DEVELOPMENT OF SUSTAINABLE LIGHTWEIGHT BLOCKS FROM CONCRETE INCORPORATING ARTIFICIAL LIGHTWEIGHT PLASTIC WASTE AGGREGATE

FINAL YEAR PROJECT UG 2020

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2024

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Final Year Project Titled

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ABSTRACT

The urgency to develop sustainable building materials has never been more critical in the face of global environmental challenges such as resource depletion and waste management crises. This thesis presents an innovative approach to sustainable construction through the development of lightweight concrete blocks by incorporating artificial lightweight plastic waste aggregate. This research not only addresses the pressing issue of plastic waste accumulation but also explores the potential of recycled plastics to replace traditional aggregates in concrete block production.

The methodology employed involves a detailed experimental analysis where plastic waste is processed into aggregates and then used in varying proportions to replace natural coarse aggregates in concrete mix designs. The plastic aggregates were developed by cleaning, shredding, and melting plastic waste materials, followed by extrusion to form bricks, and then ultimately crushing to aggregate-sized particles. These aggregates were then introduced into concrete mixes at replacement ratios of 0%, 30%, 50%, 70%, and 100% to evaluate their effect on the physical and mechanical properties of the concrete.

Extensive testing, adhering to ASTM standards, was conducted to assess the compressive strength, density, water absorption, and durability of the produced concrete blocks. The tests revealed that concrete blocks with up to 70% plastic aggregate replacement maintained acceptable levels of strength and durability, suggesting a viable pathway for substantial incorporation of plastic waste in non-load-bearing construction applications.

The research demonstrates that lightweight concrete blocks incorporating artificial lightweight plastic waste aggregate offer a promising solution to the dual challenges of waste management and sustainable material sourcing in the construction industry. This study not only advances the body of knowledge in the field of sustainable construction materials but also provides practical implications for waste management, recycling industries, and construction practices.

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CHAPTER 1

INTRODCUTION

1.1 Background

The construction industry is currently navigating a crucial transition, faced with the imperative to adapt to the multifaceted environmental, economic, and social challenges of the 21st century. Traditional construction methods, which heavily rely on non-renewable natural resources such as sand and gravel, are proving increasingly unsustainable. This unsustainability stems from rapid resource depletion, severe environmental degradation, and the tightening grip of regulatory frameworks designed to mitigate these impacts. The urgent demand for sustainable building materials has catalyzed a wave of innovation aimed at minimizing the ecological footprint of construction activities while enhancing waste management strategies.

Among the myriad of sustainable practices, the utilization of waste materials in construction emerges as a particularly promising avenue. Plastic waste epitomizes both a significant environmental challenge and a potential resource for the construction sector. Each year, the global production of plastic waste amounts to hundreds of millions of tons, a substantial portion of which contaminates landfills and natural ecosystems, exacerbating pollution and ecological damage. This research proposes a transformative use of this abundant waste: recycling it into artificial lightweight aggregates for concrete production, thereby not only mitigating environmental damage but also fostering a circular economy.

This study focuses on the development of lightweight concrete blocks that incorporate artificial lightweight plastic waste aggregate. By doing so, it seeks to convert plastic waste from an environmental liability into a valuable construction resource. This innovative approach promises to alleviate the growing waste management crisis and reduce dependence on naturally extracted aggregates, which are associated with significant ecological disturbances including habitat destruction, groundwater depletion, and landscape disfigurement. Lightweight concrete has become a focal point in sustainable construction due to its inherent properties that significantly lower the ecological footprint of buildings. Characterized by its reduced density and enhanced thermal insulation compared to conventional concrete, lightweight concrete presents a myriad of advantages including improved seismic resistance, reduced dead loads, and better thermal performance. These characteristics make it particularly suitable for non-load-bearing applications such as partition walls, façade panels, and decorative elements within buildings.

1.1.1 Evolution and Current Practices

Traditionally, lightweight concrete utilizes natural materials such as volcanic pumice, expanded clay, and shale aggregates. These materials are favored for their porous nature which contributes to the lightweight characteristics of the concrete. However, the geographical availability of these materials is limited, and their extraction and processing can be energy-intensive, which detracts from their environmental benefits. Furthermore, the global demand for lightweight aggregates has led to environmental degradation in areas where these materials are mined.

As the construction industry seeks more sustainable and locally available materials, industrial by-products like fly ash, furnace slag, and silica fume have been introduced as partial substitutes for traditional aggregates. While these materials have helped reduce the industry's carbon footprint by diverting waste from landfills and reducing the need for virgin materials, they still require significant energy for transportation and processing. Additionally, the chemical stability and long-term performance of some by-products in concrete applications are still subjects of ongoing research, necessitating cautious adoption within the industry.

1.1.2 The Potential of Plastic Waste as Aggregate

In this context, the use of recycled plastics as an alternative aggregate in concrete emerges as a transformative solution. Plastics such as polyethylene terephthalate (PET), high-density polyethylene (HDPE), and polyvinyl chloride (PVC) are not only abundant but also pose significant environmental hazards when not properly managed. These materials are predominantly sourced from consumer waste, which continues to accumulate at alarming rates globally. The durability, lightweight, and relatively inert characteristics of these plastics make them suitable candidates for incorporation into concrete.

The idea of using plastic waste in concrete is not entirely new. Various studies have explored the mechanical properties of concrete with incorporated plastic particles. These studies generally indicate that while the inclusion of plastic can reduce the density of concrete, it may also affect the strength and durability of the material adversely if not carefully managed. Therefore, the challenge lies in optimizing the content and size of the plastic aggregates to maintain the structural integrity of concrete while maximizing the environmental benefits.

1.1.3 Scientific and Practical Implications

Integrating plastic waste into concrete involves several key steps: waste collection and sorting, cleaning, shredding, and sometimes melting and pelletizing to achieve uniform particle sizes. The processed plastic aggregates are then mixed with Portland cement, water, and other components to form concrete. The variability in plastic types and the lack of a standardized process for preparing plastic waste for use in concrete pose significant challenges. These challenges are compounded by the heterogeneous nature of plastic waste, which can lead to inconsistent properties in the finished product.

From a scientific perspective, the interaction between plastic aggregates and cement matrix, the impact of plastic's thermal properties on concrete's insulation characteristics, and the long-term durability of plastic-infused concrete under various environmental conditions are critical areas of research. These studies are essential to understand the fundamental aspects of material science that govern the performance of plastic-aggregate concrete.

Practically, the use of plastic waste in concrete could significantly mitigate the environmental impact associated with the construction industry. By diverting plastic waste from landfills and oceans, this approach not only helps in tackling the global waste management crisis but also reduces the extraction and processing of natural aggregates. The potential reduction in the overall weight of concrete structures could further result in lower transportation costs and less energy consumption during construction.

1.1.4 Broader Environmental and Economic Benefits

The environmental benefits of using plastic waste in concrete extend beyond reducing landfill use. The production of Portland cement, a primary component of concrete, is one of the largest sources of carbon dioxide emissions worldwide. By substituting a portion of the aggregates with plastic, the total volume of cement used in concrete can potentially be reduced, thereby decreasing the overall carbon footprint of construction projects.

Economically, the integration of waste plastics into building materials could foster new industries and avenues for waste recycling, which are crucial for developing circular economies. The scalability of this initiative implies that it could be adapted in various regions, utilizing locally available plastic waste streams, thus promoting local economies and reducing dependency on imported building materials.

1.2 Research Significance

This research holds pivotal importance for several multifaceted reasons, fundamentally addressing the acute global issue of plastic waste accumulation. Annually, millions of tons of plastic waste are generated worldwide, with a significant percentage evading recycling processes and contributing to environmental pollution. By innovatively integrating plastic waste into concrete, this study provides a dual-benefit solution: it significantly curtails plastic pollution and diminishes the reliance on natural aggregates, whose extraction inflicts considerable ecological damage. The transformation of plastic waste into a valuable construction material not only mitigates waste but also promotes the use of locally sourced, recycled materials. This approach aligns with sustainable development goals by reducing the carbon footprint associated with the production of traditional concrete, which predominantly uses high-energy-consuming materials.

Moreover, this research is instrumental in propelling the construction industry towards more sustainable practices. It explores the use of alternative materials that are locally available from waste streams, thereby minimizing logistical costs and reducing the overall energy consumption involved in building material production. This shift towards local and recycled content is crucial for building resilience against resource scarcity and fluctuating market conditions that can affect material availability and cost.

In a practical context, the study rigorously examines the technical and environmental performance of concrete blocks incorporating plastic waste aggregates. It methodically tests various mix proportions to determine the optimal balance that does not compromise the concrete's structural integrity and longevity. This entails a detailed evaluation of the mechanical properties such as compressive strength, density, and modulus of elasticity, as well as functional characteristics including water absorption rates, thermal insulation properties, and durability under different environmental conditions. The research methodically incorporates life-cycle assessments to quantify the environmental impacts associated with the production, usage, and disposal stages of the concrete blocks.

These assessments help in understanding the broader ecological benefits of the proposed solution, from reducing landfill use and lowering carbon emissions to conserving natural resources. The empirical data gathered provides a robust basis for evaluating the sustainability credentials of using recycled plastic in concrete applications. Additionally, the study delves into the compatibility of plastic aggregates with traditional concrete components and the chemical interactions that occur, which are crucial for ensuring the longevity and safety of the construction material.

The implications of this research are extensive and far-reaching. By demonstrating the viability of plastic waste-based concrete, it sets a precedent for waste management policies and recycling practices that could be adopted globally. It offers a scalable model that can be replicated in diverse settings, adapting to local waste types and construction needs. This research has the potential to influence policymakers and stakeholders across the waste management and construction industries, encouraging a shift towards integrated industrial symbiosis where waste from one industry becomes the resource for another.

Such collaborative approaches could foster more comprehensive recycling strategies, improve material resource efficiency, and propel the adoption of circular economy principles in the construction sector. Furthermore, by providing empirical evidence of the benefits and challenges associated with plastic waste in concrete, the study aids in formulating guidelines and standards for manufacturing sustainable building materials.

This research contributes significantly to the field of sustainable construction by developing a practical and environmentally friendly alternative to traditional concrete. The successful implementation of this technology could revolutionize building practices, enhance environmental sustainability, and serve as a catalyst for policy changes and new standards in construction material production. The adoption of such innovative recycling practices is crucial for mitigating the impact of construction activities on the planet and for advancing global sustainability initiatives.

1.3 Problem statement

The construction industry, a major consumer of natural resources, faces critical challenges due to its heavy reliance on non-renewable materials like sand and gravel, necessary for concrete production. This dependence has led to significant environmental issues, including resource depletion, ecological disturbances from aggregate extraction, and high carbon emissions from cement production. Simultaneously, the world grapples with managing over 300 million tons of plastic waste annually, much of which ends up polluting the natural environment due to inadequate recycling processes. This convergence of challenges necessitates the exploration of sustainable alternatives that can mitigate these impacts. Recycled plastic waste offers a promising solution by potentially replacing natural aggregates in concrete, thus addressing both the depletion of critical natural resources and the persistent problem of plastic waste. This research aims to develop lightweight concrete blocks incorporating plastic waste, optimizing their composition to ensure structural integrity while assessing their environmental performance through comprehensive lifecycle analyses. The successful implementation of this innovation could significantly transform building practices, reduce the construction industry's environmental footprint, and pioneer a shift towards more sustainable and circular economic practices.

1.4 Objectives and scope of the study

1.4.1 Objectives of study

1. **To Characterize Plastic Waste as Aggregate:**

- Assess the physical and chemical properties of different types of plastic waste (e.g., PET, HDPE, PVC) to determine their suitability as aggregate in concrete.
- Evaluate the processing requirements necessary to convert plastic waste into a usable form for concrete production, including cleaning, shredding, and potentially melting and reforming processes.

2. **To Develop Optimized Concrete Mix Designs:**

- Formulate various concrete mixes incorporating plastic waste aggregates at different replacement ratios (0%, 30%, 50%, 70%, and 100%) to replace traditional aggregates.
- Determine the optimal mix proportions that achieve the best balance between mechanical properties (such as compressive strength and durability) and environmental benefits.

3. **To Evaluate the Mechanical and Durability Properties:**

- Conduct comprehensive testing to assess the compressive strength, tensile strength, modulus of elasticity, and durability under various environmental conditions.

- Investigate the water absorption, density, and thermal insulation properties of the developed concrete blocks to ensure they meet industry standards for non-load-bearing applications.

4. **To Assess Environmental Impact Through Life-Cycle Analysis:**

- Perform life-cycle assessments (LCAs) to evaluate the environmental impacts associated with the production, use, and disposal of plastic-aggregate concrete blocks.
- Compare the environmental footprint of concrete blocks made with plastic waste aggregate to those made with traditional materials to quantify the benefits.

5. **To Explore the Economic and Market Feasibility:**

- Analyze the cost implications of using plastic waste in concrete production, considering both the savings from reduced use of traditional aggregates and the costs associated with processing plastic waste.
- Evaluate the market readiness for adopting lightweight concrete blocks made with recycled plastic, including potential barriers and facilitators in current construction practices.

1.4.2 Scope of the Study

The scope of this research encompasses both laboratory experiments and theoretical analyses to achieve the objectives outlined. The study is geographically limited to sources of plastic waste and construction markets within urban areas where waste collection systems are well-established, ensuring a consistent supply of raw materials. The scope includes:

- **Material Sourcing and Preparation:** Utilizing post-consumer and post-industrial plastic waste from local recycling facilities to minimize the carbon footprint associated with transportation.
- **Experimental Design:** Developing and testing multiple concrete mix designs in controlled laboratory settings to isolate the effects of plastic aggregate content on the properties of concrete.
- **Performance Testing:** Employing standardized tests for concrete properties based on ASTM and other relevant standards to ensure the reliability and reproducibility of results.
- **Environmental and Economic Analyses:** Conducting LCAs using recognized methodologies and market analysis using current economic data to assess the feasibility and impact of scaling up production.

- **Stakeholder Analysis:** Identifying key stakeholders in the construction and waste management sectors to understand the potential acceptance and practical challenges of introducing new building materials to the market.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview of Concrete Production and Environmental Impact

2.1.1 Global Demand for Concrete: Statistics and trends in concrete usage globally

The global demand for concrete, the most widely used construction material, is a testament to its indispensable role in development across various sectors including residential, commercial, and infrastructure projects. Concrete's popularity stems from its durability, strength, and relatively low cost, making it a fundamental element in modern construction. This section explores the statistics and trends related to the usage of concrete globally, underpinning its pivotal role and the consequent environmental impacts of its extensive use.

2.1.1.1 Global Consumption

Concrete production is estimated at approximately 10 billion cubic meters annually, making it the second-most consumed substance on Earth after water (Scrivener et al., 2018) . The immense scale of its use is driven by urbanization and economic development, particularly in emerging economies. China, for instance, used more concrete between 2011 and 2013 than the United States did in the entire 20th century, highlighting the material's critical role in infrastructure expansion.

2.1.1.2 Trends and Projections

The upward trajectory in global concrete usage is closely tied to pervasive trends in urbanization and infrastructural expansion. As per projections by the United Nations, the percentage of the global population residing in urban areas is expected to surge from 55% in 2018 to 68% by 2050, necessitating extensive infrastructural and building developments to accommodate this shift (United Nations, 2018). The escalation is particularly notable in Asia and Africa, regions that are currently undergoing rapid urban migration and economic acceleration. This demographic and economic transformation is driving unprecedented demand for concrete, making it imperative to explore sustainable construction practices that can mitigate the environmental impacts associated with traditional concrete production. Studies such as those by (KP Mehta, 2001; Scrivener et al.,

2018) on sustainable cement and concrete production techniques highlight the critical need for innovation in construction materials to support sustainable urban growth.

2.1.1.3 Regional Variations

While emerging markets exhibit robust growth in concrete demand, developed regions show a more moderate increase. In Europe and North America, the focus is shifting towards sustainable and efficient construction practices due to environmental regulations and a higher awareness of sustainability issues. This shift influences concrete demand patterns, emphasizing the need for greener alternatives and the recycling of construction materials. Studies indicate that stringent environmental regulations in these regions have catalyzed innovations in recycled aggregates and alternative cementitious materials, which are gaining traction as viable substitutes for traditional concrete components (Flower & Sanjayan, 2007), Furthermore, the implementation of policies aimed at reducing CO2 emissions has prompted the construction industry to adopt more sustainable practices, such as using industrial by-products including fly ash and slag in concrete (Scrivener et al., 2018). These materials not only reduce the carbon footprint of concrete but also improve its mechanical properties and durability, making them an attractive option for modern construction projects (Thomas, 2013).

2.1.1.4 Environmental Impact

The vast production of concrete exerts substantial environmental pressures, primarily due to the extraction of raw materials and CO2 emissions from cement production, which is a key component of concrete. Cement manufacturing is one of the largest sources of industrial CO2 emissions, contributing about 8% of global CO2 releases (Benhelal et al., 2013). These emissions arise from both the chemical processes involved in cement production and the energy consumed by these processes, highlighting a significant area for environmental improvement.

2.1.1.5 The Push for Sustainable Alternatives

In response to the environmental challenges posed by traditional concrete production, there is a growing emphasis on developing sustainable concrete alternatives. These alternatives include the use of recycled materials such as crushed concrete from demolition waste and industrial by-products like fly ash and slag. The use of such materials not only helps in reducing the demand for virgin materials but also decreases the environmental footprint of concrete production.

Furthermore, innovations such as carbon capture, utilization, and storage (CCUS) technologies in cement manufacturing are gaining attention as a means to mitigate CO2 emissions (Scrivener et al., 2018).

2.1.2 Environmental Challenges: Impact of traditional concrete production on natural resource depletion, carbon emissions, and ecological disturbances

The production of traditional concrete imposes significant environmental challenges, including natural resource depletion, substantial carbon emissions, and a variety of ecological disturbances. This segment elucidates these impacts, underpinned by recent academic research and environmental reports.

2.1.2.1 Environmental Challenges

The production of concrete heavily relies on natural aggregates such as sand and gravel, which are harvested from riverbeds, beaches, and land quarries. The high demand for these materials has led to over-extraction, which significantly depletes these natural resources and disrupts local ecosystems. Such activities have resulted in the lowering of riverbeds, increased riverbank erosion, reduced water aquifer levels, and a loss of habitat for aquatic and terrestrial wildlife (Torres et al., 2017). The extraction processes not only scare the landscape but also lead to sedimentation and pollution of waterways.

In addition to resource depletion, concrete production is a major source of CO2 emissions, primarily from the calcination of limestone in cement manufacturing. Cement, the key ingredient in concrete, accounts for about 8% of the world's carbon dioxide emissions, underscoring a significant environmental challenge associated with modern building techniques (Benhelal et al., 2013). The kiln processes involved in cement production are energy-intensive and contribute to air quality deterioration, releasing not only CO2 but also significant amounts of NOx, SOx, and particulate matter into the atmosphere.

Moreover, the ecological disturbances caused by aggregate mining and cement production are profound. Habitats are often cleared or covered, water courses are redirected, and the natural aesthetic and biological value of the region is diminished. These ecological footprints extend beyond the immediate area of extraction and production, influencing broader ecological functions and biodiversity. The disruption of local flora and fauna through such industrial activities contributes to the broader biodiversity crisis facing many regions around the world (Scrivener et al., 2018).

2.2 Traditional and Alternative Aggregates in Concrete

The construction industry has traditionally relied on natural aggregates such as sand, gravel, and crushed stone for concrete production. However, the environmental impact of extracting these materials and the increasing demand for sustainable construction practices have driven significant interest in alternative aggregates. This section explores the types of traditional and alternative aggregates used in concrete, their environmental implications, and the potential for sustainable practices in aggregate sourcing.

The continued reliance on natural aggregates is unsustainable given the environmental degradation and resource depletion it causes. The construction industry must adopt more sustainable practices by integrating alternative materials that can provide the same benefits as natural aggregates without the associated environmental costs. This shift not only supports global sustainability goals but also ensures the long-term viability of the construction industry in a world where natural resources are increasingly scarce. Future research and innovation in aggregate technology will play a critical role in making sustainable concrete production a standard practice globally.

2.2.1 Natural Aggregates: Types, uses, and environmental implications

Natural aggregates such as sand, gravel, and crushed rock form the backbone of concrete production globally. These materials are integral to the construction industry due to their excellent mechanical properties, including compressive strength and durability, which ensure the structural integrity of concrete. Their geological origin, which includes river beds, quarries, and seashores, makes them readily available in many parts of the world, contributing to their widespread use in construction projects.

2.2.1.1 Environmental Impact of Natural Aggregate Extraction

The extraction of natural aggregates is associated with significant environmental challenges. The process typically involves mining operations that significantly alter the landscape, leading to substantial disruption of local ecosystems. For instance, river mining can lead to riverbank erosion, increased sedimentation, and disruption of aquatic life cycles, which can have cascading effects on biodiversity and the stability of local ecosystems (Rentier & Cammeraat, 2022).

In addition to ecological disturbances, the extraction operations often result in noise, dust, and traffic that affect local communities. These operations require heavy machinery that consumes large amounts of energy and emits pollutants, contributing to air quality degradation and global greenhouse gas emissions. The disturbance of the soil and vegetation cover also increases the risk of erosion and landslides, further exacerbating the environmental impact (Erşan, 2021).

2.2.1.2 Resource Depletion Concerns

The high demand for natural aggregates has led to over-exploitation in many areas, causing resource depletion that can have long-term economic and environmental implications. For example, the depletion of sand reserves in certain regions has led to illegal mining activities, which can have even more severe environmental impacts. As the most consumed raw material on earth after water, the sustainability of sand and other aggregates is a growing concern, driving the need for global governance and management strategies to ensure these resources are used responsibly (Bendixen, 2019).

2.2.1.3 Push for Sustainable Alternatives

Given these challenges, there is a pressing need within the construction industry to explore more sustainable options. Alternative materials such as manufactured sand, recycled concrete aggregates, and aggregates derived from industrial by-products like slag and fly ash are being considered to reduce dependence on natural aggregates. These alternatives not only help mitigate the environmental impact associated with traditional aggregate extraction but also contribute to the circular economy by recycling waste materials into valuable construction resources (Bravo et al., 2015).

2.2.2 Industrial By-Products as Aggregates

Industrial by-products, including fly ash, slag, and silica fume, have emerged as valuable substitutes for natural aggregates in concrete production. These materials are generated from various industrial processes such as coal combustion in power plants, steel manufacturing, and silicon metal or ferrosilicon alloy production. Their utilization in concrete not only facilitates waste management but also enhances the performance characteristics of concrete.

Industrial by-products like fly ash, slag, and silica fume represent sustainable alternatives to traditional concrete aggregates. Their use not only addresses environmental concerns associated with waste disposal and resource depletion but also enhances the technical performance of concrete. The ongoing research and development in this area are crucial for optimizing the use of these materials in concrete, promoting their wider acceptance and implementation in construction projects worldwide.

2.2.2.1 Fly Ash

Fly ash, a residue from coal combustion, is one of the most commonly used by-products in concrete. Its inclusion in concrete improves the workability and durability of the mix, reducing the water demand and enhancing the finished product's resistance to aggressive environmental conditions. Moreover, fly ash reacts with the lime produced during the hydration of cement to form additional cementitious compounds, which contribute to the long-term strength of concrete. A recent study highlighted that incorporating fly ash could reduce up to 30% of the cement content, significantly diminishing the concrete's environmental footprint by lowering CO2 emissions associated with cement production (Van Den Heede & De Belie, 2012).

2.2.2.2 Slag

Slag, a by-product of iron and steel manufacturing, is used as a supplementary cementitious material. When ground into a fine powder, slag exhibits cementitious properties that can partially or fully replace cement in concrete. The use of slag in concrete has been shown to improve the durability and mechanical properties of the concrete, particularly its resistance to sulfate attack and alkali-silica reaction. The inclusion of slag in concrete formulations also helps in reducing the thermal stress within large concrete structures by minimizing the heat of hydration (Ionescu et al., 2020).

2.2.2.3 Silica Fume

Silica fume, another industrial by-product, is derived from the production of silicon and ferrosilicon alloys. It is a highly reactive pozzolan with particles much finer than cement grains, leading to increased packing density and significantly improved strength and impermeability of the concrete. The addition of silica fume to concrete greatly enhances its mechanical properties, including compressive strength, bond strength, and abrasion resistance. Furthermore, silica fume reduces the permeability of concrete, making it more resistant to chloride penetration, thus extending the life of reinforced concrete structures, especially in marine environments (Yandrapati & Anil Kumar, 2021) .

2.2.2.4 Environmental and Economic Benefits

The use of these industrial by-products in concrete offers substantial environmental benefits by reducing the demand for virgin materials and the volume of waste sent to landfills. Economically, the use of such materials can decrease the overall cost of concrete production by utilizing less expensive or locally available substitute materials. Additionally, the enhanced properties of concrete containing these by-products can lead to longer-lasting structures, reducing maintenance and repair costs over the building's lifecycle.

2.2.3 Recycled Aggregates: Current Practices and Challenges in Using Recycled Concrete and Other Materials

Recycled aggregates, derived primarily from construction and demolition waste, have emerged as a sustainable alternative to natural aggregates in concrete production. Current practices in the use of these materials are aimed at reducing the environmental impact of construction activities by minimizing waste and conserving natural resources. However, several challenges still hinder their widespread adoption.

2.2.3.1 Current Practices

The recycling of concrete and other construction materials has become increasingly common due to technological advancements and growing environmental concerns. Recycled aggregates are typically produced by crushing and processing concrete from demolished buildings, roads, and other structures. The resulting materials are then screened and graded to be used in new construction projects. The use of recycled concrete aggregates (RCA) has been particularly notable in non-structural applications such as road base, sidewalks, and landscape architecture, where the aesthetic and structural demands are relatively lower compared to structural applications.

Recycled aggregates are not limited to crushed concrete; other materials such as demolished masonry and reclaimed asphalt pavement also contribute to the pool of recycled construction materials. These practices not only help reduce the amount of waste sent to landfills but also decrease the demand for virgin quarry materials, thus conserving natural resources and reducing carbon emissions associated with mining and transportation (Badraddin et al., 2021).

2.2.3.2 Challenges

Despite the benefits, several challenges impede the broader use of recycled aggregates in concrete. One of the main issues is the variability in quality, which can affect the consistency and predictability of concrete performance. Recycled aggregates often contain remnants of mortar and other construction materials, which can alter the water absorption and strength characteristics of the aggregate and, consequently, the concrete (Siddique et al., 2008a).

Additionally, logistical challenges such as the collection, sorting, and processing of demolition waste can complicate the supply chain for recycled aggregates. The lack of standardized regulations and specifications for recycled aggregate concrete in many regions further complicates its adoption. Ensuring that recycled aggregates meet the quality standards for specific applications requires rigorous testing and quality control processes, which can be costly and time-consuming.

Moreover, there is often a lack of awareness and acceptance among stakeholders in the construction industry regarding the use of recycled materials. Misconceptions about the quality and performance of recycled aggregate concrete can deter its use, especially in structural applications where safety and durability are paramount. Addressing these perceptions through education and demonstration of successful projects is essential for increasing acceptance and adoption of recycled aggregates.

2.2.3.3 Future Directions

Advancements in processing technology and improved quality control measures are gradually overcoming some of the technical challenges associated with recycled aggregates. Research continues into enhancing the properties of recycled concrete through the use of additives and treatments that can improve the bonding between old cement mortar and new cement paste. The development of standards and specifications that address the unique properties of recycled aggregate concrete is also critical for its broader adoption.

Sustainability initiatives and increasing regulatory pressures are likely to drive further growth in the use of recycled aggregates. As the construction industry continues to move towards more sustainable practices, the recycling of concrete and other materials is expected to play an increasingly important role in reducing the environmental impact of construction activities.

The continued development and refinement of practices and technologies for recycling concrete are vital to overcoming the existing challenges and realizing the full potential of recycled aggregates in contributing to a more sustainable construction industry.

2.3 Plastic Waste as a Global Challenge

Plastic waste represents one of the most pressing environmental concerns of the modern age, contributing to extensive environmental degradation and posing significant challenges for waste management systems worldwide. This section delves into the global issues associated with plastic waste, highlighting the urgency of finding effective management and recycling strategies.

The production of plastic has surged exponentially since the mid-20th century, driven by its versatility and cost-effectiveness. Today, an estimated 318 million tons of plastic are produced annually, a significant portion of which contributes to the solid waste stream. Despite the known durability and utility of plastic products, their disposal poses considerable challenges due to their non-biodegradable nature, leading to accumulation in landfills and natural environments (Ragossnig & Agamuthu, 2021).

One of the most visible and alarming impacts of plastic waste is on marine ecosystems. It is estimated that between 4 to 12 million metric tons of plastic waste enter the oceans each year, leading to severe consequences for marine biodiversity. Marine animals ingest or become entangled in plastic debris, causing injury or death. Additionally, plastics break down into microplastics, which contaminate the marine food web, affecting not only marine life but also humans who consume seafood (Alqattaf, 2020).

Despite the growing awareness and efforts to recycle plastic, global recycling rates remain low, primarily due to the complexity of sorting and processing different types of plastics. The lack of infrastructure for efficient recycling in many parts of the world exacerbates the problem, with significant amounts of plastic waste either incinerated, contributing to air pollution, or landfilled, where they persist for centuries (Brooks et al., 2018).

Efforts to manage plastic waste are further complicated by inadequate regulatory frameworks in many countries. While some nations have implemented bans or restrictions on single-use plastics, enforcement remains a challenge. The international nature of plastic waste trade, particularly the export of waste from developed to developing countries, has led to uneven impacts and responsibilities, necessitating coordinated global policy responses (Wagh et al., 2022).

Addressing the challenge of plastic waste requires a multifaceted approach involving improvements in materials science, waste management technologies, consumer behavior, and regulatory frameworks. Innovations in biodegradable plastics, more efficient recycling technologies, and global cooperation on waste management policies are essential to mitigate the environmental impacts of plastic waste. The role of public awareness and education also cannot be understated, as reducing plastic consumption and increasing recycling rates begin with individual actions and societal attitudes towards plastic use.

2.3.1 Production and Disposal of Plastic:Overview of global plastic production and waste management issues.

The production and disposal of plastic are critical environmental and industrial challenges that have escalated with the global surge in plastic use. The world's production of plastics has grown substantially, leading to increased waste which presents significant management challenges. The issues surrounding the production and disposal of plastic are multifaceted and require a concerted effort from global governments, industries, and individuals to develop effective management strategies. Innovations in recycling technology and improved global regulations are critical to mitigating the environmental impacts of plastic waste. The referenced papers provide a detailed insight into the complexities of plastic waste management and highlight the urgent need for integrated strategies to address this pressing global challenge.

2.3.1.1 Global Production of Plastics

Worldwide plastic production has skyrocketed from the mid-20th century, reaching approximately 359 million tons by the year 2018. This tremendous growth is propelled by the expansion of various sectors including packaging, construction, automotive, and consumer goods, each relying heavily on plastic for its low cost, lightweight, and strong performance characteristics. This increase in plastic production is projected to continue, compounding the challenges associated with plastic waste management (Geyer et al., 2017).

2.3.1.2 Waste Management and Recycling Challenges

Despite the advancements in recycling technologies, global recycling rates for plastics remain disappointingly low. As of 2020, only about 9% of plastic waste generated globally is recycled, with the rest ending up in landfills, incinerated, or improperly disposed of in the environment. This inefficiency in recycling is largely due to the complexity of sorting various types of plastics, each requiring different processes for recycling, and the lack of sufficient recycling infrastructure in many parts of the world (Alqattaf, 2020).

2.3.1.3 Environmental Impact of Plastic Pollution

The environmental impacts of mismanaged plastic waste are profound, affecting terrestrial and marine ecosystems alike. Millions of tonnes of plastic waste enter the oceans each year, leading to severe pollution issues that affect marine life and human health. Microplastics, in particular, have become ubiquitous in marine environments, entering the food chain and posing risks to marine species and humans alike. The persistent nature of plastics, which can take hundreds of years to degrade, exacerbates their impact on the environment, making effective management strategies critical (Brooks et al., 2018).

2.3.1.4 Legislative and Policy Responses

In response to the growing plastic pollution crisis, several countries have implemented policies aimed at reducing plastic waste through bans on single-use plastics, incentives for recycling, and improvements in waste management infrastructure. However, the effectiveness of these policies varies widely, with significant gaps in enforcement and coverage. The international community continues to seek better solutions for managing plastic waste, emphasizing the need for a global approach to address this pervasive issue (Wagh et al., 2022)

2.3.2 Impacts of Plastic Pollution: Environmental, social, and economic consequences of mismanaged plastic waste

Plastic pollution is a pervasive problem affecting every corner of the globe, with far-reaching environmental, social, and economic consequences. This section outlines the multi-dimensional impact of mismanaged plastic waste, drawing on the most recent findings from the Consensus Library of Papers. The widespread impacts of plastic pollution necessitate urgent and coordinated actions to improve waste management, enhance recycling technologies, and implement effective legislative measures globally. The transition towards a circular economy, where plastic is reused and recycled, minimizing waste, is crucial. Addressing plastic pollution is not only about cleaning up the mess but also about preventing its occurrence through systemic changes in how we produce, consume, and dispose of plastic products. The need for global cooperation and innovative solutions is more pressing than ever to mitigate the environmental, social, and economic challenges posed by this enduring pollutant.

2.3.2.1 Environmental Impacts

The environmental consequences of plastic pollution are both vast and varied, affecting terrestrial and marine ecosystems alike. Plastics that enter natural habitats pose severe risks to wildlife through ingestion and entanglement. Moreover, plastics contribute to the degradation of natural landscapes and waterways, impacting biodiversity and ecosystem services. Microplastics, in particular, have been found in every marine and freshwater environment tested, where they absorb toxins and enter the food chain, affecting not only aquatic life but also the health of humans who consume fish and shellfish (Beaumont et al., 2019).

2.3.2.2 Social Impacts

The social implications of plastic pollution are profound, influencing human communities, particularly in coastal regions where plastic waste accumulation affects the livelihoods of millions who depend on tourism, fishing, and marine resources. The presence of plastics in the environment also impacts public health, with chemicals leached from plastics having been linked to a range of health issues including cancer, congenital disabilities, impaired immunity, and endocrine disruption (Soares et al., 2021).

2.3.2.3 Economic Consequences

Economically, the costs of plastic pollution are staggering, affecting various industries including tourism, fishing, and shipping. The cleanup and management of plastic waste requires significant financial resources which could otherwise be invested in more productive areas. Furthermore, plastic pollution can devalue real estate, degrade tourist destinations, and increase the costs of health care. The overall economic burden of managing plastic waste and mitigating its impacts is a major concern for both developed and developing nations (Cordier et al., 2021).

2.4 Use of Plastic Waste in Concrete

The incorporation of plastic waste into concrete is a transformative approach that not only addresses the pervasive issue of plastic pollution but also enhances the sustainability of construction practices. As the global production and accumulation of plastic waste continue to rise, finding effective utilization methods for this waste becomes increasingly critical. Concrete, the most widely used man-made material on earth, presents an expansive platform for the beneficial reuse of plastic waste. This integration serves dual purposes: reducing the environmental footprint of concrete production and providing a viable solution for plastic waste management.

The concept of using plastic waste in concrete emerged in the late 1990s and early 2000s, as researchers began to explore alternative materials for enhancing the environmental profiles of concrete structures. Initial studies focused on the feasibility of replacing traditional aggregates—such as gravel and sand—with shredded or granulated plastic waste. These pioneering experiments revealed that while plastic could decrease the overall weight of concrete, making it advantageous for certain applications like lightweight panels and non-load-bearing structures, it also introduced challenges in terms of strength and binding properties.

Over the past two decades, significant advancements have been made in the methods and technologies used to integrate plastic waste into concrete. Researchers have experimented with various types of plastics—each with unique properties affecting the concrete's performance. Innovations in treatment and processing techniques, such as the modification of plastic surfaces to improve their bond with cement paste, have been critical. These advancements have expanded the types of plastic waste that can be effectively used in concrete, from polyethylene terephthalate (PET) and high-density polyethylene (HDPE) to more complex composites and multi-layered plastics.

The type of plastic waste used in concrete significantly influences the resulting material's properties. For example, PET plastic waste, commonly derived from beverage bottles, is favored for its strength and durability when converted into fibrous form and used as reinforcement in concrete. HDPE, known for its robustness and resistance to chemicals, is often used in applications where durability against environmental factors is crucial. Each type of plastic imparts different mechanical properties to the concrete, affecting its density, flexibility, and strength.

The mechanical properties of plastic-infused concrete, such as compressive strength, tensile strength, and elasticity, are critical for its application in structural elements. While early studies indicated a reduction in strength with high levels of plastic aggregate, ongoing research has focused on optimizing the proportions and surface treatments to balance these effects. The current trend involves using plastic waste not just as a filler but as a functional additive that can improve certain properties, such as thermal insulation and resistance to cracking.

Long-term durability remains a primary concern in the use of plastic waste in concrete. Studies have shown varied results regarding the aging of plastic-infused concrete and its behavior under different environmental conditions. However, recent research has pointed towards positive outcomes, such as improved resistance to water penetration and reduced permeability, which are beneficial in harsh weather conditions or corrosive environments. Additionally, the environmental impact of producing plastic-infused concrete, particularly in terms of reduced natural aggregate mining and lower carbon emissions, underscores its potential as a sustainable building material.

The use of plastic waste in concrete represents a promising area of research and application within the construction industry. As the techniques and materials continue to evolve, the potential for widespread adoption increases, offering a dual benefit of mitigating plastic waste and enhancing the sustainability of concrete structures. This ongoing evolution will likely be supported by further advancements in chemical and mechanical engineering, ensuring that the future of construction materials is both innovative and environmentally responsible.

2.4.1 Initial Studies and Applications: Historical context and early experiments

The exploration of using plastic waste in concrete began to gain significant traction in the early 2000s as a response to the dual challenges of environmental pollution from waste plastics and the increasing demand for sustainable building materials. Initial studies primarily focused on the potential of substituting traditional concrete aggregates with granulated plastic waste, aiming to find a productive use for an otherwise persistent waste material.

2.4.1.1 Early Experiments and Findings

The early experiments in this field involved replacing a portion of fine or coarse aggregates with various types of granulated plastic waste. These initial studies were pioneering, setting the groundwork for understanding the basic interactions between plastic materials and cementitious matrices. Researchers discovered that while the inclusion of plastics could lead to lighter concrete, the modifications often resulted in decreased mechanical strength and durability. The altered density and bonding characteristics between the plastic and the cement paste were identified as key factors influencing these outcomes. These findings highlighted the need for further research to optimize concrete mixes that incorporate plastic waste to maintain or improve performance while achieving sustainability goals (Sharma & Bansal, 2016).

2.4.1.2 Pioneering Studies and Their Contributions

One of the seminal studies in this area tested different types of plastic waste, including polyethylene terephthalate (PET), high-density polyethylene (HDPE), and polyvinyl chloride (PVC), to evaluate their suitability as partial replacements for traditional aggregates. These studies often involved mechanical testing to assess impact resistance, compressive strength, and flexibility. The outcomes varied significantly based on the type of plastic used, the size of the aggregate replacement, and the overall composition of the concrete mix, thus opening new avenues for specialized applications of plastic waste in concrete (Kocher & Yousif, 2022).

2.4.1.3 Subsequent Developments

Following these early experiments, subsequent studies have focused on enhancing the interface between plastic aggregates and the cement matrix to improve mechanical properties. Techniques such as surface modification of plastics, use of coupling agents, and alterations in the mixing processes have been explored to enhance the performance of plastic-infused concrete. The research has expanded to include not only the mechanical properties but also the environmental impact and sustainability assessments of using recycled plastics in construction materials (RamaDevi et al., 2020).

2.4.2 Types of Plastics Used: Characteristics of PET, HDPE, PVC, and other plastics in concrete

In the innovative realm of sustainable construction, various types of recycled plastics such as polyethylene terephthalate (PET), high-density polyethylene (HDPE), and polyvinyl chloride (PVC) are being explored for their potential use in concrete. Each type of plastic brings unique properties that can influence the behavior of concrete differently, ranging from changes in strength and durability to modifications in density and workability.

2.4.2.1 Polyethylene Terephthalate (PET)

PET is predominantly used in the manufacturing of beverage bottles and packaging materials. When recycled and used in concrete, PET particles contribute to reducing the density of concrete, making it lighter and potentially suitable for non-load-bearing applications. Studies have shown that PET can improve the thermal insulation properties of concrete while slightly reducing its compressive strength. The angular and irregular shapes of shredded PET particles can also improve the mechanical interlock in concrete mixes, which may enhance its structural integrity in certain contexts (Rahmani et al., 2013).

2.4.2.2 High-Density Polyethylene (HDPE)

HDPE is known for its strength, durability, and resistance to chemicals and moisture. In concrete applications, HDPE has been utilized to enhance the flexibility and impact resistance of concrete structures. This type of plastic tends to create a more ductile concrete, which can absorb energy more effectively than traditional concrete, making it beneficial in areas prone to seismic activity. However, incorporating HDPE into concrete can lead to a decrease in compressive strength, which limits its use to specific applications where strength is not the primary concern (Nursyamsi & Adil, 2021).

2.4.2.3 Polyvinyl Chloride (PVC)

PVC, when added to concrete, primarily influences the weight and thermal properties of the material. Due to its inherent characteristics, PVC can reduce the overall weight of concrete, making it suitable for non-structural elements and applications where lighter construction materials are advantageous. Moreover, PVC can improve the fire resistance of concrete due to its chlorine content, which acts as a natural flame retardant. However, care must be taken as PVC can release toxic fumes when exposed to high temperatures, posing potential risks during the manufacturing process and in fire scenarios (Kravanja, 2022).

2.4.2.4 Other Plastics

Other less commonly used plastics in concrete include polypropylene (PP) and low-density polyethylene (LDPE), each contributing differently to the properties of concrete. PP, for example, can improve the crack resistance and flexibility of concrete, while LDPE may enhance workability and finish ability due to its lower melting point and softer nature.

2.4.3 Mechanical Properties: Effects of Plastic Aggregates on Strength, Density, and Durability

Incorporating plastic waste into concrete as aggregate affects various mechanical properties such as compressive strength, tensile strength, modulus of elasticity, and overall durability of the concrete. Typically, replacing natural aggregates with plastic leads to a reduction in these properties due to the inherently lower stiffness and bonding characteristics of plastics compared to traditional materials. However, the specific effects depend greatly on the type of plastic used, the size and treatment of the aggregates, and the percentage of replacement in the concrete mix.

2.4.3.1 Effects on Compressive Strength and Tensile Strength

Studies have shown that the inclusion of plastic aggregates generally results in a decrease in compressive strength. For instance, concrete mixes with plastic aggregates display reduced compressive strength compared to those with conventional aggregates, particularly as the percentage of plastic increases. This is due to the less rigid nature of plastic, which does not bond with cement paste as effectively as stone or sand. The reduction in strength can range from slight to significant, depending on the type of plastic and its treatment prior to inclusion in the concrete (Ferreira et al., 2012)

Tensile strength also tends to decrease with the addition of plastic aggregates. The plastic materials do not support tension well, leading to earlier failure under tensile stress compared to traditional concrete. This characteristic limits the use of plastic-aggregate concrete in structural applications where tensile strength is a critical factor.

2.4.3.2 Impact on Density and Durability

Adding plastic aggregates typically reduces the density of concrete, which can be beneficial for non-load-bearing structures where lighter materials are advantageous. The lower density can improve the thermal insulation properties of the concrete but at the cost of reduced sound insulation and potentially increased water absorption unless properly treated.

The durability of concrete with plastic aggregates can vary. While some studies indicate that certain types of plastic aggregates can improve resistance to chemical attacks and reduce water absorption, others show an increase in porosity and permeability, which can lead to a decrease in durability over time. Environmental resistance, especially to freeze-thaw cycles, is often compromised in plastic-aggregate concrete due to the thermal expansion characteristics of plastic, which differ significantly from those of traditional aggregates (Faraj et al., 2019).

2.4.3.3 Modification Techniques

The mechanical properties of concrete with plastic aggregates can be enhanced through various modification techniques. The use of coupling agents, such as silanes or maleic anhydride, can improve the bond between plastic aggregates and cement paste, thus enhancing the mechanical properties. Surface treatment of plastic aggregates to increase roughness can also improve their interaction with cement paste, leading to better load transfer and improved strength properties.

2.4.4 Durability Studies: Long-term performance and environmental resistance of plastic-infused concrete

Durability studies focusing on the inclusion of plastic waste in concrete are crucial for assessing the long-term performance and environmental resistance of such innovative materials. These studies help determine how plastic-infused concrete can withstand various environmental conditions over extended periods, which is essential for its application in real-world construction projects.

2.4.4.1 Water Absorption and Permeability

One of the key aspects studied is the water absorption and permeability of concrete incorporating plastic waste. Generally, concrete with plastic aggregates shows an increase in water absorption due to the hydrophobic nature of plastics, which can create voids and decrease the density of the concrete. However, certain treatments and modifications in mix design can mitigate these effects and enhance the durability of the material against moisture penetration (Sičáková & Figmigová, 2021).

2.4.4.2 Freeze-Thaw Resistance

The freeze-thaw resistance of plastic-infused concrete is another critical durability factor, particularly in cold climates. Studies indicate that the incorporation of plastic waste can alter the freeze-thaw cycles' resistance, with some compositions showing decreased durability due to the formation of microcracks as temperatures fluctuate. However, optimizing the plastic aggregate content and particle size can help improve resistance (Mohammadhosseini & Tahir, 2018).

2.4.4.3 Chemical Resistance

Chemical resistance, particularly to environments containing acids, bases, and salts, is crucial for concrete used in industrial and coastal settings. Durability tests have shown that plastic-infused concrete can exhibit varying levels of resistance to chemical attack, depending on the type of plastic used and its compatibility with the cement matrix. Certain plastics may enhance the chemical resistance of concrete by reducing the permeability and limiting the transport of harmful ions through the material (Saxena et al., 2020)

2.4.4.4 Long-Term Mechanical Performance

Long-term mechanical performance is assessed through sustained load testing and aging studies. Concrete with recycled plastic aggregates typically shows a reduction in long-term strength due to the weaker mechanical bond between the plastic particles and the cement paste. However, research is ongoing to enhance the interfacial transition zone through the use of compatibilizers and surface treatment techniques, which can significantly improve the load-bearing capacity and longevity of the concrete (Abdelli et al., 2021).

2.5 Environmental Benefits of Using Recycled Plastics in Concrete

Utilizing recycled plastics in concrete not only addresses waste management challenges but also offers significant environmental advantages. The integration of plastic waste into concrete serves multiple environmental goals: it diverts substantial quantities of waste from landfills and the natural environment, reduces the need for virgin materials such as sand and gravel—whose extraction has significant ecological impacts—and lowers the overall carbon footprint of construction materials production. This process of incorporating plastic waste into concrete effectively embodies the principles of a circular economy by reusing materials at the end of their life cycle for new purposes, thus minimizing waste and reducing resource consumption. Additionally, this practice can significantly decrease carbon emissions by lessening the reliance on the production processes associated with traditional concrete components, which are energy-intensive and contribute substantially to global CO2 output. By transforming waste into a valuable construction resource, the use of recycled plastics in concrete not only mitigates the environmental impact associated with waste disposal but also promotes sustainable construction practices that are crucial for long-term ecological health.

2.5.1 Reduction in Natural Resource Use

Using recycled plastics as a substitute for traditional aggregates in concrete significantly reduces the demand for natural resources such as sand and gravel, which are facing rapid depletion due to overexploitation. By integrating plastic waste into concrete, the construction industry can conserve these vital natural aggregates, helping to preserve ecosystems that are affected by extensive mining operations.

2.5.1.1 Conservation of Natural Aggregates

The incorporation of recycled plastics in concrete serves as an effective alternative, utilizing materials that would otherwise contribute to landfill mass. This not only aids in resource conservation by reducing the extraction of virgin materials but also lessens the environmental impacts associated with aggregate mining. For example, studies have shown that substituting a portion of natural aggregates with plastic waste can lead to a substantial reduction in the extraction of these materials, thereby minimizing landscape disruption and habitat destruction associated with mining activities (Ruggiero et al., 2022)

2.5.1.2 Waste Reduction

The use of recycled plastics in concrete is a strategic approach to waste reduction. By repurposing plastic waste as an aggregate material, the amount of waste sent to landfills is significantly decreased. This not only helps in managing waste more effectively but also contributes to the reduction of environmental pollution. Recycling plastics into concrete offers a practical and sustainable use for plastic waste that would otherwise persist in the environment for centuries (Kravanja, 2022).

2.5.1.3 Economic Implications

The economic benefits of using recycled plastics in concrete also contribute to resource conservation. By reducing the need for natural aggregates, costs associated with mining, processing, and transporting these materials are also reduced. Furthermore, utilizing waste plastics can lower the overall cost of concrete production, making it an economically viable option for the construction industry. The savings accrued can be redirected towards other sustainable practices within the sector (Saha et al., 2018)

2.5.2 Decrease in Carbon Footprint

Incorporating recycled plastics into concrete significantly reduces the carbon footprint of construction materials. This critical environmental benefit is achieved through several mechanisms, each contributing to the reduction of greenhouse gas emissions associated with traditional concrete manufacturing.

2.5.2.1 Substitution of Cement and Aggregates

The production of cement, which is the primary component of concrete, is highly energy-intensive and a major source of CO2 emissions globally. By substituting a portion of the cement or aggregates with recycled plastics, the overall requirement for cement in the concrete mix is reduced. This substitution significantly lowers CO2 emissions since producing one ton of cement releases approximately one ton of CO2 into the atmosphere. Studies have demonstrated that using recycled plastics not only reduces the demand for virgin aggregates—whose extraction and processing are energy-consuming and carbon-intensive—but also decreases the cement content needed in concrete mixes (Al-Mansour et al., 2019)

2.5.2.2 Energy Efficiency in Material Processing

The recycling process for plastics, when integrated into concrete production, is generally less energy-intensive compared to the mining, crushing, and processing of new aggregates. The transportation of these lighter, recycled materials over shorter distances further contributes to energy savings and a reduction in associated carbon emissions. Recycling plastic for use in concrete effectively diverts waste from landfills and reduces the energy expenditure associated with waste management practices, such as incineration, which is another significant source of CO2 emissions (Tuladhar & Yin, 2018)

2.5.2.3 Lifecycle Emission Reductions

The lifecycle of concrete incorporating recycled plastics showcases notable reductions in carbon footprint from the manufacturing phase to the end of life. By using recycled plastics, the concrete industry can minimize the lifecycle emissions of their products, contributing to broader climate change mitigation efforts. Comprehensive studies that include lifecycle assessment (LCA) indicate that replacing traditional materials with recycled alternatives can significantly decrease overall

CO2 emissions throughout the concrete's lifecycle—from raw material acquisition through manufacturing and usage to disposal (Safiuddin et al., 2013).

2.5.3 Contribution to Circular Economy

The incorporation of recycled plastics into concrete is a prime example of applying circular economy principles within the construction industry. This approach not only manages waste effectively but also promotes sustainable practices by converting waste into valuable construction materials. This segment further explores the benefits and implications of using recycled plastics in concrete through subheadings that detail various aspects of its contribution to a circular economy.

2.5.3.1 Reuse and Recycling of Materials

Using recycled plastics in concrete supports the reuse of materials that would otherwise contribute to landfill waste. This practice extends the lifecycle of plastics by repurposing them as a valuable component in building materials. It exemplifies the "reuse" and "recycle" tenets of the circular economy, aiming to minimize resource extraction and reduce waste generation. Research shows that incorporating plastics in concrete can help close the loop of plastic usage by integrating waste back into valuable products (Nodehi & Mohamad Taghvaee, 2022).

2.5.3.2 Enhancing Resource Efficiency

The use of recycled plastics in concrete improves resource efficiency by reducing the demand for virgin raw materials such as sand and gravel, which are ecologically and economically costly to extract. By substituting a portion of these materials with plastic waste, the construction industry can decrease its ecological footprint and promote more sustainable material consumption patterns. This shift not only conserves natural resources but also reduces the energy consumption associated with the extraction and processing of traditional aggregates (Helmer Pedersen & Conti, 2017).

2.5.3.3 Economic Benefits

Implementing circular economy practices by integrating recycled plastics into concrete provides substantial economic benefits. It reduces costs associated with waste disposal and material procurement. Additionally, it can create new markets for recycled plastic materials, which can stimulate economic activity in the recycling sector. The reduction in the use of virgin materials can also lead to financial savings, making construction projects more economically viable in the long term (Anwar et al., 2021)

2.5.3.4 Promoting Sustainability

The circular economy model strives to maintain the utility and value of resources for as long as possible by reintegrating waste materials back into the economic system. Using recycled plastics in concrete promotes sustainability not only by reducing waste but also by lessening the construction industry's environmental impact. This sustainable approach aligns with global efforts to reduce greenhouse gas emissions and reliance on non-renewable resources, contributing to broader environmental and sustainability goals (Mohammadhosseini et al., 2021)

2.6 Challenges and Limitations

While the use of recycled plastics in concrete offers numerous environmental and economic benefits, several challenges and limitations exist that can impede its widespread adoption. These challenges span technical, economic, logistical, and regulatory domains, each presenting unique hurdles that need to be addressed to facilitate the integration of recycled plastics into mainstream construction practices.

2.6.1 Technical Challenges

The integration of recycled plastics into concrete presents several technical challenges that can impact the effectiveness and application of the resulting material in construction. These challenges primarily concern the compatibility of plastic materials with cementitious matrices and the variability in the properties of the resultant concrete.

2.6.1.1 Compatibility of Plastic with Cementitious Materials

2.6.1.1.1 Hydrophobic Nature of Plastics

One of the fundamental issues with incorporating plastics in concrete is their hydrophobic nature compared to the hydrophilic nature of cementitious materials. This disparity leads to poor adhesion between the plastic particles and the cement paste, resulting in weak interfacial transition zones. Such areas are prone to cracking and delamination, which can significantly compromise the structural integrity of the concrete (Babafemi et al., 2018)

2.6.1.1.2 Thermal Expansion Coefficients

Plastics and conventional concrete materials have significantly different coefficients of thermal expansion. This difference can cause differential movements within the concrete when exposed to temperature fluctuations, leading to increased risk of cracking and other forms of structural deterioration. Managing this aspect requires careful consideration of the types of plastics used and possibly the modification of the concrete mix to accommodate these differences (Nodehi & Mohamad Taghvaee, 2022b)

2.6.1.2 Variability in Results

2.6.1.2.1 Influence of Plastic Type and Form

The performance of concrete containing recycled plastics can vary significantly based on the type of plastic used (such as PET, HDPE, PVC), its form (fibers, flakes, or granules), and the processing methods applied. These variables affect how the plastic interacts with the cement matrix and can influence the overall mechanical properties of the concrete.

2.6.1.2.2 Proportion in the Mix

The proportion of plastic waste incorporated into the concrete mix also plays a critical role in determining the physical and mechanical properties of the final product. Higher percentages of plastic can lead to reduced density, strength, and durability, limiting the use of plastic-infused concrete to non-structural applications unless specific adjustments and enhancements are made (Shihada, 2020)

2.6.1.2.3 Processing Methods

The treatment and preparation of recycled plastics before their incorporation into concrete can influence the quality and consistency of the final product. Techniques such as cleaning, shredding, and sometimes even coating of plastics are necessary to improve their compatibility and performance within the concrete mix. Research is ongoing to develop more effective processing techniques that can standardize the quality of recycled plastics used in concrete production (Siddique et al., 2008b).

2.6.2 Economic and Logistical Barriers

The integration of recycled plastics into concrete poses several economic and logistical barriers that can affect its adoption in mainstream construction practices. These barriers can make it challenging to realize the potential benefits of this sustainable approach.

2.6.2.1 Economic Implications

2.6.2.1.1 Initial Investment and Cost of Processing

The process of integrating recycled plastics into concrete involves initial investments in specialized equipment and technology for collecting, sorting, cleaning, and processing plastic waste into a form usable in concrete. These upfront costs can be significant and may deter companies from pursuing this route, especially in regions where such technologies are not readily available or are cost-prohibitive (Saha et al., n.d.-b).

2.6.2.1.2 Cost of Quality Control and Testing

Ensuring that plastic-infused concrete meets required standards involves rigorous quality control and testing, which can add to the cost. This is particularly relevant given the variability in the properties of recycled plastics, which can affect the consistency and reliability of the final concrete product (Kravanja, 2022).

2.6.2.2 Logistical Challenges

2.6.2.2.1 Supply Chain Complexity

Developing a consistent and reliable supply chain for recycled plastics in concrete production involves numerous logistical challenges. These include the collection of adequate and appropriate types of waste plastics, which can vary widely in quality and composition. Additionally, the transportation and storage of recycled plastics require careful handling to prevent contamination and degradation (Abeysinghe et al., 2021)

2.6.2.2.2 Integration into Existing Production Processes

Integrating recycled plastics into the concrete production process can require significant modifications to existing manufacturing practices. This integration may involve changes in mixing techniques, curing conditions, and other process parameters, which can disrupt established workflows and require additional training for personnel (Sai Gopi et al., 2020)

2.6.2.3 Market Acceptance

Despite the potential environmental and economic benefits, there can be significant market resistance to the use of recycled plastics in concrete. Concerns about the long-term performance, durability, and safety of such materials can hinder their acceptance. Overcoming these perception barriers is crucial for broader adoption and requires concerted efforts in education, demonstration of successful projects, and robust performance data to build trust among stakeholders (Katerusha, 2021).

2.6.3 Regulatory and Standards Issues

The integration of recycled plastics into concrete poses significant regulatory and standards issues that can impact its adoption in construction practices. While the potential benefits of using recycled plastics are evident, the lack of comprehensive regulatory frameworks and established standards for their use in concrete complicates their acceptance and implementation on a larger scale.

2.6.3.1 Lack of Specific Guidelines and Standards

One of the primary challenges is the absence of specific guidelines and standards that address the use of recycled plastics in concrete. Most existing building codes and construction standards are designed around traditional materials like natural aggregates and do not account for the unique properties of plastics. This lack of specification creates uncertainty about the performance, safety, and longevity of concrete structures that incorporate recycled plastics. For widespread adoption, it is crucial to develop standardized testing and evaluation criteria that specifically assess the quality and durability of plastic-infused concrete (Czarnecki, 2019).

2.6.3.2 Compliance with Building Codes

Compliance with existing building codes presents another hurdle. Currently, most building codes do not explicitly recognize recycled plastic as a standard material in concrete production, which can prevent engineers and architects from using these materials in load-bearing applications. The incorporation of recycled plastics often requires special approvals or exceptions, which can delay project timelines and increase costs. There is a need for building codes to evolve to include provisions for alternative materials that promote sustainability without compromising safety and efficiency (Kravanja, 2022).

2.6.3.3 Certification and Quality Assurance

Ensuring consistent quality and performance of recycled plastic in concrete is essential for gaining trust and acceptance in the construction industry. The variability in plastic waste regarding type, condition, and previous usage can affect the final properties of the concrete. Establishing robust certification processes that verify the quality and suitability of recycled plastics for specific applications in construction is critical. This includes rigorous testing protocols that evaluate the mechanical properties, durability, and safety of the materials (Babafemi et al., 2018).

2.7 Theoretical Frameworks and Models

Incorporating recycled plastics into concrete not only offers practical applications but also necessitates the development and application of various theoretical frameworks and models to understand, predict, and optimize the behavior and performance of such innovative materials.

2.7.1 Life Cycle Assessment (LCA) Models: Overview of LCA studies related to concrete with plastic aggregates

Life Cycle Assessment (LCA) models are critical in evaluating the environmental impact of using recycled plastics in concrete throughout the entire lifecycle from production to disposal. LCA studies help quantify the environmental benefits, such as reduced greenhouse gas emissions and decreased energy consumption, which are associated with replacing traditional concrete components with recycled plastics. These models take into account various factors including the sourcing of raw materials, production processes, transportation, usage, and end-of-life disposal. LCA models have demonstrated that using recycled plastics in concrete can significantly lower the environmental footprint of construction projects by minimizing waste and reducing reliance on non-renewable resources (Cerchione et al., 2023).

2.7.2 Economic Models: Analysis of cost-effectiveness and economic impacts

Economic models related to the use of recycled plastics in concrete focus on assessing the cost-effectiveness of this practice. These models analyze various economic factors such as the cost of material procurement, processing of recycled plastics, production of plastic-infused concrete, and potential savings from waste reduction. Economic assessments are essential to determine the viability of recycled plastics in the construction industry, considering not only the direct costs but also the long-term economic benefits such as reduced disposal fees and potential for innovation in sustainable building materials. Studies have shown that integrating recycled plastics into concrete can be economically beneficial if supported by efficient recycling systems and market demand for sustainable construction materials (Saha et al., n.d.-a).

2.8 Research Gaps and Future Directions

The integration of recycled plastics into concrete, while promising, presents several research gaps and avenues for future investigation that are crucial for its advancement in sustainable construction practices.

2.8.1 Identification of Research Gaps: Areas lacking sufficient data or conclusive findings

2.8.1.1 Interfacial Bonding and Compatibility

One of the primary areas where data is insufficient involves the interfacial bonding characteristics between plastic aggregates and cementitious matrices. Understanding and improving the compatibility of recycled plastics with traditional concrete materials is essential for enhancing the mechanical properties and durability of the resulting concrete (Czarnecki, 2019b)

2.8.1.2 Long-Term Durability and Performance

There is also a notable gap in long-term performance data for concrete that incorporates recycled plastics. More extensive studies are needed to evaluate how these materials age under different environmental conditions and to assess their long-term durability and structural integrity (Gu & Ozbakkaloglu, 2016)

2.8.1.3 Environmental Impact Assessments

While initial studies have been conducted, comprehensive life cycle assessments (LCA) covering a wider range of environmental impacts are lacking. Such studies would provide deeper insights into the ecological benefits and potential drawbacks of using recycled plastics in concrete (Horáková & Novák, 2019).

2.8.2 Potential for Future Research: Emerging trends and technologies in sustainable concrete production

2.8.2.1 Advanced Modification Techniques

Future research could explore advanced chemical and physical modification techniques to enhance the properties of plastic aggregates. Surface treatments, compatibilizers, and hybrid composites could potentially improve the bonding characteristics and mechanical performance of plastic-infused concrete (Siddique et al., 2008).

2.8.2.2 Innovative Composite Materials

There is significant potential for developing new composite materials that combine recycled plastics with other types of recyclable wastes, such as glass and rubber, to create even more sustainable and durable construction materials (Babafemi et al., 2018).

CHAPTER 3

METHODOLOGY

3.1 Overview

This chapter delineates the comprehensive methodology adopted to investigate the viability of using artificial lightweight plastic waste aggregates in the production of sustainable concrete blocks. This chapter is structured to outline the systematic approach through three distinct but interconnected modules, each designed to explore different aspects of the project, from the initial development of the aggregate to the final production of concrete blocks. This methodology ensures a thorough examination of both the technical feasibility and environmental sustainability of the proposed materials and techniques.

3.2 Methodological Approach

The methodology for this project, as shown in the Figure 1, is divided into three modules, each focused on a specific phase of the research and development process:

- **Module 1:** Development of Artificial Lightweight Plastic Waste Aggregate
- **Module 2:** Incorporation of Artificial Lightweight Plastic Waste Aggregate in Concrete
- **Module 3:** Development of Sustainable Lightweight Concrete Blocks

This structured approach allows for a detailed exploration of each phase, ensuring that the transitions between the stages of aggregate development, concrete formulation, and block production are seamless and guided by the findings of the preceding module.

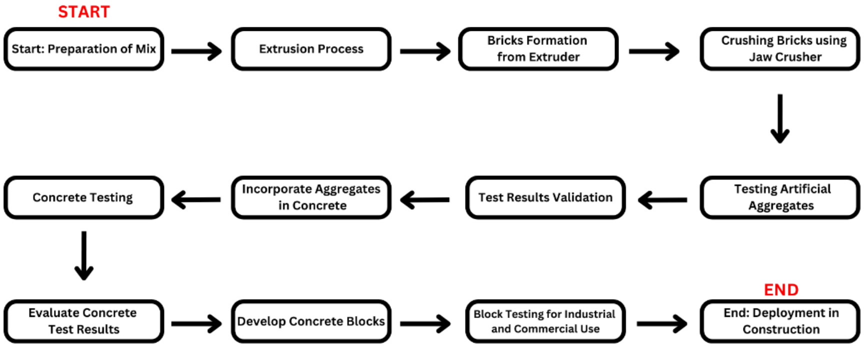

Figure 1:Methodology Flow Chart

3.3 Objectives and Outcomes of Each Module

3.3.1 Module 1: Development of Artificial Lightweight Plastic Waste Aggregate

3.3.1.1 Objective

To develop a viable aggregate from recycled plastic waste that is suitable for use in concrete production. The aim is to process and modify plastic waste into a form that is not only environmentally friendly but also maintains, or possibly enhances, the mechanical properties of concrete.

3.3.1.2 Outcomes

Identification of suitable types of plastic waste, determination of processing techniques to convert waste into aggregate, and comprehensive characterization of the aggregate's physical and chemical properties.

3.3.2 Module 2: Incorporation of Artificial Lightweight Plastic Waste Aggregate in Concrete

3.3.2.1 Objective

To assess the feasibility of using the developed plastic waste aggregate in concrete mixes. This module focuses on evaluating the performance of concrete that incorporates varying percentages of plastic waste aggregate, analyzing its impact on concrete's strength, durability, and other relevant properties.

3.3.2.2 Outcomes

Formulation of optimized concrete mixes that include plastic waste aggregate, detailed performance assessment of these mixes through standard concrete testing procedures, and evaluation of the environmental impact through preliminary life cycle assessments.

3.3.3 Module 3: Development of Sustainable Lightweight Concrete Blocks

3.3.3.1 Objective

To utilize the optimized concrete mixes for the production of lightweight concrete blocks, aiming at applications where the reduced weight and improved insulation properties offer significant benefits. This phase also explores the scalability of production and the market potential for such innovative building materials.

3.3.3.2 Outcomes

Production of concrete blocks using the developed mixes, thorough testing of blocks for compliance with building standards, and a feasibility study on the economic and environmental viability of bringing these blocks to market.

CHAPTER 4

MODULE 1: DEVELOPMENT OF ARTIFICIAL LIGHTWEIGHT PLASTIC WASTE AGGREGATE

4.1 Objective and Scope of Module 1

4.1.1 Objective of the Module 1

The primary objective of Module 1 is to develop an innovative, artificial lightweight aggregate using recycled plastic waste. This development aims to address several critical issues: reducing the environmental impact of construction materials, managing plastic waste more effectively, and creating sustainable, lightweight concrete that offers similar or enhanced performance characteristics compared to traditional concrete. The specific goals include:

1. Developing a feasible process for converting plastic waste into usable aggregate for concrete that meets or exceeds the performance standards of conventional aggregates.
2. Conducting extensive testing on the developed aggregates according to ASTM standards and comparing the results with those of natural aggregates.
3. Enhancing the environmental sustainability of concrete by reducing the reliance on natural aggregates, whose extraction has significant ecological impacts.

4.1.2 Scope of the Module 1

The scope of Module 1 encompasses several key activities designed to achieve the outlined objectives effectively:

1. **Material Selection:** Identifying and sourcing suitable types of plastic waste that can be converted into aggregates. This involves analyzing different types of plastics for their suitability based on properties such as durability, chemical stability, and environmental impact.
2. **Process Development:** Establishing a method for treating, processing, and converting plastic waste into aggregate. This includes mechanical and chemical processing steps such as shredding, melting, and reshaping the plastic into granules suitable for use in concrete.

3. **Aggregate Testing:** Conducting a series of tests to assess the physical and chemical properties of the developed aggregates. Tests include density measurement, water absorption, crushing strength, and durability tests to ensure environmental safety.

The research and development in this module are aimed at proving the concept that recycled plastic waste can be effectively and safely used in concrete production, leading to a reduction in environmental impact and advancement in material science for sustainable construction practices.

4.2 Materials Used

(a) (b)

Figure 2:Materials used for aggregate development, (a) Sand , (b) PP Plastic

4.2.1 Sand

In the development of artificial lightweight aggregates, the sand, as shown in the Figure 2(a), serves as a critical component, mixed with the polypropylene plastic waste. The addition of sand enhances the interfacial bonding between the plastic aggregate and the cement matrix, improving the mechanical stability and durability of the resulting concrete. The specific type of sand used is chosen based on its purity, grain size, and angularity to ensure optimal adherence and performance within the composite material.

4.2.2 Polypropylene (PP) Plastic

This section details the criteria and processes involved in selecting and preparing polypropylene (PP) plastic, as shown in the Figure 2(b), waste for developing the lightweight aggregates in concrete. The choice of PP and its preparation is crucial to ensuring the aggregate's suitability for concrete applications, affecting the final properties and sustainability of the construction material.

4.2.2.1 Criteria for Selecting Suitable Type of Plastic Waste

Polypropylene was chosen as the primary material for developing the artificial lightweight aggregate due to several favorable properties:

1. **Chemical Stability**: PP is chemically inert in many environments, making it less likely to react adversely with the components of concrete.
2. **Durability**: PP is known for its durability and resistance to fatigue, essential qualities for materials used in construction.
3. **Low Density**: PP's low density makes it ideal for producing lightweight aggregates, which can reduce the overall weight of the concrete without compromising its structural integrity.
4. **Recyclability**: PP is recyclable, aligning with the sustainability goals of reducing waste and reusing materials in construction.

The selection is supported by research highlighting PP's potential in concrete applications. For instance, Pavlík et al. (2019) discuss the preferable thermal attributes and optimum energy performance of concrete manufactured with waste polypropylene-based aggregates, emphasizing the ecological benefits and material properties suitable for building construction (Pavlík et al., 2019)

4.2.2.2 Processes Involved in the Preparation of Plastic Waste

The preparation of PP plastic waste involves several key steps to ensure the material is suitable for development of aggregates:

1. **Cleaning:** The PP waste is thoroughly cleaned to remove any contaminants, residues, or foreign materials that could affect the quality of the aggregate or the setting of the concrete.
2. **Sorting:** The waste is sorted to select the appropriate quality and type of PP needed for aggregate production. This step is crucial to maintain consistency in the aggregate's properties.
3. **Shredding**: The sorted PP waste is shredded into smaller pieces. The size of the shredded plastic is controlled to match the desired dimensions to be mixed with sand and passed through extrusion process in subsequent development stage.

Each step in the preparation process is designed to optimize the physical properties of the plastic waste, transforming it into a viable construction material. Research by (Ennahal et al., 2021) supports the feasibility of such processes, indicating that lightweight aggregates comprised of thermoplastic waste meet necessary mechanical properties and exhibit low water absorption, which are critical for their application in mortar and concrete.

4.3 Methodology and Experimental Setup

The experimental setup for developing artificial lightweight aggregates involved a series of controlled steps using a specific mixture of materials and equipment. This section details the methodology used to produce these aggregates by blending sand and polypropylene (PP) plastic and processing the mixture through an extrusion and molding procedure.

4.3.1 Material Mixing

The process began with a precise formulation, mixing 50% sand with 50% PP plastic by weight. The sand and plastic were dry mixed thoroughly to ensure a uniform distribution of the materials. This step was crucial for achieving consistency in the composition of the mixture, which directly impacts the quality and properties of the resulting aggregates.

4.3.2 Extrusion Process

Once mixed, the sand and plastic mix was introduced into an extruder machine, as shown in the Figure 3, which melted the mixture at a controlled temperature of 220°C. This temperature was specifically chosen to ensure the plastic reached its melting point (160°C for PP) without exceeding the threshold where thermal decomposition could occur. Maintaining this temperature was critical to avoid the degradation of the plastic and the emission of harmful gases, thereby ensuring the environmental safety of the process.

Figure 3:Extruder Machine

The molten paste-like mixture exiting the extruder was immediately cast into preformed molds shaped to dimensions of 20 x 10 cm to form bricks as shown in the Figure 4. This direct casting from the extruder ensured that the material did not cool prematurely, which is important for achieving the desired density and uniformity in the bricks.

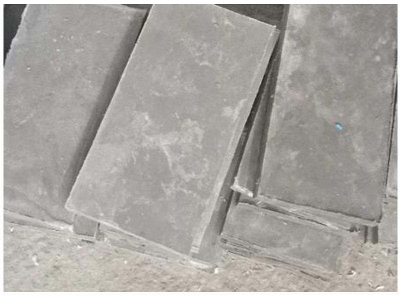

Figure 4:Plastic bricks (20 x 10 cm) made from extrusion process

After molding, the bricks were submerged in water to cool down rapidly. This quick cooling helped solidify the mixture efficiently and prevented any potential deformation or shrinkage that could occur if cooled slowly at ambient temperature. Once cooled, the bricks were demolded and left to dry and harden under controlled conditions to reach optimum mechanical strength.

4.3.3 Formation of Plastic Aggregates

Figure 5:Jaw crusher

The final step in preparation involved crushing the hardened bricks using a jaw crusher, as shown in the Figure 5, to produce aggregates of approximately 20mm in size, as shown in Figure 6

Figure 6: Developed Plastic Aggregates

This size was chosen based on typical industry standards for coarse aggregates used in concrete production. The crushing process was carefully monitored to ensure that the aggregates maintained a uniform size, enhancing the consistency of the concrete mixes in which they would be used.

4.4 Testing and Results

This section presents the testing and results, as tabulated in Table 1, of the artificial lightweight plastic waste aggregate developed in Module 1. Each test was conducted following specific standards to evaluate the performance of the plastic aggregates in comparison with natural aggregates.

Table 1: Tests and results of plastic aggregates, compared with those of natural aggregates

Test Names	**Natural Aggregate**	**Plastic Aggregate**	**Test Standard**
Specific Gravity	2.67	1.75	ASTM C-127
Water Absorption	1.37%	1%	ASTM C-127
Loose bulk Density	1331 kg/m3	848 kg/m3	ASTM C-29
Compacted bulk density	1500 kg/m3	992 kg/m3	ASTM C-29
Voids Content (compacted)	43.70%	43.20%	ASTM C-29
Impact Test	11.57%	1.22%	ASTM C-131
Crushing Strength Test	21.80%	2%	ASTM 5821
Fineness Modulus	7.9	6.5	ASTM C-136
Sulphate Soundness Test	3.30%	2.56%	ASTM C-88
Particle Shape	Angular	Sub Angular	ASTM D4791
Surface Texture	Smooth	Fibrous	ASTM D-3398

Below is a detailed analysis of each test and a comparison of the results.

4.4.1 Results Analysis

4.4.1.1 Impact Test

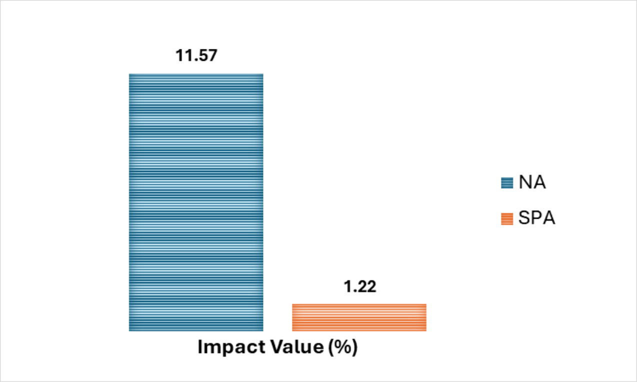

Figure 7: Impact Value Test

The much lower impact value, as shown in the Figure 7, for plastic aggregates suggest they are less susceptible to fracturing under impact compared to natural aggregates. This property could be advantageous in applications where resistance to impact is crucial, such as in lightweight concrete for protective structures.

4.4.1.2 Crushing Strength Test

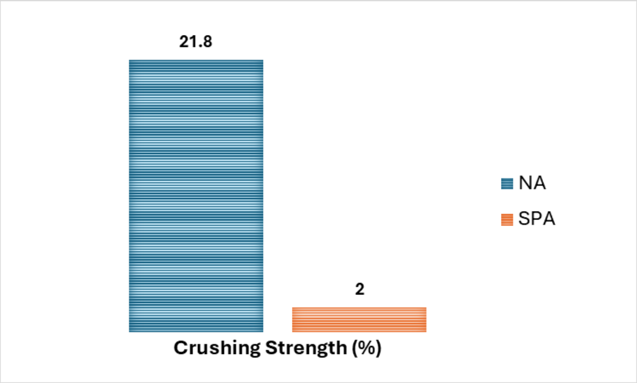

Figure 8: Crushing Value Test

The crushing strength test shows, as in the Figure 8, that plastic aggregates have significantly lower strength compared to natural aggregates. This result indicates that while plastic aggregates are less suitable for applications requiring high compressive strength, they may still be used in non-structural applications where lower strength is permissible.

4.4.1.3 Water Absorption Test

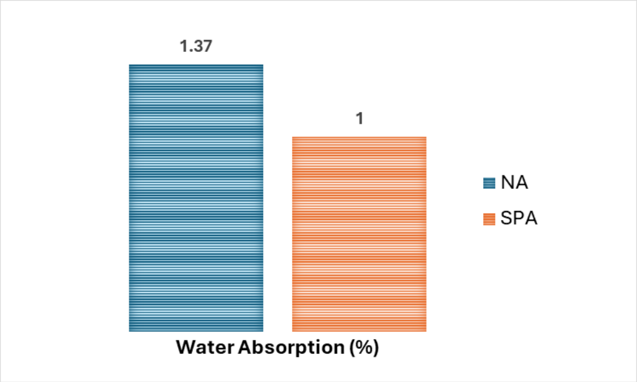

Figure 9: Water Absorption Test of Aggregates

The slightly lower water absorption rate of plastic aggregates, as shown in Figure 9, indicates better resistance to water penetration, which can be beneficial for reducing moisture-induced degradation in concrete.

4.4.1.4 Specific Gravity Test

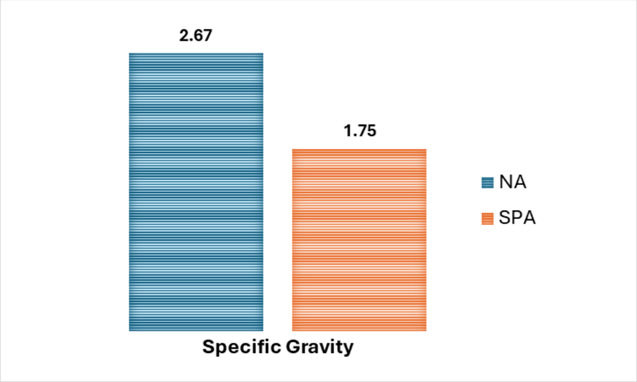

Figure 10: Specific Gravity Test of Aggregates

The lower specific gravity of plastic aggregates, as shown in the Figure 10, contributes to the lighter weight of concrete, making it suitable for applications where reduced weight is beneficial, such as in prefabricated panels and non-load-bearing structures.

4.4.1.5 Bulk Density

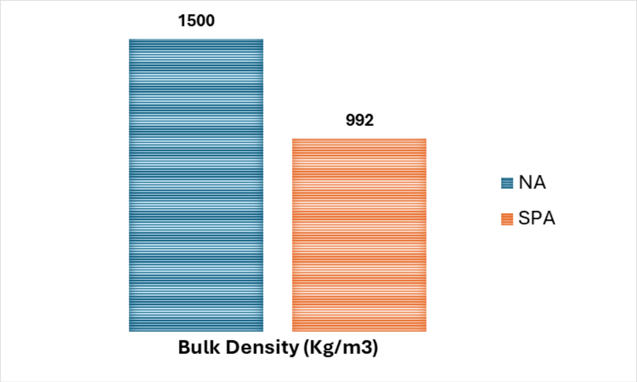

Figure 11: Bulk Density Test of Aggregates

The significantly lower bulk density of plastic aggregates, as shown in the Figure 11, can lead to lighter concrete structures, which reduces the load on foundations and structures, facilitating easier handling and installation.

4.4.1.6 Voids Content

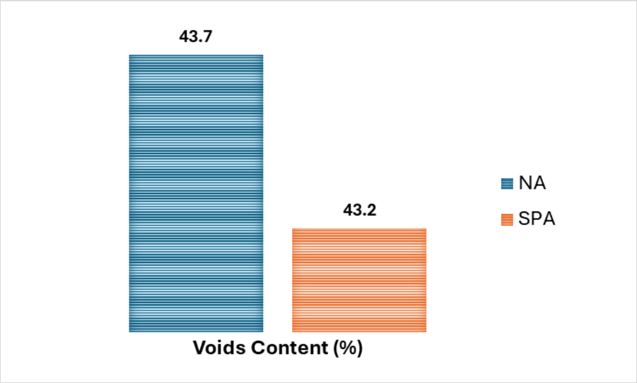

Figure 12: Voids Content Test of Aggregates

The similar voids content, as shown in the Figure 12, indicates that plastic aggregates can potentially provide similar workability as natural aggregates in concrete mixtures.

4.4.1.7 Fineness Modulus

Figure 13: Fineness Modulus of Aggregates

The lower fineness modulus of plastic aggregates suggests a finer aggregate size distribution, as shown in the Figure 13, which can influence the smoothness and finishability of the concrete surface.

4.4.1.8 Sulphate Soundness Test

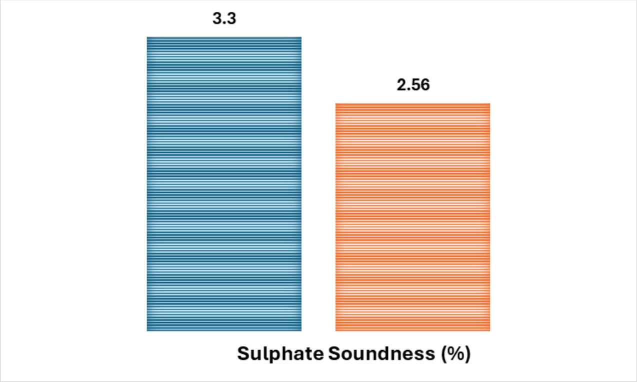

Figure 14: Sulphate Soundness Test

Lower sulphate soundness of plastic aggregates, as shown in the Figure 14, indicates better resistance to weathering and chemical attack, potentially increasing the durability of concrete in aggressive environments.

4.4.1.9 Particle Shape and Surface Texture

4.4.1.9.1 Particle Shape

The plastic aggregate's sub-angular shape, as shown in the Figure 15, compared to the angular shape of natural aggregates can affect the interlocking and thus the strength of the concrete.

Figure 15: Particle Shape of Plastic Aggregates

4.4.1.9.2 Surface Texture

The fibrous texture of plastic aggregates, as shown in the Figure 16, versus the smooth texture of natural aggregates can enhance the bond with the cement paste, potentially compensating for some strength losses due to other properties.

Figure 16: Optical Microscope Image of Plastic Aggregate Showing Surface Texture

4.5 Discussion and Conclusion

4.5.1 Discussion

The experimental results from testing artificial lightweight plastic waste aggregates present a nuanced understanding of their potential applications and limitations within the construction industry. The comparison of key properties between the developed plastic aggregates and natural aggregates reveals several important insights:

1. **Strength Considerations:** The significantly lower crushing strength and impact resistance of plastic aggregates indicate that they may not be suitable for high-load structural applications. However, their improved impact resistance suggests potential for uses in areas where shock absorption is critical, potentially opening avenues in non-structural applications such as insulation panels, lightweight fillers, and decorative elements.

2. **Durability Aspects:** The lower water absorption and sulphate soundness of plastic aggregates compared to natural aggregates suggest better long-term durability under environmental exposures. This characteristic could make them particularly useful in applications susceptible to moisture and chemical attacks, such as in coastal or chemically aggressive environments.
3. **Density and Weight Reduction:** The lower specific gravity and bulk density of the plastic aggregates can be leveraged to produce lighter concrete blocks, which reduces the structural load and enhances energy efficiency in buildings. This feature is especially beneficial for the prefabricated construction industry and in regions where transportation and handling of heavy construction materials pose logistical challenges.
4. **Environmental Impact:** The use of recycled plastic in concrete aligns with global sustainability goals by reducing landfill waste and the consumption of virgin materials. The environmental benefits, coupled with the potential economic advantages of using locally sourced recycled materials, support the integration of sustainable practices in the construction sector.
5. **Workability and Aesthetics:** The finer particle size distribution indicated by the lower fineness modulus of plastic aggregates may influence the workability and finish of concrete. Additionally, the unique sub-angular shape and fibrous texture of plastic aggregates could enhance the visual texture of finished concrete surfaces, offering new design possibilities.

4.5.2 Conclusion

The development of artificial lightweight plastic waste aggregates presents a promising opportunity to address environmental concerns associated with construction materials while also providing a novel solution to the problem of plastic waste. Although the mechanical properties of plastic aggregates do not entirely match those of natural aggregates, their advantageous features such as reduced weight, lower water absorption, and enhanced durability against chemical attacks make them suitable for specific applications.

Further research is required to optimize the properties of plastic aggregates, perhaps through the modification of plastic types, processing techniques, or by blending with other materials to enhance performance. Additionally, exploring the economic viability and market potential of these aggregates will be crucial for their broader adoption.

In conclusion, while the direct replacement of natural aggregates with plastic in load-bearing applications may be limited, the unique properties of plastic aggregates offer significant opportunities in specialized applications. The successful integration of these materials into the construction industry would not only contribute to sustainability but also stimulate innovation in building techniques and materials science. The continued development and refinement of this technology could lead to wider acceptance and regulatory approval, marking a significant step forward in sustainable construction practices.

CHAPTER 5

MODULE 2 : INCORPORATING THE ARTIFICIAL LIGHTWEIGHT PLASTIC WASTE AGGREGATE IN CONCRETE

5.1 Objective and Scope of Module 2

5.1.1 Objectives of the Module 2

The primary objective of Module 2 is to assess the feasibility and effectiveness of incorporating the developed artificial lightweight plastic waste aggregate into concrete mix designs. This module aims to explore and quantify the impacts of plastic aggregate inclusion on the mechanical properties, durability, and environmental performance of concrete. The specific goals include:

1. **Evaluating the Workability of Concrete Mixes:** To determine how the inclusion of plastic waste aggregate affects the workability of concrete, which is critical for ensuring ease of mixing, placing, and finishing in practical applications.
2. **Assessing Mechanical Properties:** To measure key mechanical properties such as compressive strength, tensile strength, and modulus of elasticity in concrete mixes containing varying proportions of plastic waste aggregate. The aim is to identify optimal replacement ratios that maintain or enhance the structural integrity of the concrete.
3. **Analyzing Durability Characteristics:** To evaluate the durability of concrete incorporating plastic waste aggregate, focusing on aspects such as resistance to water penetration, freeze-thaw cycles, and chemical degradation.
4. **Investigating Environmental Benefits:** To quantify the potential environmental advantages of using plastic waste aggregate in concrete, such as reductions in greenhouse gas emissions and natural resource consumption, supporting sustainability in the construction industry.

5.1.2 Scope of the Module 2

Module 2 involves a comprehensive series of experimental tests and trials designed to rigorously evaluate the performance of concrete mixes integrated with plastic waste aggregate. The scope of this module includes:

1. **Mix Design Formulation:** Developing various concrete mix designs that replace traditional natural aggregates with plastic waste aggregates at different percentages. This involves careful adjustment of water-cement ratios and aggregate-cement ratios to optimize the mixes.
2. **Standardized Testing of Concrete Properties:** Conducting a range of standardized tests in accordance with international norms to assess the properties of concrete. Tests include compressive strength tests, split tensile strength tests, modulus of elasticity tests, and slump tests for workability.
3. **Long-term Durability Tests:** Implementing long-term durability tests such as water absorption test to understand how the inclusion of plastic aggregates affects the lifespan and maintenance needs of concrete.
4. **Environmental Impact Assessments:** Evaluating the overall environmental impacts associated with the production and use of concrete containing plastic waste aggregates compared to conventional concrete.

5.2 Materials Used

In Module 2, a range of materials were selected to investigate the viability and performance of concrete mixes incorporating artificial lightweight plastic waste aggregate. Each material was chosen based on its typical use in standard concrete formulations and its ability to provide a baseline for comparing the effects of replacing natural aggregates with plastic ones. Here are the materials used in the experimental trials:

5.2.1 Ordinary Portland Cement (OPC)

OPC was used as the primary binder in the concrete mix due to its widespread availability and well-understood properties. It provides the necessary matrix for the aggregate materials and is crucial for the chemical reactions that set and harden the concrete.

5.2.2 Water

Water was used to hydrate the cement, initiating the chemical reaction necessary for the concrete to set and gain strength. The water-to-cement ratio was carefully measured to optimize the hydration process without compromising the concrete's strength and durability.

5.2.3 Ordinary Sand

Sand served as the fine aggregate in the concrete mixes. Its main role is to fill voids between larger aggregates and help the concrete achieve a uniform and compact structure. The sand used was clean, coarse, and free of impurities to ensure it did not adversely affect the setting time or strength of the concrete.

5.2.4 Natural Aggregates

Natural coarse aggregates were included in the study to provide a control group for comparing the effects of introducing plastic aggregates. These aggregates were typical crushed stones, known for their strength and stability in concrete mixes.

5.2.5 Plastic Aggregates

Developed in Module 1, these artificial lightweight aggregates made from recycled plastic waste were used to replace a portion of the natural aggregates in the concrete mixes. The inclusion levels varied across different batches to assess the impact on various concrete properties.

5.3 Methodology and Mix Designs

5.3.1 Methodology

The experimental methodology for assessing the properties of concrete with varying levels of plastic aggregate replacement was meticulously designed to ensure the accuracy and relevance of the results. For this purpose, concrete cylinders measuring 100 x 200 mm were cast to standardize the testing procedures.

1. **Casting Cylinders:** The concrete mix was poured into molds to form cylinders of 100x200 mm, as shown in the Figure 17, which are commonly used in compressive strength testing. This shape helps in uniformly distributing the load during the test.

Figure 17: Casting of Cylinders

2. **Variation in Plastic Aggregate Replacement:** The core of the experimental design involved varying the replacement levels of plastic aggregate with natural aggregate, as shown in the Figure 18. The replacements were set at 0%, 30%, 50%, 70%, and 100% to thoroughly explore the impact of increasing quantities of plastic aggregates on concrete properties.

Figure 18: Concrete Samples with Varying Replacements

3. **Replication for Statistical Reliability:** To ensure the reliability of the test results, three samples for each level of replacement were cast. This replication allows for the calculation of mean values and provides a robust statistical basis for evaluating the performance of the concrete, minimizing variability in the results.

Figure 19: Three Cylinder Samples for Each Test

4. **Water-Cement Ratio:** All concrete mixes maintained a water-cement ratio of 0.5. This ratio was chosen to optimize the hydration process and ensure a balance between workability and strength of the concrete.
5. **Standard Compliance and Curing:** All casting and curing processes adhered to ASTM standards, specifically designed for concrete testing. All samples were cured for 28 days, a standard duration that allows concrete to achieve approximately 80% of its total strength, thus ensuring that the tests measure near-maximum strength levels.

5.3.2 Mix Designs

The mix designs, as per 1:2:4 mixing ratio, for this study were carefully formulated to evaluate the effects of plastic aggregate replacements on concrete performance. Each mix variation was designed with a specific replacement percentage, following the same water-cement ratio, and mixing procedures to maintain consistency across all samples. The detailed compositions of each mix, reflecting different levels of plastic aggregate replacement, are tabulated in the Table 2. This structured approach allows for a direct comparison between the mixes, offering insights into the optimal use of plastic waste aggregates in concrete production. The results from these mixes will provide crucial data on the viability of recycled plastic in structural applications, potentially leading to more sustainable construction practices.

Table 2: Mix designs for concrete testing

Mix Type	Cement (kg)	Sand (kg)	Natural Aggregate (kg)	Plastic Aggregate (kg)	Water (kg)
Control	0.54	1.1	2.2	0	0.27
Mix 1	0.54	1.1	1.54	0.66	0.27
Mix 2	0.54	1.1	1.1	1.1	0.27
Mix 3	0.54	1.1	0.66	1.54	0.27
Mix 4	0.54	1.1	0	2.2	0.27

5.4 Testing and Results

To comprehensively evaluate the properties of concrete mixes incorporating varying levels of plastic waste aggregate, a series of standardized tests were conducted as tabulated in the

Table 3. These tests were aimed at assessing both the fresh and hardened properties of concrete, ensuring a thorough understanding of the material's performance under different conditions.

Table 3: Results of concrete testing

Concrete Testing	**Plastic Aggregates Replacements**				
Test Names	**0 %**	**30 %**	**50 %**	**70 %**	**100 %**
Slump Cone (mm)	160	123	98	72	45
Compaction Factor	0.96	0.92	0.91	0.88	0.86
Water Absorption (%)	2.44	2.17	1.89	1.68	1.54
Split Tensile (MPa)	0.603	0.402	0.372	0.25	0.22
Flexural Strength (MPa)	4.15	4.1	3.75	3.6	3.3
Ultrasonic Pulse Velocity (km/sec)	4.86	4.66	4.51	4.39	4.14
Compressive Strength (MPa)	22	18.6	15.5	12.9	10.5
Fresh Density (kg/m^3)	2450	2220	2050	1790	1650
Dry Density (kg/m^3)	2375	2090	1990	1730	1580
Modulus of Elasticity (GPa)	22.2	18.44	16.44	13.87	10.3

5.4.1 Results Analysis and Discussion

5.4.1.1 Compressive Strength

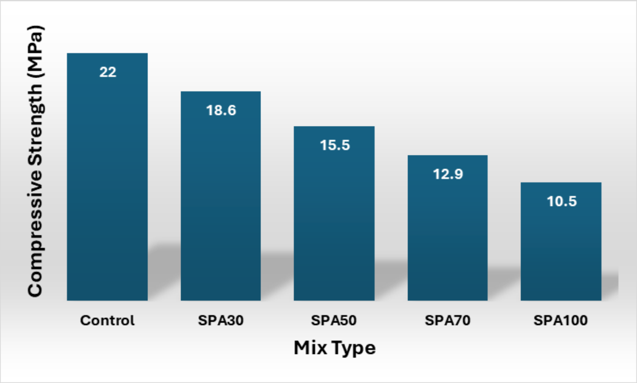

Figure 20: Compressive Strength of Concrete

The compressive strength test shows a clear decreasing trend, as shown in the Figure 20, as the replacement percentage of plastic aggregate increases. At 0% replacement, the compressive strength is the highest at 22 MPa, gradually decreasing to 10.5 MPa at 100% replacement. This indicates that while plastic aggregates can be used in concrete, their inclusion at higher percentages significantly affects the structural strength, making the concrete less suitable for load-bearing applications.

5.4.1.1.1 Discussion

The compressive strength of concrete is a crucial measure of its ability to withstand loads without failing. In our study, we observed a consistent decrease in compressive strength as the percentage of plastic aggregate replacement increased. The compressive strength was highest at 22 MPa with 0% replacement and decreased progressively to 10.5 MPa at 100% replacement. This trend indicates that while plastic aggregates can be incorporated into concrete, their structural contribution is less effective than traditional aggregates.

1. Researchers, del Rey Castillo et al., 2020, observed a similar trend where the compressive strength decreased with increasing plastic aggregate content, highlighting that although plastic aggregates can contribute to lightweight concrete, they compromise strength to a certain extent. Their optimal mix, which included 15% plastic by weight, achieved a compressive strength of 20 MPa, reflecting a balance between weight reduction and strength retention.
2. Hung Vu et al., 2021,also found that increasing the replacement of natural aggregates with recycled aggregates led to a decrease in compressive strength. Their findings suggested that a 10% replacement rate maintained acceptable strength levels, while higher levels led to significant reductions.
3. Gravina et al., 2021,conducted an extensive assessment and developed models to predict the compressive strength of concrete with plastic aggregates. Their analysis highlighted the variability and uncertainty in strength outcomes, suggesting the need for tailored mix designs based on specific aggregate types and contents.
4. D. Y. Osei, 2013, explored the use of recycled concrete aggregate as a complete replacement for natural aggregate and noted reductions in compressive strength that aligned with our findings. The study confirmed that while full replacement is feasible, it significantly affects the strength, highlighting the importance of partial replacement strategies.
5. Sangal, 2018, investigated different plastics' effects on concrete strength and found that while some types of plastic improved tensile strength, they generally reduced compressive

strength. This nuanced view supports the idea that plastic type and processing are critical in determining the outcome in concrete applications.

5.4.1.2 Split Tensile Strength

Similarly, the split tensile strength decreases, as shown in the Figure 21, as the plastic aggregate content increases. The highest tensile strength is observed in the control mix (0% replacement) at 0.603 MPa, decreasing to 0.22 MPa at 100% replacement. This reduction reflects the lower binding capacity of plastic aggregates compared to natural aggregates, affecting the concrete's ability to resist tensile forces.

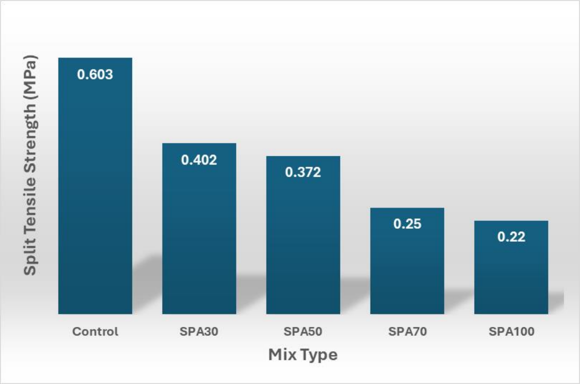

Figure 21:Split Tensile Test of Concrete

5.4.1.2.1 Discussion

Split tensile strength tests are crucial for evaluating the concrete's capacity to resist tensile forces, which is a common mode of failure in concrete structures. In our experiments, the split tensile strength displayed a noticeable decline as the percentage of plastic aggregate increased. Starting from 0.603 MPa with no plastic aggregate, the strength decreased to 0.22 MPa at 100% replacement. This decrease highlights the lower tensile strength characteristics of plastic aggregates compared to natural aggregates.

1. Silva et al., 2015, performed a comprehensive study on recycled aggregates, highlighting that tensile strength typically decreases with higher replacement levels, regardless of the aggregate's quality or origin. Their findings align with our observations that higher plastic content correlates with reduced tensile performance.
2. Sangal, 2018, explored the impact of various plastic types on concrete strength. The study noted that while some plastic types could enhance tensile strength slightly, they generally

led to a reduction in compressive strength, suggesting a complex interaction between plastic aggregate properties and concrete strength.

3. Castillo et al., 2020, investigated lightweight concrete with plastic aggregate and found similar trends where increases in plastic aggregate reduced tensile strength, although certain mix designs mitigated these effects to some extent.
4. Jaivignesh & Sofi, 2017, noted that the replacement of natural aggregates with plastic significantly affects both compressive and tensile strengths, which they attributed to the poor bonding characteristics of plastic aggregates within the cement matrix.
5. Raman, 2017, examined the use of plastic aggregates in self-compacting concrete and observed that while up to 30% replacement did not significantly alter compressive strength, tensile strength showed a more pronounced decline beyond 10% replacement.

5.4.1.3 Modulus of Elasticity

The modulus of elasticity results also diminishes, as shown in the Figure 22, with increased plastic aggregate replacement, from 22.2 GPa with no replacement to 10.3 GPa at 100% replacement. The decrease in stiffness and elastic response is significant, particularly at higher replacement levels, affecting the concrete's deformation characteristics under load.

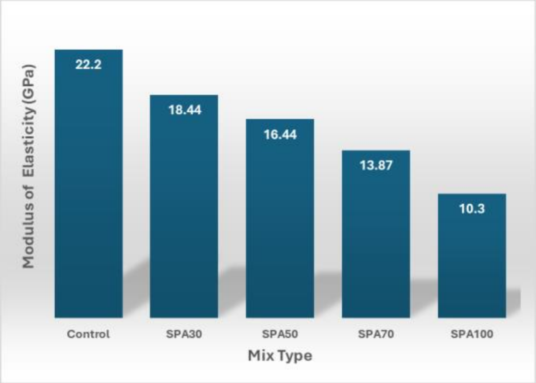

Figure 22:The modulus of elasticity Test

5.4.1.3.1 Discussion

The modulus of elasticity is a fundamental property of concrete that describes its tendency to deform elastically under load. It is closely linked to the stiffness of the material and its ability to distribute loads effectively within a structure. In our study, the modulus of elasticity showed a consistent decline as the replacement of natural aggregates with plastic aggregates increased. The results ranged from 22.2 GPa at 0% replacement to 10.3 GPa at 100% replacement, reflecting a substantial reduction in stiffness with higher plastic content.

1. Silva et al., 2015, investigated the modulus of elasticity in concrete with recycled aggregates and observed that even a partial replacement leads to a noticeable reduction in stiffness. They found that the modulus of elasticity could decrease by up to 30% with 50% replacement, indicating a similar trend to our findings.
2. Hung Vu et al., 2021, explored the impact of mixed plastic aggregates on concrete and reported reductions in the modulus of elasticity, particularly noting that changes were more pronounced at higher plastic percentages. This study corroborates the general trend observed in our results.
3. Raman, 2017, examined plastic aggregate use in self-compacting concrete and found that the modulus of elasticity decreased with increasing plastic content. This finding highlights the broader applicability of our results across different types of concrete mixes.
4. Gravina et al., 2021, developed models to predict the modulus of elasticity in concrete with plastic aggregates. Their models help understand the quantitative impact of aggregate replacement on concrete stiffness, offering a predictive tool that aligns with the trends observed in our experimental results.

5.4.1.4 Flexural Strength

Flexural strength tests reveal a gradual decline from 4.15 MPa at 0% replacement to 3.3 MPa at 100% replacement as shown in the Figure 23. Although the decrease is not as sharp as in other strength measures, it still suggests a reduction in the material's capacity to withstand bending stresses.

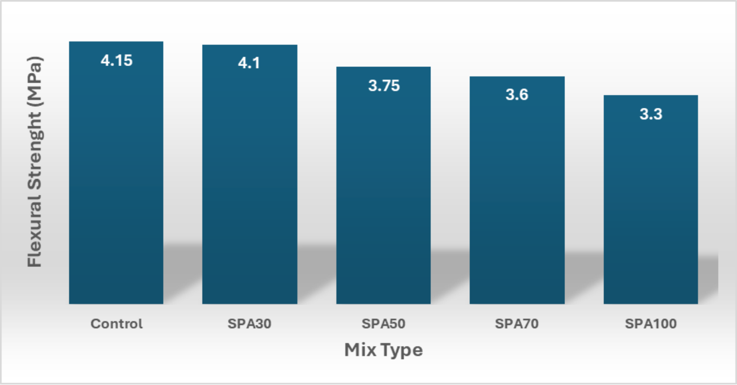

Figure 23:Flexural Strength Test

5.4.1.4.1 Discussion

Flexural strength is a critical parameter for concrete as it reflects the material's ability to resist bending or breaking under load. In our project, we observed that flexural strength generally decreased as the replacement level of natural aggregates with plastic aggregates increased. At 0% replacement, the flexural strength was the highest at 4.15 MPa, progressively decreasing to 3.3 MPa at 100% replacement. This trend indicates that while plastic aggregates can be utilized in concrete, their inclusion reduces the material's bending strength, which could limit its use in structural applications where flexural performance is critical.

1. Atoyebi & Sadiq, 2018, conducted studies on concrete elements reinforced with waste glass particles, which, similar to plastic, serve as a partial replacement for fine aggregate. They observed a decrease in flexural strength with higher levels of replacement, which aligns with our findings concerning plastic aggregates. This suggests a common trend where alternative aggregates may compromise flexural strength due to differences in material properties compared to traditional aggregates.
2. Fakhruddin et al., 2021, explored the flexural behavior of reinforced concrete beams using PET plastic as a partial replacement for coarse aggregate. They reported a reduction in flexural strength, which supports our observations that increased plastic content typically leads to weaker flexural performance.
3. Raja et al., 2016, investigated the flexural behavior of concrete partially replacing fine aggregate with E-plastic waste. They noted similar trends where increased plastic content led to decreased flexural strength, underlining the challenges associated with using high levels of plastic aggregates in load-bearing applications.

4. Sudarmono et al., 2022, studied the flexural strength of concrete with coarse aggregate replacement using waste plastic bags. Their findings indicated that a moderate replacement level could optimize the flexural strength, suggesting that the right proportion of plastic aggregate might mitigate strength reductions.

5.4.1.5 Dry Density

Dry density decreases notably from 2375 kg/m^3 at 0% replacement to 1580 kg/m^3 at 100% replacement, as shown in the Figure 24, illustrating the lightweight nature of plastic aggregates. This property is beneficial for reducing the overall weight of structural elements, which could be advantageous for certain architectural applications.

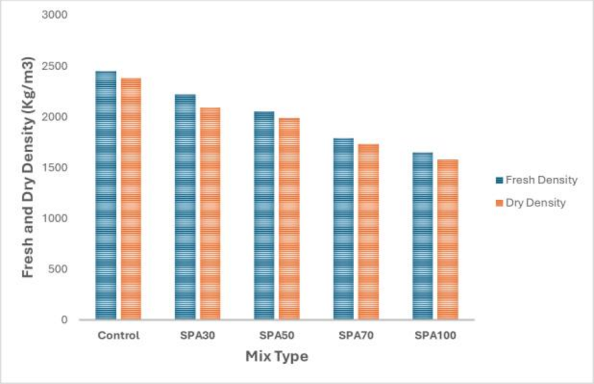

Figure 24: Dry and Fresh Density of Concrete

5.4.1.5.1 Discussion

Dry density is an important measure of concrete's weight per unit volume, which affects not only the load-bearing capacity but also influences the handling, transportation, and application of concrete in construction. In our study, dry density showed a decreasing trend with increasing plastic aggregate replacement, dropping from 2375 kg/m^3 at 0% replacement to 1580 kg/m^3 at 100% replacement. This reduction in dry density is advantageous for applications requiring lightweight concrete but could pose challenges in structural applications where higher density is often equated with strength and durability.

1. Castillo et al., 2020, explored the use of plastic waste as an aggregate in concrete and observed similar reductions in dry density with increasing plastic content. Their study highlighted that while such reductions can benefit the production of lightweight concrete, they often require adjustments in mix design to maintain adequate strength and stability.

2. AbdelMoti & Mustafaa, 2022, found that incorporating polypropylene plastic pellets as a partial replacement for fine aggregate significantly reduced the dry density of concrete. Their findings corroborate the notion that plastic aggregates contribute to lighter concrete, which can be beneficial in reducing structural loads.
3. Senthil Kumar & Baskar, 2015, also observed a decrease in dry density with the incorporation of E-plastic waste in concrete. They noted that the lightweight nature of the resulting concrete might be advantageous in structures where reduced weight is desired, such as in seismic zones.
4. Khalil & Mahdi, 2020, investigated the use of mixed plastic waste as a coarse aggregate replacement and found that increased plastic content resulted in lower dry density. They suggested that while this could limit the use of such concrete in structural applications, it offers benefits in terms of insulation and reduced structural load.

5.4.1.6 Fresh Density

Fresh density measurements follow a similar pattern to dry density, as shown in the Figure 24, decreasing from 2450 kg/m³ at 0% replacement to 1650 kg/m³ at 100% replacement. The reduced density indicates lighter concrete, which could improve handling and transportation costs and reduce the structural load.

5.4.1.6.1 Discussion

Fresh density is an essential property of concrete that indicates the unit weight of the mixture before it sets and hardens. It is critical for assessing the material's load-bearing capabilities and for determining its suitability in various construction scenarios. Our findings showed a marked decrease in fresh density with increasing percentages of plastic aggregate replacement: from 2450 kg/m³ at 0% replacement to 1650 kg/m³ at 100% replacement. This reduction is indicative of the lighter nature of plastic aggregates compared to traditional aggregates, offering potential benefits for applications requiring reduced weight.

1. Castillo et al., 2020, explored lightweight concrete by incorporating plastic aggregates and similarly noted a decrease in fresh density with higher plastic content. Their study aligns with our results, reinforcing the concept that plastic aggregates contribute significantly to reducing concrete weight.

2. Hama & Hilal, 2018, found that the incorporation of plastic as a partial substitute for fine or coarse aggregate in concrete reduces fresh density. Their findings further confirm that smaller plastic particles tend to decrease the density more significantly than larger ones, impacting the overall workability and weight of the concrete.
3. AbdelMoti & Mustafaa, 2022, observed that using polypropylene plastic pellets as a partial replacement for fine aggregate resulted in a decrease in fresh density, highlighting the potential of plastic aggregates to lighten concrete mixes.
4. Islam, 2015, studied the effects of using polyethylene terephthalate (PET) as an aggregate replacement and noted a significant reduction in concrete density, emphasizing the suitability of PET in producing lightweight concrete for non-load bearing structures.
5. Kou et al., 2009, reported on the use of PVC granules from scraped pipes as aggregates and found similar reductions in fresh density. Their study demonstrated the beneficial effects of using recycled plastic in lightweight concrete formulations.

5.4.1.7 Water Absorption

Water absorption decreases from 2.44% at 0% replacement to 1.54% at 100% replacement. This reduction, as shown in the Figure 25, is favorable as it suggests lower porosity and potentially higher impermeability, which could enhance the durability of concrete in moisture-laden environments.

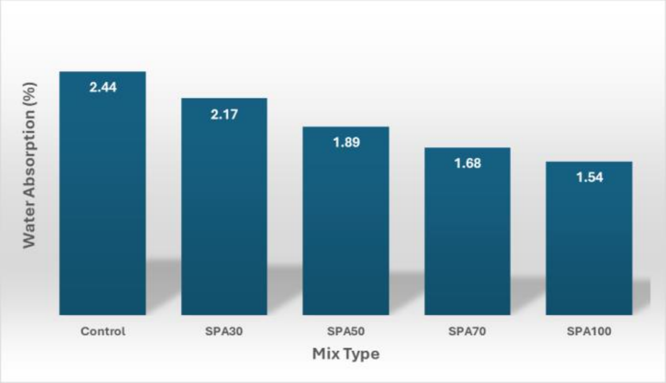

Figure 25: Water absorption test of concrete

5.4.1.7.1 Discussion

Water absorption tests are critical for assessing the porosity and permeability of concrete, which in turn influence its durability and resistance to environmental conditions. In our study, water absorption decreased as the percentage of plastic aggregate replacement increased, from 2.44% at 0% replacement to 1.54% at 100% replacement. This trend suggests that plastic aggregates, due to their inherently lower porosity compared to natural aggregates, contribute to a reduction in the overall water absorption of the concrete.

1. Barbudo et al., 2013, investigated the use of recycled aggregates in concrete, highlighting their typically higher water absorption rates compared to natural aggregates. They found that incorporating water-reducing admixtures could mitigate these effects by improving the concrete's compactness, which aligns with our findings on the beneficial impact of lower water absorption with plastic aggregates.
2. Joseph et al., 2015, explored the variability of water absorption in recycled concrete aggregates, noting that higher heterogeneity in recycled materials often leads to increased water absorption. Their study supports the concept that material consistency plays a significant role in influencing the water absorption characteristics of concrete.
3. Kim et al., 2020, discussed the high-water absorption of lightweight aggregates and its impact on concrete workability. They recommended prewetting aggregates to manage this issue, suggesting a technique that could be applicable for managing the water absorption traits of plastic aggregates in concrete.
4. Bao et al., 2020, examined the effects of recycled concrete aggregates on water and chloride transport in concrete. They found that higher replacement ratios increased the water absorption, which contrasts with our findings, highlighting the unique properties of plastic aggregates compared to other types of recycled materials.
5. Cui et al., 2015, analyzed the influence of water absorption of recycled aggregates on the properties of concrete, showing that surface modification techniques could effectively reduce water absorption rates. This approach could potentially be adapted to enhance the performance of plastic aggregates in concrete.

5.4.1.8 Slump Cone

The slump test results decrease from 160 mm at 0% replacement to 45 mm at 100% replacement, as shown in the Figure 26, indicating a reduction in workability with higher plastic content. This could complicate concrete placement and finishing in practical applications.

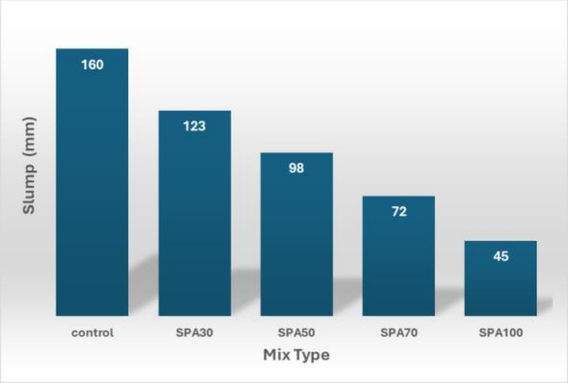

Figure 26: Slump Test

5.4.1.8.1 Discussion

The slump cone test is an essential measure of the workability of concrete, indicating its ease of placement, consolidation, and finishing. Our results revealed a notable decrease in slump values with increasing plastic aggregate content: from 160 mm at 0% replacement to 45 mm at 100% replacement. This trend suggests that incorporating higher percentages of plastic aggregates significantly affects the fluidity and workability of the concrete mix, potentially complicating its application in scenarios requiring high workability.

1. Umbarani et al., 2020, conducted extensive workability tests, including slump cone tests, on concrete mixes with varying percentages of waste Polyethylene Terephthalate (PET) plastic. They found consistent reductions in slump values with increased plastic content, highlighting the challenges in maintaining workability in such mixes.
2. Castillo et al., 2020, explored the use of plastic waste as an aggregate in concrete and observed similar reductions in fresh density and slump with increasing plastic content. Their study provides insights into the trade-offs between reducing concrete weight and maintaining workable properties.
3. AbdelMoti & Mustafaa, 2022, investigated the effects of using polypropylene plastic pellets as a partial replacement for fine aggregate on the fresh density and workability of concrete, noting significant impacts on slump results.

5.4.1.9 Compaction Factor

The compaction factor decreases from 0.96 at 0% replacement to 0.86 at 100% replacement, also reflecting reduced workability. This measurement correlates with the slump test results, suggesting that higher plastic aggregate content makes the concrete mix stiffer and less workable.

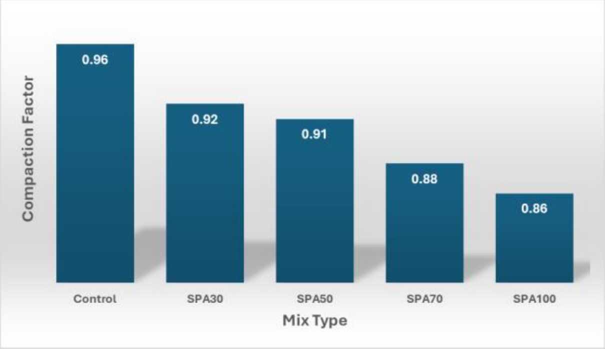

Figure 27: Compaction Factor test

5.4.1.9.1 Discussion

The compaction factor test is crucial for assessing the compactability of concrete, which influences the density and homogeneity of the finished product. In our study, the compaction factor decreased as the plastic aggregate content increased, from 0.96 at 0% replacement to 0.86 at 100% replacement. This trend suggests that higher levels of plastic aggregate incorporation reduce the concrete's ability to compact effectively under its own weight, possibly due to the differing physical characteristics of plastic compared to traditional aggregates.

1. Raman, 2017, investigated the compaction characteristics of self-compacting concrete using plastic aggregate and found similar challenges with decreasing compaction as plastic content increased. The study highlighted the need for modifying mix designs to improve the compactability of concrete with high plastic content.
2. Hama & Hilal, 2018), also reported on the fresh properties of self-compacting concrete containing plastic waste as a partial replacement for sand. Their findings indicated that while certain properties like slump were maintained, the overall workability and compaction factor tended to decrease with higher plastic content.
3. Vaishnava Kumar et al., 2022, explored the use of light expanded clay aggregate as a replacement for coarse aggregate in self-compacting concrete. They observed that

increasing the aggregate content generally decreased the compaction factor, a result aligning with our findings regarding plastic aggregates.

4. Abdulqadir & Mohammed, 2023, examined the impact of different types of plastic aggregates on the fresh properties of self-compacting concrete. Their research demonstrated that variations in plastic aggregate types could influence the compaction factor, with some types performing better than others.

5.4.1.10 Ultrasonic Pulse Velocity

Ultrasonic pulse velocity results show a decreasing trend, as shown in the Figure 28, from 4.86 km/sec at 0% replacement to 4.14 km/sec at 100% replacement. This reduction might indicate a decrease in density and uniformity of the concrete matrix as plastic content increases.

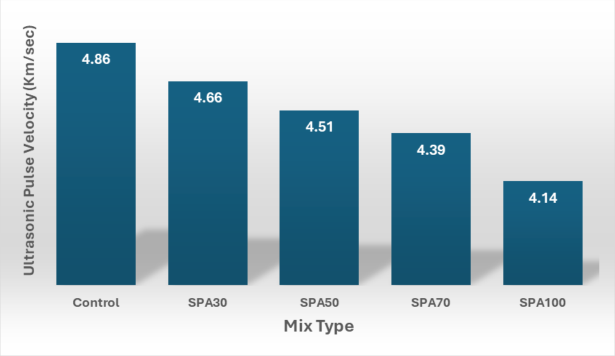

Figure 28: Ultrasonic pulse velocity test

5.4.1.10.1 Discussion

Ultrasonic pulse velocity (UPV) is a non-destructive test used to evaluate the quality and uniformity of concrete. It measures the speed at which an ultrasonic pulse travels through the material, which is indicative of its density, homogeneity, and elastic properties. In our study, the UPV values decreased as the plastic aggregate content increased, from 4.86 km/sec at 0% replacement to 4.14 km/sec at 100% replacement. This reduction suggests that the incorporation of plastic aggregates affects the material's density and uniformity, potentially indicating variations in structural integrity.

1. Silva et al., 2015, explored the impact of recycled aggregates on UPV and found that higher contents of such aggregates typically lead to lower UPV values, which they attributed to

the less dense and more heterogeneous nature of recycled materials compared to natural aggregates. This aligns with our findings on the impact of plastic aggregates on UPV.

2. Mohammad & Mohammed, 2020, investigated high-strength concrete with PVC waste aggregate and observed a decrease in UPV with increased PVC content, similar to our results with plastic aggregates. They noted that even small changes in aggregate type can significantly impact UPV, emphasizing the sensitivity of this measurement to material composition.
3. Mohammed et al., 2021, conducted a detailed experimental study on concrete made with recycled brick aggregate and observed that UPV is influenced by the quality of aggregates used. Their findings support the idea that lower UPV in concrete with recycled or alternative aggregates is often due to reduced density and increased porosity.
4. Hong et al., 2014, used UPV to estimate the compressive strength of recycled aggregate concrete and found a clear correlation between lower UPV values and reduced compressive strength, which is consistent with our observations of reduced UPV correlating with higher plastic aggregate content.
5. Bogas et al., 2013, evaluated the compressive strength of structural lightweight concrete using UPV and also noted that UPV is an effective predictor of material properties, especially in concretes with varying densities and aggregate types, supporting the relevance of our UPV findings.

5.5 Conclusion

Module 2 of this project focused on the incorporation of artificial lightweight plastic waste aggregate into concrete mix designs and the subsequent evaluation of various properties of the resulting concrete. The comprehensive series of tests conducted provided valuable insights into how replacing natural aggregates with plastic aggregates impacts concrete's mechanical properties, durability, and overall performance.

5.5.1 Key Findings

1. **Mechanical Properties:** The tests revealed a general decline in mechanical properties such as compressive strength, split tensile strength, and modulus of elasticity as the percentage of plastic aggregate replacement increased. This indicates that while plastic aggregates can

be used in concrete, their inclusion at higher percentages significantly affects the structural integrity of the material.

2. **Durability:** Despite the reduction in some mechanical properties, the use of plastic aggregates improved certain durability aspects of concrete. Notably, the water absorption tests showed a decrease in water permeability with higher plastic content, suggesting potential benefits in moisture resistance and durability against environmental exposure.
3. **Workability:** The workability of concrete, as evidenced by the slump and compaction factor tests, was adversely affected by the increased inclusion of plastic aggregates. This underscores the need for adjustments in the mix design or the addition of specific admixtures to enhance workability when using high levels of plastic aggregates.
4. **Density:** The reduction in both fresh and dry densities of concrete with the inclusion of plastic aggregates offers potential advantages in applications requiring lightweight materials, such as in non-load-bearing structures or where reduced weight is beneficial for ease of handling and decreased transportation costs.

5.5.2 Comparative Analysis with Other Studies

The trends observed in this project are generally consistent with findings from other researchers who have explored the use of various types of recycled aggregates in concrete. While the benefits of using sustainable materials like plastic waste in concrete are clear, particularly in terms of environmental impact and resource conservation, the challenges in maintaining the mechanical performance and workability are also evident.

5.5.3 Future Directions

To optimize the use of plastic aggregates in concrete, further research is needed to enhance the interfacial bonding between the plastic aggregates and the cement matrix. Techniques such as surface treatment of the aggregates or the use of innovative admixtures could improve the mechanical properties and workability of the concrete. Additionally, exploring hybrid mix designs that combine plastic aggregates with other types of recycled or natural aggregates might provide a balance between sustainability and performance.

5.5.4 Overall Implications

The findings from Module 2 contribute to a broader understanding of the potential and limitations of using recycled plastic waste as an aggregate in concrete. By advancing knowledge in this area, this research supports the development of more sustainable construction materials, aligning with global efforts to reduce waste and minimize the environmental footprint of the construction industry. Future developments in this field will likely focus on refining the properties of plastic-aggregate concrete to meet the demanding specifications of modern construction applications while continuing to promote sustainability.

CHAPTER 6

MODULE 3: DEVELOPMENT OF SUSTAINABLE LIGHTWEIGHT CONCRETE BLOCKS

6.1 Objectives and Scope of Module 3

6.1.1 Objectives of Module 3

The primary objective of Module 3 is to utilize the concrete mixes developed in Module 2, incorporating artificial lightweight plastic waste aggregate, to produce sustainable lightweight concrete blocks. This module aims to translate the findings from earlier experiments into practical applications by creating concrete blocks that are not only structurally sound but also environmentally friendly. The specific goals include:

1. **Production of Lightweight Blocks:** To manufacture concrete blocks that influence the reduced weight properties of plastic aggregate incorporated concrete, potentially reducing structural loads and enhancing energy efficiency in buildings.
2. **Evaluation of Structural and Non-structural Applications:** To assess the suitability of these blocks for various construction purposes, both structural and non-structural, to determine their performance in real-world scenarios.
3. **Enhancement of Environmental Sustainability:** To contribute to the construction industry's sustainability by using recycled materials, thereby reducing waste and the consumption of natural resources.
4. **Market Viability Assessment:** To evaluate the economic feasibility and market potential of these sustainable lightweight blocks, identifying barriers to market entry and opportunities for commercialization.

6.1.2 Scope of Module 3

Module 3 encompasses a comprehensive range of activities designed to achieve the stated objectives effectively:

1. **Block Manufacturing:** Developing a production process for the lightweight concrete blocks, including the formulation of block dimensions, mix proportions, and curing techniques based on the optimal mix designs identified in Module 2.
2. **Performance Testing:** Conducting rigorous testing of the blocks to assess their mechanical properties (such as compressive strength and durability), thermal insulation characteristics, and overall structural integrity.
3. **Environmental Impact Analysis:** Performing detailed life cycle assessments (LCAs) to quantify the environmental benefits of using recycled plastic in concrete block production, including reductions in greenhouse gas emissions and resource consumption.
4. **Market Analysis:** Analyzing the market demand for lightweight sustainable building materials, identifying potential customers and partners, and developing strategies for scaling production and distribution.

6.2 Material Used and Methodology

6.2.1 Materials Used

In Module 3, the concrete blocks were manufactured using a select group of materials that were consistent with the mixes tested in previous modules, ensuring compatibility and the ability to directly compare results. The materials used include:

1. **Sand:** Fine aggregate that fills voids between coarse aggregates and helps to produce a dense and compact concrete mix.
2. **Cement**: Ordinary Portland Cement (OPC) was used as the primary binder to facilitate the chemical reaction that hardens the mix into a solid mass.
3. **Water:** Essential for the hydration of cement, the quantity of water was carefully measured to achieve the desired workability without compromising the strength and durability of the blocks.
4. **Natural Aggregates:** Coarse aggregates provided the necessary bulk and helped define the structural integrity of the concrete blocks.
5. **Plastic Aggregates:** Crushed to a size of 10mm, these recycled aggregates were used to replace natural aggregates at various percentages to evaluate their effect on the properties of the blocks.

6.2.2 Methodology

The methodology for creating the sustainable lightweight concrete blocks was meticulously planned to ensure the production of high-quality blocks suitable for testing and potential commercial use. The process involved:

1. **Mix Design:** The concrete was mixed using a standard 1:2:4 mixing ratio by volume, which is a common mix for non-load-bearing applications where lower compressive strength is acceptable.
2. **Sample Preparation:** Five samples of solid concrete blocks measuring 300 x 100 x 200 mm, as shown in the Figure 29, were cast for each replacement level (0%, 30%, 50%, 70%, and 100%). This allowed for comprehensive testing and comparison across different levels of plastic aggregate content.
3. **Mixing Process:** The components were mixed thoroughly to ensure uniform distribution of materials, particularly focusing on achieving a consistent dispersion of plastic aggregates within the mix.
4. **Casting:** The concrete mix was poured into molds corresponding to the desired block dimensions. Each mold was vibrated properly to ensure there were no air pockets and that the mixture settled evenly.
5. **Curing:** Following casting, the blocks were demolded and subjected to standard curing conditions for 28 days to achieve optimal strength development. The curing process was critical, especially for higher plastic aggregate content mixes, to ensure maximum hardness and durability.

Figure 29: Concrete Block Incorporating Plastic Aggregates

6.3 Mix Designs

The mix designs, as tabulated in the Table 4, for the concrete blocks in Module 3 was carefully formulated to assess the impact of replacing natural aggregates with plastic aggregates on the physical and mechanical properties of concrete. Using a standard 1:2:4 mixing ratio by volume (cement:sand:aggregate), this design was chosen to balance ease of mixing, sufficient workability, and adequate strength for non-structural applications. Each mix was prepared with different replacement levels of plastic aggregates—0%, 30%, 50%, 70%, and 100%—to explore a wide range of material characteristics and behaviors.

Table 4: Mix Designs for Concrete Blocks

Mix Type	Cement (kg)	Sand (kg)	Natural Aggregate (kg)	Plastic Aggregate (kg)	Water (kg)
Control	2.06	4.12	8.24	0	1.03
Mix 1	2.06	4.12	5.77	2.47	1.03
Mix 2	2.06	4.12	4.125	4.125	1.03
Mix 3	2.06	4.12	2.47	5.77	1.03
Mix 4	2.06	4.12	0	8.24	1.03

6.4 Testing and Results

6.4.1 Compressive Strength

In Module 3, the compressive strength of concrete blocks made with varying percentages of plastic aggregate replacement was tested to assess their structural integrity. The results, as shown in the Figure 30, shows a trend of decreasing compressive strength with increasing plastic content.

This trend reflects the expected decrease in mechanical properties as the more deformable and less stiff plastic aggregates replace the harder and more robust natural aggregates. The reduction in strength highlights the influence of aggregate type on the overall structural performance of concrete blocks.

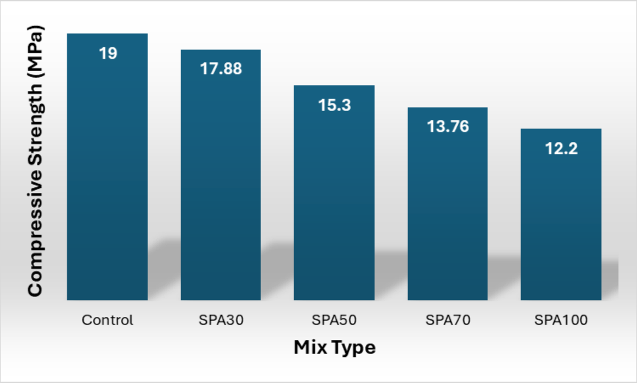

Figure 30: Compressive Strength Test of Blocks

6.4.1.1 Analysis and Discussion

Comparative analysis with other researchers who have explored the incorporation of plastic aggregates in concrete blocks provides broader context to our findings:

1. (Ohemeng, 2015), found that the compressive strength of concrete pavement blocks decreased as plastic content increased, supporting our observations of strength reduction with higher plastic aggregate contents. Their study emphasizes the statistical significance of aggregate type on block strength.
2. (Vanitha et al., 2015), also reported a decrease in compressive strength in their concrete blocks with increased plastic waste, which is consistent with our findings of strength reduction at higher replacement levels.
3. (Ling, 2011), conducted tests on rubberized concrete blocks and observed similar trends where increased lightweight material led to reduced compressive strength. This parallel suggests a common impact of alternative, less dense aggregates on concrete strength.
4. (Deng et al., 2018), used deep learning models to predict the strength of recycled aggregate concrete and demonstrated that increased recycled material generally leads to lower strength, which supports our results and suggests broader applicability of predictive modeling in assessing material substitutions.
5. Supit & Priyono, 2023, explored the use of modified plastic waste in concrete blocks and found decreased compressive strength with increased plastic aggregate, especially when combined with certain types of sand. This study underlines the complex interactions between plastic types and other concrete components affecting strength.

6.4.2 Thermal Conductivity Test

The thermal conductivity test for the concrete blocks made with plastic aggregate replacements provided valuable insights into the insulation properties of the materials used. The test results showed an 8% improvement in thermal insulation across the range of plastic aggregate replacements. This increase in insulation capability indicates that the inclusion of plastic aggregates enhances the thermal resistance of the concrete blocks, making them more suitable for applications where thermal insulation is a critical factor.

6.4.2.1 Analysis and Discussion

The improved insulation performance can be attributed to the inherent properties of plastic aggregates, which generally have lower thermal conductivity compared to natural aggregates. This characteristic of plastic contributes to a less conductive concrete matrix, thereby enhancing the block's ability to resist heat flow. The presence of plastic aggregates introduces more air voids and discontinuities within the concrete, further reducing the material's overall thermal conductivity.

1. Wang et al., 2016, on lightweight concrete also observed improved insulation properties when traditional aggregates were replaced with lighter materials, such as plastics. Their findings confirm that lighter aggregates contribute to lower thermal conductivity, aligning with the results from our tests.
2. Khatib, 2015, focused on the use of recycled plastic in concrete and found similar improvements in thermal resistance, further supporting the potential for using plastic aggregates to enhance insulation properties in building materials.
3. Jin, 2017, explored the thermal properties of concrete incorporating different types of recycled materials and noted that materials with lower bulk density, such as plastics, significantly decrease thermal conductivity. This observation underlines the relevance of our findings in a broader context.

6.5 Market Feasibility Study

The market feasibility study for sustainable lightweight concrete blocks incorporating artificial lightweight plastic waste aggregate focuses on the potential market applications and the economic viability of these blocks within the construction industry in Pakistan. This study explores the target applications, analyzes market demand, assesses cost-effectiveness, and outlines strategies for commercialization and market entry.

6.5.1 Target Applications and Potential Market

Sustainable lightweight concrete blocks have significant potential in various sectors of the Pakistani construction industry, especially in urban development projects that prioritize environmental sustainability and energy efficiency. Potential applications include residential and commercial buildings, particularly in non-load-bearing structures such as partition walls, where the lightweight and insulation properties of the blocks can be fully utilized. Recent infrastructure projects in Pakistan have begun to adopt green building materials as part of a broader push towards sustainability, suggesting a growing market for innovative construction materials like those developed in this project.

6.5.2 Market Demand and Cost-Effectiveness

There is an increasing demand for construction materials that offer both environmental benefits and cost savings over the lifecycle of a building. The incorporation of recycled plastic not only helps reduce waste but also lowers the overall cost of materials by substituting more expensive or scarce natural resources. A study by Khan et al., 2015 evaluated the feasibility of using recycled plastics for energy production, highlighting the economic benefits of plastic recycling in Lahore, Pakistan, which can be paralleled in the construction sector for material cost reductions.

6.5.3 Competitive Positioning

In the competitive landscape, these sustainable blocks must be positioned as both a high-performance and environmentally friendly alternative to traditional concrete blocks. The unique selling proposition revolves around their lower environmental impact, enhanced insulation properties, and contribution to green building certifications, which can attract developers and contractors looking to enhance their sustainability credentials.

6.6 Conclusion

Module 3 has demonstrated that it is technically feasible and economically promising to produce and utilize sustainable lightweight concrete blocks made with recycled plastic aggregate in Pakistan. The successful implementation of this module not only provides a viable pathway for addressing plastic waste management challenges but also contributes to the development of sustainable building materials that can reduce the environmental footprint of the construction industry. Moving forward, the project's findings can serve as a benchmark for similar sustainability initiatives globally, promoting broader adoption of recycled materials in construction and fostering innovation in green building technologies.

6.6.1 Achievements

1. **Successful Block Production**: The project successfully manufactured concrete blocks using varying percentages of plastic aggregate replacements, ranging from 0% to 100%. These blocks were rigorously tested for compressive strength and thermal conductivity, affirming that they meet certain usability and performance criteria.
2. **Improved Insulation Properties**: One of the standout features of the developed blocks is their enhanced thermal insulation properties, attributed to the lower thermal conductivity of plastic aggregates. This improvement suggests that the blocks can contribute significantly to energy-efficient building practices, particularly in Pakistan's diverse climatic zones.
3. **Market Feasibility and Commercial Viability:** The market feasibility study identified substantial potential for these sustainable blocks in Pakistan’s construction market, especially in light of increasing environmental awareness and regulatory support for green building materials. The analysis highlighted the economic benefits, competitive positioning, and strategies for market entry, establishing a solid foundation for the commercialization of these blocks.

6.6.2 Challenges and Opportunities:

1. **Performance Under Load:** While the blocks exhibit favorable properties such as reduced weight and increased insulation, the decrease in compressive strength with higher levels of plastic replacement presents challenges for load-bearing applications. Future research could focus on optimizing the mix design to improve the strength characteristics without compromising the environmental benefits.
2. **Scaling Production:** Transitioning from pilot-scale production to commercial volumes requires careful planning and investment in manufacturing facilities. It also involves

continuous engagement with stakeholders across the construction industry to ensure that the blocks meet both market expectations and regulatory standards.

CHAPTER 7

CONCLUSION & RECOMMENDATIONS

7.1 Conclusion

This project successfully demonstrated the development and evaluation of sustainable lightweight concrete blocks incorporating artificial lightweight plastic waste aggregate. Through a systematic approach over three distinct modules, we explored the properties, viability, and application of using recycled plastic in concrete production.

Key Conclusions:

1. **Effective Utilization of Plastic Waste:** The project validated that plastic waste could be effectively utilized as an aggregate in concrete, contributing to environmental sustainability by reducing landfill waste and the depletion of natural resources.
2. **Impact on Concrete Properties:** The inclusion of plastic aggregates influenced various concrete properties, including reduced density and improved thermal insulation, although at the cost of decreased mechanical strengths such as compressive and tensile strengths.
3. **Market Viability:** The market feasibility study indicated a positive outlook for the adoption of sustainable concrete blocks in Pakistan's construction market, especially given the growing emphasis on sustainable construction practices.

7.2 Recommendations

To build on the findings of this project and promote broader adoption of sustainable building materials, the following recommendations are proposed:

1. **Optimization of Mix Designs:** Continue research to optimize concrete mix designs that incorporate plastic aggregates, aiming to improve the mechanical strengths while maintaining or enhancing other beneficial properties like thermal insulation and reduced weight.
2. **Expansion of Research Scope:** Expand the scope of research to include other types of recycled materials and explore the integration of multiple waste products into composite construction materials, enhancing sustainability across different aspects of construction.

3. **Standardization and Certification:** Work towards the standardization of testing and certification of recycled plastic aggregate concrete to build trust and acceptance among construction professionals and regulatory bodies.
4. **Commercialization Strategy:** Develop a detailed commercialization strategy that includes partnerships with construction companies and marketing initiatives to promote the uptake of these innovative products in the market.

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