International Journal of Environmental Pollution and Environmental Modelling, Vol. 6(3):128-135 (2023) (Review Article)

A Review of The Recyclable Packaging Design in Flexible Packaging Industry

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Received 25.05.2022; Accepted 26.10.2023

Abstract: Rapid progress of technology, increasing population, industrialization efforts and the increase in the rate of unconscious plastic consumption negatively affect the world and the environment. Food packaging wastes constitute large proportion of today's plastic waste since they have multilayer composite structure such as PET, metalized PET (PETMET), Aluminum, PE, BOPP etc. Because of the different structures in composite packaging, recycling cannot be performed. In this study, the main criteria required for recyclable packaging design are and different recycling methods were mentioned. Films that can be used in flexible packaging designs suitable for these methods and the main properties that these films provide to the packaging were also included. In the comparison section, the compatibility of flexible packaging to the different recycling methods has been evaluated. By making a comparison between the methods, the technologies used today were detailed.
Keywords; Flexible Packaging, Recyclable, Mono Material, Food Packaging, Sustainability, Recyclability

INTRODUCTION

Flexible packaging plastic waste (FPPW) is the major type of waste which is known as quite difficult to handle. Due to its large scale of using areas and advantages of packaging, a great scale of FPPW has continuously accumulated. By the time 2015, global plastic production amount had been reached 8,2 billion tons, about 6,2 billion tons of this amount was reserved as plastic waste. Especially with COVID-19 conditions after March 2020, the accumulation of FPPW, including the single use packaging plastics, plastic films, bags, flexible food and health packaging plastics (including single-layer and multi-layer material types) and other disposable materials, has gained acceleration (Ryberg et al., 2019; Geyer et al., 2017).

Food industry is the main user of packaging with nearly 60 % of total packaging production. The use of packaging has seen almost every aspect of our daily lives. However, as a downside consequence, packaging waste has resulted in massive environmental issues. The reason of this is mainly related to the traditional linear consumption model which packaging is designed to be manufactured, transported, consumed and disposal. Plastics are the most prevalent type of materials used in the packaging industry (Faraca and Astrup, 2019).

Flexible packaging is a subcategory for plastics industry in the US, and the major part is consisted of single use polyolefin materials which are prepared by polymerization of an olefin as the naphta based original monomer and this part takes 41% of total municipal solid waste (MSW). The largest part of this waste (about 76%) is sent to solid waste landfill sites, while 14% of it is incinerated, and only 8% is recycled and 2% of it is leaked to soil and ocean currents. As a result, it is directly leaked to the natural environment and food chain (Heller et al., 2020).

Considering the environment effected by this increasing packaging waste, innovative steps have been taken that require packaging to be designed, produced, consumed and recycled in a more sustainable way. The circular economy has focused on this purpose deeply (Zhu et al., 2022)

In the light of the pressing need for a healthier and sustainable ecosystem, the concept of the circular economy (CE) was proposed by policy makers from the European Union (EU) and China to

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tackle the global environmental issues via closing the loop of the product lifecycle. The fundamental notion of a circular economy is the closed loop where resources are used, reused and recycled while creating additional values throughout the multiple lifecycles. Goods towards their end of service life are turned into resources for others, forming a closed loop, whereby minimizing waste (Zhu et al., 2022).

Designing flexible packaging to efficiently separate into suitable material fractions for recycling is the key issue in the circular economy. Material recycling can be achieved by using recycled materials or materials containing a high percentage of recycled material. Only in this way it can be added a value to the sustainable economy. Therefore, the packaging should be designed when considering life cycle of package in the value chain. Innovating and developing solutions to make flexible packaging to serve the circular economy must move towards this goal. CEFLEX guidelines play an important role in the operation of waste reduction and recycling processes. The risk of product waste and growing consumption in packaging materials has led to the significant development of packaging design to become easily disposal or reusable. Recycling processes and waste management are the main focusing area.

Recycling and waste management processes are the methods which developed to reuse plastic materials and significantly reduce the impact of damage to the environment. (Waste and Repealing Certain Directives, 2022). Detailed modeling of plastic recycling methods is very important as polymers may have different recycling potentials. As seen in Figure 1, the steps applied in the separation facility to make a plastic waste ready for the recycling process are schematized. Separation of collected packaging waste is a basic requirement for monomaterial collections as a first step. It is the process of removing any residue, contamination and/or unknown material before packaging is delivered to recycling facilities and sorting them. Packaging is collected in single-material collections should be reclassified prior to recycling to filter out any contaminated or incorrectly assigned material, as these materials will make the waste less suitable for recycling and reduce its commercial value. As seen in Figure 1, the packages collected as mixed light packages are separated into marketable fractions and pressed into portable bales. It is then sent to the relevant recycling facility for recycling or energy recovery. Thus, the first decomposition of plastic waste takes places. (Bünemann et al., 2020).

Two different recycling methods are used in the industry, which are mechanical and chemical processes. The composition of the plastic materials is the key factor to decide the recycling process type. Because the same recycling process cannot be applied for every plastic material. (Faraca and Astrup, 2019)

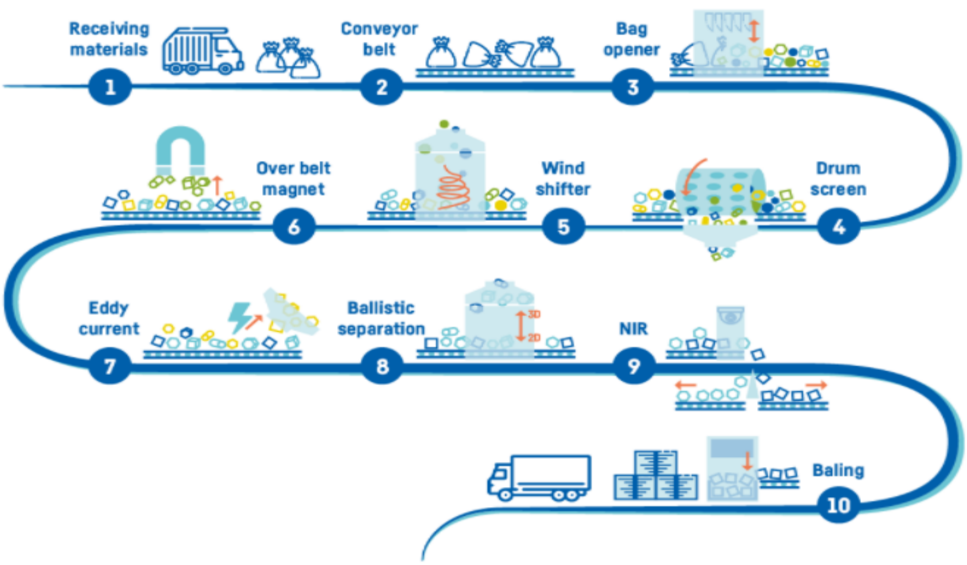

Figure 1. Sorting Process for Packaging Waste (Pietrelli et al., 2017).

MECHANICAL AND CHEMICAL RECYCLING TECHNOLOGY

Mechanical Recycling Technology

Mechanical recycling is a recycle way for thermoplastic waste after collecting and sorting them to obtain deposits separated into 'homogeneous' polymer families. This mechanism includes steps as washing, crushing, re-extruding (waste transformation by means of extrusion where the plastic is melted and re-granulated) and transforming into flakes or granules and then these materials can be used as recycled raw materials or secondary raw materials, without modifying the structure of the main polymer (Plastics Recyclers Europe, 2019; European Bioplastics, 2020).

The following figure illustrates the key steps of a basic mechanical recycling process for polyolefin-based flexible packaging. When considering the most recycling activities, sorting is the best way for unbaled packaging wastes and this facility includes *metal separation* and *NIR optical sorting* stations.

Wind shifting is a station for separating waste form on the density of material using the principles of controlled air. The input material is separated into two fractions varying from light to heavy. Density separation step is used to separate polyolefins structure from other plastics such as PET, polyvinyl chloride (PVC) or polystyrene (PS). Polyolefins have a density of <1.2 g/cm^3 and will float in the process, whereas the non-polyolefins have a density of >1,2 g/cm^3 and will sink. Final stage is *drying* and *extrusion* steps, where the plastics are melted, filtered and pelletized. Based on the processes, recycling plants have different type and numbers of equipment.

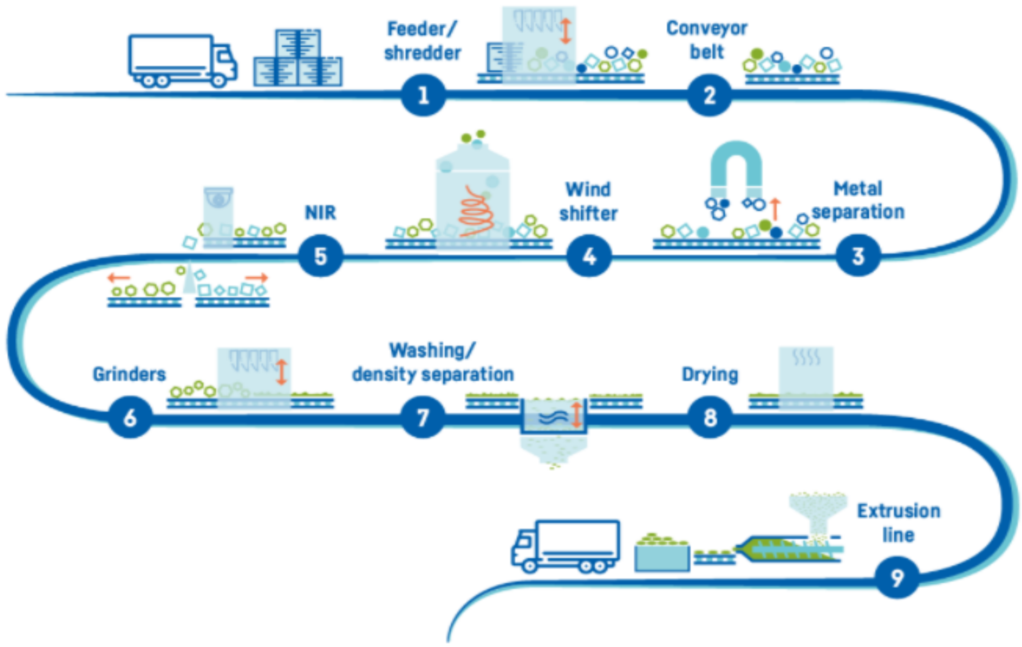

Figure 2. Mechanical Recycling Process for Polyolefin-Based Flexible Packaging (CEFLEX Technical Report, 2022)

According to the international standard (International Organization for Standardization, 2016) on life cycle assessment (LCA) separates between two different types of recycling process 'closed loop' and 'open loop' which are differentiated by the final application of the recycled product.

Closed loop recycling occurs when either the product is recycled at the end of its life into the same product system, or the product is recycled into a different product system but the materials undergo no change in inherent properties of the recycled materials. In both cases, the material resulting from the recycling process displaces virgin production in a 1:1 ratio, and the environmental benefits allocated to recycling reflect this. In general, the sorting, washing, grinding and reextrusion steps cannot remove the internal contamination in polymers caused by the addition of additives. But if the plastic waste to be processed is very specific, the granules containing polymers and additives obtained after re-extrusion can be used as feedstock for high added-value products manufacturing (IFPEN, 2022; Williams et al., 2010).

However, this ideal scenario, which is known as open loop recycling, is rarely the case. Actually, the variety of the collected waste streams, even after sorting into polymer types, could convert to granules with additives of various origins that worsen recycled plastic properties during reprocessing and make it impossible to recreate the initial products. This makes it available only for less claiming applications that are less concerned with the quality of the granules and this should be considered. In open loop recycling, the environmental benefits associated with the recycling process are then not associated with displaced virgin production of the original material (Williams et al., 2010). Plastic value chain and these two different types of recycling methods can be seen in Figure 3.

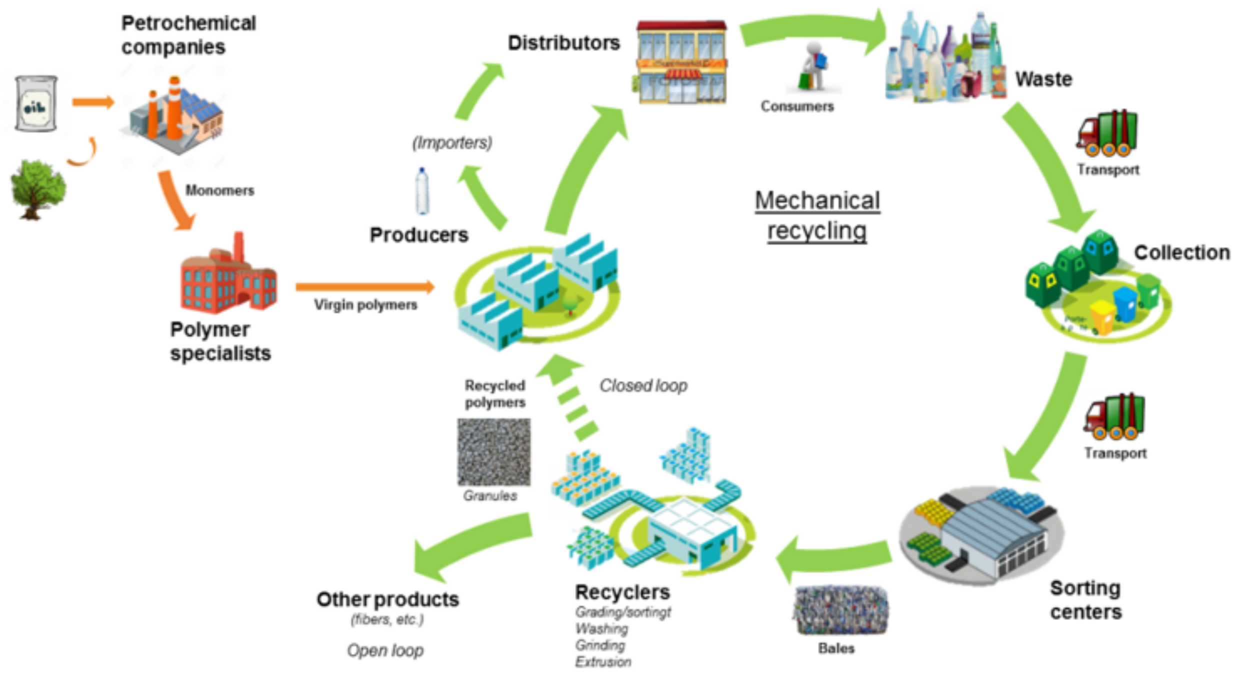

Figure 3. Plastic Value Chain: From Resource to Post-Consumer Waste Recycling (IFPEN, 2022).

With the global trends turning towards sustainability and circular economy circular economy becomes very important, developments are accelerating in terms of applicability in other recycling types, especially in chemical recycling, when compared to mechanical recycling.

Chemical Recycling Technology

Chemical recycling is used to describe the technology which provides waste management mainly based on depolymerization process which occurs by breaking down the polymer structure to obtain the original monomers or valuable secondary raw materials (Achilias et al., 2007).

Chemical recycling processes can be done with the help of different chemical reactions which are depolymerization partial oxidation (gasification) and cracking (pyrolysis) processes (Panda et al. 2010).

Pathway of the chemical recycling technologies is mainly based on feedstock/sorted plastic waste stream and desired product at the end of reaction.

Pyrolysis (thermal degradations under inert atmosphere) is a common method for recycling polyolefins and other addition polymers. Pyrolysis products are liquid and gaseous substances containing (Panda et al., 2010). On the other hand, at the end of gasification process petroleum fuel substitutes and combustible gases are mainly obtained. In depolymerization process, pure value-added products can be achieved and when compared the other technologies it requires less energy input. In brief, choices of these technologies based on requirements and end-products (Manzuch et al., 2021). Basically, chemical recycling processes steps can be shown in Figure 4.

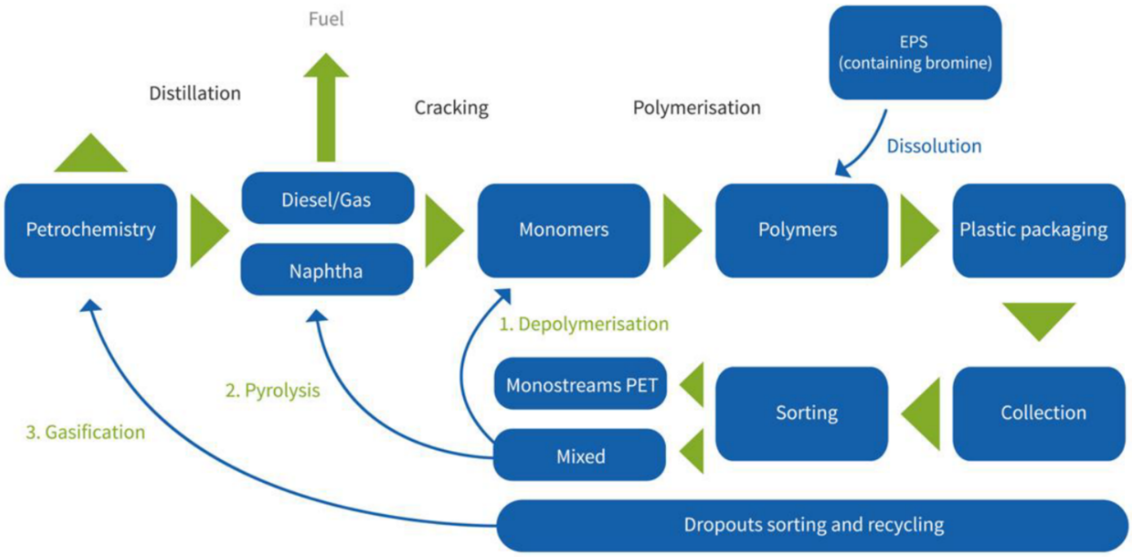

Figure 4. Overview Chemical Recycling Technology

Comparison of Chemical and Mechanical Recycling

Mechanical recycling is a commonly applied technique because of its technical and economic feasibility. In the study of Civancik-Uslu et al. (2021), mechanical recycling was founded favored by taking into consideration global warming, terrestrial acidification and resource consumption (Huysveld et al. 2022).

On the other hand, chemical recycling is generally prefered to manufactured value added product and it can be used to produce chemicals, fuels or pure plastics with the same performance as the original materials. If separation is not viable or feasible, chemical recycling technique has high potential for heterogeneous and contaminated plastic waste material since mechanical recycling technique requires mono polymer structures. However, chemical recycling has complex operations and requires high volumes to be cost effective (Ragaert et al. 2017). The chemical recycling technique does not provide CO2 savings, as it requires more energy in the process of making a different chemical product from the inputs. Chemistry of this technique is still unknown and in the research phase because lack of technical informations (Osterath et al. 2020).

Although mechanical recycling is not suitable for composite plastics and contaminated wastes, it is useful for removing non-melting contaminants and well known cost effective technology. Therefore, plastic converters have to be awareness about which polymer structure, inks and additives can be used to construct suitable packaging structures to apply mechanical recycling.

MATERIAL AND METHOD

In this study, mechanical recycling was evaluated and packaging materials were choosen considered convenience of mechanical recycling. At the core of the separation process is the Magnetic Density Separator (MDS). This separator separates the crushed mixed input waste in four different density ranges, classifying them into polymer products and a fifth product or residue (eg metals, glass, etc.) that is much heavier than water. The inlet typically has a particle size of 1 mm to 10 mm and thickness of 0.3 mm to 3 mm. System capacity changes according to particle thickness. However, industrial units' capacities are approximately 3 tons per hour. Different types of polymers are used in packaging industry. Olefins are the most commonly used polymer types in flexible packaging market. They can be used in the form of mono layer or multi layers. Each layer can be in the form of different olefin groups in packaging structure (Anonymous1, 2022).

Poly-olefins

Polyolefins are thermoplastic product and they are simple alkenes such as polypropylene, butene, pentene and ethylene. PE (polyethylene) and PP (polypropylene) are the most widely polyolefins used in packaging sector due to its advantages such as good physical and chemical properties, easy processability and low price (Crow, 2022). Physical and chemical properties of the PP and PE films are different. These materials, whose surface properties differ from each other, can be used alone or as a mixture depending on the characteristics of the product needs. Since the plastics are melted and re-granulated in the recycling operations, melting point is a key factor for the process. Melting points of PE and PP are closer to each other, 110 to130 °C and 160 °C respectively. Hence, it can be processed with combination of PE and PP in recycling operations (Crow, 2022). To summarize, in order to use of recyclate as a raw materials, industries aim to use polyolefin based products.

Polypropylene and cast polypropylene (BOPP & CPP)

PP is widely used thermoplastic in the packaging films due to several properties such as clear glossy, high strength and puncture resistance. It has also moderate gas and excellent moisture barrier. It can be stretched although not as much as PE. Owing to this, it is used in similar application with PE. Thus, it can be processed in the form of monomaterial (Allahvaisi, 2012).

Commonly two types of PP films are used in the industry. These are BOPP (Biaxially Oriented PP) and CPP (Cast PP) BOPP is transparent, highly stable and highly temperature-resistant properties while CPP films have more elasticity and peelability. According to requirement of packaging, PP based materials can be used as printing layer, sealing layer, perforated layer, single layer for bag applications (Anonymous2, 2022).

In order to enhance its gas barrier performance coating applications have been used for years. Coating materials have been selected from aluminum and water based polymeric solutions.

As a result, PP based materials can be used as mono PP packaging.

Polyethylene

PE stands out among polyolefin films due to its lowest melting point, similar density with PP and different types of monomers with different mechanical and physical properties. It shows strong sealing behavior because it has a low melting temperature. Hence, it is generally used as a sealing layer in laminated films. To design a mono PE structure it has to be a printing layer as well, this is its bottle-neck.

Two types of printing techniques are generally used in the Flexible Packaging Industry. These are rotogravure printing and flexographic printing systems. In the rotogravure, printing tools are steel printing cylinders, the film that takes the ink from the color units lined up sequentially passes through ovens at high temperatures for the solvent to evaporate. Rotogravure requires being free of weaknesses in printability, toughness and heat resistance, which is not possible with conventional PE.

Thus, machine direction oriented (MDO) stretched PE film is developed. In the developed MDO PE structure, PE film has resistance up to 130°C.

Because of the poor oxygen barrier property of PE, it is necessary to be coextruded with another polymeric material which is naturally resistant to oxygen such as polyamide, ethylene vinyl alcohol.

In conclusion, to produce a mono PE structure with rotogravure printing technique, MDO PE must be used as a printing layer and conventional PE could be used as a sealing layer. Any kind of improved PE could be selected as a sealing layer in terms of the product and process needs.

Mono-olefins

Separation of PP and PE prior compounding is derived from processing PP and PE mixture with the standard technology generally results with deformation of physical properties of the obtained mixture. Mainly, elongation and strain at break and tensile and impact strength are affected. In this situation, PP and PE are incompatible although they have similar chemical structure. Hereby, separation of polyolefin mixture into PP and PE improves the quality of recycling products (Hu et al. 2013).

In addition, since heat required to granulate a plastic film, process heat values are determined according to raw material compound with the highest melting point of mixture. Hence, single type of polymer usage is most suitable for the flexible packaging recycling. To meet the necessary parameters for the mono polymer type of packaging, single type of polymer can be modified with the changing process and various additives (modifiers, stabilizers, etc.)

Recycling Calculations

Recycling calculations were made according to CEFLEX based on the unit weight of the materials used in the packaging. In general, monomaterials contain one type of material such as PE, PP. Besides polymer films, components were also used such as adhesives, inks etc. These components are not recyclable materials. Thus, recyclability percentage should be mean >90% according to CEFLEX for mono materials. However, recyclability percentage can be changed according to sorting center capabilities (CEFLEX Technical Report, 2022).

CONCLUSION

Flexible packaging is formed by using different kinds of polymers (polyethylene, polypropylene, polyamide, pet, etc.) and non-polymer additional materials (aluminum, paper, glue, etc.) from polymer-based multi-layer packaging materials. The purpose of this composite packaging structure is to provide and increase the function of the packaging by combining the physical & chemical properties of polymeric and auxiliary materials. With this approach, it is aimed to adequately protect sensitive food products with heat seal integrity, moisture/oxygen/light barrier and thus to provide the desired shelf life.

In the current packaging structure design, PET-based film is used for printing due to its high gloss value and stiffness, PE film with low density and high sealing ability used for sealing, Aluminum foil or PETMET films are generally used to provide the barrier. Since these composite structures are not suitable for recycling due to their melting points and viscosity differences, these multi-component (composite) structures are generally disposed of by various methods or incinerated. In order to overcome this situation, market has tended to use mono material based packaging.

Within the scope of this project, the recycling process which could not be carried out due to the different structures in the packages included in the composite class consisting of multi-layered structures, has been made suitable for recycling by single polymeric component or polyolefin structure. Since BOPP films are suitable for printing applications and PE has sealing ability, mono polyolefin structures were developed easily. There were several challenges while developing mono PE and mono PP structures, but these difficulties were eliminated by using improved materials and changing production process parameters.

In order to develop mono PE structure, conventional PE is not suitable for rotogravure printing it has not sufficient gas barrier. MDO PE was used to overcome printing problems and specialty chemicals were used to improve barrier property. Besides, coated PP films and PP films which have low temperature sealing ability also used to design mono PP structures. The recycling percentages of the recyclable structures were calculated and the recycling rates reached up to 100%. With this way, flexible packaging sector has been ready for processing of recyclable structures.

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