# Upcycling Textile and Plastic Waste into Thermally Efficient Composite Insulation Panels

Suzan Ozdemir, Janset Oztemur-Sezgin, Kasim Erdem, Hande Sezgin, and Ipek Yalcin-Enis

***Abstract*—Textile and plastic packaging wastes pose significant environmental threats due to their high volume and limited biodegradability. Converting these materials into composite materials for thermal insulation applications offers a sustainable and value-added solution, particularly in response to growing energy demands and climate challenges. In this study, fiber-reinforced composite panels are developed by combining waste cotton or polyester fabrics with discarded polypropylene packaging materials. Initially, the polypropylene waste is transformed into flat sheets through hot pressing and then laminated onto fabric waste. These laminated structures are subsequently shredded using an industrial knife mill and hot-pressed again to form recycled composite panels. To examine the effect of recycling degree, the panels undergo one and three cycles of shredding and reprocessing. Thermal performance tests are carried out to evaluate how the reinforcement material and degree of recycling influence the insulation properties of the resulting materials. The study highlights the potential of thermoplastic textile composites as recyclable and thermally efficient materials for use in construction and automotive sectors. It also emphasizes the environmental and economic advantages of diverting textile and plastic waste from landfills by repurposing them into functional insulation products that support energy conservation and sustainable material use.**

***Keywords*—Fiber-Reinforced Composite, Hot Pressing, Textile Waste, Thermal Insulation, Upcycling.**

## I. Introduction

A substantial amount of textile waste is annually discarded through landfilling or incineration, resulting in significant resource depletion and environmental burden [1]. Global textile waste is currently estimated at 92 million tons per year and is expected to rise to 134 million tons by 2030, with about 75 % ending up in landfills and less than 1 % reused in new garments. These figures emphasize the urgent need for advanced recycling strategies to mitigate waste accumulation and promote sustainable resource utilization [2]. In addition to textile waste, the widespread use of disposable plastics, especially polypropylene (PP) as the second most common thermoplastic with low recycling rates, aggravates environmental problems by increasing waste accumulation and degradation concerns [3, 4]. While researchers have explored the conversion of such waste into composite materials as a partial solution, the long-term sustainability of this approach depends on the implementation of appropriate production and recycling strategies, since these composites may otherwise face the same end-of-life disposal challenges [5]. Thus, recycling thermoplastic composites is also vital for sustainable waste management, as it allows material recovery while minimizing environmental impacts, though the economic viability of mechanical recycling is limited by constituent degradation compared to thermal and chemical methods [6].

Textile waste-reinforced composites are increasingly applied in automotive, biomedical, packaging, and construction sectors, including uses in flooring, furniture, interior design, thermal insulation, sound insulation, and concrete or brick reinforcement. Their adoption in these applications contributes significantly to reducing carbon footprints [7]. Among these applications, thermal insulation is particularly noteworthy, as it functions by reducing heat transfer, and fibrous materials are especially effective owing to the presence of fine pores that are predominantly occupied by air. The performance of an insulating material is primarily evaluated through its thermal conductivity, where values lower than 0.07 W/mK are generally considered indicative of superior insulating capacity [8]. Although synthetic polymers, mineral-based products, and natural fibers are widely used as insulation materials, conventional options such as plastics and rock wool, which account for more than 90% of the market, pose environmental and health concerns due to their non-renewability, waste accumulation, and disposal challenges [9]. These limitations have driven increasing interest in textile-reinforced composites as promising insulating alternatives, with thermoplastic matrices offering enhanced environmental sustainability [10, 11].

Several studies in the literature have investigated the fabrication of insulation panels from textile waste fibers and assessed the thermal performance of these composites. Darda et al. (2025) fabricated cotton fiber-reinforced PP composites via compression molding to investigate their heat-insulating performance. Four fiber-to-matrix volume ratios were examined (30:70, 40:60, 50:50, 60:40). The results indicated that increasing the cotton fiber content, owing to its

Manuscript received August 22, 2025. This work was supported by Istanbul Technical University Scientific Research Projects under Grant 46307.

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intrinsically low thermal conductivity and lumen-induced air pockets, enhanced the thermal insulation of the composites. The 60:40 composition exhibited the best performance, achieving a minimum thermal conductivity of 0.063 $W \cdot m^{-1} \cdot K^{-1}$, while higher PP fractions (thermal conductivity: 0.22 $W \cdot m^{-1} \cdot K^{-1}$) reduced thermal resistance [12]. In another study of Sezgin et al. (2021), fully recycled composite insulation panels were produced using cotton fibers from waste denim as reinforcement and PP/PE granules from discarded plastics as the matrix (70:30 wt%). Panels of 5, 10, and 20 mm thickness were fabricated by hot pressing. Thermal analysis showed that increasing thickness enhanced insulation, with the 20 mm samples achieving the highest thermal resistance (0.11 $m^2 \cdot °C/W$) [13]. Additionally, Bogale et al. (2023) developed recycled cotton/polyester (PET) selvedge waste nonwovens using chemical bonding with polyvinyl acetate (PVA) as a binder. Among the tested fiber ratios, the 50:50 and 60:40 cotton/PET blends showed the lowest thermal conductivity (0.128 and 0.127 $W \cdot m^{-1} \cdot K^{-1}$), outperforming 100% PET (0.166 $W \cdot m^{-1} \cdot K^{-1}$) and comparable to 100% cotton (0.137 $W \cdot m^{-1} \cdot K^{-1}$), confirming their potential as effective thermal insulation materials [14].

In this study, fiber-reinforced composites were developed for thermal insulation by using cotton and polyester fabrics as reinforcement and PP from yogurt containers as the matrix. The composites were manufactured through hot pressing and the effect of different recycling cycles (1 and 3) on their thermal properties was examined.

## II. Materials and Methods

### A. Materials

The reinforcement phase consisted of waste cotton denim fabrics with a twill weave (132.7 $g \cdot m^{-2}$) and waste polyester single jersey knitted fabrics (250 $g \cdot m^{-2}$), whereas the matrix phase was obtained from PP yogurt containers (Figure 1).


Fig. 1. Reinforcement and matrix materials used in the study.

### B. Methods

**Manufacturing of composite panels**

*A. Preparation of composite laminates*

Prior to the production of composite laminates, waste PP yogurt containers were thoroughly cleaned, followed by hot pressing at 170 °C under 10 tons of pressure for 60 minutes to obtain PP plates. For laminate fabrication, cotton/polyester fabric (104 g) and PP plate (52 g) (Figure 2), obtained from yogurt containers, were stacked between Teflon sheets, maintaining a 1:2 matrix-to-fabric weight ratio. The stack was subsequently hot-pressed at 180 °C with an applied pressure of 20 tons for 60 minutes.

Fig. 2. PP plates and fabrics used for composite laminates.

*B. Recycled composite production*

Following fabrication, the composite laminates were mechanically recycled. Samples were first cut into smaller pieces with scissors and subsequently reduced to finer fragments using a knife mill (Grindomix GM 200, Retsch, Germany) operated at 10,000 rpm for 2.5 minutes, ensuring a uniform particle distribution (Figure 3). These fragments were reprocessed in a hot press at 180 °C under 6 tons of pressure for 60 minutes, employing the same procedure as in the initial laminate production. To ensure consistency in both geometry and material distribution, the recycled composites were produced with a fixed thickness of 5 mm using steel rings, while the pressing area was adjusted according to the predetermined amount of material.

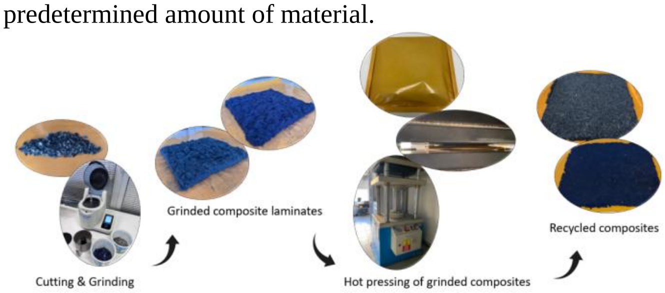


Fig. 3. Manufacturing steps of the recycled composites.

The recycling cycle was repeated three times for all specimens, and their corresponding codes are listed in Table I.

TABLE I: CODES AND MATERIAL CONTENTS OF THE SAMPLES

| Sample code | Content | Matrix type | Recycling degree | Sample code |
|---|---|---|---|---|
| C1 | Cotton | PP | 1 | C1 |
| C3 | Cotton | PP | 3 | C3 |
| P1 | Polyester | PP | 1 | P1 |
| P3 | Polyester | PP | 3 | P3 |

*C. Physical and thermal characterization*

Following the fabrication of the insulation materials, three circular specimens with 110 mm diameter were cut from each sample. The thicknesses and weights of the composite panels were determined using a digital micrometer (CD-15CPX, Mitutoyo, Japan) and a precision digital balance (Precisa, model 1212 M SCS). Subsequently, the bulk densities of the panels were calculated.

The thermal conductivity of the composites was measured using a guarded hot-plate-type apparatus (E. Schiltknecht, Zürich) in accordance with ASTM E1530 [15]. The apparatus consists of three copper plates, each equipped with a thermocouple to monitor the plate temperature. A glass layer (thermal conductivity: 0.868 W/m·K) was placed between the lower and middle plates, while the test specimen was mounted between the middle and upper plates. The lower plate (hot plate) was maintained at 30 °C and the upper plate (cold plate) at 15 °C to impose a constant temperature gradient. After assembly, the system was allowed to reach steady-state conditions for 1 h. Subsequently, temperature data were collected at 10-minute intervals over a 2 h period. The heat flux through the glass layer was used as the calibration basis, and the thermal conductivity of the specimen was determined from the recorded steady-state temperature differences. The reported values represent the average of multiple readings obtained under these controlled conditions.

## III. Results & Discussion

Thermal analysis of the samples provided significant findings regarding their insulation performance, as presented in Table II.

When the density values are compared, cotton-reinforced composites (C1: 0.35 g/cm$^3$, C3: 0.40 g/cm$^3$) exhibited slightly lower densities than polyester-reinforced ones (P1: 0.38 g/cm$^3$, P3: 0.42 g/cm$^3$). This difference can be attributed to the porous structure of cotton fibers, which contain lumen and inter-fiber voids, thereby reducing the bulk density of the composites [16]. On the other hand, the density of the samples increased progressively with higher recycling degrees. This is explained by the grinding process, in which the composite constituents are broken down into smaller particles with each cycle, resulting in a more compact structure and consequently higher density [17].

TABLE II: Density and thermal conductivity values of the samples

| Samples | ρ (g/cm3) | T1 (K) | T2 (K) | T3 (K) | k (W/mK) |
|---|---|---|---|---|---|
| C1 | 0.35 ± 0.05 | 302.201 | 298.936 | 288.365 | 0.120 |
| C3 | 0.40 ± 0.04 | 302.517 | 298.993 | 288.694 | 0.125 |
| P1 | 0.38 ± 0.03 | 302.239 | 299.050 | 288.279 | 0.109 |
| P3 | 0.42 ± 0.02 | 302.655 | 299.280 | 288.665 | 0.112 |

In addition to density, thermal conductivity results revealed an unexpected trend. Cotton-reinforced composites showed higher thermal conductivity values (0.120 and 0.125 $W \cdot m^{-1} \cdot K^{-1}$ for C1 and C3, respectively) compared to polyester-reinforced composites (0.109 and 0.112 $W \cdot m^{-1} \cdot K^{-1}$ for P1 and P3, respectively). Although cotton fibers are intrinsically less conductive (~0.05 $W \cdot m^{-1} \cdot K^{-1}$) [18] than polyester (~0.14 $W \cdot m^{-1} \cdot K^{-1}$) [19], the opposite behavior was observed in the composite systems. This can be explained by the interfacial incompatibility between polar cotton fibers and the non-polar PP matrix, a well-known challenge frequently highlighted in the literature [20, 21]. Since polypropylene itself has a higher conductivity (~0.22 $W \cdot m^{-1} \cdot K^{-1}$) than cotton [12], weak fiber–matrix adhesion limited the ability of cotton fibers to act as thermal barriers, and heat transfer predominantly occurred through the PP matrix. As a result, the insulating efficiency expected from cotton reinforcement could not be achieved, leading to higher effective thermal conductivity compared to polyester/PP composites. It is reported in literature that insufficient interfacial adhesion could restrict the contribution of fibers to thermal insulation [22].

Furthermore, thermal conductivity increased slightly with recycling (0.120 to 0.125 $W \cdot m^{-1} \cdot K^{-1}$ for C1 to C3; 0.109 to 0.112 $W \cdot m^{-1} \cdot K^{-1}$ for P1 to P3). This behavior is consistent with the density trend: as recycling progressed, finer particle sizes led to higher packing efficiency, which in turn increased density. It is well established that thermal conductivity in polymer-based composites increases with density, primarily due to enhanced solid-to-solid contact between particles and elimination of insulating air voids [23], this explains the positive correlation observed between density and conductivity in the present study.

Comparable findings have been reported by Sakthivel et al. (2021), who achieved thermal conductivity values of 0.123–0.130 $W \cdot m^{-1} \cdot K^{-1}$ in recycled cotton/polyester nonwoven composites [24]. Notably, the values obtained in this study (0.109–0.125 $W \cdot m^{-1} \cdot K^{-1}$) are slightly lower, indicating superior insulation efficiency relative to similar recycled textile-based systems.

## IV. Conclusion

This study demonstrated that cotton/PP and polyester/PP composites can be repeatedly recycled and reused as thermal insulation materials. Density increased with recycling due to finer particle sizes and improved compaction, which also led to slightly higher thermal conductivity. Cotton/PP composites exhibited higher conductivity (0.120–0.125 $W \cdot m^{-1} \cdot K^{-1}$) than polyester/PP composites (0.109–0.112 $W \cdot m^{-1} \cdot K^{-1}$), despite the lower intrinsic conductivity of cotton fibers. This unexpected result was attributed to poor interfacial compatibility between polar cotton fibers and the non-polar PP matrix, which allowed heat transfer to occur predominantly through the PP phase. Consequently, the expected insulating efficiency of cotton reinforcement could not be fully achieved. Overall, the results indicate that both cotton- and polyester-reinforced composites retain acceptable thermal insulation properties after multiple recycling cycles, supporting their potential use as sustainable insulation materials.

## Acknowledgment

The authors gratefully acknowledge the support of Istanbul Technical University Scientific Research Projects (Grant No. 46307).

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