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Research Article

Investigation of the Properties of Recycled PET Materials

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Abstract – Polyethylene Terephthalate (PET) waste has started to reveal serious economic and environmental problems. Environmental and economic factors, as well as energy saving problems, have led to the need for large-scale recycling of pet, it has ceased to be just a trend or a new marketing strategy to make a profit. Products made from recycled plastic can save capital by 50-60% compared to buying the same product from pure resin.
This study aims to characterize the physical and thermal properties of recycled polyethylene terephthalate (PET) materials. Color determination, specific gravity measurements, and thermogravimetric analysis (TGA) were conducted based on two parallel experimental procedures.
Color analysis revealed that the recycled PET flakes exhibited light tones with a slight blue-green hue. According to the CIE Lab* color space, the L*, a*, and b* values were determined to be 61.12, -2.24, and -6.68, respectively. Specific gravity measurements indicated that the density of the samples ranged between 1.35 and 1.40 g/cm³, suggesting that the recycled PET retains properties comparable to virgin PET and is suitable for reuse. Thermogravimetric analysis showed a mass loss of up to 89% between approximately 200 °C and 490 °C, indicating a single-stage degradation profile with the maximum decomposition rate occurring around 430 °C. An endothermic reaction was observed within this temperature range on the corresponding DTA curve.
In conclusion, this study provides significant data that support the reuse potential of recycled PET in various industrial applications by assessing its colorimetric, density, and thermal characteristics.

Keywords – Polyethylene terephthalate, Recycling, Color analysis, Thermo gravimetric analysis, Mass loss

I. INTRODUCTION

Plastics are hard or soft materials that can be transformed into different shapes under specific pressure and temperature conditions. They can be made more functional by adding certain additives. Common plastic polymers include polyethylene, polyethylene terephthalate, polystyrene, polycarbonate, polypropylene, polyvinyl chloride, polylactic acid, acrylic, acrylonitrile butadiene styrene (ABS), fiberglass, and polyamide (nylon) [1]. Polyethylene terephthalate (PET) is a thermoplastic polymer widely used in the packaging industry around the world [2]. Due to its high mechanical strength, barrier properties against gases and moisture, transparency, and recyclability, PET is commonly used especially in food and beverage packaging [3]. It is utilized in a wide range of products, including beverage bottles, food containers, film layers, and microwaveable trays [4]. One of the most notable advantages of PET is its suitability for recycling [5]. Recycled PET (rPET) can be reused in the packaging sector, which contributes to environmental sustainability. In regions such as Europe and North America, the use of rPET is increasingly promoted to reduce packaging waste and lower the carbon footprint [6]. The widespread use of PET in the packaging industry not only helps reduce production costs but also extends product shelf life. Furthermore, PET's high transparency and excellent printability allow for designs that enhance brand visibility [7]. These features make PET an important material in packaging design from both functional and aesthetic perspectives [8]. However, the increasing frequency of PET usage has made its environmental impacts more apparent. In particular, the widespread use of single-use packaging products has created significant challenges in waste management [9].

Due to its non-biodegradable nature, PET waste can persist in the environment for long periods. This contributes to serious pollution problems in both terrestrial and aquatic ecosystems and facilitates the formation of microplastics [10]. A significant portion of plastic waste in the oceans consists of PET derivatives, posing a threat to marine life [11]. In many developing countries, the lack of an effective recycling infrastructure results in the uncontrolled disposal of PET waste into the environment. Additionally, low public awareness of recycling and the inadequacy of waste separation systems lead to the accumulation of unmanaged PET waste [12].

In this context, studies focusing on the recycling and reuse of PET within the framework of circular economy principles have gained momentum. Particularly, "bottle-to-bottle" recycling technologies are among the promising solutions to address this issue [13]. The circular economy of PET promotes an economic model where resources are used with maximum efficiency, waste is re-evaluated, and closed-loop production systems are adopted. This approach offers an effective framework for reducing the environmental impacts of long-lasting waste materials such as plastics [14]. Thanks to its suitability for both mechanical and chemical recycling methods, PET makes a significant contribution to circular economy goals. Especially the bottle-to-bottle recycling of high-volume PET products such as beverage containers helps reduce raw material usage, preserve natural resources, and lower energy consumption. In line with sustainability principles, the use of rPET (recycled PET) in the packaging sector is steadily increasing. As a result, carbon emissions are reduced, and plastic waste management becomes more efficient. Moreover, in many regions especially in EU countries—legislation now mandates the use of recycled content in packaging production [15].

The fifth United Nations Environment Assembly (UNEA-5) has adopted a landmark resolution urging countries to reach a legally binding agreement on controlling plastic pollution by the end of 2024 [16]. Plastic is an anthropogenic material, extensively used in industry and nearly all aspects of daily life [17]. However, the municipal waste management systems in many developing countries often lack the infrastructure needed to cope with the increasing volume of plastic waste resulting from both industrial and residential activities. This inadequacy leads to severe environmental degradation caused by uncontrolled plastic pollution [18]. The environmental damage includes widespread contamination of water, soil, air, and animal biomass [19–20].

Determining the physical, chemical, and thermal properties of recycled PET materials plays a critical role in ensuring their safe and effective reuse in production processes. Characterization methods such as color determination, specific gravity measurements, and thermogravimetric analysis (TGA) provide essential data for quality control of the material [21]. In this context, studies have reported that for assessing the reuse performance of recycled PET, key analysis parameters include physical purity (such as color and density) and thermal stability (via TGA) [22]. Furthermore, density values can offer insight into the presence of foreign additives within the polymer structure, while color measurements may reveal the extent of contamination during the production process [23].

Recycled polyethylene terephthalate (rPET) has found significant application particularly in the packaging and textile industries. Due to the contribution of recycling processes to environmental sustainability, the use of rPET has become a major focus of scientific research in recent years [24]. These studies investigate both the physical and mechanical properties of rPET as well as the performance of recycling technologies. Van de Voorde et al. (2022) demonstrated that processing temperatures and additives play a crucial role in the mechanical properties of recycled PET. Research also suggests that while rPET may exhibit reduced thermal stability compared to virgin PET, such differences can be mitigated through appropriate modifications [25]. The use of rPET in food packaging has also been examined in terms of potential migration and safety concerns. Geueke et al. (2018) emphasized the importance of thorough chemical safety assessments in rPET materials, recommending close monitoring of chemical residues especially in food-contact applications [26]. Life cycle assessments conducted in countries such as Germany and the Netherlands have shown that rPET significantly reduces environmental impact (Gensch et al., 2020). In addition, policies aimed at improving consumer recycling habits are being developed to enhance the feasibility of “bottle-to-bottle” recycling systems [27]. Numerous studies in the literature on recycled PET (rPET) have primarily focused on the material's mechanical, thermal, and chemical properties. However, the direct analysis of waste PET samples collected from the field remains limited in many of these studies. Additionally, quantitative analyses of aesthetic properties such as color changes in recycled PET have received relatively little attention [28].

Unlike existing studies, the present research conducted color analysis, density determination, and TGA analysis on recycled PET flakes obtained directly from a production site. In this regard, the study contributes to waste characterization not only at a theoretical level but also at a practical level. Particularly, applications related to color determination represent a significant factor influencing the reuse potential of PET material. While this subject has been scarcely addressed in the literature, this study provides a detailed evaluation of color measurement results [29]. Moreover, the thermogravimetric analysis (TGA) examines the degradation behavior of PET, offering valuable data that contribute to understanding the technical limits of recyclability [30].

In this context, the study is one of the few to comprehensively examine the color, density, and thermal stability properties of recycled PET using site-specific samples. It offers direct contributions to quality control processes in recycling from both academic and industrial perspectives. Furthermore, investigating the potential contributions of these materials within the frameworks of environmental sustainability and circular economy highlights another important aspect of the study. The visual and aesthetic evaluation of PET flakes was conducted through color analysis, while the TGA analysis provided insight into their thermal degradation, physical suitability, and potential applicability in various industrial sectors.

II. Materials and Method

A.1. Color Measurement

Color analysis was performed using a spectrophotometric method to assess the homogeneity and identify potential contaminants in the recovered PET flakes. The transparency of the samples and the presence of bluish hues are considered significant indicators of color stability. The color measurements of the PET flakes were conducted using a Konica Minolta CR-400 colorimeter.

A.2. Specific Gravity (Density) Determination

Density values were determined using the water displacement method in accordance with ASTM D792 standard. The density of the PET flakes was found to be in the range of 1.35–1.40 g/cm³, which indicates the material’s purity and the preservation of the polymer structure.

A.3. Thermogravimetric Analysis (TGA)

TGA was employed to determine the thermal stability of the recycled PET samples. The analysis was carried out under an inert atmosphere within the temperature range of 30–600 °C. A mass loss of approximately 89% was observed between 200–400 °C, indicating main chain degradation of the polymer.

III. Results

The PET flakes used in the characterization experiments were obtained from a recycling facility operating in the packaging industry. The primary analyses conducted included color measurement, specific gravity determination, and thermogravimetric analysis (TGA).

Figure 1. PET flakes obtained from the facility

Figure 1 shows the PET flakes collected from the recycling facility.

A.1. Color Measurement

The colorimeter measures the L, a, and b values. As the material's transparency increases, the L value approaches 100. The a value shifts from positive to negative, indicating a color transition from red to green. Similarly, the b value moves from positive to negative, reflecting a shift from yellow to blue.

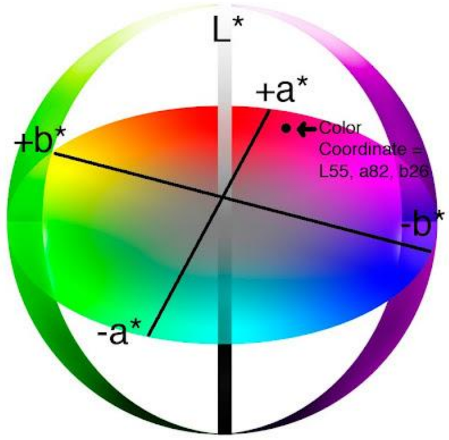

Figure 2. Working principle of the Konica Minolta CR-400 colorimeter

Table 1. Results of L, a, and b values measured from different PET flakes

Unite	Measured Average Value
L [(0) black – (100) white]	61,12
a [(+)red– (-) green]	- 2,24
B [(+)yellow– (-) blue]	- 6,68

As seen in Table 3.1, according to the color analysis results, the L value indicates that the PET flakes obtained from the company tend toward a white color, exhibiting transparency, although their transparency is not very high. The negative sign of the a value indicates a shift toward green, while the negative sign of the b value shows a shift toward blue. The L value represents the lightness of the color tone, and the value of 61.12 suggests that the sample has a moderately light color. This implies that the recycled PET is not fully transparent but has a color close to light gray tones. The a axis value of -2.24 indicates a shift from red to green, with a slight dominance of green tones. Since this value is close to the neutral center, there is no significant red/green deviation. The b axis value of -6.68 clearly shows a color tendency toward blue. This indicates that the recycled PET has a slightly bluish appearance.

A.2. Specific Gravity (Density) Determination

Density measurement was performed using the AD-1653 specific gravity measurement kit. The density of PET was calculated using the following equation:

$$P_{pet} = A / (A - B) \times (P0 - d) + d$$

where:

- A = weight of the sample in air
- B = weight of the sample in ethanol
- P_0 = density of ethanol (for the experiment conducted at 30 °C, this value is 0.7838 g/cm^3)
- d = density of air (0.001 g/cm^3)

Based on two parallel experiments, the specific gravity (density) values of the recycled PET (rPET) samples were found to be in the range of 1.35 – 1.40 g/cm^3. This density range may reflect the semi-crystalline structure of PET as well as the possible presence of additives, degraded chain structures, or residual impurities in the recycled material. Pure, newly produced PET typically has a density range of 1.37 – 1.41 g/cm³. In this context, the obtained results indicate that the physical properties of recycled PET are quite close to those of the original material. A slightly lower value around 1.35 g/cm³ may suggest molecular chain breakage, a decrease in crystallinity, or the presence of organic contaminants.

A value near 1.40 g/cm³ indicates a high-density and more ordered rPET sample. This suggests that the recycling process has not significantly disrupted the material's structure and that the material retains sufficient quality for reuse.

A.3. TGA Analysis of PET Flakes

The analysis was conducted to determine the thermal and gravimetric changes occurring within the PET flakes as the temperature increased. The TGA analysis graph is shown in Figure 7.3. The analysis was performed in a nitrogen (N_2) atmosphere over a temperature range from 23.3 °C to 490 °C. According to the results, four endothermic reactions occurred at the temperatures marked as T1, T2, T3, and T4 in Figure 7.3, up to 200 °C. At point T2, approximately 110 °C, continuing until 200.72 °C, a mass loss of 4.5392% was observed, corresponding to the removal of crystalline and bound water from the sample. Following this, between 200 °C and 400 °C, a mass loss of 84.594% was recorded, attributed to the decomposition and removal of organic compounds and impurities within the PET. In total, approximately 89% mass loss occurred. The organic compounds in the PET polymer structure were decomposed, leaving around 11% residual mass. The degradation temperature of the PET polymer was determined to be 490.32 °C.

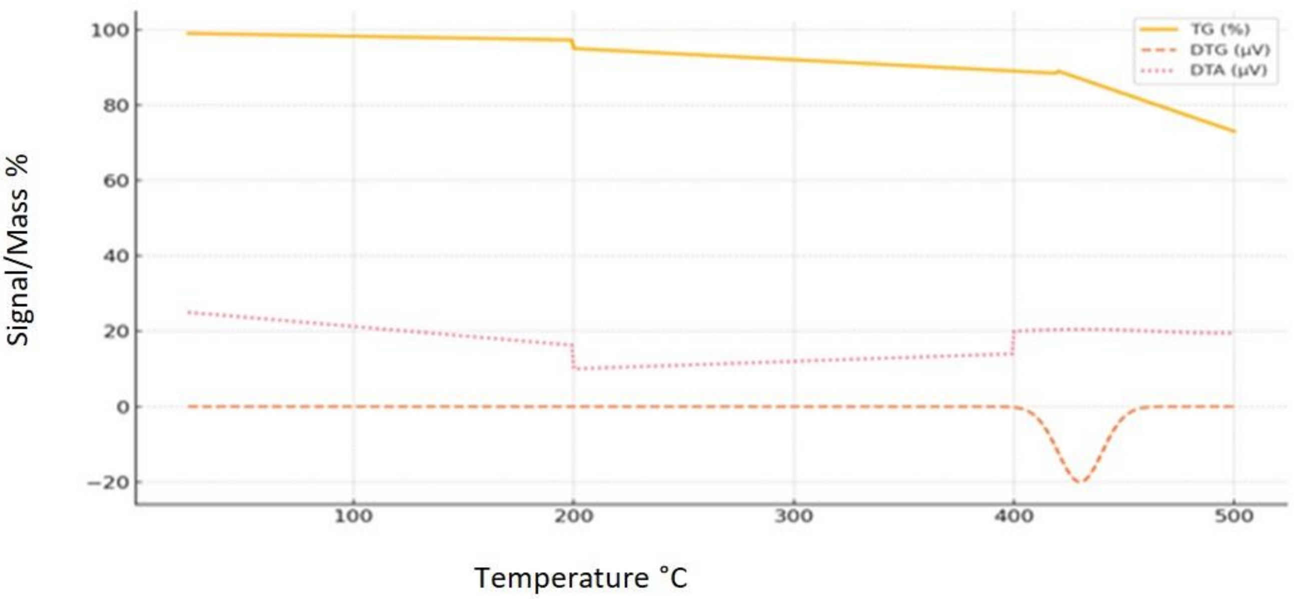

Figure 3. TGA/DTA Analysis Results of PET Flakes

As shown in Figure 3.3, the TGA curve indicates that the PET sample undergoes a mass loss of approximately 84.5% between 200 °C and 490 °C. This suggests that PET experiences a single-step thermal degradation process and loses its thermal stability within a certain temperature range. The DTG curve displays a distinct peak between approximately 430 °C and 490 °C, representing the main decomposition temperature range of PET. Within this temperature interval, the degradation rate reaches its maximum. The DTA curve illustrates the endothermic and exothermic reactions occurring during the thermal processes of the sample. The thermal event observed around 430–490 °C indicates a significant endothermic reaction coinciding with the degradation temperature of PET.

IV. CONCLUSION

Within the scope of this study, fundamental physical and thermal properties of recycled polyethylene terephthalate (rPET) materials—including color determination, specific gravity measurement, and thermogravimetric analysis (TGA)—were evaluated.

Color analysis results revealed that the PET flakes exhibit light tones with a blue-green directional color profile in the Lab* color space. This suggests the material's potential for reuse from an aesthetic quality perspective. Specific gravity values obtained from density analysis ranged between 1.35 and 1.40 g/cm³, indicating that the material's structure remains close to that of virgin PET and retains usability after the recycling process. TGA results showed that PET undergoes a single-stage degradation between 200 °C and 490 °C, with a mass loss of approximately 89%. A marked increase in degradation rate was observed around 430 °C, providing valuable information regarding the thermal stability of PET.

Overall, this study provides scientific data supporting the reuse potential of recycled PET materials through their physical and thermal characterization. The findings can contribute to recycling applications in line with environmental sustainability and circular economy principles.

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