

A Comprehensive Review of Defect Characterization and Quality Analysis in Blow-Molded Products Manufactured Using Reprocessed Material

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Abstract—The growing use of reprocessed polymers in blow-molded products has created significant opportunities for sustainable and cost-effective manufacturing. However, variations in recycled material properties often lead to defects affecting product quality, dimensional stability, and mechanical performance. This review paper examines studies related to blow molding, recycled polymer behavior, defect formation, and process parameter optimization. The review also focuses on identifying suitable proportions of virgin and reprocessed material required to maintain product quality while reducing defects such as wall-thickness variation, shrinkage, surface irregularities, and reduced strength. The study highlights research gaps and emphasizes the need for optimized industrial processing strategies.

Index Terms—Blow Molding, Defect Analysis, Process Optimization, Quality Evaluation, Reprocessed Material, Virgin Polymer Ratio

I. INTRODUCTION

The increasing demand for sustainable manufacturing and effective plastic waste management has encouraged industries to utilize recycled and reprocessed polymer materials in various manufacturing applications. The extensive use of plastics in packaging, automotive, construction, healthcare, and consumer products has significantly increased plastic waste generation worldwide. Recycling and reuse of plastic materials help reduce environmental pollution, minimize landfill waste, conserve natural resources, and lower manufacturing costs [16], [24].

Blow molding is one of the most widely used polymer processing techniques for manufacturing hollow plastic products such as bottles, containers, drums, fuel tanks, and industrial packaging products due to its high production efficiency, low manufacturing cost, and excellent design flexibility [9], [10], [21]. Among different thermoplastic materials, High-Density Polyethylene (HDPE) is extensively used in blow molding because of its excellent chemical resistance, durability, lightweight nature, and good processability [20], [23].

Despite the advantages of recycled polymer utilization, the use of reprocessed material introduces several challenges associated with material degradation and product quality variation. Researchers have reported that repeated recycling can lead to oxidation, contamination, crystallinity variation, unstable melt-flow behavior, and reduced mechanical strength [3], [5], [8]. These changes directly affect the blow-molding process and result in manufacturing defects such as shrinkage, warpage, bubbles, flash formation, uneven wall thickness, and surface irregularities [10], [14], [19].

The quality of blow-molded products is highly dependent on process parameters such as barrel temperature, blowing pressure, cooling rate, screw speed, and cycle time [9], [13]. In addition, the proportion of virgin and reprocessed material significantly influences dimensional accuracy, mechanical strength, and surface finish. Several studies have shown that excessive recycled content can reduce tensile strength and increase defect occurrence [1], [11], [12], whereas optimized blend

ratios can maintain acceptable product quality while reducing manufacturing cost [17].

Several researchers have investigated recycled polymers, blow-molding processes, and defect analysis techniques. However, limited research is available on the combined influence of reprocessed material proportion and processing parameters on the quality of blow-molded HDPE products under industrial conditions. Therefore, this review paper focuses on defect characterization, quality analysis, and process optimization in blow-molded products manufactured using reprocessed HDPE material while identifying important research gaps for sustainable and defect-minimized manufacturing.

II. LITERATURE REVIEW

1. Singh et al. (2023)

Singh et al. (2023) investigated the influence of recycled HDPE content on the quality of blow-molded containers. The study evaluated dimensional accuracy, wall-thickness distribution, and surface finish for different material compositions. Results showed that increasing recycled content led to higher shrinkage and surface roughness, while optimized blend ratios maintained acceptable product quality and reduced production cost. The authors concluded that careful selection of recycled material proportion is necessary for industrial applications [12].

2. Chen et al. (2022)

Chen et al. (2022) studied the rheological behavior of recycled HDPE during extrusion blow molding. The research reported that repeated thermal processing reduced melt strength and affected parison stability, leading to wall-thickness variations and dimensional inconsistencies. The study emphasized the importance of controlling processing conditions to minimize quality deterioration and improve manufacturing performance [15].

3. Patel and Shah (2022)

Patel and Shah (2022) analyzed the mechanical performance of HDPE products manufactured using virgin and recycled material blends. The study found that moderate recycled content maintained acceptable tensile strength and dimensional stability while reducing raw material costs. However, higher recycled proportions caused a noticeable decline in mechanical

properties and increased defect occurrence during processing [11].

4. Mohan et al. (2022)

Mohan et al. (2022) applied statistical quality-control techniques in blow-molded plastic manufacturing. The researchers identified key process variables affecting product rejection and demonstrated that systematic monitoring significantly reduced defect rates. The study highlighted the effectiveness of quality-control methods in improving manufacturing consistency and product reliability [18].

5. Pivnenko et al. (2021)

Pivnenko et al. (2021) reviewed the challenges associated with recycling plastic packaging materials. The study identified contamination, thermo-oxidative degradation, and unstable melt-flow behavior as major factors affecting recycled polymer quality. The authors emphasized the need for proper material characterization and process optimization to improve the industrial usability of recycled plastics [8].

6. Ghosh and Roy (2021)

Ghosh and Roy (2021) investigated the effect of virgin and recycled polymer ratios on product quality and manufacturing cost. The study concluded that optimized blend ratios can achieve significant cost savings while maintaining acceptable product performance. The authors highlighted the importance of balancing economic benefits with quality requirements in recycled polymer processing [17].

7. Kumar and Joshi (2021)

Kumar and Joshi (2021) utilized Design of Experiments (DOE) techniques to optimize HDPE blow-molding parameters. The study evaluated the effects of barrel temperature, cooling time, and blow pressure on dimensional accuracy and wall-thickness distribution. Results demonstrated that parameter optimization significantly reduced manufacturing defects and improved process consistency [13].

8. Brouwer et al. (2020)

Brouwer et al. (2020) examined the impact of recycled polymer content on blow-molded product quality. The researchers observed reductions in mechanical strength and dimensional stability with increasing recycled material proportions. Surface defects and

wall-thickness variations were also reported due to contamination and material degradation, highlighting the need for controlled recycled content usage [1].

9. Reddy et al. (2020)

Reddy et al. (2020) investigated shrinkage and warpage defects in HDPE blow-molded products under different cooling conditions. The study found that improper cooling caused dimensional instability and deformation, negatively affecting product quality. Optimized cooling parameters were recommended to reduce defect formation and improve dimensional accuracy [14].

10. Yilmaz and Demir (2020)

Yilmaz and Demir (2020) analyzed surface defects in recycled polymer blow molding. The researchers identified bubbles, burn marks, and surface roughness as common defects resulting from contamination and unstable melt flow. The study concluded that proper material preparation and controlled processing

conditions are essential for maintaining product quality and minimizing defects [19].

A. Comparative Observation

From the reviewed studies, it is evident that the use of recycled HDPE offers significant economic and environmental benefits; however, increasing recycled content can adversely affect mechanical properties, dimensional stability, and surface quality. Recent studies have focused on recycled material characterization, process optimization, and defect reduction techniques. Nevertheless, limited research has investigated the combined effect of reprocessed HDPE ratio and blow-molding process parameters on quality, defect formation, and cost optimization simultaneously. This gap forms the basis of the present dissertation, which aims to determine the optimum virgin-to-reprocessed HDPE proportion for manufacturing high-quality blow-molded pharmaceutical bottles with minimum defects and reduced production cost.

B. Comparative Analysis of Literature

Ref.	Author & Year	Material/ Process	Research Focus	Methodology	Major Findings	Research Limitation
[1]	Brouwer et al. (2020)	Recycled plastic packaging	Effect of recycling on product properties	Material property analysis	Higher recycled content reduced optical clarity and mechanical strength	Limited focus on blow-molding defects
[3]	Badia et al. (2009)	Recycled polymers	Thermal degradation behavior	Thermal analysis techniques	Reprocessing altered crystallinity and thermal stability	No industrial quality evaluation
[5]	La Mantia and Vinci (1994)	Reprocessed polymers	Effect of repeated recycling	Experimental material analysis	Repeated recycling reduced melt strength and processing stability	Limited defect characterization
[8]	Pivnenko et al. (2021)	Plastic packaging waste	Mechanical recycling challenges	Review-based analysis	Reported thermo-oxidative degradation and melt-flow instability	No process optimization study
[9]	Michaeli and Brandenburg (2019)	Extrusion blow molding	Process parameter optimization	Blow-molding parameter analysis	Temperature and blowing pressure significantly	Limited study on recycled HDPE

Ref.	Author & Year	Material/ Process	Research Focus	Methodology	Major Findings	Research Limitation
					affected wall thickness	
[10]	Throne (2018)	Blow-molded products	Defect identification	Review of molding defects	Identified defects: warpage, bubbles, flash, uneven wall thickness	No recycled material analysis
[11]	Patel and Shah (2022)	Recycled and virgin HDPE blends	Mechanical property evaluation	Tensile and impact testing	Increased recycled content reduced tensile strength and impact resistance	Limited processing parameter study
[12]	Singh et al. (2023)	Recycled HDPE containers	Surface quality and dimensional analysis	Comparative experimental study	Higher recycled content increased surface roughness and dimensional variation	Limited industrial-scale validation
[13]	Kumar and Joshi (2021)	HDPE blow molding	Optimization of process parameters	DOE-based experimental analysis	Temperature, cooling time, and air pressure influenced product quality	No blend ratio optimization
[17]	Ghosh and Roy (2021)	Virgin and recycled polymer blends	Blend ratio optimization	Experimental quality evaluation	Optimized virgin-to-recycled ratio maintained acceptable quality with lower cost	Limited defect prediction analysis

C. Case Study: Blow Molding of Mechanically Recycled Post-Consumer Rigid Polyethylene Packaging Waste

A significant industrial case study related to recycled HDPE blow molding was conducted by Ezgi Ceren Boz Noyan and Antal Boldizar at Chalmers University of Technology, Sweden, in 2024. The study investigated the feasibility of manufacturing blow-molded containers using mechanically recycled post-consumer rigid polyethylene (PE) packaging waste. The research focused on washing, compounding, rheological characterization, and industrial blow molding of recycled polyethylene material.

In the study, post-consumer rigid polyethylene packaging waste was collected, washed using different washing methods, compounded under controlled

processing conditions, and compared with virgin-grade HDPE material. The researchers analyzed important material properties such as crystallinity, thermo-oxidative stability, viscosity, melt elasticity, melt strength, and drawability before performing industrial-scale blow molding.

The results showed that recycled polyethylene exhibited lower crystallinity, lower thermo-oxidative stability, reduced viscosity, lower melt elasticity, and reduced melt strength compared to virgin HDPE. Material degradation during repeated recycling and contamination from packaging waste significantly affected the processing behavior of recycled polymers. During blow molding, the recycled material showed lower resistance to flow and reduced drawability, which affected wall-thickness uniformity and

dimensional consistency. In some cases, surface defects such as fisheye formation and color variation were observed due to contamination. However, the researchers successfully manufactured 4-liter blow-molded containers using 100% recycled polyethylene material under optimized processing conditions.

The study further reported that the mechanical properties of the blow-molded recycled containers were not significantly different from those manufactured using virgin HDPE. The case study concluded that recycled HDPE material can be effectively used in industrial blow molding applications when appropriate process control and material characterization techniques are implemented. Reference: Noyan, E. C. B., and Boldizar, A., "Blow Molding of Mechanically Recycled Post-Consumer Rigid Polyethylene Packaging Waste," *Polymer Engineering & Science*, vol. 64, no. 12, pp. 5968–5983, 2024.

D. Research Gaps Identified

Existing research on blow molding and recycled polymers mainly focuses on recycling techniques, material degradation, thermal analysis, and mechanical property evaluation. Although several studies discuss defects such as warpage, wall-thickness variation, shrinkage, bubbles, and surface irregularities, limited research is available on the combined influence of reprocessed material proportion and blow-molding process parameters on final product quality under real industrial conditions. Most studies analyze either material properties or processing conditions individually, while very few provide an integrated approach for quality evaluation and defect minimization. Existing literature does not clearly define the acceptable percentage of reprocessed material that can be used without significantly affecting dimensional accuracy, mechanical strength, and surface quality. Furthermore, there is a lack of research combining material characterization, statistical quality analysis, and defect prediction methods for sustainable and defect-minimized blow-molding production.

III. PROPOSED WORK

To address the limitations identified in existing studies related to blow-molded products using reprocessed material, a systematic quality and defect analysis

framework is proposed. The proposed methodology focuses on analyzing the relationship between reprocessed material proportion, blow-molding process parameters, and final product quality for achieving defect-minimized and sustainable manufacturing.

A. Step 1: Material Selection and Blend Ratio Analysis

HDPE is proposed as the base material due to its good processability, high chemical resistance, durability, low cost, and wide industrial application in blow-molded products. The study proposes the use of different virgin-to-reprocessed material ratios such as 100:0, 90:10, 80:20, 70:30, and 60:40 to analyze the effect of recycled content on product quality and defect formation. Comparative analysis of these ratios will help identify the optimum blend proportion for minimizing defects while maintaining acceptable mechanical and dimensional properties.

B. Step 2: Blow-Molding Process Evaluation

Blow molding is proposed for this study because it is more suitable for manufacturing hollow plastic products with uniform wall thickness, lower material wastage, and higher production efficiency compared to injection molding. The methodology includes the evaluation of important blow-molding parameters such as barrel temperature, blowing pressure, cooling rate, screw speed, and cycle time. Design of Experiments (DOE) and statistical parameter analysis techniques are proposed for studying the influence of processing conditions on product quality and defect generation.

C. Step 3: Quality Evaluation and Defect Analysis

The proposed framework includes quality evaluation methods such as wall-thickness measurement, dimensional inspection, surface finish analysis, and mechanical property evaluation. Defect analysis techniques including visual inspection, statistical quality control, and comparative defect mapping will be used to analyze defects such as shrinkage, warpage, bubbles, flash formation, and surface irregularities caused by varying recycled material proportions and processing conditions.

D. Step 4: Optimization Framework

Based on literature findings and comparative analysis, an optimized framework for blow molding using

reprocessed HDPE material will be proposed. The methodology aims to identify suitable material proportions and stable process parameters for

minimizing defects, improving product quality, and supporting sustainable industrial manufacturing applications.

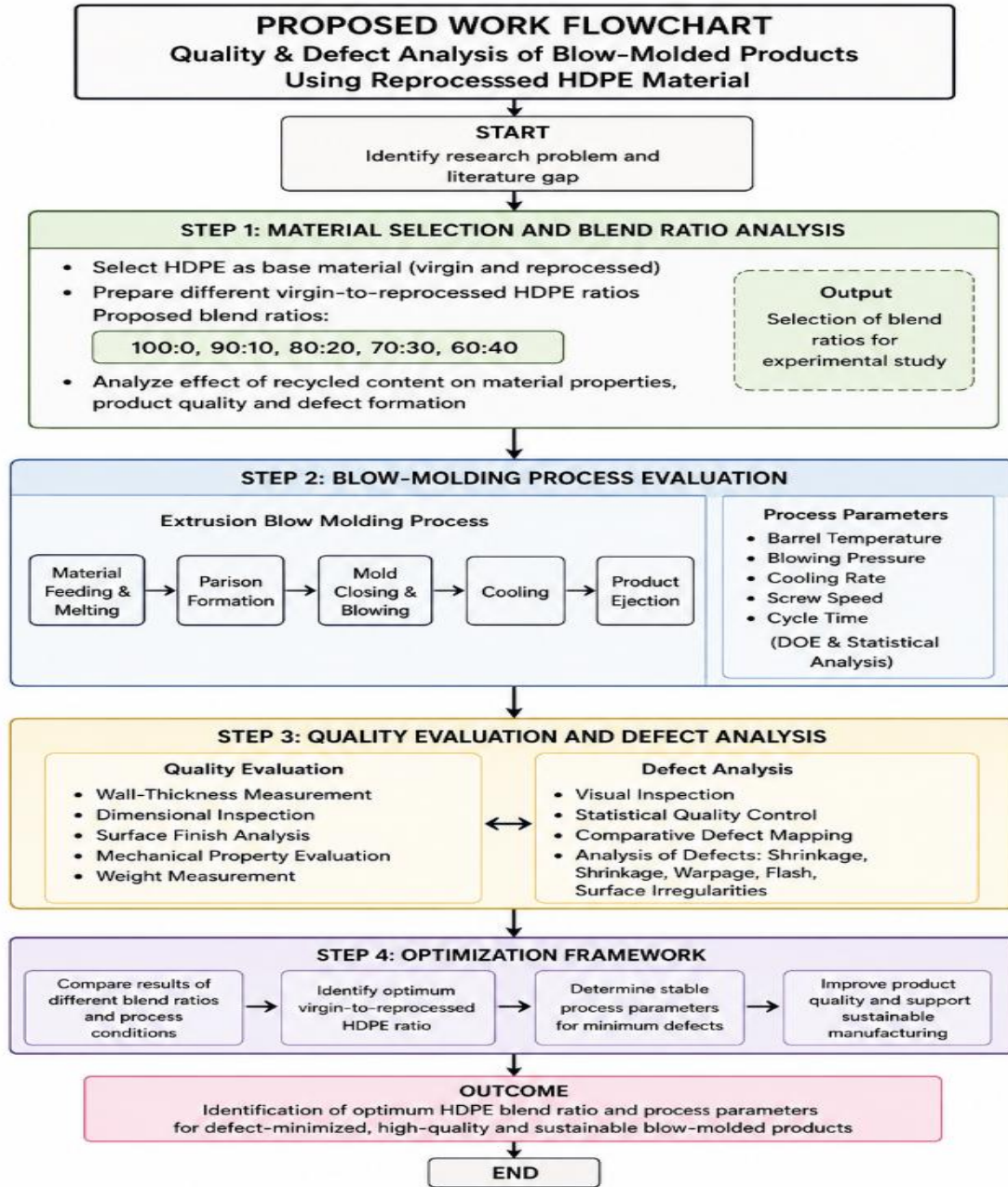


Fig:1 Proposed Framework

IV. MATHEMATICAL MODEL

The quality of blow-molded products depends on material composition and processing conditions. The overall product quality Q can be represented as a

function of material proportion and process parameters:

$$Q = f(R, T, P, C, S) \dots (I)$$

Where: Q = Product Quality; R = Ratio of virgin to reprocessed material; T = Processing Temperature; P

= Blowing Pressure; C = Cooling Rate/Time; S = Screw Speed.

The defect generation in blow-molded products can be represented as:

$$D = f(R_d, T_v, P_v, C_v) \dots\dots\dots (II)$$

Where: D = Defect occurrence; R_d = Reprocessed material percentage; T_v = Temperature variation; P_v = Pressure variation; C_v = Cooling variation.

The quality of the product is inversely proportional to defect formation: $Q \propto 1/D$. This indicates that as defect occurrence increases, the overall quality of the blow-molded product decreases. The proposed model helps in understanding the relationship between material composition, process parameters, and defect generation for identifying optimized manufacturing conditions.

V. CONCLUSION

This review paper analyzed existing studies related to blow molding, reprocessed polymers, product quality, and defect formation in blow-molded products manufactured using recycled material. The review identified that the use of reprocessed material offers significant advantages such as reduced manufacturing cost, lower plastic waste generation, and improved sustainability. However, issues such as material degradation, contamination, unstable melt-flow behavior, and improper processing conditions lead to defects including shrinkage, warpage, wall-thickness variation, bubbles, and surface irregularities.

The study also highlighted the importance of selecting appropriate virgin-to-reprocessed material proportions and optimized blow-molding parameters for maintaining dimensional accuracy, mechanical strength, and surface quality. Based on the reviewed studies, the paper concludes that proper material characterization, process optimization, and defect analysis techniques are essential for achieving defect-minimized and sustainable blow-molding production.

REFERENCES

- [1] M. T. Brouwer, C. Picuno, E. U. Thoden van Velzen, K. Kuchta, S. De Meester, K. Ragaert, and K. Van Geem, "The Impact of Recycling on Plastic Packaging Properties," *Packaging Technology and Science*, vol. 33, no. 7, pp. 263–275, 2020.
- [2] F. Welle, "Twenty Years of PET Bottle to Bottle Recycling—An Overview," *Resources, Conservation and Recycling*, vol. 55, no. 11, pp. 865–875, 2011.
- [3] J. D. Badia, F. Vilaplana, S. Karlsson, and A. Ribes-Greus, "Thermal Analysis as a Quality Tool for Recycled Polymers," *Polymer Testing*, vol. 28, no. 2, pp. 169–175, 2009.
- [4] D. Ciolacu, F. Ciolacu, and V. I. Popa, "Amorphous Cellulose—Structure and Characterization," *Cellulose Chemistry and Technology*, vol. 40, no. 5, pp. 445–450, 2006.
- [5] F. P. La Mantia and M. Vinci, "Recycling of Polymers: Effects of Reprocessing on Properties," *Polymer Degradation and Stability*, vol. 45, no. 1, pp. 121–125, 1994.
- [6] M. Whitt, K. Vorst, W. Brown, and C. Baker, "Migration of Contaminants in Recycled Plastics," *Food Additives & Contaminants*, vol. 33, no. 11, pp. 1726–1735, 2016.
- [7] M. K. Eriksen, A. Damgaard, and T. F. Astrup, "Characterization and Quantification of Metal Contamination in Recycled Plastics," *Waste Management*, vol. 78, pp. 174–182, 2018.
- [8] K. Pivnenko, M. K. Eriksen, J. A. Martín-Fernández, E. Eriksson, and T. F. Astrup, "Recycling of Plastic Packaging: Challenges and Opportunities," *Waste Management*, vol. 119, pp. 245–251, 2021.
- [9] W. Michaeli and G. Brandenburg, "Extrusion Blow Molding: Process Optimization and Quality Improvement," *International Polymer Processing*, vol. 34, no. 4, pp. 410–418, 2019.
- [10] J. L. Throne, *Technology of Blow Molding*, 3rd ed. Munich, Germany: Hanser Publishers, 2018.
- [11] R. Patel and M. Shah, "Mechanical Performance of Recycled HDPE Blends for Industrial Applications," *Materials Today: Proceedings*, vol. 56, pp. 2210–2215, 2022.
- [12] A. Singh, P. Kumar, and S. Verma, "Effect of Recycled HDPE Content on Blow Molded Containers," *Journal of Polymer Engineering*, vol. 43, no. 2, pp. 145–153, 2023.
- [13] N. Kumar and R. Joshi, "Optimization of HDPE Blow Molding Parameters Using DOE Technique," *Materials Manufacturing Processes*, vol. 36, no. 5, pp. 611–619, 2021.
- [14] K. V. Reddy, A. Sharma, and P. Rao, "Analysis of Shrinkage and Warpage Defects in Blow

- Molded HDPE Products,” *International Journal of Advanced Manufacturing Technology*, vol. 109, no. 3, pp. 889–897, 2020.
- [15] X. Chen, Y. Li, and H. Wang, “Rheological Behavior of Recycled HDPE During Blow Molding,” *Polymer Engineering and Science*, vol. 62, no. 8, pp. 2154–2162, 2022.
- [16] S. M. Al-Salem, P. Lettieri, and J. Baeyens, “Recycling and Recovery Routes of Plastic Solid Waste,” *Waste Management*, vol. 29, no. 10, pp. 2625–2643, 2019.
- [17] S. Ghosh and D. Roy, “Effect of Virgin and Recycled Polymer Ratios on Product Quality,” *Journal of Materials Processing Technology*, vol. 287, pp. 116–124, 2021.
- [18] R. Mohan, S. Patil, and A. Deshmukh, “Statistical Quality Control in Blow Molded Plastic Manufacturing,” *International Journal of Quality & Reliability Management*, vol. 39, no. 6, pp. 1305–1318, 2022.
- [19] O. Yilmaz and H. Demir, “Surface Defect Analysis in Recycled Polymer Blow Molding,” *Polymer Testing*, vol. 89, pp. 106–114, 2020.
- [20] ASTM D4976-20, “Standard Specification for Polyethylene Plastics Molding and Extrusion Materials,” ASTM International, West Conshohocken, PA, USA, 2020.
- [21] D. V. Rosato and D. V. Rosato, *Blow Molding Handbook*. Boston, MA, USA: Springer, 2004.
- [22] M. M. Fisher, “Design and Processing Considerations for Blow Molded Products,” *Plastics Engineering*, vol. 58, no. 4, pp. 22–29, 2002.
- [23] A. B. Strong, *Plastics: Materials and Processing*, 3rd ed. Upper Saddle River, NJ, USA: Pearson Education, 2006.
- [24] J. Hopewell, R. Dvorak, and E. Kosior, “Plastics Recycling: Challenges and Opportunities,” *Philosophical Transactions of the Royal Society B*, vol. 364, no. 1526, pp. 2115–2126, 2009.
- [25] F. Vilaplana and S. Karlsson, “Quality Concepts for the Improved Use of Recycled Polymeric Materials,” *Macromolecular Materials and Engineering*, vol. 293, no. 4, pp. 274–297, 2008.
- [26] R. J. Crawford, *Plastics Engineering*, 3rd ed. Oxford, U.K.: Butterworth-Heinemann, 1998.
- [27] T. A. Osswald and J. P. Hernández-Ortiz, *Polymer Processing: Modeling and Simulation*. Munich, Germany: Hanser Publishers, 2006.
- [28] C. A. Harper, *Handbook of Plastics Processes*. Hoboken, NJ, USA: Wiley-Interscience, 2005.
- [29] G. Beall, “Recycling and Reuse of HDPE in Industrial Applications,” *Journal of Plastic Film and Sheeting*, vol. 21, no. 3, pp. 145–156, 2005.
- [30] Z. Tadmor and C. G. Gogos, *Principles of Polymer Processing*, 2nd ed. Hoboken, NJ, USA: Wiley, 2013.