



**An-Najah National University**

**Faculty of Graduate Studies**

**EFFECT OF RECYCLED PET PLASTIC ON THE  
MECHANICAL AND THERMAL PROPERTIES OF  
HOLLOW CONCRETE BLOCKS**

**By**

**Majdi Abd-al-Ghani Hamdi Seifi**

**Supervisor**

**Dr. Abdel Fattah R. Hasan**

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Master of Water and Environmental Engineering, Faculty of Graduate Studies, An-  
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Majdi Abd-al-Ghani Hamdi Seifi

This Thesis was Defended successfully on 16/11/2025 and approved by

Dr. Abdel Fattah R. Hasan

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Supervisor

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signature

Dr. Mahmoud Shakarnah

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External Examiner

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signature

Dr. Amjad Issa

---

Internal Examiner

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signature

## **Dedication**

To my Mother & father

To my brothers and my Family

To all friends and colleagues

To my teachers

To My Home, Society; Holy Land Palestine.

To everyone working in this field

To all of them

**I literally dedicate this work**

## **Acknowledgment**

First of all, praise is to Allah for helping me in making this research possible.

Then, I would like to express great thanks and sincere gratitude to my  
supervisor:

Dr. Abdel Fattah R. Hasan

For their guidance, suggestions  
and assistance during the preparation of this thesis.

Special mention goes to my Parents

My brothers and my Family

My Friends and colleagues.

أنا الموقع أدناه مقدم الرسالة التي تحمل عنوان:

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**Students' Name:**

اسم الطالب: مجدي عبدالغني حمدي صيفي

**Signature:**

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## List of Abbreviations

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<b>Abbreviation</b>	<b>Definition</b>
ANOVA	Analysis of variance
ASTM	American society for testing and materials
CO <sub>2</sub>	Carbon dioxide
DTR	Diurnal temperature ranges
EPE	Expanded polyethylene
EPR	Extended producer responsibility
HCB	Hollow concrete block
HDPE	High-density polyethylene
HFM	Heat flow meter
ISO	International organization for standardization
ITZ	Interfacial transition zones
K	Thermal conductivity
LDPE	Low-density polyethylene
LWC	Lightweight concrete
m <sup>2</sup> ·°C/W	Square meter degree Celsius per watt (r-value unit)
MPa	Megapascal (unit of pressure or stress)
MWL	Municipal waste landfill
N/mm <sup>2</sup>	Newton per square millimetre
OPC	Ordinary portland cement
PCBS	Palestinian central bureau of statistics
PET	Polyethylene terephthalate
PP	Polypropylene
PS	Polystyrene
R-value	Thermal resistance
SD	Standard deviation
SG	Specific gravity
SPSS	Statistical package for the social sciences
SSD	Saturated surface-dry
U-value	Thermal transmittance (heat transfer coefficient)
W/m·°C	Watts per meter per degree Celsius

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## List of Symbols

Symbol	Definition	Unit
$f_c$	Compressive strength of concrete	MPa
$K$	Thermal conductivity	$W/m \cdot ^\circ C$
$R$	Thermal resistance	$m^2 \cdot ^\circ C/W$
$U$	Overall heat transfer coefficient	$W/m^2 \cdot ^\circ C$
$q$	Heat flux	$W/m^2$
$\Delta T$	Temperature difference between hot and cold faces	$^\circ C$
$\Delta t$	Time to reach steady state in thermal test	hours
$V_{net}$	Net volume of the block (excluding voids)	$m^3$
$W_{block}$	Weight of the block	kg
$\gamma$	Specific weight (density)	$kg/m^3$
D10,D30,D50,D60	Particle size at 10%, 30%, 50%, and 60% passing	mm
$C_u$	Coefficient of uniformity $c_u=d_{60}/d_{10}$	—
$C_c$	Coefficient of curvature $c_c=d_{30}/(d_{10} \cdot d_{60})$	—
$\gamma$	Specific weight	$kg/m^3$
$V$	Volume of the block	$m^3$
$W$	Measured weight	kg
$d$	Block thickness	m
$s$	Sample standard deviation	—
$n$	Number of observations in the sample	number
$N$	Required number of specimens per group	number
$f$	Effect size	number
$k$	Number of groups	number
$a$	Z-score at $1 - \beta$	—
$b$	Z-score at $1 - \alpha/2$	—
$\beta$	Statistical power	—
$\alpha$	Significance level	—
$\sigma$	Standard deviation	—

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## **Abstract**

The accumulation of plastic waste, particularly polyethylene terephthalate (PET), poses significant environmental issues due to its durability and detrimental degradation byproducts. The construction industry faces pressure to minimize reliance on natural resources like sand. Utilizing PET as a partial sand replacement in hollow concrete block production in Palestine presents a sustainable solution, reducing plastic waste and conserving natural aggregates.

This research investigated the impact of PET plastic waste as a partial fine aggregate (Sand) substitute in hollow concrete blocks, assessing different replacement ratios on compressive strength, unit weight, and thermal insulation. Four concrete mixtures were created with PET-to-sand replacement ratios of 0%, 10%, 15%, and 20% by weight. Shredded PET was sourced from post-consumer waste, and full-sized hollow blocks were cast. Testing evaluated compressive strength at 7 and 28 days, as well as block mass, specific weight, and thermal conductivity.

Increased PET content consistently decreased block weight while significantly enhancing thermal insulation. Thermal conductivity decreased from 1.12 to 0.47 W/m·°C, and R-values more than doubled. Compressive strength reduced at 10% and 15% PET but recovered at 20%, achieving 6.66 MPa at 28 days, similar to the control mix. PET-modified blocks showed brittle failure patterns. PET waste can be effectively reused in non-loadbearing hollow concrete blocks, enhancing thermal resistance and reducing weight while maintaining adequate strength, supporting sustainable building practices.

**Keywords:** Compressive strength, Hollow concrete blocks, Palestine, polyethylene terephthalate, Recycling, Sand replacement, Sustainable construction, Thermal insulation.

# 1 Introduction

## 1.1 Overview:

Plastic waste has emerged as a critical environmental issue, generating approximately 400 million tons globally in 2023 (Pilapitiya et al., 2024), largely stemming from increased plastic usage in packaging, consumer goods, and industrial sectors. Single-use plastics are particularly problematic due to their brief service life and poor recycling rates, leading to significant environmental concerns as plastic waste accumulates in landfills and natural habitats. (Redko et al., 2024).

In Palestine, plastic waste constitutes a major portion of municipal solid waste, with around 265,000 tons produced annually, accounting for 14–17% of the total waste stream. Surprisingly, less than 1% of this plastic is recycled (PCBS, 2023), underscoring the inefficacy of the national recycling system. The Palestinian National Strategy for Solid Waste Management advocates for sustainable practices through the 5Rs framework—Refuse, Reduce, Reuse, Recycle, and Repurpose. However, practical implementation remains limited due to structural hurdles such as inadequate private sector involvement, lack of financial incentives, and the absence of extended producer responsibility (EPR) systems (Thöni et al., 2019). Consequently, substantial amounts of plastic waste continue to accumulate in any place in this world especially in landfills, inflicting serious environmental harm and squandering valuable resources.

Conversely, Palestine's cement block industry is in dire need of modernization, particularly as global trends shift towards energy-efficient and environmentally conscious building materials. Integrating recycled plastic waste into cement-based products presents a dual opportunity: alleviating the environmental burden of plastic waste while simultaneously reducing the CO<sub>2</sub> emission due to extraction of material used in this industry and improving the performance of concrete blocks. Specifically, polyethylene terephthalate (PET) waste, commonly from beverage bottles and packaging, has demonstrated potential as

a lightweight additive or partial aggregate substitute in concrete. Its inclusion may enhance thermal insulation, decrease material density, and reduce overall costs especially in green building perspective, although its effects on compressive strength are complex and often detrimental. Addressing both the plastic waste challenge and the evolution of construction materials could yield a significant ecological benefit and turning PET into eco-friendly materials.

Despite advancements globally, there is a significant lack of localized research in Palestine assessing the practical and technical feasibility of incorporating PET waste into concrete blocks, particularly in the prevalent hollow block design used in construction. This study aims to fill this void by investigating the impact of varying PET-to-sand ratios on crucial properties of 15 cm hollow concrete blocks. The focus is on evaluating three main characteristics: compressive strength at 7 and 28 days, thermal insulation performance, and specific weight (bulk density). Four sets of blocks will be analyzed, corresponding to PET content levels of 0%, 10%, 15%, and 20% based on sand weight.

To frame the investigation, several key research questions were posed:

- What environmental advantages could arise from utilizing PET waste in construction materials?
- How does the incorporation of PET influence the structural integrity and thermal properties of the hollow blocks?
- Can these modified blocks serve as substitutes for traditional insulation materials, such as expanded polyethylene foam boards (EPE), in building applications?
- What potential exists to diminish single-use plastic waste in landfills through this method
- Are there any risks involved, such as emissions of harmful gases or hazardous fire impacts?
- Does the plastic waste enhance sound insulation performance?

By addressing these questions, the study aspires to contribute to sustainable development within Palestine's construction industry. It aims to provide evidence-based insights into the integration of recycled PET in concrete block production, ultimately aiding both environmental preservation and innovation in building materials. Thus, the research endeavors not only to explore the practical aspects of PET waste reuse but also to promote a more sustainable construction approach in the region.

## 1.2 Objectives:

This research investigates if the construction industry, especially hollow cement block production, can sustainably utilize plastic waste, particularly single-use plastics. It evaluates the integration of recycled PET waste to create construction materials that serve as structural elements and engineered landfills, contributing to waste reduction, environmental protection, and impacts on the main characteristics of blocks by focusing on the following objectives:

- **Asses the feasibility of PET Integration:**  
Investigate sustainable utilization of PET plastic waste in hollow concrete block manufacturing to support waste reduction and environmental goals.
- **Evaluate the effects on Block Performance:**  
Evaluate the impact of different PET-to-sand replacement ratios on mechanical properties (compressive strength) and thermal insulation of non-load-bearing blocks.
- **Analyze of Results:**  
Compare experimental findings with regional and international literature, identifying agreements and discrepancies, noting unique contributions to the Palestinian context.
- **Demonstrate methodological Rigor:**  
Employ a systematic program involving material characterization, block preparation, testing, and statistical analysis for reliable results.

- **Provide practical Implications:**  
Present evidence-based conclusions on PET's suitability for block production, offering recommendations for industry application and future research.

## **1.3 Literature review**

### **1.3.1 Plastic Waste: History, Types, and Environmental Impact**

Since the plastic rise in the mid-20th century, plastics have transformed packaging, manufacturing, and daily life due to their low cost, strength-to-weight ratio, resistance to chemicals, and long-life span (Mouna et al., 2024). Unfortunately, these same properties make plastic a long-lasting pollutant in the environment, requiring hundreds of years to decompose (Chamas et al., 2020). Current estimates reveal that less than 10% of plastic waste is recycled globally, with most of it ending up in landfills or unmanaged environments (Al-Khatib et al., 2023)

Plastics commonly found in municipal waste include Polyethylene Terephthalate (PET), Polypropylene (PP), High-Density Polyethylene (HDPE), Low-Density Polyethylene (LDPE), and Polystyrene (PS). These thermoplastics differ in mechanical behavior, melting points, and recyclability as shown in table 1 below.

**Table 1**

*Table of sorted plastics by abbreviated name, RIC ID and there before and after recycling uses(Al-Sinan et al., 2022).*

<b>RIC NO</b>	<b>Abbreviated Name</b>	<b>Product Use</b>	<b>New Products After Recycling</b>
1	PET or PETE	Water, soft drink and juice bottles, carpet, polar fleece	Food containers, carpet fibers, filling for jackets and cushions
2	HDPE	Milk jugs, bottles, shopping bags	Bins, pipes, new containers
3	PVC	Wrapping and packaging, pipes	Pipes, traffic cones
4	LDPE	Plastic bags, squeezable bottles	Rubbish bin liners, compost bins, outdoor furniture
5	PP	Refrigerated food containers, dishware	Tools, trays
6	PS	Disposable plates, cutlery, protective packaging	Light switches, packaging, moldings
7	O	Acrylic, nylon, composite plastics	Low-grade bottles, outdoor products

Prolonged landfill storage of plastic waste contributes to environmental pollution via chemical leachates, greenhouse gas emissions, and land consumption (Skibicki et al., 2021). In the West Bank, plastic accounts for approximately 10.1% of the municipal solid waste stream with major

percentage of PET with 25-28%. Yet, there is minimal infrastructure for recycling, and most waste is dumped illegally or landfilled (Al-Khatib et al., 2023).

### **1.3.2 Plastic Recycling and the 5R Approach**

(Balwan et al., 2022) adheres the "5R" hierarchy: Refuse, Reduce, Reuse, Repurpose, and Recycle. In Palestine a huge effort to comply with these global strategies especially the Recycling, being the third priority, has been adopted across various sectors, notably construction. PET has become a focus due to its advantageous properties and prevalence as post-consumer waste (Sainz-Aja et al., 2022). Researchers have utilized shredded or powdered PET in concrete to substitute fine aggregates or serve as reinforcement fibers.

The incorporation of PET in concrete blocks demonstrates both environmental and performance enhancements (Haba et al., 2025; Nyoman et al., 2024) , Successfully produced plastic bricks from melted PET and waste engine oil, (Yesilata et al., 2009) achieved compressive strengths reaching 2.5 MPa. Additionally, shredded PET has improved thermal insulation by 19%, while PET-based blocks are characterized by reduced weight, enhanced weather resistance, and lower water absorption (Chowdhury et al., 2013; Uvarajan et al., 2022).

### **1.3.3 Concrete Industry and Block Production in the West Bank**

In the West Bank, low-rise residential and institutional buildings predominantly use concrete blocks. The Palestinian Central Bureau of Statistics (PCBS, 2017) reported that 40% of buildings utilized hollow blocks for external walls, amounting to around 158,977 structures. In 2022, 21,447 licensed housing units were constructed with cement blocks, averaging 167 m<sup>2</sup> in floor area. This data illustrates significant production levels and emphasizes the potential for incorporating plastic waste into the block industry. However, a notable gap persists in research on PET-modified blocks in this region, highlighting the need for investigation amid concerns over energy performance and waste management.

### **1.3.4 Hollow Concrete Blocks: Properties and Applications**

Hollow concrete blocks are favored for their cost-effectiveness, lightweight nature, and straightforward installation, frequently employed in non-load-bearing walls. Yet, their conventional structure, composed of cement and natural aggregates, limits thermal insulation capabilities. The quest to enhance building thermal performance has prompted investigation into alternative materials. Foam boards show thermal conductivity (K-values) between 0.03-0.05 W/ m·K and (Akçaözöğlü et al., 2013) shows that for solid blocks has a K-values ranges between 1 -1.8 W/ m·K, while standard hollow blocks range from 0.6 to 0.9 m<sup>2</sup>·K/W (Zhukov et al., 2022). Research by (Briga-Sá et al., 2022a) revealed that incorporating plastic fillers or foam can enhance these values by 18–30%, leading to reduced heat transfer and improved energy efficiency. Consequently, PET's low thermal conductivity and hydrophobic nature present a promising approach for improving block insulation.

### **1.3.5 Effects of PET on Concrete Properties and Optimum Ratios**

Studies reveal differing outcomes related to the mechanical and thermal properties of concrete incorporating PET. (Batayneh et al., 2007) showed a 70% reduction in compressive strength when 20% of fine aggregate was replaced with plastic waste, while (Kangavar et al., 2022) indicated that specific configurations of PET fibers enhanced ductility and tensile strength. The ideal PET volume for mechanical enhancement is estimated to be between 0.5% and 1% (Mouna et al., 2024).

Thermal resistance benefits notably from PET utilization. (Yesilata et al., 2009) reported a 19% improvement in insulation with 10–15% PET, whereas (Todaro et al., 2023) noted a 21% decline in thermal conductivity. In contrast, foam boards exhibit k-values as low as 0.030 W/m·K, while conventional hollow concrete blocks fall between 1.0 and 1.8 W/m·K. The incorporation of PET can decrease thermal conductivity by 15–20%, contingent on the mixture design and PET concentration.

### 1.3.6 Study Contribution and PET Volume Ratios

This study explores sand replacement with recycled PET in hollow concrete blocks at rates of 10%, 15%, and 20% by weight. These ratios correspond approximately to 3%, 5%, and 7% PET content by block volume and also represents 20%,30% and 40% by volume, respectively. A summary of these values is presented in Table 2 below. The focus is on evaluating compressive strength, unit weight, and thermal resistance, offering empirical insights into PET-concrete performance in full-size hollow blocks.

**Table 2**

*Table for study group distributions: PET-sand ratio by weight, volume; PET-block ratio volume.*

<b>Group</b>	<b>PET-sand (% by Sand Weight)</b>	<b>PET-sand (%by Sand Volume)</b>	<b>PET (% by Block Volume)</b>
I	0%	0%	0%
II	10%	~20%	~3%
III	15%	~30%	~5%
X	20%	~40%	~7%

### 1.3.7 summary

The literature highlights the ecological and practical advantages of utilizing recycled PET plastic in hollow concrete blocks. Although many studies validate thermal and mechanical advantages in certain situations, differences in methodologies and regional contexts create inconsistencies in standardization and implementation. This study adds to knowledge by examining the often-overlooked West Bank area and assessing PET-blocks made from local materials and conditions. It seeks to promote sustainable building practices and green architecture by minimizing plastic waste, improving thermal insulation, and providing data-based solutions for environmentally friendly concrete manufacturing.

## **2 Methodology**

### **2.1 Overview:**

This chapter outlines the experimental methods used to evaluate the incorporation of recycled polyethylene terephthalate (PET) plastic waste in the manufacturing of hollow concrete blocks with most suitable plastic to sand ratio. The research is mainly quantitative, concentrating on lab tests to assess how different ratios of PET to sand influence the compressive strength, thermal insulation, and other properties of the concrete hollow blocks. All experimental methods were carried out in the laboratories of An-Najah National University, adhering to standard protocols and calibration procedures to guarantee the reliability and consistency of the tests.

An initial field visits were conducted to various plastic waste collection and recycling centres in Nablus to aid in choosing PET waste as the main material. These visits were not included in a formal data gathering procedure, but they played a crucial role in examining local plastic waste flows and recognizing PET as one of the least recycled and most environmentally enduring plastic kinds. This decision was likewise backed by results from earlier studies regarding plastic waste distribution in the West Bank (Saadeh et al., 2022). Therefore, PET was chosen not only for its environmental consequences but also for its significant presence in local landfills, especially as post-consumer packaging and drink containers that defined globally as “single-use Plastic”.

The information produced from laboratory examinations was evaluated using Microsoft Excel and SPSS to investigate trends and identify the statistical significance of performance variations between block groups.

### **2.2 Materials:**

This section outlines the materials and equipment utilized to prepare and test 15cm thickness hollow concrete blocks incorporating recycled PET waste. The blocks were created using cement, aggregates, shredded PET, water and

pigments, with varying PET percentages replacing fine aggregates. Laboratory tools facilitated mixing, casting, curing, and testing.

### **2.2.1 Cement and Water**

CEM II 42.5 N/B-LL cement has been used, a local blended Portland-limestone variant prevalent in West Bank called Nisher. It features moderate early strength from a mix of clinker and finely ground limestone. While classified per EN 197-1, its properties align with (*ASTM-C150M*, 2007), making it suitable for general construction and concrete block production with given characteristics. In other hand, Water in the concrete industry is vital for cement hydration, impacting concrete's strength, durability, and workability. According to (*ASTM-C1602M*, 2006), mixing water must be clean, free from harmful impurities like oils and acids. Potable water is usually adequate unless overly contaminated. Adhering to these standards ensures proper hydration and prevents negative effects on concrete properties.

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

Natural river sand was used as the fine aggregate due to its cleanliness, well-graded particle distribution, and compliance with ASTM C33 standards. It serves as a filler material, enhancing workability and improving the matrix density of the concrete. Crushed limestone with a maximum size of 10 mm(*ASTM-C150M*, 2007), sourced locally and meeting ASTM C33 specifications, was employed as the coarse aggregate. Its angular particles contribute to mechanical interlock, thereby increasing the compressive strength of the cement blocks. Maintaining aggregates in a saturated surface dry (SSD) condition is crucial for preventing water-to-cement ratio fluctuations, ensuring consistent strength and workability. Controlled storage environments, like stockpiles in summer and silos in winter, preserve moisture, supporting accurate batching and reliable performance in hollow blocks.

All specific gravity and unit weight values for cement, natural river sand, crushed limestone, and water were experimentally determined at An-Najah National University's civil engineering materials laboratory, adhering to ASTM

standards. The specific gravity of cement followed ASTM C188, while fine and coarse aggregate properties were measured according to ASTM C128 and ASTM C127. The bulk density of aggregates was obtained via ASTM C29/C29M, ensuring accuracy and comparability with global construction material standards.

### **2.2.3 Polyethylene Terephthalate (PET) Waste**

In this study, polyethylene terephthalate (PET) waste was utilized as a partial substitute for fine aggregate (sand) in the production of 15cm hollow concrete blocks. The PET waste, sourced from post-consumer plastic packaging like bottles, was collected from public areas and informal networks in Nablus. It was sent to a local recycling company, Tala Plus for Palestinian Plastic Recycling Industries, where an initial cleaning process removed contaminants including soil and chemical residues through manual sorting, high-pressure washing, and drying. After cleaning, the PET was shredded using industrial machines with a 10 mm sieve, resulting in non-uniform particle sizes. A sieve analysis was conducted to evaluate the size distribution of PET and natural aggregates.

In this study, PET plastic waste was incorporated into concrete as a partial sand replacement at ratios of 10%, 15%, and 20% by weight, compared to a control group with 0% PET. Due to PET's different specific gravity compared to sand, weight alone would disrupt mix volume. Consequently, PET quantities were adjusted based on volumetric equivalency to maintain consistent total volume. Thus, actual substitution levels became 0%, 20%, 30%, and 40% in volumetric terms. This approach ensures accurate comparisons of material behaviour across groups and aligns with established practices in prior research, enhancing the study's technical rigor.

A new comparative metric will be introduced, measuring the percentage of PET relative to total block volume, enhancing the environmental clarity and traceability of plastic content in hollow concrete block production and evaluating plastic waste utilization.

## 2.2.4 Pigments

Iron oxide dye was introduced as a visual marker for the clear identification and separation of four experimental groups during sample preparation and testing (*ASTM-C979M*, 2005), which allow the use of non-reactive, inorganic pigments like iron oxides in concrete. A 4% dosage by weight of cement, about 2 kg, was utilized for the whole groups to maintain sample differentiation without introducing additional variables in PET-containing mixtures, preserving internal validity. Furthermore, printing spray was employed on-site to enhance group distinction and minimize human error during sorting and handling. This combination of iron oxide dye and printing spray streamlined the identification process, reducing misclassification risk. The pigment dosage adhered to ASTM C979 guidelines, which recommend a maximum of 10% by weight of cement, ensuring no significant effects on cement hydration, setting time, or compressive strength. Thus, the inclusion of dye and spray was controlled to ensure they were purely for labeling without impacting test result reliability.

## 2.3 Sample Preparation and Casting:

The preparation of concrete block specimens occurred at Al Najah Block Factory in Nablus, utilizing a semi-automatic casting system. Four concrete mixes were tested with around 40 blocks for each group, with PET replacing fine aggregate at 0% (control), 10%, 15%, and 20% by weight, while keeping a constant water-to-cement ratio. Physical markings in the mixer drum indicated material levels, and volume calculations as shown below, which ensured consistent batching based on accurately measured weights for reliable mix proportions.

$$\text{Required Depth (cm)} = 100 * \frac{\text{Volume (m}^3\text{)}}{\text{Specific Weight (kg/m}^3\text{)}} \text{----- Equation 1}$$

A vertical cylindrical mixer with a 1.6-meter diameter and 75 cm height was utilized for mixing. Following ASTM C192, coarse aggregates were added first, then sand and shredded PET, mixed for about 2 minutes. simultaneously, pigments for identification were dissolved in water separately. This coloured water was introduced to ensure a consistent hue per group while adhering to pigment limitations per ASTM C979. Cement was added next, followed by remaining mixing water, with the process continuing for an additional 3 minutes to create a homogeneous mixture based on the mix design proportions that will be outlined in the Mix Design section.

Blocks were cast in standard hollow molds with internal dimensions of 400 mm × 200 mm × 150 mm, using a semi-automatic casting system incorporating vibration and compaction stages. An electric scraper transported freshly molded blocks and are visually identified with spray paint symbols and colouring pigments to denote mix groups and ensure traceability as shown in table 3 below.

**Table 3**

*Group Symbols, Color Codes, and Block ID Ranges.*

<b>Group Notes</b>	<b>Group symbol</b>	<b>Block-ID</b>	<b>total number of blocks per group</b>	<b>colour</b>
0% Control	I	1-46	46	Dark Grey
10%	II	47-87	41	light red
15%	III	88-124	37	Dark red
20%	X	125-164	40	Light Grey

After curing for 24 hours at the factory, on April 30, 2025, the blocks were transferred to An-Najah National University's Civil Engineering Laboratory. Each block received a numerical code for random sampling to maintain statistical reliability. Random number generation in Microsoft Excel facilitated the objective selection of specimens for scheduled tests, ensuring mix-up prevention and systematic testing as shown in table F 1:

In summary, the scheduled tests were distributed as follows:

- 7-Day Compressive Strength Test: Conducted on May 6, 2025
- 28-Day Compressive Strength Test: Conducted on May 27, 2025
- Thermal Insulation Test: Conducted on May 13, 2025 (14th day); samples were surface-dried to ensure test accuracy
- Other Physical Tests: Including specific weight, specific gravity, and mass measurements were conducted between the 7th and 28th days, depending on curing progress and specimen availability.

## 2.4 Sieve Analysis:

Sieve analysis was performed to assess particle size distribution for fine aggregate (natural sand), coarse aggregate (crushed limestone), and shredded PET waste in concrete block mixes. This test aimed to confirm each material's grading characteristics and evaluate the feasibility of using shredded PET as a natural sand substitute. A manual sieving method was employed for enhanced accuracy and control, particularly beneficial due to the lightweight and irregular shape of shredded PET particles. The procedure adhered to ASTM C136 standards, utilizing about 2 kilograms of each material. Samples were sourced from Al Najah Block Factory's storage area, collected randomly from multiple points in the stockpile to ensure representativeness for the approximately 2 tons utilized in casting the 160-hollow block. The sieving utilized standard sieve sizes, as detailed in Table 4 below.

**Table 4**

*Sieve sizes and number according to ASTM-C136*

<b>Sieve Size (mm)</b>	<b>ASTM Sieve No.</b>
19.0 mm	$\frac{3}{4}$ in
12.5 mm	$\frac{1}{2}$ in
9.5 mm	$\frac{3}{8}$ in
4.75 mm	No. 4
2.36 mm	No. 8
1.18 mm	No. 16
0.60 mm	No. 30
0.15 mm	No. 100
0.075 mm	No. 200

The mass retained on each sieve was noted, and cumulative percentage passing was calculated to develop particle size distribution curves, crucial for characterizing shredded PET waste. This facilitated the determination of representative particle sizes and gradation characteristics. These values aided comparative analysis and validation of PET's compatibility with natural sand. Full results and detailed data are in Chapter 4.

## **2.5 Experimental Testing Procedures:**

A series of laboratory tests at An-Najah National University evaluated the performance of hollow concrete blocks with recycled PET waste. Key physical and mechanical properties, such as compressive strength, thermal insulation, and specific weight were assessed. By comparing various PET to sand replacement ratios, the study quantifies the benefits or drawbacks of using PET waste as a fine aggregate substitute. Recommendations for the optimal PET ratio for each test will be discussed.

### **2.5.1 Compressive Strength Test:**

The compressive strength test assessed the mechanical behaviour of non-loadbearing hollow concrete blocks with various percentages of shredded PET plastic waste used as a partial fine aggregate replacement. Conducted per ASTM C140 standards, the test followed procedures for testing concrete masonry units, while performance requirements were based on ASTM C129, which outlines strength and quality criteria for non-structural concrete blocks and compared with Palestinian standard for hollow block PS6.

The Structural Engineering Laboratory at An-Najah National University adapted load application principles from ASTM C140 for testing hollow blocks, using 2 cm-thick solid steel plates for uniform load transfer. Manual levelling and centering the specimens eliminated casting irregularities, enhancing load distribution accuracy during the test setup.

The test utilized a MATEST TREVILOLO concrete compression testing machine with a 2000 kN capacity, calibrated annually per ISO standards, with

the latest certificate in the Appendix D. Following ASTM C140 and PS6, the recommended loading rate for masonry units up to one half of the expected maximum load per minute which is between 0.15 MPa/s and 0.35 MPa/s. A loading rate of 5 kN/sec have been used which is less than the minimum rate which gives a less compressive strength that have been used to make sure that the load is uniform without using the capping (approx. 0.085 MPa/s for a block area of 150mmx400mm = 60,000 mm<sup>2</sup>) was applied, According to ASTM C129, the minimum compressive strength for non-loadbearing hollow concrete blocks is 3.5 MPa, serving as the performance evaluation criterion:

$$f'c(\text{Mpa}) = \frac{P(N)}{A(\text{m}^2)} \text{----- Equation 2}$$

Where:

- f'c: Compressive strength (MPa)
- P: Maximum applied load in Neutron (N)
- A: Cross-sectional area of the block (mm<sup>2</sup>)

Four block groups were tested, based on PET-to-sand weight replacement ratios:

- ❖ Group 1: 0% PET (control group)
- ❖ Group 2: 10% PET
- ❖ Group 3: 15% PET
- ❖ Group 4: 20% PET

Each group comprised eight blocks tested at 7 days and eight at 28 days, with a total of 64 specimens. Random selection for testing was conducted via Microsoft Excel to maintain statistical neutrality and prevent sampling bias. Blocks were labelled, cleaned, and checked for dimensions prior to testing. During tests, they were aligned centrally between loading platens, with steel distribution plates in place. Continuous axial load led to complete failure, with

failure modes documented and illustrated in Chapter 4, featuring compressive strength results.

### **2.5.2 Specific Gravity and Mass Measurement:**

Specific gravity (SG) and mass measurements were performed on natural sand, coarse aggregate, and shredded PET plastic waste to assess their relative density against water. These values facilitated the conversion of volumetric mix designs into weight-based proportions for precise batching. The specific gravity of cement from Neshar Cement Company was assumed to be 3.15, typical for OPC.

To ensure reliable laboratory test results, distributed sampling was conducted for all granular materials. Natural sand and coarse aggregate were collected from multiple locations at Al Najah Block Factory's storage stockpiles, representing the approximately 2 tons used in the production of the 160 hollow block that have been used in this study. Similarly, shredded PET plastic waste was sampled from various batches by Tala Plus, representing cleaned post-consumer PET processed through a 15 mm screen. This method enhances statistical validity and reduces bias. Specific gravity tests followed ASTM standards, grouping each material according to appropriate methods.

#### **❖ Fine Aggregate and PET Plastic Waste**

Shredded PET waste was used to replace fine aggregate in concrete mixes, and both materials were tested according to ASTM C128 for specific gravity and absorption. Each sample weighed 2000g, with the sand oven-dried at 110 °C for 24 hours, while the PET was factory-dried. After cooling, the sand's dry mass was determined, and a 570 mL Le Chatelier flask with a vacuum system measured displaced water volume, ensuring trapped air was removed. The bulk specific gravity, apparent specific gravity, and absorption capacity were calculated, which was particularly critical for PET's irregular shape and low density.

❖ Coarse Aggregate

The specific gravity of crushed limestone aggregate was measured following ASTM C127, focusing on specific gravity and absorption as following:

1. Oven-drying the sample at 110 °C until constant mass was achieved.
2. Immersing the aggregate in water for 24 hours.
3. Measuring the saturated surface-dry (SSD) mass, submerged mass, and oven-dry mass.

Bulk SG, apparent SG, and absorption capacity calculated using ASTM formulas.

❖ Specific Gravity Calculation

For coarse materials, the bulk specific gravity (SSD) was calculated using the following general equation for coarse aggregate:

$$SG_{bulk, SSD} = \frac{W_{dry}}{W_{SSD} - W_{submerged}} \text{ ----- Equation 3}$$

Where:

- $W_{dry}$  = Oven-dry weight (g)
- $W_{SSD}$  = Saturated surface-dry weight (g)
- $W_{Submerged}$  = Weight of the specimen while submerged in water (g)

For fine materials (sand and PET), water displacement was measured using the Le Chatelier flask, and equivalent equations were applied using flask readings as shown below.

$$SG_{PET} = \frac{\text{Weight of dried PET}}{\text{Weight of water of equivalent PET volume}} \text{ ----- Equation 4}$$

Specific gravity is crucial for accurately determining material quantities in concrete mixtures. It aids in calculating each component's volume contribution in hollow concrete blocks and converts volumetric proportions into weight-based quantities (kg). This ensures consistency, precision, and comparability across PET replacement groups, vital for assessing material performance.

#### ❖ Block Mass Measurement

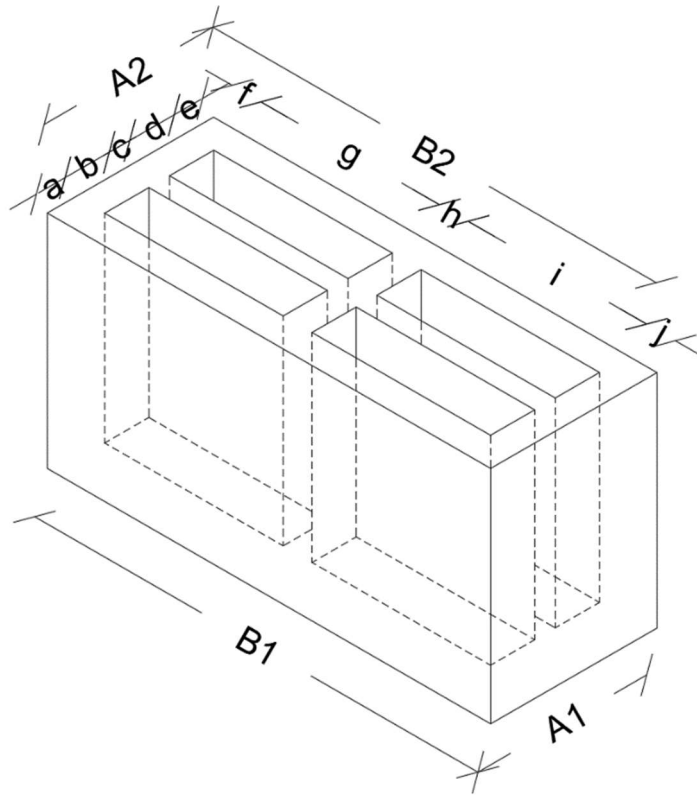
Before conducting compressive strength tests at 7 and 28 days, the mass of each concrete block was measured using a calibrated scale and compared with PS6 standard which indicated the weight of hollow concrete block of 15cm width about 16 Kg. Weighing was done immediately before testing for accuracy. These measurements were later used to calculate the specific weight (density) of the concrete blocks, enabling a detailed comparison of how varying PET content levels impact the overall unit weight across the mix groups.

#### **2.5.3 Specific Weight (Density) of Blocks:**

To evaluate the impact of PET plastic waste on the unit weight of hardened concrete blocks, the specific weight (density) was determined. This is crucial for understanding how PET influences the structural and thermal properties of the blocks due to its lower density compared to traditional aggregates. While there isn't a specific ASTM standard for full-sized concrete blocks, the method follows ASTM C642 for density evaluation, in contrast the Palestinian standard PS6 mentions some test for the shape and size of blocks which will be used to determine the Specific weight of block and other characteristics. A simplified dry-weight to volume approach was employed for dry, cured blocks. Each block was weighed before compressive strength tests at 7 and 28 days using a calibrated scale, and for Block dimensions, callipers has been used to measure the exact volume of block which is approximately (400 mm x 150 mm x 200 mm) and measuring the internal hollow volumes as shown in figure below.

**Figure 1**

*Hollow block dimension catalog*



After all knowing these parameters will leads to calculate the specific weight ( $\gamma$ ) as following equation:

$$\gamma \left( \frac{Kg}{m^3} \right) = \frac{W (Kg)}{V (m^3)} \text{ ----- Equation 5}$$

Where:

- $\gamma$  = Specific weight ( $kg/m^3$ )
- $W$  = Measured weight of the block (kg)
- $V$  = Volume of the block ( $m^3$ )

The calculation was performed for each specimen in PET replacement groups (0%, 10%, 15%, 20%) by weight. Average specific weights facilitated comparative analysis in Chapter 4, examining PET replacement's effects on density, thermal insulation, and structural behaviour.

## **Figure 2**

*Hollow block samples after manufacturing*



### **2.5.4 Thermal insulation tests:**

This section examines the thermal properties of hollow concrete blocks containing different percentages of shredded PET plastic waste, measuring thermal conductivity ( $k$ ), thermal resistance ( $R$ ), thermal transmittance ( $U$ -value), and heat flux ( $q$ ). These properties are crucial for assessing thermal insulation in real world applications, particularly in climates changes especially in Palestine.

Testing was conducted with a Heat Flow Meter (HFM-8301.54) at An-Najah National University's Thermal Laboratory, following ASTM C518 and ISO 8301 standards for thermal transmission properties. The HFM-8301.54 features

two flat plates; a hot plate at 55°C and a cooling top plate at 22°C to 27°C depending on water source's temperature as shown in figure below.

### Figure 3

*HFM component at An-Najah University lab.*



The average temperature difference ( $\Delta T$ ) of approximately 18-22°C simulates typical diurnal temperature ranges (DTR) in Palestinian climate zones (Ali Omar et al., 2019; Red Crescent Climate Centre, 2024) which will make this test more realistic and evaluate what the hollow block is assumed to face in sites and buildings. The total clear sensing area was 450 mm  $\times$  450 mm, with six sensors for precise heat flux measurements.

### Figure 4

*HFM two censored plates*



The heat flux ( $q$ ) was measured in watts per square meter ( $W/m^2$ ), allowing calculation of thermal conductivity ( $k$ ) for each specimen using Fourier's Law.

$$k = \frac{q \cdot d}{\Delta T} \text{ ----- Equation 6}$$

Where:

- $k$  = Thermal conductivity ( $W/m \cdot ^\circ C$ )
- $q$  = Heat flux ( $W/m^2$ )
- $d$  = Block thickness (m)
- $\Delta T$  = Temperature difference across the specimen ( $^\circ C$ )

Before testing, blocks were air-dried to prevent moisture interference on thermal behaviour, then trimmed and smoothed from one side approximately 14.3 cm in width for compatibility with the HFM device. Manual sanding (fractioning) minimized deformation and ensured uniform contact between plates and specimens. Each test used two vertically stacked hollow blocks to guarantee full sensor coverage and prevent false readings, as single blocks showed inconsistent results from sensors exposed to air. Calibration utilized a 3 cm polyethylene foam sheet, confirming consistent readings despite the HFM not being formally recalibrated since 2003. Additional tests on foam samples highlighted the importance of complete sensor coverage for accurate results. After determining thermal conductivity, the thermal resistance of each block configuration was calculated accordingly the U thermal transmittance value can be calculated as the inverse of thermal resistance as shown below.

$$R = \frac{1}{U} = \frac{d}{K} \text{ ----- Equation 7}$$

Where:

- $R$  = Thermal resistance ( $m^2 \cdot ^\circ C/W$ )
- $d$  = Thickness of the block (m)

- $k$  = Thermal conductivity (W/m·°C)
- $U$  = Thermal transmittance (W/m<sup>2</sup>·°C)

Each PET content group (0%, 10%, 15%, and 20%) comprised four blocks (2 tests), randomized via Excel. Average values of  $q$ ,  $k$ ,  $R$ , and  $U$  were computed for each group to assess the link between PET percentage and thermal performance. Results and supporting documentation are discussed in the following Chapter and Appendix.

## 2.6 Statistical Analysis:

Data analysis for the experimental results was conducted using Microsoft Excel and IBM SPSS, focusing on compressive strength in four PET replacement groups (0%, 10%, 15%, and 20%). A pilot study of four specimens in the 15% PET group produced compressive strength results of 6.36, 4.99, 5.08, and 3.65 MPa, with an average mean of approximately 5.04 MPa. And with standard of deviation founded to be 0.9568 using the following equation.

$$s = \sqrt{\frac{1}{n-1} * \sum_{i=1}^n (Xi - X')^2} \text{ ----- Equation 8}$$

Where

- $s$  = sample standard deviation
- $n$  = number of observations in the sample
- $Xi$  = each individual observation
- $X' = \bar{x} = \bar{x} =$  sample mean (average)

One-way ANOVA determined mean variance among four groups, with Tukey's HSD for significant differences. Assumptions included normal distribution and

homogeneity of variance confirmed by Levene's test using the following equation.

$$N = \frac{2*(k-1)*(a-b)^2}{K*f^2} \text{----- Equation 9}$$

Where

- N = required number of specimens per group
- f = effect size [ f =  $\Delta(\text{expected}) / \sigma(\text{calculated})$ ]
- k = number of groups
- a = Z-score at 1-  $\beta$  (Statistical power)
- b = Z-score at 1-  $\alpha/2$  (significance level)

To determine minimum sample size for One-Way ANOVA, with 4 groups (k=4), expected mean difference ( $\Delta=2$  MPa), standard deviation ( $\sigma=1$  MPa), significance level ( $\alpha=0.05$ ), and power ( $1-\beta=0.95$ ), critical values founded by using excel are found to be  $Z_{1-\alpha/2}=1.96$  and  $Z_{1-\beta}=1.645$ , as a result the minimum number of samples for each test is around 5 samples for each group

The final sample design comprises 8 specimens per group for both 7-day and 28-day compressive strength tests, 4 specimens per group for thermal insulation testing, and 8 backup specimens per group for physical property tests. The total minimum required sample count for tests is 112 as shown in table 5 below.

**Table 5**

*required number of hollow block samples for both thermal and mechanical tests*

<b>Test Type</b>	<b>Samples per Group</b>	<b>Number of Groups</b>	<b>Total Samples</b>	<b>Purpose</b>
Compressive Strength	8	4	32	7-day strength tests
Compressive Strength	8	4	32	28-day strength tests
Thermal Insulation	4	4	16	Heat transfer resistance tests
Backup Samples	8	4	32	For specific weight, sound, etc.
The minimum number of required samples in this study			112	For the study

A total of **160** samples will be produced, with 40 samples per group, to meet factory-scale mixing batch requirements and due to the limitations of semi-automatic block manufacturing equipment lacking precise measurement sensors. Bulk production ensures consistent mix ratios, minimizes waste, and reflects real production conditions. Statistical analysis, including p-values, box plots, and confidence intervals, will be detailed in Chapter 4 and in the appendices

## **2.7 Mix Design Table:**

This study developed a concrete mix design for non-structural (non-load bearing) 15cm hollow concrete blocks using shredded PET plastic waste as a partial sand replacement. Four groups were tested: 0% (control group), 10%,

15%, and 20% PET by weight, while keeping cement, water, and coarse aggregate constant. Target dimensions were 400 mm × 150 mm × 200 mm, following industry standards. Due to differences in actual block volume that have been shown by the pilot study, the measured volume informed total mix quantities, discussed in the results chapter. Mix ratios were calculated for individual blocks and scaled for 40 blocks per group as shown in tables below to facilitate batch casting, testing, and contingency planning.

**Table 6**

*Mix Design for Control Group (0% PET) component per cement ratio – Per Block*

	<b>Pigment (Dye)</b>	<b>water</b>	<b>Cement</b>	<b>Aggregate</b>	<b>Sand</b>	<b>PET (Polyethylene terephthalate)</b>
<b>Ratio</b>	0.040	0.350	1.000	9.000	2.240	0
<b>Weight (gm / block)</b>	50	437.5	1250	11250	2800	0

Laboratory-specific gravity values were crucial for converting volumetric mix ratios into weight-based proportions. The significantly lower specific gravity of PET compared to natural sand allowed PET to be used as a volumetric substitute in concrete mix design. Replacing sand with equal weight of PET would cause discrepancies in volume, affecting mix volume, block density, and performance. To maintain design integrity, PET was added in weights corresponding to the volume of sand removed, preserving volumetric proportions for reliable comparisons as shown in table below.

**Table 7***Total Material Weights for 40 Hollow Blocks per Group*

<b>Group</b>	<b>Dye [Kg]</b>	<b>Water [Kg]</b>	<b>Cement [Kg]</b>	<b>Aggregate [Kg]</b>	<b>Sand [Kg]</b>	<b>PET [Kg]</b>	<b>PET/SAND by weight</b>	<b>PET / sand by volume</b>	<b>PET / block by volume</b>
I	2	17.5	50	450	112	0	0.00%	0.00%	0.00%
II	2	17.5	50	450	100.8	11.2	10.00%	20.00%	3.00%
III	2	17.5	50	450	95.2	16.8	15.00%	30.00%	5.00%
X	2	17.5	50	450	89.6	22.4	20.00%	40.00%	7.00%

## **2.8 Study Workflow and Timeline:**

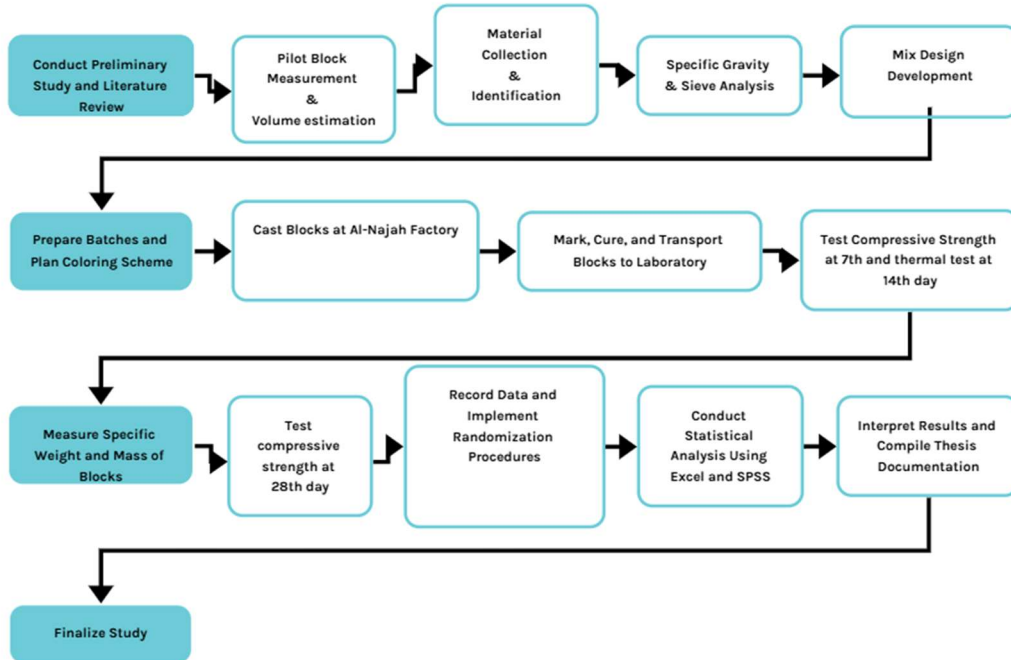
This section summarizes the experimental methodology, detailing the workflow from planning to testing and analysis, alongside a general time plan reflecting scheduling and project management for the research execution.

### **2.8.1 Process Workflow:**

The study process, depicted in the figure below which outlines sequential steps from material collection and preparation to laboratory testing and data analysis, highlighting operations and decision points.

**Figure 5**

*Thesis comprehensive Working Flowchart*

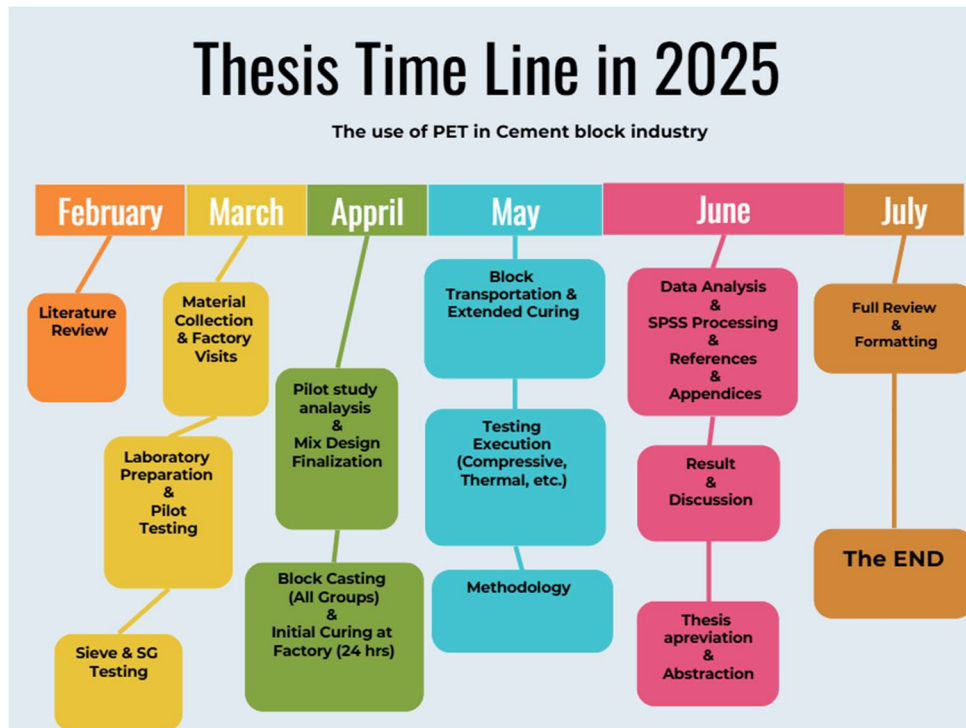


### 2.8.2 Time Planning and Management:

The study utilized a time managed framework for laboratory bookings, curing times, and testing appointments, detailing approximate durations for each work phase as shown in figure below.

**Figure 6**

*Timeline of Main Thesis Activities at 2025*



### 3 Results

#### 3.1 Overview:

This chapter details the experimental results of using polyethylene terephthalate (PET) plastic waste as a partial substitute for fine aggregate in 15 cm hollow concrete blocks industry. The study aimed to assess how the variation of PET-to-sand ratios impact the blocks' physical, mechanical, and thermal performance, identifying the optimal mix.

Four groups were tested with PET replacement levels of 0% (control), 10%, 15%, and 20% by the weight, reflecting volumetric replacements of 0%, 20%, 30%, and 40%. Performance was evaluated through various laboratory tests as listed below:

- **Sieve analysis** to study particle size distribution of raw materials.

- **Specific gravity and bulk density** tests to understand material properties.
- **Block dimensions and Finish appearance** to insure the physical shape is suitable and usable in project and according to specifications.
- **Block mass and density** measurements to assess physical weight changes for the hollow blocks.
- **Compressive strength** tests at 7 and 28 days to determine structural performance.
- **Thermal insulation** testing, including measurements of thermal conductivity and resistance.

The Test's results, detailed trends and comparisons between control mix and PET-modified mixes in subsequent sections will be mentioned in each section.

### **3.2 Sieve Analysis of materials**

Sieve analysis was conducted per ASTM C136 to assess particle size distribution of aggregates: natural sand, crushed limestone coarse aggregate, and shredded PET plastic waste, determining each material's suitability for concrete block manufacturing according to American standard.

#### **3.2.1 Coarse Aggregate (Crushed Limestone)**

The crushed limestone coarse aggregate, with a maximum size of 10 mm, showed a particle size distribution within ASTM C33 standards. Results indicated a  $D_{60}$  of 11.51 mm and  $D_{10}$  of 3.00 mm, yielding a coefficient of uniformity (Cu) of approximately 3.84, classifying it as moderately graded. The  $D_{50}$  was 9.8 mm which represent the average particle size.

All these parameters highlighting large, angular particles beneficial for enhancing structural stability via internal locking in concrete blocks.

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

Natural river sand, used as fine aggregate, demonstrated well-graded distribution per ASTM C33, with  $D_{50}$ (average size) at 0.78 mm ,  $D_{10}$  at 0.13 mm and  $D_{60}$  at , resulting in a Cu of 9.11. This broad particle size range promotes improved packing density and workability. The coefficient of curvature (Cc) was 0.64, aligning with natural sands. Cleanliness and grain shape also support its use for structurally sound concrete blocks.

### **3.2.3 Shredded PET Plastic Waste**

Shredded PET waste, from cleaned post-consumer bottles, was sieved through a 10 mm screen, showing a  $D_{50}$  of 4.25 mm and  $D_{10}$  of 1.42 mm, with Cu at 3.96. Its gradation differs from mineral aggregates, and due to its flake-like structure and low density, it falls outside ASTM C33 grading limits. Nonetheless, its size suggests it may function as a partial fine aggregate substitute with appropriate adjustments. A combined particle size distribution graph will illustrate differences among the materials.

### **3.2.4 Sieve analysis summary**

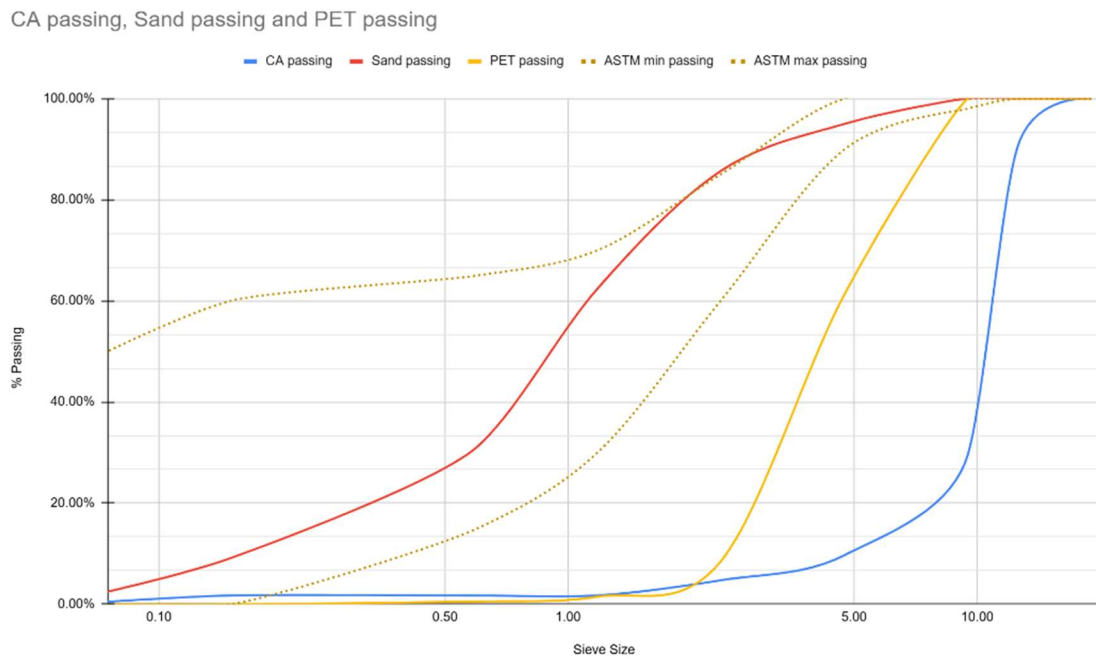
Each of the three materials was analyzed for particle size and compared to grading limits. ASTM C33 does not specify gradation for aggregates in hollow block manufacturing especially for sand and PET, so lightweight concrete mixture grading criteria ASTM C330 has been used. This choice is justified due to the smaller aggregate sizes in lightweight blocks, which align with the particle sizes of shredded PET waste, making the comparison more relevant to the study's context.

fine aggregates meet ASTM standards, but PET's grading does not. However, PET's particle size distribution comes between sand and coarse aggregate which is functionally acceptable. Figure 7 displays the comparative particle size

distribution, and tables summarizes the key gradation parameters and more detailed results will be shown in appendix A.

**Figure 7**

*Particle size distribution curves for coarse aggregate, natural sand, and shredded PET waste compared with ASTM C331*



**Table 8**

*Sieve analysis parameters include characteristic diameters ( $D_{10}$ ,  $D_{30}$ ,  $D_{50}$ ,  $D_{60}$ ) and uniformity coefficients ( $C_u$ ,  $C_c$ ).*

Material	$D_{10}$ (mm)	$D_{30}$ (mm)	$D_{50}$ (mm)	$D_{60}$ (mm)	$C_u$	$C_c$	ASTM C330 Compliance
Natural Sand	0.13	0.32	0.78	1.21	9.11	0.64	Yes
Coarse Aggregate	3.00	6.40	9.80	11.51	3.84	1.19	-----
Shredded PET	1.42	3.14	4.25	5.62	3.96	1.23	No

### **3.3 Specific Gravity of materials**

Determining specific gravity and bulk density of concrete materials is crucial for assessing mass, density, and overall performance. Specific gravity influences volumetric proportions, while bulk density affects packing characteristics and indicates porosity and weight contribution.

#### **3.3.1 Cement, Water, and Pigment**

For this study, Portland-limestone blended cement (CEM II 42.5 N/B-LL) with a specific gravity of 3.15 was utilized across all mixes. Potable tap water, assumed to have a specific gravity of 1.00, was used, along with a small amount of iron oxide pigment, which had a specific gravity of 3.50, to maintain consistent batching in different PET replacement groups.

#### **3.3.1 Coarse and Fine Aggregates**

The crushed limestone aggregates and natural sand showed specific gravity values of 2.60 and 2.55, respectively, aligning with typical construction-grade aggregates. The denser sand resulted from its finer grain size and lower voids. These values contributed to total mix weight calculations and the density of hardened concrete blocks.

#### **3.3.2 Shredded PET Plastic Waste**

Conversely, shredded PET plastic waste from post-consumer bottles had a low specific gravity of 1.30, less than half of sand's, necessitating volumetric substitution instead of weight-based replacement. The PET particles' irregular shape and internal voids led to lower bulk density which has been measure to be 600 kg/m<sup>3</sup>, trapping air during mixing, reducing overall block mass, and enhancing thermal insulation in PET-modified mixes.

#### **3.3.3 Summary of Material Specific Gravities**

Table 10 in appendix F presents the specific gravity values of all key components, facilitating the conversion of volumetric ratios into accurate

weight-based mix proportions and clarifying trends seen in results throughout the chapter.

### **3.4 Dimension and appearance of Block**

According to PS6 and ASTM C129 these characteristics are compulsory to insure the correct use and serviceability of block in projects so ,blocks were visually inspected post-demolding, after 24 hours of initial curing, and upon arrival at the university. Evaluation results, documented photographically, compared PET replacement groups to identify changes in block finish quality with increasing PET content and for dimension that will be taken while measuring the block weight using a caliper.

### **3.5 Specific Weights of Block**

The blocks in this study measured 15 cm × 40 cm × 20 cm, resulting in a gross volume of 0.012 m<sup>3</sup>. However, the effective volume of solid material, accounting for internal voids, was approximately 0.00752 m<sup>3</sup>, determined using a caliper for accurate measurement. This effective volume was crucial for calculating specific weight and thermal properties reflective of the material's structural behavior. Each block's mass was measured with a calibrated scale before putting the block samples in the compression test machine, which required for specific weight calculations by dividing mass by the effective volume. Theoretical mass values were estimated based on material properties from the mix design but the actual block's mass will be used.

Paradoxes were notably observed in PET-modified blocks due to PET's irregular shape and lower specific gravity, compounded by defects in molds from repeated use affecting block dimensions. Variations also may come from inconsistencies in hydraulic compression during the vibration process, impacting block density. Further inconsistencies emerged during manual mixing, especially with increasing PET content, which intensified deviations from expected mass. This highlighted the importance of accurate mix design for

recycled polymers. A summary of measured block masses and specific weights can be found in Table 9 and table 10 below with respect to figure 1 in previous chapters.

**Table 9**

*Average Dimensions and Standard Deviations for hollow Concrete Blocks*

Symbol	Dimension Description	Average Value (mm)	Standard Deviation (mm)
a	Face shell width -left	24.4	±0.14
b	Core width-left	40.1	±0.17
c	Internal web width	20.1	±0.13
d	Core width-right	40.1	±0.19
e	Face shell width -right	24.3	±0.14
A1	Outer width -bottom	148.4	±0.13
A2	Outer width -top	148.9	±0.46
f	End shell width -left	25.0	±0.17
g	Core length-left	163.1	±0.56
h	Internal face width	24.3	±0.22
i	Core length-right	162.4	±0.18
j	End shell width -right	25.2	±0.16
B1	Outer length-bottom	394.9	±0.26
B2	Outer length-top	400.0	±0.56
Hf	Core height	179.1	±0.18
Hb	Outer height	191.0	±0.18
Vg (gross volume)		0.01128179892	m <sup>3</sup>
VT (total volume)		0.006607936243	m <sup>3</sup>

Table 10

*Average Mass and Specific Weight of Blocks by PET Replacement Group*

<b>Group</b>	<b>PET Replacement (%)</b>	<b>Average Mass (kg)</b>	<b>Gross Volume (m<sup>3</sup>)</b>	<b>Net Solid Volume (m<sup>3</sup>)</b>	<b>Specific Weight of Block (kg/m<sup>3</sup>)</b>	<b>Specific Weight of Mortar (kg/m<sup>3</sup>)</b>
I	0% (Control)	15.781	0.01128	0.00661	1398.76	2388.11
II	10%	15.004	0.01128	0.00661	1329.91	2270.57
III	15%	14.918	0.01128	0.00661	1322.27	2257.53
X	20%	14.830	0.01128	0.00661	1314.53	2244.31

### 3.6 Compressive Strength

Compressive strength testing was performed on concrete blocks with varying percentages of PET plastic waste at 7 and 28 days, following ASTM C39 standards as the following:

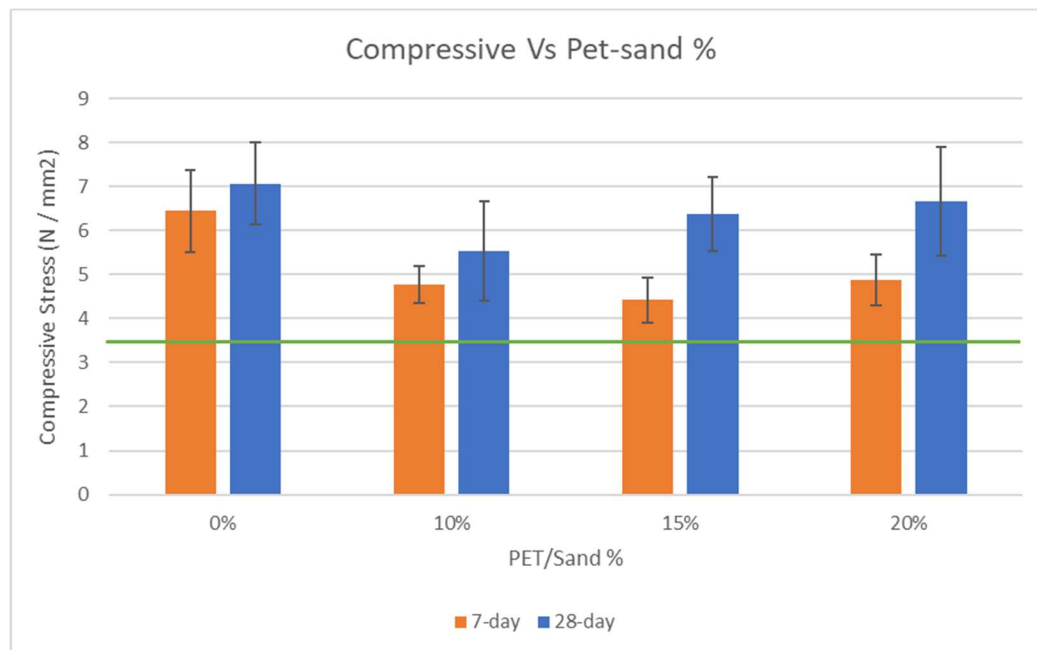
- At 7 days, the control group (0% PET) showed the highest compressive strength due to its complete mineral composition and dense aggregate packing. However, blocks with 10%, 15%, and 20% PET replacements experienced a decrease in early-age strength, attributed to PET's lower specific gravity, smoother texture, and suboptimal chemical interaction with cement hydration products. The irregular shape of PET may also introduce internal voids and weaken interfacial bonding, negatively impacting early mechanical performance.

- At 28 days, all samples gained strength as cement hydration continued. While the control mix retained the highest overall compressive strength, the 20% PET mix outperformed the 10% and 15% mixes, showing potential benefits from better packing and internal stress redistribution due to PET's geometric properties. The relationship between PET content and compressive strength over time is illustrated in a figure, highlighting the balance between integrating plastic waste for sustainability and maintaining structural performance in load-bearing applications.

Figure 8 illustrates the correlation between PET content and compressive strength as time progresses. Table F 3 presents average strength values, demonstrating a nearly linear reduction up to 15% PET, followed by a significant rebound at 20% after 28 days, emphasizing the equilibrium between sustainability and structural stability

**Figure 8**

*Compressive strength development at 7 and 28 days for concrete blocks containing varying PET replacement percentages*



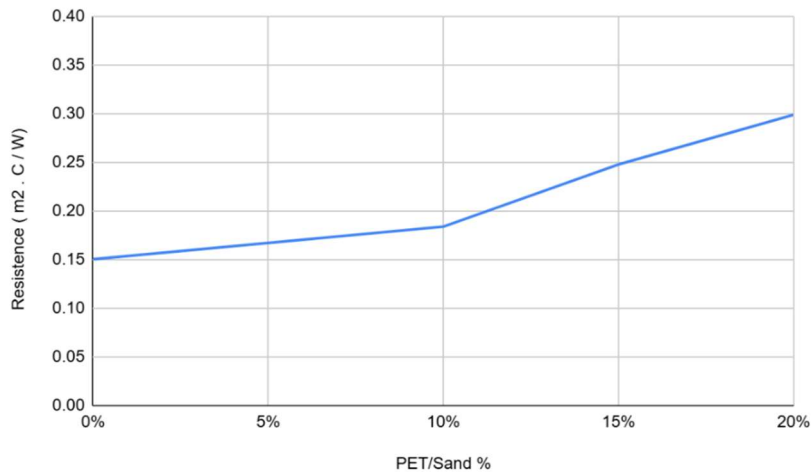
### 3.7 Thermal Insulation Test Results

In the thermal insulation test, concrete blocks' performance was analyzed to determine suitability for construction in varying climates. Conducted with a heat flow meter (HFM) per ISO 8301, the study measured thermal conductivity (k-value), resistance (R-value), and overall thermal transmittance (U-value) with different PET contents. Each test utilized pairs of blocks from the same PET group, stacked together and positioned between HFM plates, with a consistent temperature gradient applied. All blocks were uniform in size (15 × 40 × 20 cm) and cured for 28 days and dried by weather for 2-4 days.

Results indicated that increased PET content reduced thermal conductivity, with the control group (0% PET) showing the highest k-value. The lowest k-value was found in the 20% PET mix, highlighting superior insulation due to PET's lower thermal conductivity and increased air content from its irregular structure. Accordingly, R-values increased with higher PET content, peaking in the 20% group, while U-values showed a decrease, indicating enhanced insulation and energy efficiency. Detailed results for each PET group are summarized in Table 14 in appendix F, accompanied by a graphical representation of the correlation between PET content, thermal conductivity, and resistance in Figure 9.:

**Figure 9**

*Relationship between PET-to-sand ratio and thermal resistance (R-value), showing the increase in R-value as the PET content increases.*



## **4 Discussion**

### **4.1 Introduction**

This chapter interprets experimental results from Chapter 4 regarding the use of polyethylene terephthalate (PET) plastic waste as a partial fine aggregate replacement in 15 cm hollow concrete blocks. It assesses the impact of PET on physical, mechanical, and thermal properties while exploring sustainable construction implications.

Four concrete mix groups were analysed with PET replacing natural sand by weight replacement of 0%, 10%, 15%, and 20%, reflecting respective volumetric ratios of 0%, 20%, 30%, and 40%. Evaluations included particle size distribution, specific gravity, mass and density, compressive strength at 7 and 28 days, and thermal insulation properties. Statistical methods, such as standard deviation analysis and hypothesis testing, validated observed differences. Limitations are discussed, and future work directions in high-performance, eco-friendly concrete products are suggested.

### **4.2 Interpretation of Key Results**

#### **4.2.1 Block Dimensions and Appearance**

The evaluation of the 15-cm hollow concrete blocks produced in this study adhered to the Palestinian Standard PS 6 for concrete masonry units, which allows a dimensional variation of  $\pm 3$  mm for height (H) and width (B). The measurements demonstrated exceptional accuracy, with standard deviations of  $\pm 0.18$  mm for height and  $\pm 0.41$  mm for width, well within permitted limits. For the external block shell thickness, which has a tolerance of  $\pm 0.1$  mm, the blocks achieved an average standard deviation of  $\pm 0.142$  mm, indicating that they complied with manufacturing tolerances and none of these dimensions was less than 13mm.

Regarding appearance and finish quality, the blocks were examined for surface defects, cracking, and uniformity. They were found to meet the criteria of both

ASTM C129 and PS 6, showing no significant defects that would impact structural performance or durability. Minor surface irregularities and small chips, commonly associated with handling and manufacturing, were noted but did not warrant rejection as per ASTM C129 guidelines.

Overall, the 15-cm hollow concrete blocks exhibited excellent dimensional stability, sufficient shell thickness, and an acceptable finish quality. The incorporation of PET did not adversely affect the geometric or visual integrity of the blocks, affirming their potential for use in construction.

#### **4.2.2 Sieve Analysis**

The particle size distribution of natural sand, crushed limestone coarse aggregate, and shredded PET plastic waste was analysed through sieve analysis to assess compliance with grading standards, specifically ASTM C330 for lightweight concrete. Natural sand met the required particle size limits, confirming its suitability for hollow concrete block production aimed at reduced weight.

The crushed limestone coarse aggregate, with a maximum particle size of 10 mm, was evaluated under ASTM C33 for normal-weight concrete. Although not directly applicable to lightweight concrete, it served as a reference and met the necessary grading standards for structural use. Conversely, shredded PET waste did not conform to either ASTM C330 or C33 standards, exhibiting an irregular particle size distribution between natural sand and coarse aggregate. This irregularity is attributed to PET's flake-like geometry and unique polymer structure. For this study, it was assumed that the hollow concrete block mixture behaves like lightweight concrete due to the modified aggregate composition with PET, using ASTM C330 as a reference.

While not conforming to standard limits, PET's intermediate size and uniform shape may allow compatibility as a partial fine aggregate substitute. However, its coarser profile compared to natural sand may hinder optimal packing density, potentially increasing porosity or reducing bonding efficiency. Further refinement of PET's particle size could enhance its compatibility with fine

aggregates, and dual use with both sand and coarse aggregate may be explored in future studies to optimize PET's role in sustainable masonry units.

### **4.2.3 Specific Gravity**

The specific gravity of materials was crucial, influencing calculations of mass, volume, and density of hollow concrete blocks. Shredded PET plastic waste had a specific gravity of 1.30, notably lower than natural sand (2.60) and crushed limestone (2.55). This disparity impacted volumetric proportions during weight-based sand replacement, affecting physical and mechanical behaviour. Substituting sand with PET increased its volumetric fraction, reducing overall block mass and creating internal voids. These changes diminished compressive strength due to lower packing density and weaker bonding. However, the structural modifications likely enhanced thermal resistance by increasing air and polymer content, disrupting heat conduction pathways.

These outcomes are consistent while comparing with previous studies. (Todaro et al., 2023) reported that incorporating plastic particles into concrete leads to reductions in density and strength, while (Bamigboye et al., 2021) observed that the effect is more pronounced when plastics are used as fine aggregate replacements. This highlights the need to account for the mass and volume impacts of lightweight polymers like PET in mix design.

The reduced unit weight of PET-modified blocks provides significant benefits, such as lower dead loads on structures, enabling smaller column and beam sizes, thus promoting sustainable construction with less material use and lower CO<sub>2</sub> emissions. They are easier to handle on-site, enhancing construction speed and reducing labour needs. Future research should investigate optimized PET particle grading and aggregate replacement strategies for improved material performance.

#### 4.2.4 Block Weight and Density

Incorporating PET plastic waste into hollow concrete blocks resulted in a reduction in block mass and specific weight as the percentage of replacement increased. The 20% PET replacement group, which is about 40% by volume relative to the sand replaced, accounted for roughly 7% of the total solid volume of the block. This small volume fraction significantly affected unit weight due to PET's low specific gravity and irregular shape. As PET substituted for heavier sand, the mixture's overall density decreased, leading to lighter blocks.

The study focused primarily on the effects of PET-modified blocks on thermal and compressive strength while weight reduction being a secondary, yet advantageous, effect. The specific weight decreased from 1398.76 kg/m<sup>3</sup> (0% PET) to 1314.53 kg/m<sup>3</sup> (20% PET) which is less than the maximum specific weight of block as determined in ASTM C129 and PS6 with a maximum value of 1600 kg/m<sup>3</sup>, validating the effect of PET on physical properties. Although weight reduction provides logistical benefits such as easier handling and reduced dead loads, it is not the main value of PET inclusion. Notably, discrepancies between theoretical and actual block weights at higher PET contents were observed, likely due to low packing efficiency, mold inconsistencies, and compaction variability, impacting block dimensions and net volume calculations while maintaining a clear trend in weight reduction.

Literature indicates that incorporating plastics in concrete reduces block or panel density, as noted by (Dawood et al., 2021) and (Uche et al., 2023), though the impact differs by plastic type, size, and mix design. The study retained normal-weight aggregates to balance thermal benefits and material handling.

In summary, the block weight reduction aids construction and sustainability with respect of local and world codes and specifications and has a reasonable results comparing with other scientific paper.

#### 4.2.5 Compressive Strength

Compressive strength tests revealed that substituting fine aggregate with PET plastic waste led to an initial decline in early-age strength, with a notable recovery at higher replacement levels after 28 days. The control group (0% PET) exhibited the highest strength, achieving 6.45 MPa at 7 days and 7.06 MPa at 28 days. The 20% PET group displayed a significant rebound, reaching 6.66 MPa at 28 days, despite previous declines in the 10% and 15% groups. This trend indicates that higher PET content may support internal microstructural adjustments and ongoing hydration, partially offsetting early performance loss. However, the 20% PET blocks manifested more destructive failure during compressive tests, fracturing into loose fragments rather than retaining form, raising safety concerns for load-bearing applications. This brittle failure mode contrasts with the ductile failure of control samples, likely due to PET's non-reactive surface, irregular geometry, and increased voids weakening interfacial transition zones (ITZ). These deficiencies compromise ductility and prompt worries about the long-term reliability and predictability of PET-modified blocks under load.

The compressive strength behavior in PET-modified concrete varies markedly across studies. Many report strength reductions with increased PET content due to compromised interfacial bonding and elevated internal porosity. Some studies indicate non-linear trends where initial strength diminishes, then stabilizes or recovers at certain replacement levels. In this study, control groups reached about 88% of their 28-day strength at 7 days, while PET-modified groups achieved 70–85%. This is higher than typical conventional concrete, which attains only 60–65% at 7 days. The dry mix used in concrete masonry unit production accelerates early-age strength development, while PET consistently lowers strength at both ages, influenced by following mechanisms:

- PET particles absorb less water than natural sand, increasing free water and the local water-cement ratio.
- Lower water-cement ratio in control group leads to higher initial compressive strength of hollow blocks as shown at 7-day result

- Replacement with PET creates voids and lowers packing density due to its low stiffness and hydrophobicity.
- PET's reduced density and increased porosity improve weight reduction and thermal insulation, despite compressive strength decline.
- Having specific amount of PET with specific size and shape may enhance the bonding between concrete and plastic particles

These outcomes suggest that PET can be added to concrete block mixtures with minimal impact on compressive strength, but the failure mode and cohesion need careful assessment. For applications needing mechanical and thermal performance, PET-modified blocks provide a viable option, while structural uses may require enhanced treatment for better bonding and reduced brittleness.

#### **4.2.6 Thermal Insulation Performance**

The study shows that incorporating PET plastic waste enhances the thermal insulation properties of hollow concrete blocks. With increasing PET content, thermal conductivity (K) decreased from 0.95 W/m·°C (0% PET) to 0.47 W/m·°C (20% PET), while thermal resistance (R-value) increased from 0.15 m<sup>2</sup>·°C/W to 0.299 m<sup>2</sup>·°C/W. This improvement arises from PET's lower thermal conductivity compared to mineral aggregates and its structure, which creates micro voids that interrupt the heat conduction. The overall heat transfer coefficient (U-value) also decreased significantly from 6.64 W/m<sup>2</sup>·°C to 3.35 W/m<sup>2</sup>·°C with 20% PET, highlighting its effectiveness as an insulating material.

Previous studies, including (Athithan & Natarajan, 2025; Briga-Sá et al., 2022b; Caruana et al., 2017; Yesilata et al., 2009), indicate that adding PET or similar plastics to concrete reduces thermal conductivity through increased porosity and the insulating properties of plastics, aligning with this study's findings on PET's effectiveness in masonry block production.

PET-modified blocks provide enhanced insulation, benefiting energy efficiency in climates with significant temperature variations, like Palestine. They lower heat transfer through walls, reducing cooling loads and energy consumption while improving indoor comfort. This makes them an environmentally conscious choice aligning with sustainable construction. However, further research on long-term thermal stability, aging, and fire performance is advisable. The findings confirm that even small amounts of PET can enhance the insulation of hollow concrete units without affecting structural integrity.

#### **4.2.7 Statistical Validation and Significance Testing**

In this study, **one-way ANOVA** was applied to assess the impact of PET content on concrete block properties, specifically compressive strength and weight. Compressive strength was evaluated at 7 and 28 days with eight specimens per group, surpassing the minimum five required for 95% confidence. Standard deviations from 0.42 MPa to 1.24 MPa were recorded, with mean differences across groups exceeding 1.5 MPa, illustrating significant variation. For instance, the control group's compressive strength of 7.06 MPa contrasted significantly with the 10% PET group at 5.52 MPa. Weight analysis showed expected trends, where block weights declined from 15.78 kg (0% PET) to 14.83 kg (20% PET), aligning with PET's lower specific gravity and supporting the hypothesis of its effect on mechanical strength and mass.

The experimental design met initial assumptions, utilizing an expected standard deviation of 1 MPa and an effect size of 2 MPa, ensuring sufficient statistical power to identify significant differences at the 95% confidence level. Overall, the limited number of thermal insulation tests (two blocks per group) prevented confident application of inferential statistics. However, a notable trend of decreasing thermal conductivity and U-value supports earlier descriptive conclusions. While this study used one-way ANOVA to assess group differences, additional statistical methods like correlation analysis and regression modelling could enhance understanding of relationships between compressive strength, block weight, and thermal resistance in future research. Full outputs are in Appendix E.

## 5 Conclusions and Recommendations

### 5.1 Summary of Key Findings

The study explored using polyethylene terephthalate (PET) plastic waste to partially replace natural sand in 15 cm hollow concrete blocks. It aimed to evaluate how varying PET content (0%, 10%, 15%, 20%) affects compressive strength, unit weight, and thermal insulation. Four concrete mix groups were created based on these ratios. Laboratory tests assessed particle size distribution, specific gravity, density, compressive strength at 7 and 28 days, and thermal resistance to determine the feasibility of using plastic waste in construction, the results revealed the following main output:

- Compressive strength decreased at 10% and 15% PET replacement but recovered to 6.66 MPa at 20% PET after 28 days, nearing the control group (7.06 MPa).
- PET-modified blocks failed brittlely, raising concerns for load-bearing use.
- Block weight and specific weight declined with higher PET content, with the 20% PET group showing about 6% mass reduction relative to control.
- Thermal conductivity improved from 0.95 W/m·°C (control) to 0.47 W/m·°C (20% PET), with R-value more than doubling.
- One-way ANOVA confirmed significant effects of PET on compressive strength and weight at 95% confidence; limited samples restricted the thermal result validation.

Those findings support the feasibility of using PET waste in hollow concrete blocks as non-loadbearing blocks, thermally driven applications, offering a dual benefit of sustainability and functional performance.

## 5.2 Practical Implications

This study highlights the effective integration of shredded PET plastic waste in the production of hollow concrete blocks, particularly at a 20% replacement level by weight, which enhances thermal insulation without compromising mechanical integrity. The modified blocks demonstrate lower thermal conductivity and higher R-values, making them ideal for non-loadbearing applications such as partition walls, especially in energy-sensitive regions like Palestine, where indoor cooling energy demands are high. The lighter weight of these blocks also facilitates easier handling, contributing to logistical advantages on construction sites. From an environmental standpoint, utilizing PET plastic waste in concrete blocks addresses critical issues related to solid waste management and the persistence of plastics in landfills, which can last for decades and release harmful chemicals during degradation. This approach not only promotes waste valorisation and efficiency but also aligns with circular economy principles by transforming plastic waste into valuable construction materials. By reducing the ecological footprint of both the waste and construction sectors, PET-modified concrete blocks provide a sustainable solution that supports energy efficiency while contributing positively to environmental goals, including reduced reliance on natural resources and healthier ecosystems.

### 5.3 Study Limitations

The study's findings highlight promising potential but reveal several limitations that need consideration for proper interpretation and future explorations. Compressive strength tests were limited to 7-day and 28-day curing periods, neglecting longer-term strength development, durability under environmental stresses such as freeze-thaw cycles and water absorption, and flexural behavior. These unassessed factors could significantly impact the viability of PET-modified blocks in wider structural applications. Moreover, the failure mode evident in high PET-content blocks, which exhibited sudden disintegration under load, raises concerns about their fracture behavior and toughness, aspects not addressed in this study.

Thermal insulation improvements were noted with increased PET content, however, the limited sample size of two per group hindered robust statistical analysis of thermal parameters. While the trends observed were consistent and indicative, larger sample sizes are necessary to confirm the reproducibility and reliability of these thermal benefits. Additionally, the manufacturing process contributed to variability, as the molds exhibited signs of wear, causing slight deviations in block dimensions, which consequently affected net volume calculations and specific weight values. The introduction of PET in shredded flake form, without size standardization, may have impacted packing density and interfacial bonding quality with the cement paste.

Lastly, although the environmental performance related to thermal efficiency and waste reduction shows promise, other critical factors such as fire resistance, chemical stability, and microbiological degradation were not evaluated. Addressing these attributes is crucial for ensuring the long-term safety and environmental compatibility of PET-modified blocks in varying climatic conditions. Despite these limitations, the study effectively illustrates the technical feasibility and thermal performance advantages of incorporating PET plastic waste into hollow concrete blocks, establishing a foundation for more comprehensive investigations into optimizing mix design, production methods, and real-world performance.

## 5.4 Recommendations for Future Work

Building on the findings and limitations of this study, several recommendations are proposed to improve the reliability, applicability, and scope of future research in this area.

- Conduct future studies using fully automated block manufacturing to minimize variability from manual processes.
- Extend research on PET replacement ratios beyond the four investigated (0%, 10%, 15%, 20%) to include finer increments (e.g., 5%, 12.5%, 25%) for better optimal level identification.
- Explore other plastic waste types (HDPE, LDPE, PP) as fine aggregate substitutes in future comparative studies under identical conditions.
- Secure greater financial investment and institutional support for future research to expand sample sizes, buy precise equipment.
- Foster collaboration between researchers and plastic recycling companies in the West Bank to access critical data on waste processing and material outputs; emphasize mutual benefits to build partnerships.
- Include long-term durability testing (water absorption, shrinkage, fire resistance, chemical resistance) and assess life cycle impacts of PET-modified blocks in future research to ensure environmental and structural viability over time and under varied conditions.

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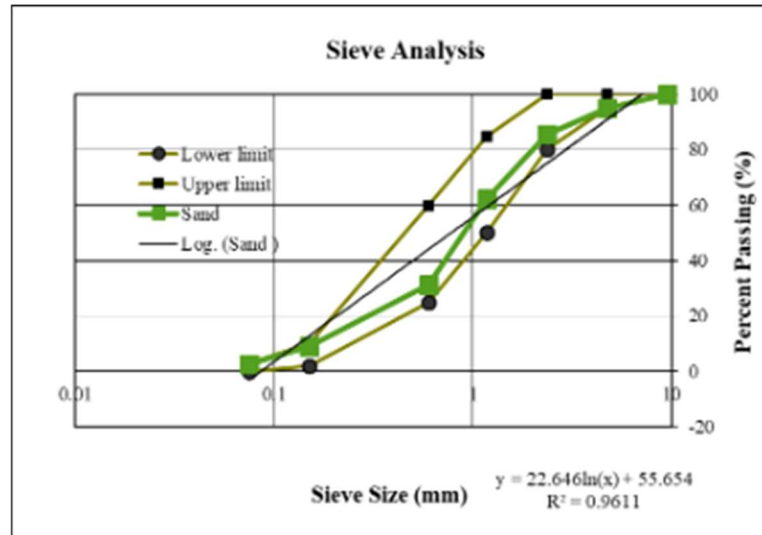
## 7 Appendices

### Appendix A: Sieve analysis data for block component

Sieve analysis was conducted in accordance with ASTM C136 to determine the particle size distribution of raw material that have been used in the concrete block mixture. Three materials were tested: natural sand, crushed limestone (coarse aggregate), and shredded PET plastic waste. The analysis supports material classification and compliance with the assumed lightweight concrete grading standards due to the absence of a specific ASTM gradation for hollow block mixtures and have been shown as the following:

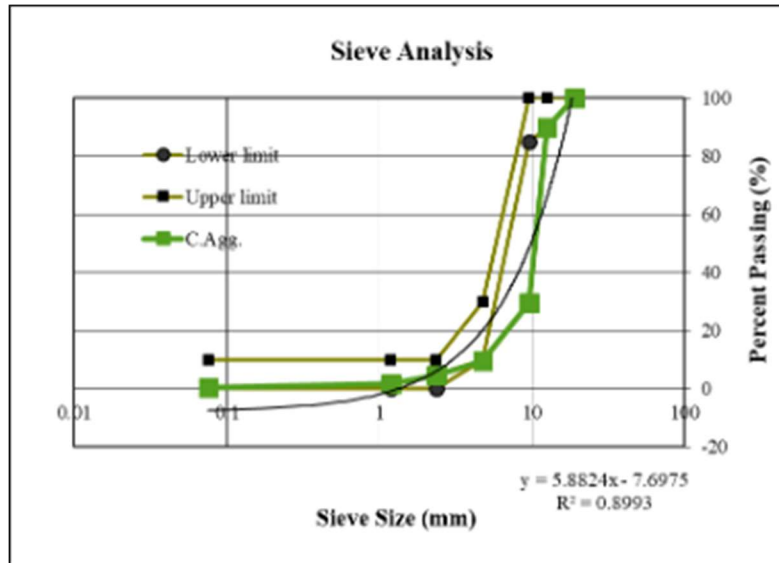
- Sand

Sieve Size (mm)	Mass Retained (gm)	% Retained	Cumulative Retained (gm)	%cumulative retained	% Passing
9.5	0	0.00%	0	0	100.00%
4.75	100	5.00%	100	5.00%	95.00%
2.36	187	9.35%	287	14.35%	85.65%
1.18	465	23.25%	752	37.60%	62.40%
0.6	625	31.25%	1377	68.85%	31.15%
0.15	440	22.00%	1817	90.85%	9.15%
0.075	133	6.65%	1950	97.50%	2.50%
Pan	50	2.50%	2000	100.00%	0.00%
Total	2000				



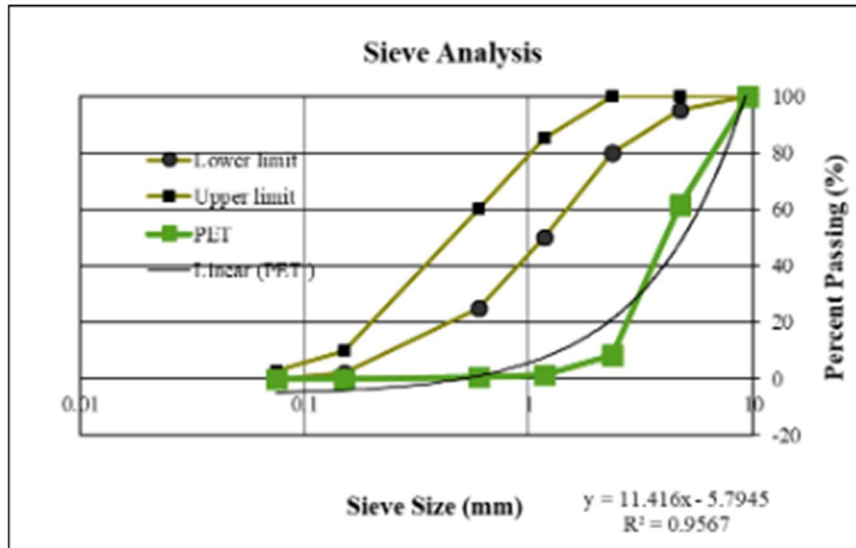
- Coarse aggregate

Sieve Size (mm)	Mass Retained (gm)	% Retained	Cumulative Retained (gm)	%cumulative retained	% Passing
19	0	0.00%	0	0	100.00%
12.5	200	10.00%	200	10.00%	90.00%
9.5	1205	60.25%	1405	70.25%	29.75%
4.75	400	20.00%	1805	90.25%	9.75%
2.36	100	5.00%	1905	95.25%	4.75%
1.18	60	3.00%	1965	98.25%	1.75%
0.075	25	1.25%	1990	99.50%	0.50%
Pan	10	0.50%	2000	100.00%	0.00%
Total	2000				



- PET

Sieve Size (mm)	Mass Retained (gm)	% Retained	Cumulative Retained (gm)	%cumulative retained	% Passing
9.5	0	0.00%	0	0.00%	100.00%
4.75	771	38.55%	771	38.55%	61.45%
2.36	1060	53.00%	1831	91.55%	8.45%
1.18	139	6.95%	1970	98.50%	1.50%
0.6	19	0.95%	1989	99.45%	0.55%
0.15	11	0.55%	2000	100.00%	0.00%
0.075	0	0.00%	2000	100.00%	0.00%
Pan	0	0.00%	2000	100.00%	0.00%
Total	2000				



- Summary

Sieve Size (mm)	CA passing	Sand passing	PET passing	ASTM min passing	ASTM max passing
19.00	100.00%	100.00%	100.00%	100.00%	100.00%
12.50	90.00%	100.00%	100.00%	100.00%	100.00%
9.50	29.75%	100.00%	100.00%	98.00%	100.00%
4.75	9.75%	95.00%	61.45%	90.00%	100.00%
2.36	4.75%	85.65%	8.45%	60.00%	85.00%
1.18	1.75%	62.40%	1.50%	30.00%	70.00%
0.60	1.75%	31.15%	0.55%	15.00%	65.00%
0.15	1.75%	9.15%	0.00%	0.00%	60.00%
0.075	0.50%	2.50%	0.00%	0.00%	50.00%
Pan	0.00%	0.00%	0.00%	0.00%	0.00%

## Appendix B: Specific gravity, volume and amount of component used in mixing design

- Specific gravity

As mentioned in chapter 3 “Methodology” the specific gravity was measured using ASTM C128 and C127 for coarse aggregate and sand respectively which was crucial in determining an semi-accurate amount of these component using the following equation:

$$SG_{bulk, SSD} = \frac{W_{dry}}{W_{SSD} - W_{submerged}} = \frac{W_{dry}}{Volume * P_{water}}$$

For Pet the volume have been measured by the displaced water in 250ml le chatelier flask using mass measurement method, so making SG of PET as a sample calculation as shown below

W<sub>dry</sub> (PET + flask) = 129.2 gm , W of PET fully submerged with 250ml of water=507.4 gm , W vacuumed water with PET = 601.5 gm and water density (P<sub>water</sub>) = 1 g / ml

The volume of submerged water = 601.5 – 502.4 = 99.1 mg → 99 ml

So the SG PET = 129.2 / (99 \* 1) = 1.304 which is approximately

1.3 for calculation simplicity

- Volume measurement

As mentioned before , using caliber to find the whole dimensions of many block and finding the avg value for these parameters will help in finding the volume of block which will lead to have the amount of hollow block main component that needed using equation and the design mix below:

$$SG \text{ of } x = \frac{(\text{mass of } x)}{(\text{Vol of } x) * (\text{density of water})}$$

	Pigment (Dye)	water	Cement	Aggregate	Sand	PET (Polyethylene terephthalate)
Ratio	0.040	0.350	1.000	9.000	2.240	0.000

So the volume for example for sand to the total volume of hollow block is  $2.24 / (0.04+0.35+1+9+2.24=12.63) = 0.177$  of the volume of the block which have been calculated using calibar and found to be  $V_{net}$  block = **0.006488788 m<sup>3</sup>** → so the volume of sand is around **0.001076 m<sup>3</sup>**

So if we know that SG of sand is **2.6** and the density of water is 1000 kg/m<sup>3</sup> and using the volume of calculated sand ,so the amount of mass required for this design ratio for sand is **2.81 kg**

As a result using the same process for PET , coarse aggregate , cement and water for producing 40 block for each group as mention in table 6 in chapter 3 and shown below:

	Pigment (Dye)	water	Cement	Aggregate	Sand	PET (Polyethylene terephthalate)
Group	PET/Sand	Pigment (Dye) [Kg]	Water [Kg]	Cement [Kg]	Aggregate [Kg]	Sand [Kg]
I	0%	2	17.5	50	450	112
II	10%	2	17.5	50	450	100.8
III	15%	2	17.5	50	450	95.2
X	20%	2	17.5	50	450	89.6

### Appendix C: Weighting of blocks theoretically and comparison with experimentally

According to table B1 and the real weight from table below ,a summary table have been made as shown below to determine the error percentages in this study

Group Notes	Group Symbol	Calculated Weight (g)	Actual Weight (g)	% Error (Weight)
0 plastic	I	15,788	15,781	0.0444%
10%	II	15,508	15,004	3.3571%
15%	III	15,368	14,918	3.0157%
20%	X    ----	15,228	14,830	2.6786%

## Appendix D: compressive strength test result

In compressive strength test there was two tests and have been divided into 7-day and 28-day test as shown below

- 7-day compressive test

<b>Group</b>	<b>Sample-ID</b>	<b>Weight (mg)</b>	<b>Force (KN)</b>	<b>Stress (Mpa)</b>
I	6	16,768	422.43	7.05
I	15	15,488	328.08	5.47
I	19	16,183	382.22	6.38
I	26	15,558	404.643	6.75
I	30	15,443	366.17	6.11
I	35	16,417	475	7.92
I	39	15,423	298.9	4.99
I	41	15,320	413	6.89
II	47	15,363	239.176	3.99
II	50	15,127	257.8	4.3
II	54	15,261	302.645	5.05
II	61	14,531	299.931	5
II	69	14,456	288.059	4.81
II	79	14,946	285.65	4.77
II	84	15,135	315.19	5.26

<b>Group</b>	<b>Sample-ID</b>	<b>Weight (mg)</b>	<b>Force (KN)</b>	<b>Stress (Mpa)</b>
II	85	15,252	296.42	4.95
III	90	15,508	247.658	4.13
III	91	15,308	297.55	4.96
III	98	14,250	290.344	4.84
III	100	15,771	236.4	3.94
III	102	15,017	210.168	3.51
III	111	15,615	283.4	4.73
III	116	14,245	265.908	4.44
III	122	14,569	288.61	4.82
X	128	14,999	273.314	4.56
X	133	14,938	302.789	5.05
X	137	14,415	305.5	5.1
X	140	14,182	296.614	4.95
X	143	14,908	302.927	5.05
X	150	14,880	337.236	5.63
X	154	15,125	217	3.62
X	159	14,528	301.06	5.02

- 28-day compressive test

<b>Group</b>	<b>Sample-ID</b>	<b>Weight (mg)</b>	<b>Force (KN)</b>	<b>Stress (Mpa)</b>
I	4	15,705	421.87	7.04
I	7	15,911	489.9	8.17
I	9	15,555	508.96	8.49
I	25	15,626	381.04	6.36
I	28	15,405	366.81	6.12
I	32	15,859	357.21	5.96
I	40	15,582	409.64	6.83
I	45	16,245	451.24	7.53
II	48	15,400	325.64	5.43
II	53	15,300	336.2	5.61
II	62	15,100	276.69	4.62
II	65	15,000	329.66	5.5
II	72	14,690	254.15	4.24
II	76	15,000	330.37	5.51
II	82	14,800	314.07	5.24
II	83	14,700	481.95	8.04
III	88	15,000	487.25	8.13
III	97	15,124	401.02	6.69

<b>Group</b>	<b>Sample-ID</b>	<b>Weight (mg)</b>	<b>Force (KN)</b>	<b>Stress (Mpa)</b>
III	99	14,837	386.16	6.44
III	104	14,888	346.26	5.78
III	107	14,900	316.92	5.29
III	117	14,000	393.94	6.57
III	119	14,800	372.26	6.21
III	120	14,850	356.35	5.94
X	125	15,307	369.2	6.16
X	129	14,320	531.6	8.86
X	130	14,160	487.5	8.13
X	138	15,164	398.2	6.64
X	141	14,600	379	6.32
X	155	15,278	308.8	5.15
X	160	15,161	381.57	6.36
X	162	15,319	340.14	5.67

- Sample calculation

After taking the highest compressive strength that have been applied at the hollow block (upper face) which a solid plate have been added between the compression cylinder and the hollow block, the compressive strength can be measured using the following equation:

$$\text{Stress} \left( \frac{N}{\text{mm}^2} \right) = \frac{\text{applied force (KN)} * 1000}{\text{contact area of block (mm}^2\text{)}}$$

Knowing that the area of upper face have been measured by 150mm\*400mm = 60000 mm<sup>2</sup>

## Appendix E: Thermal Insulation Test Results

The appendix details the raw data and methods for calculating the R-value of hollow concrete blocks with recycled PET used as partial sand replacement, employing the heat flow meter technique per ISO 9869 standards on 14.2 cm thick specimens.

- Group1 (0% pet)

<b>DATE</b>	<b>TIME</b>	<b>t interval</b>	<b>T Hot</b>	<b>T cold</b>	<b>q (Heat flow)</b>	<b>K (conduct.)</b>	<b>R (resistance)</b>
M/D/Y	Hr:min:sec	min	C	C	W / m <sup>2</sup>	W / m C	m <sup>2</sup> . C / W
6/17/2025	8:20:26	5	47	26.14	-3.523254	-0.01689	-8.407341622
6/17/2025	8:25:26	5	48.82	26.26	6.63264	0.0294	4.829931973
6/17/2025	8:30:26	5	49.87	26.41	18.542784	0.07904	1.796558704
6/17/2025	8:35:26	5	50.55	26.59	33.225332	0.13867	1.024013846
6/17/2025	8:40:26	5	51.07	26.79	48.557572	0.19999	0.7100355018
6/17/2025	8:45:26	5	51.41	27.05	61.942608	0.25428	0.5584395155
6/17/2025	8:50:26	5	51.7	27.26	77.012884	0.31511	0.4506362857

<b>DATE</b>	<b>TIME</b>	<b>t interval</b>	<b>T Hot</b>	<b>T cold</b>	<b>q (Heat flow)</b>	<b>K (conduct.)</b>	<b>R (resistance)</b>
M/D/Y	Hr:min:sec	min	C	C	W / m2	W / m C	m2 . C / W
6/17/2025	8:55:26	5	51.93	27.46	92.469683	0.37789	0.3757707269
6/17/2025	9:00:26	5	52.13	27.69	104.275704	0.42666	0.3328177003
6/17/2025	9:05:26	5	52.28	27.91	114.846062	0.47126	0.3013198659
6/17/2025	9:10:26	5	52.39	28.14	124.603775	0.51383	0.2763559932
6/17/2025	9:15:26	5	52.46	28.3	134.892528	0.55833	0.2543298766
6/17/2025	9:20:26	5	52.58	28.46	145.438776	0.60298	0.2354970314
6/17/2025	9:25:26	5	52.66	28.54	155.945448	0.64654	0.2196306493
6/17/2025	9:30:26	5	52.69	28.66	163.817316	0.68172	0.2082966614
6/17/2025	9:35:26	5	52.77	28.8	167.976966	0.70078	0.2026313536
6/17/2025	9:40:26	5	52.81	28.95	171.193114	0.71749	0.197912166
6/17/2025	9:45:26	5	52.84	29.09	174.3345	0.73404	0.1934499482
6/17/2025	9:50:26	5	52.87	29.2	178.036272	0.75216	0.1887896192
6/17/2025	9:55:26	5	52.92	29.27	183.573665	0.77621	0.1829401837
6/17/2025	10:00:26	5	52.91	29.2	194.296337	0.81947	0.1732827315
6/17/2025	10:05:26	5	52.94	29.14	203.21392	0.85384	0.1663075049
6/17/2025	10:10:26	5	52.99	29.19	203.47096	0.85492	0.1660974126

<b>DATE</b>	<b>TIME</b>	<b>t interval</b>	<b>T Hot</b>	<b>T cold</b>	<b>q (Heat flow)</b>	<b>K (conduct.)</b>	<b>R (resistance)</b>
M/D/Y	Hr:min:sec	min	C	C	W / m <sup>2</sup>	W / m C	m <sup>2</sup> . C / W
6/17/2025	10:15:26	5	53	29.31	198.733041	0.83889	0.169271299
6/17/2025	10:20:26	5	53.01	29.72	184.370627	0.79163	0.179376729
6/17/2025	10:25:26	5	53.01	29.84	182.804349	0.78897	0.1799814949
6/17/2025	10:30:26	5	53.01	29.87	191.527466	0.82769	0.1715618166
6/17/2025	10:35:26	5	53.02	30.05	187.972698	0.81834	0.173522008
6/17/2025	10:40:26	5	53.03	30.17	187.20054	0.8189	0.173403346
6/17/2025	10:45:26	5	53.03	30.23	190.22724	0.83433	0.1701964451
6/17/2025	10:50:26	5	53.05	30.35	189.58586	0.83518	0.1700232285
6/17/2025	10:55:26	5	53.06	30.49	187.315201	0.82993	0.1710987674
6/17/2025	11:00:26	5	53.05	30.58	188.015478	0.83674	0.1697062409
6/17/2025	11:05:26	5	53.09	30.63	190.440586	0.84791	0.1674706042
6/17/2025	11:10:26	5	53.08	30.73	190.647735	0.85301	0.1664693263
6/17/2025	11:15:26	5	53.1	30.7	194.80832	0.86968	0.1632784472
6/17/2025	11:20:26	5	53.12	30.71	198.53019	0.8859	0.1602889717
6/17/2025	11:25:26	5	53.12	30.75	198.71271	0.8883	0.1598559045
6/17/2025	11:30:26	5	53.12	30.75	200.453096	0.89608	0.1584679939

<b>DATE</b>	<b>TIME</b>	<b>t interval</b>	<b>T Hot</b>	<b>T cold</b>	<b>q (Heat flow)</b>	<b>K (conduct.)</b>	<b>R (resistance)</b>
M/D/Y	Hr:min:sec	min	C	C	W / m <sup>2</sup>	W / m C	m <sup>2</sup> . C / W
6/17/2025	11:35:26	5	53.13	30.85	198.162776	0.88942	0.1596546064
6/17/2025	11:40:26	5	53.13	30.93	195.2046	0.8793	0.161492096
6/17/2025	11:45:26	5	53.14	30.98	195.480008	0.88213	0.1609740061
6/17/2025	11:50:26	5	53.13	31.05	195.547104	0.88563	0.1603378386
6/17/2025	11:55:26	5	53.15	31.05	197.86572	0.89532	0.1586025108
6/17/2025	12:00:26	5	53.16	30.99	202.378845	0.91285	0.1555567727
6/17/2025	12:05:26	5	53.13	31.03	202.436	0.916	0.1550218341
6/17/2025	12:10:26	5	53.16	31.1	199.106942	0.90257	0.1573285175
6/17/2025	12:15:26	5	53.15	31.14	197.865498	0.89898	0.1579567955
6/17/2025	12:20:26	5	53.16	31.26	194.86182	0.88978	0.159590011
6/17/2025	12:25:26	5	53.16	31.36	191.53916	0.87862	0.1616170813
6/17/2025	12:30:26	5	53.16	31.43	191.156637	0.87969	0.1614205004
6/17/2025	12:35:26	5	53.16	31.53	189.548016	0.87632	0.1620412635
6/17/2025	12:40:26	5	53.15	31.6	188.771535	0.87597	0.1621060082
6/17/2025	12:45:26	5	53.18	31.64	190.174506	0.88289	0.1608354382
6/17/2025	12:50:26	5	53.16	31.67	191.538221	0.89129	0.1593196378

<b>DATE</b>	<b>TIME</b>	<b>t interval</b>	<b>T Hot</b>	<b>T cold</b>	<b>q (Heat flow)</b>	<b>K (conduct.)</b>	<b>R (resistance)</b>
M/D/Y	Hr:min:sec	min	C	C	W / m <sup>2</sup>	W / m C	m <sup>2</sup> . C / W
6/17/2025	12:55:26	5	53.18	31.67	193.409316	0.89916	0.1579251746
6/17/2025	13:00:26	5	53.17	31.68	194.869171	0.90679	0.1565963454
6/17/2025	13:05:26	5	53.18	31.75	192.985722	0.90054	0.1576831679
6/17/2025	13:10:26	5	53.2	31.77	192.437114	0.89798	0.1581326978
6/17/2025	13:15:26	5	53.18	31.84	191.876476	0.89914	0.1579286874
6/17/2025	13:20:26	5	53.21	31.91	189.6552	0.8904	0.1594788859
6/17/2025	13:25:26	5	53.2	31.94	190.695822	0.89697	0.1583107573
6/17/2025	13:30:26	5	53.19	31.95	192.166776	0.90474	0.1569511683
6/17/2025	13:35:26	5	53.2	32.01	190.968518	0.90122	0.1575641908
6/17/2025	13:40:26	5	53.23	32.03	190.93992	0.90066	0.1576621589
6/17/2025	13:45:26	5	53.22	32.04	192.64269	0.90955	0.1561211588
6/17/2025	13:50:26	5	53.24	32.08	192.010072	0.90742	0.1564876243
6/17/2025	13:55:26	5	53.23	32.13	190.89803	0.90473	0.1569529031
6/17/2025	14:00:26	5	53.25	32.14	191.989117	0.90947	0.1561348918
6/17/2025	14:05:26	5	53.23	32.18	191.46238	0.90956	0.1561194424
6/17/2025	14:10:26	5	53.25	32.24	189.255979	0.90079	0.1576394054

<b>DATE</b>	<b>TIME</b>	<b>t interval</b>	<b>T Hot</b>	<b>T cold</b>	<b>q (Heat flow)</b>	<b>K (conduct.)</b>	<b>R (resistance)</b>
M/D/Y	Hr:min:sec	min	C	C	W / m <sup>2</sup>	W / m C	m <sup>2</sup> . C / W
6/17/2025	14:15:26	5	53.25	32.31	187.928124	0.89746	0.158224322
6/17/2025	14:20:26	5	53.26	32.32	189.027474	0.90271	0.1573041176
6/17/2025	14:25:26	5	53.26	32.32	191.205234	0.91311	0.1555124793
6/17/2025	14:30:26	5	53.25	32.3	192.968355	0.92109	0.1541651739
6/17/2025	14:35:26	5	53.26	32.32	193.041672	0.92188	0.1540330629
6/17/2025	14:40:26	5	53.27	32.34	192.553907	0.91999	0.1543495038
6/17/2025	14:45:26	5	53.26	32.29	195.373296	0.93168	0.1524128456
6/17/2025	14:50:26	5	53.25	32.22	199.641996	0.94932	0.1495807525
6/17/2025	14:55:26	5	53.27	32.15	202.965312	0.96101	0.1477612096
6/17/2025	15:00:26	5	53.26	32.04	206.48121	0.97305	0.1459328914
6/17/2025	15:05:26	5	53.26	31.98	207.658752	0.97584	0.1455156583
6/17/2025	15:10:26	5	53.27	31.98	205.069538	0.96322	0.1474221881
6/17/2025	15:15:26	5	53.26	31.97	203.398273	0.95537	0.1486335137
6/17/2025	15:20:26	5	53.26	31.99	201.882078	0.94914	0.1496091198
6/17/2025	15:25:26	5	53.25	32	200.28125	0.9425	0.15066313

- Group2 (10% PET)

<b>DATE</b>	<b>TIME</b>	<b>t interva l</b>	<b>T Hot</b>	<b>T cold</b>	<b>q (Heat flow)</b>	<b>K (conduct.)</b>	<b>R (resistance)</b>
M/D/Y	Hr:min:se c	min	C	C	W / m <sup>2</sup>	W / m C	m <sup>2</sup> . C / W
5/29/202 5	8:45:17	5	45.4	24.93	17.24962	0.1196602853	1.186692808
5/29/202 5	8:50:17	5	46.99	25.01 5	13.36304	0.08635047463	1.644461141
5/29/202 5	8:55:17	5	48.58	25.1	9.47645	0.05731072828	2.477721088
5/29/202 5	9:00:17	5	49.22	25.28	5.57065	0.03304228488	4.297523628
5/29/202 5	9:05:17	5	49.86	25.46	1.66484	0.00968882295 1	14.65606305
5/29/202 5	9:10:17	5	50.23	25.52	5.56015	0.03195229866	4.444124709
5/29/202 5	9:15:17	5	50.59	25.58	9.45546	0.05368553858	2.645032605
5/29/202 5	9:20:17	5	50.85	25.69	11.19509	0.06318373529	2.247413822
5/29/202 5	9:25:17	5	51.11	25.8	12.93472	0.07256934966	1.956748967

<b>DATE</b>	<b>TIME</b>	<b>t interva l</b>	<b>T Hot</b>	<b>T cold</b>	<b>q (Heat flow)</b>	<b>K (conduct.)</b>	<b>R (resistence)</b>
M/D/Y	Hr:min:se c	min	C	C	W / m <sup>2</sup>	W / m C	m <sup>2</sup> . C / W
5/29/202 5	9:30:17	5	51.31	25.84	18.20888	0.1015179018	1.398768074
5/29/202 5	9:35:17	5	51.5	25.88	23.48304	0.1301558033	1.091000143
5/29/202 5	9:40:17	5	51.65	26.01 5	24.49482	0.1356841989	1.046547801
5/29/202 5	9:45:17	5	51.79	26.15	25.5066	0.1412612012	1.005230019
5/29/202 5	9:50:17	5	51.91	26.24 5	29.50294	0.1632346573	0.8699133036
5/29/202 5	9:55:17	5	52.02	26.34	33.49928	0.1852374517	0.76658364
5/29/202 5	10:00:17	5	52.1	26.55	32.81814	0.1823943593	0.778532848
5/29/202 5	10:05:17	5	52.17	26.76	32.13699	0.1795927816	0.7906776584
5/29/202 5	10:10:17	5	52.25	26.92	35.26861	0.1977158555	0.7182023902

<b>DATE</b>	<b>TIME</b>	<b>t interva l</b>	<b>T Hot</b>	<b>T cold</b>	<b>q (Heat flow)</b>	<b>K (conduct.)</b>	<b>R (resistence)</b>
M/D/Y	Hr:min:se c	min	C	C	W / m <sup>2</sup>	W / m C	m <sup>2</sup> . C / W
5/29/202 5	10:15:17	5	52.33	27.08	38.40024	0.215953825	0.6575479737
5/29/202 5	10:20:17	5	52.39	27.19 5	43.13687	0.2431210772	0.5840711206
5/29/202 5	10:25:17	5	52.45	27.31	47.87349	0.2704071432	0.5251340564
5/29/202 5	10:30:17	5	52.5	27.39	52.10417	0.2946552027	0.4819192015
5/29/202 5	10:35:17	5	52.54	27.47	56.33484	0.3190884436	0.4450176836
5/29/202 5	10:40:17	5	52.59	27.61 5	57.52137	0.32704843	0.4341864597
5/29/202 5	10:45:17	5	52.63	27.76	58.70789	0.3352038754	0.4236227873
5/29/202 5	10:50:17	5	52.67	27.83	63.2183	0.3613928583	0.3929242007
5/29/202 5	10:55:17	5	52.71	27.9	67.72871	0.3876451761	0.3663143739

<b>DATE</b>	<b>TIME</b>	<b>t interva l</b>	<b>T Hot</b>	<b>T cold</b>	<b>q (Heat flow)</b>	<b>K (conduct.)</b>	<b>R (resistence)</b>
M/D/Y	Hr:min:se c	min	C	C	W / m <sup>2</sup>	W / m C	m <sup>2</sup> . C / W
5/29/202 5	11:00:17	5	52.74	27.96	71.64381	0.410549678	0.3458777527
5/29/202 5	11:05:17	5	52.77	28.02	75.55891	0.4335097059	0.3275589868
5/29/202 5	11:10:17	5	52.8	28.01	81.34057	0.4659282348	0.3047679651
5/29/202 5	11:15:17	5	52.83	28	87.12223	0.4982423141	0.2850018876
5/29/202 5	11:20:17	5	52.86	27.98	90.61071	0.5171511584	0.2745812278
5/29/202 5	11:25:17	5	52.89	27.96	94.09918	0.5359840979	0.2649332332
5/29/202 5	11:30:17	5	52.92	28.12	90.07654	0.5157608339	0.27532141
5/29/202 5	11:35:17	5	52.94	28.28	86.05389	0.4955252384	0.2865646167
5/29/202 5	11:40:17	5	52.96	28.34	89.20439	0.5145013558	0.2759953854

<b>DATE</b>	<b>TIME</b>	<b>t interva l</b>	<b>T Hot</b>	<b>T cold</b>	<b>q (Heat flow)</b>	<b>K (conduct.)</b>	<b>R (resistence)</b>
M/D/Y	Hr:min:se c	min	C	C	W / m2	W / m C	m2 . C / W
5/29/202 5	11:45:17	5	52.98	28.4	92.35489	0.5335392343	0.26614725
5/29/202 5	11:50:17	5	53.01	28.45 5	94.9961	0.5493563918	0.2584842957
5/29/202 5	11:55:17	5	53.04	28.51	95.63731	0.5536281296	0.2564898574
5/29/202 5	12:00:17	5	53.045	28.61	94.81086	0.5509777827	0.2577236405
5/29/202 5	12:05:17	5	53.05	28.71	93.98441	0.5483067469	0.258979122 2
5/29/202 5	12:10:17	5	53.06 5	28.83 5	93.91891	0.5504121015	0.257988513 7
5/29/202 5	12:15:17	5	53.08	28.96	93.85342	0.5525367181	0.256996495 2
5/29/202 5	12:20:17	5	53.09 5	28.93 5	99.26192	0.5834102914	0.243396460 6
5/29/202 5	12:25:17	5	53.11	28.91	104.6704 2	0.6141818033	0.231201900 2

<b>DATE</b>	<b>TIME</b>	<b>t interva l</b>	<b>T Hot</b>	<b>T cold</b>	<b>q (Heat flow)</b>	<b>K (conduct.)</b>	<b>R (resistance)</b>
M/D/Y	Hr:min:se c	min	C	C	W / m2	W / m C	m2 . C / W
5/29/202 5	12:30:17	5	53.12	28.84	109.5211 7	0.6405274357	0.221692299 3
5/29/202 5	12:35:17	5	53.13	28.77	114.3719 1	0.666699968	0.212989360 8
5/29/202 5	12:40:17	5	53.14	28.69 5	117.8732 7	0.6847209793	0.207383743 6
5/29/202 5	12:45:17	5	53.15	28.62	121.3746 3	0.7026170999	0.202101543
5/29/202 5	12:50:17	5	53.16 5	28.67 5	118.3753 3	0.686373902	0.206884322 9
5/29/202 5	12:55:17	5	53.18	28.73	115.3760 2	0.6700774986	0.211915786 3
5/29/202 5	13:00:17	5	53.18	28.77	115.3152 8	0.6708221942	0.211680533 6
5/29/202 5	13:05:17	5	53.18	28.81	115.2545 5	0.6715693927	0.211445014 5
5/29/202 5	13:10:17	5	53.19	28.83	116.2207 4	0.67747722	0.209601143 5

<b>DATE</b>	<b>TIME</b>	<b>t interva l</b>	<b>T Hot</b>	<b>T cold</b>	<b>q (Heat flow)</b>	<b>K (conduct.)</b>	<b>R (resistance)</b>
M/D/Y	Hr:min:se c	min	C	C	W / m2	W / m C	m2 . C / W
5/29/202 5	13:15:17	5	53.2	28.85	117.1869 2	0.6833898415	0.207787695 1
5/29/202 5	13:20:17	5	53.2	28.77 5	121.8281 9	0.7082744311	0.20048726
5/29/202 5	13:25:17	5	53.2	28.7	126.4694 6	0.7330066661	0.193722658 4
5/29/202 5	13:30:17	5	53.21 5	28.69	126.1455 7	0.7303841362	0.194418242 4
5/29/202 5	13:35:17	5	53.23	28.68	125.8216 8	0.7277669475	0.195117407 4
5/29/202 5	13:40:17	5	53.24	28.83 5	119.5561 2	0.6956348715	0.204130077 2
5/29/202 5	13:45:17	5	53.25	28.99	113.2905 6	0.6631186941	0.214139642 3
5/29/202 5	13:50:17	5	53.24 5	29.11	112.0579 4	0.6593009107	0.215379650 9
5/29/202 5	13:55:17	5	53.24	29.23	110.8253 3	0.6554434344	0.216647223 2

<b>DATE</b>	<b>TIME</b>	<b>t interva l</b>	<b>T Hot</b>	<b>T cold</b>	<b>q (Heat flow)</b>	<b>K (conduct.)</b>	<b>R (resistance)</b>
M/D/Y	Hr:min:se c	min	C	C	W / m2	W / m C	m2 . C / W
5/29/202 5	14:00:17	5	53.25 5	29.17	116.4451 5	0.686535657	0.206835578 8
5/29/202 5	14:05:17	5	53.27	29.11	122.0649 7	0.7174348402	0.197927382 4
5/29/202 5	14:10:17	5	53.26 5	29.06	124.6727 2	0.7313995555	0.194148326 9
5/29/202 5	14:15:17	5	53.26	29.01	127.2804 6	0.7453123843	0.190524138 6
5/29/202 5	14:20:17	5	53.28	29.02	126.0360 8	0.7377214905	0.192484564 7
5/29/202 5	14:25:17	5	53.3	29.03	124.7917	0.7301368521	0.194484088 3
5/29/202 5	14:30:17	5	53.3	29.05 5	124.2488 5	0.7277103197	0.195132590 8
5/29/202 5	14:35:17	5	53.3	29.08	123.7060 1	0.7252788365	0.195786769
5/29/202 5	14:40:17	5	53.31	29.1	123.7086 3	0.7255937819	0.195701787 3

<b>DATE</b>	<b>TIME</b>	<b>t interva l</b>	<b>T Hot</b>	<b>T cold</b>	<b>q (Heat flow)</b>	<b>K (conduct.)</b>	<b>R (resistance)</b>
M/D/Y	Hr:min:se c	min	C	C	W / m <sup>2</sup>	W / m C	m <sup>2</sup> . C / W
5/29/202 5	14:45:17	5	53.32	29.12	123.7112 5	0.7259089876	0.195616809 3
5/29/202 5	14:50:17	5	53.32 5	29.13	124.2733 6	0.7293580128	0.194691766 6
5/29/202 5	14:55:17	5	53.33	29.14	124.8354 6	0.7328084051	0.19377507
5/29/202 5	15:00:17	5	53.33 5	29.04 5	129.1934 1	0.7552681853	0.188012685 8
5/29/202 5	15:05:17	5	53.34	28.95	133.5513 6	0.7775437934	0.182626369 4
5/29/202 5	15:10:17	5	53.34	28.93 5	133.0488 9	0.7741422815	0.183428813 3
5/29/202 5	15:15:17	5	53.34	28.92	132.5464 2	0.7707449484	0.184237341 2

- Group3 (15% PET)

<b>DATE</b>	<b>TIME</b>	<b>t interva l</b>	<b>T Hot</b>	<b>T cold</b>	<b>q (Heat flow)</b>	<b>K (conduct.)</b>	<b>R (resistance)</b>
M/D/Y	Hr:min:se c	min	C	C	W / m2	W / m C	m2 . C / W
6/1/202 5	8:47:43	5	48.88	27.78	-48.46366	- 0.326153541 2	- 0.435377765 5
6/1/202 5	8:52:43	5	50.07	27.86	-44.52007	-0.2846397992	- 0.4988761249
6/1/202 5	8:57:43	5	50.77	27.8	-32.281	-0.1995603831	- 0.7115640779
6/1/202 5	9:02:43	5	51.24	27.52	-16.07125	- 0.0962106871 8	- -1.47592751
6/1/202 5	9:07:43	5	51.59	27.46	-8.68375	- 0.0511020513 9	- -2.778753419
6/1/202 5	9:12:43	5	52	27.61 5	-9.97589	- 0.0580921213 9	- -2.444393433
6/1/202 5	9:17:43	5	52.215	27.64	-3.90846	- 0.0225839804 7	- -6.287642703

<b>DATE</b>	<b>TIME</b>	<b>t interva l</b>	<b>T Hot</b>	<b>T cold</b>	<b>q (Heat flow)</b>	<b>K (conduct.)</b>	<b>R (resistance)</b>
M/D/Y	Hr:min:se c	min	C	C	W / m2	W / m C	m2 . C / W
6/1/202 5	9:22:43	5	52.385	27.65 5	2.883895	0.0165593647 4	8.575208182
6/1/202 5	9:27:43	5	52.65	27.81	11.091005	0.0634026855 9	2.239652764
6/1/202 5	9:32:43	5	52.72	27.86	13.31396	0.0760491681 4	1.867213061
6/1/202 5	9:37:43	5	52.77	27.9	15.16223	0.0865716389 2	1.640260041
6/1/202 5	9:42:43	5	52.82	27.94	17.0105	0.0970856511 3	1.462626025
6/1/202 5	9:47:43	5	52.89	28.12	18.59845	0.1066201009	1.331831416
6/1/202 5	9:52:43	5	52.92	28.18	20.85717	0.1197137486	1.18616284
6/1/202 5	9:57:43	5	52.95	28.24	23.11589	0.1328391898	1.068961654
6/1/202 5	10:02:43	5	52.985	28.21 5	28.71231	0.164600243	0.8626961746

<b>DATE</b>	<b>TIME</b>	<b>t interva l</b>	<b>T Hot</b>	<b>T cold</b>	<b>q (Heat flow)</b>	<b>K (conduct.)</b>	<b>R (resistence)</b>
M/D/Y	Hr:min:se c	min	C	C	W / m2	W / m C	m2 . C / W
6/1/202 5	10:07:43	5	53.02	28.19	34.30873	0.1962077994	0.7237225044
6/1/202 5	10:12:43	5	53.055	28.14	39.672645	0.2261093955	0.6280145929
6/1/202 5	10:17:43	5	53.09	28.09	45.03656	0.2558076608	0.5551045639
6/1/202 5	10:22:43	5	53.115	28.09 5	47.00626	0.2667821311	0.5322695318
6/1/202 5	10:27:43	5	53.14	28.1	48.97596	0.2777390703	0.5112712441
6/1/202 5	10:32:43	5	53.165	28.16	48.85788	0.2774572669	0.5117905239
6/1/202 5	10:37:43	5	53.19	28.22	48.7398	0.2771746736	0.5123123197
6/1/202 5	10:42:43	5	53.205	28.23	50.779415	0.288715793	0.4918331572
6/1/202 5	10:47:43	5	53.22	28.24	52.81903	0.3002522922	0.4729356067

<b>DATE</b>	<b>TIME</b>	<b>t interva l</b>	<b>T Hot</b>	<b>T cold</b>	<b>q (Heat flow)</b>	<b>K (conduct.)</b>	<b>R (resistance)</b>
M/D/Y	Hr:min:se c	min	C	C	W / m <sup>2</sup>	W / m C	m <sup>2</sup> . C / W
6/1/202 5	10:52:43	5	53.24	28.27	54.862475	0.3119932499	0.455138052
6/1/202 5	10:57:43	5	53.26	28.3	56.90592	0.3237436154	0.4386186885
6/1/202 5	11:02:43	5	53.29	28.36 5	56.84607	0.3238572493	0.4384647875
6/1/202 5	11:07:43	5	53.32	28.43	56.78622	0.3239712029	0.438310562
6/1/202 5	11:12:43	5	53.34	28.45	58.79927	0.3354558594	0.423304575
6/1/202 5	11:17:43	5	53.36	28.47	60.81234	0.34694063	0.4092919299
6/1/202 5	11:22:43	5	53.375	28.46 5	64.135105	0.3656035692	0.388398834
6/1/202 5	11:27:43	5	53.39	28.46	67.45787	0.384236564	0.369563996
6/1/202 5	11:32:43	5	53.4	28.45	70.11333	0.399041798	0.3558524463

<b>DATE</b>	<b>TIME</b>	<b>t interva l</b>	<b>T Hot</b>	<b>T cold</b>	<b>q (Heat flow)</b>	<b>K (conduct.)</b>	<b>R (resistance)</b>
M/D/Y	Hr:min:se c	min	C	C	W / m <sup>2</sup>	W / m C	m <sup>2</sup> . C / W
6/1/202 5	11:37:43	5	53.41	28.44	72.76879	0.4138233152	0.3431416133
6/1/202 5	11:42:43	5	53.415	28.38	76.518945	0.4340199796	0.3271738783
6/1/202 5	11:47:43	5	53.42	28.32	80.2691	0.4541120398	0.3126981616
6/1/202 5	11:52:43	5	53.445	28.27 5	83.351445	0.4702385852	0.3019743689
6/1/202 5	11:57:43	5	53.47	28.23	86.43379	0.486275680 7	0.292015425 9
6/1/202 5	12:02:43	5	53.465	28.17 5	88.24884	0.495505546 9	0.286576004 9
6/1/202 5	12:07:43	5	53.46	28.12	90.06389	0.504698989	0.281355824 2
6/1/202 5	12:12:43	5	53.48	28.18 5	87.82218	0.493012435 7	0.288025189 1
6/1/202 5	12:17:43	5	53.5	28.25	85.58047	0.481284227 3	0.295043951

<b>DATE</b>	<b>TIME</b>	<b>t interva l</b>	<b>T Hot</b>	<b>T cold</b>	<b>q (Heat flow)</b>	<b>K (conduct.)</b>	<b>R (resistance)</b>
M/D/Y	Hr:min:se c	min	C	C	W / m2	W / m C	m2 . C / W
6/1/202 5	12:22:43	5	53.52	28.32	83.91003	0.472826359 5	0.300321666
6/1/202 5	12:27:43	5	53.54	28.39	82.23959	0.464334862	0.305813781 4
6/1/202 5	12:32:43	5	53.54	28.32 5	85.89491	0.483723070 4	0.293556393 5
6/1/202 5	12:37:43	5	53.54	28.26	89.55023	0.503011576 7	0.282299665 8
6/1/202 5	12:42:43	5	53.54 5	28.34 5	88.952545	0.501240531 3	0.283297122 1
6/1/202 5	12:47:43	5	53.55	28.43	88.35486	0.499458205 4	0.284308073 1
6/1/202 5	12:52:43	5	53.56 5	28.41	88.758195	0.501040099	0.283410450 2
6/1/202 5	12:57:43	5	53.58	28.39	89.16153	0.502617596 7	0.282520948 2
6/1/202 5	13:02:43	5	53.59 5	28.38 5	91.58589	0.515874509 3	0.275260741 6

<b>DATE</b>	<b>TIME</b>	<b>t interva l</b>	<b>T Hot</b>	<b>T cold</b>	<b>q (Heat flow)</b>	<b>K (conduct.)</b>	<b>R (resistence)</b>
M/D/Y	Hr:min:se c	min	C	C	W / m2	W / m C	m2 . C / W
6/1/202 5	13:07:43	5	53.61	28.38	94.01025	0.529110404 3	0.268374991
6/1/202 5	13:12:43	5	53.60 5	28.43	92.99797	0.524556573 6	0.270704833 7
6/1/202 5	13:17:43	5	53.6	28.48	91.98569	0.519982801 8	0.273085955
6/1/202 5	13:22:43	5	53.61	28.47 5	92.44379	0.522260520 4	0.271894953 7
6/1/202 5	13:27:43	5	53.62	28.47	92.90189	0.524535522 1	0.270715698
6/1/202 5	13:32:43	5	53.62	28.46 5	95.181355	0.537298843 6	0.264284953 7
6/1/202 5	13:37:43	5	53.62	28.46	97.46082	0.550057092 2	0.258155020 7
6/1/202 5	13:42:43	5	53.63	28.44 5	98.159915	0.553452766 7	0.256571126 8
6/1/202 5	13:47:43	5	53.64	28.43	98.85901	0.556841706 5	0.255009634 4

<b>DATE</b>	<b>TIME</b>	<b>t interva l</b>	<b>T Hot</b>	<b>T cold</b>	<b>q (Heat flow)</b>	<b>K (conduct.)</b>	<b>R (resistance)</b>
M/D/Y	Hr:min:se c	min	C	C	W / m2	W / m C	m2 . C / W
6/1/202 5	13:52:43	5	53.65 5	28.48 5	97.5176	0.550158887 6	0.258107254 5
6/1/202 5	13:57:43	5	53.67	28.54	96.17619	0.543454794 3	0.261291282 2
6/1/202 5	14:02:43	5	53.68	28.54	96.54826	0.545340211 6	0.260387913 8
6/1/202 5	14:07:43	5	53.69	28.54	96.92032	0.547224073 2	0.259491508 1
6/1/202 5	14:12:43	5	53.68 5	28.58	97.03587	0.548858535 7	0.258718760 4
6/1/202 5	14:17:43	5	53.68	28.62	97.15142	0.550498868 3	0.257947850 9
6/1/202 5	14:22:43	5	53.68	28.54	100.57166 5	0.568065888 2	0.249971003 3
6/1/202 5	14:27:43	5	53.68	28.46	103.99191	0.58552146	0.242518865 2
6/1/202 5	14:32:43	5	53.69	28.43	106.419	0.598238242 3	0.237363628 7

<b>DATE</b>	<b>TIME</b>	<b>t interva l</b>	<b>T Hot</b>	<b>T cold</b>	<b>q (Heat flow)</b>	<b>K (conduct.)</b>	<b>R (resistance)</b>
M/D/Y	Hr:min:se c	min	C	C	W / m2	W / m C	m2 . C / W
6/1/202 5	14:37:43	5	53.7	28.4	108.84608	0.610914757 3	0.232438320 2
6/1/202 5	14:42:43	5	53.71 5	28.44 5	105.92658	0.595234442 4	0.238561464
6/1/202 5	14:47:43	5	53.73	28.49	103.00708	0.579516852 6	0.245031700 7
6/1/202 5	14:52:43	5	53.73	28.49	102.64088 5	0.577456643	0.245905907 8
6/1/202 5	14:57:43	5	53.73	28.49	102.27469	0.575396433 4	0.246786375
6/1/202 5	15:02:43	5	53.73	28.55 5	101.60169	0.573085997 2	0.247781311 5
6/1/202 5	15:07:43	5	53.73	28.62	100.92869	0.570763599 4	0.248789516 6

- Group4 (20% PET)

DATE	TIME	t interva l	T Hot	T cold	q (Heat flow)	K (conduct.)	R (resistance)
M/D/Y	Hr:min:se c	min	C	C	W / m2	W / m C	m2 . C / W
6/2/202 5	9:59:49	5	47.2	27.75	-28.73377	0.2097786807	- 0.676903866 1
6/2/202 5	10:04:49	5	48.01	27.535	-22.09203	-0.153214567	- 0.9268048251
6/2/202 5	10:09:49	5	48.82	27.32	-15.45029	-0.1020437758	-1.391559641
6/2/202 5	10:14:49	5	49.255	27.12	-10.8221	0.06942571493	- -2.045351642
6/2/202 5	10:19:49	5	49.69	26.92	-6.1939	0.03862686869	- -3.676197549
6/2/202 5	10:24:49	5	49.965	26.86	-5.45035	0.03349706557	- -4.239177301
6/2/202 5	10:29:49	5	50.24	26.8	-4.7068	0.02851389078	- -4.980028894
6/2/202 5	10:34:49	5	50.44	26.765	-3.97429	0.02383734657	- -5.957038867

<b>DATE</b>	<b>TIME</b>	<b>t interva l</b>	<b>T Hot</b>	<b>T cold</b>	<b>q (Heat flow)</b>	<b>K (conduct.)</b>	<b>R (resistance)</b>
M/D/Y	Hr:min:se c	min	C	C	W / m2	W / m C	m2 . C / W
6/2/202 5	10:39:49	5	50.64	26.73	-3.24178	-0.0192527294	-7.375577615
6/2/202 5	10:44:49	5	50.795	26.68	-0.80839	- 0.00476016504 3	-29.83089845
6/2/202 5	10:49:49	5	50.95	26.63	1.625	0.00948807565 8	14.96615385
6/2/202 5	10:54:49	5	51.09	26.72	0.27503	0.00160255478	88.60851543
6/2/202 5	10:59:49	5	51.23	26.81	-1.07493	- 0.00625061670 8	-22.71775837
6/2/202 5	11:04:49	5	51.35	26.855	-0.95076	- 0.00551165217 4	-25.76359965
6/2/202 5	11:09:49	5	51.47	26.9	-0.82658	- 0.00477714122 9	-29.72489051
6/2/202 5	11:14:49	5	51.57	26.975	0.77674	0.00448453262 9	31.6643922

<b>DATE</b>	<b>TIME</b>	<b>t interva l</b>	<b>T Hot</b>	<b>T cold</b>	<b>q (Heat flow)</b>	<b>K (conduct.)</b>	<b>R (resistance)</b>
M/D/Y	Hr:min:se c	min	C	C	W / m <sup>2</sup>	W / m C	m <sup>2</sup> . C / W
6/2/202 5	11:19:49	5	51.67	27.05	2.38006	0.01372739724	10.34427704
6/2/202 5	11:24:49	5	51.75	27.13	3.12801	0.01804132494	7.870818827
6/2/202 5	11:29:49	5	51.83	27.21	3.87596	0.02235525264	6.351974737
6/2/202 5	11:34:49	5	51.915	27.235	7.64354	0.04397822853	3.228870393
6/2/202 5	11:39:49	5	52	27.26	11.41112	0.06549632336	2.168060629
6/2/202 5	11:44:49	5	52.06	27.27	15.44245	0.08845614764	1.605315219
6/2/202 5	11:49:49	5	52.12	27.28	19.47378	0.1113235411	1.275561293
6/2/202 5	11:54:49	5	52.175	27.22	25.93819	0.1475945895	0.9620948879
6/2/202 5	11:59:49	5	52.23	27.16	32.4026	0.1835328759	0.7737033448

<b>DATE</b>	<b>TIME</b>	<b>t interva l</b>	<b>T Hot</b>	<b>T cold</b>	<b>q (Heat flow)</b>	<b>K (conduct.)</b>	<b>R (resistance)</b>
M/D/Y	Hr:min:se c	min	C	C	W / m <sup>2</sup>	W / m C	m <sup>2</sup> . C / W
6/2/202 5	12:04:49	5	52.285	27.01	39.57325	0.2223304253	0.6386890134
6/2/202 5	12:09:49	5	52.34	26.86	46.74389	0.2605036256	0.5450979797
6/2/202 5	12:14:49	5	52.375	26.93	45.51767	0.2540188304	0.5590136753
6/2/202 5	12:19:49	5	52.41	27	44.29144	0.2475161149	0.5737000197
6/2/202 5	12:24:49	5	52.465	27.115	40.69754	0.227970441	0.6228877716
6/2/202 5	12:29:49	5	52.52	27.23	37.10364	0.2083320237	0.6816042846
6/2/202 5	12:34:49	5	52.55	27.27	40.32224	0.2264935949	0.6269492965
6/2/202 5	12:39:49	5	52.58	27.31	43.54083	0.244669484	0.5803747884
6/2/202 5	12:44:49	5	52.605	27.26	49.55472	0.2776393861	0.511454812

<b>DATE</b>	<b>TIME</b>	<b>t interva l</b>	<b>T Hot</b>	<b>T cold</b>	<b>q (Heat flow)</b>	<b>K (conduct.)</b>	<b>R (resistance)</b>
M/D/Y	Hr:min:se c	min	C	C	W / m2	W / m C	m2 . C / W
6/2/202 5	12:49:49	5	52.63	27.21	55.5686	0.3104146814	0.4574525901
6/2/202 5	12:54:49	5	52.665	27.19	58.94996	0.328592515	0.4321461796
6/2/202 5	12:59:49	5	52.7	27.17	62.33132	0.3466920266	0.4095854219
6/2/202 5	13:04:49	5	52.72	27.22	62.01021	0.3453117576	0.4112226035
6/2/202 5	13:09:49	5	52.74	27.27	61.6891	0.3439282371	0.412876829 1
6/2/202 5	13:14:49	5	52.775	27.32	61.78731	0.3446787672	0.411977799 3
6/2/202 5	13:19:49	5	52.81	27.37	61.88551	0.3454301266	0.411081689 4
6/2/202 5	13:24:49	5	52.8175	27.382 5	62.878455	0.3510415023	0.404510575 2
6/2/202 5	13:29:49	5	52.825	27.395	63.8714	0.3566550845	0.398143770 1

<b>DATE</b>	<b>TIME</b>	<b>t interva l</b>	<b>T Hot</b>	<b>T cold</b>	<b>q (Heat flow)</b>	<b>K (conduct.)</b>	<b>R (resistance)</b>
M/D/Y	Hr:min:se c	min	C	C	W / m2	W / m C	m2 . C / W
6/2/202 5	13:34:49	5	52.832 5	27.407 5	64.86434	0.3622708468	0.391971921 7
6/2/202 5	13:39:49	5	52.84	27.42	65.85728	0.3678888183	0.385986181
6/2/202 5	13:44:49	5	52.852 5	27.437 5	66.56692	0.3719261318	0.381796243 5
6/2/202 5	13:49:49	5	52.865	27.455	67.27656	0.3759650342	0.377694697 8
6/2/202 5	13:54:49	5	52.877 5	27.472 5	67.9862	0.3800055265	0.373678776
6/2/202 5	13:59:49	5	52.89	27.49	68.69584	0.3840476094	0.369745824 5
6/2/202 5	14:04:49	5	52.897 5	27.502 5	69.53199 5	0.388798712	0.365227547 4
6/2/202 5	14:09:49	5	52.905	27.515	70.36815	0.3935516857	0.360816647 9
6/2/202 5	14:14:49	5	52.92	27.54	72.04045	0.4030631954	0.352302074 7

<b>DATE</b>	<b>TIME</b>	<b>t interva l</b>	<b>T Hot</b>	<b>T cold</b>	<b>q (Heat flow)</b>	<b>K (conduct.)</b>	<b>R (resistance)</b>
M/D/Y	Hr:min:se c	min	C	C	W / m2	W / m C	m2 . C / W
6/2/202 5	14:19:49	5	52.945	27.535	75.68364	0.4229467485	0.335739665 8
6/2/202 5	14:24:49	5	52.97	27.53	77.32683	0.4316198844	0.328993183 9
6/2/202 5	14:29:49	5	52.985	27.53	79.16201	0.4416030414	0.321555756 4
6/2/202 5	14:34:49	5	53	27.53	80.99719	0.4515744397	0.314455353 3
6/2/202 5	14:39:49	5	53.01	27.56	81.47643	0.4546032637	0.312360274
6/2/202 5	14:44:49	5	53.02	27.59	81.95568	0.4576369076	0.310289659
6/2/202 5	14:49:49	5	53.045	27.605	82.57265	0.460900798	0.308092328 4
6/2/202 5	14:54:49	5	53.07	27.62	83.18961	0.4641620676	0.305927627 3
6/2/202 5	14:59:49	5	53.085	27.645	84.80565	0.4733648703	0.299980013 1

DATE	TIME	t interva l	T Hot	T cold	q (Heat flow)	K (conduct.)	R (resistance)
M/D/Y	Hr:min:se c	min	C	C	W / m2	W / m C	m2 . C / W
6/2/202 5	15:04:49	5	53.1	27.67	84.12546	0.4697528635	0.302286608 6
6/2/202 5	15:09:49	5	53.1	27.61	83.5056	0.4651940055	0.305248989 3
6/2/202 5	15:14:49	5	53.1	27.55	81.78942	0.4545635084	0.312387592 4
6/2/202 5	15:19:49	5	53.115	27.505	85.49613	0.4740511699	0.299545722 1

- Sample Calculations:

Using data from group4 and using the following formula

$$k = \frac{q \cdot d}{\Delta T} \text{ ----- Equation 10}$$

Where:

- k = Thermal conductivity (W/m·°C)
- q = Heat flux (W/m<sup>2</sup>)
- d = Block thickness (m)
- ΔT = Temperature difference across the specimen (°C)

And  $R = 1 / U = d / K$

Using the  $T_{\text{cold}} = 27.505 \text{ C}$  and  $T_{\text{hot}} = 55.115 \text{ C} \rightarrow \Delta T = 27.61 \text{ C}$

With heat flux (q) have been measured from HFM =  $85.49613 \text{ W/m}^2$  and  $d = 0.142 \rightarrow K = 0.4740511699 \text{ W / m} \cdot \text{C}$  and  $R = 0.2995457221 \text{ m} \cdot \text{C / W}$

## Appendix F: Thesis Tables

- Table for groups of blocks for compressive strength tests

*Table F1*

*Block ID Numbers Assigned for 7-Day and 28-Day Compressive Strength Tests.*

<b>Group</b>	<b>7-day [Block-ID]</b>	<b>28-day [Block-ID]</b>	<b>other tests [Block-ID]</b>
I	6	4	2
I	15	7	8
I	19	9	11
I	26	25	18
I	30	28	22
I	35	32	31
I	39	40	36
I	41	45	38
II	47	48	49
II	50	53	52
II	54	62	68
II	61	65	75
II	69	72	77
II	79	76	80
II	84	82	83
II	85	83	87
III	90	88	96
III	91	97	103
III	98	99	112
III	100	104	114
III	102	107	118
III	111	117	121
III	116	119	123
III	122	120	124
X	128	125	126

<b>Group</b>	<b>7-day [Block-ID]</b>	<b>28-day [Block-ID]</b>	<b>other tests [Block-ID]</b>
X	133	129	131
X	137	130	139
X	140	138	142
X	143	141	144
X	150	155	148
X	154	160	159
X	159	162	161

- Table for Material's Specific Gravities

*Table F 2*

*Specific gravity for hollow block component*

<b>Material</b>	<b>Specific Gravity (SG)</b>
Cement (CEM II)	3.15
Water	1.00
Natural Sand	2.60
Coarse Aggregate	2.55
Shredded PET Waste	1.30
Iron Oxide Pigment	3.50

- Average strength results for this thesis

**Table F 3**

*Average Compressive Strength and Standard Deviation at 7 and 28 Days*

<b>Group</b>	<b>PET/Sand (%) [by weight]</b>	<b>7-Day Strength (MPa)</b>	<b>Std. Dev. (7-Day)</b>	<b>28-Day Strength (MPa)</b>	<b>Std. Dev. (28-Day)</b>
I	0%	6.445	±0.927	7.063	±0.936
II	10%	4.766	±0.420	5.524	±1.127
III	15%	4.421	±0.516	6.381	±0.843
X	20%	4.873	±0.583	6.661	±1.237

- Table for thermal test results

**Table F 4**

*Thermal insulation results of concrete blocks addressed PET-sand ratios, time, temperatures, heat flow, K, R and U-values*

<b>Group</b>	<b>PET/Sand</b>	<b>ΔTime (Hr)</b>	<b>ΔTemp. (C)</b>	<b>q (W / m<sup>2</sup>)</b>	<b>K (W / m. C)</b>	<b>R (m<sup>2</sup> . C / W)</b>	<b>U (W / m<sup>2</sup> . C)</b>
I	0%	7	22.4	200.2	0.947	0.1505	6.64
II	10%	6.5	24.6	132.6	0.77	0.184	5.44
III	15%	6	25	101	0.57	0.248	4.04
X	20%	5.5	24.8	85.5	0.47	0.299	3.35

## Appendix G: Thesis Figures

- Figure of cement bags used in block preparation

*Figure G 1*

*CEM II 42.5 N/B-LL Nisher cement*



- Photo for the block factory

*Figure G 2*

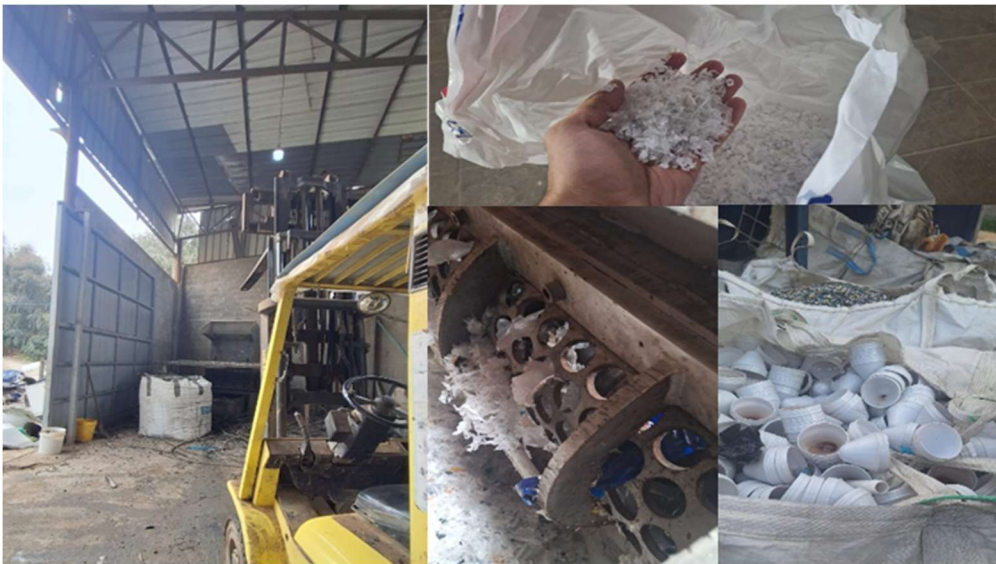
*An-Najah block factory's silo and stock pile for aggregates*



- Plastic shredding company

*Figure G 3*

*PET before and after shredding*



- Dies used for coloring each block group

*Figure G 4*

*Iron oxide pigments for concrete products*



- Block manufacturing process

*Figure G 5*

*hollow block production process*



- An-najah scientific lab

Figure G6

*MATEST compression test machine*



- Block storage area

Figure G 7

*Four groups of 15cm hollow block for the study.*



- Weighting plastic for determining some parameters

*Figure G 8*

*balancing and using vacuum for PET to calculated the Specific gravity*



- Oven for determining some parameters

*Figure G 9*

*Oven and balance used to calculate coarse aggregate specific gravity*



- Weighting of hollow blocks

*Figure G 10*

*Weighting hollow block sample before compressive strength test*





جامعة النجاح الوطنية

كلية الدراسات العليا

تأثير نفايات بلاستيك PET المعاد تدويرها على الخواص الميكانيكية والحرارية للطوب الخرساني  
المجوف

اعداد

مجدي عبدالغني حمدي صيفي

اشراف

د. عبد الفتاح راسم عبد الفتاح الملاح

قدمت هذه الأطروحة استكمالاً لمتطلبات الحصول على درجة الماجستير في هندسة المياه و البيئة بكلية  
الدراسات العليا في جامعة النجاح الوطنية، نابلس – فلسطين.

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## الملخص

يمثل التراكم الواسع لنفايات بولي إيثيلين تيرفتالات (PET) تحديًا بيئيًا بسبب بطء تحلل البلاستيك بشكل عام والذي قد يصل إلى مئات السنين. تسعى الدراسة إلى استكشاف تأثير استبدال الرمل جزئيًا بنفايات PET في صناعة البلوك الخرساني المجوف، للتخفيف من التلوث البلاستيكي والحفاظ على الموارد الطبيعية. تم تحضير أربع خلطات خرسانية بنسب استبدال مختلفة (0%، 10%، 15%، و20% بالوزن) من PET، وجرى استخدام رقائق PET المعاد تدويرها. أظهرت النتائج زيادة محتوى PET انخفاضًا في وزن البلوك وتحسنًا في الأداء الحراري، حيث انخفض معامل التوصيل الحراري من 1.12 إلى 0.47 واط/س.م<sup>°</sup>. بينما انخفضت مقاومة الضغط عند نسب 10% و15%، إلا أنها ارتفعت عند نسبة 20% (6.66 ميغاباسكال بعد 28 يومًا). ومع ذلك، عانت البلوكات التي تحتوي على نسب عالية من PET من انهيار هش. تشير النتائج إلى إمكانية إعادة استخدام نفايات PET بشكل فعال كبديل جزئي للرمل، مما يحسن خصائص العزل الحراري ويقلل الوزن مع الحفاظ على مقاومة ضغط مقبولة، مما يدعم البناء المستدام ويقلل من التلوث البلاستيكي والانبعاث الكربوني من الرمل المستعمل في صناعة الطوب.

الكلمات المفتاحية: استبدال الرمل، إعادة التدوير، البلوك الخرساني المجوف، البناء المستدام، العزل الحراري، فلسطين، مقاومة الضغط، نفايات البولي إيثيلين.