Development of Lightweight Energy-Efficient Construction Blocks Incorporating Recycled Plastic and Alternative Materials

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Abstract: This study investigates the formulation, characterization, and performance of energy-efficient construction blocks utilizing recycled plastics combined with alternative raw materials. The objective is to reduce cement consumption, thereby lowering CO_2 emissions, while maintaining structural strength and thermal insulation in compliance with European standards. River sand, crushed brick, basalt aggregate, volcanic ash, and shredded secondary plastics were used. Thermal conductivity, compressive strength, and density tests confirm that the blocks achieve a density of 500–650 kg/m³, compressive strength of 2.2–3 MPa, and thermal conductivity below 0.4 W/m·K.

Keywords: Energy-efficient blocks, recycled plastic, thermal insulation, cement reduction, lightweight construction, sustainable materials

1. Introduction

Concrete and cement-based construction materials are major contributors to global CO_2 emissions. Traditional cement production consumes large amounts of energy and releases significant CO_2 per ton. Reducing cement usage without compromising structural integrity is a key challenge in sustainable construction.

Recycled plastics offer potential for lightweight construction, improving thermal insulation and reducing environmental impact. Combining plastics with secondary aggregates, such as crushed brick, volcanic ash, and basalt, enables blocks with lower density while retaining sufficient compressive strength.

This study focuses on the systematic development of such blocks and provides experimental evaluation of their thermal and mechanical performance.

2. Materials and Methods

2.1 Raw Materials

- **Cement:** Ordinary Portland Cement, reduced proportion (10–15%)
- **Aggregates:** River sand, crushed brick, basalt
- **Volcanic Ash:** Pozzolanic additive to improve microstructure
- **Recycled Plastics:** Shredded secondary plastics, density 150–250 kg/m³, non-toxic, non-reactive

2.2 Block Composition

The proportion of each component was optimized to achieve:

- **Density:** 500–650 kg/m³
- **Thermal Conductivity:** <0.4 W/m·K
- **Compressive Strength:** 2.2–3 MPa

2.3 Experimental Methods

- Blocks were cast in standardized molds and cured for 28 days.
- **Density (ρ):** Measured according to EN 772-13
- **Compressive Strength (σ):** Tested according to EN 1015-11
- **Thermal Conductivity (λ):** Measured with a heat flow meter method

3. Results and Discussion

3.1 Material Performance

- Recycled plastics reduced the overall weight, allowing block density as low as 500 kg/m³.
- Cement reduction by 40–50% did not compromise compressive strength.

- Thermal insulation improved due to microvoids created by plastics, achieving λ < 0.4 W/m·K.

3.2 Optimization

- The ratio of volcanic ash to cement was critical for maintaining structural integrity.
- Crushed brick and basalt acted as fillers, increasing strength while reducing cement demand.

3.3 Environmental Impact

- Cement reduction leads to lower energy consumption and CO_2 emissions.
- Utilizing recycled plastics diverts waste from landfills, promoting circular economy principles.

Composition and Properties of Blocks **Table 1**

component	Proportion %
Crushed Brick	20–25
Cement	10–15
Crushed Brick	20–25
Basalt	10–15
Volcanic Ash	10–15
Recycled Plastic	15–20
Density (kg/m³)	500–650
Compressive Strength (MPa)	2.2–3
Thermal Conductivity (W/m·K)	<0.4

mparative Performance **Table 2**

~Type of Block	Density (kg/m³)	σ (MPa)	λ (W/m·K	Cement Reduvti
Conventional	1800	12-15	1.2	0
Proposed	500-650	2.2-3	<0.4	40-50

figure 1. Experimental setup with embedded temperature sensors (place photo here)

Figure 2. Block structure

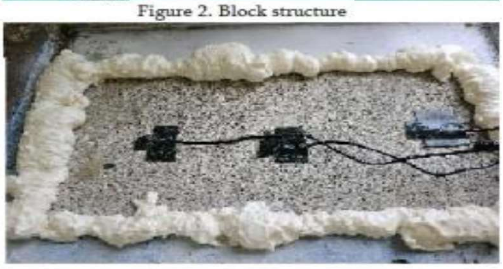

Figure 3. Block hermetically attached to the stand

4. Mathematical logarithm of block mix fraction optimization

The starting parameter in the research was the heat transfer coefficient, the maximum energy-efficient norm of which is determined by the Government Resolution No. 354. In the manufacture of secondary plastic blocks, in order to ensure the strength of lightweight blocks, we used a large 40% dose of cement. To reduce the specified dose, we added various inert materials to the mixture during the manufacture of the block, which increased the volumetric weight of the block mixture, and this addition, in turn, allowed us to reduce the proportion of cement. River sand, quarry basalt-containing gravel were used as additional admixtures. Residual slag from the factory's blast furnaces, porous light admixture accompanying coal, volcanic ash, crushed brick mass, and residual secondary raw materials accumulated over decades at the lithophone factory. The raw materials of the Gumbri mines, which were sent to Azerbaijan for oil refining, were tested on a stand at high temperatures, the raw materials from the mine were decomposed under the influence of a temperature of 53 for 15 minutes. When compiling the material proportions, we took into account two crucial parameters: the heat transfer coefficient and the strength of lightweight concrete. After completing the studies, it was determined that when preparing the mixture using the presented materials, the block made of the finished mixture fully met the specified indicators. In order to correctly describe the specified proportion, the logarithm of the mathematical description of the process was used. The logarithmic relationship between density and thermal conductivity has the form:

$$\lambda \rightarrow aL_n(\rho)-b$$

where; a, b are coefficients whose values are determined empirically:

$$a = 0.02, b = -0,05$$

Accordingly:

$$\lambda \rightarrow 0.02L_n(\rho)\text{ -0.05}$$

Mathcad It allows the ability to present the characteristics of materials in a tabular form using the above logarithm.

Table 3. Relationship between density and heat transfer

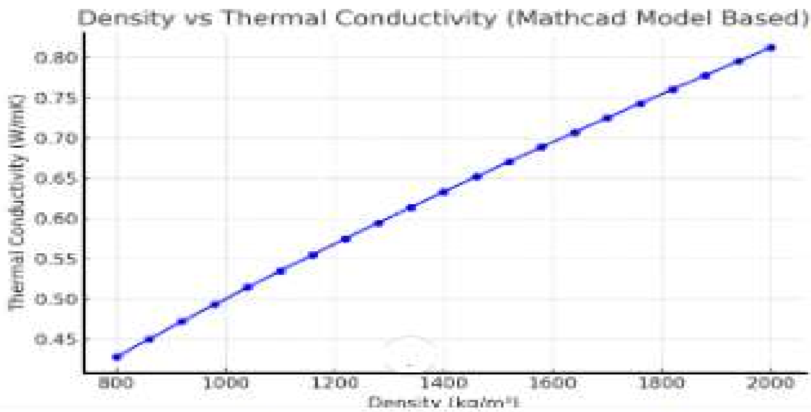

Diagram 1. Relationship between density and thermal conductivity

Density of the mixture $(kg \cdot m^3)$	Thermal conductivity $\lambda(W/m \cdot k)$
800	0.19
1000	0.22
1500	0.30
2000	0.36

Diagram 1 presents a graphical representation of the relationship between thermal conductivity and densityDependence. Through a mathematical optimization model, it is possible to determine the required parameters in order to provide the desired, specified characteristics according to the resolution. C , P, F The corresponding indicators for the optimal proportion of plastic, cement and filler material.

$U \leq$ Targeted heat transfer and

$\rho \geq$ Minimum allowable strength of lightweight blocks.

$$\log(U) \rightarrow a \cdot \log(C) + b \cdot \log(p) + c \cdot \log(F)$$

Where:

a, b, c

The coefficients determining the physical and mechanical properties of a material are,

U - The heat transfer coefficient is.

C, P, F -It is an indicator of the percentage of cement plastic and filler material.

$$\rho = k \cdot C + m \cdot P + n \cdot F$$

Where: k, m, n Relevant materials

$k = 5.0, m = 2.0, n = 8.0$

The results obtained for a specific case are presented in Table 5.

Sample	C(%)	P(%)	F(%)	Density $\rho, kg \cdot m^3$
Volcanic ash	30	10	60	840
Quarry gravel with basalt	25	15	60	820
River sand	35	10	55	860

5.Conclusion

The study demonstrates that integrating recycled plastics and secondary aggregates in construction blocks:

- Achieves lightweight, energy-efficient materials
- Reduces cement usage and associated CO_2 emissions
- Maintains compressive strength and complies with European thermal standards
- Supports sustainable building practices and circular economy principles

References

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