OPTIMIZING DENSITY, WATER ABSORPTION AND COMPRESSIVE STRENGTH OF PAVING BLOCKS MOULDED FROM PLASTIC WASTE TO ADDRESS PLASTIC POLLUTION

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Declaration

I, Ronald Henry Kibiina, declare that this dissertation is my own original work and that it has not been presented to any other University for a similar or any other degree award.

Signature ……………………………………

Date 07/11/2024

Approval

The undersigned certify that they have read and hereby recommend for examination by Busitema University a dissertation titled: ***Optimizing Density, Water Absorption and Compressive Strength of Paving Blocks Moulded from Plastic Waste to address Plastic Pollution***, The Case Study of Tororo District, in (Partial) fulfilment of the requirements for the award of the degree of Master of Science in Physics of Busitema University.

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Dedication

This dissertation is dedicated to my Mother Nabukalu Phoebe Kisitu and Father Kisitu Deo, my siblings Semitala Titus, Kisitu God, Ssengendo Mathias and Nakimuli Josephine.

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Abstract

The production and usage of plastics are rapidly increasing in our daily lives, leading to significant disposal challenges, including landfill overflow, environmental pollution, microplastic formation, emissions from incineration, and increased economic costs associated with waste management. This study, therefore, aims to mitigate these effects by investigating the optimization of the physical properties of paving blocks moulded using plastic waste as a binding material, thus offering a sustainable solution for plastic disposal through construction. Two types of waste plastic materials were used: Polyethylene Terephthalate (PET) and Polyvinyl Chloride (PVC). Additionally, two sand particle sizes, 0.5 mm and 1.2 mm, were selected to comprehensively evaluate their impact on the physical properties of the paving blocks and to identify the optimal mixture for enhanced performance. These particle sizes represent a range of fine and coarse sand, allowing for a thorough investigation of how varying sizes influence the response variables. PET plastic was collected from disposal points, dustbins, and surroundings in Tororo municipality while PVC from construction sites still in Tororo municipality, Eastern Uganda, while the sand was sourced from a construction site at Tororo Girls' School in Tororo municipality. The molten waste plastic and sand were mixed in different proportions based on Central Composite Design (CCD), a statistical method within Response Surface Methodology (RSM) that systematically explores multiple factors affecting response variables, ensuring the optimal combination for the desired physical properties. RSM was employed to analyze the experimental data and model the relationships between the variables, enabling the identification of optimal conditions for achieving the desired physical properties, (density, water absorption, and compressive strength) of the paving blocks. Models were developed to fit the experimental results, with all density models being successful. The water absorption model for PET was successful for both sand particle sizes, the water absorption model for PET was successful for both sand particle sizes; in contrast, no model could be established for PVC molded pavers, as absorption values consistently registered at 0.000 across all composition ratios. This outcome indicates that the hydrophobic nature of PVC not only contributes to its resistance to water absorption but also facilitates effective bonding of sand particles, without pore spaces formation. Only the combination of PET with a sand particle size of 1.2 mm produced a successful model for compressive strength, while other combinations did not yield satisfactory results. This combination exhibited successful models for all evaluated responses, highlighting its potential as the optimal combination for moulding the desired paving blocks. Using the Response Surface Methodology (RSM), the optimal combination for molding the paving blocks was determined to be 148.28 g of sand and 50.0 g of PET plastic, which meets the parameters of low density, low water absorption, and high compressive strength. The results imply that utilizing plastic waste as a binding material in paving blocks not only offers a sustainable solution for reducing plastic waste but also producing high performance pavers, thereby addressing the critical issue of plastic pollution while creating durable paving blocks.

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List of Acronyms and Abbreviations

PET	Polyethene Terephthalate
HDPE	High Density Polyethylene
PVC	Polyvinyl Chloride
LDPE	Low Density Polyethylene
PE	Polystyrene
PP	Polypropylene
PC	Polycarbonate
RSM	Response Surface Methodology
CCD	Central Composite Design
MPa	mega pascals
DOE	Design of Experiment
ANOVA	Analysis of Variance

CHAPTER ONE: INTRODUCTION

1.1 Background

Plastics are organic compounds having long chained hydrocarbon synthesized from petroleum products (Vijayakumar and Sebastian, 2018) and were invented by Alexander Parkers in 1862 (Yadav et al., 2020). Plastics are classified in various ways according to an establishment by the Society of the Plastics Industry (SPI) in 1988 (Goverment-UK, 2012) as shown in Table 1.1 (Mariotti et al., 2019).

Table1.1: International Standard Classification of plastics

Symbol	*Type of Plastics*	*Main Use*
1 PETE	Polyethylene Terephthalate (PET)	PET is used for containers for foods and liquid, soft drink bottles, fibers for clothing.
2 HDPE	High Density Polyethylene (HDPE)	HDPE is used for bottles, piping for water and sewer, milk jugs, detergent bottles, nursery pots, oil containers, snowboards, boats and chairs
3 V	Polyvinyl Chloride (PVC)	PVC (or vinyl) is common for products such as plumbing products, medical tubing, pressure pipes, electrical cable insulation, outdoor furniture, liquid detergent containers, etc.
4 LDPE	Low Density Polyethylene	This polyethylene is ductile and, thus, used for shopping bags, food containers, films or bags and stretch wrap
5 PP	Polypropylene (PP)	PP is a thermoplastic polymer and one of the worldwide most common used plastic. It is used for laboratory equipment, automotive parts, medical devices, etc.
6 PS	Polystyrene (PS)	PS is commonly used for yoghurt pots, foodservice containers, CD cases, envelope windows, video cassettes, appliance housings as televisions.
7 OTHER	Other types of plastics	Various usages.

Every year, tons of plastics are manufactured and put to use in various applications (Shaw and Sahni, 2014). Plastics are vital in our daily lives; they are found in virtually everything we use, including watches, television sets, mobile phones, and hair dryers, to name a few (Andrady and Neal, 2009). Plastics are commonly used because of their unique properties, such as toughness, low weight, good resistance to chemical attacks, and low thermal conductivity. Additionally, they are easy to reuse, can be fabricated easily, are durable, and are non-biodegradable (Kane et al ., 2016). Since plastics are non-biodegradable, it is very difficult to eliminate plastic waste; consequently, much of it ends up in the environment, harming the ecosystem.

In Uganda, municipal waste management practices are underdeveloped, and in many areas, waste collection points, such as bins, are insufficient and not readily available. Even the few that exist are not classified, leading to indiscriminate dumping of waste. As a result, the public has begun to dispose of waste (including plastic waste) inappropriately throughout the environment. A common problem associated with plastic waste is the blockage of drainage systems as shown in Figure 1.1 and mismanaged landfills. This has resulted in occasional flooding and reduced land productivity, particularly around urban centers. Consequently, plastic waste has become a significant threat to the environment; however, if managed properly, it can be transformed into useful materials (Komakech et al., 2014).

Figure 1.1 illustrates how plastic waste can obstruct drainage systems, leading to environmental pollution and infrastructure damage (Kehinde et al., 2020).

Figure 1.1: Plastic Waste Causing Blockage in Drainage Systems.

Looking into the construction business globally, large amounts of construction materials are required; this is a potential area to utilize plastic waste by turning it into a construction material. Plastic can be added to sand to obtain high strength paving blocks and tiles (floor and roof tiles) leading to controlled pollution from disposing of plastics and reducing on the general cost of construction (Sellakutty, 2016). In this study, the use of plastic as binder material in the moulding of paving blocks was investigated. The ratio of sand to plastic, types of plastic waste and sand particle size was varied in order to optimize the properties of paving blocks manufactured. The optimization process was carried out with the help of response surface methodology (RSM). RSM is a statistical method that can be used to optimize process conditions. It can also be used to determine the influence of various factors and their interactions on the indexes under investigation (response value) during technological operation. (Bal et al., 2019; Zare et al., 2019).

1.2 Problem Statement

The increasing demand and production of plastic materials have led to a global waste crisis, with millions of tons of plastic ending up in landfills and oceans annually. These plastics, particularly non-biodegradable types, pose a significant environmental threat as they take centuries to decompose. While efforts have been made to repurpose plastic waste into construction materials, particularly paving blocks, current research lacks clarity on the most effective types of plastic and sand particle sizes for achieving durable, environmentally friendly paving blocks. Paving blocks made from plastic waste could provide a dual solution by reducing environmental pollution and meeting the demand for cost-effective, durable construction materials. However, optimizing the physical properties of these blocks to match or exceed traditional materials requires further investigation. This study aims to fill this gap by identifying the optimal plastic type, plastic composition, and sand particle size for producing paving blocks with improved physical properties like compressive strength and durability.

1.3 Objectives of the Study

1.3.1 Main Objective

The main objective of this study is to optimize the physical properties of paving blocks molded using plastic waste as a binder, thereby addressing the issue of plastic waste management and promoting sustainable construction practices.

1.3.2 Specific objectives

(i) To mould paving blocks using plastic as a binder material.

(ii) To analyse how variations in sand-plastic composition and sand particle size influence the physical properties of the paving blocks, with measurable parameters including density, water absorption, and compressive strength.

(iii) To establish the optimal experimental conditions for producing paving blocks with the best physical properties, focusing on specific ratio of sand to plastic and type of plastic.

1.4 Justification

The poor disposal of plastic waste, compounded by limited disposal sites in Tororo municipality, has resulted in significant environmental challenges, including land infertility, flooding due to blocked water channels, and disease outbreaks such as malaria from stagnant water. This research aims to provide a sustainable solution by utilizing plastic waste, specifically types like PET and PVC, as a binder in paving blocks, which can enhance their durability and compressive strength. By addressing both local and broader plastic waste management challenges, this study not only contributes to the environmental sustainability of construction materials but also has the potential for scalability beyond Tororo to other regions facing similar issues. Furthermore, it builds on existing research by exploring optimal mixing ratios and methodologies that have yet to be thoroughly investigated, highlighting the innovative approach of repurposing plastic waste. Additionally, this research could lead to economic benefits by reducing raw material costs and promoting new industries focused on recycling plastic, thereby supporting both environmental and economic incentives for sustainable development.

1.5 Significance of the Study

Plastic waste is one of the main global environmental concerns, and finding effective ways to manage and recycle it is both important and valuable. This study seeks to address this issue by promoting the recycling and reuse of plastic waste, thereby reducing its accumulation in landfills and minimizing its impact on ecosystems and wildlife. Specifically, utilizing plastic waste as a binder in paving blocks offers several economic benefits. For instance, this approach could lower material costs for construction by reducing dependence on traditional materials like cement, which is often expensive and resource-intensive. Additionally, it could reduce municipal waste management expenses, as less plastic waste would require disposal.

The development of sustainable construction materials is essential for fostering environmentally friendly practices in the construction industry, particularly in developing countries like Uganda. By adopting plastic waste-based paving blocks, the construction industry could see a shift in practices, encouraging policy changes around the use of eco-friendly materials and potentially influencing urban planning standards. This could lead to a greater acceptance of innovative materials and reduce the demand for conventional materials such as concrete.

From a technical perspective, this research advances scientific knowledge in material optimization. By identifying optimal plastic-to-sand ratios and determining the best types of plastics, such as PET and PVC, the study enhances the compressive strength and durability of paving blocks. These innovations make plastic waste-based materials more competitive with traditional options, contributing to improved performance in construction applications.

Furthermore, the findings of this study have global applicability. The solutions developed could be replicated in other regions facing similar plastic waste challenges, particularly in countries with high plastic waste generation and limited waste management infrastructure. This research aligns with global sustainability initiatives, including the United Nations' Sustainable Development Goals (SDGs), by promoting responsible consumption and production patterns.

In terms of long-term environmental benefits, utilizing plastic waste in construction not only reduces plastic waste but also lowers the carbon footprint associated with traditional construction materials. By decreasing reliance on resource-intensive materials like cement, this approach contributes to a more sustainable construction industry. Additionally, it offers life cycle benefits through the reuse of plastics and significantly reduces landfill use, promoting a circular economy.

1.6 Scope

This study was conducted in Tororo district, specifically within the administrative unit of Tororo municipality in eastern Uganda. It addresses the pressing issue of plastic waste by optimizing the physical properties of paving blocks manufactured using locally sourced plastic waste as a binding material. The primary focus is on polyethylene terephthalate (PET), predominantly derived from discarded beverage bottles as illustrated in Figure 1.2 (Dadzie et al., 2020), collected from the surrounding community. Additionally, polyvinyl chloride (PVC) sourced from construction sites was included due to its widespread availability and potential to enhance durability. Collecting PET locally reflects the study's aim to utilize readily available waste materials, while purchasing PVC ensures consistent quality. The study will evaluate various sand types, focusing on particle sizes and the sand-to-plastic proportions, which are critical for optimizing the paving blocks' physical properties. Specifically, the optimization process will focus on enhancing compressive strength, density, and water absorption. Performance evaluation will involve laboratory testing, including compressive strength tests and water absorption tests, to assess the effectiveness of the optimization process and ensure the paving blocks meet required standards for durability and sustainability.

Figure 1.2: Beverage Bottles as Primary Contributors to PET Plastic Waste

CHAPTER TWO: LITERATURE REVIEW

2.1 Categories of Plastics

Plastics are categorized in different ways. (i) Natural plastics; these are naturally occurring materials and are said to be plastics because they can be shaped and molded by heat, for example amber, often used in jewelry manufacture. (ii) Semi synthetic plastics; which are made from naturally occurring materials, mixed with other materials. A good example is cellulose acetate. (iii) Synthetic plastics, which are materials that are derived from breaking down carbon-based materials, usually crude oil, coal or gas, so that their molecular structure changes (Prager and Dill, 1960).

Among these categories, synthetic plastics, particularly polyethylene terephthalate (PET) and polyvinyl chloride (PVC), are especially relevant for construction materials. Their inherent properties; such as durability, flexibility, and resistance to environmental degradation make them suitable for use in paving blocks. Additionally, both PET and PVC have significant recycling potential, allowing for the repurposing of waste materials into valuable construction resources (Adiyanto et al., 2023; Makris et al., 2020). This study explores these synthetic plastics to optimize the physical properties of paving blocks, demonstrating their viability as sustainable alternatives in the construction industry.

2.2 Harmful Effects of Plastics

Plastics are non-biodegradable materials that take an exceptionally long time to decay, with an estimated decomposition time of up to 500 years (Vijayakumar and Sebastian, 2018). In most developed societies domestic organic waste, including plastics packaging, is disposed of in sanitary land filled or by incineration. During early 2000, the largest amount of plastic wastes is disposed of by land filling (65-70%), and incineration (20-25%). Recycling is only about 10% (Alla et al., 2014). If the disposal of plastics is not properly managed, it can lead to significant environmental hazards. These hazards may include: (i) littered plastics spoiling the beauty of the surroundings and making public places unsightly, (ii) burning plastic waste, which can cause air pollution by emitting harmful gases, (iii) garbage mixed with plastic waste leading to operational problems in landfills, and (iv) plastic waste blocking drainage systems (Kumar et al., 2014). Incorporating plastics into construction can provide a viable solution for the safe disposal of plastic waste and helping in mitigating various environmental issues, as illustrated in Figure 2.1 (Geneva Environment Network, 2021).

Figure 2.1: The Plastic Life Cycle and its Impacts on People and Environment

2.3 Plastic as Construction Material

Efforts to convert plastic waste into construction materials are ongoing worldwide. Using plastic waste in manufacturing paving blocks offers several advantages: (i) it eliminates plastic shrinkage cracking, (ii) reduces drying shrinkage, and (iii) slightly increases tensile strength (Konin, 2011). Numerous studies have focused on using plastic waste as a binder for paving blocks and tiles, particularly examining the compression behavior of various sand-plastic mixtures(Agyeman et al., 2019). The strength of the paving blocks depends on the sand to plastic ratio, with laboratory tests indicating an optimum mixture of 3:1. Paving blocks usually contain more sand than plastic, as plastic acts primarily as a bonding agent. (Zulkernain et al., 2021).

A number of scholars have made studies related to using plastic waste as a binder; (1) Analysis was made on the possibility of making a composite material from waste plastic and it was found out that it is possible to manufacture roof tiles from recycled HDPE and sand. The polymer roof tile containing 70% of High Density Polyethylene (HDPE) with 30% sand produced the best quality-roofing tile (Seghiri et al., 2017). (2): A study on recycling low-density polyethylene (LDPE) water sachets in developed countries found a negative correlation between sand particle size and density. It revealed that larger sand particles decreased compressive strength and increased porosity, while particles smaller than 500 μm yielded the highest compressive strengths (Kumi et al., 2018). (3): The use of plastic waste as a binding material in tile manufacturing, based on polypropylene, showed that these tiles possessed relatively low porosity, making them practically impervious compared to micro-concrete tiles. This property helped prevent discoloration over time and allowed for a reduced slope in their installation. A 40% plastic binder proportion yielded the best physical and mechanical results (Konin, 2011). (4): A case study conducted at a selected dumping site in Ogbomoso, Nigeria, explored the pilot recycling of pure waste sachets and bottles into composite floor tiles. The study found that water absorption tests, both cold and hot, demonstrated no water absorption after 30 minutes. Additionally, the composite plastic tiles exhibited a higher frictional coefficient compared to conventional tiles. The study concluded that plastic waste, which poses hazards to humans and the environment, can be effectively repurposed in tile production (Temitope et al., 2015).

While previous research studies focused on testing individual properties of paving blocks, this study aimed to optimize the physical properties of paving blocks using plastic waste as a binder through response surface methodology (RSM). The key response factors evaluated included (i) density, (ii) water absorption rate, and (iii) compressive strength. This study not only seeks to optimize the physical properties of paving blocks but also aligns with broader environmental goals. By utilizing plastic waste in construction, the research aims to reduce landfill accumulation, lower greenhouse gas emissions associated with traditional materials, and promote sustainable practices in the construction industry.

2.4 History of Paving Blocks

Paving blocks have a rich history that dates back to ancient civilizations, where they were used for constructing roads and public spaces. Over time, the evolution of paving blocks has witnessed significant advancements in materials and manufacturing processes, transitioning from natural stones to modern concrete and composite materials (Shtayat et al., 2020). This evolution reflects the ongoing need for durable, cost-effective, and environmentally friendly construction solutions.

2.5 The Gap in Current Paving Solutions

Despite the availability of conventional paving materials, there is a growing gap in the market for sustainable alternatives that address pressing environmental concerns, particularly the global crisis of plastic waste. The increasing accumulation of plastic waste poses significant hazards to human health and ecosystems worldwide, contributing to pollution and resource depletion. As plastic waste continues to be a pervasive issue, there is an urgent need for innovative paving solutions that not only utilize recycled materials but also meet the performance standards required for modern construction. By repurposing plastic waste into paving blocks, we can mitigate its environmental impact while promoting sustainability in the construction industry.

2.6 Commonly Available Paving Blocks

Commonly available paving blocks include porous concrete paving blocks (PCPB), which are characterized by continuous voids incorporated into the concrete matrix (Nur Hidayah et al., 2015). These paving blocks are further categorized based on their applications, including walkway, road, and parking paving blocks (Namarak et al., 2018), as well as by their various shapes, as illustrated in Figure 2.2 (Bilir et al., 2022). Research on common concrete paving blocks has demonstrated a range of properties, including: (a) compressive strength values between 2.99 MPa and 3.60 mega pascals (MPa) after 28 days of curing, increasing to between 3.20 MPa and 3.60 MPa after 90 days; (b) water absorption rates ranging from 6.1% to 7.0%; and (c) densities between 1.99 gcm^{-3} and 2.11 gcm^{-3} (Rodríguez et al., 2017). In contrast, paving blocks made from plastic waste offer several advantages that address the environmental and economic issues associated with traditional materials. Using plastic waste can reduce costs, lower the carbon footprint, and enhance durability. For instance, plastic waste paving blocks may exhibit improved tensile strength and resistance to shrinkage compared to conventional blocks, making them a more sustainable choice for construction. These properties underscore the importance of understanding the mechanical and physical characteristics of paving blocks in the context of their application in sustainable construction practices. (Tulashie et al., 2020). Table 2.1: Comparison of Key Properties of

Conventional and Plastic Waste Paving Blocks further summarizes the comparative advantages of plastic-made paving blocks over concrete blocks.

Figure 2.2: Different Colors and Shapes of Paver Blocks.

Table 2.1: Comparison of Key Properties of Conventional and Plastic Waste Paving Blocks

Property	Conventional Paving Blocks	Plastic Waste Paving Blocks
Compressive Strength	2.99 MPa - 3.60 MPa	Higher potential with optimization
Water Absorption Rate	6.1% - 7.0%	Potentially lower, depending on formulation
Density	1.99 gcm^{-3} - 2.11 gcm^{-3}	Varies based on plastic content
Cost	Higher due to raw materials	Lower due to recycling waste

2.7 Optimization of Process Parameters Using Response Surface Method (RSM)

Response Surface Methodology (RSM) is a statistical technique utilized to optimize process conditions and to determine the influence of various factors and their interactions on the response variables during technological operations. This approach employs quadratic polynomial models fitted through Central Composite Design (CCD), allowing for comprehensive experimental design and result expression. RSM is based on the premise that a response variable, denoted as '$\boldsymbol{y}$' is a function of a set of independent variables $x_1, x_2, \ldots., x_n$. This relationship can be approximated within a certain region of the polynomial model, expressed as $y = f(x_i)$, or more generally $y = f(x_1, x_2, \ldots., x_n)$. Here the response variable '$\boldsymbol{y}$' depends on '$\boldsymbol{n}$' independent variables (Amin et al., 2015; Bal et al., 2019; Zare et al., 2019).

When the factors are known, the estimated effects and interactions of the model can be represented graphically. If the factors are unknown, they are initially determined using a screening method, followed by estimating interaction effects through a first-order model represented by equation 2.1.

$y = \alpha_0 + \alpha_1 x_1 + \alpha_2 x_2 + \varepsilon$……………………………………………………………...2.1

If curvature is identified, RSM is employed, using a second-order model to approximate the response variable represented by equation 2.2.

$y = \alpha_0 + \alpha_1 x_1 + \alpha_2 x_2 + \alpha_{12} x_1 x_2 + \alpha_{11} \alpha_1^2 + \alpha_{22} x_2^2 + \varepsilon$……………………………………...2.2

Subsequently, a graph is constructed to identify stationary points, such as maximum response, minimum response, or saddle points, using the obtained values$x_1, x_2, \ldots \ldots \ldots \ldots., x_n$ (Kleijnen, 2015).

RSM offers significant advantages, including a reduction in the number of computational experiments required for assessment, analysis, and optimization. Compared to traditional one-variable or full-factor trials, RSM is a more efficient and cost-effective strategy for data gathering (Rahman et al., 2022). The flow of RSM is illustrated in Figure 2.3 (Gani et al., 2016), which presents a schematic representation of the methodology, outlining the sequential steps involved in designing experiments, analyzing results, and optimizing process parameters. RSM will be employed to optimize the physical properties of paving blocks by determining the best plastic-sand ratio. This approach systematically varies the proportions of plastic waste and sand, allowing for a detailed analysis of their effects on compressive strength, water absorption, and density. Previous studies have successfully utilized RSM in similar applications, demonstrating its effectiveness in optimizing material compositions.

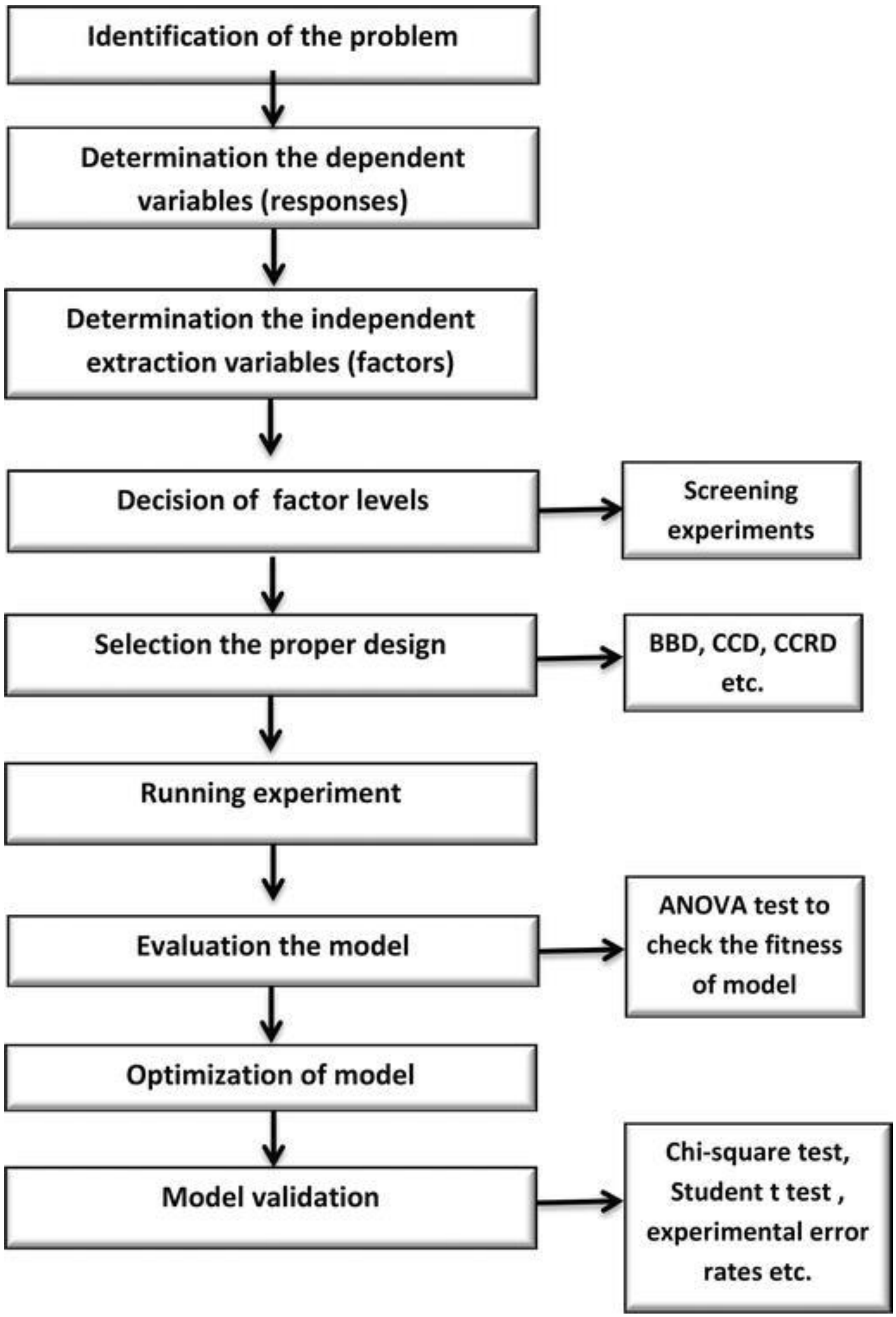

Figure 2.3: Schematic Representation of RSM.

CHAPTER THREE: MATERIALS AND METHODOLOGY

3.1 Materials

The materials utilized in this study comprised two types of plastic waste:

(a) Polyethylene Terephthalate (PET): This includes used mineral water and soda bottles. PET was selected due to its prevalence and tendency to be poorly disposed of; individuals frequently consume beverages from these bottles and often neglect proper recycling.

(b) Polyvinyl Chloride (PVC): Commonly used in water pipes and building foundations, PVC is a durable and long-lasting plastic that poses significant environmental challenges when discarded.

(c) River sand sieved through a 1.2 mm and 0.5mm sieves.

3.2 Collection

3.2.1 Plastic

The collection of plastic waste for this study was carried out from various sources in and around Tororo municipality:

(a) The PET bottles were gathered from local environments, including waste bins and community areas where they had been discarded.

(b) The PVC was sourced from construction sites in Tororo municipality, where builders often dispose off leftover materials.

3.2.2 Sand

River sand from a construction site in Tororo girls' school was selected for this study due to its abundant availability at the time of research, as well as its favorable properties for construction applications. River sand typically has a well-rounded grain structure, which enhances the workability and strength of concrete mixtures. Additionally, its natural washing process helps reduce impurities that could adversely affect the quality of the final product (Subedi et al., 2022).

3.3 Preparation

3.3.1 Plastic

To prepare the PET bottles for recycling, the tops were removed because they are often made from a different type of plastic, such as high-density polyethylene (HDPE) or polypropylene (PP)

(Makris et al., 2020), which are not suitable for the intended application. The bottle necks were also cut off to ensure uniformity in size and facilitate more efficient processing during the subsequent stages of the study. The remaining bottle sections were washed, dried, and cut into small plastic pieces of approximately equal size as illustrated in Figures 3.1, and then stored for later use. The PVC was similarly washed, dried, and stored in a separate clean container.

Figure 3.1: Chopped Plastic Pieces for Melting

3.3.2 Sand

The river sand was collected from the construction site in Tororo girls' school using a wheelbarrow and poured onto an old roof sheet for sorting. To ensure the quality of the material, the sand was meticulously sorted to remove foreign particles that were not sand and then left to sun-dry, as illustrated in Figure 3.2.

This drying process lasted for three days, during which the sand was turned every three hours during daylight hours to guarantee that all particles were thoroughly exposed to sunlight. After drying, the sand was sieved through two different mesh sizes to achieve the desired granulation. The first sieve, with pore size of 1.2 mm (Figure 3.3), was used to remove larger particles and ensure a more uniform texture, while the second sieve, with pore size of 0.5 mm (Figure 3.4), was employed to refine the sand further by eliminating finer particles.

The selection of these sieve sizes is crucial for controlling the physical properties under investigation, specifically density, water absorption, and compressive strength. Proper grain size distribution and pore size can significantly influence these properties (Gomez et al., 2010). By achieving an optimal particle size distribution through this dual sieving process, the study aims to enhance the mechanical performance of the resulting paving blocks. The separated sand fractions were then stored appropriately, as shown in Figures 3.5 and 3.6, respectively. The sand was stored in open containers to allow for air circulation. This method of storage was chosen to prevent moisture buildup, which could lead to clumping or contamination. However, it is important to note that the sand was exposed to environmental conditions, including dust and humidity. The containers used were standard plastic bags, which provided a basic level of protection against large debris but did not offer airtight sealing. Future studies should consider the potential impact of environmental factors on the quality of the sand and may benefit from more controlled storage conditions.

Figure 3.2: Sand Spread for Drying

Figure 3.3: Sieve with Pore Size 1.2 mm

Figure 3.4: Sieve with Pore Size 0.5 mm

Figure 3.5: Sand Particles Passing Through a Sieve with 1.2 mm Pore Size

Figure 3.6: Sand Particles Passing Through a Sieve with 0.5 mm Pore Size

3.4 Design of experiments and response surface methodology

The moulding process for the paving blocks was investigated using CCD, a statistical technique used to optimize the relationship between input factors and response variables (Adiyanto et al., 2023). In this study, the independent variables selected for analysis were the amount of plastic and the amount of sand, which included two different particle sizes and two distinct types of plastic waste.

The experimental design was executed using Minitab 17, a widely used statistical software package for designing and analysing experiments. Minitab facilitates efficient management of the experimental layout and comprehensive analysis of the results (Arnold, 2006).

Both the amount of sand and the amount of plastic were evaluated at five coded levels: $-\alpha$, -1, 0, 1, and α as shown in Table 3.1. These levels allow for a systematic exploration of the response surface, capturing both linear and interaction effects between the variables (Alman-Abad et al., 2020). Figure 3.7 illustrates the Central Composite Design (CCD) for the two independent variables, highlighting the experimental layout and corresponding coded levels. The design incorporates either a full factorial or fractional factorial approach, enhanced by axial points as detailed in Table 3.2. This structure facilitates the assessment of curvature in the response surface, ensuring a comprehensive exploration of the parameter space and enabling the identification of optimal conditions for the production of paving blocks.

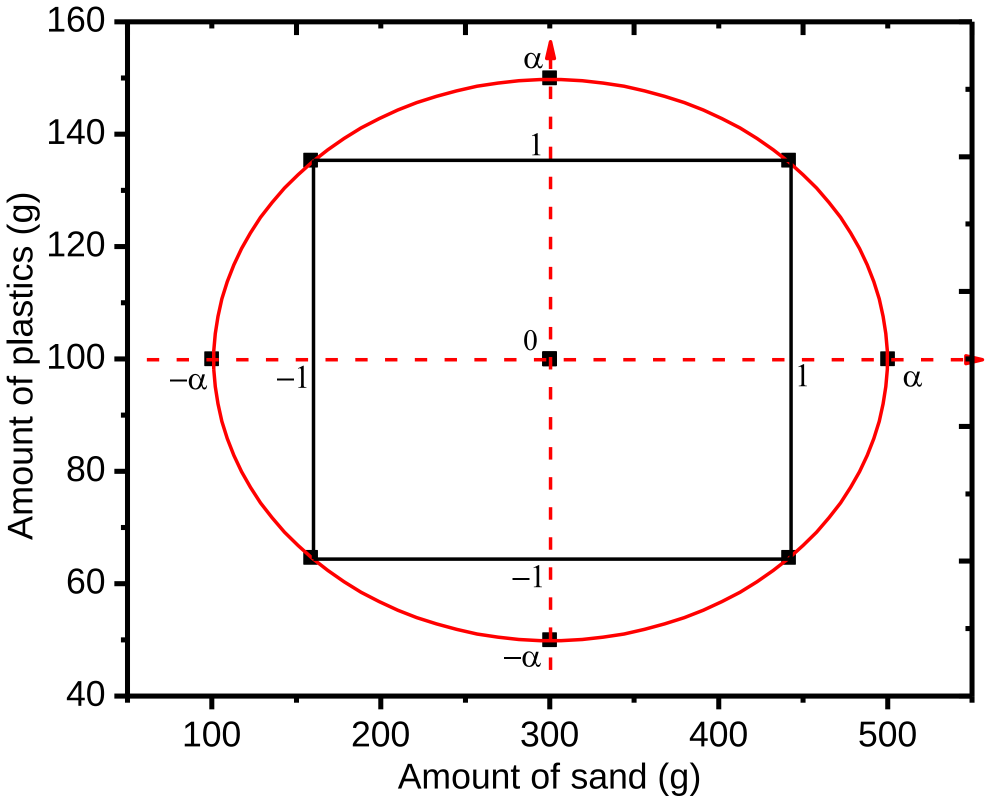

Figure 3.7: Contour Plot of Sand and Plastic Amounts in Actual and Coded Terms Using Central Composite Design (CCD)

Table 3.1: Factor Values for the DOE

Factors	Factor Codes	Levels				
		$-\alpha$	-1	0	1	α
Amount of Sand (g)	x_1	100	158.58	300	441.42	500
Amount of Plastic (g)	x_2	50	64.64	100	135.36	150

Thirteen experimental points were generated for each plastic type and each sand particle size, following the Central Composite Design (CCD) approach. The total number of runs, N, was calculated using the formula in Equation 3.1 (Asghar et al., 2014):

$$N = k^2 + 2k + n \quad (3.1)$$

where k represents the number of factors (in this case, two: plastic type and sand particle size), and n denotes the number of replicated centre points. For this study, $k = 2$, leading to the calculation of 13 experimental points as shown in Equation 3.2:

$$N = 2^2 + 2(2) + 5 = 13 \quad (3.2)$$

These points included four axial points, four factorial points, and five replicated center points, as shown in Table 3.2. The coded levels represented different amounts of plastic and sand used in the molding process of paving blocks, facilitating a comprehensive analysis of their effects on the response variable The replication of the center points five times is a standard practice aimed at improving the estimation of experimental error. This approach enhances the reliability of the results by providing a better understanding of the variability in the data, thereby validating the experimental findings (Bhattacharya, 2021).

Table 3.2: Showing Thirteen experimental points with corresponding factor values

Exp #	Point type	Amount of sand, X_1 (g)	Amount of Plastic, X_2 (g)
1	Centre	300	100
2	Centre	300	100
3	Factorial	158.58	135.36
4	Axial	500	100
5	Axial	300	50
6	Centre	300	100
7	Factorial	441.42	135.36
8	Axial	300	150
9	Factorial	158.58	64.64
10	Centre	300	100
11	Factorial	441.42	64.64
12	Centre	300	100
13	Axial	100	100

3.5 Moulding of Paving blocks

The amounts of plastic and sand were carefully measured and stored in transparent, massless polythene bags, as illustrated in Figure 3.8. This choice ensured accuracy and consistency, allowing for easy visual verification of the contents while minimizing any additional weight that could affect measurements. An electric weighing balance was utilized to obtain precise measurements according to the ratios specified in Table 3.2. This procedure was conducted for two distinct types of plastics and two variations of sand particle sizes.

Figure 3.8: Measuring Sand Quantity

The cooking stove was ignited, and an aluminum cooking pan was placed on it for approximately two to five minutes to ensure that any moisture in the pan was evaporated. Following this, the predetermined ratio of plastic was added to the cooking pan (Figure 3.9), and a lid was placed on top while the mixture was heated (as shown in Figure 3.10). At intervals of 5 to 10 minutes, the lid was removed to check the melting progress of the plastic. Once the plastic had completely melted, the appropriate proportion of sand was added to the melted plastic. The mixture was then stirred, and the lid was replaced. At intervals of 5 minutes, the lid was removed again to stir the mixture until the sand was fully and uniformly incorporated into the plastic (Figure 3.11).

Figure 3.9: Chopped Plastics in the Pan

Figure 3.10: Heating of Plastic Materials

Figure 3.11: Mixture of Sand and Molten Plastic

The moulds, constructed from wood sourced from a nearby carpentry workshop, measured an average of 6 cm by 6 cm by 3 cm. This specific choice of dimensions was selected to ensure the production of paving blocks that are manageable in size for handling and testing, while also optimizing material use. The wooden moulds were smeared with used motor engine oil and placed on a flat table surface (Figure 3.12). This treatment facilitated the easy removal of the paving blocks from the moulds after setting.

Once the mixture was thoroughly combined, the uniform plastic-sand paste was scooped and placed into a mould (as shown in Figure 3.13). The mixture was then pressed to eliminate any air spaces (illustrated in Figure 3.14). The hot, uniform paste mixture of plastics and sand within the mould was allowed to set for approximately 20 to 30 minutes (see Figure 3.15). After the mixture had set, the paving blocks were carefully removed from the moulds and placed on a clean table surface for curing for over three hours. Finally, the moulds were cleaned to remove any residual plastic and re-oiled in preparation for the next production of paving blocks

Figure 3.12: Molds Smeared with Used Engine Oil

Figure 3.13: Placement of Mixture into Mould

Figure 3.14: Pressing of Mixture in Moud

Figure 3.15: Pressed Mixture Left to Set and Cool

3.6 Characterization of the Paving Block Samples

The production of paving blocks involved a total of 13 experimental runs for each type of material utilized, as detailed in Table 3.2. Given the inclusion of two distinct types of plastics and two variations of sand particle sizes, this resulted in a comprehensive total of 52 samples.

To evaluate the performance and quality of the paving blocks, several key response variables were assessed:

(a) **Density (D)**: This response measures the mass per unit volume of the paving blocks, providing insights into their structural integrity.

(b) **Absorbance Rate (A)**: This parameter quantifies the capacity of the blocks to absorb water, which is critical for durability and performance in environmental conditions.

(c) **Compression Strength (C)**: This response assesses the load-bearing capacity of the blocks, indicating their suitability for various applications.

The characterization of these samples was conducted to ensure a thorough understanding of how the selected materials and their respective proportions influenced the overall properties of the paving blocks.

3.6.1: The density

Four sets of measurements for the length (l), width (w), and height (h) of the paving blocks were obtained using vernier calipers, as illustrated in Figure 3.16. The average values for these dimensions were calculated and recorded. The volume (v) of the paving blocks was then determined using the formula presented in Equation 3.3:

$$v = l * w * h \quad (3.3)$$

To ensure accuracy, the paving blocks were cleaned to remove any dust and debris using a dry painting brush. The mass (m) of each paving block was measured with an electric beam balance, providing a precision of one decimal place, as shown in Figure 3.17. The density (D) of each paving block was subsequently calculated using the formula outlined in Equation 3.4 (Jock et al., 2022):

$$D = \frac{m}{v} \quad (3.4)$$

The results of these measurements were systematically recorded in Tables 4.1, 4.2, 4.3, and 4.4.

Figure 3.16: Measuring of sides of the Paving Block using Vernier calipers

Figure 3.17: Measuring of mass of Paving Blocks using a Beam Balance

3.6.2: Water absorption test

The initial masses of the dry paving blocks, previously measured using the electric beam balance (as shown in Figure 3.17), were recorded as $\mathbf{M_1}$. Each paving block was then securely tied using inextensible strings and submerged in water by clamping the strings to a retort stand for a duration of three hours (Figure 3.18). This extended soaking time was selected based on prior studies indicating that no significant water absorption occurs after approximately 30 minutes (Temitope et al., 2015); thus, a three-hour period ensures full saturation for accurate assessment. Upon completion of the soaking period, the paving blocks were carefully removed from the basin, and any excess surface water was blotted dry using absorbent paper. The new masses $\mathbf{M_2}$ of the paving blocks were immediately measured using the electric beam balance. The change in mass was calculated using the formula $M_2 - M_1$, and the water absorption percentage (A) was determined using the formula presented in Equation 3.5 (Jock et al., 2022):

$$A = \left(\frac{m_2 - m_1}{m_1}\right) \times 100\% \quad \ldots\ldots (3.5)$$

The results of the water absorption tests were systematically recorded in Tables 4.1, 4.2, 4.3, and 4.4.

Figure 3.18: Paving Blocks Fully Immersed in Water

3.6.3 Compressive Strength Test

The compressive strength (C) of the paving blocks was evaluated using a compressive testing machine, specifically the TESTOMERIC model DBBMTCL 2500 kg-1.5-000, with serial number 57027. The cross-sectional area of the selected paving block was calculated using the formula

$Area = l \times w$ where l and w represent the average length and width, respectively, as determined from Figure 3.19.

The selected paving block was positioned on the compressive testing machine, and a gradually increasing load was applied until failure occurred, as depicted in Figure 3.22. The maximum load at which the paving block fractured was recorded. The compressive strength (C) was subsequently calculated using the formula presented in Equation 3.6 (Jock et al., 2022):

$$C = \frac{Maximun\ load}{crosectional\ area} \qquad (3.6)$$

Thereafter, the results of the compressive strength were recorded in Tables 4.1, 4.2, 4.3, and 4.4.

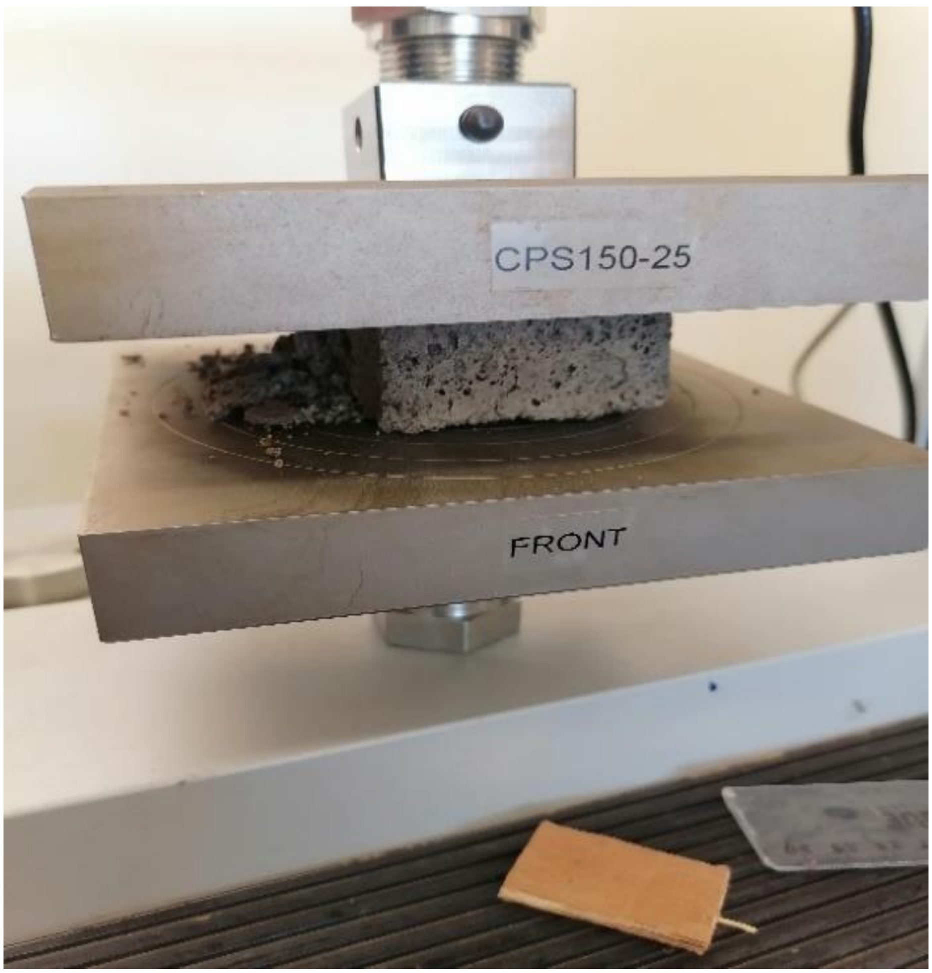

Figure 3.23: Paving block under crushing machine

3.7 Optimization

The experimental results presented in Tables 4.1, 4.2, 4.3, and 4.4 lay the foundation for a comprehensive optimization analysis of the paving blocks. Following the collection of these data, Response Surface Methodology (RSM) was employed to explore the relationships between the input factors; specifically, the amounts of sand and plastic used and the resultant physical properties of the paving blocks, namely density, water absorption, and compressive strength.

RSM is a powerful statistical technique that enables the modelling and analysis of complex processes, making it particularly suitable for optimizing material formulations (Baghaee et al., 2015). By applying regression analysis to the obtained responses, we derived fitted quadratic polynomial equations, which allow for the prediction of outcomes based on varying input conditions. This polynomial regression approach is essential, as it captures not only the linear relationships but also any potential interactions and curvature between the factors, providing a more nuanced understanding of the material behaviour (Tulashie et al., 2020).

To further validate the effectiveness of the RSM model, Analysis of Variance (ANOVA) was conducted, which is essential for assessing the significance of the factors and their interactions within the regression model. ANOVA partitions the total variability of the response variables into components attributable to various sources, allowing us to determine whether the input factors significantly affect the outcomes. Key statistics derived from ANOVA, such as the P-value and R-squared values, play crucial roles in this analysis. The P-value indicates the probability that the observed results are due to chance; a low P-value (typically < 0.05) suggests that the corresponding factor has a statistically significant effect on the response variable. Meanwhile, the R-squared value measures the proportion of variability in the response data that can be explained by the model, with a higher R-squared value indicating a better fit. By utilizing ANOVA, we can identify which factors contribute meaningfully to the model, thereby enhancing the reliability of the fitted polynomial equations and ensuring that our optimization process is both robust and relevant (Bittner, 2022).

Additionally, the validation process included examining the percentage error in measured outcomes compared to expected values. A percentage error below 20% is typically considered acceptable, indicating that the model's predictions align closely with actual measurements (José et al., 2013). In this analysis, the measured values for density, water absorption, and compressive strength were compared to their targeted values, and the resulting errors were calculated. Since these errors fell below the acceptable threshold, it reinforces the reliability of the fitted polynomial equations and the overall optimization process.

Tables 4.5 and 4.6 present the coded terms of the input factors and the corresponding responses utilized in the fitted polynomial equations. These coded terms facilitate the interpretation of the regression model, allowing for easier manipulation of the variables within specified ranges. The derived equations enable the identification of optimal conditions for achieving desired material properties, thereby enhancing the performance and sustainability of the paving blocks.

Table 3.3: denoted symbols for factors

Factor (g)	Symbols
Amount of sand	x_1
Amount of plastic	x_2

Table 3.4: Denoted symbols for responses

Response	Symbols	Sand particle size (mm)	Type of plastic
Density (gm^{-3}), **D.**	D_1	0.5	PET
	D_2	1.2	PET
	D_3	0.5	PVC
	D_4	1.2	PVC
Absorbance, **A**.	A_1	0.5	PET
	A_2	1.2	PET
Compressive strength (Pa), **C**.	C_1	0.5	PET
	C_2	1.2	PET
	C_3	0.5	PVC
	C_4	1.2	PVC

3.8 Validation

Validation of the experimental results was conducted to ensure the reliability and accuracy of the paving block formulations. The percentage error method was employed to compare the moulded values with the experimental measurements. This method quantifies the deviation of experimental results from predicted values, providing a measure of accuracy. The formula for calculating percentage error is given in Equation 3.7:

$$Percentage\ error = \left(\frac{Experimental\ Value - Predicted\ Value}{Predicted\ Value}\right) * 100\% \quad (3.7)$$

In this study, a validation threshold of 20% was established as acceptable, indicating that the experimental results should not deviate more than 20% from the predicted values. This threshold is commonly used in material testing to account for variability in material properties and experimental conditions, affirming that the experimental results align closely with the predicted values and thus confirming the robustness of the optimization process. (José et al., 2013).

CHAPTER FOUR: PRESENTATION AND DISCUSSION OF RESULTS

4.0 Introduction

This section presents and discusses the experimental results obtained from the evaluation of paving blocks produced using various combinations of plastic types and sand particle sizes. The primary responses assessed; density, water absorption, and compressive strength are critical indicators of the performance and durability of the paving blocks.

The results, detailed in Tables 4.1 through 4.4, provide insights into how differing material compositions influence the physical properties of the blocks. By systematically analyzing these responses, this discussion aims to explain the relationships between the input variables and their impact on the overall quality of the paving blocks. The findings are contextualized within existing literature, enabling a comprehensive understanding of the implications for sustainable construction practices utilizing recycled materials. The results are organized into separate tables to distinctly highlight the three responses for each combination of plastic type and sand particle size, facilitating systematic comparison and analysis of the effects of these variables on the performance of the paving blocks.

4.1 Physical Properties of the Paving Block Samples

4.1.1 Density, Water Absorption, and Compressive Strength of PET and Sand Particles with Pore Size of 0.5 mm

The table 4.1 shows values of response parameters; Density, Water Absorption, and Compressive Strength of PET and Sand Particles with Pore Size of 0.5 mm

Table 4.1: Values of Density, Water Absorption, and Compressive Strength of PET and Sand Particles with Pore Size of 0.5 mm

Exp #	Amount of sand, **X_1,** (g)	Amount of plastic, **X_2,** (g)	Density, **D,** (gcm^{-3})	Absorbance, **A,**	Compressive strength, **C,** (Pa)
1	300	100	1.83	0.26	6818222
2	300	100	1.82	0.27	6786667
3	158.58	135.36	1.67	0.28	1282361
4	500	100	1.82	0.26	6634306
5	300	50	1.76	1.89	6692028
6	300	100	1.82	0.26	6863611
7	441.42	135.36	1.84	0.52	6840000
8	300	150	1.70	0.00	1246750
9	158.58	64.64	1.78	0.28	6916972
10	300	100	1.83	0.26	6346111
11	441.42	64.64	1.85	2.34	1308306
12	300	100	1.81	0.27	6489972
13	100	100	1.59	0.28	861250

The results presented in Table 4.1 for paving blocks produced from PET and sand particles with a pore size of 0.5 mm reveal a density range of 1.59 gcm^{-3} to 1.85 gcm^{-3}, indicating that higher sand content correlates with increased density; however, this density is lower than the average range of 2.5 gcm^{-3} to 2.8 gcm^{-3} typically observed in Interlocking Concrete Block Paving (ICBP) blocks. This discrepancy may be attributed to the lower weight of plastic, resulting in an overall reduced density for the plastic-moulded paving blocks. The water absorption values exhibit significant variability, ranging from 0.00 to 2.34, which aligns closely with the reported value of 2.12% for ICBP blocks (Bilir et al., 2022). Notably, Experiment 5 demonstrates a high-water absorption of 1.89, suggesting enhanced porosity. Conversely, the result of 0.00 in Experiment 8 may reflect a robust bond between the materials, indicative of effective mixing or a dense structure that enhances impermeability.

Compressive strength values span from **1,246,750 Pa** to **6,818,222 Pa**, with the highest strengths observed in mixtures featuring a 3:1 sand-to-plastic ratio. This finding corroborates existing literature that emphasizes the significance of optimal material composition in enhancing mechanical properties (Agrawal et al., 2023). The variability in water absorption indicates that the ratios and particle sizes critically influence porosity, consistent with studies that suggest increased sand content generally leads to improved structural integrity and reduced water absorption. Overall, these findings contribute to a growing body of research that underscores the importance of material ratios in achieving desirable performance characteristics in sustainable construction materials.

4.1.2 Density, Water Absorption, and Compressive Strength of PVC and Sand Particles with Pore Size of 0.5 mm

The table 4.2 shows values of response parameters; Density, Water Absorption, and Compressive Strength of PVC and Sand Particles with Pore Size of 0.5 mm

Table 4.2: Values of Density, Water Absorption, and Compressive Strength of PVC and Sand Particles with Pore Size of 0.5 mm

Exp #	Amount of sand, $\mathbf{X_1}$ (g)	Amount of plastic, $\mathbf{X_2}$ (g)	Density, **D,** (gcm^{-3})	Absorbance, **A,**	Compressive strength, **C,** (Pa)
1	300	100	1.70	0.00	6668111
2	300	100	1.71	0.00	6628333
3	158.58	135.36	1.36	0.00	6531083
4	500	100	1.81	0.00	6552416
5	300	50	1.57	0.00	6799389
6	300	100	1.69	0.00	6945111
7	441.42	135.36	1.78	0.00	6575333
8	300	150	1.57	0.00	6530833
9	158.58	64.64	1.68	0.00	6796083
10	300	100	1.71	0.00	6715556
11	441.42	64.64	1.81	0.00	6331250
12	300	100	1.69	0.00	6566750
13	100	100	1.74	0.00	6642889

The results in Table 4.2 demonstrate a density range of 1.36 gcm^{-3} to 1.81 gcm^{-3} for the PVC-based paving blocks. This range indicates that variations in the sand-to-plastic ratios influence density, with higher sand content generally leading to increased density, similar to trends observed in previous studies (Kumi-Larbi et al., 2018; Nur Hidayah et al., 2015; Ridha et al., 2019). Notably, the density values are lower compared to those found in PET-based blocks, suggesting that the material properties of PVC may contribute to a lighter overall composition.

All water absorption values recorded for the samples are **0.00**, indicating that these PVC blocks exhibit minimal water absorption. This uniform result suggests a strong impermeability in the mixtures, potentially due to effective bonding between the PVC and the sand particles or simply a dense structure that does not allow water penetration. The absence of water absorption across all experiments may also highlight the need for further exploration of the mixing processes to optimize material interaction.

The compressive strength values range from **6,331,250 Pa** to **6,668,111 Pa**, with the highest strength observed in Experiments 1 and 2, where the sand-to-plastic ratio was consistently maintained at 3:1. This finding supports the hypothesis that optimal material composition is crucial for enhancing mechanical properties, as higher ratios of sand appear to contribute positively to compressive strength (Agrawal et al., 2023).

4.1.3 Density, Water Absorption, and Compressive Strength of PET and Sand Particles with Pore Size of 1.2 mm

The table 4.3 shows values of response parameters; Density, Water Absorption, and Compressive Strength of PET and Sand Particles with Pore Size of 0.5 mm

Table 4.3: Values of Density, Water Absorption, and Compressive Strength of PET and Sand Particles with Pore Size of 1.2 mm

Exp #	Amount of sand, X_1 (g)	Amount of plastic, X_2 (g)	Density, **D,** (gcm^{-3})	Absorbance, **A**	Compressive strength, **C,** (Pa)
1	300	100	1.85	0.51	6937278
2	300	100	1.84	0.47	6815583
3	158.58	135.36	1.66	0.58	912333
4	500	100	1.76	3.14	5737528
5	300	50	1.65	2.82	3853000
6	300	100	1.85	0.51	6740944
7	441.42	135.36	1.82	1.49	6614389
8	300	150	1.72	0.53	4541194
9	158.58	64.64	1.71	1.10	5878917
10	300	100	1.85	0.50	6600306
11	441.42	64.64	1.53	4.45	1384861
12	300	100	1.85	0.51	6729444
13	100	100	1.91	0.50	6669861

The results in Table 4.3 indicate a density range of 1.53 gcm^{-3} to 1.91 gcm^{-3} for the PET-based paving blocks. This range suggests that the density of the blocks remains relatively consistent across different mixtures, with a slight increase observed in Experiment 13, where a 1:1 sand-to-plastic ratio was used. This higher density may reflect an effective combination of materials that enhances the overall composition of the block.

The absorbance values exhibit notable variability, ranging from 0.47 to 4.45, with Experiment 4 recording the highest water absorption at **3.14**. This suggests increased porosity in that mixture, which could be beneficial for applications requiring improved drainage. Conversely, the lower water absorption values in other experiments indicate that certain formulations achieve a more impermeable structure, which may enhance durability (Zulkernain et al., 2021). The absorbance results highlight the influence of the sand-to-plastic ratio and the particle size on the material's water retention characteristics.

Compressive strength values range from **387,300 Pa** to **6,937,278 Pa**, with the highest strengths observed in Experiments 1 and 2, where a consistent 3:1 sand-to-plastic ratio is maintained. This finding reinforces the notion that optimal material composition significantly enhances mechanical properties, particularly compressive strength. In contrast, the lower compressive strength in Experiment 5, with a 6:1 sand-to-plastic ratio, indicates that excessively high sand content may compromise the structural integrity of the block.

4.1.4 Density, Water Absorption, and Compressive Strength of PVC and Sand Particles with Pore Size of 12 mm

The table 4. shows values of response parameters; Density, Water Absorption, and Compressive Strength of PVC and Sand Particles with Pore Size of 1.2 mm

Table 4.4: Values of Density, Water Absorption, and Compressive Strength of PVC and Sand Particles with Pore Size of 1.2 mm

Exp #	Amount of sand, X_1 (g)	Amount of plastic, X_2 (g)	Density, **D,** (gcm^{-3})	Absorbance, **A**	Compressive strength, **C,** (Pa)
1	300	100	1.69	0.00	6747056
2	300	100	1.69	0.00	6223083
3	158.58	135.36	1.28	0.00	6462861
4	500	100	1.64	0.00	6537222
5	300	50	1.79	0.00	6161917
6	300	100	1.70	0.00	6554444
7	441.42	135.36	1.67	0.00	6922167
8	300	150	1.57	0.00	6566417
9	158.58	64.64	1.61	0.00	6592778
10	300	100	1.69	0.00	6657555
11	441.42	64.64	1.79	0.00	7351083
12	300	100	1.70	0.00	6717528
13	100	100	1.62	0.00	6682194

The results in Table 4.4 indicate a density range of **1.28** gcm^{-3} to **1.79** gcm^{-3} for the PVC-based paving blocks. The density values suggest that variations in the sand-to-plastic ratios significantly affect the overall density, with the highest density observed in Experiment 5, which features a 6:1 sand-to-plastic ratio. This finding implies that a careful balance of materials can enhance the density of the paving blocks while still maintaining performance characteristics.

All absorbance values recorded across the experiments are **0.00**, indicating that these PVC blocks exhibit excellent impermeability. This consistent result suggests a strong bond between the PVC and sand particles, reflecting effective mixing and a denser structure that prevents water penetration. The absence of water absorption across all experiments highlights the potential for these blocks to perform well in environments where moisture resistance is critical.

Compressive strength values range from **6,162,917 Pa to 7,351,083 Pa**, with the highest strength recorded in Experiment 11. This strong performance reinforces the idea that the optimal sand-to-plastic ratio contributes positively to the mechanical properties of the blocks. The consistent compressive strengths across different formulations suggest that PVC, when combined with sand, yields robust structural integrity.

4.2 General Comparison and Contrast of the Results

The experimental results for paving blocks made from PET and PVC, utilizing sand particles of different sizes (0.5 mm and 1.2 mm), reveal distinct differences in physical properties and performance characteristics influenced by both the type of plastic and the sand particle size.

4.2.1 Density

For both PET and PVC blocks with a sand particle size of 0.5 mm, the density values ranged from 1.59 gcm^{-3} to 1.85 gcm^{-3} for PET and from 1.28 gcm^{-3} to 1.79 gcm^{-3} for PVC with a particle size of 1.2 mm. PET blocks consistently exhibited higher densities compared to PVC blocks. The higher density in PET blocks may be attributed to the material's inherent properties, which contribute to a more robust composition when mixed with sand. In contrast, PVC blocks generally showed lower density, particularly at the 1.2 mm particle size, suggesting that variations in material properties significantly impact the overall density.

4.2.2 Water Absorption

Water absorption values differed notably between the two plastic types and particle sizes. PET blocks with a sand size of 0.5 mm displayed a range of absorbance values, with some experiments indicating improved porosity. Conversely, all PVC samples, regardless of sand particle size, registered an absorbance of 0.00, indicating superior impermeability. This suggests that PVC's chemical composition may facilitate a stronger bond with sand, resulting in a dense structure that effectively prevents water penetration.

4.2.3 Compressive Strength

The compressive strength of the blocks varied significantly between the different materials and sand sizes. For PET blocks with a 0.5 mm sand size, compressive strength values ranged from 1,246,750 Pa to 6,818,222 Pa, while the PVC blocks exhibited values between 6,162,917 Pa and 7,351,083 Pa for the 1.2 mm sand size. Notably, the highest compressive strengths for PET were recorded at a 3:1 sand-to-plastic ratio, reinforcing the importance of optimal material composition. In comparison, PVC blocks also demonstrated strong compressive strength across various formulations, indicating robust structural integrity.

4.2.4 Influence of Particle Size

The change in sand particle size from 0.5 mm to 1.2 mm affected both the density and absorbance characteristics significantly. PET blocks with a larger sand particle size showed a slight increase in density but varied in compressive strength and water absorption. In contrast, PVC blocks maintained a consistent lack of water absorption regardless of particle size, suggesting that larger sand particles do not compromise the impermeability of the PVC mixture.

In conclusion, the comparison of PET and PVC paving blocks across different sand particle sizes illustrates the critical role that material selection and composition play in determining physical properties. While PET blocks may offer higher density and variable compressive strength, PVC blocks demonstrate superior impermeability and consistent mechanical performance. This analysis underscores the potential for tailoring material formulations to optimize performance characteristics in sustainable construction applications.

4.3 Optimization of the Process Parameters for the Paving block Samples

To ensure the robustness of the models developed in this study, an Analysis of Variance (ANOVA) was conducted, with results documented in Tables 4.4 through 4.8. Following the application of regression analysis to elucidate the relationships between the responses and the input factors, several regression equations were derived: equations (4.1), (4.2), (4.3), and (4.4) were generated for density; equations (4.5) and (4.6) addressed water absorption; and equations (4.7), (4.8), (4.9), and (4.10) were formulated for compressive strength. These equations serve as predictive models, enabling the identification of optimal parameter settings for achieving desired material properties.

4.3.1 Optimization of Process Parameters for Density

With reference to coded terms in Tables 3.3 and 3.4, the final regression equations (4.1). (4.2), (4.3) and (4.4) were generated for density.

$$D_1 = 1.474 + 0.001248x_1 + 0.00244x_2 - 12.8x_1^2 - 0.000005x_2^2 + 0.000005x_1x_2 \;\ldots\ldots\; (4.1)$$

$$D_2 = 1.368 - 0.001110x_1 + 0.01234x_2 - 0.000001x_1^2 - 0.000081x_2^2 + 0.000017x_1x_2.\; (4.2)$$

$$D_3 = 1.689 - 0.00189x_1 + 0.00541x_2 + 0.000002x_1 - 0.000055x_2^2 + 0.000041x_1x_2 \;.\; (4.3)$$

$$D_4 = 1.709 + 0.00095x_1 - 0.00202x_2 - 0.000002x_1^2 - 0.000019x_2^2 + 0.000011x_1x_2..\; (4.4)$$

Table 4.5: ANOVA for density of paving blocks modelled using PET waste plastic

Source	DF	Adj SS	Adj MS	F-value	P-value	Remark
PET 0.5mm						
Model	5	0.063713	0.012743	8.53	0.007	Significant
Linear	2	0.045187	0.022593	15.13	0.003	Significant
x_1	1	0.039941	0.039941	26.74	0.001	Significant
x_2	1	0.005246	0.005246	3.51	0.103	Insignificant
Square	2	0.016027	0.008013	5.36	0.039	Significant
x_1^2	1	0.012053	0.012053	8.07	0.025	Significant
x_2^2	1	0.005901	0.005901	3.95	0.087	Insignificant
2-way interaction	1	0.002500	0.002500	1.67	0.237	Insignificant
x_1x_2	1	0.002500	0.002500	1.67	0.237	Insignificant
Error	7	0.010456	0.001494			
Lack of fit	3	0.010176	0.003392	48.46	0.001	Significant
Pure Error	4	0.000280	0.000070			
Total	12	0.074169				
R-squared	85.90%					
PET 1.2mm						
Model	5	0.122913	0.024583	8.61	0.007	Significant
Linear	2	0.021100	0.010550	3.70	0.080	Insignificant
x_1	1	0.006736	0.006736	2.36	0.168	Insignificant
x_2	1	0.014365	0.014365	5.03	0.060	Insignificant
Square	2	0.072912	0.036456	12.77	0.005	Significant
x_1^2	1	0.004885	0.004885	1.71	0.232	Insignificant
x_2^2	1	0.071668	0.071668	25.11	0.002	Significant
2-way interaction	1	0.028900	0.028900	10.13	0.015	Significant
x_1x_2	1	0.028900	0.028900	10.13	0.015	Significant
Error	7	0.019980	0.002854			
Lack of fit	3	0.019900	0.006633	333.66	0.000	Significant
Pure Error	4	0.000080	0.000020			
Total	12	0.142892				
R-squared	86.02%					

Table 4.6: ANOVA for density of paving blocks modelled using PVC waste plastic

Source	DF	Adj SS	Adj MS	F-value	P-value	Remark
PVC 0.5mm						
Model	5	0.134781	0.026956	4.54	0.036	Significant
Linear	2	0.067962	0.033981	5.72	0.034	Significant
x_1	1	0.052649	0.052646	8.86	0.021	Significant
x_2	1	0.015312	0.015312	2.58	0.152	Insignificant
Square	2	0.045794	0.022897	3.85	0074	Insignificant
x_1^2	1	0.007924	0.007924	1.33	0.286	Insignificant
x_2^2	1	0.032880	0.032880	5.54	0.051	Insignificant
2-way interaction	1	0.021025	0.021025	3.54	0.102	Insignificant
x_1x_2	1	0.021025	0.021025	3.54	0.102	Insignificant
Error	7	0.041588	0.005941			
Lack of fit	3	0.041188	0.013729	137.29	0.000	Significant
Pure Error	4	0.000400	0.000100			
Total	12	0.176369				
R-Squared	76.42%					
PVC 1.2mm						
Model	5	0.146967	0.029393	4.26	0.042	Significant
Linear	2	0.117157	0.058579	8.49	0.013	Significant
x_1	1	0.044743	0.044743	6.48	0.038	Significant
x_2	1	0.072414	0.072414	10.49	0.014	Significant
Square	2	0.018785	0.009392	1.36	0.317	Insignificant
x_1^2	1	0.016617	0.016617	2.14	0.165	Insignificant
x_2^2	1	0.003965	0.003965	0.57	0.473	Insignificant
2-way interaction	1	0.011025	0.011025	1.60	0.247	Insignificant
x_1x_2	1	0.011025	0.011025	1.60	0.247	Insignificant
Error	7	0.048325	0.006904			
Lack of fit	3	0.048205	0.016068	535.61	0.000	Significant
Pure Error	4	0.000120	0.000030			
Total	12	0.195292				
R-square	75.25%					

The final regression equations for density, represented as equations (4.1), (4.2), (4.3), and (4.4), were derived using Response Surface Methodology (RSM) to model the relationships between the independent variables (amounts of sand and plastic) and the dependent variable (density). These quadratic equations incorporate linear, square, and interaction terms, allowing for a thorough representation of how varying amounts of sand and plastic influence the density of the paving blocks. The inclusion of square terms captures curvature in the response surface, indicating that the effects of each variable may not be strictly linear, while interaction terms elucidate how the combination of both variables affects density.

To assess the significance of the regression models and the individual coefficients, an Analysis of Variance (ANOVA) was conducted. The p-values obtained from ANOVA serve as indicators of statistical significance for the model and its terms. Specifically, a p-value less than 0.05 suggests that the model or term is statistically significant, providing strong evidence against the null hypothesis (which posits that the term has no effect). For instance, the PET model with a sand size of 0.5 mm shows a significant p-value of 0.007, indicating a robust relationship, while the linear term for sand (x_1) in this model has an even lower p-value of 0.001, emphasizing its substantial influence on density.

In contrast, a p-value greater than or equal to 0.05 indicates a lack of statistical significance. For the PET 1.2 mm model, both the linear terms for sand and plastic yield p-values above 0.05, suggesting that their direct impacts on density are not significant in this context. The F-values from the ANOVA provide additional insight into the relative importance of each term; a higher F-value indicates a greater proportion of variability explained by that factor compared to residual variability (Kleijnen, 2015). For the 0.5 mm sand size, the F-value for the amount of sand (x_1) is 26.74, significantly higher than that for plastic (x_2), which is 3.51. This result indicates that for smaller sand particle sizes, the amount of sand plays a more critical role in determining density.

Conversely, for the 1.2 mm sand size, the F-values for the amount of plastic (x_2) exceed those for sand (x_1), indicating that plastic becomes more influential in determining density as the particle size increases. The R-squared values further elucidate the model fit; the PET 1.2 mm model exhibits the highest R-squared value of 86.02%, suggesting a strong explanation of variance in density. In contrast, the PVC models display lower R-squared values of 76.42% for 0.5 mm and 75.25% for 1.2 mm, indicating a less effective overall fit. This discrepancy suggests that additional factors or interactions may need to be considered to fully capture the behaviour of PVC-based blocks.

4.3.2 Optimization of Process Parameters for Water Absorption

Water absorbance is one of the factors that affect the durability of the paving blocks and once the absorbance levels are high then there will be low chloride resistance as well as low water penetration resistance (Namarak et al., 2018). No RSM analysis was done for absorbance of PVC waste plastic modeled paving blocks because it was observed that the results for absorbance were all 0.000 as seen from tables 3.6 and 4.2, for all the modelled paving blocks. This was because the PVC plastics tightly held the sand particles together such that no pore spaces were left. ANOVA analysis was only possible for PET waste plastic modelled paving blocks and yielded regression equations (5) and (6) to show the relationship between absorbance and the factor (amounts of sand and plastic).

$A_1 = 2.03 + 0.00916x_1 - 0.0530x_2 + 0.000003x_1^2 + 0.000322x_2^2 - 0.000091x_1x_2$…..... (4.5)

$A_2 = 5.258 - 0.00172x_1 + 0.08745x_2 - 0.000035x_1^2 + 0.000502x_2^2 - 0.000122x_1x_2$... (4.6)

A table to show the ANOVA was generated and shown in table 4.4.

Table 4.7: The ANOVA results for PET-based paving blocks

Source	DF	Adj SS	Adj MS	F-value	P-value	Remark
PET 0.5mm						
Model	5	5.12380	1.02476	8.05	0.008	Significant
Linear	2	3.16831	1.58416	12.44	0.005	Significant
x_1	1	0.64509	0.64509	5.07	0.059	Insignificant
x_2	1	2.52323	2.52323	19.82	0.003	Significant
Square	2	1.12739	0.56369	4.43	0.057	Insignificant
x_1^2	1	0.02928	0.02928	0.23	0.646	Insignificant
x_2^2	1	1.12630	1.12630	8.85	0.021	Significant
2-way interaction	1	0.82810	0.82810	6.50	0.038	Significant
x_1x_2	1	0.82810	0.82810	6.50	0.038	Significant
Error	7	0.89117	0.29702			
Lack of fit	3	0.89105	0.29702	9900.53	0.000	Significant
Pure Error	4	0.00012	0.00003			
Total	12	6.01497				
R-squared	85.18%					
PET 1.2mm						
Model	5	20.5510	4.11019	310.21	0.000	Significant
Linear	2	13.6294	6.81471	541.33	0.000	Significant
x_1	1	7.9871	7.98705	602.82	0.000	Significant
x_2	1	5.6424	5.64236	425.85	0.000	Significant
Square	2	5.4331	2.71657	205.03	0.000	Significant
x_1^2	1	3.4026	3.40261	256.81	0.000	Significant
x_2^2	1	2.7337	2.73372	20633	0.000	Significant
2-way interaction	1	1.4884	1.48840	112.34	0.000	Significant
x_1x_2	1	1.4884	1.48840	112.34	0.000	Significant
Error	7	0.0927	0.01325			
Lack of fit	3	0.0915	0.03052	101.72	0.000	Significant
Pure Error	4	0.0012	0.00030			
Total	12	20.6437				

The ANOVA results for PET-based paving blocks revealed that both models, one for 0.5 mm sand particle size and another for 1.2 mm, were statistically significant, with p-values below 0.05. Notably, the model for the 1.2 mm sand particle size exhibited particularly strong significance, with the lowest p-value of 0.000. This indicates a robust correlation between the independent variables; the amounts of sand and plastic and the absorbance response. For the 0.5 mm sand size, the amount of plastic had the highest F-value of 19.82, signifying its substantial influence on absorbance compared to the amount of sand, which had an F-value of 5.07. This trend can be attributed to the finer sand particles creating a denser matrix that allows the plastic to effectively fill voids and bind the particles, thus minimizing water absorption. In contrast, for the 1.2 mm sand size, the amount of sand yielded the highest F-value of 602.82, highlighting its dominant effect on water absorption, while the amount of plastic also showed a significant influence with an F-value of 425.85. The larger sand particles tend to create more significant voids within the composite, which can lead to increased water absorption if not adequately filled. Therefore, optimizing the amount of sand becomes critical for controlling water ingress, while the plastic still plays a substantial role in binding the larger particles and reducing effective porosity.

The R-squared values for both models demonstrated a strong fit, with the PET model using 1.2 mm sand achieving an R-squared of 85.18%. This indicates that the model effectively explains a significant portion of the variance in water absorption, reinforcing the validity of the relationships captured between the input factors and the absorbance response. The significant p-values for all terms in the PET 1.2 mm model further confirm the robustness of the findings, suggesting that both the amounts of sand and plastic, along with their interactions, play critical roles in determining the water absorption characteristics of the paving blocks.

The insights gained from this study have crucial implications for the design of durable paving materials. By optimizing the proportions of sand and plastic, manufacturers can enhance the water resistance of PET-based paving blocks, which is vital for their performance in environments prone to moisture exposure. Understanding the relationships described by the statistical analyses allows for tailored formulations that balance durability with desirable physical properties (Komakech et al., 2014).

4.3.3 Optimization of Process Parameters for Compressive Strength.

This is always carried out by a compression test which is a common test done on hardened concrete material as an early test to show performance ability and a desirable characteristic of paving blocks (Kaviya, 2016). So, it was done by using a compressive machine called TESTOMERIC of type DBBMTCL 2500kg-1.5-000 and of serial number 57027 and final regression equations (7), (8), (9) and (10) to show the relationship between Compressive strength and the factor (amount of sand and plastic) were generated.

$C_1 = 20010882 - 42676x_1 - 180896x_2 - 10.0x_1^2 - 71x_2^2 + 558x_1x_2$ .... (4.7)

$C_2 = 9622221 - 43392x_1 + 52949x_2 - 12.8x_1^2 + 1008x_2^2 + 510x_1x_2$ .... (4.8)

$$C_3 = 7127906 - 876x_1 - 2962x_2 - 3.59x_1^2 - 30.5x_2^2 + 25.5x_1x_2 \quad (4.9)$$

$$C_4 = 6141202 - 646x_1 + 7982x_2 + 5.06x_1^2 - 17x_2^2 - 14.9x_1x_2 \quad (4.10)$$

Table 4.8: ANOVA for Compressive Strength of paving blocks modelled using PET waste plastic

Source	DF	Adj SS	Adj MS	F-value	P-value	Remark
PET 0.5mm						
Model	5	4.73×10^{13}	9.46×10^{12}	1.12	0.431	Insignificant
Linear	2	1.58×10^{13}	7.92×10^{12}	0.93	0.437	Insignificant
x_1	1	8.23×10^{12}	8.23×10^{12}	0.97	0.357	Insignificant
x_2	1	7.61×10^{12}	7.61×10^{12}	0.90	0.375	Insignificant
Square	2	3.05×10^{11}	1.52×10^{11}	0.02	0.982	Insignificant
x_1^2	1	2.77×10^{11}	2.77×10^{11}	0.03	0.862	Insignificant
x_2^2	1	5.47×10^{10}	5.47×10^{10}	0.01	0.938	Insignificant
2-way interaction	1	3.12×10^{13}	3.12×10^{13}	3.68	0.097	Insignificant
x_1x_2	1	3.12×10^{13}	3.12×10^{13}	3.68	0.097	Insignificant
Error	7	5.93×10^{13}	8.48×10^{12}			
Lack of fit	3	1.58×10^{13}	5.25×10^{12}	0.48	0.712	Insignificant
Pure Error	4	4.36×10^{13}	1.09×10^{13}			
Total	12	1.07×10^{14}				
R-square	44.37%					
PET 1.2mm						
Model	5	3.73×10^{13}	7.46×10^{12}	5.41	0.024	Significant
Linear	2	1.93×10^{11}	9.63×10^{10}	0.07	0.933	Insignificant
x_1	1	1.53×10^{09}	1.53×10^{09}	0.00	0.974	Insignificant
x_2	1	1.90×10^{11}	1.91×10^{11}	0.14	0.721	Insignificant
Square	2	1.11×10^{13}	5.55×10^{12}	4.03	0.069	Insignificant
x_1^2	1	4.57×10^{11}	4.57×10^{11}	0.33	0.583	Insignificant
x_2^2	1	1.10×10^{13}	1.10×10^{13}	8.01	0.025	Significant
2-way interaction	1	2.60×10^{13}	2.60×10^{13}	18.87	0.003	Significant
x_1x_2	1	2.60×10^{13}	2.60×10^{13}	18.87	0.003	Significant
Error	7	9.64×10^{12}	1.34×10^{12}			
Lack of fit	3	5.38×10^{12}	1.79×10^{12}	1.68	0.307	Insignificant
Pure Error	4	4.27×10^{12}	1.09×10^{12}			
Total	12	4.69×10^{13}				
R-squared	79.45%					

Table 4.9: ANOVA for Compressive Strength of paving blocks modelled using PVC waste plastic

Source	DF	Adj SS	Adj MS	F-value	P-value	Remark
PVC 0.5mm						
Model	5	1.64 x 10^{11}	3.28 x 10^{10}	1.89	0.214	Insignificant
Linear	2	5.77 x 10^{10}	2.88 x 10^{10}	1.66	0.257	Insignificant
x_1	1	3.76 x 10^{10}	3.76 x 10^{10}	2.17	0.185	Insignificant
x_2	1	2.01 x 10^{10}	2.01 x 10^{10}	1.16	0.318	Insignificant
Square	2	4.17 x 10^{10}	2.08 x 10^{10}	1.20	0.356	Insignificant
x_1^2	1	3.59 x 10^{10}	3.59 x 10^{10}	2.06	0.194	Insignificant
x_2^2	1	1.01 x 10^{10}	1.01 x 10^{10}	0.58	0.471	Insignificant
2-way interaction	1	6.48 x 10^{10}	6.48 x 10^{10}	3.73	0.095	Insignificant
x_1x_2	1	6.48 x 10^{10}	6.48 x 10^{10}	3.73	0.095	Insignificant
Error	7	1.22 x 10^{11}	1.74 x 10^{10}			
Lack of fit	3	3.74 x 10^{10}	1.25 x 10^{10}	0.59	0.652	Insignificant
Pure Error	4	8.41 x 10^{10}	2.10 x 10^{10}			
Total	12	2.86 x 10^{11}				
R-squared	57.45%					
PVC 1.2mm						
Model	5	2.30 x 10^{11}	4.61 x 10^{10}	0.39	0.843	Insignificant
Linear	2	1.28 x 10^{11}	6.41 x 10^{10}	0.54	0.606	Insignificant
x_1	1	1.28 x 10^{11}	1.28 x 10^{11}	1.08	0.334	Insignificant
x_2	1	2.18 x 10^{07}	2.18 x 10^{07}	0.00	0.990	Insignificant
Square	2	7.98 x 10^{10}	3.99 x 10^{10}	0.34	0.726	Insignificant
x_1^2	1	7.13 x 10^{10}	7.13 x 10^{10}	0.60	0.464	Insignificant
x_2^2	1	3.23 x 10^{09}	3.23 x 10^{09}	0.03	0.874	Insignificant
2-way interaction	1	2.24 x 10^{10}	2.24 x 10^{10}	0.19	0.678	Insignificant
x_1x_2	1	2.24 x 10^{10}	2.24 x 10^{10}	0.19	0.678	Insignificant
Error	7	8.32 x 10^{11}	1.19 x 10^{11}			
Lack of fit	3	6.51 x 10^{11}	2.17 x 10^{11}	4.80	0.082	Insignificant
Pure Error	4	1.81 x 10^{11}	4.52 x 10^{10}			
Total	12	1.06 x 10^{12}				
R-square	21.68%					

The ANOVA results indicate that, except for the PET waste plastic combined with a sand particle size of 1.2 mm, all other models (including PET at 0.5 mm, PVC at 0.5 mm, and PVC at 1.2 mm) were statistically insignificant, showing low R-squared values of 44.37% for PET 0.5 mm, 57.45%

for PVC 0.5 mm, and 21.68% for PVC 1.2 mm. These values suggest a poor fit for the models and a weak relationship between the response (compressive strength) and the factors (amounts of sand and plastic), as highlighted by Bal et al. (2019).

In contrast, the PET 1.2 mm model exhibited a significant relationship with a p-value of 0.024 and a higher R-squared value of 79.45%, indicating a better fit for the model. This suggests that the combination of PET with 1.2 mm sand particles results in a more effective interaction between the components, leading to improved compressive strength. The interaction between the amounts of sand and plastic is likely a critical factor that enhances the overall structural integrity of the paving blocks.

The significant model for PET 1.2 mm implies that optimizing these parameters can lead to better mechanical properties, which is essential for applications requiring durable paving materials. The findings highlight the importance of material selection and the need for tailored formulations to achieve desirable performance characteristics in paving blocks.

4.4 Optimization Summary

Table 4.10 shows a summary of the ANOVA

Table 4.10: General summary of the ANOVA for the responses

RESPONSE	CODE	COMPOSITION	R – Squared	P-value OF MODEL	REMARK
Density	D_1	PET, 0.5mm	85.80%	0.007	Significant
	D_2	PET, 1.2mm	86.02%	0.007	Significant
	D_3	PVC, 0.5mm	76.42%	0.036	Significant
	D_4	PVC, 1.2mm	75.25%	0.042	Significant
Absorbance	A_1	PET, 0.5mm	85.18%	0.008	Significant
	A_2	PET, 1.2mm	99.55%	0.000	Significant
Compressive strength	C_1	PET, 0.5mm	44.37%	0.431	Insignificant
	C_2	PET, 1.2mm	79.42%	0.024	Significant
	C_3	PVC, 0.5mm	57.45%	0.214	Insignificant
	C_4	PVC, 1.2mm	21.68%	0.843	Insignificant

The ANOVA summary indicates that only the paving blocks moulded with PET waste plastic and 1.2 mm sand produced successful models across all responses, as shown in Table 4.10. This formulation achieved an impressive R-squared value of 99.55% for absorbance and a significant P-value of 0.000, indicating a strong relationship between the factors and the response variable. In contrast, compressive strength models for PET 0.5 mm and PVC showed low R-squared values (44.37% and 21.68%, respectively), suggesting poor fits and weak relationships.
The significant model for PET 1.2 mm, with an R-squared of 79.42% and a P-value of 0.024, underscores the importance of sand particle size in enhancing mechanical properties (Gao, 2024). Studies by Uchida et al. (2011) and Kaviya (2016) further contextualize these findings, emphasizing the influence of material composition and methodological choices on performance (Greve, et al., 2016).

To deepen the understanding of the relationships between factors and response variables (density, absorbance, compressive strength), 2-D and 3-D plots will be generated as seen from Figure 4.1 to Figure 4. These visual tools will aid in identifying optimal factor settings and validating the models, ultimately supporting the development of high-performance paving materials from recycled plastic waste.

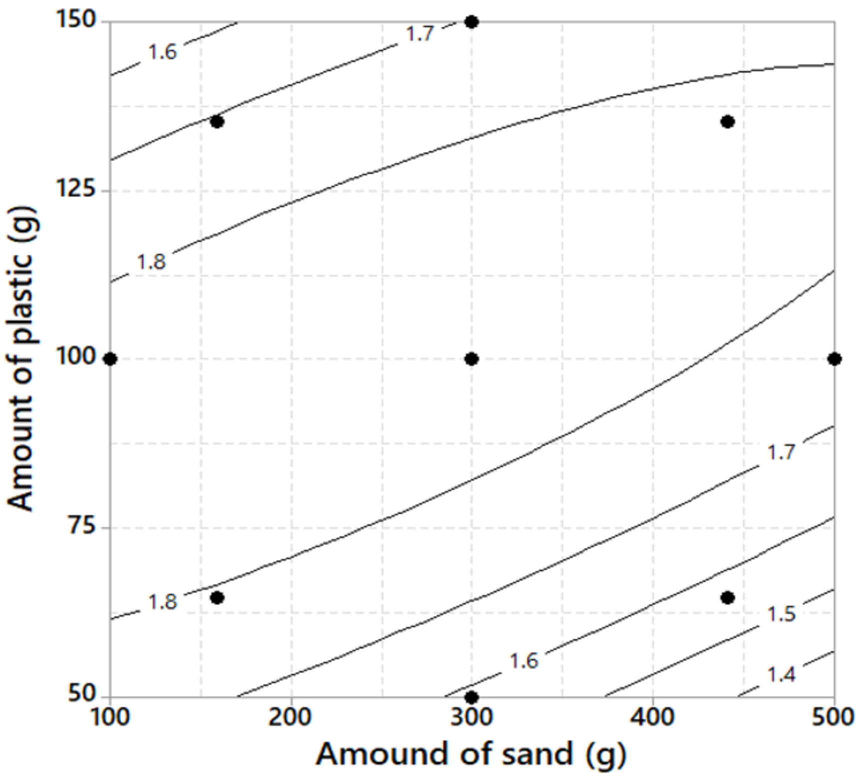

Figure 4.1: Surface Plot Showing the Effects of PET and Sand Particle Size (1.2 mm) on Density in 2-D

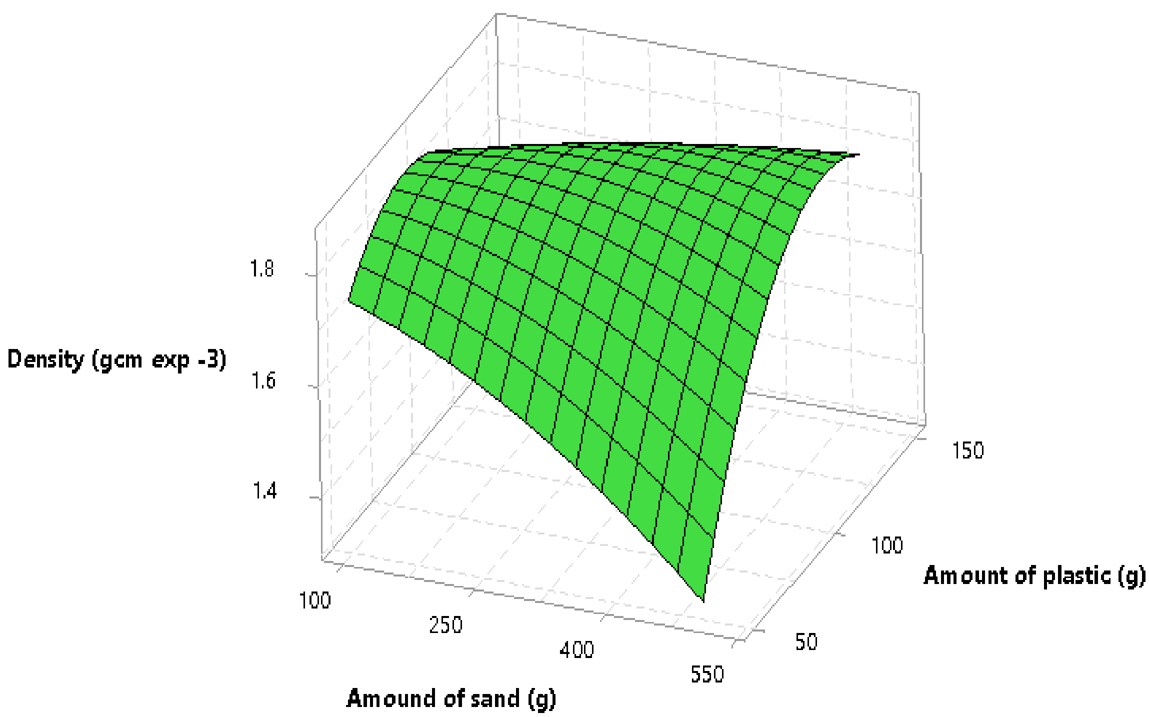

Figure 4.2: Surface Plot Showing the Effects of PET and Sand Particle Size (1.2 mm) on Density in 3-D

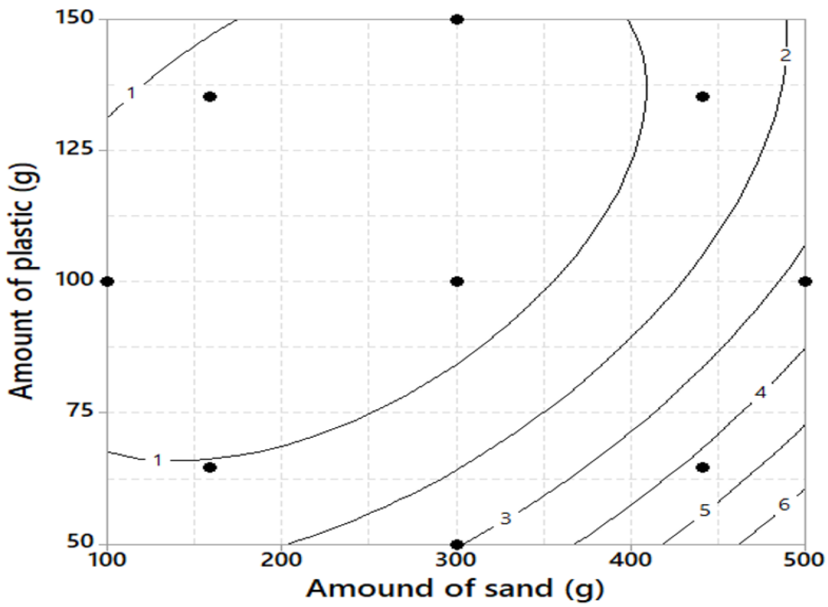

Figure 4.3: Surface Plot Showing the Effects of PET and Sand Particle Size (1.2 mm) on Density in 3-D

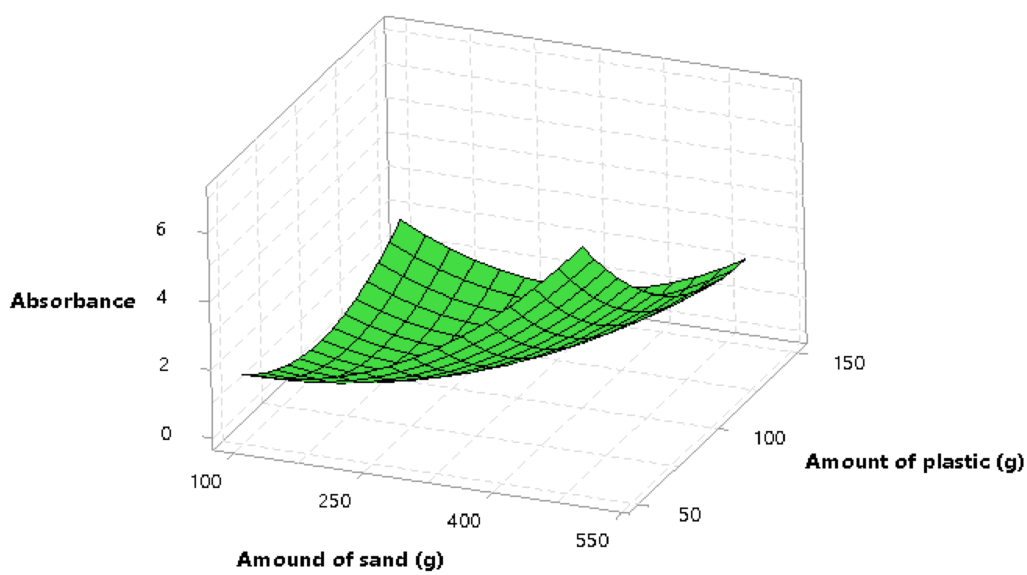

Figure 4.4: Surface Plot Showing the Effects of PET and Sand Particle Size (1.2 mm) on Absorbance in 3-D

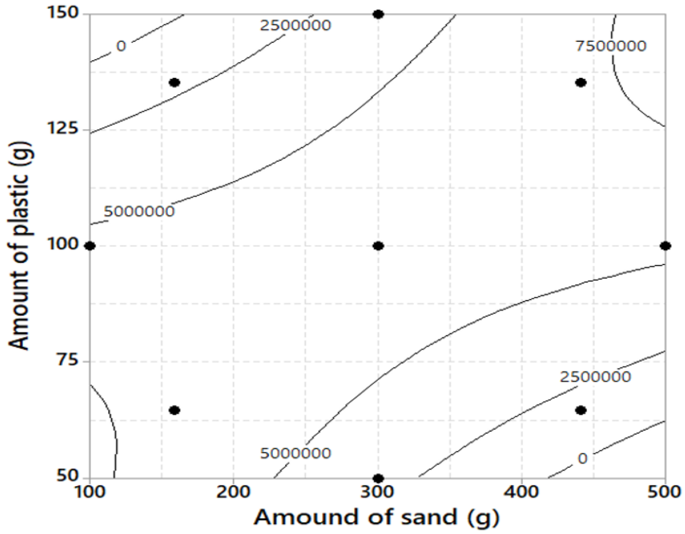

Figure 4.5: Surface Plot Showing the Effects of PET and Sand Particle Size (1.2 mm) on Compressive Strength in 2-D

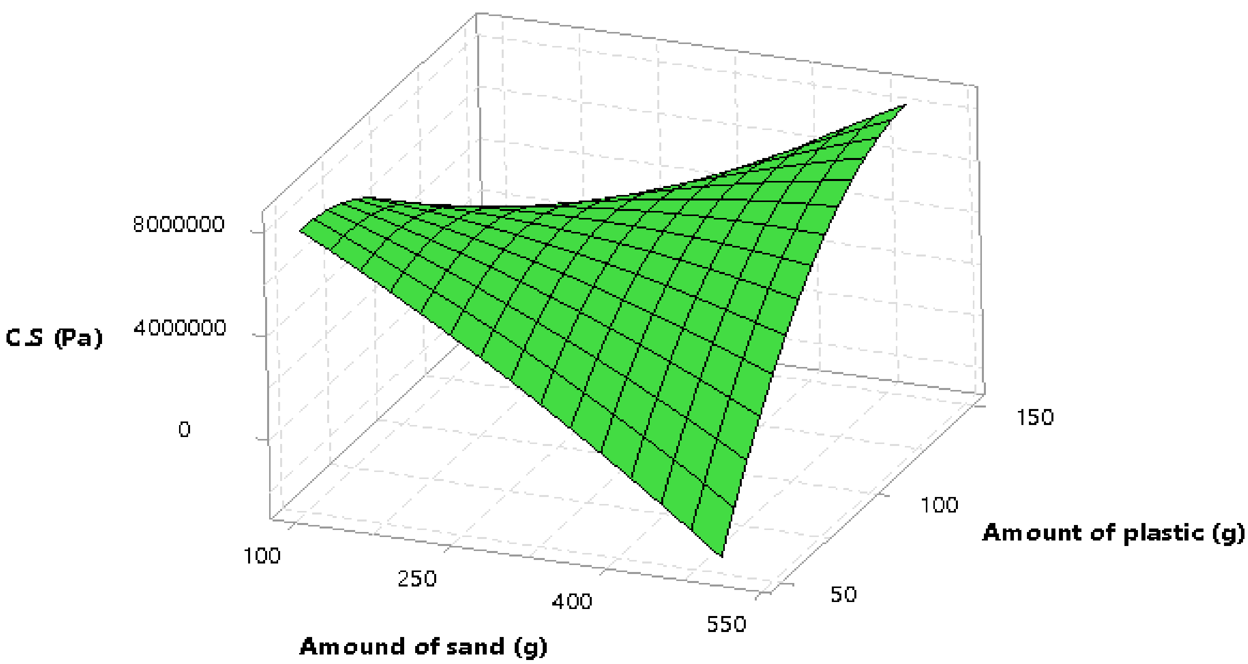

Figure 4.6: Surface Plot Showing the Effects of PET and Sand Particle Size (1.2 mm) on Compressive Strength in 3-D

4.5 Relationship Between Water Absorption, Density, and Compressive Strength in Paving Blocks

There is an inverse relationship between water absorption and density in paving blocks, as established by (Namarak et al., 2018). A decrease in density corresponds to an increase in water absorption levels, primarily due to the presence of pore spaces within the material. Increased water absorption indicates a higher volume of voids, which reduces the mass of the paving block, leading to lower density. Consequently, paving blocks with higher density tend to exhibit lower water absorption rates.

Data presented in Figures 4.1 to 4.6 demonstrate that at a low binder material content of 50 g of plastic, increasing the sand content from 100 g to 500 g results in a gradual decrease in density from approximately 1.8 g/cm^3 to about 1.4 g/cm^3. Simultaneously, water absorption rises from around 1% to over 6%, while compressive strength declines from 7.5 MPa to approximately 2.5 MPa, this inverse relationship that exists between water absorption and compressive strength is consistent with the findings by Kashiyani et al., (2013).

This phenomenon can be explained by three key factors: (1) With low binder content, an increase in sand leads to inadequate binding between particles, resulting in numerous pore spaces that enhance water absorption. (2) The increase in pore spaces leads to a reduction in overall mass, contributing to the decline in density. (3) Excessive pore spaces compromise the structural integrity of the paving block, making it more susceptible to breakage, which explains the reduction in compressive strength as sand content increases.

These findings align with previous studies by Ling (2012), Namarak et al. (2018), and Veerakumar (2018), which highlight the critical role of material composition in determining the mechanical properties of paving blocks.

Therefore, it is essential to establish optimal values for the amounts of sand and plastic in moulding paving blocks. This will ensure a balance that maximizes performance characteristics while maximizing compressive strength, minimizing high water absorption and low density, as indicated in Table 4.11. Ultimately, this knowledge is vital for advancing sustainable construction practices by effectively leveraging recycled materials.

4.6 Determining Values of Input Factors

Maintaining low density in paving blocks is crucial for several reasons that align with addressing plastic waste through construction. First, low density enhances thermal insulation, contributing to energy efficiency in buildings by regulating temperature variations. Second, it improves internal curing by allowing moisture retention within the concrete matrix, which promotes optimal hydration of cement and enhances strength development. Additionally, low density facilitates better compatibility between the paste and aggregate, resulting in a cohesive bond that improves the mechanical properties and durability of the paving blocks. Furthermore, lightweight paving blocks are easier to handle and install, which can lower labour costs and improve construction efficiency.

In addition to low density, low absorbance in paving blocks is critical for enhancing resistance to damage, as it increases durability and minimizes the risk of damage from freeze-thaw cycles and other environmental stressors. Low absorbance also provides superior chloride and sulphate resistance by limiting the ingress of aggressive ions that can cause chemical deterioration and corrosion of reinforcement. High compressive strength is fundamental for ensuring durability and performance, as it allows paving blocks to withstand significant mechanical loads without deformation, thereby extending their service life. Moreover, durable paving blocks require less frequent maintenance and repair, lowering lifecycle costs and enhancing sustainability. Finally, high compressive strength ensures that paving blocks can effectively carry heavy loads without fracturing, making them suitable for high-traffic applications (Davari et al., 2016; Kashiyani et al., 2013)

These properties collectively address the challenge of plastic waste by promoting the use of recycled materials in construction, resulting in paving blocks that are not only environmentally sustainable but also high-performing. This dissertation aims to highlight the potential of using plastic waste in paving block formulations, thereby contributing to sustainable construction practices and mitigating plastic waste challenges.

Utilizing the Surface Response Optimizer in Minitab 17, the optimal formulation for paving blocks characterized by low density, low water absorption, and high compressive strength was determined. Specifically, the desired characteristics of low for density, low for water absorption, and high for compressive strength were input. The software then automatically generated the corresponding predicted values for the response variables, as shown in Table 4.11.

In addition to these response values, Minitab also provided the required amounts of input factors necessary for moulding the ideal paving blocks, detailed in Table 4.12. The analysis indicated that to achieve the desired characteristics, the optimal amounts of factors were approximately 140 g - 155 g of sand and 45g - 55 g of plastic. This range accounts for variability in material properties and manufacturing conditions, ensuring flexibility in the production process.

This comprehensive optimization process not only highlights the effectiveness of statistical tools in formulating paving blocks that meet specific performance criteria but also directly addresses the pressing issue of plastic waste.

Table 4.11: Generated Response Values for Optimal Paving Block Characteristics

Factors	**Characteristics**	**Value**
Density	Low	1.715 gcm^{-3}
Absorbance	Low	1.049
Compressive strength	High	3.815 MPa

Table 4.12: Optimal Input Factors for Modeling Ideal Paving Blocks

Factor	**Amount (g)**
Sand	140 – 155
Plastic	45 – 55

The specific amounts presented are derived from regression models generated by Minitab, which utilized experimental data to identify optimal conditions for the paving blocks. This methodology ensures that the recommendations are robust and applicable in real-world manufacturing scenarios, allowing for adjustments based on varying material properties and environmental factors**.**

4.7 Validation of Model Results and Experimental Samples

Following the determination of the optimal amounts of sand and plastic required for the moulding of the paving blocks, two samples were produced for validation experiments. The validation process involved measuring various physical properties of the samples, with results systematically recorded in Tables 4.13 and 4.14 for density, Table 4.15 for absorbance, and Table 4.16 for compressive strength. To assess the accuracy of the experimental measurements, the percentage error was calculated using Equation 3.7:

4.7.1 Density

To ensure reliability, each measurement of the dimensions of the samples was taken four times, with averages calculated accordingly. The recorded values for Sample 1 are noted in Tables 4.13 and 4.14

Table 4.13: Measured Dimensions and Mass of Sample 1

	Length (cm)				Width (cm)				Height (cm)				Mass (g)
	L_1	L_2	L_3	L_4	W_1	W_2	W_3	W_4	H_1	H_2	H_3	H_4	
	5.93	5.94	5.96	5.94	6.08	6.05	6.08	6.05	2.98	3.02	2.98	3.01	
Average	**5.94**				**6.06**				**3.02**				**194.0**

The density of Sample 1 was calculated using the formula:

$$\boldsymbol{Density_1 = \frac{194.0}{5.94 * 6.06 * 3.02} = 1.784 gcm^{-3}}$$

Table 4.14: Measured Dimensions and Mass of Sample 2

	Length (cm)				Width (cm)				Height (cm)				Mass (g)
	L_1	L_2	L_3	L_4	W_1	W_2	W_3	W_4	H_1	H_2	H_3	H_4	
	5.89	5.89	5.89	5.93	6.06	6.06	6.08	6.08	3.00	3.00	3.00	3.00	
Average	**5.90**				**6.07**				**3.00**				**191.0**

The density of Sample 2 was calculated as follows:

$$\boldsymbol{Density_2 = \frac{191.0}{5.90 * 6.07 * 3.00} = 1.778 gcm^{-3}}$$

The average density of both samples is calculated as:

$$\boldsymbol{Average\ density} = \frac{\mathbf{1784 + 1.778}}{\mathbf{2}} = \mathbf{1.781} \boldsymbol{gcm^{-3}}$$

The percentage error in density is calculated as:

$$\%\ error = \left(\frac{1.781 - 1.715}{1.715}\right) * 100\% = 6.6\%$$

Since the percentage error is below 20%, the validation of the density measurement is deemed acceptable (José et al., 2013).

4.7.2 Absorbance

The initial dry mass m_1 of the samples was determined by weighing them on a beam balance, as recorded in Table 4.15. The samples were then suspended in water at room temperature for three hours. After removal, surface water was blotted away using drying paper, and the new mass m_2 was recorded. The water absorbance was calculated and subsequently averaged, as indicated in Table 4.15.

Table 4.15: Individual and Average Water Absorbance Measurements of Samples

	m_1 (g)	m_2 (g)	$\left(\frac{m_2 - m_1}{m_1}\right) \times 100\%$
Sample 1	194.0	196.0	1.031
Sample 2	191.0	193.5	1.309
Average absorbance			**1.170**

The percentage error in absorbance is calculated as:

$$\%\ error = \left(\frac{1.170 - 1.049}{1.049}\right) * 100\% = 11.5\%$$

Since the percentage error is below 20%, the validation of the absorbance measurement is confirmed (José et al., 2013).

4.7.3 Compressive strength.

To assess compressive strength, the samples were subjected to a crushing machine, where a load was applied until each paving block failed. The force at which each sample broke was recorded, and the compressive strength was calculated using the formula in Equation 3.6:

For sample 1:

$$Compressive\ strength = \frac{14950}{(5.94\ *\ 6.04) \times 10^{-4}} = 4.167\ MPa$$

For sample 2:

$$Compressive\ strength = \frac{14569.6}{(5.90\ *\ 6.07) \times 10^{-4}} = 4.068\ MP$$

Table 4.16: Individual and Average Compressive Strength Measurements of Samples

Sample	$l\ (cm)$	$l\ (cm)$	$copressive\ strenth\ (Pa)$
1	5.94	6.04	4.467
2	5.90	6.07	4.068
Average compressive strength			4.118

The percentage error in compressive strength is calculated as:

$$\%\ error = \left(\frac{4.118 - 3.815}{3.815}\right) * 100\% = 7.9\%$$

Since the percentage error is below 20%, the validation of the compressive strength measurement is confirmed (José et al., 2013).

CHAPTER FIVE: CONCLUSION AND RECOMMENDATIONS

The results of this study demonstrate that plastic waste, particularly PET, can be effectively integrated into construction practices, providing an innovative solution to the pressing issue of plastic disposal. This research aimed to address the environmental challenge posed by plastic waste while exploring alternative construction materials. Specifically, the use of PET plastic in combination with sand particles of 1.2 mm size, at optimal input amounts ranging from approximately 140 g to 155 g of sand and 45 g to 55 g of plastic, yielded paving blocks with desirable characteristics. These blocks exhibited a low density of about 1.715 gcm^{-3}, a low water absorption rate of 1.049%, and a commendable compressive strength of approximately 3.815 MPa. The experimental analyses, particularly the ANOVA, indicate that using plastic as a binder material presents a viable alternative to traditional binders like cement. This approach not only mitigates plastic waste in the environment but also lessens the depletion of natural resources. Furthermore, a comparative analysis reveals that while traditional cement offers strong performance, the use of PET as a binder can reduce costs associated with raw materials and waste disposal, suggesting a practical application for sustainable construction.

The successful optimization process is validated by the percentage error falling within the acceptable threshold of 20%, reflecting a strong correlation between the predicted values from the model and the observed values from the validation experiments. However, it is essential to recognize the challenges and limitations encountered during this study. Issues related to the long-term durability of the paving blocks and variability in the quality of recycled materials may impact their performance in real-world applications.

While this study primarily focused on optimizing the physical properties of density, absorbance, and compressive strength, further research is warranted to evaluate additional aspects such as the long-term durability of these paving blocks and the environmental impact of using plastic as a binder. Additionally, assessing the feasibility of scaling up production for mass manufacturing of these paving blocks could significantly enhance their practical application and contribute to sustainable construction practices.

Recommendations

1. **Durability Studies**: Future research should conduct long-term studies to assess the durability and performance of paving blocks made with plastic waste under various environmental conditions.

2. **Environmental Impact Assessment**: Evaluating the environmental implications of using plastic as a binder will provide insights into the sustainability of this practice and its effects on surrounding ecosystems.
3. **Mass Production Feasibility**: Investigating the logistics and economics of scaling up production for these paving blocks can facilitate their adoption in the construction industry, promoting widespread use.

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