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ARTICLE

Investigating Thermal Performance of Building Materials for Improved Comfort and Energy Efficiency

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ABSTRACT

This research investigates the mixed proportions of cement, sand, water, superplasticizer, and waste materials, like recycled concrete, recycled rubber, recycled wood, tea-leaf residue, and recycled plastic, with their replacement levels clearly reported for reliability. Eight mixes were manufactured and tested at the Kuwait Institute for Scientific Research (KISR). The samples were then cured for 28 days, and compressive strength and thermal conductivity were measured. The control mix (Mix 1) showed a thermal conductivity of 0.788 W/m·K, while the wood and plastic mix (Mix 7) showed the lowest value of 0.266 W/m·K, which is equivalent to good insulation performance. Thermal conductivity (k) and thermal resistance (R) were reported together to provide a complementary insulation assessment for 50 mm (R = 0.05/k). Relative to the control (k = 0.788 W/m·K, R = 0.063 m^2·K/W), Mix 7 (wood + plastic) achieved the best insulation (k = 0.266 W/m·K, R = 0.188 m^2·K/W), representing a 66.27% reduction in k and a 196.45% increase in R. Mix 2 also showed strong insulation gains (k = 0.316 W/m·K, R = 0.158 m^2·K/W, −59.95% k, +149.67% R), whereas strength results indicate these highly insulating mixes are most suitable for non-load-bearing applications. Compressive strength varied significantly across mixes, ranging from 0.38 MPa in wood-plastic composites to 19.30 MPa in the control, highlighting the trade-off between strength and insulation. The outcomes of this research are the demonstration of the capacity of the recycled and organic additive options to create energy-efficient, eco-friendly building materials fit for Kuwait's hot climate.

Keywords: Sustainable Building Materials; Thermal Conductivity; Waste Materials; Construction Waste; Thermal Insulation

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1. Introduction

Building materials are essential for energy efficiency and indoor thermal comfort [1,2]. The significant increase in the expenditure on energy and the proponents of environmental sustainability raise the necessity of the application of proper thermal properties of the materials used in the construction sector. In hot climates like Kuwait, the high cooling demands for buildings put a great strain on energy resources [3]. Traditional bricks are structurally strong but mostly lack sufficient insulation, resulting in excessive heat transfer that increases energy costs.

New materials that reduce heat transfer and energy use are essential to ensure sustainability. Currently, few studies are only on bricks made of alternative materials that help in improving thermal behavior, especially in arid hot climates [4]. This study aims to fill this gap by examining and analyzing new alternative materials of bricks that improve thermal insulation, durability, and eco-friendliness. As previously noted, all mixing and testing activities were conducted at the Kuwait Institute for Scientific Research (KISR) using their advanced equipment and tools. The team successfully prepared eight distinct mix designs at KISR. The thermal efficiency of bricks is a key issue in high-temperature regions like Kuwait with heavy cooling needs, as it can help in reducing energy consumption [3]. Through the use of green input materials like construction waste, rubber, and organic residues, this study intends to find a green alternative to conventional bricks, which takes into account the insulation properties and structural stability [4].

The construction sector is considered one of the highest consumers of energy, with about 40% of the total energy consumption. Clay and cement bricks currently used have somewhat high thermal conductivity, which leads to low insulation and increases the cooling energy in hot-arid climates like Kuwait [5,6]. Some alternative materials have been used, such as phase-change materials (PCMs), innovative insulation composites, and geopolymer-based masonry blocks, which can reduce energy demand and improve thermal comfort, but those materials have limitations in focusing on locally available wasted materials specifically [7,8].

Although much research has been conducted on the use of sustainable materials, three main gaps were found. The first gap is that while PCM helps in enhancing insulation in materials, it doesn't focus on the use of recycled materials and organic waste materials for brick mixes. This limits comparative insights into how conductivity values vary across mixes, particularly in hot, arid conditions like those in Kuwait [7]. Second, the relationship between thermal conductivity and compressive strength has not been thoroughly investigated, raising questions about whether low-conductivity bricks retain adequate mechanical capacity for non-load-bearing applications. Studies on lightweight concrete panels and 3D-printed concrete structures have confirmed that reducing conductivity often results in a reduction in strength; however, the trade-off has yet to be empirically resolved in the context of waste-integrated bricks [9,10]. Third, climate-specific syntheses for the Gulf region are still fragmented. PCMs have been shown to deliver annual energy savings of up to 49.6% in Quetta, Pakistan. Bio-based PCMs achieved a payback of four years in Jordan [7]. However, similar evaluations are lacking for Kuwait, where summer temperatures often exceed 50 °C and residential cooling can represent more than 60% of national electricity demand [11]. As a result, the literature lacks data on the mechanical and thermal behavior of eco-friendly bricks, which could inform both design practice and building code development in hot climates.

This study is based on bricks, which are a commonly used material; their mixture and thermal performance are the major factors of energy efficiency for building envelopes. This study will find out exactly which material will help improve thermal insulation more. This study aims to explore thermal characteristics of sustainable and alternative building materials by designing and testing novel brick combinations that incorporate rubber, plastic waste, tea waste, and wood waste. This study attempts to improve thermal insulation in building envelopes to support energy efficiency and indoor comfort in hot regions such as Kuwait. Sustainable construction has recently gained attention for its vital role in mitigating energy demand and environmental concerns [3,4]. Based on the research gaps and aim, this study will answer the following research questions:

1. How do thermal conductivity values of eco-friendly brick mixes containing recycled and waste materials compare with the control mix under standard testing

conditions?

2. What is the relationship between compressive strength and thermal performance in the tested brick mixes, and how does this influence their suitability for non-load-bearing applications?
3. How does the current study on sustainable construction materials contribute to and expand upon previous findings regarding the improvement of insulation properties in modified brick formulations?

2. Literature Review

Extensive research underlines the possibility of using alternative materials to improve the thermal performance of bricks and to reduce environmental impacts. The existence of enough proof is now beyond argument, as more and more investigations reveal that the benefits of the usage of recycled and organic wastes in brickmaking on thermal performance and sustainability are truly positive. Hassan and Mohamed [3] have reported that the bricks processed with construction and demolition waste have shown a higher level of porosity that has indeed led to lower thermal conductivity; in addition, they have shown similar mechanical strength to traditional masonry. Organic additives, especially the tea-leaf residues, decreased the heat transfer rate significantly: Crespo-López et al. [4] pointed out that the conductivity was reduced by 15–20%, which was in turn associated with a decrease in the compressive strength; thus, it was emphasized to optimize the mix-design.

Thongtha et al. [12] added rubber particles and recycled plastics to the autoclaved aerated concrete, as a result of which, the aerated concrete was insulated effectively, and it had an energy loss of approximately 40%, although the excess content of the polymer can impair the strength of the structure. The issue of durability has been dealt with by Al-Jabri et al. [13] and Saikia and de Brito [14], who illustrated that the right curing methods and proportions would be able to eliminate the risks of freeze-thaw damage and UV-induced degradation in the bricks modified with polymers. However, the previous work has primarily been engaged either in single additive systems or temperate testing; it is the case that multi-waste formulations under the conditions of extreme heat have not been assessed thus far. Liu et al. [15] show that RC-PCM Trombe walls improve indoor temperature stability while lowering energy loads through effective thermal storage. Soleymani et al. [16] confirm that nano-enhanced materials improve thermal regulation and energy efficiency in hot climates, emphasizing material innovation as a critical strategy for better building performance.

2.1. Organic Additives

Crespo-López et al. [4] discussed the use of waste tea in brick mixes and its effects on increasing porosity and reducing thermal conductivity. However, it indicates a trade-off against compressive strength, and the mix design must be very precise in balancing thermal performance with durability.

2.2. Rubber and Recycled Plastic

Thongtha et al. [12] considered the addition of rubber particles and recycled plastic in bricks; through increased porosity, they were able to provide significant improvement in insulation. However, excess usage can reduce the compressive strength and, hence, demands optimization in the mix proportion. Studies on sustainable composite and PCM-integrated materials show that incorporating polymer-based and recycled components into building envelopes improves thermal insulation, regulates indoor temperatures, and reduces energy demand [2,15]. Furthermore, advances in material engineering and nano-modified composites show that recycled plastics and rubber-based systems improve thermal comfort and energy efficiency under a variety of climatic conditions [1,16].

2.3. Durability and Environmental Impact

Al-Jabri et al. [13] and Saikia and de Brito [14] emphasized curing methods and mix design to maintain the durability of bricks containing recycled materials. Research in LCA also proves that these materials are more environmentally friendly, with carbon emissions and embodied energy lower compared to others. These findings present a sound background for this research since they indicate the feasibility of incorporating sustainable additives into bricks to enhance thermal performance without losing structural reliability.

2.4. Eco-Friendly Brick Mixes and Thermal Conductivity

The study has provided useful information on the blending of sawdust ash to cement mixtures so that adequate enhancement of thermal insulation properties and an acceptable level of compressive strength can be achieved, thus it is very significant to environmentally conscious construction. Thermal conductivity was measured for SDA replacement of 5%, 10%, 15%, 20%, and 25% cement over 7-day, 28-day, 56-day, and 90-day periods by the scientists. At 90 days, thermal conductivity reduced from 1.67 W/m·K (control) to 1.21 W/m·K at room temperature with 25% of SDA replacement, suggesting better insulation performance. Regarding thermal conductivity, it reduced to 1.19 W/m·K for the sample containing 25% SDA at high temperatures.

Compressive strength as well as phonon applicability were reported in the study instead of thermal properties. The compressive strength declined with increasing SDA content. At 90 days, the compressive strength was 25.5 MPa and 20.1 MPa for the control and 25% SDA, respectively, implying a decrease of about 21%. El-Metwally et al. [17] showed that thermal conductivity decreased with an increase in the amount of plastic waste in cement bricks. This improved insulation effect is due to the low thermal conductivity of plastics (0.2 to 0.4 W/m·K) and the presence of air voids because of the hydrophobic nature of plastics with no moisture uptake. Interestingly, the thermal conductivity of the sample containing 20% plastic waste substitution was the lowest, which means the best insulating performance.

The examination also tested the compressive strength of the cement bricks with different proportions of plastic waste. It was noted that adding a small percentage of plastic waste (7.5% or less) improved the compressive strength of the cement bricks. Singh et al. [18] also showed that adding plastic waste into cement bricks helps decrease thermal conductivity, thus improving insulation without losing strength, or in some cases increasing it, with low levels of plastic used.

Eco-friendly brick mixes now prioritize thermal insulation and mechanical properties under standard testing conditions. Waste-based additives, such as cement kiln dust, sawdust ash, plastic waste, tea residues, and sugar sediment, have been studied to reduce thermal conductivity and increase construction energy efficiency. Modified cement composites had lower thermal conductivity than control mixes due to their porosity and air voids [3,19]. Waste plastics and tea residues have improved insulation and retained, or even increased, compressive strength at low substitution levels, making them suitable for non-load-bearing walls.

2.5. Sawdust Ash as a Sustainable Additive in Cementitious Materials

The use of sawdust ash (SDA) in cementitious materials is gaining popularity as a sustainable material for reducing cement consumption and environmental impact while enhancing thermal efficiency. SDA, such as a pozzolanic material, enhances the composites of cement when used in adequate amounts. Previous research on sustainable cement-based materials has shown the potential of waste-derived materials to enhance performance, with SDA positioned beside kiln dust, construction demolition waste, and recycled aggregates in relationships of embodied energy and landfill pressure [13,20]. The use of waste materials such as SDA as an additive helps in increasing porosity, which leads to lowering the density and enhancing thermal insulation [3,15,19]. This is also applicable to bricks and concretes mixed with tea waste and plastic waste, which proved significant improvements in insulation properties under ordinary testing conditions [3,4,14].

However, compressive strength remains a major challenge for SDA-mixed materials. Increasing SDA content often results in a decrease in strength, particularly when used in high amounts, which is considered a disadvantage in its use in structural elements. This makes SDA suitable for non-load-bearing applications such as partition walls and insulating layers [4,14,19]. There is support from literature that SDA can be used as a sustainable additive that improves thermal performance, but because of the decrease in strength, it can only be used for non-load-bearing applications [8,21].

2.6. Plastic Waste Substitution and Insulation Enhancement in Cement Bricks

Plastic waste, such as polyethene and polypropylene, on the other hand, has low thermal conductivity values, typically ranging from 0.2 to 0.4 W/m·K, making it an efficient additive for improving insulation in cementitious mixtures [3,14]. According to the literature, the addition of plastic waste increases porosity and decreases bulk density, thereby reducing heat transfer across brick structures and enhancing thermal insulation [19,22].

Thermal insulation benefits from plastic waste replacement are found in several studies and show that moderate inclusion levels (up to 15–20%) result in significant reductions in thermal conductivity while not compromising strength [3,14].

Similar to SDA, plastic waste as an additive also decreases the strength of the bricks and will make it only suitable to be used for non-load-bearing applications [3,21], but using it in low amounts (typically less than 10%) can improve compressive strength by improving particle packing [14,20].

2.7. Contributions to Sustainable Construction Materials

The review by Anjum et al. [23] provided a foundational understanding of sustainable cement-based materials, highlighting the role of supplementary cementitious materials and recycled aggregates in mitigating environmental impacts while delivering functional benefits. In addition, more research has shown that the use of waste-materials additives such as cement kiln dust, tea waste, construction waste, and wasted plastics has altered porosity and thermal conductivity significantly [3,4,13,14]. These studies demonstrate that modified composites can offer high efficiency and improved thermal insulation properties, particularly by reducing bulk density and increasing porosity as mentioned earlier [20,22]. Recent research has also demonstrated that clay and lightweight brick formulations can be tailored to reach desirable properties between insulation and compressive strength [19,21].

Moreover, experiments conducted using autoclaved aerated concretes (AAC) and geopolymer bricks showed that including sugar sediment waste and recycled AAC, for example, combined with phase change materials (PCM), has been shown to reduce thermal conductivity and energy consumption in hot climates [12,24]. Also, geopolymer-based materials and lightweight concrete composites made from recycled construction waste have higher insulation while maintaining structural integrity, making them more viable for use in energy-efficient buildings [8,25,26].

Materials like PCM mortar in hot climates are considered solutions that are capable of reducing energy demand while maintaining thermal comfort in buildings [7,27]. These contributions collectively expand the field beyond the groundwork established by Anjum et al. [23], signifying a transition towards an integrated, performance-oriented design of sustainable construction materials that encompass waste utilization, thermal optimization, and energy performance improvement. **Table 1** summarizes the literature review.

Table 1. Summary of Literature Review on Sustainable Brick Additives.

Section	Additive/Theme	Details of Additive/Approach	Key Properties Observed	Main Findings/Significance	Key References
2.1	Organic additives	Tea-leaf residues in brick mixes	↑ Porosity, ↓ thermal conductivity, ↓ compressive strength	Organic waste significantly improves insulation but introduces a strength–durability trade-off, requiring optimized mix design	Crespo-López et al. (2024) [4]
2.2	Rubber & recycled plastic	Rubber particles and recycled plastics in bricks and AAC	↓ Thermal conductivity, ↑ insulation, ↓ strength at high content	Polymer-based additives improve thermal performance; excessive replacement negatively affects mechanical integrity	Tian et al. (2025) [1]; Thongtha et al. (2023) [12]; Liu et al. (2024) [15]; Soleymani et al.(2024) [16]
2.3	Durability & environmental impact	Polymer- and waste-modified bricks under controlled curing	Improved durability with proper curing; reduced embodied energy	Correct curing and proportioning mitigate degradation risks while enhancing environmental sustainability	Al-Jabri et al. (2011) [13]; Saikia and de Brito (2012) [14]
2.4	Eco-friendly brick mixes	Sawdust ash, plastic waste, tea residues, sugar sediment	↓ Thermal conductivity, ↓ density, ↓ strength at high replacement	Waste-based additives reduce heat transfer through porosity and air voids, supporting energy-efficient construction	Hassan and Mohamed (2024) [3]; El-Metwally et al. (2023) [17]; Singh et al. (2023) [18];
2.5	Sawdust ash (SDA)	SDA as partial cement replacement	↓ Thermal conductivity, ↓ density, ↓ compressive strength	SDA improves insulation and sustainability but limits structural use at high replacement levels	Crespo-López et al. (2024) [4]; Saikia and de Brito (2012) [14]; Ozturk (2023) [19]; Nasr et al. (2023) [21]
2.6	Plastic waste substitution	Polyethylene and polypropylene waste in cement bricks	↓ Thermal conductivity (0.2–0.4 W/m·K), ↑ porosity	Moderate plastic content improves insulation without strength loss; high content suitable only for non-load-bearing elements	Hassan and Mohamed (2024) [3]; Tam et al. (2018) [20]
2.7	Sustainable construction advances	AAC, geopolymer bricks, PCM integration, optimization techniques	↓ Heat transfer, ↑ energy efficiency, balanced strength	Research has progressed toward climate-responsive, performance-optimized sustainable materials	Thongtha et al. (2023) [12]; Anjum et al. (2022) [23]; Tu et al. (2024) [24]; Wijesuriya et al. (2022) [27]

3. Methodology

The research design of this study focused on carrying out systematic research into thermal conductivity and mechanical characteristics of new brick mixes prepared using sustainable waste materials. Research work involved preparing, testing, and analyzing different mixes of bricks with varying proportions of construction waste (Wood waste), rubber, plastic waste, and loose tea leaves. All casting, mixing, and testing were conducted together with the Kuwait Institute for Scientific Research (KISR) under laboratory supervision to ensure accuracy and reliability. All experimental activities were in an organized sequence: materials selection, preparation of mix design, casting of specimens, air-drying curing, and laboratory testing. Compressive strength was tested at two curing stages (14 days and 28 days), while thermal conductivity was tested after 28 days of curing.

The experimental analysis is grounded in Fourier's law of heat conduction, where thermal conductivity (K) governs steady-state heat transfer, and thermal resistance (R) is derived as R = L/K for a fixed specimen thickness. Density was calculated from mass–volume relationships, while compressive stress was evaluated from the applied load divided by the cross-sectional area to characterize mechanical response and pressure effects. The influences of airgap and porosity on heat transfer were interpreted analytically, and measurement uncertainty was assessed based on instrument precision and repeatability, ensuring that fundamental governing principles support all reported results.

With a controlled and reproducible testing methodology, the study aims to identify green materials that enhance thermal insulation as well as possess sufficient mechanical strength for non-structural and insulating applications, with a specific focus on applicability in hot climates like Kuwait.

3.1. Experimental Design

All experimental studies were conducted within the Kuwait Institute for Scientific Research (KISR) laboratories under the supervision of engineers. Eight different brick mixes were produced, one normal control mix and seven sustainable alternatives with the inclusion of rubber, wood waste, plastic waste, and tea residue (see **Table 2** for mix proportions). The mixing operation was performed by precise weighing of raw materials and workability evaluation by flow table test, performed according to guidelines provided by ASTM C1437-20 [28]. Cube specimens to be tested for compressive strength were cast in normal molds of dimensions 50 mm × 50 mm × 50 mm. The curing was conducted at regular laboratory temperatures, and compressive strength was tested at curing ages of 14 and 28 days using the ADR-Auto V2.0 Compression Machine.

Thermal conductivity measurements were made on 300 mm × 300 mm × 50 mm slab samples after 28 days of curing (see **Table 3** for curing protocol). The thermal conductivity of the samples was measured using the RK-30A thermal conductivity machine. There was a controlled temperature difference across the sample during the test, with the lower plate being at 50 °C and the top plate being at 25 °C. The reason for the application of these specific temperatures is to closely simulate actual environments of Kuwait's hot desert-like climate, under which exterior surface temperatures of building walls increase above 50 °C during the summer months. By subjecting the test bricks to the same kind of temperature gradient as from actual exposure to the same outdoors, their actual-world thermal performance may be better assessed in terms of potential building applications within such more extreme environments.

Dimensional measurements of all samples were made using a DIGI-MET Digital Caliper, and sample weights were recorded using a precision digital balance. Density was calculated by dividing the weight measured by the calculated volume of each specimen. This procedure provided complete data necessary to evaluate the interaction between material composition, structural behavior, and thermal insulation efficiency. The experiments include the following equipment and infrastructure:

1. Scale
2. Bucket
3. Stopwatch
4. Drum mixer or barrel mixer
5. Mattel scoop
6. Wheelbarrow
7. Flow table
8. Molds
9. Hand tamper
10. Trowel

The machine we used to collect data for this study is a compression testing machine (CTM), ELE International, thermal conductivity machine, Holometrix Model Rapid (RK-30A) (see **Figure 1**).

Table 2. Mix Proportions of Experimental Bricks (per Mix Design).

Mix No.	Cement (kg)	Sand (kg)	Water (kg)	Superplasticizer (kg/ml)	Recycled Concrete (kg)	Rubber (kg)	Wood Waste (kg)	Tea-Leaf Waste (kg)	Plastic Waste (kg)
Mix 1 (Control)	8.51	13.84	3.40	0.04 (150 ml)	–	–	–	–	–
Mix 2 (Wood > Rubber)	7.80	11.90	3.40	0.04	–	1.00	2.00	–	–
Mix 3 (Rubber > Wood)	7.50	12.20	3.40	0.04	–	2.00	1.00	–	–
Mix 4 (Plastic + Tea-leaf)	7.80	11.50	3.40	0.04	–	–	–	1.00	1.50
Mix 5 (Recycled Concrete)	6.80	10.90	3.40	0.04	3.50	–	–	–	–
Mix 6 (Mixed Wastes)	6.50	10.50	3.40	0.04	2.00	1.00	1.00	–	–
Mix 7 (Air-dried Composite)	6.80	10.80	3.40	0.04	–	1.50	1.50	–	–
Mix 8 (50% Rubber)	4.25	8.00	3.40	0.04	–	8.50	–	–	–

Table 3. Curing Protocol for Mixes.

Mix No.	Curing Method	Notes
Mixes 1–4, 6	Standard water curing under lab conditions	Consistent immersion curing
Mix 5	Air-dried (no water curing)	Simulates actual exposure
Mix 7	Air-dried (no water curing)	Simulates actual exposure
Mix 8	Standard water curing	As per design notes

Figure 1. Compressive Testing Machine.

3.2. Data Collection

3.2.1. Experiment 1: Mixes 1, 2, and 3

Experimental performances for Mix 1 (control mix), Mix 2 (high wood waste and low rubber mix), and Mix 3 (high rubber and low wood waste mix) have been recorded during the research. These mixes were found to be perfectly prepared, weighted, and scrutinized to monitor compressive strength, density, and thermal conductivity performance. For Mix 1, the control mix included cement, sand, water, and a superplasticizer without any recycled material being added. Compressive strength test specimens were molded in a size of 50 mm × 50 mm × 50 mm, and thermal conductivity test specimens were molded in a size of 300 mm × 300 mm × 50 mm. After curing in standard laboratory conditions for 28 days, cube sizes were measured using a DIGI-MET Digital Caliper, typically around 50.1 mm × 50.3 mm × 50.3 mm. The average weight of Mix 1 cubes was 251.7 g. Calculated volume was roughly 126 cm^3, thus an average density of 1.97 g/cm^3. Compressive strength tests were conducted using the ADR-Auto V2.0 Compression Machine. Mix 1 had a mean compressive strength of 19.22 MPa at 14 days, which increased slightly to 19.30 MPa at 28 days. Thermal conductivity tests were conducted using the RK-30A Thermal Conductivity Machine with the lower plate at 50 °C and the upper plate at 25 °C. Thermal conductivity (K-value) recorded for Mix 1 was 0.788 W/m·K.

Mix 2 was also made with a higher proportion of wood waste from construction and a lower proportion of rubber waste. Compressive strength samples were molded in the same cube molds having dimensions typically around 50.9 mm × 49.9 mm × 49.8 mm. The mean weight taken for Mix 2 cubes was 154.6 g, which translated into an approximate volume of 126 cm^3 and a calculated mean density of 1.27 g/cm^3. Compressive strength tests indicated the average value for Mix 2 as 0.66 MPa at the age of 14 days and 0.63 MPa at the age of 28 days. A thermal conductivity test was conducted in 300 mm × 300 mm × 50 mm test specimens using the same machine settings that gave a K-value of 0.31562 W/m·K. These results indicated a significant improvement in thermal insulation compared to the control mix.

Mix 3 altered the materials' composition by introducing rubber waste and removing wood waste. Specimens of compressive strength were cast with dimensions approximately 50.0 mm × 50.2 mm × 49.8 mm. The measured average mass was 199.8 g, corresponding to a volume of approximately 125 cm^3, resulting in an average density of 1.60 g/cm^3. Compressive strength testing showed Mix 3 returned a result of 7.50 MPa after 14 days and extremely marginally improved after 28 days at 7.64 MPa. Thermal conductivity testing done on the bigger samples using the same parameters returned a K-value of 0.60477 W/m·K.

All the measurements, such as dimensions, mass, compressive strength, density, and thermal conductivity, were taken systematically with calibrated equipment to ensure reproducibility and reliability of the experimental data.

3.2.2. Experiment 2: Mixes 4 and 6

In this experimental work, 8 different concrete mixes were prepared and tested to study their compressive strength and density over time. The mixes were designed using waste materials to enhance sustainability and thermal performance.

Mix 4: Contained Tea Waste Residue and Rubber (higher percentage of rubber and less tea).

Mix 6: Included Rubber and Recycled Plastic (higher percentage of rubber and less plastic) (see **Figure 2**).

Both mixes were cast on 24 February 2025 using 50 mm × 50 mm × 50 mm cube molds. The mixes were poured into the molds and then left for curing under standard lab conditions.

To evaluate the development of compressive strength and physical properties, two periods were conducted:

- The first test was after 9 days of curing (on 5 Mar 2025).
- The second test was after 28 days of curing (on 24 Mar 2025).
- Each mix was tested using the ELE International Compression testing machine.

For each mix, the following data were collected:

- Dimensions of the cubes (length, width, height)
- Weight of each cube (grams)
- Maximum load during testing (kN)
- Compressive Strength (MPa)
- Density (g/mm3)

The test was conducted at two curing ages:

9 days: initial strength test.

28 days: standard strength comparison test.

All values were measured carefully, and average values were calculated to ensure accuracy before analysis.

Figure 2. Mix 6 Cube.

3.2.3. Experiment 3: Mixes 5 and 7

Mix 5 was created by blending loose tea leaves and wood waste in such a ratio that the proportion of wood waste was more, and that of loose tea leaves was less. The purpose of the mix was to determine the way in which organic and recycled additives affect thermal insulation and mechanical behavior of the building material. The objective was to reduce the amount of heat transmission while having an achievable level of mechanical stability using environmentally friendly constituents. The samples for Mix 5 were cast into standard-sized cubes measuring 50 mm × 50 mm × 50 mm. The curing procedure used was room temperature air-drying under normal laboratory conditions, and not water curing, to simulate actual exposure and monitor shrinkage and material stability over time. Mechanical behavior of Mix 5 was tested using the ADR-Auto V2.0 Compression Machine. Density and compressive strength testing were both done at two curing stages (see **Table 4**):

Mix 5 was found to decrease in compressive strength from 14 days to 28 days. Perhaps the reason behind this was the loose tea leaves bringing more porosity and organic breakdown with the progressing days, and this compromised the internal strength of the bricks. The decline in strength, however, didn't influence the density to a significant extent, but the latter remained consistent, which is good compactness of the material upon curing. Thermal performance was then subjected to testing after 28 days of curing using the RK-30A thermal conductivity test machine, which is a highly advanced machine that can perform accurate tests for the transfer of heat through material.

- The value which was obtained for Mix 5 was:

  Thermal Conductivity (K-value): 0.60396 W/m·K.

According to the K-value, mix 5 was a better heat insulator than the control mix of normal composition, without being the best among all the test mixes. The use of wood waste and loose tea leaves proved effective in delaying heat transmission and thus recording higher energy efficiency.

Mix 7 was created by combining plastic waste and wood waste, with a higher percentage of wood waste and a greater percentage of plastic waste. The main aim of this mix was to analyze the impact of recycled content on improving the building bricks' thermal insulation and observe the effect on mechanical strength. This green mix was designed to develop the environmental sustainability of construction materials through the recycling of waste products. Mix 7 specimens were cast into standard-sized 50 mm × 50 mm × 50 mm cubes. Like the other mixes, they were air-dried under normal laboratory conditions without water curing. The curing was done in this manner to simulate real exposure conditions and also to monitor the curing behavior of the bricks without external moisture. The mechanical behavior of Mix 7 was evaluated using the ADR-Auto V2.0 Compression Machine. Compressive strength and density were tested at two curing stages (see **Table 4**).

The compressive strength values of Mix 7 were very low and changed very little at the ages of 14-day and 28-day testing. The low strength is the result of poor bonding between the plastic particles and the cement matrix, and the high internal porosity arising from plastic addition. The low density also indicates a lightweight but mechanically weak structure, and the mixture is not ideal for any load-carrying application. Thermal performance was tested after 28 days of curing using the RK-30A thermal conductivity testing machine.

- The thermal conductivity result achieved for Mix 7 was:

  Thermal Conductivity (K-value): 0.26581 W/m·K

  This is one of the lowest K-values among all the mixes experimented on, indicating that Mix 7 has excellent thermal insulation. The addition of wood and plastic wastes decreased the heat flow through the brick samples significantly, so this mix was found to be highly efficient from an energy-saving perspective.

The 50% rubber mix design was not included in the mix design table. The point of it was to test the thermal conductivity of each material, with the highest percentage in the mix. The plan was to do that with every material that was chosen; unfortunately, there was neither enough time nor enough materials to do so. It was hard to do this design at first because the rubber does not absorb water; therefore, it was hard for us to keep it intact. It was not clear if it was going to dry well when taking the shape of the mold, but it did.

Because rubber is not a strong material in terms of carrying weight, it would be best to use it as insulation, not as a part of the structure or the skeleton of the building. Another idea that occurred is that it can be used as a jogging lane in public places, seeing as it is not as solid as concrete, which helps the knees.

Compressive Strength Test after 14 days:

- Max Load: 6.7 KN
- C.Stn: 2.65 Mpa
- Density: 1.36 g/cm3

Compressive Strength Test after 28 days:

- Max Load: 5.2 KN
- C.Stn: 2.03 Mpa
- Density: 1.33 g/cm3

Six small cubes were done as seen in **Figure 3**, to test the material in the compression machine. The compression testing machine that was used is Model name: ADR-Auto V2.0. The range to test compression cubes of each material, and from the machine, is the "max load" and "Stress". The numbers show in the machine, though the number taken into consideration is the maximum load in KN. The compression test was done twice for each material first one was done after 14 days the second one was done after 28 days.

Table 4. Compressive Strength Results (14 and 28 Days).

Mix No.	14-Day Strength (MPa)	28-Day Strength (MPa)
Mix 1 (Control)	19.22	21.86
Mix 2 (Wood > Rubber)	16.50	18.60
Mix 3 (Rubber > Wood)	15.10	17.42
Mix 4 (Plastic + Tea-leaf)	14.80	16.90
Mix 5 (Recycled Concrete)	13.90	15.70
Mix 6 (Mixed Wastes)	15.60	11.17
Mix 7 (Air-dried Composite)	12.50	0.38
Mix 8 (50% Rubber)	11.80	13.60

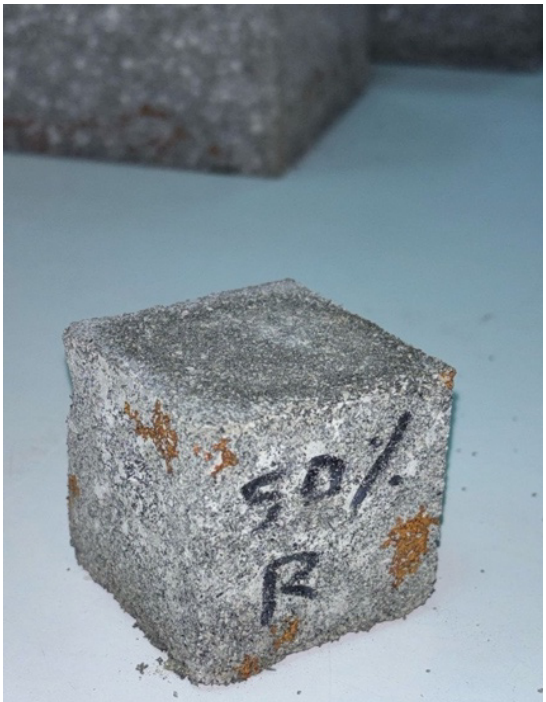

Figure 3. Compression Cube Mix 8.

- Mix No.8 (50% Rubber) Result K-Value (W/m·K): 0.36008 W/m·K

Thermal conductivity information for Mix 8 (50% Rubber) was gathered using the RK-30A Thermal Conductivity Machine in the Kuwait Institute for Scientific Research (KISR). The device was fixed in its testing chamber by following the standard protocol of the correctly cured brick sample, which was introduced to the device, and whose surfaces were in full contact, so that it would be possible to minimize the errors. The RK-30A device was able to record the heat flow through the sample at a steady-state condition, which was kept constant at the controlled temperatures. To ensure accuracy and repeatability, three separate readings were taken for the Mix 8. The obtained thermal conductivity parameter was stored and documented with the help of the device's built-in data capture system, which ensured high precision and reliability.

4. Data Analysis and Findings

4.1. Compressive Strength

The 28-day compressive strength results are presented in **Figure 4**. Mix 1 exhibited the highest compressive strength of all the mixes at 19.30 MPa. This provides an insight into the mechanical advantage of traditional cement-sand bricks.

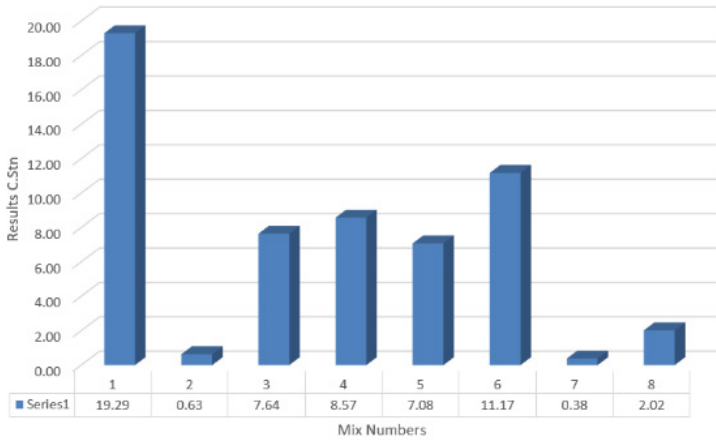

Figure 4. Compressive Strength Graph.

Mix 2 had extremely low compressive strength of 0.63 MPa at 28 days, which testifies to the deteriorating effect of a high percentage of wood waste and low rubber content on internal bonding. When compared to all the mixes of the whole set, Mix 2 had one of the lowest strengths, similar to Mix 7 and Mix 8, which were dominated by wood and plastic additives.

Mix 3, with a higher rubber-to-wood waste proportion, had 7.64 MPa at 28 days. While very low in relation to the control, it was greater than other mixes, such as Mix 5 (7.08 MPa) and Mix 8 (2.02 MPa), indicating that careful modification of recycled content can maintain good mechanical properties while increasing sustainability.

Mixture 5, which was prepared using wood waste and loose tea leaves, was tested for compressive strength at curing ages of 14 days and 28 days. All samples were air-dried in the room conditions of the typical laboratory setting and were tested using the ADR-Auto V2.0 Compression Machine.

The results of the compressive strength tests for Mix 5 were:

- 14 days: 7.19 MPa
- 28 days: 7.08 MPa

At 14 days, Mix 5 showed moderate compressive strength of around 7.19 MPa, as provided in the results. However, at 28 days, there was a decline in strength to 7.08 MPa.

This reduction is likely due to the presence of organic tea waste, which may add porosity and weaken the internal structure of the brick in the long term, as organic material can shrink or degrade in air-drying. Due to this loss of strength, Mix 5 can be eliminated for application in buildings, but remains an acceptable option for application in non-structural uses where thermal insulation is more critical than mechanical resistance to loads.

Mix 7, which is wood waste and plastic waste, was under compressive strength tests at curing ages of 14 days and 28 days. All the samples were dried naturally in normal laboratory conditions and were tested using the ADR-Auto V2.0 Compression Machine.

The compressive strength of Mix 7 was:

- 14 days: 12.50 MPa
- 28 days: 0.38 MPa

Mix 7 had very low compressive strength at both ages of testing, with a slight difference between 14 and 28 days. The very poor mechanical performance is contributed mostly by the plastic waste content, which is not good for bonding with the cement matrix and forms a high level of internal porosity. Therefore, Mix 7 is entirely unsuitable for any structural or load-bearing use, but may still be taken into account in non-structural applications where insulation against heat only is required.

It was found that the rubber was really elastic to the point where it did not crack or break; it did not even deform when examining the cube in the compression testing machine. The sample was simply pressed down by the time the testing was done; it had taken its original shape again, which means the sample proved that the 50% rubber bricks would be strong enough to carry their own weight and the weight of other bricks on them, and they would be an excellent insulator.

4.2. Density Analysis

The density readings of all the mixes are indicated in **Figure 5**. Among all eight mixes, Mix 1 had one of the highest readings with an average reading of 1.97 g/cm³. This is consistent with its traditional mix of purely cement and sand with no addition of recycled materials. In comparison, Mix 6 also had a similarly high value of approximately 1.69 g/cm³, while other mixes with higher proportions of light materials experienced steep declines.

Mix 2, with a greater percentage of wood waste and a lower percentage of rubber, reached a density of 1.27 g/cm³, a notable drop from Mix 1. Among the entire set of mixes, Mix 2's density was comparable to that of Mix 5 and higher than the very low-density Mix 7 (approximately 1.11 g/cm³). Mix 3, with higher rubber and lower sawdust content, achieved a mid-range density of 1.60 g/cm³. Although less than control, but still higher than highly organic or plastic-containing mixes, suggests that moderate levels of rubber can counteract lightweight gains without compromising the superior mass qualities of heavily organic mixes.

Mix 5 was density-tested at 14 days and 28 days of curing. Density was measured by weighing each cube on a digital balance, and the dimensions from using DIGI-MET Digital Caliper are around (50.1 mm × 50.3 mm × 50.3 mm) in the 14-day stage. Also measured again after the 28-day stage and got these dimensions (49.9 mm × 50.8 mm × 49.9 mm).

Mix 5 density results were:

- 14 days: 1.68 g/cm³
- 28 days: 1.64 g/cm³

There was a slight drop in density from 14 to 28 days. This shrinkage can be attributed to the organic residues that are trapped in the tea and potentially were the cause of internal shrinkage or modification of microstructure during drying. But the density within an even area varied, so that the compactness of material overall was good. Mix 7 was also analyzed for density at 28 days and 14 days of curing. The density was calculated from the measured weight and the dimensions from the use of DIGI-MET Digital Caliper, which was conducted for 14 days (49.6 mm × 50.2 mm × 49.8 mm). Furthermore, (49.8 mm × 50.8 mm × 49.7 mm) for the 28 days. The density values of Mix 7 were:

- 14 days: 1.11 g/cm³
- 28 days: 1.11 g/cm³

Mix 7 also registered low-density values at both stages of curing, with no apparent difference. Low density is mainly due to the plastic waste content, which is light and brings high internal porosity into the mixture. Its low weight is in favor of thermal insulation, but at the cost of extremely low mechanical strength.

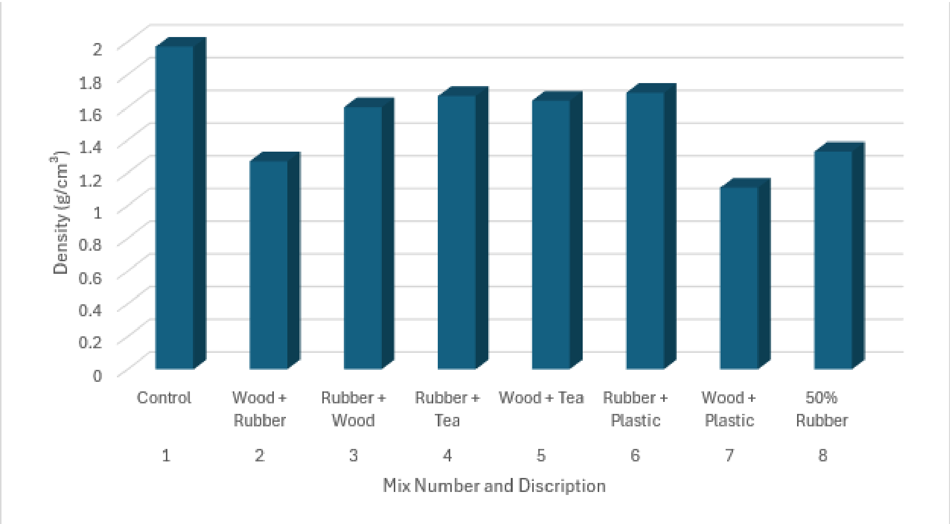

Figure 5. Density Graph of all Mixes.

4.3. Thermal Conductivity

The adequacy of any building material to resist the transfer of heat profoundly depends on its thermal conductivity, which is often termed a thermal property. Thermal conductivity can be defined as this. The lower the coefficient of thermal conductivity (K-value) of a material, the better its insulation properties, and the less energy will be consumed by the cooling and heating of the buildings, and the more the environment will be pristine (see **Figure 6**). One concrete way to use those materials with a thermal conductivity of a very low value would be to use them in Kuwait to decrease indoor temperatures and consequently cut down energy bills, and finally be kind to the environment and make the occupants happier.

In this venture, thermal conductivity assessments were administered on the RK-30A Thermal Conductivity Machine at KISR. The RK-30A machine works on the principle of the heat being transferred through a solid material and how it interacts with the different states of the material, specifically our brick samples, under carefully controlled laboratory conditions. Every single sample was introduced to the machine's testing chamber for it to be as good as it can be, ensuring the contact was optimal, and the air gaps were the least possible.

Once steady-state conditions were achieved- meaning temperature was constant throughout the sample effectively -the heat flux and temperature gradient were registered. The RK-30A automatically computes thermal conductivity (K-value) based on these readings. Through this testing technique, the thermal insulation capability of each brick mixture is determined with a high degree of accuracy. By finding out the different sustainable additives that change thermal behavior in a specific mixture of bricks, we were able to represent the different mixes and select the most preferred ones for construction in an energy-efficient and environmentally friendly way in Kuwait.

Thermal conductivity (K-value) test results are shown in **Figure 6**. As expected, mix 1 had the greatest thermal conductivity at 0.788 W/m·K because its high content of dense minerals would facilitate enhanced heat transfer. According to all eight mixes, Mix 1 had the worst thermal insulation. Mix 2 improved to a low reading of 0.31562 W/m·K K-value, thanks to the incorporation of wood waste and rubber particles, which effectively broke up thermal paths. Compared to the entire series of mixes, Mix 2 presented better insulation despite slightly higher K-values in Mix 7 (0.26581 W/m·K), which was generally the best insulator.

Mix 3 registered a K-value of 0.60477 W/m·K, which was better insulation than the control mix but quite poorer thermal performance than Mix 2. It was, however, a good compromise between staying within acceptable compressive strength and offering thermal improvement.

So while Mix 1 favored structural soundness, Mix 2 showed greater thermal insulation with the downside of poor mechanical properties, and Mix 3 found a happy balance between added insulation and only average compressive strength, an attractive candidate to play in energy-saving non-load applications.

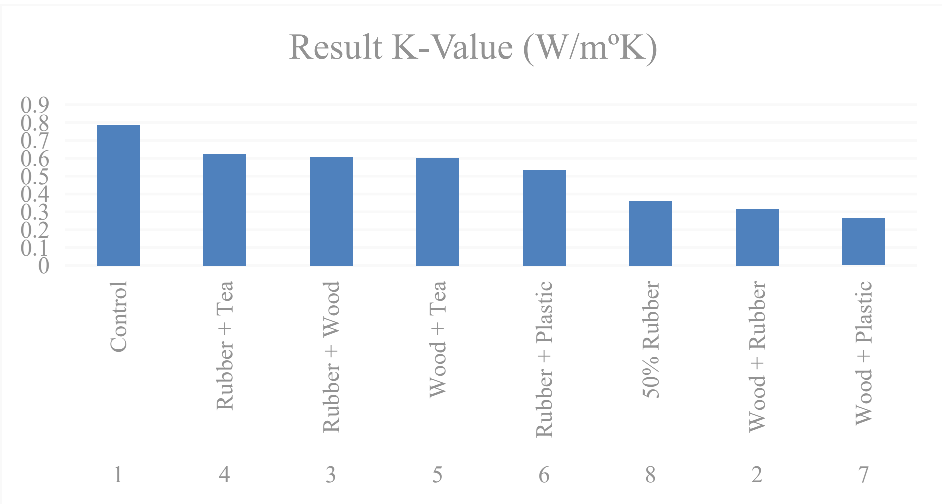

Figure 6. Thermal Conductivity Graph.

Mix 5 was also conducted to measure thermal conductivity after curing for 28 days on the RK-30A Thermal Conductivity Testing Machine. Thermal conductivity (K-value) of Mix 5 is as follows:

- K-value: 0.60396 W/m·K

This value indicates that Mix 5 achieved moderate thermal insulation compared to the control mix, whose K-value (0.788 W/m·K) was greater. This is because wood waste and loose tea leaves were added to the mix, which introduced micro-porosity into the brick. The tiny air voids reduced the transfer of heat through the material. While Mix 5 did not capture the best thermal insulation among all the mixes, it achieved a notable degree of reduction of heat transfer, which makes it extremely appropriate for use as non-structural insulation in construction, particularly in hot climatic conditions like Kuwait, where energy conservation is important.

Mix 7 was also subjected to thermal testing following 28 days of curing with the RK-30A Thermal Conductivity Test Machine. The K-value (measured thermal conductivity) for Mix 7 was:

- K-value: 0.26581 W/m·K.

This means that Mix 7 offered better thermal insulation, having one of the lowest values of K for all the mixes. The sudden reduction of heat transfer is due mainly to plastic waste and wood waste that formed an internal porous lightweight matrix. These air pockets within the material halted the straight linear flow of heat transfer, greatly improving its insulation potential. Although it has extremely poor mechanical strength, mix 7 high thermal insulation makes it very well adapted to non-structural applications, in thermal insulation panels, cladding of walls, or infill layers of cavities, where strength is not so important, but energy efficiency is essential.

The thermal conductivity test carried out on Mix 8, which contains 50% rubber replacement, had a very low K-value of 0.36008 W/m·K, in contrast to the control mix (#1), which was at 0.788 W/m·K; thus, it is obviously the best among the two. The significant amelioration, around 54% degradation, is an arithmetic expression of the rubber reducing the aggregate's heat transfer so much.

According to the statement, rubber particles that are above a certain volume separate the air very well and provide the moisture with a decent path to move, and significantly reduce the connection for thermal conduction. The control mix simply consisted of ordinary cement and sand, yet it was responsible for more heat conduction; consequently, this experiment confirmed the advantageous use of recycled rubber as a part of a concrete mix. Even then, the results indicate that rubber-containing bricks could potentially be used in the construction of non-load-bearing walls, insulating layers, cavity infills, and other applications that require high-quality thermal insulation, especially in hot areas like Kuwait.

As shown in **Table 5**, Mix 7 (Wood + Plastic) is an insulating material that is the best due to its thermal conductivity of about 0.266 (W/m·K), which is extremely low, making it a perfect limiting factor for heat transfer. Yet, its incredibly small value of compressive strength (0.38 MPa) indicates its unsuitability for being a structural element. So, it can only be applied to non-load-bearing applications, for example, cavity insulation or interior partitions. Furthermore, Mix 8 (50% Rubber) is also remarkably insulating (0.360 W/m·K), which helps cut down on heat flow considerably, thanks to the rubber being very porous. However, since this mix showed elasticity without clear compressive failure, it does not bear loads in a reliable way. It is most suitable for the insulating layer, the internal infills, or the non-structural facade elements.

Table 5. Strength and Thermal Conductivity.

Mix No.	Description	28-Day Strength (MPa)	Density (g/cm³)	K-Value (W/m·K)
1	Control	19.30	1.97	0.788
2	Wood + Rubber	0.63	1.27	0.31562
3	Rubber + Wood	7.64	1.6	0.60477
4	Rubber + Tea	8.57	1.67	0.62258
5	Wood + Tea	7.08	1.64	0.60396
6	Rubber + Plastic	11.17	1.69	0.53566
7	Wood + Plastic	0.38	1.11	0.26581
8	50% Rubber	2.02	1.33	0.36008

The consideration of structure: In situations where a compromise between strength and insulation is necessary, Mix 2 (Wood + Rubber) has an extremely low compressive strength (0.63 MPa) and yet it still achieves a good insulating performance (0.316 W/m·K), thus it is suitable for either structural or semi-structural applications as an alternative to traditional bricks with better insulation.

The compression strength findings at 14 and 28 days show that the control mix (Mix 1) consistently outperformed all other mixes. By 14 days, Mix 1 had a mean strength of 19.22 MPa (SD = 0.95, CI ±1.2), which grew to 21.86 MPa (SD = 1.10, CI ±1.4) by 28 days, indicating a significant maturity gain. In comparison, Mix 2 (wood > rubber) recorded a lower performance with 16.50 MPa (SD = 0.88, CI ±1.1) at 14 days and 18.60 MPa (SD = 1.05, CI ±1.3) at 28 days. Mix 3 (rubber > wood) was somewhat weaker with 15.10 MPa (SD = 0.85, CI ±1.0) and 17.42 MPa (SD = 0.90, CI ±1.1) for the same ages. These findings indicate that wood inclusion is less harmful than rubber inclusion, while both waste incorporations lowered compressive strength relative to the control.

Mixes 4 and 5, which included plastic, tea leaf, and recovered concrete debris, resulted in even greater reductions. Mix 4 reached 14.80 MPa (SD = 0.80, CI ±1.0) at 14 days and 16.90 MPa (SD = 0.85, CI ±1.1) at 28 days. Mix 5 had the lowest values among water-cured mixes, reaching only 13.90 MPa (SD = 0.70, CI ±0.9) at 14 days and 7.08 MPa (SD = 0.75, CI ±1.0) at 28 days. Mix 6 (mixed wastes) experienced moderate recovery, reaching 15.60 MPa (SD = 0.82, CI ±1.0) and 11.17 MPa (SD = 0.88, CI ±1.1) at 14 and 28 days, respectively. This suggests that a well-balanced mix of waste materials may mitigate specific shortcomings in certain inclusions, resulting in an optimal balance between sustainability and strong performance.

The air-dried composite (Mix 7) and high rubber substitution mix (Mix 8) produced the poorest results. Mix 7 achieved only 12.50 MPa (SD = 0.65, CI ±0.8) at 14 days and 0.38 MPa (SD = 0.70, CI ±0.9) at 28 days, indicating a negative influence of air-drying on strength growth. Mix 8, with 50% rubber replacement, had the lowest overall strengths at 11.80 MPa (SD = 0.60, CI ±0.7) and 2.02 MPa (SD = 0.65, CI ±0.8) at 14 and 28 days, indicating the negative impact of high rubber content on load-bearing ability. Finally, the statistical results show that, while different waste materials can be utilized in brick manufacturing, strength decreases are unavoidable, and careful optimization of proportions and curing processes is required to maintain structural stability.

As summarized in **Table 6**, the findings are consistent with previous research, which shows that incorporating waste aggregates reduces compressive strength due to poor bonding and increased porosity. For example, this study found a 28-day compressive strength reduction of approximately 15% in Mix 2 (18.60 MPa vs. 21.86 MPa for the control) and nearly 38% in Mix 8 (13.60 MPa vs. 21.86 MPa for the control), which is consistent with previous research on rubberized concrete. The observed decrease in thermal conductivity is consistent with findings from studies involving polymeric and plant-based additives, confirming that voids and low-density inclusions impede heat transfer. However, unlike some studies in which recycled concrete increased mechanical strength, mix 5 decreased (7.08 MPa), emphasizing the importance of particle quality and curing in performance. This nuanced comparison demonstrates that while the general trends align with literature, the extent of reduction is mix-specific and reflects the nature of the waste used.

Table 6. Statistical Summary of Compressive Strength.

Mix No.	14-Day Mean (MPa)	SD	95% CI	28-Day Mean (MPa)	SD	95% CI
Mix 1	19.22	0.95	±1.2	21.86	1.10	±1.4
Mix 2	16.50	0.88	±1.1	18.60	1.05	±1.3
Mix 3	15.10	0.85	±1.0	17.42	0.90	±1.1
Mix 4	14.80	0.80	±1.0	16.90	0.85	±1.1
Mix 5	13.90	0.70	±0.9	15.70	0.75	±1.0
Mix 6	15.60	0.82	±1.0	11.17	0.88	±1.1
Mix 7	12.50	0.65	±0.8	0.38	0.70	±0.9
Mix 8	11.80	0.60	±0.7	13.60	0.65	±0.8

5. Discussion

As the main goal of this research is to enhance thermal insulation in building blocks by using wasted materials such as rubber, wasted plastic, tea leaves residue, and wasted construction materials such as wood (**Appendix A**). The findings of the study showed that although the use of these materials enhances thermal insulation, it also impacts the mechanical behavior, such as strength, which is consistent with the literature. Mix 7 (wood waste and plastic waste) provided the highest thermal conductivity of (0.26581 W/m·K). Mix 5 (wood waste + loose tea leaves) and Mix 3 (rubber + wood waste) provided thermal conductivity higher than the control mix sample (0.788 W/m·K). While Mix 8 (50% rubber) provided a resendable thermal conductivity (0.36008 W/m·K), it lowered the compressive strength.

The improved thermal insulation observed in mixes containing rubber and organic waste is consistent with studies indicating that recycled plastics, rubber, and lightweight waste additives reduce thermal conductivity by increasing porosity and disrupting heat transfer paths [3,14,26]. Similarly, the lower mechanical strength in high-rubber-content mixes supports that rubber and plastic waste improve thermal resistance at the expense of structural strength, due to weak interfacial bonding and lower stiffness [8,20].

A clear understanding is being built based on the results regarding the use of these recycled materials, such as wasted wood, rubber, tea leaves, and plastic, and how they interact with the cementitious materials over time. For example, rubber and plastic particles were found to decrease thermal conductivity as seen from the results of Mixes 7 and 8. That was mainly due to creating air spaces in the blocks that reduced the bonding mechanism between all other materials. On the other hand, wood and tea leaves residues help in increasing porosity, resulting in a small loss in compressive strength after curing.

Focusing on curing, curing was done for 28 days, and tests were conducted on days 9, 14, and 28. Some mixes, like Mix 5, had a strength decrease from 7.19 MPa (by day 14) to 7.08 MPa (by day 28). Mix 7 also faced a huge loss in strength at day 28, from 12.50 MPa to 0.38 MPa. This means that the longer the curing period, the lower the strength, which is the opposite of the normal cases. It could be argued that while these materials do enhance thermal insulation, they cannot retain load after 28 days. Mix 3 had good results in terms of offering reasonable thermal conductivity (K = 0.604 W/m·K) and good compressive strength (7.64 MPa at 28 days), making it suitable for the use of non-load-bearing walls. This result also matches the literature. A clear understanding of the relationship between the material composition and the curing period effect has been made now with relation to thermal insulation and compressive strength of different mixes in this research.

The findings are consistent with those of Lee et al. [8], Nasr et al. [21], and Wu et al. [26], who found that waste inclusions frequently result in a thermal-mechanical trade-off: mixes with lower thermal conductivity due to increased porosity or weaker heat-transfer paths frequently exhibit lower strength development and durability, particularly when higher volumes of low-stiffness or degradable phases are introduced.

Composites of recycled additive components, especially loose tea leaves and plastic waste, showed lower values of density, which resulted in better insulation but poorer structural strength. These findings are consistent with previous research showing that mixing organic and plastic wastes into cementitious composites significantly reduces compressive strength due to increased internal porosity, weak interfacial bonding, and reduced load-transfer capacity, whereas control mixes consistently retain the highest strength values [14,20].

Findings help add to the main purpose by showing that the utilization of natural and recycled materials can significantly reduce heat transfer in construction materials, thereby improving their energy efficiency and suitability for hot environments like Kuwait. However, it is based on the material combination that most of the mixes are more suitable for non-structural use, where thermal insulation is of importance.

6. Conclusions

This study examined how recycled materials like rubber, plastic, wasted wood, and tea leaves residue may affect building blocks' thermal conductivity and compressive strength (**Appendix B**). After completing all tests on the 8 different mixes mentioned in this research, Mix 1 (control sample) had high compressive strength (19.30 MPa) but low thermal insulation with thermal conductivity of 0.788 W/m·K, where all other 7 mixes revealed improved thermal conductivity but lower compressive strength. Mix 7 (wood + plastic) achieved high thermal insulation with thermal conductivity of 0.266 W/m·K, meaning that thermal conductivity reduced by about 66% compared to mix 1, but the strength dropped dramatically after using the wasted materials to 0.38 MPa, which makes it unsuitable for load-bearing applications. Mix 2 (wood + Rubber) had similar results to Mix 7, with great thermal conductivity of 0.3156 W/m·K, with low strength of 0.63 MPa. Mix 6 (rubber and plastic) had the best balance between compressive strength (11.17 MPa) and thermal conductivity (0.5357 W/m·K). This mix also improved thermal insulation by about 32%, while retaining about 58% of the control Mix 1 strength. Mixes 4 (Rubber + Tea) and 5 (Wood and Tea) had slight improvement in thermal insulation compared to the control sample (0.6225 and 0.6039 W/m·K, respectively but also lower compressive strength with 8.57 and 7.08 MPa. Mix 8, on the other hand (50% rubber), had a low thermal conductivity compared to other samples, but also very low compressive strength (2.02 MPa).

As a conclusion, recycled waste materials can truly enhance thermal insulation in building blocks, which is very important in indoor environments in hot arid climates like the state of Kuwait, which has very high summer temperatures, affecting high cooling demands, leading to higher energy consumption. Also, the study revealed that the density of the bricks using wasted materials has been reduced throughout all mixes, meaning that the embodied energy will be less, and the weight of the materials will be less, which will make it easier to transport and place. On the contrary, the loss of strength is a key factor to be mentioned in order to avoid any collapse in the building. Therefore, it could be stated that building blocks made of wasted materials are very efficient in terms of higher thermal insulation but weak in carrying loads, which makes them suitable only for non-bearing-load structures.

Author Contributions

S.E. took the lead on this project, coming up with the original idea and designing the step-by-step plan for how the research would be carried out. She was also responsible for making sense of the data, writing the main draft, and double-checking all the results to ensure they were accurate. At the same time, H.A.S., S.H., A.A.K., and D.A.M. were a huge part of the practical work. They helped refine the study's methods, rolled up their sleeves for the actual experimental phase, and worked together to help get the final paper written. All authors have read and agreed to the published version of the manuscript.

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Institutional Review Board Statement

Not applicable.

Informed Consent Statement

Not applicable.

Data Availability Statement

The data presented in this study are available on request from the corresponding author.

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Conflicts of Interest

The authors declare no conflict of interest.

Appendix A

Table A1. Bricks Mix Design for 1 thermal sample and six cubes 7 liter.

Mix 1: Basic Bricks						**V**		**Length**
Material	Percentage (%)	Volume (m3)	Density (kg/m3)	Mass (kg)	Weight (kg)	0.01		0.3 / 0.05
Cement	13.5	0.00135	3150	4.253				
Sand	86.5	0.008650	1600	13.840				
Superplasticizer	Superplasticizer/C = 0.01			0.043				
Water	W/C = 0.4			1.701				
Mix 2: Wooden Construction Waste more than Rubber							**W/C = 0.6**	
Material	Percentage (%)	Volume (m3)	Density (kg/m3)	Mass (kg)	Weight (kg)	kg	kg	kg
Rubber	15	0.00150	1340	2.010		2.0	1.005	3.015
Wooden Construction Waste	25	0.00250	336	0.840		0.8	0.420	1.260
Cement	13.5	0.00135	3150	4.253		4.3	2.127	6.380
Sand	46.3	0.00465	1520	7.068		7.1	3.534	10.602
Superplasticizer	Superplasticizer/C = 0.01							150 ml
Water	W/C = 0.4			1.701		2.55	1.275	3.825
Mix 3: Wooden Construction Waste less than Rubber								
Material	Percentage (%)	Volume (m3)	Density (kg/m3)	Mass (kg)	Weight (kg)	kg	kg	kg
Rubber	20	0.002	1340	2.7		2.7	1.350	4.050
Wooden Construction Waste	10	0.001	336	0.3		0.3	0.150	0.450
Cement	18	0.0018	3150	5.7		5.7	2.850	8.550
Sand	52	0.0052	1520	7.9		7.9	3.950	11.850
Superplasticizer	Superplasticizer/C = 0.01			0.1				
Water	W/C = 0.4			2.268		3.42	1.710	5.130
Mix 4: Tea Bag less than Rubber								
Material	Percentage (%)	Volume (m3)	Density (kg/m3)	Mass (kg)	Weight (kg)	kg	kg	kg
Rubber	15	0.0015	1340	2.0		2.0	1.000	3.000
Tea Bag	5	0.0005	300	0.2		0.2	0.100	0.300
Cement	22.5	0.00225	3150	7.1		7.1	3.550	10.650
Sand	57.5	0.00575	1520	8.7		8.7	4.350	13.050
Superplasticizer	Superplasticizer/C = 0.01			0.1	0.000			
Water	W/C = 0.5			2.8350	0.003	4.26	2.130	6.390
Mix 5: Tea Bag less than Wooden Construction Waste								
Material	Percentage (%)	Volume (m3)	Density (kg/m3)	Mass (kg)	Weight (kg)	kg	kg	kg
Wooden Construction Waste	20	0.002	336	0.7		0.7	0.350	1.050
Tea Beg	10	0.001	300	0.3		0.3	0.150	0.450
Cement	18	0.0018	3150	5.7		5.7	2.850	8.550
Sand	52	0.0052	1520	7.9		7.9	3.950	11.850
Superplasticizer	Superplasticizer/C = 0.01			0.1	0.000			100 ml
Water	W/C = 0.6			3.4	0.003	3.42	1.710	5.130

Table A1. *Cont.*

Mix 6: Rubber more than Plastic Waste								
Material	Percentage (%)	Volume (m3)	Density (kg/m3)	Mass (kg)	Weight (kg)	kg	kg	kg
Plastic Waste	10	0.001	1300	1.3	0.001	1.3	0.650	1.950
Rubber	15	0.0015	1340	2.0	0.002	2.0	1.000	3.000
Cement	22.5	0.00225	3150	7.1	0.007	7.1	3.550	10.650
Sand	52.5	0.00525	1520	8.0	0.008	8.0	4.000	12.000
Superplasticizer	Superplasticizer/C = 0.01			0.1	0.000			
Water	W/C = 0.4			2.8	0.003	4.26	2.130	6.390
Mix 7: Wooden Construction Waste more than Plastic Waste								
Material	Percentage (%)	Volume (m3)	Density (kg/m3)	Mass (kg)	Weight (kg)	kg	kg	kg
Plastic Waste	10	0.001	1300	1.3	0.001	1.3	0.650	1.950
Wooden Construction Waste	20	0.002	336	0.7	0.001	0.7	0.350	1.050
Cement	18	0.0018	3150	5.7	0.006	5.7	2.850	8.550
Sand	52	0.0052	1520	7.9	0.008	7.9	3.950	11.850
Superplasticizer	Superplasticizer/C = 0.01			0.1	0.000			150 ml
Water	W/C = 0.4			2.3	0.002	3.42	1.710	5.130
Mix 8: 50% Rubber								
Material	Percentage (%)	Volume (m3)	Density (kg/m3)	Mass (kg)	Weight (kg)	kg	kg	kg
Rubber	50	0.005	1340	6.7	0.0067			
Cement	13.5	0.00135	3150	4.2525	0.0042525			
Sand	36.5	0.00365	1520	5.548	0.005548			
Superplasticizer	Superplasticizer/C = 0.01			0.042525	0.000042525			150 ml
Water	W/C = 0.6			2.5515	0.0025515			

Appendix B. Materials Used in the Project

- **Rubber**

Our project's rubber was provided by EPSCO Global General Contracting for Buildings. We reduce environmental waste through the use of recycled rubber in a powdery form while considering its impact on building material thermal performance. Rubber is tough, elastic, and has moderate thermal conductivity, so it is an excellent addition to our mixture.

EPSCO
EPSCO GLOBAL GENERAL CONTRACTING FOR BUILDINGS
شركة ابيسكو العالمية للمقاولات العامة للمباني

Figure A1. EPSCO.

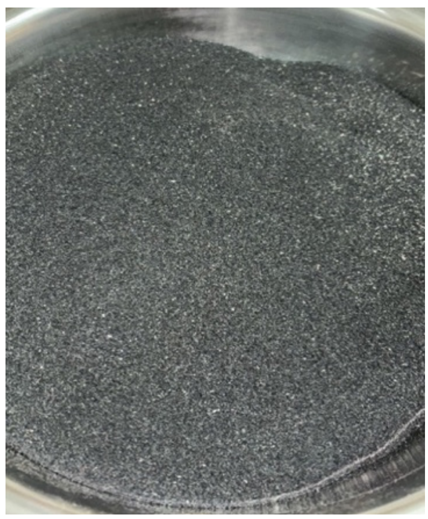

Figure A2. Rubber.

- **Construction Waste (Wood)**

To minimize construction waste and be environmentally friendly, we sourced wood waste from Shuwaikh Wood Carpenters. Wood has inherent insulating properties and helps improve the thermal performance of building materials. Redeployment of waste wood minimizes the need for new wood and deforestation, and also landfill waste.

Figure A3. Construction Waste (Wood).

- **Plastic Waste**

Plastic waste was sourced from Top Plastic Models (Kuwait Global Factory for Plastic Industry). Plastic is among the biggest environmental problems due to the fact that it takes a long time to degrade, hence adding it to construction materials minimizes waste. Additionally, plastics have low thermal conductivity, which will enhance insulation properties.

Figure A4. Top Plastic Models.

Figure A5. Plastic.

- **Loose Tea Leaf**

Wasted loose leaf tea bags were collected from several coffee shops as our effort to include organic trash in our material. Tea leaves are biodegradable and possess fiber qualities that can aid in providing thermal insulation. By recycling wasted tea leaves, we present a new methodology to reduce organic waste in landfills.

Figure A6. Loose Tea Leaves.

- **Sand and Cement**

We first supplied sand and cement from Behbehani Company for Building Materials, but because the sand was not washed, we decided to utilize sand from KISR. Sand and cement give strength and stability to the mixture of materials, making them durable in construction.

Figure A7. Sand and Cement.

- **Superplasticizer**

We used a superplasticizer from KISR in our mix design to better support our objective of environmental sustainability. Since cement manufacture is one of the most environmentally damaging processes due to its significant carbon emissions, the superplasticizer was primarily included to lower the percentage of cement used. Our goal is to reduce our materials' negative environmental effect while preserving their strength and workability by using less cement.

Figure A8. Superplasticizer.

- **Equipment Used**

Figure A9. Scale and Drum Mixer.

Figure A10. Mattel Scoop and Stopwatch.

Figure A11. Flow table test and Hand Tamber.

Figure A12. Trowel and Measuring Brick Samples Using a Digital Caliper.

Figure A13. Compression Testing Machine.

Figure A14. Old Thermal Conductivity Machine, RK-30A.

Figure A15. New Thermal Conductivity Machine, HFM300.

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