International Journal of Scientific Engineering and Science
Volume 10, Issue 4, pp. 57-63, 2026.
ISSN (Online): 2456-7361

Sustainable Additive Manufacturing Using Recycled PET for Environmental Pollution Mitigation

Chirath A.B. Senanayaka, P.M.Y.G Senarathna, P.T.D Tharuka, S. Braveenan, A.M.L.V. Abeysinghe, P.G.N.S. Perera, Udara S.P.R. Arachchige*
Department of Mechatronic and Industrial Engineering, Faculty of Engineering, NSBM Green University, Sri Lanka
Email address: *udara.a@nsbm.ac.lk

Abstract**—***The increasing accumulation of plastic waste has become a major global environmental concern, primarily because most synthetic polymers are non-biodegradable and persist in the environment for long periods of time. Among these plastics, polyethylene terephthalate (PET), widely used in beverage bottles and packaging, represents a significant portion of post-consumer waste but also shows strong potential as a recyclable feedstock for additive manufacturing. This review examines the potential of recycled PET (rPET) as a sustainable filament material for extrusion additive manufacturing, particularly fused filament fabrication (FFF). It summarizes current research on PET recycling pathways, filament production techniques, and the mechanical and thermal performance of rPET compared to commonly used FFF materials such as PLA, ABS, PETG, and Nylon. Mechanical recycling, which involves shredding, cleaning, drying, and re-extruding PET waste into filament, is the most widely used method, but repeated thermal processing can lead to polymer degradation and reduced mechanical properties. Chemical recycling methods offer the possibility of recovering PET monomers and producing higher-quality polymers but require more complex processing. The review discusses key challenges in rPET printing, including moisture sensitivity, crystallization behavior, inconsistent filament diameter, and weaker interlayer bonding. Material modifications such as chain extenders, elastomeric modifiers, and fiber reinforcement are highlighted as approaches to enhance performance. Overall, rPET has greater potential for sustainable additive manufacturing and supports circular-economy approaches by converting plastic waste into functional products.*

Keywords**—** *Additive Manufacturing: Circular Economy; Fused Filament fabrication; Material extrusion: Polymer recycling; Recycled PET: Sustainability; Thermoplastics; 3D Printing.*

I. INTRODUCTION

Global plastic production has created a long-term waste deposit because most polymers are not biodegradable on a human timescale, and traditional waste management has disposed of the waste rather than recycling it [1]. Material flow analysis has estimated that by 2015, approximately 6300 Mt of plastic waste had been generated, with only ~9% recycled and ~79% accumulating in landfills or the natural environment. Due to improper land-based management, 4.8-12.7 Mt of plastic waste had been driven to the ocean in 2010 [1],[2]. Mechanical recycling is commonly used industrially for recycling, but its effectiveness is limited because of contamination, poor mixing between different plastics, and degradation during repeated recycling [3],[4]. Material extrusion additive manufacturing (fused filament fabrication, FFF) plays a significant role in circular manufacturing because it has the potential to transform recycled thermoplastics into customized, higher-value components while requiring minimal facilities, and it promotes recycling and production networks [5],[6]. But, FFF performance is strongly influenced by microstructure, including void formation, incomplete interlayer bonding, and process-induced anisotropy, leading to reductions in toughness and strength that do not usually occur in conventional polymers [7]. These microstructural problems become more complex when printing semicrystalline materials, as the material cools and forms crystals. This crystallization depends on the polymer's temperature history. These issues affect the dimensional accuracy of the 3D-printed component. Therefore, acceptable printing conditions are more limited for semi-crystalline plastics than for amorphous plastics [8],[9].

In this context, polyethylene terephthalate (PET) is a representative and attractive, yet technically challenging, option for sustainable FFF, as it is widely used in packaging and consumer products, primarily available in post-consumer waste streams, and offers strong mechanical performance. However, its moisture sensitivity and semi-crystalline behavior can negatively affect printability and dimensional stability when feedstock conditions are not adequately controlled.[9], [10],[11].

Initial demonstrations confirm that mechanically recycled PET can be extruded into filaments and can be printed. However, these demonstrations also revealed practical challenges related to FFF printing, including diameter control, drying, and parameter sensitivity [12]. Following these initial findings, systematic studies have demonstrated that extrusion and FFF processing parameters can critically change the crystallinity of recycled PET and its mechanical response. For example, a set of parameters may increase tensile strength while reducing impact resistance and performance through microstructural changes [13]. To overcome challenges associated with PET recycling, including polymer chain degradation and brittleness, researchers use reactive compounding approaches, such as chain extenders, to rebuild melt strength and stabilize extrusion. At the same time, elastomeric impact modifiers and compatibilizers improve the ductility and toughness of recycled PET feedstocks. [10],[14],[15]. Further, reinforcement strategies, such as combining PET with recycled short carbon fibers, are used to increase stiffness and improve shrinkage behavior. Still, they also experience failures at the interface between the plastic and the fiber, indicating the need for further advancements in reinforcement and process control [11]. Recent studies have focused on rPET feedstock preparation, formal optimization, and qualification approaches, including multi-objective process optimization comparing both virgin PET and rPET in FFF, as well as systematic research on the effects of temperature on density, warpage, and surface quality in PET and rPET printed components [16],[17]. Generally, for FFF, a filament-based root is used; however, direct printing on PET has also been demonstrated as a recycling pathway using large machines with shredded PET flakes. However, moisture and continuous feeding are key challenges identified in that pathway [18]. Emerging upcycling-by-design approaches further extend PET recycling by converting PET flakes into higher-performance networks, such as vitrimer-based filaments with higher heat resistance and the ability to produce repairable printed components, indicating that closing PET recycling loops is functional rather than merely replacing virgin material [19].

Accordingly, this review synthesizes peer-reviewed studies on the production, modification, and performance of reclaimed PET feedstock for material extrusion additive manufacturing, focusing on identifying critical research and technological gaps in developing reliable rPET filaments for 3D printing, and including how recycling history and compounding chemistry influence melt flow behavior and crystallization, how extrusion (FFF) parameters control defects and anisotropy, and how environmental and techno-economic assessment can be integrated to support robust, scalable circular manufacturing. .

II. COMMON THERMOPLASTIC MATERIALS FOR FDM PRINTING

Modern Fused Deposition Modeling (FDM) printers use several types of thermoplastic filaments, including PLA, ABS, PETG, and Nylon. This section studies the advantages and limitations of each thermoplastic filament for 3D printing (TABLE I).

A. Polylactic acid (PLA)

Polylactic acid is a biodegradable polyester. It is made from renewable resources like corn starch, cassava, and sugarcane. This polylactic acid is usually used in FDM 3D printing. To print with PLA, low extrusion temperatures (~190-200 °C) and no heated bed are required in most cases [20]. PLA has many advantages, such as high tensile strength (often 50-60 MPa in 3D printing [21]), a high elastic modulus, minimal warping or low shrinkage, and high dimensional accuracy with fine printing [20]. When printing, PLA is non-toxic in solid form and emits a mild Odor, unlike ABS. Like any material, PLA has limitations, such as brittleness, low impact resistance, and mechanical limitations [21]. PLA has limited thermal properties, such as a glass transition temperature of 55-60°C; the printed part can soften or deform at modest temperatures [22]. PLA’s stiffness (2.3-2.6GPa) is higher than that of many plastics [21]. But it has less durability and cracks under stress. Also, at higher temperatures, PLA can be sensitive to humidity-induced hydrolysis. In printing, PLA shows lower distortion than ABS. In summary, PLA is a low-cost and easy-to-print material. It also has good strength and stiffness, which is really suited for prototyping and low-load applications. However, brittleness and poor heat resistance are significant problems with PLA, which limit its wide applications [20].

B. Acrylonitrile Butadiene Styrene (ABS)

ABS is a super-tough plastic derived from petroleum. It's widely used in FDM 3D printing due to its toughness. There are several advantages to ABS, including good impact strength and durability. In FDM printing, it can reach a maximum tensile strength of 30-40 MPa [21], and it tends to bend rather than shatter under pressure. ABS is much more heat-resistant than PLA (its glass transition is ~105 °C). Therefore, it’s a better choice for parts that need to retain their shape in high-temperature environments [22]. When considering ABS limitations, the main issue is its sensitivity to temperature changes. It tends to curl or shrink, so it requires a heated bed to prevent delamination. While ABS isn’t quite as stiff as PLA, it's about 1.5 GPa. It also emits unpleasant fumes during printing [20]. Overall, ABS is a low-cost, widely used engineering filament, but achieving good print quality requires a controlled environment to prevent warping and fumes.

C. Polyethylene Terephthalate Glycol (PETG)

PETG is made from PET modified with glycol. It is a standard FDM printing material that offers both strength and ease of use. When considering the advantages of PETG, it provides excellent toughness, chemical resistance, and better flexibility compared to PLA [23]. Printed components using PETG typically have a tensile strength of approximately 30-50 MPa, similar to ABS materials [21]. PETG is less brittle than PLA and has higher heat resistance, with a glass transition at ~80 °C, which expands its applications in warm environments. And also, it shows hydrophobic and more moisture and chemical resistance compared to PLA and ABS [22]. Importantly, PETG maintains its dimensional accuracy even without a printer enclosure, and it has minimal warping tendency [23]. In particular, PETG can provide good interlayer adhesion, increasing the printed part's durability. However, PETG also has considerable limitations. Mainly, PETG’s Young’s modulus is ~1.2 – 1.5 GPa [21]. Young’s modulus, which represents stiffness, indicates that PETG is more flexible than PLA. And PETG may produce delicate strings due to material oozing when the printing parameters are not correctly optimized for PETG. Even less than nylon, PETG can absorb moisture, so it requires drying 5the filament before printing for better results. Typically, PETG is printed at a nozzle temperature of 230-250 °C, and it prints better with a heated bed at around 70-90 °C. Overall, PETG is a durable, semi-rigid filament that combines ABS-like strength and moderate heat resistance with good printability, similar to PLA. As a result, it is widely used in FDM printing [22].

D. Polyamide (NYLON)

In FDM printing, Nylon is a polyamide similar to PA6 and PA12. Due to the use of strong, tough, and wear-resistant

Nylon, it is recognized as a quality polyamide. There are several advantages of Nylon, such as good tensile and flexural strength and high ductility. It has higher strength and higher strain at break than ABS or ASA [23]. In terms of strength,

Injection-molded Nylon can achieve a tensile strength of 50-70 MPa. The adequate strength of FDM-printed Nylon is relatively low (20-30 MPa). This is primarily due to weak inter-layer bonding[21]. Nylon has good impact and fatigue resistance. It also performs perfectly with impact, demonstrating high impact resistance, and performs well in cyclic loading and load-bearing applications. Also, Nylon has high thermal resistance. Its high melting point is around 250°C. Without losing much strength, Nylon can be used at 120-150°C. Among common FDM plastics, Nylon has the best thermal stability. Nylon has a few limitations. When printing, it's challenging. because Nylon absorbs moisture very easily. Any humidity in the filament can cause bubbling during extrusion, poor surface quality, and reduced mechanical strength[24]. Dry storage and filament drying are mandatory. When cooling, Nylon shrinks a lot. It requires a heated bed and preferably an enclosure to maintain the temperature[20]. Bed adhesion is difficult because it needs special adhesives or a built-in surface. Printed Nylon is relatively flexible (lower Young's modulus ~0.5-1 GPa [21] unless fiber-reinforced), and PLA/ABS surfaces are much smoother than Nylon. Also, Nylon filament is very expensive. In summary, Nylon offers high performance, but it requires careful printing conditions (high nozzle temperature ~240-270°C, heated chamber, dry filament) to achieve good results [20].

TABLE I. Comparative matrix of PET vs Standard 3D printing materials

Material	**Tensile strength (MPa)-FDM Print**	**Thermal Stability (Heat Resistance)**	**Cost (Filament)**	**Recyclabilty**	**Print Quality & Ease**
PLA (Polylactic Acid)	~50-60 MPa (high for FDM) [21].	Low-softens ~60°C (Poor heat resistance) [22].	Low-cheap bioplastic [20].	Partially biodegradable, industrial composting can be mechanically recycled.	Excellent: very easy to print, low shrinkage, but parts are brittle[20].
ABS (Acrylonitrile butadiene styrene)	~30-40 MPa (moderate), good impact strength[21].	High-Glass transition ~105°C (Handles higher temperatures)[22].	Low- Inexpensive as Petro plastic[20].	Thermoplastic recyclable (can be remelted), not biodegradable.	ABS can wrap or crack without proper heat control and produces fumes while printing [20].
PETG (Polyethylene Terephthalate Glycol)	~30-50 MPa(moderate), excellent toughness[21].	Moderate – Glass transition at ~80°C, better heat resistance than PLA [22].	Low- similar to ABS, widely available	Thermoplastic recyclable (PET-based).	Good: low warping, strong layer adhesion; needs drying for best results [22].
PA (Nylon)	~20-30 MPa when printed (lower due to bonding), 50MPa, but with injection, then 50 MPa [21].	High – semi crystalline, Melting ~ 250°C, usable when heated to more than 100°C.	Moderately more expensive than PLA/ABS	Thermoplastic recyclable, not biodegradable (but durable).	Poor: difficult to print as it is heavily wrapped, hygroscopic (must be dry), requires high temperatures, and requires an enclosure[20].
rPET (recycled PET)	Pure rPET filaments can reach tensile strengths of 30-40 MPa, but they can become brittle if not modified[21].	Moderate- glass transition ~75°C (similar to PETG), can crystallize on slow cooling to improve the heat resistance.	Very Low cost; the filament raw material can be supplied from waste feedstock, depending on the processing [24].	High – it's a recyclable material. It can be recycled further through multiple processing cycles, which may degrade its quality[24].	Printability depends on preparation. Must be dry, tends to be brittle, and may shrink if not modified. Additives significantly improve print quality [25], [26].

Note: Tensile strength values are representative of FDM-printed parts. Thermal stability qualitatively indicates the service temperature range. Cost is relative; actual price can vary. Recyclability refers to the ability to reuse or reprocess a material. Print quality summarizes the ease of achieving a good print, including warping, adhesion, and other factors.

III. Recycled Pet (RPET) Filament For 3D Printing

Recycled PET (rPET) means 3D printing filament made from recycled polyethylene terephthalate. This is used to make beverage bottles and food packaging. Using rPET as a filament can reduce plastic waste and material costs. There are two methods for producing rPET filament.

A. Mechanical Recycling of PET

Mechanical recycling is a secondary recycling method that engages with reprocessing waste PET plastic through melting and extrusion. Post-consumer PET bottles are collected, sorted, cleaned of contaminants, and shredded into flakes. The flakes or pellets are then extruded into filament using a filament extruder. This process is basically a physical re-extraction and retains the polymer's chemical structure. Mechanical recycling is an economical and straightforward process, but it is limited. Polymer's molecular weight can be decreased through a thermal cycling process so that several recycling loops can decrease PET's mechanical properties. For example, recycled PLA shows a decline in tensile strength after multiple extrusion processes. Likewise, PET should not be reheated excessively, as this can lead to significant loss. Impurities or mixed plastic waste pose challenges, including issues with raw material quality and stability, which are critical factors. Given these challenges, mechanical recycling is the primary method for producing rPET filament [24, 27].

Processing example: There are a few steps to follow. First, granulate the PET bottles into flakes. Then remove moisture by drying the flakes. Once dried, feed them into the extruder to form 1.75 mm (or 2.85 mm) filament strands, which are then cooled with air under constant tension. When waste is used to manufacture clean industrial PET scrap, the process is called closed-loop recycling. This process can yield properties close to those of virgin PET with filament. Also, sometimes recycled PET can achieve tensile strength and hardness up to 100% of those of virgin PET when properly processed [23]. However, there are still some remaining challenges, such as maintaining a consistent filament diameter and preventing damage. Now, distributed recycling models and low-cost extruders are being developed to make rPET filament production [26].

B. Chemical Recycling of PET

Chemical recycling is a method that uses chemical reactions to break the polymer chains. It breaks down PET into monomers or shorter oligomers. There are several chemical methods, including glycolysis, hydrolysis, and methanolysis. PET can be converted into monomers such as BHET (bis(2-hydroxyethyl) ether), TPA (terephthalic acid), and EG (ethylene glycol). These monomers can be reformed to produce virgin-equivalent PET and PETG filaments. There are multiple advantages to using chemical recycling, such as better handling of contaminated, mixed plastics than mechanical recycling and the production of high-quality polymers. High cost and greater complexity compared to mechanical recycling, Energy Intensity due to high temperature and pressure, and the release of volatile compounds (carbon, sulfur, etc.) into the environment are challenges to face when using chemical recycling. Managing and ensuring the process is environmentally essential. Chemical recycling of PET is producing high-quality rPET for applications where mechanical recycling might fall short in performance. For example, chemical upcycling can convert PET into PETG, which is more amenable to FDM. Both recycling methods advance circular-economy goals by reusing PET. But mechanical recycling is mainly used to make PTM due to its lower cost and simpler technology. Sometimes, both approaches can be used: mechanical recycling as much as possible and the chemical route to deal with solid PET[24].

IV. CHALLENGES IN USING RPET

Using recycled PET in the 3D printing industry presents challenges that must be addressed to maintain print quality, part performance, and bonding between each recycled particle, matching the performance of virgin 3D printing materials.

A. Printability and Processing Issues

Recycled PET filaments are becoming popular in the 3D printing industry because they support improving sustainability and the economy. But it has some drawbacks compared to standard materials like PLA or ABS. One of the main challenges is moisture sensitivity [24]. rPET absorbs water from the air easily, and if it is not dried correctly before printing, this moisture can cause chemical breakdown in the hot end. Therefore, bubbling, decreased viscosity, weak layers, and overall poor print strength can occur [24]. The rPET also tends to crystallize more than PETG; therefore, maintaining a proper dry environment during printing is very important [28]. So, if cooling is not controlled or printing is too slow, crystallization can occur. Parts can warp or distort during printing.

Another practical issue is filament quality. Recycled pellets can produce filaments with uneven diameters or oval shapes, leading to inconsistent extrusion or nozzle jams. Compared with commercial filaments, dry rPET often shows greater variation, making the printing process less reliable. In addition, fumes or volatile particles may be released if the recycled material contains contaminants or degraded compounds, so ventilation and safety should be prioritized. Overall, rPET is a sustainable material, but good drying, stable extrusion conditions, and careful handling are needed to achieve high-quality prints [28].

B. Polymer Degradation and Stability

Recycled PET always has lower mechanical performance than virgin materials, because the polymer chains become shorter during use and processing. Heat, sunlight, and environmental exposure can break down the material before it is even recycled, and each melt cycle during recycling further reduces chain length. Shorter polymer chains result in reduced tensile strength and impact resistance, so parts printed from rPET can sometimes be brittle or break more easily [26]. Another issue is thermal stability. rPET starts to degrade at slightly lower temperatures, and yellowing during printing can occur due to thermal oxidation of the polymers [27]. Because of these degradation effects, additives such as chain extenders and stabilizers are sometimes added during filament production to increase molecular weight and improve stability. These additives can help restore strength and toughness to levels comparable to those of virgin PET. Without such measures, researchers recommend limiting the number of recycling cycles to prevent excessive property loss [24]. Overall, maintaining polymer quality is a key challenge with rPET, and degraded rPET generally produces weaker parts if used on its own.

C. Mechanical Strength and Performance Deficiencies

Even when recycled PET prints correctly, the mechanical properties of the final part can be lower than those of virgin 3D printing materials. Studies have reported that printed rPET can exhibit reduced strength relative to expected PET values due to weaker layer bonding and less-optimized printing parameters. [29]. Poor layer binding has been described as “diminished adhesive properties,” which contributes to brittleness and anisotropy in printed parts (especially in the Z-direction) [27]. Impact resistance is also a concern, since unnotched impact tests often show brittle failure unless the material is toughened. In addition, Mechanical strength can be reduced during printing if moisture causes slight foaming or if shrinkage leaves small internal voids [25].

As a result, printed rPET can sometimes reach only around 40–60% of the flexural strength of an equivalent injection-molded PET component [25]. To fill these mechanical limitations, researchers have blended rPET with modifiers such as elastomers, impact additives, or small fractions of virgin PET to improve ductility and inter-layer cohesion [25]. For example, a reactive elastomer toughening agent (EBA-GMA) can increase the impact strength by 2.5× (unnotched) and 9× (notched), enabling rPET parts with more balanced mechanical properties comparable to ABS[25]. Overall, rPET can perform well, but achieving good mechanical properties usually requires material modification and careful, precise tuning.

Recycled PET is a sustainable 3D printing material, but it presents several challenges. It absorbs moisture, which can cause bubbling, weak layers, and poor print quality. rPET also crystallizes faster, warps when cooled slowly, and has an uneven filament diameter, leading to jams. Its polymer chains are shorter due to prior use and recycling, making printed parts brittle, weaker, and prone to yellowing. Layer adhesion and impact strength are lower, and internal voids can form, further reducing strength. Additives and careful tuning are needed to improve toughness and reliability

V. COMPARATIVE ANALYSIS OF RECYCLING PET VS. STRANDED MATERIALS

Recycled PET (rPET) filament falls in the mid-range performance category compared to other filaments. It surpasses Nylon (~20 MPa) in tensile strength, with a range of 30-40 MPa, comparable to those of filaments like ABS and PETG. However, it remains below PLA (~55 MPa) [21]. While appropriate processing of PLA can improve the printability of rPET, unmodified rPET retains its brittle behavior due to its low elongation at break [21]. So, PLA is performing with its high tensile strength as it's printed (~50 MPa), when compared with other materials [21]. But the problem with PLA is that it is brittle and not harsh. rPET (and PETG/ABS) are tougher, but they perform slightly lower in their ultimate strength, and they represent the ability to absorb energy before fracture. In terms of thermal stability, PLA performs worse than PET, as it dissolves at 60 °C [22]. But rPET is slightly lower than ABS. Further, rPET behaves under heat almost the same as normal PET, softening around 75°C. Functionally, rPET can withstand a moderate warm environment, unlike PLA, which cannot. However, for very high temperatures or better load bearing at elevated temperatures, ABS and Nylon are more suitable than both PLA and rPET [22].

Considering the cost, rPET has considerable potential to be the cheapest filament, as it uses waste feedstock. However, in the current market, commercial rPET/PETG filaments are priced slightly comparable to PLA and ABS, as the high cost is allocated to processing, cleaning, sorting, quality control, and branding to produce the final rPET output. The main advantage is the low cost of waste plastic as a raw material, which is cheaper than other raw materials, such as PLA derived from crops. If local recycling is widely implemented, rPET filament could significantly reduce the cost barrier to 3D printing in some regions [26]. All the standard 3D printing filament materials (PLA, ABS, PETG, Nylon) are produced on a larger scale, so they generally have lower production costs[20]. But nylon costs more because of its complex chemistry. Overall, rPET offers clear advantages in raw material costs and sustainability, though processing and quality assurance are also significant at the production level.

rPET is considered excellent for recyclability because it is produced from recycled plastics and, most importantly, can be recycled multiple times. Although PLA is a naturally degradable material, it is commonly considered unhandleable by conventional recycling systems because it degrades only under specific industrial conditions. Mixing PLA with PET can affect PLA's recyclability. Further, ABS, PETG, and nylon can technically be recycled, but the problem is that they are produced using virgin polymers, whereas the use of rPET directly addresses plastic waste reduction. It also provides a strong foundation for the circular economy framework, as rPET directly supports a closed-loop recycling process, turning waste PET bottles into functional 3D-printed products. Most importantly, life cycle assessment studies show a significant reduction in carbon emissions when recycled polymers are used instead of virgin materials[27]. However, recycling can weaken plastic properties over time, so to maintain strength and printing quality, additives or virgin plastics are used to preserve the properties of the rPET filaments. This opens the door to a hybrid material that is effective and sustainable for many 3D printing applications [26].

When comparing printing quality and user experience, PLA ranks higher because of its ease of printing and few issues. At the same time, rPET requires more care, similar to PETG or even closer to Nylon, due to the need to dry the filament and maintain a controlled environment. PETG is also considered a good balancing material because many rPET filaments on the market are actually a mix of PETG and recycled PET, since it is easier to print than unmodified PET. Pure recycled PET, if not modified with PETG, tends to wrap or shrink during printing due to its higher crystallinity. Considering all factors, such as chemical and mechanical properties and printability, rPET is typically rated as a moderate material because it does not offer the plug-and-play ease of PLA. However, with the proper setup that facilitates controlled drying, enclosure, and an adhesive bed, rPET can also be printed successfully using standard FDM machines. The accessibility of rPET has increased significantly with social trends such as community-driven recycling initiatives, recycling bots, and social pressure to recycle, but maintaining consistent filament quality remains a critical challenge [26].

As shown in the matrix comparison (Table 01), rPET performs competitively across many categories. It is also a filament with mid-grade mechanical strength. Further, it performs better in thermal environments than PLA and, importantly, addresses environmental problems sustainably while offering cost advantages. Brittleness and printing difficulties are among its weaknesses, but with further advancements in polymer science, these problems are being addressed. According to current studies that have tested and modified rPET, it can be improved in impact resistance, and behavior analysis has demonstrated behavior similar to ABS, indicating that rPET filaments can replace some ABS applications [25]. These findings support future predictions of rPET's use as a high-performance filament in FDM applications.

VI. CONCLUSION

Recycled PET (rPET) filament is an environmentally friendly option for the 3D printing industry. It uses waste PET bottles to print small objects in the 3D printing industry. This paper explained the fundamental properties of common 3D printing materials, such as virgin PLA, ABS, PETG, and Nylon, and compared rPET with them. Pet filament is made by either mechanically re-melting and extruding PET or by chemically breaking it down and rebuilding it. It can reduce environmental pollution while providing mechanical strength comparable to that of regular plastic filaments. However, there are some challenges. rPET can absorb moisture into small particles, which can degrade the material and cause problems during printing. To solve these problems, researchers heat the rPET, remove moisture, add chain extender additives to restore polymer strength, and add elastomer additives to improve toughness. These methods have helped enhance print quality and reliability [25][27]. Research shows that recycled materials are approaching the performance of virgin (new) plastics. Some studies show that PETG and PET can be recycled up to 6 times with only minor quality losses [27]. In some cases, improved recycled blends can even outperform the original material [27].

Using rPET can reduce material costs and lower carbon emissions for both hobbyists and industries [27]. With improvements in recycling technology, such as local or distributed recycling systems [27], with advances in materials science, recycled filaments are expected to become more common. In the future, standard FDM 3D printers may regularly use recycled filaments without losing print quality. To achieve this, we need better recycling processes, improved filament formulations, quality standards, and proper guidance for users on how to print successfully with rPET [27].

In conclusion, rPET has developed from an experimental idea into a practical 3D printing material. Its mechanical properties are now close to traditional filaments, and it offers environmental sustainability. Compared with PLA, ABS, PETG, and Nylon, each material has its own strengths, such as PLA's ease of printing and biodegradability, and ABS and PETG's good balance of strength and heat resistance. Nylon offers high-performance applications. While rPET provides environmentally friendly printing material. With continued innovation, recycled PET and other recycled plastics could become an essential part of the FDM 3D printing industry. This would allow manufacturers to create valuable products from waste plastic while maintaining quality and performance. Combining 3D printing with recycling has strong potential for both manufacturing and environmental sustainability [24].

REFERENCES

[1] R. Geyer, J. R. Jambeck, and K. L. Law, "Production, use, and fate of all plastics ever made," Sci. Adv., vol. 3, no. 7, Jul. 2017, doi: 10.1126/sciadv. 1700782.

[2] J. R. Jambeck et al., "Plastic waste inputs from land into the ocean," Science (1979), vol. 347, no. 6223, pp. 768–771, Feb. 2015, doi: 10.1126/science. 1260352.

[3] K. Ragaert, L. Delva, and K. Van Geem, "Mechanical and chemical recycling of solid plastic waste," Waste Management, vol. 69, pp. 24–58, Nov. 2017, doi: 10.1016/j.wasman.2017.07.044.

[4] A. Rahimi and J. M. García, "Chemical recycling of waste plastics for new materials production," Nat. Rev. Chem., vol. 1, no. 6, p. 0046, Jun. 2017, doi: 10.1038/s41570-017-0046.

[5] B. Brenken, E. Barocio, A. Favaloro, V. Kunc, and R. B. Pipes, "Fused filament fabrication of fiber-reinforced polymers: A review," Addit. Manuf.,vol. 21, pp. 1–16, May 2018, doi: 10.1016/j.addma.2018.01.002.

[6] F. A. Cruz Sanchez, H. Boudaoud, M. Camargo, and J. M. Pearce, "Plastic recycling in additive manufacturing: A systematic literature review and opportunities for the circular economy," J. Clean. Prod., vol. 264, p. 121602, Aug. 2020, doi: 10.1016/j.jclepro.2020.121602.

[7] Y. Tao et al., "A review on voids of 3D printed parts by fused filament fabrication," Journal of Materials Research and Technology, vol. 15, pp. 4860–4879, Nov. 2021, doi: 10.1016/j.jmrt.2021.10.108.

[8] D. Vaes and P. Van Puyvelde, "Semi-crystalline feedstock for filament-based 3D printing of polymers," Prog. Polym. Sci., vol. 118, p. 101411, Jul. 2021, doi: 10.1016/j.progpolymsci.2021.101411.

[9] P. Burgos Pintos, A. Sanz de León, and S. I. Molina, "Large format additive manufacturing of polyethylene terephthalate (PET) by material extrusion," Addit. Manuf., vol. 79, p. 103908, Jan. 2024, doi: 10.1016/j.addma.2023.103908.

[10] 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," Sci. Rep., vol. 13, no. 1, p. 16041, Sep. 2023, doi: 10.1038/s41598-023-41744-8.

[11] A. Katalagarianakis et al., "The effect of carbon fiber content on physico-mechanical properties of recycled poly(ethylene terephthalate) composites additively manufactured with fused filament fabrication," Addit. Manuf., vol. 60, p. 103246, Dec. 2022, doi: 10.1016/j.addma.2022.103246.

[12] N. E. Zander, M. Gillan, and R. H. Lambeth, "Recycled polyethylene terephthalate as a new FFF feedstock material," Addit. Manuf., vol. 21, pp. 174–182, May 2018, doi: 10.1016/j.addma.2018.03.007.

[13] B. Van de Voorde et al., "Effect of extrusion and fused filament fabrication processing parameters of recycled poly(ethylene terephthalate) on the crystallinity and mechanical properties," Addit. Manuf., vol. 50, p. 102518, Feb. 2022, doi: 10.1016/j.addma.2021.102518.

[14] N. E. Zander and Z. R. Boelter, "Rubber toughened recycled polyethylene terephthalate for material extrusion additive manufacturing," Polym. Int., vol. 70, no. 6, pp. 742–748, Jun. 2021, doi: 10.1002/pi. 6079.

[15] C. Suescun Gonzalez et al., "Compatibilizer effectiveness for the reuse of mixed post-consumer solid waste plastic towards Distributed recycling additive manufacturing," Materials Today Sustainability, vol. 34, p. 101323, Jun. 2026, doi: 10.1016/j.mtsust.2026.101323.

[16] R. Ben Amor, S. Souissi, A. Elloumi, and H. Bentaher, "Parametric optimization and modeling of fused filament fabrication (FFF) using recycled PET from water bottles: a comparative study with virgin PET," International Journal on Interactive Design and Manufacturing (IJIDeM), Oct. 2025, doi: 10.1007/s12008-025-02418-z.

[17] V. Mishra, C. K. Ror, S. Negi, and D. Veeman, "Recycling PET Waste into Functional 3D Printing Material: Effect of Printing Temperature on Physio-mechanical Properties of PET Parts," J. Mater. Eng. Perform., vol. 34, no. 22, pp. 26778–26790, Nov. 2025, doi: 10.1007/s11665-025-11184-8.

[18] H. A. Little, N. G. Tanikella, M. J. Reich, M. J. Fiedler, S. L. Snabes, and J. M. Pearce, "Towards Distributed Recycling with Additive Manufacturing of PET Flake Feedstocks," Materials, vol. 13, no. 19, p. 4273, Sep. 2020, doi: 10.3390/ma13194273.

[19] S. Sabeeh, S. Algburi, Q. Alkhawlani, F. I. Jabbar, M. El-Meligy, and H. A. Mahmoud, "Upcycled PET vitrimer filaments via reactive extrusion for high-strength heat-resistant and repairable FDM parts," Polym. Test., vol.153,p.109027,Dec. 2025, doi:10.1016/j.polymertesting.2025.109027.

[20] A. Dey, I. N. R. Eagle, and N. Yodo, "A review on filament materials for fused filament fabrication," Sep. 01, 2021, MDPI AG. doi: 10.3390/jmmp5030069.

[21] R. F. Martins et al., "Mechanical Properties of Additively Manufactured Polymeric Materials—PLA and PETG—For Biomechanical Applications," Polymers (Basel), vol. 16, no. 13, Jul. 2024, doi: 10.3390/polym16131868.

[22] S. Prajapati, J. K. Sharma, S. Kumar, S. Pandey, and M. K. Pandey, "A review on comparison of physical and mechanical properties of PLA, ABS, TPU, and PETG manufactured engineering components by using fused deposition modelling," Mater. Today Proc., May 2024, doi: 10.1016/j.matpr.2024.05.018.

[23] R. Djonyabe Habiba, C. Malça, and R. Branco, "Exploring the Potential of Recycled Polymers for 3D Printing Applications: A Review," Jun. 01, 2024, Multidisciplinary Digital Publishing Institute (MDPI). doi: 10.3390/ma17122915.

[24] I. Ibrahim, A. G. Ashour, W. Zeiada, N. Salem, and M. Abdallah, "A Systematic Review on the Technical Performance and Sustainability of 3D Printing Filaments Using Recycled Plastic," Sep. 01, 2024, Multidisciplinary Digital Publishing Institute (MDPI). doi: 10.3390/su16188247.

[25] L. Toth, E. Slezák, K. Bocz, and F. Ronkay, "Progress in 3D printing of recycled PET," Materials Today Sustainability, vol. 26, p. 100757, Jun. 2024, doi: 10.1016/J.MTSUST.2024.100757.

[26] M. Oyinlola, S. A. Okoya, T. Whitehead, M. Evans, and A. S. Lowe, "The potential of converting plastic waste to 3D printed products in Sub-Saharan Africa," Resources, Conservation and Recycling Advances, vol. 17, May 2023, doi: 10.1016/j.rcradv.2023.200129.

[27] A. Kassab, D. Al Nabhani, P. Mohanty, C. Pannier, and G. Y. Ayoub, "Advancing Plastic Recycling: Challenges and Opportunities in the Integration of 3D Printing and Distributed Recycling for a Circular Economy," Oct. 01, 2023, Multidisciplinary Digital Publishing Institute (MDPI). doi: 10.3390/polym15193881.

[28] A. Yousaf, A. Al Rashid, R. Polat, and M. Koç, "Potential and challenges of recycled polymer plastics and natural waste materials for additive manufacturing," Sep. 01, 2024, Elsevier B.V. doi: 10.1016/j.susmat.2024.e01103.

[29] E. S. Pepek and J. C. Hanan, "3D Printing with Recycled PET as a Sustainable Thermoplastic Alternative Comparing Printed and Filament Material Properties," Polymer-Plastics Technology and Materials, vol. 64, no. 14, pp. 2238–2252, Sep. 2025, doi: 10.1080/25740881.2025.2501164.