4%, with strength increasing to 12.37 MPa, possibly due to better compaction and reduced voids. Despite the minor reduction in strength at higher dosages, all samples still satisfied the minimum strength requirement for medium-duty paving stones as prescribed by BS EN 1338:2003.

It was observed that the 3-day compressive strengths were marginally higher than the 7-day results in some mixes. This deviation from the expected strength gain pattern may be attributed to differences in curing exposure and surface drying, which could have affected hydration. Similar irregularities have been reported by Dawodu *et al.* (2022), who noted that inconsistent curing conditions can temporarily reduce later-age strength.

From the findings of this research, the following conclusions can be drawn:

- i. The inclusion of small quantities (around 1%) of polypropylene waste in concrete paving stones enhances strength, reduces permeability, and improves the sustainability profile of the material.
- ii. Higher additions (beyond 2%) tend to reduce compressive strength due to poor bonding between the plastic particles and the cement paste.

- iii. The specific gravity of polypropylene (0.91) confirms its lightweight characteristics, which can be beneficial in applications requiring reduced load and easier handling.
- iv. All mixes tested met the minimum strength and durability requirements for paving stones, confirming the feasibility of incorporating recycled plastic in construction.

## **5.2. RECOMMENDATIONS**

- i. The addition of polypropylene waste should be limited to around 1% by weight of cement, as this level provided the best compressive strength and durability characteristics.
- ii. Polypropylene waste particles should be uniformly dispersed in the mix to prevent clustering and ensure even distribution, which enhances the interfacial bonding with the cement paste.
- iii. Future studies could investigate chemical or mechanical surface treatment of polypropylene waste to improve its adhesion with cement and further enhance compressive strength.
- iv. Longer curing durations (14–28 days) should be explored to observe the long-term strength development of PP-modified paving stones.
- v. Further tests such as abrasion resistance, impact strength, and freeze–thaw resistance are recommended to assess the long-term performance of the paving stones in field conditions.

- vi. The use of polypropylene waste in paving stone production should be tested at industrial or community scale to evaluate cost–benefit, production feasibility, and real-world performance.
- vii. Government agencies and construction stakeholders should promote the reuse of plastic waste in building materials through policy incentives and awareness programmes, contributing to waste management and sustainable development goals (SDGs 9, 11, and 12).

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## APPENDIX



Sandcretes during casting



Mixing sandcrete