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Characterization of Mechanical Properties and Melt Flow Behavior of rPET from Waste Bank Sources Using Twin-Screw Extrusion

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ABSTRACT

Polyethylene terephthalate (PET) is one of the most widely used thermoplastic polymers in packaging applications, contributing significantly to global plastic waste generation. Mechanical recycling of post-consumer PET (rPET) offers a practical solution to reduce environmental impact; however, the variability of feedstock obtained from decentralized waste collection systems, such as waste banks, poses challenges in ensuring consistent material performance. This study aims to characterize the mechanical properties and melt flow behavior of post-consumer rPET derived from waste bank sources and processed using twin-screw extrusion. PET bottle waste was collected, cleaned, and processed into pellets under controlled extrusion conditions. The resulting material was evaluated through melt flow index (MFI) tested at 270°C with an applied load of 2.16 kg in accordance with ASTM D1238, alongside tensile strength, hardness, and elongation at break tests. The results show that the recycled PET exhibits an average MFI of 60.8 g/10 min, tensile strength of 64.1 MPa, hardness of 84.9 Shore D, and elongation at break of 10.9%. The tensile strength falls within the range previously reported for mechanically recycled PET (48.3–72.4 MPa), while the low elongation at break reflects reduced ductility consistent with thermo-mechanical degradation. This study provides preliminary baseline data on the properties of rPET sourced from waste bank systems, offering foundational insights into its potential suitability for rigid secondary manufacturing applications where structural stability is prioritized over flexibility, pending broader validation with larger sample sizes and direct comparative testing against commercially recycled PET.

1. INTRODUCTION

Polyethylene terephthalate, a widely utilized thermoplastic polymer in packaging applications—particularly for beverage bottles and food containers—is valued for its superior mechanical strength, transparency, and chemical resistance [1], [2]. The pervasive application of PET has precipitated a marked escalation in post-consumer plastic waste, notably in developing countries like Indonesia [3]. Mechanical recycling emerges as one of the most viable strategies for PET waste management, attributable to its

comparatively low cost and technological simplicity relative to chemical recycling approaches [4].

In mechanical recycling processes, PET is subjected to successive thermo-mechanical treatments that may trigger chain scission and a concomitant reduction in molecular weight. Such degradation typically manifests in rheological alterations, including elevated melt flow index values, with potential implications for mechanical properties [5]. Nevertheless, the degree of these modifications is largely contingent upon feedstock quality and processing parameters. Within practical recycling contexts—particularly decentralized systems—the

heterogeneity of input materials emerges as a pivotal determinant of the final attributes of recycled PET [6].

In Indonesia, community-based waste bank systems (bank sampah) collect a significant portion of post-consumer plastic waste, supporting circular economy initiatives and reducing environmental pollution through manual sorting and decentralized collection. However, these processes introduce variability in material quality—including contamination levels, prior thermal exposure, and polymer heterogeneity—posing challenges to feedstock consistency and processing efficiency, as noted in previous studies [7], [8].

Such variability significantly influences the rheological and mechanical behavior of recycled PET. The preponderance of existing rPET research employs controlled laboratory or industrial settings with homogeneous, well-sorted feedstocks, which may not adequately represent the material characteristics arising from real-world decentralized recycling systems in developing countries [9]. Furthermore, while twin-screw extrusion is recognized for its superior mixing capability and processing control relative to single-screw alternatives, its application to heterogeneous post-consumer PET sourced from community-based collection systems remains underexplored. Crucially, the simultaneous characterization of melt flow behavior alongside a comprehensive set of mechanical properties—tensile strength, hardness, and elongation at break—for rPET derived specifically from waste bank feedstock has received limited attention in the literature.

Therefore, the novelty of this study lies in providing systematic baseline characterization of both the mechanical properties and melt flow behavior of rPET sourced exclusively from Indonesian waste bank systems and processed under controlled twin-screw extrusion conditions. By addressing the gap between idealized laboratory studies and the material realities of decentralized recycling practice, this work aims to generate foundational data to support evidence-based evaluation of waste bank-derived rPET for potential use in secondary manufacturing applications.

2. LITERATURE REVIEW

Thermo-mechanical degradation constitutes a primary process in the mechanical recycling of polyethylene terephthalate, predominantly arising from chain scission during successive extrusion cycles. This degradation results in diminished molecular weight and intrinsic viscosity, thereby influencing the material's rheological characteristics. The melt flow index serves as a prevalent

measure of these alterations, with elevated MFI values signifying reduced molecular weight and melt viscosity. Such modifications impact processability and can modify the mechanical properties of recycled PET [10], [11]

Prior investigations indicate that the interplay between degradation and mechanical properties is intricate and often non-linear [12], [13], [14], [15]. Although molecular weight reduction generally impairs ductility, its effect on tensile strength varies according to processing conditions and structural factors like crystallinity [16]. In certain instances, enhanced crystallinity or molecular orientation induced by processing may offset molecular weight loss, thereby sustaining tensile strength amid substantial degradation [17]. Nevertheless, elongation at break consistently demonstrates heightened sensitivity to degradation, exhibiting pronounced declines across multiple processing iterations [18].

Beyond tensile attributes, hardness represents a critical mechanical metric indicative of surface resistance and material stiffness, especially pertinent to applications demanding structural integrity. Despite its importance, hardness data remain scarce in recycled PET literature, which predominantly emphasizes tensile strength and elongation. This paucity limits comprehensive insights into the mechanical profile of rPET, particularly for uses where surface durability is paramount.

Feedstock variability arising from decentralized collection systems further compounds the complexity of rPET characterization. Inconsistent sorting practices, contamination, and varied usage histories inherent to community-based waste bank systems introduce heterogeneity that affects both rheological and mechanical outcomes [17]. Yet despite its practical significance, this source of variability remains underexplored in existing scholarship, with most studies relying on well-sorted or pre-processed feedstocks that do not reflect real-world decentralized recycling conditions.

Collectively, these gaps highlight the need for baseline characterization studies that account for feedstock heterogeneity under controlled processing conditions. This study directly addresses this need by reporting on the mechanical properties and melt flow behavior of rPET obtained from waste bank feedstock processed via twin-screw extrusion, providing data that bridges idealized laboratory findings and the material realities of community-based recycling systems.

3. METHODOLOGY

Post-consumer PET bottle waste was collected from local waste collection centers in Indonesia during a three-month period. Bottles were manually sorted to remove caps, labels, and contaminants, then washed with detergent and rinsed with distilled water. Clean flakes were obtained by cutting the bottles into pieces of approximately 5 mm × 5 mm. The flakes were dried in a vacuum oven at 80 °C for 12 h to reduce moisture content below 0.02% prior to extrusion.



Figure 1. Plastic Waste Collection Process at Harapan Jaya Waste Bank

PET flakes were processed into pellets using a co-rotating twin-screw extruder with an L/D ratio of 25. The extrusion temperature profile was set from 240 °C (feeding zone) to 270 °C (die zone), and the screw speed was maintained at 120 rpm. The melt was pushed through a strand die, cooled in a water bath, and then made into regranulated pellets.

The extrusion process, a widely utilized method in mechanical recycling for producing regranulated material, allows for partial control of degradation by varying temperature and screw speed [14]. These pellets then underwent characterization for their melt flow index and subsequent mechanical performance evaluation to assess the impact of the extrusion process on their material properties. To produce specimens conforming to the tensile standard, rPET pellets were molded into tensile specimens using an injection molding process. Due to limited material and testing capacity, three specimens were prepared for tensile testing. Hardness was measured on one molded specimen at five locations.

Tensile testing was conducted according to ASTM D638 using three specimens, and tensile strength and elongation at break were recorded and reported as mean ± standard deviation. The melt flow index was measured according to ASTM D1238 at 270°C/2.16 kg based on three replicate measurements and reported in g/10 min. Shore D hardness was assessed according ASTM D2240 at five points on one specimen, and the mean and standard deviation of these readings were reported.

4. RESULT AND DISCUSSION

4.1. Hardness Testing

The hardness assessment of recycled PET plastic was performed in accordance with the ASTM D2240 standard, which prescribes the Shore D durometer device for quantifying the hardness of plastics. Measurements were conducted using a calibrated Shore D durometer equipped with a standardized indenter. This technique involved applying a regulated force to the surface of the PET samples while measuring the extent of penetration.

Hardness is measured by applying pressure at five result points on a specimen. Table 1 presents the hardness testing results for a single rPET specimen.

Table 1. Hardness Testing Result

Point	Hardness (Shore D)	Avg. Hardness (Shore D)
1	84.5	84.9
2	84.0	
3	84.5	
4	86.5	
5	85.0	

The hardness testing findings indicated that the recycled PET samples had an average Shore D hardness value of 84.9. The uniformity of hardness observed in the tested samples indicates consistent mechanical properties throughout the recycled PET material. This hardness value is consistent with rigid polymer materials and supports the overall mechanical characterization of the rPET pellets.

This hardness level is consistent with rigid thermoplastic materials and falls within the typical range reported for recycled PET in previous studies [19]. The observed hardness suggests that, despite potential variability in waste bank feedstock, the extrusion process was able to produce a material with stable surface resistance and rigidity. This characteristic is particularly relevant for applications requiring dimensional stability and wear resistance.

4.2. Tensile Strength Testing

Tensile testing is a method used to ascertain certain mechanical characteristics of a material. The process involves clamping a specimen known as a dog-bone, as shown in figure 2, with the device. The specimen is then exposed to carefully regulated tensile stress (measured in N/mm²) until it breaks.

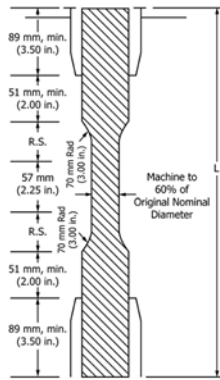


Figure 2. A Tensile Test Specimen Dimension (ASTM D638)

Table 2 below presents the tensile strength results for rPET with average result is 64.1 N/mm². The results reveal a notable set of properties that exhibit characteristics typical of a more fragile material.

Table 2. Tensile Strength Result

Sample	Tensile Strength (N/mm ²)	Avg. Tensile Strength (N/mm ²)
1	63.5	64.1
2	64.1	
3	64.6	

The obtained tensile strength (64.1 MPa) is comparable to previously reported values for recycled PET (48.3–72.4 MPa) [20], these results suggest that rPET derived from waste bank sources can achieve mechanical performance comparable to conventionally recycled PET under controlled processing conditions. This finding supports its potential application in products where strength and rigidity are prioritized.

4.3. Elongation Strength Testing

An extensometer was utilized alongside a tensile testing machine to ascertain the elongation at break of recycled PET. The Table 3 below presents the elongation test results for rPET with average result is 10.9%.

Table 3. Elongation Strength Result

Sample	Elongation Strength (%)	Avg. Elongation at Break (%)	SD (%)
1	12.7	10.8	2.42
2	8.1		
3	11.7		

The average elongation at break was 10.9% with a standard deviation of 2.42%, indicating moderate inter-specimen variability. This spread is most notably reflected in Sample 2 (8.1%), which deviated considerably from Samples 1 (12.7%) and 3 (11.7%), likely attributable to localized specimen defects or heterogeneity in the waste bank

feedstock rather than a systematic processing issue. Despite this variability, all values consistently indicate limited ductility, which is characteristic of mechanically recycled PET subjected to thermo-mechanical degradation. Chain scission during recycling reduces molecular entanglement and limits the material's capacity for plastic deformation, resulting in the brittle behavior observed across all specimens. Compared to tensile strength, elongation at break is more sensitive to molecular degradation [21]. The relatively low elongation observed in this study suggests that the recycled material exhibits a more brittle behavior, which is commonly reported in the literature for mechanically recycled PET.

This characteristic should be considered in application design, as the material may be less suitable for products requiring high flexibility or impact resistance but still appropriate for rigid structural components.

4.4. MFI Testing

The MFI test quantifies the flow characteristics of thermoplastics, including rPET. In accordance with ASTM D1238, the test was conducted at 270°C with an applied load of 2.16 kg, exposing the material to regulated temperature and pressure to determine its flow rate. The MFI value quantifies the viscosity of a material and is commonly expressed in grams per 10 minutes [22]. Table 4 presents the melt mass flow rate results for rPET, with an average result of 60.8 g/10 min.

Table 4. MFI Testing Result

Sample	MFI Value (g/10 min)	Avg. MFI Value (g/10 min)
1	61.2	60.8
2	59.8	
3	61.3	

This relatively high MFI value indicates increased melt flowability and reduced viscosity, which are commonly associated with decreased molecular weight due to thermo-mechanical degradation [23]. In the context of processing, higher MFI values generally facilitate easier flow during extrusion and molding operations. However, this increase in processability often reflects underlying degradation mechanisms that may influence mechanical performance. The obtained MFI value falls within the upper range typically reported for recycled PET, suggesting that the material has undergone significant, yet expected, structural changes during recycling.

Despite the high MFI, the mechanical properties measured in this study remain within acceptable ranges for recycled PET, indicating that the material retains functional performance for certain applications. This observation

highlights the importance of evaluating both rheological and mechanical properties to obtain a comprehensive understanding of recycled polymer behavior.

5. CONCLUSION

This study has presented a characterization of the mechanical properties and melt flow behavior of post-consumer recycled PET (rPET) derived from waste bank feedstock and processed using twin-screw extrusion. The results indicate that the material exhibits an average tensile strength of 64.1 MPa and hardness of 84.9 Shore D, with tensile strength falling within the range previously reported for mechanically recycled PET (48.3–72.4 MPa), indicating measurable strength and rigidity under the tested processing conditions. However, the elongation at break was relatively low ($10.9\% \pm 2.42\%$), indicating reduced ductility due to thermo-mechanical degradation during recycling.

The measured melt flow index (60.8 g/10 min) suggests a decrease in molecular weight, which is consistent with the expected effects of repeated thermal processing. Despite this, the material maintains functional mechanical performance for applications where basic rigidity is the primary requirement, though broader application suitability requires further characterization.

These findings suggest that rPET obtained from decentralized waste bank systems can be processed into materials with consistent and usable properties under controlled extrusion conditions. As a baseline study, this work provides fundamental data for evaluating the potential utilization of waste bank-derived rPET in non-critical rigid applications, pending further validation through impact, flexural, thermal, and long-term performance testing.

Future work is recommended to include a larger sample size, additional mechanical and thermal characterization, and molecular-level analysis to better understand structure–property relationships and to improve material performance.

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REFERENCES

- [1] H. K. Mohajan, “Polyethylene Terephthalate (PET): An Overview on Production, Consumption, and Recycling,” *Art and Society*, vol. 4, no. 6, p. 30, Aug. 2025, doi: 10.63593/as.2709-9830.2025.07.004.
- [2] R. Patel, M. L. Chaudhary, and R. K. Gupta, “Introduction to PET and Its Recycling Journey,” in *ACS Symposium Series*, American Chemical Society, 2025, p. 1. doi: 10.1021/bk-2025-1511.ch001.
- [3] D. Trisyanti, K. Rangi, R. Rachmawati, and R. Akib, “Advancing the Potential of PET and PP-Based Beverage Packaging to Support Circular Economy,” *Journal of Environmental Science and Sustainable Development*, vol. 5, no. 2, Dec. 2022, doi: 10.7454/jessd.v5i2.1154.
- [4] G. G. Marques, A. Couffin, P. Hajji, R. Inoubli, V. Bounor-Legaré, and R. Fulchiron, “A Review on the Formulation and Rupture Properties of Polyethylene Terephthalate in a Mechanical Recycling Context,” *Industrial & Engineering Chemistry Research*, vol. 63, no. 2, p. 887, Jan. 8, 2024, doi: 10.1021/acs.iecr.3c02376.
- [5] M. A. S. Spinacé and M. D. Paoli, “Characterization of Poly(Ethylene Terephthalate) After Multiple Processing Cycles,” *Journal of Applied Polymer Science*, vol. 80, no. 1, p. 20, Apr. 2001, doi: 10.1002/1097-4628(20010404)80:1<20::aid-app1069>3.3.co;2-j.
- [6] H. Li et al., “Expanding Plastics Recycling Technologies: Chemical Aspects, Technology Status and Challenges,” Jun. 2022, doi: 10.26434/chemrxiv-2022-9wqz0-v2.
- [7] Y. Zahrah, J. Yu, and X. Liu, “How Indonesia’s Cities Are Grappling with Plastic Waste: An Integrated Approach Towards Sustainable Plastic Waste Management,” *Sustainability*, vol. 16, no. 10, p. 3921, May 2024, doi: 10.3390/su16103921.
- [8] R. Subekti, “A Circular Economy-Based Plastic Waste Management Policy in Indonesia (Compared to China and EU),” *Yustisia Jurnal Hukum*, vol. 12, no. 2, p. 168, Aug. 2023, doi: 10.20961/yustisia.v12i2.72177.
- [9] J. Zheng, M. Arifuzzaman, X. Tang, X. C. Chen, and T. Saito, “Recent Development of End-of-Life Strategies for Plastic in Industry and Academia: Bridging Their Gap for Future Deployment,” *Materials Horizons*, vol. 10, no. 5, p. 1608, Jan. 2023, doi: 10.1039/d2mh01549h.
- [10] M. T. Brouwer, E. U. T. van Velzen, K. Ragaert, and R. ten Klooster, “Technical Limits in Circularity for Plastic Packages,” *Sustainability*,

- vol. 12, no. 23, p. 10021, Nov. 2020, doi: 10.3390/su122310021.
- [11] S. M. Rajapaksha et al., "Development of PP/r-PET Low-Speed Wheels: An Approach to Value Added Recycling of PET Along with Minimizing Virgin Plastic Usage in the Industry," *Advances in Technology*, vol. 1, no. 1, May 2021, doi: 10.31357/ait.v1i1.4893.
- [12] C. Fiorillo et al., "Molecular and Material Property Variations During the Ideal Degradation and Mechanical Recycling of PET," *RSC Sustainability*, vol. 2, no. 12, p. 3596, Jan. 2024, doi: 10.1039/d4su00485j.
- [13] D. Y. Kim, T. H. Park, J. E. Choo, and S. W. Hwang, "Evaluation of PET Recyclability and Characterization of Modified Reprocessed-PET for Industrial Application," *Journal of Applied Polymer Science*, vol. 141, no. 24, Mar. 2024, doi: 10.1002/app.55506.
- [14] H. Li et al., "Expanding Plastics Recycling Technologies: Chemical Aspects, Technology Status and Challenges," *Green Chemistry*, vol. 24, no. 23, p. 8899, Jan. 2022, doi: 10.1039/d2gc02588d.
- [15] G. G. Marques et al., "Effect of Mechanical Recycling on Structural Modification and Mechanical Behavior of PET," *Industrial & Engineering Chemistry Research*, vol. 64, no. 6, p. 3383, Jan. 2025, doi: 10.1021/acs.iecr.4c03818.
- [16] V. C. Kwansa, H. M. K. Essandoh, B. Dwumfour-Asare, and E. Awuah, "Assessing the Conformity of Single-Use Food Plastic Packaging Products to the Applicable Standards: A Seven-Year Study of Tests Conducted at the Ghana Standards Authority," *Research Square*, Oct. 2023, doi: 10.21203/rs.3.rs-3424390/v1.
- [17] F. Grønberg, "Polymer-Based Materials: Expanding Properties Through Parts, Processes, and Materials," *Research Portal Denmark*, p. 239, Jan. 2024, Accessed: Jul. 2025. [Online]. Available: <https://local.forskningsportal.dk/local/dki-cgi/ws/cris-link?src=dtu&id=dtu-566704cd-54ed-4695-a164-a3510bf11d6d&ti=Polymer-Based%20Materials%3A%20Expanding%20properties%20through%20Parts%2C%20Processes%2C%20and%20Materials>
- [18] P. T. Lai et al., "Upcycling Plastic Waste into Fully Recyclable Composites Through Cold Sintering," *Materials Horizons*, vol. 11, no. 11, p. 2718, Jan. 2024, doi: 10.1039/d3mh01976d.
- [19] L. Viora et al., "A Comparative Study on Crystallisation for Virgin and Recycled Polyethylene Terephthalate (PET): Multiscale Effects on Physico-Mechanical Properties," *Polymers*, vol. 15, no. 23, p. 4613, Dec. 2023, doi: 10.3390/polym15234613.
- [20] I. Villafañe, C. Keogh, T. P. Curran, and E. G. Reynaud, "Assessment of the Mechanical Properties of PET Polymer Material from Recovered Plastic Bottles," *Present Environment and Sustainable Development*, vol. 12, no. 1, p. 203, Jun. 2018, doi: 10.2478/pesd-2018-0016.
- [21] F. Slimani, A. Hedir, M. Moudoud, A. Durmus, M. Amir, and M. Megherbi, "Prediction of Long-Term Physical Properties of Low Density Polyethylene (LDPE) Cable Insulation Materials by Artificial Neural Network Modeling Approach Under Environmental Constraints," *Turkish Journal of Electrical Engineering & Computer Sciences*, vol. 29, no. 5, p. 2437, Jun. 2021, doi: 10.3906/elk-2105-27.
- [22] K. Oubellaouch et al., "A Novel Experimental–Numerical Procedure for the Rheological Characterization of Thermoplastic Polymers Applied to Injection Molding," *The International Journal of Advanced Manufacturing Technology*, Sep. 2025, doi: 10.1007/s00170-025-16522-7.
- [23] O. Rashwan et al., "Extrusion and Characterization of Recycled Polyethylene Terephthalate (rPET) Filaments Compounded with Chain Extender and Impact Modifiers for Material-Extrusion Additive Manufacturing," *Scientific Reports*, vol. 13, no. 1, Sep. 2023, doi: 10.1038/s41598-023-41744-8.