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Preparation and Physicochemical Analysis of Polymer Composites from Recycled PET Waste

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ABSTRACT
Objective: *This study investigates the physicochemical properties of polymer composite materials based on recycled PET and CaCO3.* ***Method:*** *The thickness of the samples was selected in compliance with the standard requirements: 3,49 mm for sample 1, 3,43 mm for sample 2, and 3,91 mm for sample 3.The experiment was initiated at an ambient temperature of 22,5°C, with a controlled heating rate of 50°C per hour. Under an applied load of 10 N, the penetration of the needle to a depth of 1 mm for the first sample was achieved after 118,68 minutes, corresponding to a temperature of 152,4°C.* ***Results:*** *The results indicate that optimal performance is achieved at 5–15% CaCO3, demonstrating the potential of recycled PET composites for cost-effective industrial applications.* ***Novelty:*** *The results indicate that optimal performance is achieved at 5–15% CaCO3, demonstrating the potential of recycled PET composites for cost-effective industrial applications.*

INTRODUCTION

Recycled PET, recognized as a valuable local resource, is increasingly employed in the production of polymer composite materials, although such processes are often associated with the generation of various technological by-products [1]. The rapid expansion of industrial and manufacturing sectors has significantly increased the performance requirements for polymers used in automotive, construction, and household applications. In particular, there is a growing demand for materials with improved mechanical strength, thermal stability, and durability [2]. Under these conditions, the modification of polymers through the incorporation of functional fillers—without altering their chemical structure—has become a highly effective approach. This strategy enables the development of cost-efficient composite materials with enhanced physico-mechanical properties and broad application potential [3].

Literature Review.

In polymer processing industries, secondary raw materials are often utilized as a source of organic fuel. However, a critical drawback of this approach is that the combustion of such materials leads to the release of significant amounts of toxic gases into the atmosphere. These emissions include harmful compounds that contribute to air pollution and pose serious risks to environmental safety and public health. Consequently, this practice negatively affects ecological balance and underscores the necessity for more sustainable and environmentally friendly methods of recycling polymer waste [4].

Repeated processing of (PET) leads to gradual deterioration in the properties of the resulting secondary materials. In particular, multiple recycling cycles can negatively affect the physico-mechanical characteristics due to thermal and oxidative degradation of the polymer structure. To overcome these limitations and enhance performance, various modifiers and additives are introduced into recycled PET compositions [5]. The incorporation of such components not only improves mechanical strength and stability but also facilitates processing and reduces overall production costs. Consequently, modified recycled materials become more suitable for practical applications across different industrial sectors [6].

RESEARCH METHOD

The softening temperature of the polymer composite was determined using a Vicat/HDT laboratory apparatus in accordance with GOST 15088-2014 (ISO 306:2004) [7].

To evaluate the softening behavior of recycled PET waste, three test specimens were prepared and analyzed. The thickness of the samples was selected in compliance with the standard requirements: 3,49 mm for sample 1, 3,43 mm for sample 2, and 3,91 mm for sample 3 [8].

The experiment was initiated at an ambient temperature of 22,5°C, with a controlled heating rate of 50°C per hour. Under an applied load of 10 N, the penetration of the needle to a depth of 1 mm for the first sample was achieved after 118,68 minutes, corresponding to a temperature of 152,4°C [9].

RESULTS AND DISCUSSION

Experiment 1. Determination of the Softening Temperature of Recycled PET.

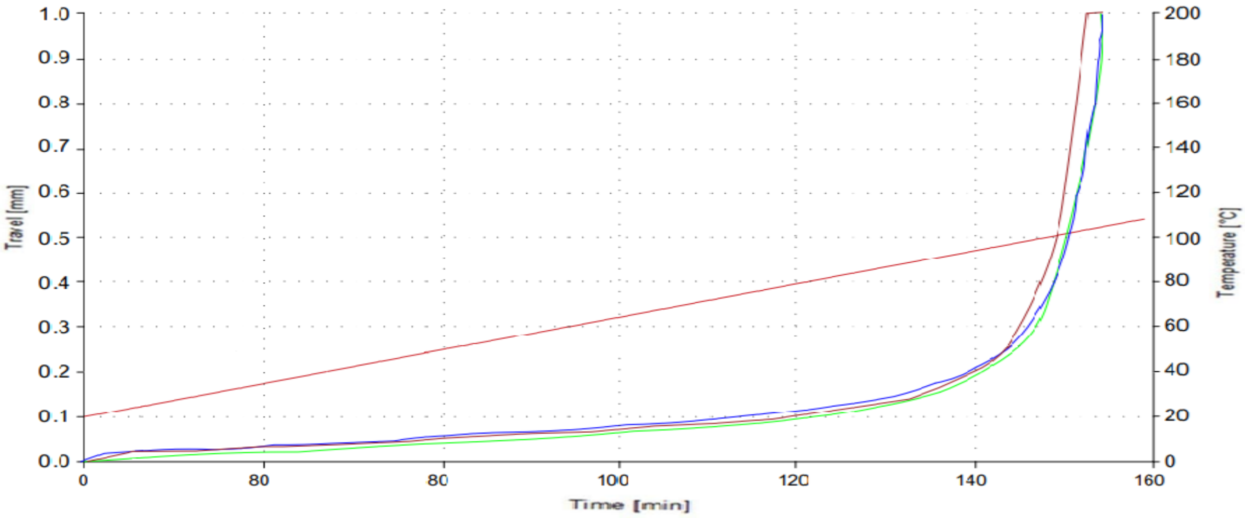

Figure 1. Softening temperature of recycled PET.

Experiment 2. Determination of the softening temperature of recycled PET with 5% $CaCO_3$.

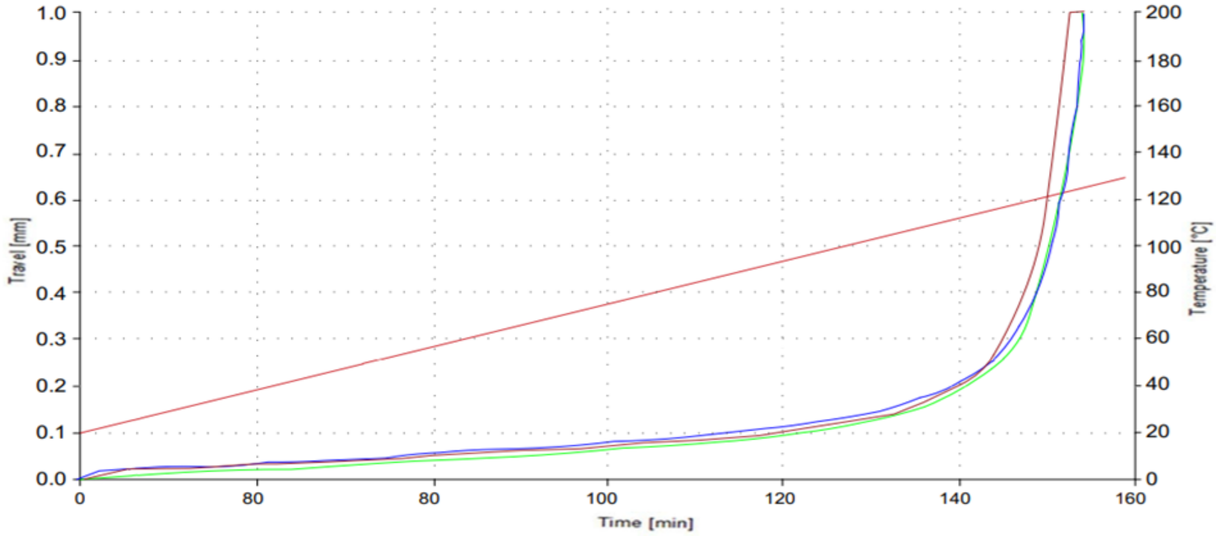

Figure 2. Softening temperature of recycled PET with 5% $CaCO_3$.

Experiment 3. Determination of the softening temperature of recycled PET with 15% $CaCO_3$.

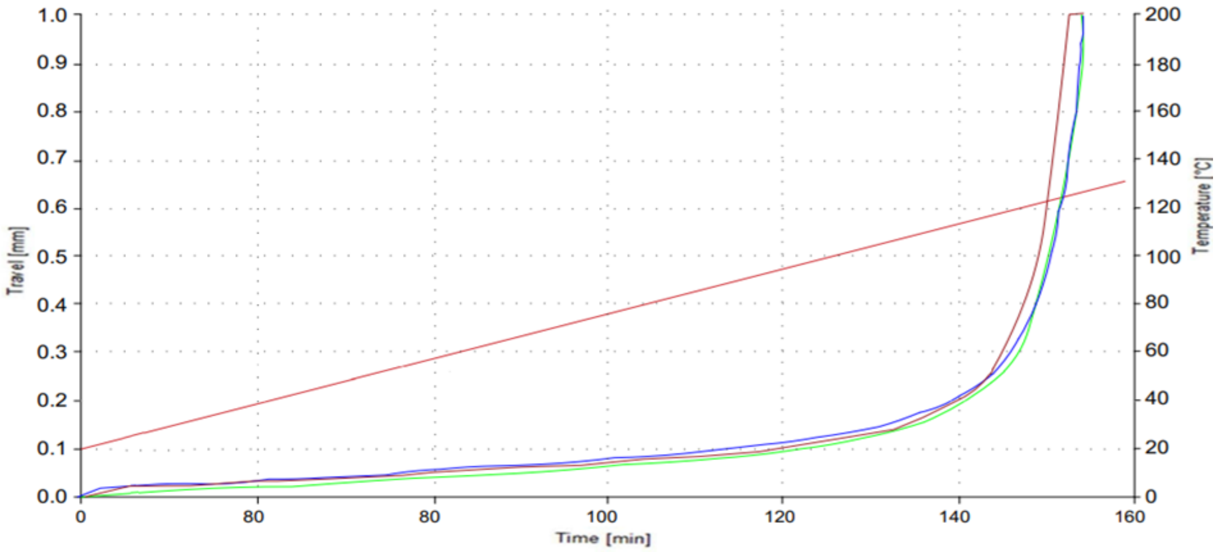

Figure 3. Softening temperature of recycled PET with 15% $CaCO_3$.

The presented graph illustrates the relationship between needle penetration depth, temperature, and time during the Vicat softening test of recycled PET-based materials. The horizontal axis represents time (min), while the left vertical axis corresponds to penetration depth (mm), and the right vertical axis indicates temperature (°C) [10].

At the initial stage, all samples exhibit minimal deformation, indicating stable structural behavior under increasing temperature. As the temperature gradually rises, a slow increase in penetration depth is observed. However, after approximately 140–150 minutes, a sharp increase in deformation occurs, which corresponds to the softening region of the material [11].

The curves show that samples containing $CaCO_3$ demonstrate slightly delayed and reduced penetration compared to pure recycled PET, indicating improved resistance to thermal deformation. This behavior confirms that the addition of $CaCO_3$ enhances the thermal stability and stiffness of the composite material [12].

The experimental results obtained during the investigation of the softening temperatures of recycled materials are presented in Table 1.

Table 1. Softening temperatures of compositions based on recycled PET waste.

Names of polymers	Softening temperature, ^0C
Recycled PET	150
Recycled PET + $CaCO_3$ 5%	155,7
Recycled PET + $CaCO_3$ 15%	172,3

As shown in Table 1, the softening temperature of recycled PET is slightly lower than that of the recycled PET + $CaCO_3$ composites. This indicates that the incorporation of $CaCO_3$ as a filler leads to a moderate increase in the softening temperature of the material. The observed effect can be attributed to the presence of $CaCO_3$, which enhances the thermal stability of the composite system [13].

CONCLUSION

Fundamental Finding : Based on the conducted experiments, the physicochemical properties of recycled PET and PET/$CaCO_3$ composites were systematically investigated. The results demonstrate that the incorporation of calcium carbonate significantly influences the thermal and mechanical behavior of the material [14]. It was found that the addition of $CaCO_3$ leads to a noticeable increase in the softening temperature compared to pure recycled PET. This effect is attributed to the enhanced rigidity and improved thermal stability of the composite structure. Furthermore, the presence of the filler contributes to increased stiffness, although excessive filler content may reduce the material's flexibility. The experimental data indicate that composites containing 5–15 % CaCO3 exhibit the most balanced performance in terms of strength, thermal resistance, and processability [15]. At higher filler concentrations, a tendency toward increased brittleness was observed. Overall, the study confirms that recycled PET can be effectively modified with CaCO3 to produce cost-efficient composite materials with improved physicochemical properties [16]. **Implication :** For practical applications, it is recommended to use $CaCO_3$ in moderate concentrations (5–15%) to achieve optimal material performance. From an industrial perspective, the developed materials can be applied in the production of construction panels, technical packaging, and household products, contributing to sustainable waste management and resource efficiency [17]. **Limitation :** Furthermore, the presence of the filler contributes to increased stiffness, although excessive filler content may reduce the material's flexibility. The experimental data indicate that composites containing 5–15 % CaCO3 exhibit the most balanced performance in terms of strength, thermal resistance, and processability [15]. At higher filler concentrations, a tendency toward increased brittleness was observed. **Future**

Research : Future research should focus on improving interfacial adhesion between PET and filler particles, for example, through surface modification techniques. In addition, further investigations involving advanced characterization methods such as scanning electron microscopy (SEM) and differential scanning calorimetry (DSC) are suggested to better understand the structural and thermal behavior of the composites.

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