DOI: 10.54254/2755-2721/2025.GL27943

Recycling and Functionalization of Post-Consumer Recycled (PCR) Plastics in the Packaging Industry

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Abstract. With the deepening of the concept of sustainable development, recycled plastics play an increasingly important role in environmental protection and resource utilization. However, in the past, the recycling of recycled materials has faced many challenges in practical applications, which has made it difficult to increase the utilization rate of recycled plastics. Therefore, the aim of this paper is to investigate the challenges in the application of recycled materials for packaging suitability. In order to solve the above problems, this study analyzes the advantages and disadvantages of intelligent sorting technology, compares the differences between physical and chemical sorting, and explores the performance defects and modification methods of PCR plastics by comparing different literatures, summarizing case studies and experimental data. It is found that PCR plastic needs technological innovation to break through the bottleneck of sorting and modification, and low-cost and high-precision sorting technology, high-performance modifier and high-efficiency catalysts should be researched and developed in the future, so as to promote its shift from "low-quality recycling" to "high-quality closed-loop", and to provide support for the scale application of sustainable packaging and recycled materials to provide support for sustainable packaging and large-scale application of recycled materials.

Keywords: recycled materials, intelligent sorting, PCR plastic modification

1. Introduction

The traditional linear economic model of "extraction-production-disposal" is facing serious challenges against the background of global resource shortage and increasing environmental pollution. The annual global production of primary plastic products has increased from 234 million tons in 2000 to 460 million tons in 2019, and the global production of waste plastics has increased from 156 million tons in 2000 to 353 million tons in 2019, and the global production of plastic products will exceed 400 million tons in 2023, of which only 9% will be materialized for recycling, 19% will be incinerated, about 50% will be landfilled, and the remaining 22% will be disposed of. The remaining 22%is disposed of in unmanaged landfills, burned in the open or leaked into the environment [1]. These waste plastics, which are difficult to degrade, not only cause waste of resources, but also lead to ecological problems such as soil pollution and greenhouse gas emissions. In order to promote the recycling of resources and build a low-carbon sustainable development economic system, recycled materials have emerged. Because they play a key role in relying on

DOI: 10.54254/2755-2721/2025.GL27943

primary resources and reducing waste emissions, they have become an important support for the development of circular economy. In particular, post-consumer recycled materials have become the focus of research in the field of recycled materials due to their wide sources, broad application prospects and reprocessing difficulties.

In recent years, although PCR materials have made some progress in recycling process, intelligent sorting, and performance modification, they still face challenges such as poor performance stability, non-uniform technology path, poor supply chain, and difficulty in material sorting [2], especially in the lack of systematic technical support in the key aspects such as the impurity separation precision, the maintenance of mechanical properties of regenerated materials, and the control of recycling costs. Therefore, this paper will focus on PCR plastics, a typical post-consumer recycled material, and systematically sort out the core links involved in the recycling process, including waste sorting technology, physicochemical recycling pathway, material performance degradation mechanism, and enhancement of modification strategies, and discuss the feasibility of its actual industrialization process and the bottleneck technologies faced in combination with practical application scenarios. By comparing different literatures, summarizing typical cases, and comparing relevant experimental data, we intend to build a technical link between raw material process and skill application, so as to provide theoretical support and application reference for the efficient recycling and functional reuse of post-consumer recycled materials in the future.

2. Overview of recycled materials and PCR plastics

Recycled materials refer to all kinds of waste items, construction materials and industrial wastes generated in the production and consumption chain, and are used again in the production process through recycling, processing and treatment, including recycled paper, recycled metals, recycled plastics, recycled aggregates, recycled glass and so on [3]. The use of recycled materials directly reflects the level of waste recycling, which is crucial in reducing the dependence on natural resources, reducing the intensity and total amount of carbon emissions, promoting the recycling of resources, guaranteeing the security of national resources, etc., and contributing to the realization of sustainable development [4]. From the point of view of sources and processing methods, recycled materials can be categorized into post-consumer recycled materials, industrial recycled materials, and construction recycled materials. This paper focuses on post-consumer recycled materials, which are converted into materials through the recycling system into processing after being used and discarded by consumers. Compared with industrial recycled materials and construction recycled materials, their raw materials come from a wide range of sources, directly from the end-consumption scenarios, such as homes, shopping malls, etc., and their use covers a wide range.

Post-consumer recycled materials are mainly polymer materials and fiber materials, which are typically represented by PCR plastics, recycled pulp and recycled PET. Among them, recycled pulp has a more complex composition, and special attention needs to be paid to its quality control in order to avoid negative impacts on paper mesh felts and prolong their service life [5]. However, the treatment process of recycled pulp, such as pulping, can have an impact on the strength and durability properties of paper. Recycling and utilization of waste paper resources has now become an important industry in China, and the production of recycled pulp and its proportion of total pulp consumption have increased significantly, promoting the development of a circular economy[6]. Recycled PET (polyethylene terephthalate) is a plastic that is re-made by recycling discarded PET plastic bottles and other products through the process of crushing, washing, melting, etc., which has excellent fiber properties and has the characteristics of green and renewable. Recycled PET has a

DOI: 10.54254/2755-2721/2025.GL27943

lower carbon footprint than virgin PET and can effectively reduce the problem of "white pollution" [7]. The application areas of recycled PET include textiles, chemical fibers and packaging materials. Among them, recycled PET fibers are widely used in spinning raw materials, nonwoven materials, technical textiles, and functional fibers [8]. However, the consistency of the properties of recycled PET is poor, especially in the mechanical method of recycling process, due to the pelletizing pyrolysis will reduce the viscosity and produce oligomers and oxidation reaction, resulting in the degradation of properties, and generally can only be downgraded to use. At present, the recycled PET industry is facing rapid development and transformation, the recycling utilization rate of recycled PET is increasing, the scale of the international and domestic PET recycling market is continuously expanding, the market competition is intense, the technological advancement is rapid, and a variety of recycling technologies, including mechanical and chemical methods, are being widely used. Nevertheless, there are still some problems in the recycled PET industry, such as the uneven construction of recycling networks and the high cost of recycling technologies. In addition, the recycling plants of recycled PET are characterized by fierce homogeneous competition and overcapacity, and the sales channels are relatively narrow. However, with the support of national policies and technological advances, the recycled PET industry is expected to achieve further development in scale, intelligence and diversification [9].

PCR plastics, Post-Consumer Recycled Plastic (PCR), are sustainable plastic raw materials formed by reconstructing waste plastics through closed-loop recycling technology. The application of this type of material is valued for its contribution to waste minimization, environmental protection, and carbon reduction. Specifically, the production process of PCR plastics usually includes the recycling of post-consumer end-use plastic products (e.g., daily chemical packaging, electronic housings, etc.), which are re-pelletized through sorting, melt blending, and other processes [10].The core features of PCR plastics are reflected in the significant environmental protection value, and the energy consumption of the production process is significantly reduced compared to virgin plastics, such as PCR, PET, can be reduced by about 70%, and the carbon emissions are reduced by At the same time, it can directly digest the plastic waste at the consumption end, and each recycled ton can reduce the amount of landfill by about 3.3 tons, which can effectively alleviate the problems of "white pollution" and micro-plastics, and provide a strong support for the "dual-carbon" goal and waste reduction actions. In terms of performance, the mechanical properties and chemical stability of PCR plastics processed by standardized technology are close to those of virgin plastics, which can meet the needs of most non-high-end scenarios. For example, PCR can be used to make detergent bottles, garbage cans and other daily necessities, but due to the impact of mixed raw materials and aging, the purity, color and weather resistance of some products may be slightly inferior, and there will be a "degradation cycle" after multiple regenerations. "degradation cycle", usually need to be blended with virgin plastic to ensure quality.

In specific applications, PCR plastics are widely used in a number of fields due to their sustainability, such as automotive manufacturing, consumer electronics, packaging industry, household appliances, and lighting products. Due to its lightweight, heat-resistant and aesthetically pleasing characteristics, PCR plastics are particularly suitable for interior and exterior parts of automobiles. The intelligent fine sorting and high-end pelletizing digital zero-carbon plant project for PCR plastics constructed by Shanghai Ossel Material Technology Co., Ltd. will promote closed-loop recycling of automotive plastics and help the automotive industry crack the challenges of carbon tariffs and green trade barriers through localized closed-loop projects, aiming to provide closed-loop, high-value solutions for the automotive industry and promote the development of a recycling economy [11]. Dow has developed and commercialized a new PCR-formulated resin that

DOI: 10.54254/2755-2721/2025.GL27943

contains 40% post-consumer recycled material, which can be used 100% in the intermediate layer of heat shrink film, resulting in 13% to 24% recycled material content in the overall shrink film structure, and creating a film with properties similar to those of virgin resin. The new PCR resin developed by Dow not only provides brand owners and consumers with a guarantee of safe product transportation, but also reduces waste plastics in the environment, realizing both economic and environmental benefits [12].PCR plastics, with its environmental friendliness, energy efficiency, and low carbon footprint, have demonstrated great potential in a variety of fields, providing a great opportunity to drive the industry toward greener, more environmentally friendly development of the industry in a greener and more environmentally friendly direction and the realization of sustainable development goals.

3. Key technologies of PCR recycling

3.1. Intelligent sorting technology for waste plastics

The recycling of waste plastics is mainly divided into physical and chemical methods, both physical and chemical recycling need to go through the treatment of removing impurities, cleaning, crushing, sorting, etc. Among them, the sorting of waste plastics is relatively complex and difficult, and it is also the core step of the waste plastics pre-treatment technology. The traditional sorting method is mainly manual sorting, which not only requires the sorting personnel to have rich experience, but also has relatively low sorting efficiency and high labor cost. In order to solve these problems, intelligent sorting technology came into being.

Intelligent sorting technology for waste plastics is a key step in realizing the efficient recycling of waste plastics, which not only ensures the stable operation of the subsequent process, but also improves the stability of the product. At present, the more widely studied mainly include density sorting, optical sorting, electric sorting, solvent sorting and so on. Density sorting is based on the density of different types of plastic differences in classification methods, the sorting effect of the technology by the plastic particle size, shape and other factors have a greater impact. At present, the more widely used density sorting technology is mainly floating and sinking sorting and wind sorting [13]. Floatation-sinking sorting is mainly utilized to sort different kinds of plastics in the same solvent with different buoyancy. This method has a good separation effect on different types of plastics with large density differences, but it is relatively difficult to separate plastics with similar densities, and it is difficult to realize the precise separation of mixed waste plastics. And this method is greatly affected by the degree of cleanliness of plastics, and waste water will be generated in the separation process. Wind sorting is a method of sorting waste plastics according to the different particles in the air flow due to the shape, particle size, density and other differences in the size of the wind and drift distance. This method can not only realize the separation of plastics with large differences in density, but also better remove the dense metal or stone sand in plastics. However, due to the influence of factors such as the difference in the crushing size of mixed plastics or the density change caused by additives, the precision of wind sorting is low and the error is large. Wind sorting often needs to be combined with other sorting techniques in order to improve the sorting precision and realize the efficient separation of different plastics. Optical sorting mainly utilizes different types of plastics with different spectral properties for sorting. At present, optical sorting mainly includes near-infrared spectroscopic sorting (NIR), mid-infrared spectroscopic sorting (MIR), X-ray fluorescence sorting (XRF sorting), Raman spectroscopic sorting, laser-induced breakdown spectroscopic sorting (LIBS sorting), hyperspectral imaging technology sorting (HSI sorting), etc., and it is one of the main research directions of plastics sorting technology [14]. Among them,

DOI: 10.54254/2755-2721/2025.GL27943

infrared spectral sorting is the most widely used and scaled optical sorting method among the current waste plastics sorting methods. Infrared spectral sorting technology is a nondestructive detection method based on the vibration and rotational energy level jumps of material molecules [15], which has the advantages of high sorting efficiency, high accuracy, and a wide range of applicability, and it is one of the key technologies for realizing the high-value utilization of waste plastics. In 2018, Li et al. reported an automated on-line identification and sorting of ABS, PS, and PP plastics, which was achieved by an independently designed software to dynamically analyze the near-infrared spectra of plastics in the range of 1050-1350 nm online, together with an air blow-out system, to achieve efficient separation of ABS, PS, and PP mixed plastics, which are difficult to separate, with a separation accuracy of up to 99% [16]. Subsequently, Zhu et al. developed a solid waste sorting and identification system based on near-infrared spectral detection and analysis, combined with PCA-SVM (Principal Component Analysis-Support Vector Machine) classification model, to achieve efficient identification of PP, PS, PE, polymethylmethacrylate (PMMA), ABS, and PET plastics, with an accuracy of identification up to 97.5% [17]).In 2021, Duan et al. proposed a test and analysis method combining PCA, SVM, Linear Discriminant (LDA) and Partial Least Squares Discriminant Analysis (PLS-DA) using near-infrared spectroscopy to realize the identification of seven types of plastics, including PET, high-density polyethylene (HDPE), PVC, low-density polyethylene (LDPE), PP, PS, and PC. common household plastics were categorized [18]. In addition, Wang Lei found through experimental comparison and verification that, in terms of sorting accuracy, infrared spectral sorting technology reached 97.8%, which is 9.2 percentage points higher than the 88.6% of manual sorting, in terms of sorting speed, the processing capacity of infrared spectral sorting technology reached 3600 pcs/hour, which is 6 times higher than that of manual sorting speed, and in terms of resource recovery, infrared spectral sorting technology reached 95.2%, which is 7.4 times higher than that of manual sorting by 7.4 percentage points [19]. This indicates that IR spectral sorting technology has significant cost advantages and economic benefits in long-term operation. Electrical sorting is a method to separate different materials based on different electrical properties, including electrostatic sorting and friction charged sorting. When materials are rubbed against each other, the two plastics generate opposite charges, which separate the different plastics according to different trajectories in the electrosorting equipment, and can also be used to remove ferromagnetic metal impurities mixed with them [20]. However, the environmental humidity has a significant effect on the separation efficiency during the electrosorting process. In order to solve this problem, significant progress has been made in the application of magnetic technology in plastic sorting. By immersing plastic particles in paramagnetic media and placing them in a magnetically levitated structure, efficient separation of a wide range of plastics has been achieved, and the method has a wide adaptability to the size of plastic particles without the need for precise control, while the paramagnetic solution is capable of recycling, thus demonstrating its excellent economic savings and environmental protection advantages. Solvent sorting is an innovative waste plastics sorting technology based on the difference in solubility of different plastics in the same solvent. Following the principles of similar solubility and similar solubility parameters, it can effectively separate a variety of plastics (including packaging materials for food, pharmaceuticals, etc.), and the properties of the recovered materials are basically the same as the original materials. In recent years, the solvent sorting method has made progress in separating a variety of plastics such as LDPE, HDPE and other composite films, aluminum foils and plastics in drug packaging, etc. It has also been applied to the separation of aluminum foils and plastics in PE, EVOH, PET composite films as well as in the packaging of discarded medicines, which has further broadened the scope of its application [21]. In addition, the solvent sorting method has the

DOI: 10.54254/2755-2721/2025.GL27943

advantages of good product adaptability, high sorting quality, and simple operation, which makes its application promising. However, the cost of solvents continues to increase, and the problem of energy consumption restricts its large-scale application. In the future, we need to focus on exploring low-cost solvent substitutes, optimizing the process to reduce energy consumption, and strengthening the research on solvent recovery and recycling technology, so as to promote it to play a greater role in the recycling of waste plastics and help the circular economy.

3.2. Comparison of physical and chemical sorting

In waste plastics recycling, physical sorting and chemical sorting are two types of core technologies, and there are significant differences between the two in terms of principle, performance, and applicable scenarios.

Physical sorting is to realize recycling in the state of not changing the chemical composition of plastics through mechanical recycling and modification [22]. Specifically, it includes sorting, cleaning, and melting and reprocessing molding of waste plastics to produce new plastic products. It is based on the differences in physical properties of plastics (such as density, electrical conductivity, optical properties, hardness, etc.) to achieve separation, for example, by density flotation method to separate PE and PET with different densities, near-infrared spectroscopy to identify the material of plastics, electrostatic sorting to use the differences in the electrically charged properties of different plastics to separate PP and PS, and so on. The advantages of physical sorting are simple operation, low cost, no need for complex chemical reagents, environmentally friendly, suitable for processing mixed plastics with relatively single composition and light pollution (such as clean beverage bottles and packaging films), and large-scale continuous sorting can be realized, and it is the mainstream technology in the pre-treatment stage of PCR plastics recycling (accounting for more than 80% of the total). However, the limitations are obvious, the sorting precision is low for complex mixed systems (such as multi-layer composite film, heavily contaminated plastics), susceptible to color and impurity interference, and difficult to separate plastics with close physical properties (such as HDPE and PP) [23].

At present, physical sorting technology has been developed and matured, and its industrial chain shows a stable trend. This technology has significant advantages such as easy operation, low processing costs and no new pollution in the regeneration process. However, its limitations should not be ignored: as the number of times of recycling increases, the performance of the recycled products will gradually decay, resulting in most of the recycled materials can only be used in the field of secondary products. At the same time, the advantages of this technology at the economic cycle level have not yet been fully realized, so the improvement of physical recycling technology still needs to be deepened. In particular, the hydrolysis phenomenon caused by the pre-treatment and sorting part of the recycling process, as well as the pyrolysis problem in the pelletizing stage, need to be effectively solved. In addition, it is necessary to start from the key links of sorting, softening, drying, extrusion, etc., to continuously optimize the recycling system, and to design differentiated physical recycling processes for different plastic categories, so as to enhance the utilization value of recycled materials.

Compared with traditional landfill, incineration and physical sorting, chemical sorting is a sustainable, environmentally friendly disposal method for waste plastics with considerable environmental and economic benefits. Its core advantage is the high purity of separation, and it can handle complex scenarios that are difficult to deal with in physical separation, such as multi-layer composite plastics (PE/EVOH/PET composite films), plastics containing contaminants, or structurally similar plastics (e.g., LDPE and HDPE). Chemical sorting mainly involves thermal

DOI: 10.54254/2755-2721/2025.GL27943

cracking and catalyzing. Thermal cracking of waste plastics is a process in which high temperatures provide the activation energy to stimulate the breakage of long polymer chains into shorter ones, and the products include high calorific value gases, short-chain hydrocarbons, cracking oils, and charcoal. Its disadvantages are easy coking and carbon accumulation, high viscosity, poor fluidity, secondary environmental pollution caused by the reaction process, and high pollutant emissions.Bai et al. conducted gasification decomposition of polypropylene using thermal cracking technology, and found that the gasification yield of PP had a significant increase with the continuous increase of the reaction temperature and the extension of the reaction time, and that the content of hydrogen molecules in the gaseous product would be reduced at 750°C and The hydrogen molecule content in the gaseous product peaks at 750°C and 60 min reaction temperature and time [24]. Jaafra et al. found that the gas yield increased with increasing temperature at a heating rate of 20°C/min in the cracking reaction of polyethylene (PE) as a feedstock [25]. It was found that the heating rate can directly affect the residence time of the reaction, thus affecting the amount of waste plastics processed and the composition and properties of the products. Catalytic sorting technology refers to the addition of catalysts in the pyrolysis process, the addition of catalysts can make the reaction activation energy and reaction temperature lower, and improve the reaction conversion rate. Different components of plastics are synthesized in different ways, resulting in different structures and properties, and thus different mechanisms when cracking waste plastics. There is a wide variety of catalysts used for catalytic cracking of waste plastics, and the more researched ones are zeolite molecular sieves and catalytic cracking (FCC) catalysts, in addition, metal oxides, clays, and activated carbons are also used for catalytic cracking of waste plastics [26]. Chemical recycling of waste plastics through cracking, depolymerization and other chemical reactions to convert waste plastics into monomers, fuels or chemicals, although it can break through the bottleneck of material property degradation in the physical recycling, but the current development still faces multiple limitations. At the technical level, the reaction process is easily affected by the complexity of the plastic composition, and the difference in the cracking temperature of different plastics may reduce the purity of the products. At the same time, some of the products of the process have a wide distribution, and require complex subsequent separation and purification steps, which increases the technical difficulty. In addition, chemical sorting is economically weak due to high solvent procurement, recovery and treatment costs, and may cause secondary pollution if the solvent recycling technology is not mature. Despite these limitations, the future prospects of chemical recovery are still worth looking forward to. The development of new catalysts (e.g., molecular sieve catalysts, metal-organic framework materials) is expected to improve the reaction selectivity and efficiency, and reduce the energy consumption and by-product generation; while the application of new processes, such as microwave-assisted cracking and supercritical fluid technology, can further optimize the reaction conditions and enhance the added value of the products [27].

Overall, chemical recycling methods have great potential compared to traditional methods that pollute the environment and physical methods that cannot efficiently upgrade recycled plastics. In the vigorous chemical recycling technology, the reaction efficiency and yield are very high, but the product selectivity still needs to be improved. In contrast, mild chemical recycling methods are just now taking off and face the biggest problem of low conversion efficiency. In the future, researchers will focus on efficiency, selectivity, conditions and other core elements to explore more energy-saving and environmentally friendly technologies and develop efficient catalysts, so as to continuously improve the chemical recycling of waste plastics.

DOI: 10.54254/2755-2721/2025.GL27943

4. PCR plastic modification and performance improvement

As an important renewable resource, PCR plastics are collected, sorted, cleaned and processed to make waste plastic products usable plastic raw materials again, which has a broad application prospect in the fields of automobile, electronics, home appliances, medical care, construction and so on. However, due to the multiple thermal oxidation, mechanical shear and impurity contamination of PCR plastics during recycling, PCR plastics usually suffer from molecular weight loss, mechanical property attenuation, poor processing stability, and high impurity content, which limits their application in high value-added fields. Therefore, improving the performance of PCR plastics through modification technology is the core means to promote its recycling and reduce the dependence on virgin plastics.

The performance defects of PCR plastics are mainly manifested in the following aspects: attenuation of mechanical properties, deterioration of thermal stability, fluctuation of processing fluidity, and decline in aging resistance.PCR plastics are processed through multiple melt processing, resulting in molecular chain breakage, molecular weight reduction, tensile strength, impact strength, elastic modulus, etc., and their mechanical properties are significantly reduced. For example, the impact strength of recycled PET may only be 60%-70% of that of virgin material. In addition, the unstable structure in the molecular chain (such as carbonyl and hydroxyl produced by oxidation) increases, and it is easy to be degraded during high-temperature processing, which leads to discoloration of the recycled products, deterioration of the performance, and reduction of heat resistance. The molecular weight distribution in the recycled material is wide and may be mixed with different types of plastics (e.g., a small amount of PE mixed in PCR and PP), resulting in unstable melt index (MI) and molding difficulties, and the recycling process will also have residual ink, adhesives, dust and other impurities, which will affect the appearance of the products and mechanical properties. The problems of impurities and color difference are especially prominent in demanding applications, such as appliance housings and automotive interiors [28].

Aiming at the above-mentioned performance defects of PCR plastics generated during recycling and other processes, researchers have improved the performance of PCR plastics through various methods. Yang Lei et al. addressed the problem that food packaging containing residual fluorescence enters the recycling system with the regeneration process, and avoided homochromatic heterogeneity by developing UV absorbers of suitable structure to absorb UV light and avoid fluorescence generated by energy level jumps of fluorescent whitening agents, which is of great significance for the removal of residual fluorescence from the product for the application of PCR-PP [29]. In addition, the modification of PCR plastics needs to take into account the mechanical properties and apparent properties of each material to make the best use of the modified utilization, need to consider the regional, seasonal and fluctuating nature of recycled raw materials for appropriate modification. PCR plastics can be filled with modification, to enhance the strength of the material, temperature resistance, dimensional stability and the texture of the product, as well as to reduce the cost of the product, which is the most widely used modification method [30].). Common inorganic fillers include glass fiber (GF), calcium carbonate ($CaCO_3$), and talc, where GF improves the tensile strength and heat resistance of PCR plastics, and $CaCO_3$ and talc improve the rigidity at a lower cost. In addition, it can also be modified with nanomaterials, nano-montmorillonite, carbon nanotubes, etc. can improve both strength and heat resistance, and the amount of addition is low (1%-5%). For example, the addition of 3% nanomontmorillonite to PCR enhances the tensile strength by 15% and the thermal stability by 10 °C. Toughening modification of PCR plastics is a modification that enhances the toughness of the product through the addition of appropriate thermoplastic elastomers and high impact polypropylene, and at the same time improves

DOI: 10.54254/2755-2721/2025.GL27943

the product's Low temperature resistance is also improved [31]. Toughening modification of recycled polypropylene needs to take into account the effects of product aging and impurities compared to the toughening modification of new materials, and the decomposition of non-temperature-resistant components during the modification process will reduce the toughening effect. In recent years, bio-based toughening agents have received attention for their environmentally friendly properties. For example, the bio-based plasticizer BPCP600, with a bio-based content of 95%, has the characteristics of flame retardant, antibacterial, colorless, odorless, etc., which can significantly improve the flexibility and processing performance of PCR plastics. In addition, the epoxy resin adhesive with bio-based polyurethane toughening agent can form a polymer with interpenetrating network structure of soft and hard chain segments during the curing process, which solves the problem of insufficient toughness and large brittleness of traditional epoxy adhesive and significantly improves its durability and mechanical properties.

Based on the influence of recycled materials on the mechanical properties of new materials, Chen Feiyan et al. studied the differences in the mechanical properties of polypropylene (PP) and recycled PP (RPP) blended with different ratios of new materials, and found that when the tensile, flexural, and impact properties of new materials are better than the properties of the recycled materials, the higher the recycled content, the lower the performance of the blended materials [32]. From this, it can be seen that the reasonable adjustment of the proportion of new and recycled materials can make their blended materials to achieve the optimal performance [33].

5. Conclusion

The efficient recycling and functional reuse of PCR plastics should be centered on technological innovation to promote the continuous progress of sorting and modification technologies, and at the same time, combine with policy guidance and industrial chain integration to establish a stable raw material supply system and standardized process paths. Future research should focus on the development of low-cost high-precision sorting technology, high-performance modifier R & D and chemical recycling catalyst efficiency, in order to break through the existing technological bottlenecks, to realize the PCR plastic from the "low-quality recycling" to the "high-quality closed-loop" transformation, for sustainable This will provide more solid theoretical and practical support for the large-scale application of sustainable packaging and recycled materials.

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