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LUT School of Energy Systems
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MECHANICAL AND CHEMICAL PROCESSING OF MULTILAYER MATERIALS AS A PART OF RECYCLING PROCESS

Examiners: Professor Timo Kärki
D.Sc. Ville Lahtela

ABSTRACT

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Unarguably light weight and multiple functionalities of multilayer material are the prime reason for its increasing market in the packaging industry. Nevertheless, considering circular economy into consideration it is challenging task to recover multilayer materials from the waste stream. LUT University intends to study and investigate the viability of recycling post-consumer multilayered packaging waste and present the current pathways for its processing methods.
Starting with an overview on possible composition of polymers in multilayer materials, this thesis highlights the available processing technique and compare the properties of recycled materials with the virgin ones. The section on processing of multilayer materials contains an overview of sorting technique, different classified groups of polymers and possible test to evaluate mechanical performances of recycled materials. The results from the test is then utilized to compare the performance and content of recycled multilayer materials.
Additionally, this research discusses about the difficulty and main challenges occurred during the processing of multilayer materials, thus giving an overall suggestion to perform future research work.

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Shekhar Silwal

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ABBREVIATIONS

CAGR	Compound annual growth rate
$CaCO_3$	Calcium carbonate
$CaSiO_3$	Wollastonite minerals
DSC	Differential Scanning Calorimetry
EDS	Energy Dispersive spectroscopy
EVA	Ethylene vinyl acetate
EVOH	Ethylene vinyl alcohol
EU	European Union
E_o	Young's Modulus
HDPE	High-density polyethylene
IV	Intrinsic Viscosity
LDPE	Low density Polyethylene
LLDPE	Linear low-density polyethylene
MPa	Mega Pascal
mt	Million ton
NaCl	Sodium chloride
NIR	Near-infrared
PA	Polyamide
PC	Polycarbonate
PE	Polyethylene
PEN	Polyethylene naphthalate

PET	Polyethylene terephthalate
PP	Polypropylene
PS	Polystyrene
PVC	Polyvinylchloride
PVDC	Polyvinylidene chloride
RIC	Resin Identification code
SEM	Scanning Electron Microscopy
SiO_2	Silicon oxide
UV	Ultraviolet

1 INTRODUCTION

The principle of material science is to design materials with specified properties. When required properties cannot be obtained from single material then two or more materials are combined to make multilayer material that inhibits improved mechanical performance and the barrier properties. Largest fraction of multilayer materials is used for packaging industry and its major constituents are polymers such as Polyethylene/Polyamide or Polyethylene/Polyethylene terephthalate and also consists of aluminum layers. For example, polymer multilayer films are used in food packaging with the functionality to protect the food, but also to retain aroma and flavors with extend shelf life while complying with food safety regulations. (Guillory, et al., 2009)

Considering circular economy into consideration it is essential to recycle multilayer materials and make sure that they are recovered and doesn't end up in the environment. However, it poses a challenge to separate individual layer effectively in large volume. As a result, multilayer materials have poor recyclability and undoubtedly it ends up at the landfill which is perceived as a key weakness in circular economy. It is therefore necessary to address the end of life option for such waste stream to achieve its fullest potential in circular economy. There is no current option for mechanical recycling of multilayer materials due to its complex structures. Very few studies have been carried out previously on this topic. Ragaert, et al. (2017) published an article giving detailed description for the recycling of solid waste plastics using both mechanical and chemical recycling. The author mentioned pyrolytic decomposition as a promising option for recycling of multilayer packaging.

It is crucial to identify the composition of post-consumer multilayer materials for its effective recyclability. This research aims to find effective recycling technique. Several approaches to the mechanical and chemical identification and characterization of multilayer materials are described in this research. Once individual materials are distinguished and separated, the end of life treatment of separated materials is then discussed. Most importantly the processed material will be analyzed to conclude its reusability as a virgin material.

1.1 Multilayer materials

Multilayered materials consist of material stacked in layers where each layer imparts different attributes to the layered structures. Multilayers material can lead to new properties that are not found in the bulk material and aims to meet the requirement of particular application. The customized product created by combining different materials consumes least possible resources making it lighter and economic than one single material without compromising the properties. For more than six decades multilayered material has demonstrated its importance in the global market for providing protective, functional and decorative properties (Langhe & Michael, 2016).

In multilayer materials each layer is bonded to each other by co-extrusion, blown film extrusion or lamination. When two or more layers are not suitable for co-extrusion process, lamination is done to combine them into single structures (Morris, 2017). Multilayer materials are used in wide ranging variety of applications such as food packaging, automotive industries and in agricultural field to protect plants. Packaging industry is dominating the market as the prime consumer of multilayer materials. Multilayer materials are tailored to meet the packaging design requirement by combining different properties of different base materials (Dixon, 2011).

An individual layer can be polymer blends, virgin material, recycled material or additives. Each layer has its own specific functional properties like as barrier or tensile strength. Some important properties that need to be considered includes optics, formability, sealability, adhesion and machinability. Considering all the key requirements of the applications field, different materials are selected to create the multilayer materials.

1.1.1 Structures of materials

Following the end user needs such as improved barrier properties, durability, stiffness and heat seal performance, multiple materials are selected to meet the functional requirements. A typical multilayer structure of single use bags produced by Saint-Gobain is shown in Figure 1. The structure of bag is optimized for bioprocess production applications. It consists of three different layers of polymer where each layer has its specific thickness and functional properties. Low density Polyethylene (LDPE) is the fluid contact layer as it is suitable for safe handling of different pharmaceuticals liquids. Ethylene vinyl alcohol (EVOH) functions as a gas barrier that prevents the transmission of oxygen and carbon dioxide. Nylon, which is the outer layer of the bag has very good impact and tear resistance and act as a strength layer (Saint-Gobain, 2015).

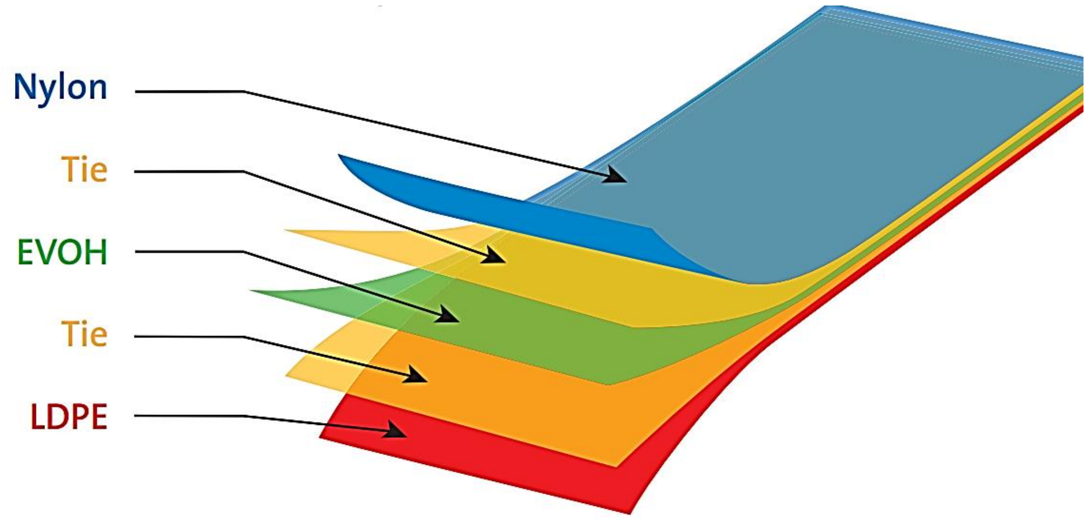

Figure 1: A typical three-layer multilayer film structure *(Saint-Gobain, 2015)*

Tie structure provides bonding between incompatible layers and adds overall performance of the structures. The bonds that are mechanical or chemical in nature happens in molten state. Ethylene vinyl acetate (EVA), Polypropylene (PP), Low density Polyethylene (LDPE), Linear low-density polyethylene (LLDPE), High-density polyethylene (HDPE), acid copolymers and acrylate copolymers are common tie layer resins. (Wagner, 2010).

Figure 2: Standard aluminum laminated plastic pouch *(Nonclercq, 2017)*

Figure 2 shows the standard aluminum pouch with its different layers. Each layer has different thickness and imparts different properties. The pouch consists mainly of three different materials. The polyethylene terephthalate (PET) layer, which is the outermost layer with a thickness of 12 μm provides gloss, good printability, strength and barrier properties. The middle aluminum layer with a thickness of 7 μm is responsible for providing barrier against light, gases and odors. Polyethylene (PE) is the innermost layer with a thickness of 75μm that is responsible for providing stiffness, good sealability and good strength. The layers are laminated with polyurethane (PUR) adhesives (Nonclercq, 2017).

1.1.2 Application of multilayer materials

Application of multilayer materials have evolved over the last several decades. Advancement in multilayer technology have created broad application space due to its enhanced performance properties and durability. They are widely used in food and beverage industries, health care and electronics industry. The dominant consumer of multilayer material is the packaging industry including food and medical packaging. Multilayer films with the combination of usually 3-12 different polymers are used to take create suitable packages for the application. Such packages have ability to control the transmission rate of different gases and moisture which is the key in preserving the content of the packages.

Figure 3: An example of multilayer packaging with its schematic *(Gotro, 2017)*

Conventional packaging materials like paper, aluminium foil, tin and glasses are replaced by it. For packaging with demanding functionality, plastic films are laminated with aluminium film or combined with a metalized film. Laminating aluminium layer makes the packages more effective vapour and aroma barrier. Figure 3 gives an overview about different packaging with its schematic of different plastics films used. Primarily there are three main division of packaging. It includes food packaging, nonfood packaging and other packaging. Food packaging are used to preserve foods, fruits and groceries. Non-food packaging includes agricultural field, medical field and industrial field. The other type of packaging where multilayer film is found are stretch and shrink wrap which are used in a variety of applications ranging from overwrapping fresh meats to securing shipping cartons to pallets. Beside packaging multilayer films are used to produce trash bags, can liners, agricultural film, construction films and different medical and health care films (Pratt, 1997). Bottles that need to store viscous content in it has the main requirement of prevention of moisture, excellent preservation and safe to use. The requirements are fulfilled by a multilayer bottle with the structure shown in Figure 4.

Figure 4: Multilayer bottle with the structure *(Dixon, 2011)*

Other applications such as multi-layered optical films are used for infrared, visible and ultraviolet light reflection. For example, such optical films are used for window glass to improve its toughness, block Ultraviolet (UV) light and improve glazing. In depth knowledge and research about the structure and properties of multilayer materials has expanded its application area beyond packaging to include energy storage, optical devices and sensors (Langhe & Ponting, 2016).

1.1.3 Multilayer materials markets and trends

The growth of global multilayer material market is driven by the need for operative packaging solution among different industries. Eminent properties of multilayer material are the key for its augmented demand. It has been a challenge to estimate the exact volume of multilayer waste stream as all types of waste are collected together blurring the statistics. Nonclercq (2017) reported that the share of multilayer packaging in Europe is around 0.8 million tons in 2015. It was mentioned that out of total plastic demand in Europe only 32% is used for packaging. However, this data was extracted from a limited number of countries, so it is not the verified data to be considered globally.

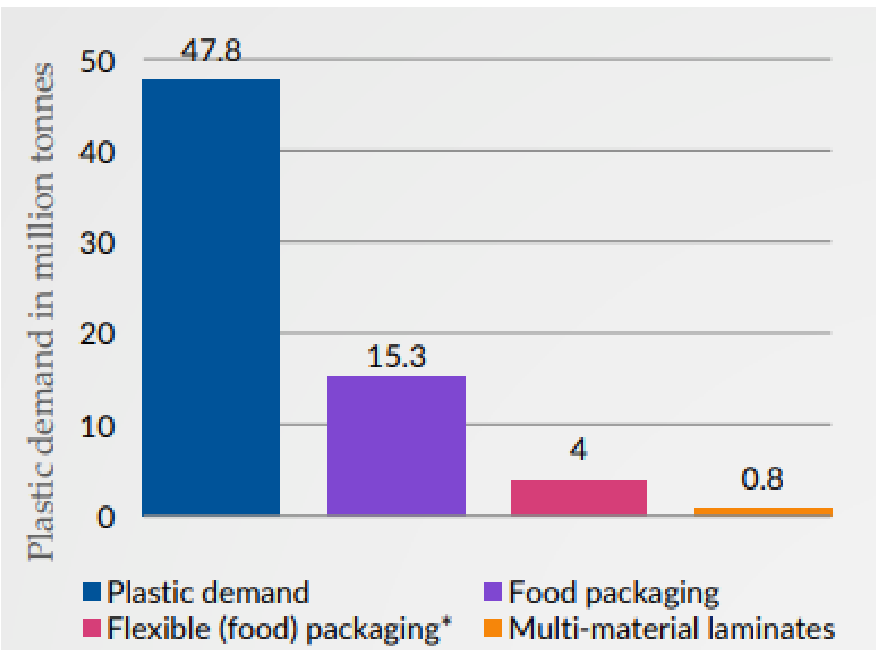

Figure 5: Plastic distribution in Europe *(Nonclercq, 2017)*

According to plastic information Europe, in Europe there was a demand of 49.9 mt plastics in 2016. Out of the total demand 39.9% was used for packaging industry which accounts to 19.91 mt of plastics (PlasticsEurope, 2017). In a research made by Zenon (2010) , he reported that in the world of packaging, multilayer materials have an occupancy of approximately 17%. So, if we use the data from plastic information Europe, it results to be 3.38 mt of multilayer materials used for packaging only.

Table 1: Types of plastics used in packaging industry (Forrest, 2016)

Plastic Type	**Share of total packaging (%)**
Polystyrene	4.7
Polyurethane	6.7
PET	8.6
PVC	11.3
LDPE	11.5
HDPE	17.9
PP	18.6
Other	20.7

Multilayer materials are included in others plastic type due to its multiple unknown composition. Table 1 shows that other plastic type has the largest share of total packaging. This suggest that most of the post-consumer waste will have more shares of multilayered waste.

According to the research made by Market research future, the global multilayer packaging market is expected to grow at a Compound annual growth rate (CAGR) of around 4.82% by 2023. Based on end users, the multilayer packaging market has been divided into food and beverages, industrial, personal care, healthcare and others. Food & beverage is among the fastest growing sector with the expected growth rate of 5.23 % by 2023. Asia pacific holds the largest share in the global market followed by North America and Europe (MRFR, 2019).

Transparency market research (2017) conducted a research about the about the global consumption of multilayer material based on the number of film layers. According to the report, the total market of multilayer film was valued at $5.7 billion in 2017 which is expected to grow at a CAGR of 4.4% during the year 2018-2026.

Figure 6: Multilayer blown film market based on different layer *(Transparency Market Research, 2017)*

The research included different application types such as bags, pouches, wrap, food & beverages and consumer goods (Transparency Market Research, 2017). Global multilayer film market revenue based on different layer is shown in Figure 6. Multilayer film with 7-layer structure has the largest revenue as compared with other multilayer films. In 2017, 7-layer segment of multilayer film market was valued at 1,63 billion dollars. This is due to the fact that 7-layer structure can meet the wide range of customer demands as it includes more functional and barrier properties compared to others. Multilayer film with 2-layer structure has the lowest revenue in the market.

The research about the global multilayer blown films market conducted by Research and Markets which included various applications such as industrial films, lamination films, printing films and packaging films. It was found that in 2017 the total of $5,50 billion was accounted for multilayer films market. With the growing 6,4% CAGR, it is expected to reach $9,58 billion dollar by 2026. This is due to the increasing demand for qualitative packaging solutions among different sector of industries. (Research and Markets, 2019)

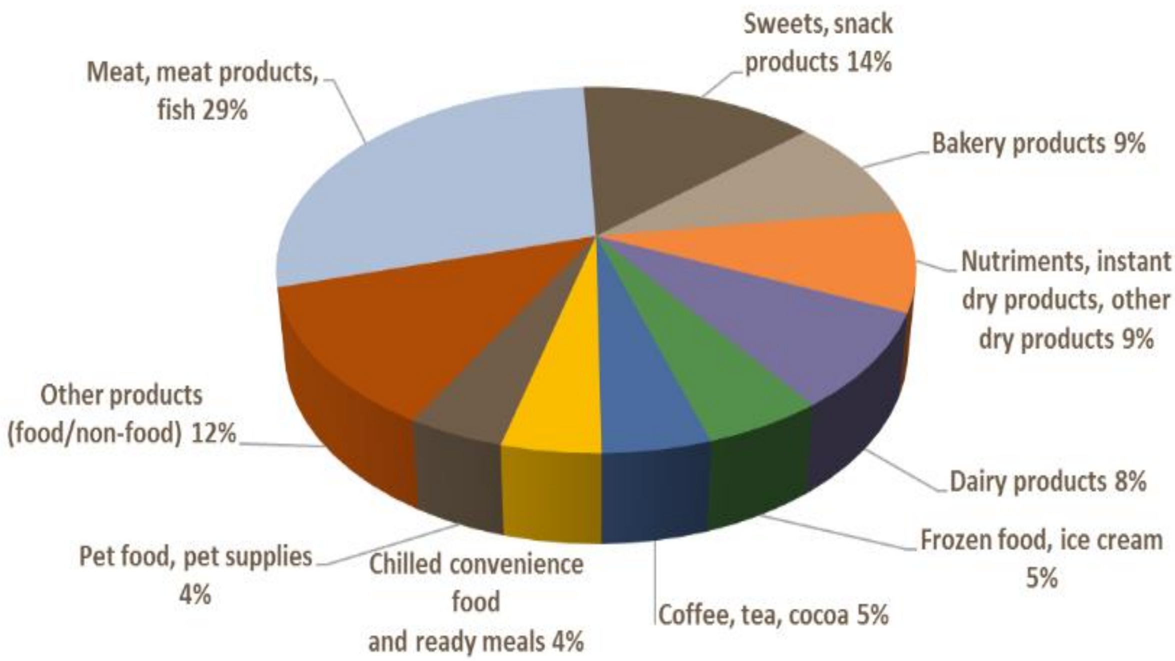

Figure 7: Surface area of plastic composites in Germany 2016 by product categories *(Mainz, 2016)*

According to all the report considered here concludes that Asia pacific region holds the largest market for multilayer film applications. This help us to figure out that the post-consumer waste stream of multilayer material is expected to grow with the same rate as it is consumed globally. Most of the consumed multilayer products globally comprises of more than 5 layers of films. Mainz (2016) studied the trends and perspectives of multilayer material markets in Germany and in Europe. Figure 7 shows the different market areas in Germany where multilayer materials are used. It concludes that the use of multilayer material is widely applicable in almost all field of packaging.

1.2 Composition of multilayer materials

This section covers some of the most common materials used in the manufacturing of multilayer materials. Selection of material is the key to multilayer materials performance. The properties of material are determined based on its constituent. Multilayer material is designed to meet the properties that cannot be found in single material. As a solution, two or more than two materials are combined to create a single structure where each material is contributing at least one of the desired properties. The common materials used for the production of multilayer materials are polyethylene (LDPE, HDPE, LLDPE), polypropylene, polyamide, polyesters, cardboard, paper or barrier materials such as aluminum, polyethylene terephthalate or ethylene vinyl alcohol (Mieth, et al., 2016).

Regulation (EU) No 10/2011 specifies that, those plastics recycled from commingled postconsumer waste must not be in direct contact with food. However, they can be incorporated in an inner layer of the packaging if they are divided by a functional barrier that restricts the transfer of non-authorized materials from the recycled layer to the foodstuff (Kaiser, et al., 2017). A packaging with two layers of different materials consists of an inner side that is facing the product and an outer layer. In this case the material used in the inner part is responsible to provide seal ability whereas the outer material provides resistance against different barriers. Both the material is generally combined with the help of adhesives. Change in the material composition and increasing the number of layers provides even greater flexibility to the finished product.

1.2.1 Plastic Polymers

Plastic polymers are widely used for the manufacturing of multilayer materials. Polyethylene (PE), polypropylene (PP), ethylene-vinyl alcohol (EVOH), polyamide (Nylon, PA), ionomers (EAA, EMAA), and ethylene vinyl acetate (EVA) are the most common polymers used in multilayer materials. To simplify the idea about different types of polymer used in multilayer materials, an example giving the types of plastic polymers with its specific functions is shown in Table 2.

Table 2: Material used in multilayer materials (Mieth, et al., 2016)

Material	**Functions in multilayer**
Polyethylene (PE)	Sealing, moisture barrier Freezable can be combined with gas/aroma barriers (e.g. PA, EVOH)
Polypropylene (PP)	moisture barrier to provide mechanical strength can be coated with heat seal coatings (PVDC coatings, PA, EVOH)
Polyamide (PA)	To provide mechanical strength

	gas/aroma barrier puncture resistance heat resistance
Polyethylene terephthalate (PET)	Gas barrier moisture barrier heat resistant to provide mechanical strength
Ethylene vinyl alcohol (EVOH)	gas Barrier needs to be protected from moisture → often sandwiched (coextruded) between PE or PP, in some applications also sandwiched between PET, PA or PS
Polyvinylidene chloride (PVDC)	Sealing and gas barrier moisture barrier to protect the surface firm scratches and abrasion
Polystyrene (PS)	gas permeability printability can be combined with gas/aroma barriers
Polycarbonate (PC)	Mechanical strength heat resistance moisture barrier
Polyethylene naphthalate (PEN)	Gas/aroma and moisture barrier heat resistance
Polyvinylchloride (PVC)	gas/aroma barrier mechanical strength

The Society of the plastics Industry, in 1980s classified the plastic resins into 7 different groups. Each of the group differs in transparency and strength as well as other characteristics. Identification code is given to each of the resin groups. Most of the plastic packages have a printed figure of triangular recycling symbol with specific number mentioned inside it.

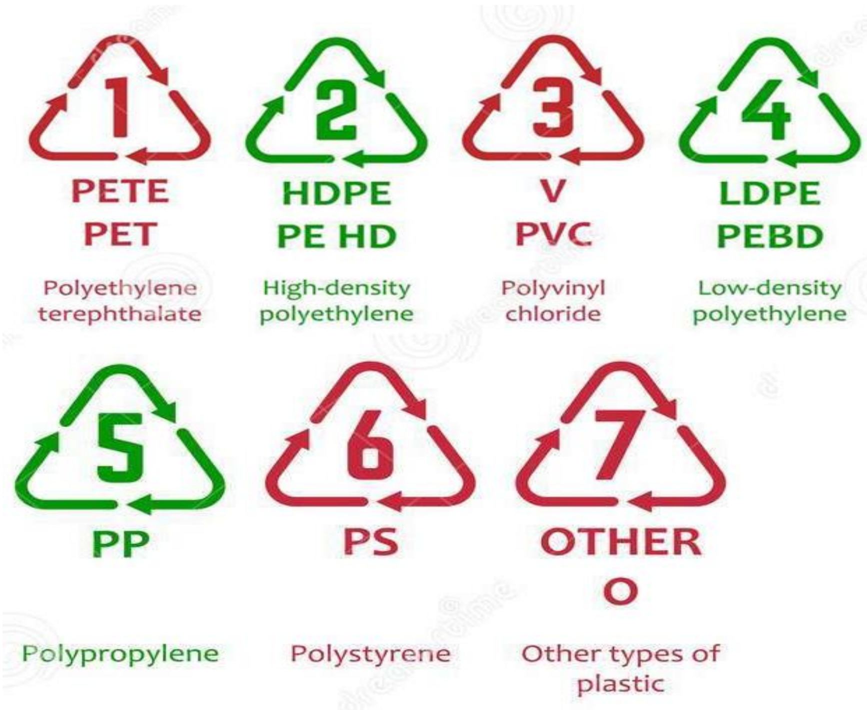

Figure 8: Resin identification code symbol *(Dreamstime, 2019)*

Resin Identification code (RIC) is used in the plastic packaging in an effort to develop consistency in the manufacturing and reprocessing of plastics. Figure 8 depicts the different polymer groups with their identification symbols.

1.2.2 Aluminum foil

Aluminum foil with its unique properties is an everyday presence in our lives. It is made from aluminum alloy sheets and has a thickness between 0.004 and 0.24mm. It is light flexible and easily recyclable. It is considered as the ideal core packaging materials for different varieties of product. Most of the multilayer materials has aluminum foil as it is an active barrier contrary to humidity, air, odors and UV lights. Aluminum is used mostly for the packaging purpose in food industry and pharmaceutical industry. It is sterile and thus hygienic. Aluminum foil is tasteless, odorless, recyclable and dimensionally stable even in soft state (Alfipa, 2018).

1.2.3 Bonding of the different layers

During the manufacturing process of multilayer materials two or more materials are bonded by co-extrusion or by lamination process. Using co-extrusion process to bond two molten polymer, an extrudable adhesives is necessary to be applied in between. For an example, in the co-extrusion of PE and PA, anhydride modified polyethylene or anhydride modified EVA can be used as extrudable adhesives. Whereas extrusion lamination process bonds two or more plastics or non-plastics materials in web form with the use of definite type of adhesive between them (Mieth, et al., 2016). In multilayer materials additives are used in individual layers to achieve certain property. Initial effects of additives such as reinforcement, functional property, suitability for application purpose and cost are the important factors to be considered while choosing the additives.

Thermal lamination can also be used for the bonding of two materials through the application of heat. In general, tie layers are used for adhesion to bond two incompatible layers. The bonding which are mechanical or chemical in nature occurs in molten state. EVA, PP, LDPE, LLDPE, HDPE, acid copolymers and acrylate copolymers are the common tie layers resins which can be modified with rubbers, tackifiers or maleic anhydride (Wagner, 2010).

1.3 Processing Techniques

Processing of multilayer material is topic of great interest to both the designer and manufacturer. There is a row of complication during processing of multilayer materials. In case of multilayer materials, identification of polymer's waste is almost impossible in large scale. There are very few researches that studies processing of multilayer materials and getting of new composed materials. Post-industrial multilayer material waste requires complete scanning of composition range in order to evaluate the possibility of recycling the waste of multilayer materials (Uehara, et al., 2015). The current state of research suggests two general ways of processing the multilayer materials: Mechanical Processing and chemical processing.

1.3.1 Mechanical processing

Mechanical processing of multilayer materials is a multi-step process. It starts with collection, sorting and separation of collected waste. It is necessary to sort different material groups prior to mechanical recycling. It is then reprocessed and compounded into new component. The new component may or may not possess same properties as the original one as deterioration of product properties occurs in every life of mechanical recycling process. This section covers the theory behind the mechanical processing of multilayer materials.

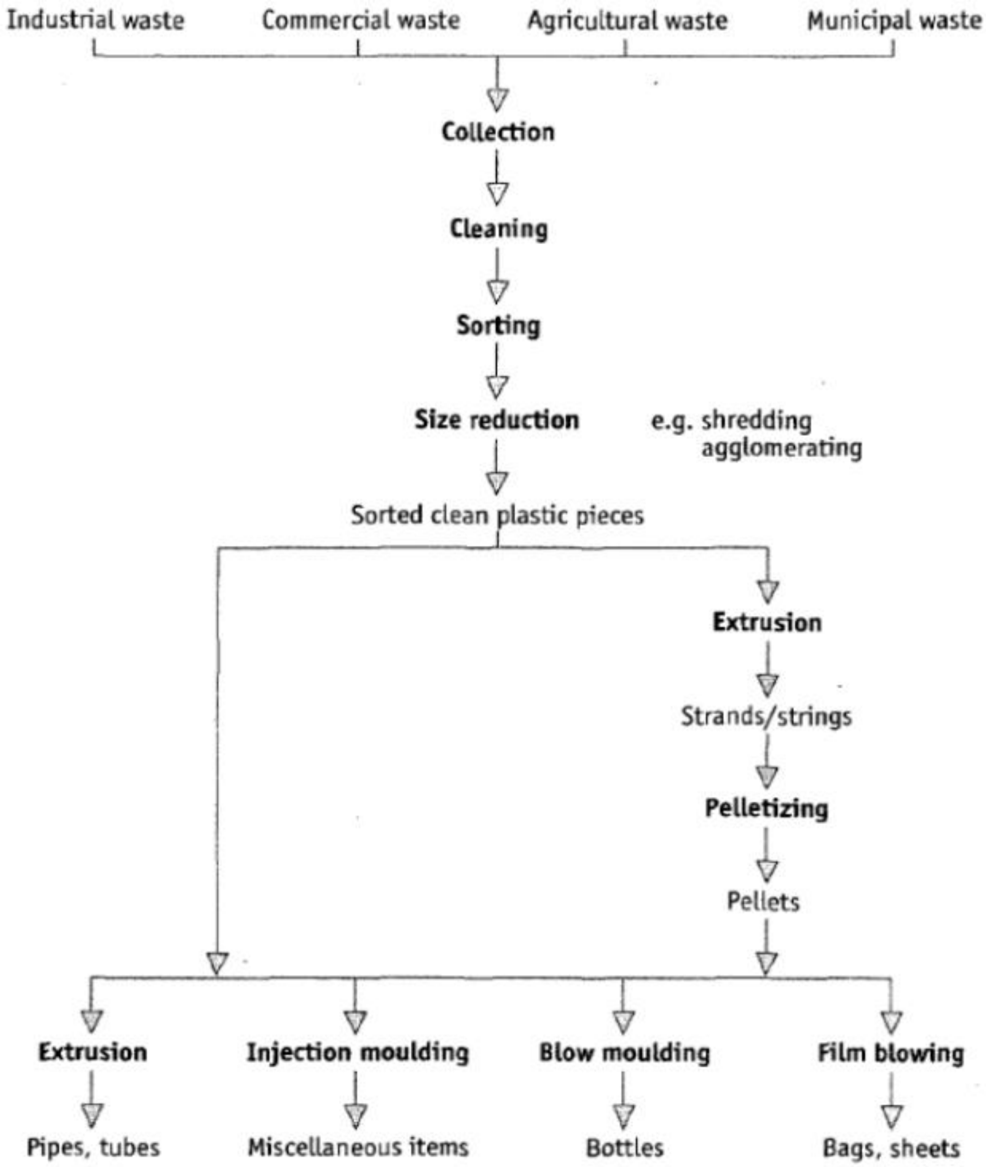

Figure 9: Mechanical processing steps for the management of waste plastic *(Villanueva & Eder, 2014)*

Figure 9 gives an outline of how plastics are processed mechanically. Identification of plastics is the important task before recycling process as it helps to avoid the contamination of different batches of plastics to be recycled. Beforehand the multilayer materials are recycled it is necessary to identify the composition of each layer. Identification of plastics can be done using different techniques that vary according to physical and chemical composition. Use of spectroscopic instrument for the identification of plastic is an easy and quick process. Many readings of one sample can be done in a short period of time to identify the unknown plastics enabling multiple scanning of same materials to ensure the proper identification. Once the materials are identified and sorted, separation of contaminants are carried out that helps to separate paper and ferrous metals from plastics. Table 3 below shows general operations carried out for the recycling of plastic waste mechanically.

Table 3: Mechanical recycling operations (Villanueva & Eder, 2014)

Process	Description
Cutting	Large plastic parts are cut by saw or shears for further processing
Shredding	Plastics are chopped into small flakes, allowing the separation of materials (e.g. metals, glass, paper) and plastic types (e.g. PET bottles from PP lids).
Sorting	Additional sorting (e.g. NIR) once the material has been shredded.
Contaminants separation	Contaminants (e.g. paper, ferrous metals) are separated from plastic in cyclone separators and magnets. Liquids/glues can be separated in a wet phase (see below).
Floating/Cleaning	Different types of plastics are separated in a floating tank according to their density. The density of the liquid can be modified to enable separation (e.g. adding salt to water). The wet phase can also be used for washing residuals (e.g. organic)
Extrusion	The flakes /pellets/agglomerates are fed into an extruder where they are heated to melting state and forced through, converting into a continuous polymer product (strand).
Filtering	The last step of extrusion may be filtering with a metal mesh (e.g. 100-300 micron)
Pelletizing	The strands are cooled by water and cut into pellets, which may be used for new polymer products manufacturing.

For mechanical recycling of multilayer plastic waste, its identification is the main challenges. So, it is necessary to carefully sort and classify the multilayer waste before processing it. Various methods are available for the analysis of multilayer materials structures including Near-Infrared Spectroscopy

Near infrared (NIR) spectroscopy shows an enormous potential for the identification of different layers in multilayer materials. Application of NIR spectroscopy for processing of multilayer material can result in fast speed, high efficiency, high stability and accuracy. Usually no sample preparation is necessary to carry out the analysis using this technique. Figure 10 gives an overview of how NIR spectroscopy functions.

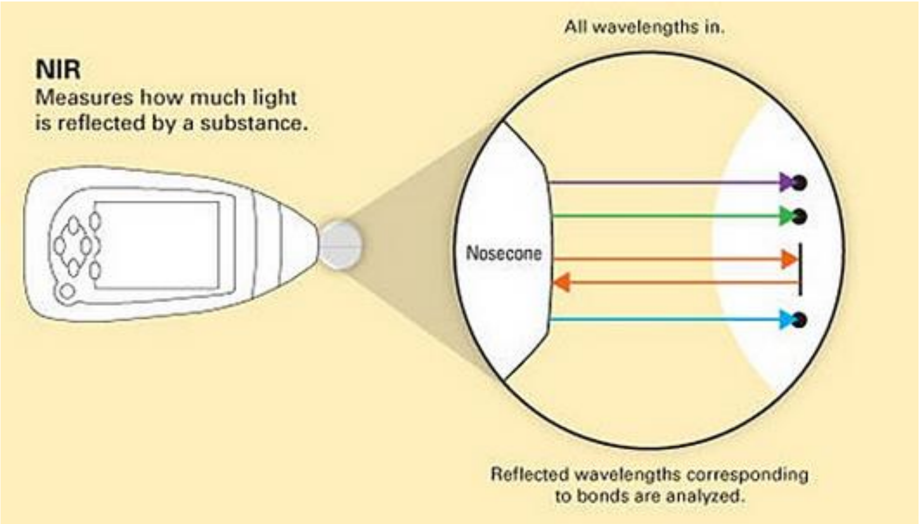

Figure 10: An overview of NIR spectroscopy *(Thermofisher Scientific, 2019)*

In NIR, the sample is illuminated with a broad spectrum (ranges from 780nm to 2500 nm) of near infrared light that can be absorbed, transmitted and reflected by sample of interest. The intensity of light is then measured before and after interacting with the sample which are characteristic for every NIR active bond. The data measured using NIR is then converted into actionable information that can be used for analysis. NIR spectroscopy penetrate much more into a sample so it is not considered as chemically specific as FTIR (Thermofisher Scientific, 2019).

1.3.2 Chemical Processing

Chemical recycling is the process where chemicals are used to degrade polymers to smaller molecules usually monomers, liquids, and gases which can be then used as a raw material (Ignatyev, et al., 2014). Multilayer material with unknown chemical composition is difficult to identify. The section on chemical processing collects a state-of-the-art on techniques such as chemolysis, pyrolysis, fluid catalytic cracking, hydrogen techniques and gasification. Currently there is not any suitable alternative chemical processing method for multilayered packaging. As a result, most of the recycling company prefer tertiary recycling option until there is an any alternatives to multilayer packaging. In case of tertiary recycling of multilayered waste, pyrolysis and gasification are considered as key technologies.

1.4 Aim of study

This work aims to identify different structures of multilayer materials and its recyclability. It presents a challenge to separate layers into mono-materials and it changes to complex blend when mechanically recycled. Embedding circular thinking to improve the circularity of multilayered materials various methods will be discussed for its end of life recycling. So, this research aims to find effective physical and chemical processing of multilayer materials and its challenges.

The thesis aims to answer the following questions.

- How can multilayered materials be identified?
- What are the possible separation techniques?
- What is the end of life treatment of multilayer materials?
- How can the separated materials be processed and reused as a raw material?
- What are the challenges and recycling strategy?
- What is the end use of recycled materials?

2 MATERIALS AND METHODS

2.1 Material details

Materials used in this research were the waste packages collected from the University's restaurant (LUT Buffet) and from households. The waste stream consisted mostly of the packages used for food packaging. In this research all the possible packages that are used commonly are considered and collected. The waste stream collected consisted of different categories of packages such as boxes, slide boxes, pouches and bottles. Figure 11 below shows different types of packages used in this experiment.

Figure 11: Waste packages used in this research

Initially, all the waste was separated into four main groups based on their structure manually. After the separation of waste into different groups, the weight of each group was measured. Table 4 shows the total materials used during the experiment with classified groups and their measured weights. As shown in Figure 12, the packages were separated manually into foils, slide boxes, boxes and bottles. However, at this stage the plastic was only classified on the basis of their structure or appearance.

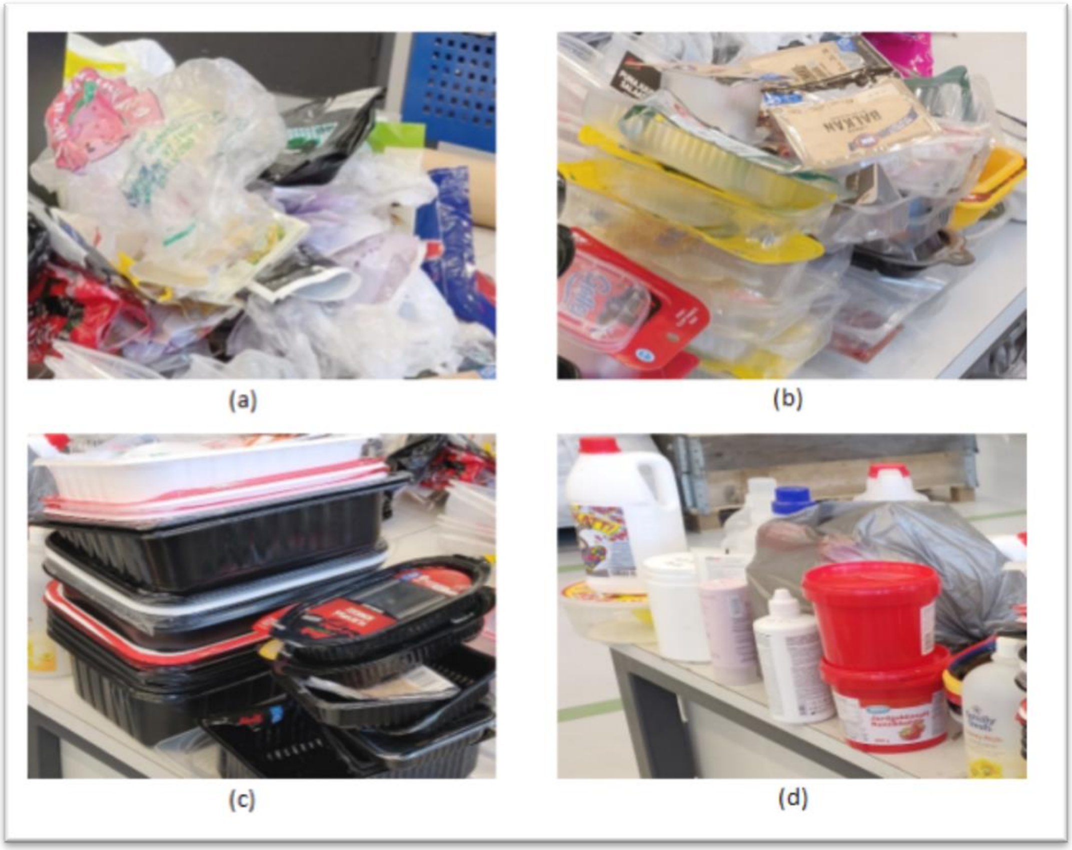

Figure 12: (a) Foils, (b) Slide boxes, (c) Boxes, (d) Bottles

Once the waste streams were classified into four main group, measurement of their weight was carried out.

Table 4: Classification of packages with their weight

S no.	Groups	Weight in gram
1	Foils	355,90
2	Slide boxes	587,95
3	Boxes	1347,90
4	Bottles	1748,69

Table 4 shows the total weight of each classified group that are used to carry out further experiment. There four groups were then used for further distinct classification based on their plastic types.

2.2 Experimental setup

Processing of multilayer packaging waste is a multi-step process. It starts with collection, sorting and separation of collected waste. In this experiment, multi-step process as shown in Figure 9 will be followed for further processing of collected waste. It is necessary to sort different material groups prior to mechanical recycling. Various equipment will be used for further processing of multilayered packaging waste.

2.2.1 Separation procedure

The total waste stream was initially separated into four main group as shown in Figure 12. Those separated waste consisted of different groups of polymers. Initially, the packages were sorted into their respective polymer group based on their resin identification code. There were some packages without the labels or RIC marked on it. In that case, NIR spectroscopy was used to identify the types of polymer used in that packages. In our experiment portable NIR spectroscopy equipment called microPHAZIR Analyzer produced by Thermo Scientific Company was used to identify unknown plastics. The instrument used is shown in Figure 13 below.

Figure 13: Portable NIR spectroscopy equipment

With the help of NIR spectroscopy it was possible to identify and sort all groups of plastic excluding group 7, which consisted multiple layer of plastic groups. After the identification of each packages they were separated into their respective group. Separation procedure using the principle of microPHAZIR Analyzer was simple process. Each unidentified piece of plastic was manually placed on tip of the equipment and trigger was pressed for some seconds for examination.

The tip of the equipment disperses light on the work piece placed on tip of the equipment. Some of the light is absorbed and reflected, the equipment reads the reflected spectrum identifying the polymer type.

2.2.2 Processing Technique

Once specific groups of plastics were classified, it is necessary to obtain granules of the waste stream to conduct further processing method. The separated polymer waste was shredded into small pieces with the low-speed granulator. The granulator available in the Laboratory of Fiber Composites was SG-1635N granulator manufactured by Shini as shown in Figure 14.

Figure 14:Low-speed granulator

In this process the polymer waste was fed through the hopper into the staggered blades where polymer was cut into small pieces in the form of granules. The granules were then collected in the collection box. Granulation of each classified plastic groups were carried out separately with regular cleaning of granulator after each granulation process to avoid mixing of different types of plastics.

Once the granulation process was completed, samples of each group was prepared for further analysis. For the preparation of sample or the test piece, injection molding process was used. The working principle of single screw injection molding is simple and easy.

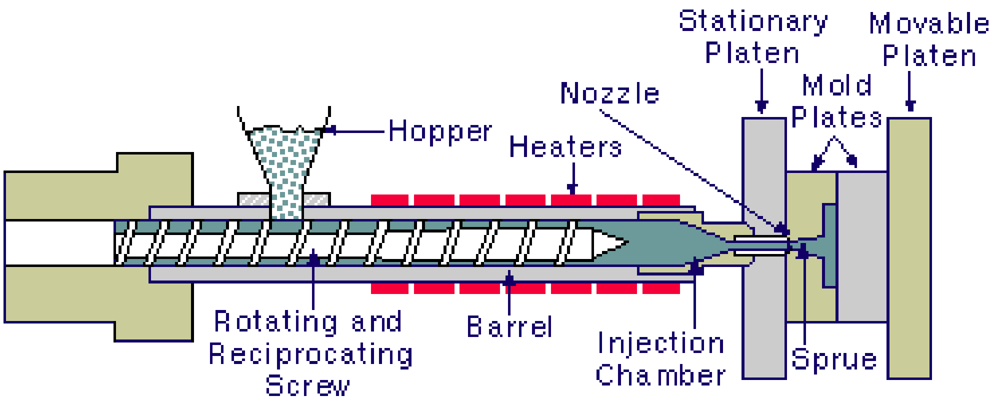

Figure 15: A single screw injection molding machine *(Santa clara University, 2019)*

As shown in Figure 15, the plastic granules are fed through the hopper, which is then carried into the heating chamber with a rotating and reciprocating screw. The plastics are heated, melted and mixed thoroughly with a rotating screw.

Table 5: Specifications of injection molding machine

Specifications	**Values**
Pressure	69 bars
Pump pressure	140 bars
Mold Pressure	112 bars
Melt Temperature	170°C (standard temperature)
Stroke Length	60 mm
Nozzle Temperature	170°C
Injection Time	3 seconds

The injection molding machine used in this experiment was BOY 30. The injection molding machine was a single screw injection molding machine with the specification given in Table 5 above. The plastic which is in the molten state is injected through the nozzle into the mold that results in the final work piece as shown in Figure 16.

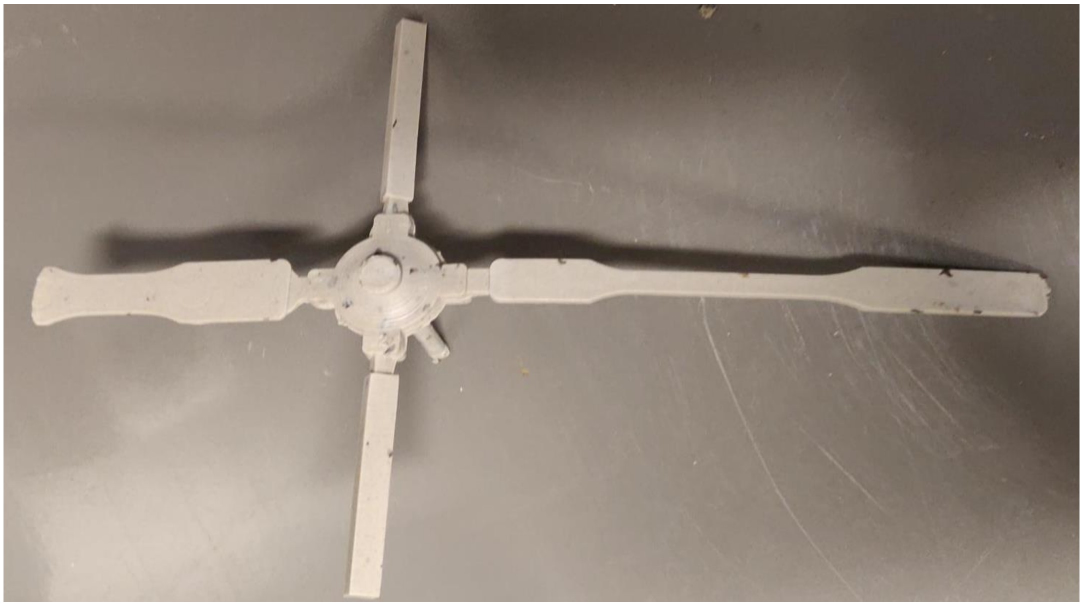

Figure 16: Sample structure of molded plastic

Test sample for all the plastic groups that were granulated was made using injection molding machine. In this experiment 15 samples for each group of plastics were made to perform further analysis.

2.3 Analysis

The behavior of material can be analyzed by different testing methods. It is always necessary to analyze the properties of materials before an application, for quality control or to know materials reaction upon other types of forces. The different groups of plastics used in our experiment also must go through different test so that its physical and chemical properties can be analyzed. There are different methods of analysis to estimate the material properties or behavior. In this experiment three main test was performed to analyze its mechanical and chemical properties, which were Melt flow index (MFI) test, Tensile test and Scanning Electron Microscope (SEM) with Energy Dispersive spectroscopy (EDS) test.

2.3.1 Melt Flow Index

The melt flow index (MFI) test is usually used to identify the viscosity and melt flow rate of plastic resins while it is in a molten state. Different properties of plastics like hardness, density and strength are related with the flow rate of the plastics. In this experiment, Dynisco LMI500 series Melt Indexer was used to analyze the melt properties of the specimens. The main purpose of this test was to gather the information about the density and flowrate of different groups of plastics. The melt indexer instrument used in this experiment is shown in Figure 17.

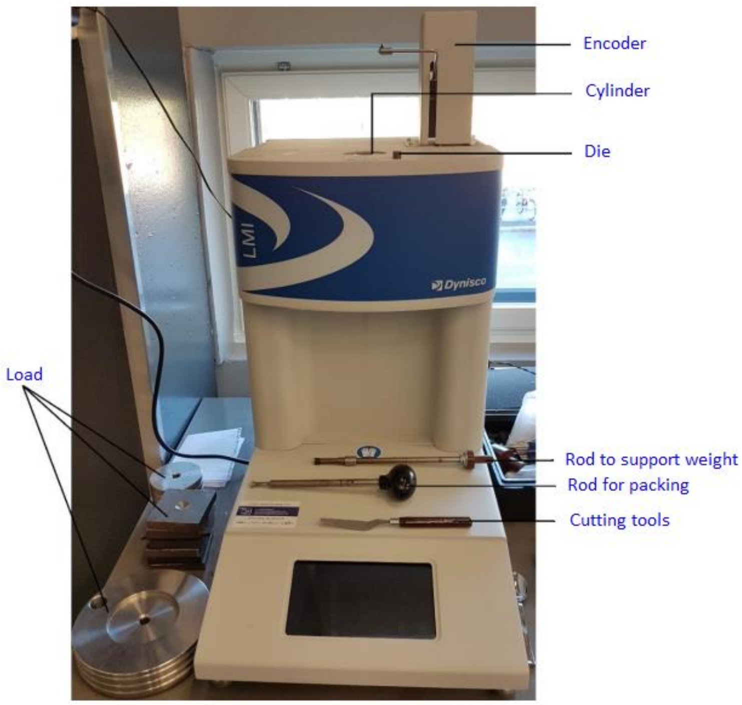

Figure 17: Dynisco LMI500 series melt Indexer

The working principle of Dynisco LMI500 series melt indexer is easy and simple. Initially the die is placed in the bottom of the cylinder and the temperature is set before starting the test. In order to get the standard extruded filament, the standard ISO 1133-1 was followed for the diameter of die. The standard melt temperature was set to 230°C for all the samples. In case some groups of plastics don’t melt at that temperature; it can be changed according to demand. To perform this test, the granules were fed from the top of the cylinder which is packed with the help of packing rod to fill the cylinder as needed. The granules are then kept inside to cylinder and allowed to melt. After some time, the rod with the piston and weight support is placed inside the cylinder. In our experiment we are using the weight of 2,16kg which is placed on the top of the rod. The encoder is raised as the weight is fixed over the rod. The weight placed over the rod forces the molten granules to pass through die in the form of filament. Then the instruction shown in the display panel in then followed properly. The extruded filament is cut manually as directed and the resulted filament is weighted. The resulting weight is recorded in the equipment, which gives MFR (Melt mass flow rate), MVR (Melt volume-flow rate), and density. Three tests for each sample was carried out following the same process and the information were recorded.

2.3.2 Tensile test

The tensile properties of the material is necessary to find the reaction of the materials to resist when force are applied in tension. This test aims to find information about the ultimate tensile strength, tensile elongation, elastic limit and tensile modulus of elasticity . Every materials have different tensile properties which can be determined through tensile testing. Tensile testing produces a load versus elongation curve which is converted into stress versus strain curve (Elsevier Ltd., 2019).

The specimens for tensile testing were manufactured using the injection molding machine which follows the standard EN 527-2/1BA. The sample used in this experiment with its dimensions is shown in Figure 18.

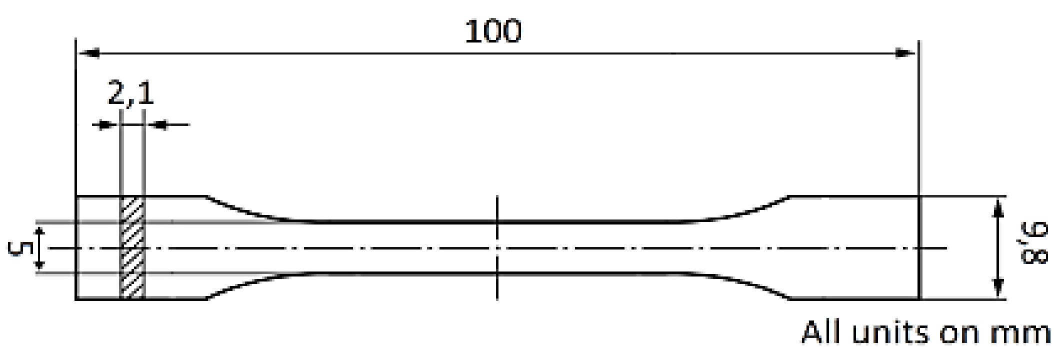

Figure 18: Specimen for tensile test with its dimensions

The samples were kept on a conditioning chamber for more than 16 hrs before tensile test was performed. The conditioning of the chamber was set with the temperature of 23 °C and humidity of 50 % RH. The tensile test was done for 15 samples of each group. The equipment used for tensile testing is Zwick/Roell Z020.

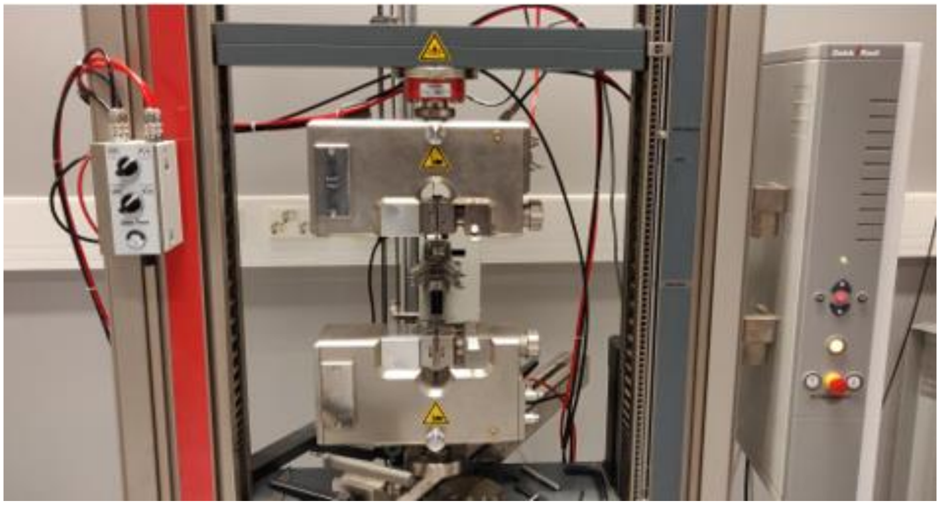

Figure 19: Zwick/Roell Z020 tensile testing equipment

The test sample is clamped between the cross head and the movable head jaws. It is then streched along the major longitudinal axis with constant elongation rate until the test sample breaks. The test mainly measures the amount of force applied and the elongation of the sample. The values obtained from the test are presented in the form of stress-strain curve.

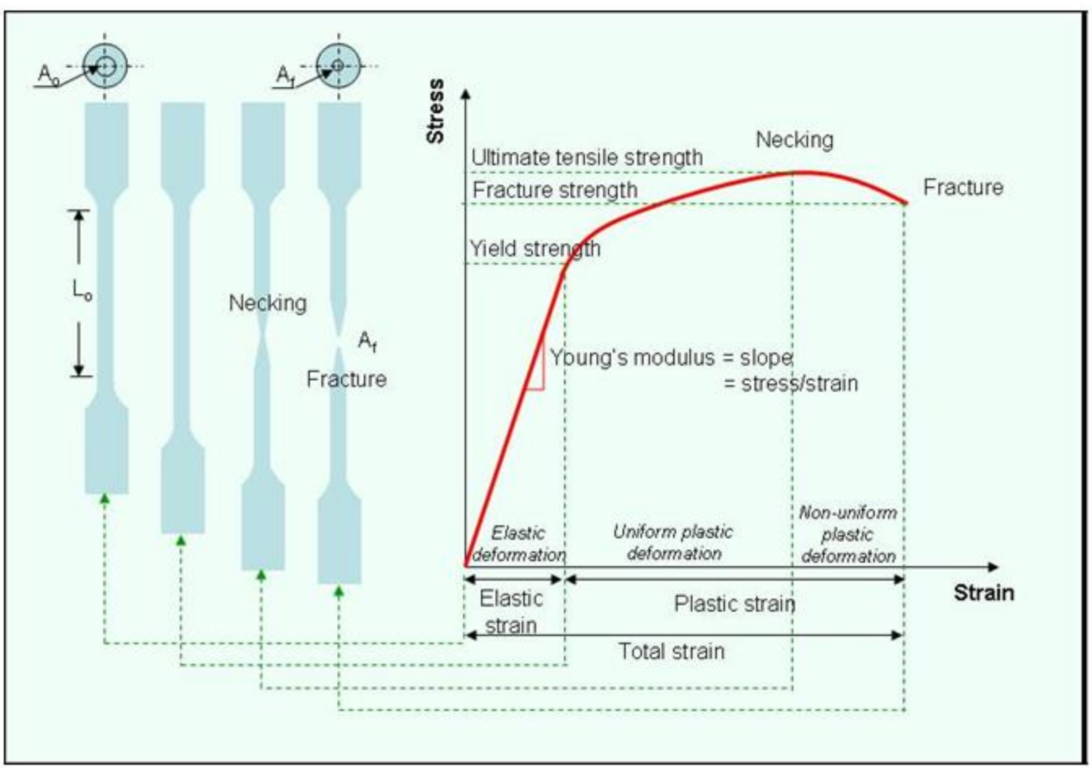

Figure 20: Stress-Strain Diagram *(Faridmehr, et al., 2013)*

2.3.3 Scanning Electron Microscope with Energy Dispersive spectroscopy

Scanning Electron Microscope (SEM) with Energy Dispersive spectroscopy (EDS) can be used to produce detailed high-resolution images of specimen and analyze elemental distribution in the sample. In this research, Hitachi SU3500 Scanning electron microscope is used to perform the test. Information about surface topology of specimens were obtained with SEM. EDS was used to gather the information about elemental composition with their proportion present in each specimen.

Figure 21: Scanning Electron Microscope SU3500 *(Hitachi, 2019)*

The analysis was performed with an accelerating voltage of 15kV to analyze the specimens between the range of 50 micrometer and 500micrometer. Initially, the samples were glued to the specimen stub and then placed inside the specimen chamber. To increase the accuracy of results, an inert atmosphere was created inside the chamber by vacuuming out the air and gases present inside the chamber. Then scanning of specimens were carried out by passing the beam of electrons with certain accelerating voltage. The back scattered electrons are collected to generate the image of the specimen. Magnification and working distance are the variable parameters used to obtain a clear picture of samples topography.

3 RESULTS

3.1 Experimental results

Initially, the waste streams were classified into four categories based on their identification code and using the NIR spectroscopy for those groups of plastics which were not labeled with RIC. The main groups of packages classified were foils, slide boxes, boxes and bottles. Each group has different types of polymer groups in it. The results of the classification of different polymer types is shown in Table 6 below.

Table 6: Classified polymer with its measured weight

Types of Packages	Polymer groups	Weight in gram
Foils	PE	105,29
	PP	37,90
	Group 7	200,83
Slide Boxes	PP	44,36
	Group 7	527,02
Boxes	PP	1043,10
	PE	76,72
	Group 7	214,50
Bottles	PE-HD	682,20
	PE-LD	14,37
	PP	353,36
	PET	468,57

The main groups of plastics identified were PE, PP and PET. Unidentified plastics were sorted as a group with multilayer plastics or group 7. The different types of packages included in Table 8 were then divided into 7 main groups of plastics to carry out further processes.

Figure 22:(a) PP boxes, (b) PP bottles, (c) PE bottles, (d) PP-PE foils, (e) Group 7 foils, (f) Group 7 slide boxes, (g) PET bottles

Figure 22 shows the seven main groups of plastics that were classified on the basis of their specific plastic group. Once all the waste streams were sorted into specific group, granulation of each polymer group was performed. After the granulation process, small granules of individual group of plastic were obtained. Table 7 below shows the weight of plastics after granulation.

Table 7: Weight of granules of each polymer group

Plastic categories	Weight (gram)
Boxes (PP)	1038,8 g
Bottles (PP)	342,83 g
Bottles (PE)	659,40 g
Foil (PE&PP)	135,11 g
Foil (group 7)	201,76 g
Slide boxes (group 7)	510,67 g
Bottles (PET)	453,98 g

Figure 23:(a) PP Boxes, (b) Group 7 slide boxes, (c) Group 7 foils, (d) PP Bottles, (e) PE bottles, (f)PET, (g) Foils other than group 7

3.2 Results of analysis

This section includes the results gathered via MFI test, tensile test and Scanning Electron Microscopy with Energy Dispersive Spectroscopy (SEM-EDS). The data obtained is used to evaluate the material properties and performances. Melt flow rate (MFR) and Melt volume rate (MVR) are evaluated using MFI method. Tensile test was used to obtain the information about tensile strength, Young's modulus and elongation. Finally, SEM-EDS test result has been performed to obtain information about surface morphology and chemical elemental composition.

3.2.1 Melt flow index

The melt properties obtained using the equipment Dynisco LMI500 series Melt indexer are MFR (Melt flow rate) and MVR (Melt volume flow rate). The melt properties are determined according to the standard ISO 1133-1. MFI test was carried out to measure the ease of flow of molten plastic. The MFI test helps to know how well or poorly the material flows when the material is heated up to specific temperature and specific weight is placed to push the plastic through the die. Standard temperature of 230°C was set to perform this experiment. However due to high melting temperature of some plastic groups, variation in temperature and weight can occur. The test condition used for all groups of plastic are shown in Table 8 below.

Table 8: Melt flow index conditions

Material	**Weight used (Kg)**	**Temperature(°C)**
PP boxes	2,16	230
PP bottles	2,16	230
PE bottles	2,16	230
PP-PE foils	2,16	230
Group 7 foils	2,16	275
Group 7 slide boxes	5,00	275
PET	2,16	275

The general concept that can be obtained from the result of MFI test is that material with low melt flow has higher mechanical strength and material with high melt flow rate has lower mechanical strength. Following the test conditions mentioned in Table 8, MFI test was carried out and the results are shown in Table 9 below.

Table 9: MFI test results

Material	**MFR (G/10min)**	**MVR (CC/10min)**
PP boxes	2,96	4,42
PP bottles	19,69	32,54
PE bottles	3,27	8,18
PP-PE foils	5,34	7,39
Group 7 foils	12,91	18,13
Group 7 slide boxes	22,25	46,41
PET	48,39	36,66

The result shows that PP and PE has relatively lower MFR and MVR values as compared with PET and group 7 plastic. Figure 24 and Figure 25 below shows the comparison of MFR and MVR of different plastic groups.

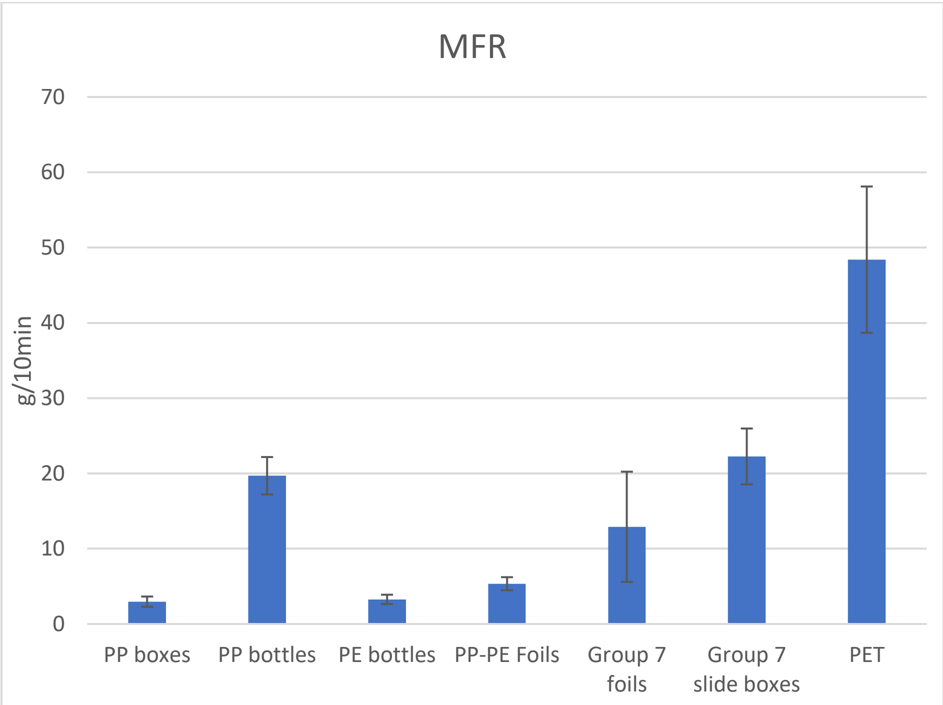

Figure 24: MFR results

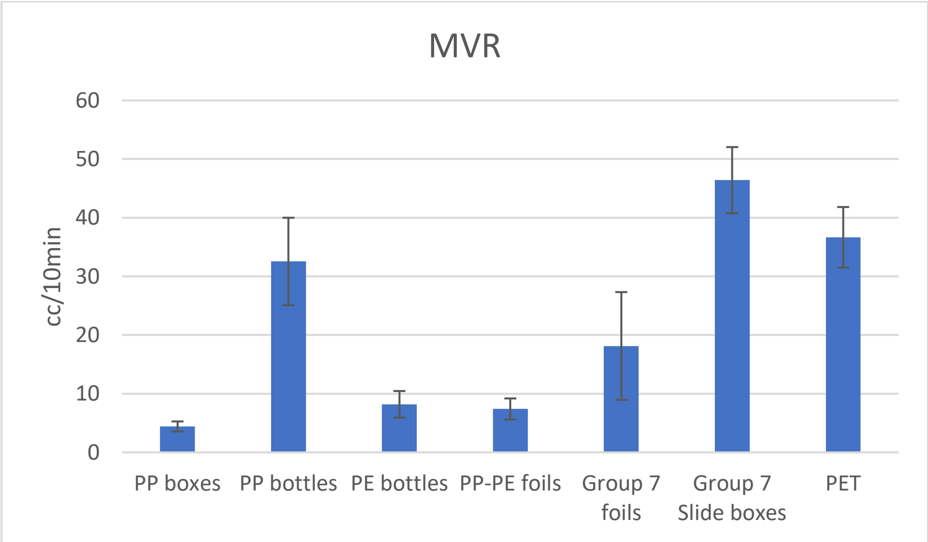

Figure 25: MVR results

During the MFI test, the densities of each specimens were also calculated. The density was calculated using the mass and volume of sample piece. Five samples were taken for each group to get the average density for each plastic group. The comparison chart of densities of each group of plastics are shown in Figure 26 below.

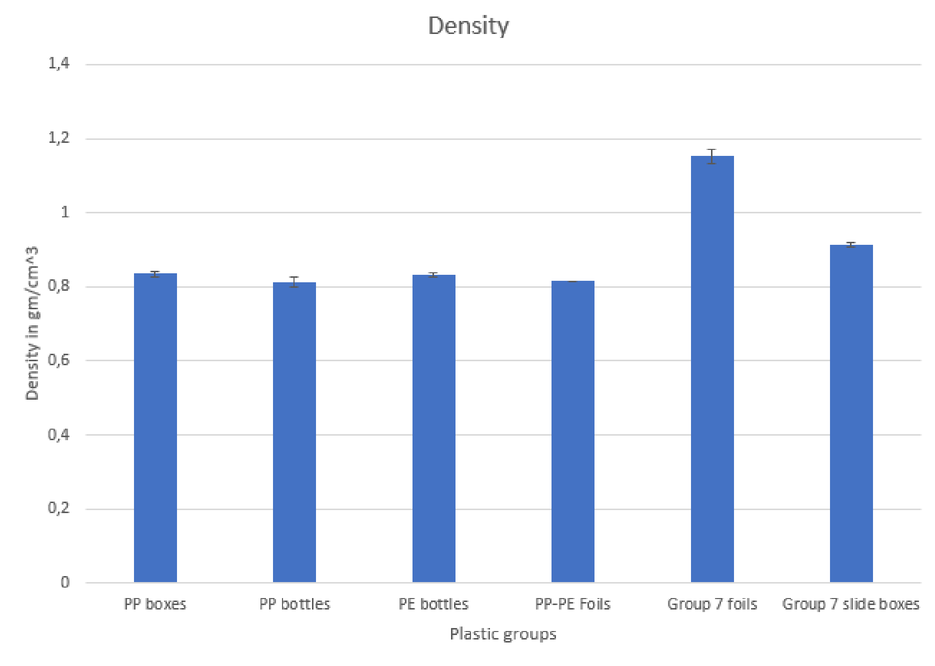

Figure 26: Density results

The result shows that excluding group 7 slide boxes, all other groups of plastics have the similar density as compared with virgin plastics of that group. It shows that multilayer materials have relatively higher density than other plastics.

3.2.2 Tensile test

Tensile test was performed for all categories of plastics to find the durability of materials under stress. 15 specimens were taken for each group of plastics to perform the tensile test. Standard DIN EN ISO 527-1 and the specimen type EN527-2/1BA was used to perform the tensile test. The average results were then obtained for each group of plastics. The main properties of material obtained from tensile test are tensile strength, modulus of elasticity and elongation. Figure 27 below shows the ultimate tensile strength (MPa) and standard deviation of all types of plastics used in this experiment. From the graph it can be seen that PP bottles has the highest tensile strength with tensile stress value of 30,538 MPa whereas Group 7 foils has the least tensile strength with 9,7611 MPa. However, slide box of group 7 has good tensile strength of 25, 69 MPa

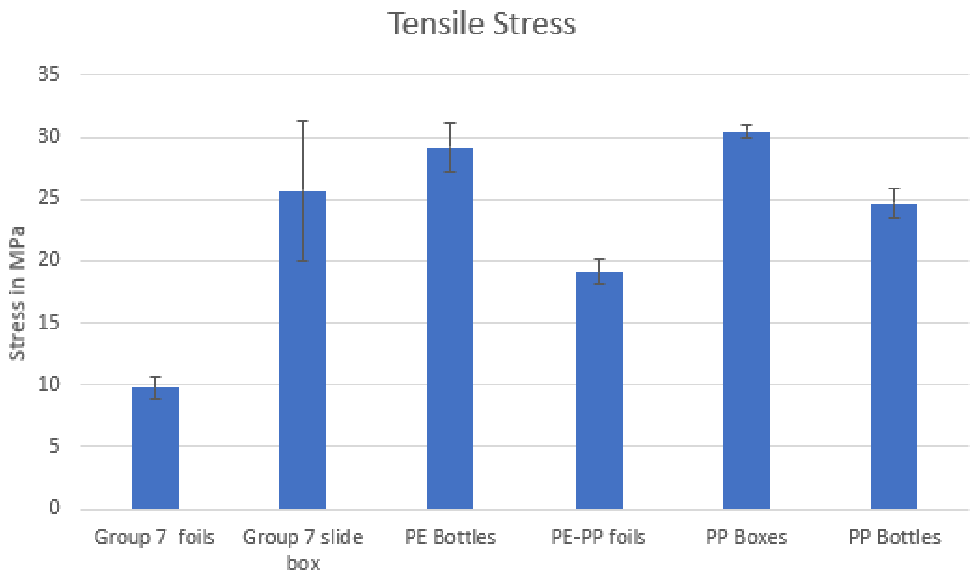

Figure 27: Comparison of ultimate tensile strength

For the analysis of stiffness of specimens, comparison of modulus of elasticity (E_0) was performed for all categories of plastic groups from strain 0,05% to 0,25%. The result shows that group 7foils has the least modulus of elasticity followed by PP-PE foils. PE and PP has satisfying result as compared with virgin materials. The result with the comparison of Young’s modulus is illustrated in Figure 28.

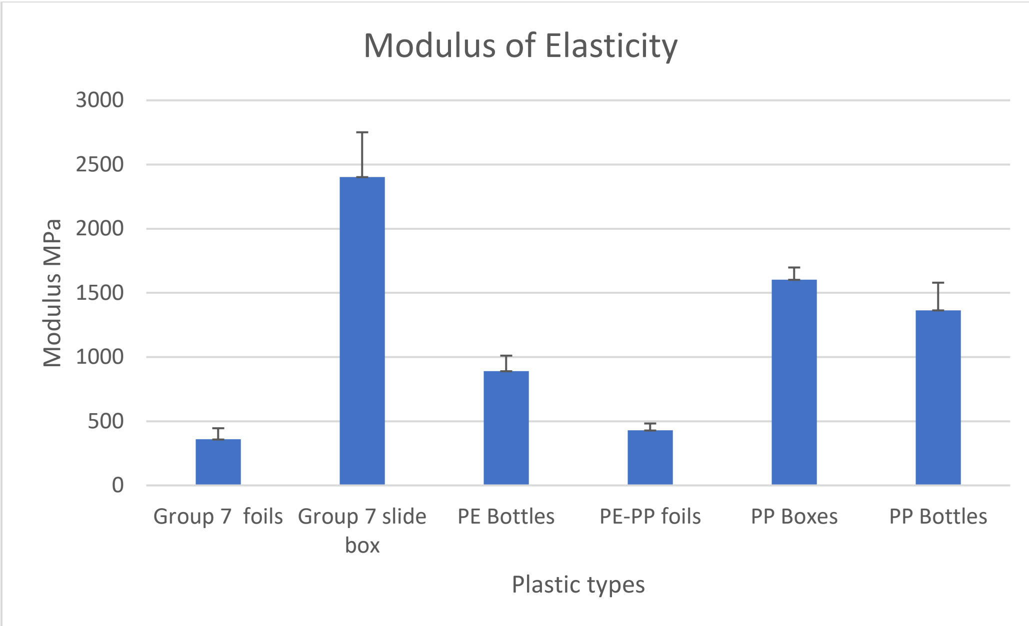

Figure 28: Comparison of modulus of elasticity

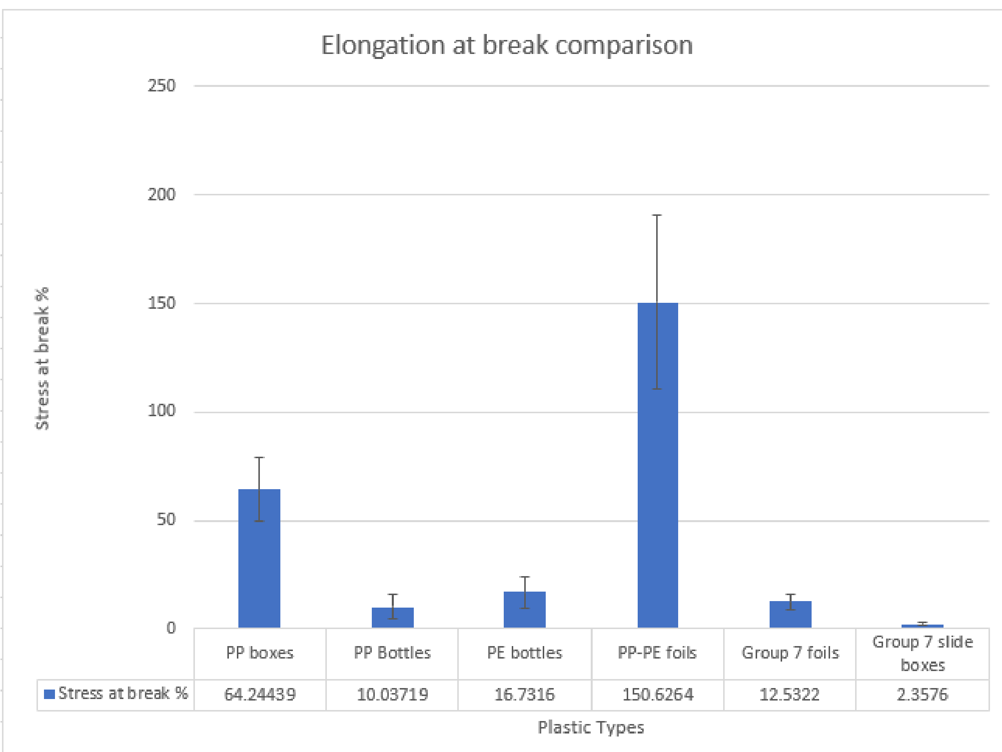

Figure 29: Comparison of elongation at break

Figure 29 shows the Elongation at break (ε_M) or fracture strain results of all groups of plastics. The result show that PE-PP has comparatively very high elongation at break value. Group 7 slide boxes has the least elongation at break. However, elongation at break value of group 7 foils looks good as compared with group 7 slide boxes which shows it has the better capability to resist changes of shape without crack formation. From the elongation at break result it can be seen that beside PP boxes and PP-PE foils, all other groups have very less elongation at break which means they have poor resistance to change shape without cracking.

Table 10 below shows the shows the mechanical properties of all group of plastic calculated from the tensile test.

Table 10: Mechanical properties determined from the tensile test

No.	Material	Area [mm^2]	σ_M [MPa]	ε_M [%]	E_0 [MPa]
1	PP boxes	10,66	9,76	64,2	1602,50
2	PP bottles	10,86	24,62	10,03	1364,2
3	PE bottles	10,57	29,16	16,73	890,21
4	PP-PE foils	10,24	19,15	150,62	428,58
5	Group 7 foils	10,12	9,76	12,53	358,55
6	Group 7 slide boxes	10,53	25,69	2,35	2402,69

To simplify the idea about the tensile comparison of all groups of plastic included in this research, the result was compared between each other. The results of the stress test were obtained based on stress-strain curve of each material. Figure 30 below shows the stress-strain curve of all groups of materials.

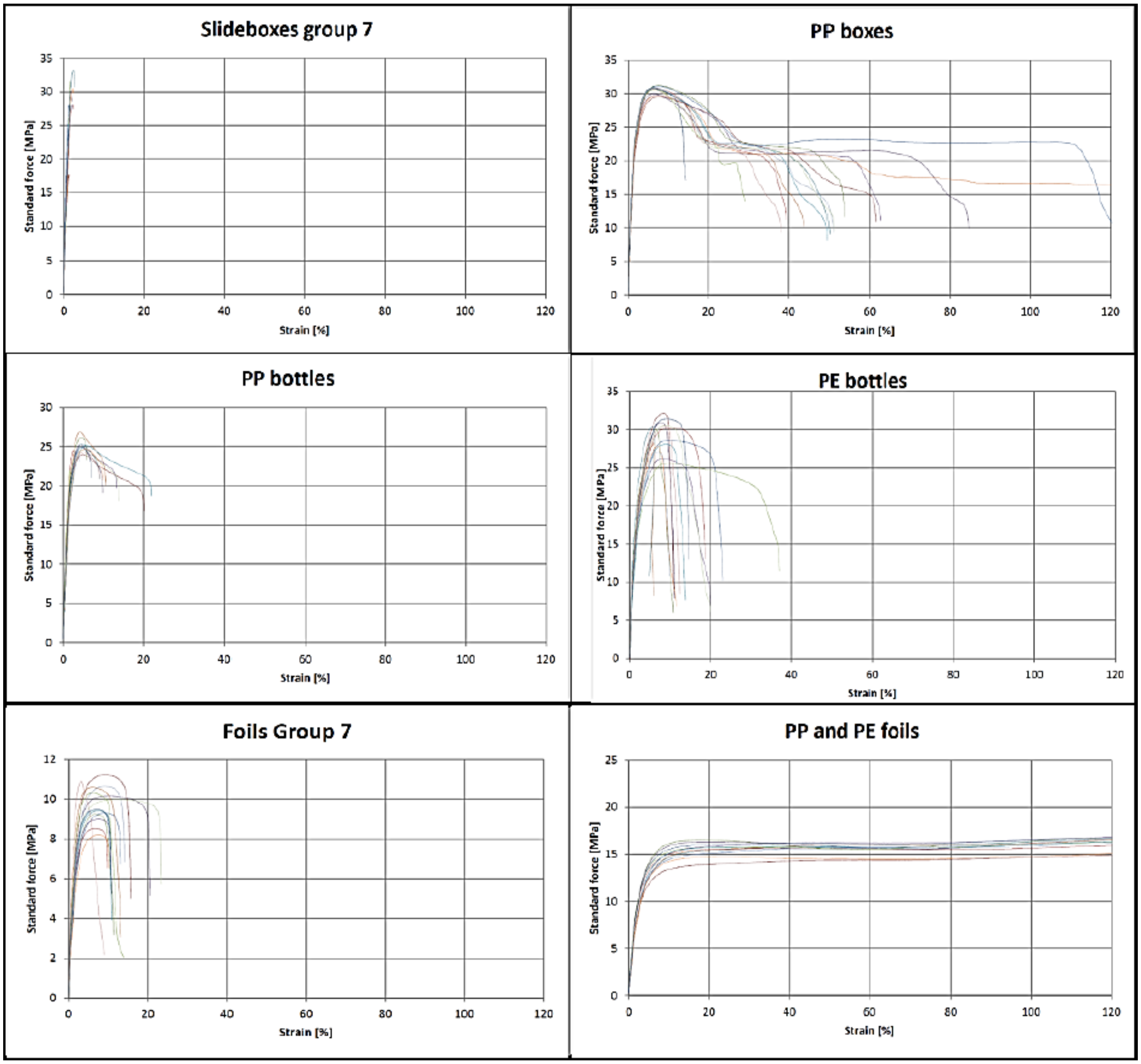

Figure 30: (a) Stress-strain curve of slide boxes group 7, (b) Stress-Strain curve of PP boxes, (c) Stress-Strain curve of PP bottles, (d) Stress-Strain Curve of PE bottles, (e): Stress-Strain curve of Group 7 foils, (f) Stress-Strain curve of PP-PE foils

3.2.3 SEM-EDS Results

Scanning electron micrographs obtained from the cut piece of specimens shows how porous the materials are and what are the different impurities present in it. For a closer view on surface of each groups of plastics the analysis of scanning microscopic structure was performed. Two samples for each group were scanned to obtain six different results for each plastic group. The results obtained helps to find a lot of particles and pores in different shapes and sizes.

The surface topography of group 7 foils obtained with SEM is shown in Figure 31. Due to presence of different foreign materials and multiple groups of plastics blended together, the surface is uneven and indicates low immiscibility among multiple groups of plastics. Group 7 foils combines all groups of resins together, it is difficult get strong bond between all the groups of plastics while processing it. As a result, there are many cracks on its surfaces with non-uniform distribution of particles. The specimen also consists of a larger number of cavities

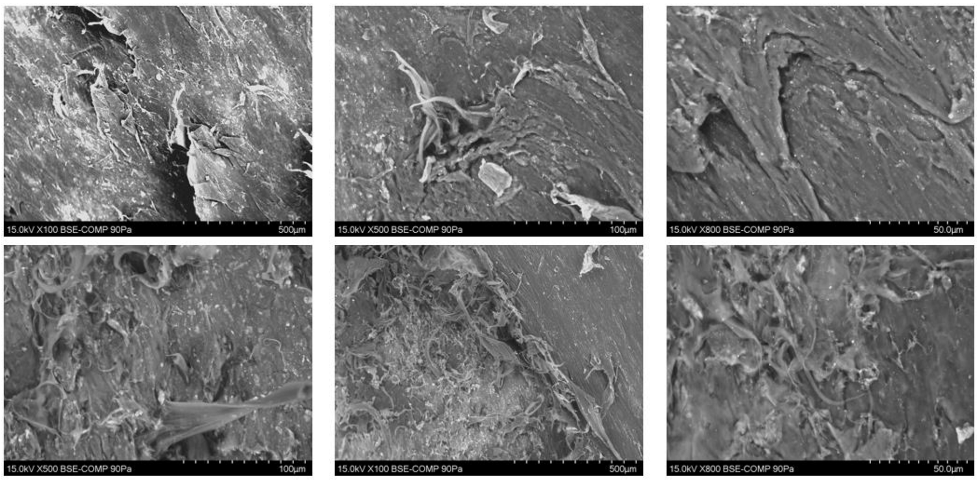

Figure 31: Microscopic images of Group 7 foils

Figure 32 below shows the close view of the group 7 slide boxes. The result shows different inclusions, impurities, and foreign materials are present in the specimens. The microscopic image shows there are very few cracks and fractures resulting in the uneven surface of specimen.

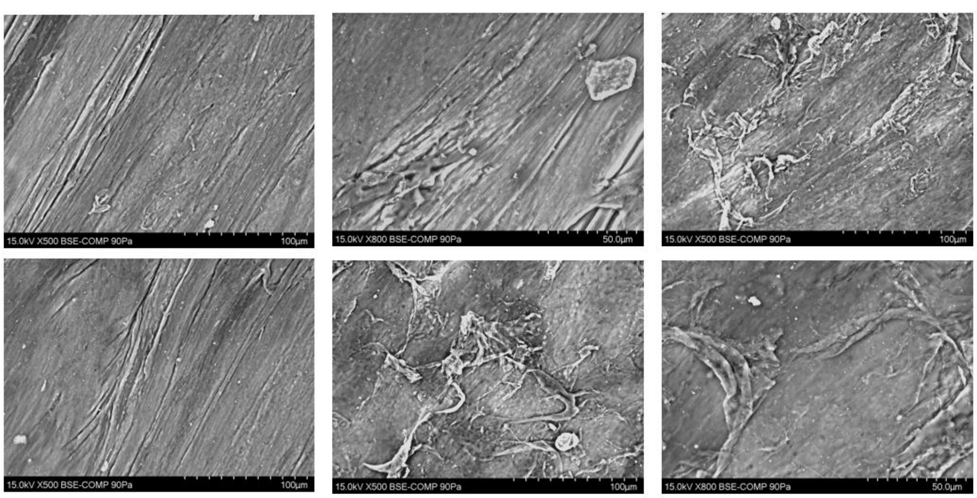

Figure 32: Microscopic images of Group 7 slide boxes

Figure 33 below shows the microscopic images of PE bottles. As seen in the result there are some impurities present on the surfaces. Although the specimens are prepared completely from recycled PE bottle there can be some impurities from the adhesives or paper stickers used in the bottles.

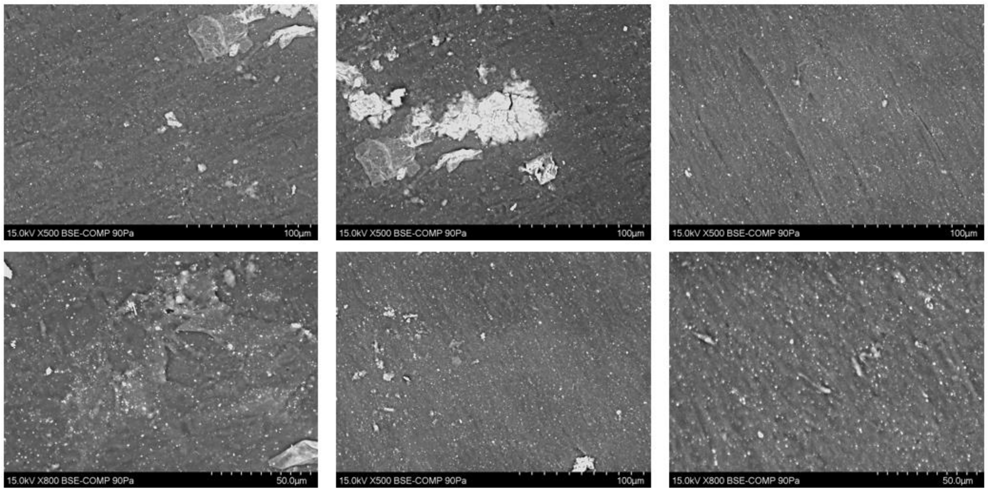

Figure 33: Microscopic images of PE Bottles

Figure 34, Figure 35 and Figure 36 below shows the microscopic image of PP-PE foils, PP boxes and PP bottles respectively. In all specimens shown below, the surface looked more evenly with presence of negligible fractures and cracks as compared with group 7 plastic specimens. However, there are still some impurities present on the surfaces.

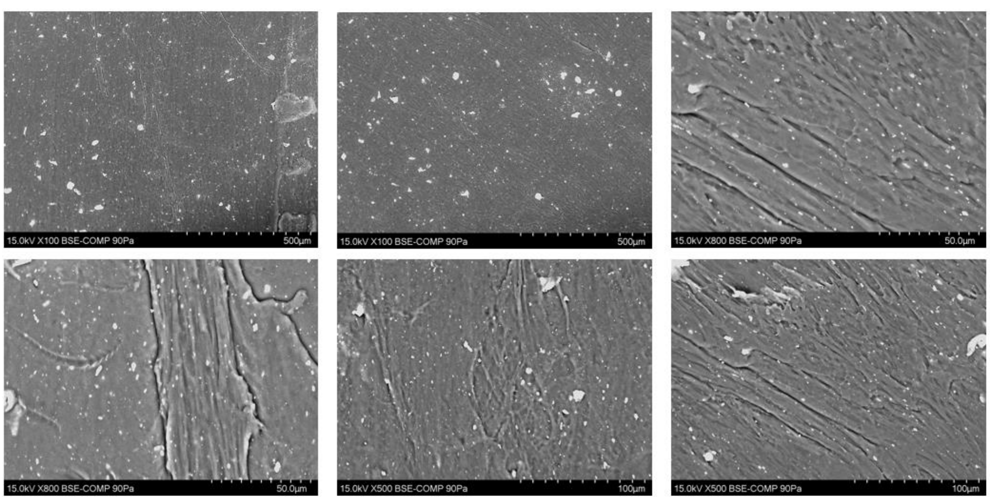

Figure 34: Microscopic images of PE-PP foils

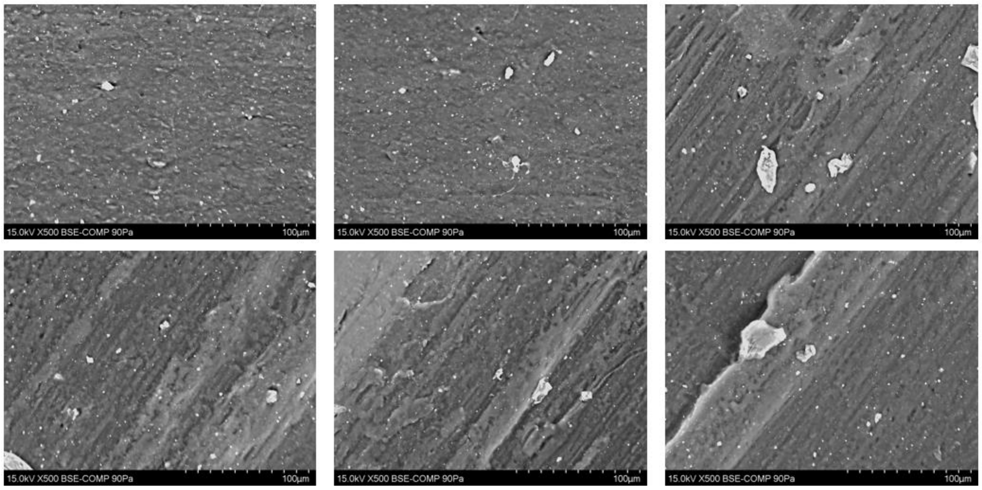

Figure 35: Microscopic images of PP boxes

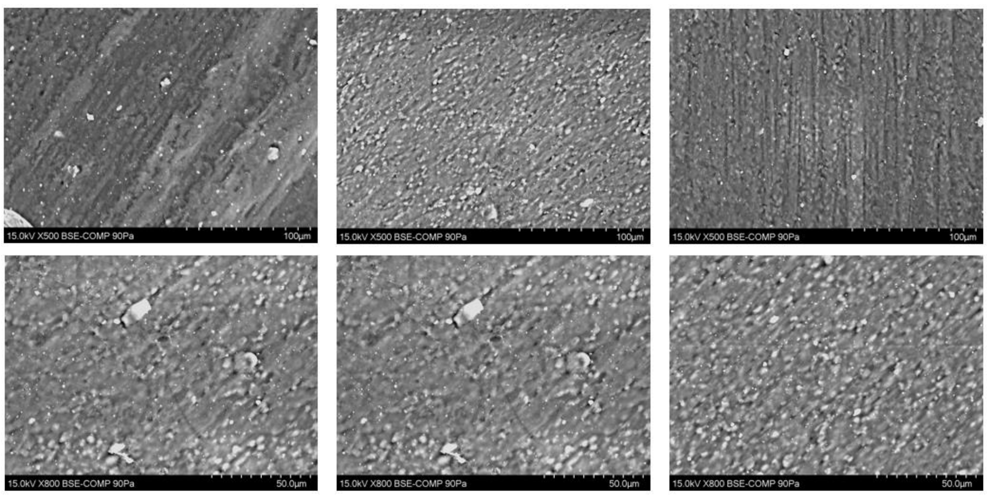

Figure 36: Microscopic images of PP bottles

The elemental composition of different test material and its distribution and relative intensity of elements over the scanned area is obtained from Energy Dispersive Spectroscopy (EDS). The result helped to analyze different chemical constituent present in the specimen of each group.

Table 11: Elements present in Group 7 foils

Element	Group 7 Foils		
	Line Type	**Weight %**	**Weight % error**
Carbon	k	77,83	0,39
Nitrogen	k	10,24	0,26
Oxygen	k	8,90	0,07
Sodium	k	0,13	0,01
Magnesium	k	0,02	0,01
Aluminum	k	0,37	0,01
Silicon	k	0,10	0,00
Sulphur	k	0,04	0,01
Chlorine	k	1,26	0,02
Potassium	k	0,17	0,01
Calcium	k	0,09	0,01
Titanium	k	0,84	0,01
Palladium	k	0,0	0,03

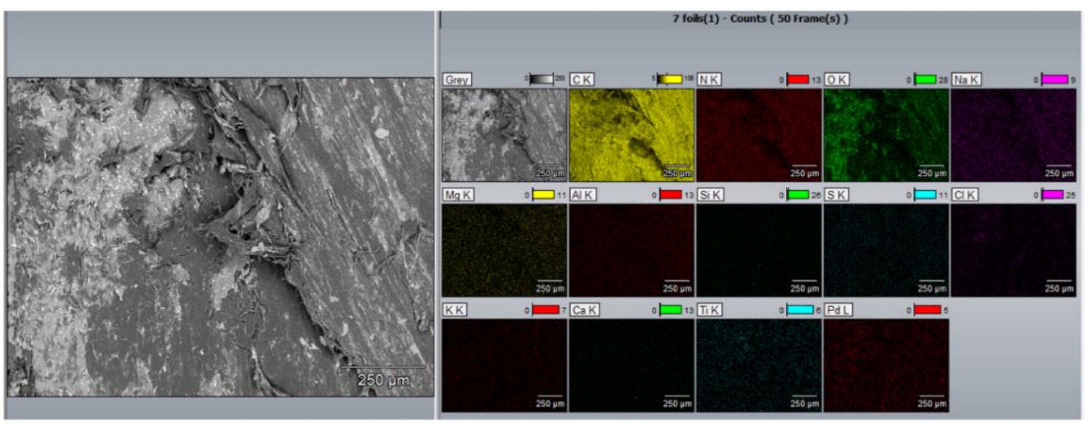

Figure 37: Distribution and relative intensity of elements over the scanned area

Group 7 foils, which consisted of different groups of plastic has various element present in it as expected. As seen in Table 11, carbon has the biggest volume followed by nitrogen and oxygen. There is presence of chlorine, which seems quite unusual in normal plastics.

Table 12: Elements present in group 7 slide boxes

Element	Group 7 Slide Boxes		
	Line Type	**Weight %**	**Weight % error**
Carbon	k	77,66	0,22
Oxygen	k	21,03	0,10
Sodium	k	0,08	0,01
Magnesium	k	0,04	0,01
Aluminum	k	0,62	0,02
Silicon	k	0,10	0,01
Chlorine	k	0,07	0,01
Potassium	k	0,09	0,01
Calcium	k	0,14	0,02
Titanium	k	0,16	0,03

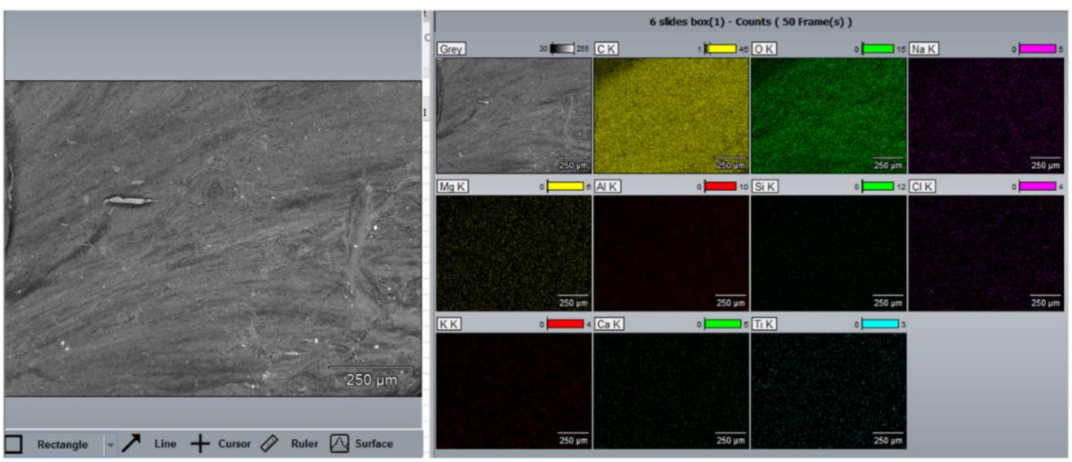

Figure 38:Distribution and relative intensity of elements over the scanned area of group 7 slide boxes

Table 12 above gives the information about different elements present in group 7 slide boxes. The result shows that this group also has carbon as its main constituent followed by oxygen. This group also has presence of chlorine in it. However, the volume seems less than in foils of group 7. Multilayer materials are bonded using different additives that resulted in the presence of numerous elements in group 7 plastics.

Table 13- Table 16 below gives the elements present in PE bottles, PP-PP foils, PP boxes and PP bottles. All the groups have carbon as its major content as expected. The other elements present in all the groups is due to the additives or other foreign impurities present in it.

Table 13: Elements present in PE bottles

Element	**PE Bottles**		
	Line Type	**Weight %**	**Weight % error**
Carbon	k	99,11	0,22
Aluminum	k	0,28	0,01
Silicon	k	0,06	0,00
Potassium	k	0,04	0,001
Calcium	k	0,12	0,001
Titanium	k	0,39	0,02

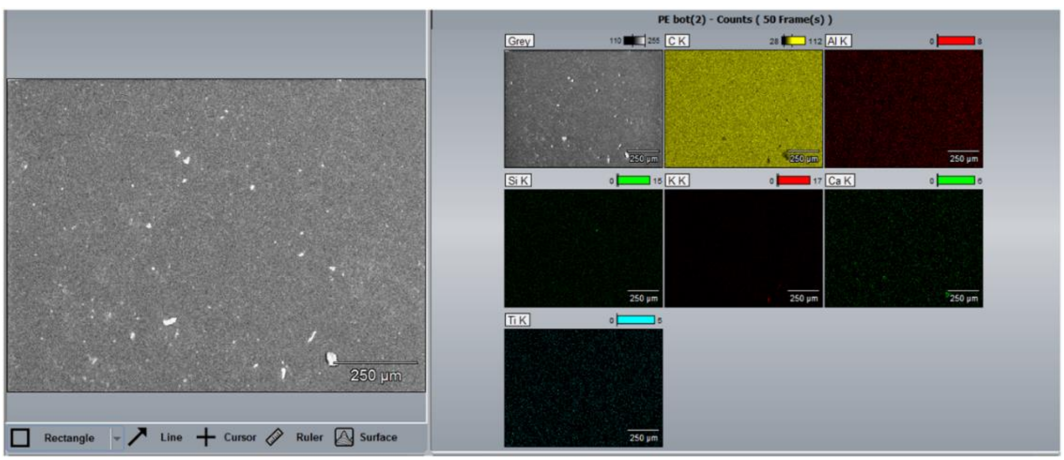

Figure 39: Distribution and relative intensity of elements over the scanned area pf PE bottles

Table 14: Elements present in PE-PP foils

Element	PP-PE foils		
	Line Type	**Weight %**	**Weight % error**
Carbon	k	99,36	0,22
Aluminum	k	0,21	0,01
Silicon	k	0,05	0,00
Potassium	k	0,06	0,01
Calcium	k	0,05	0,01
Titanium	k	0,28	0,01

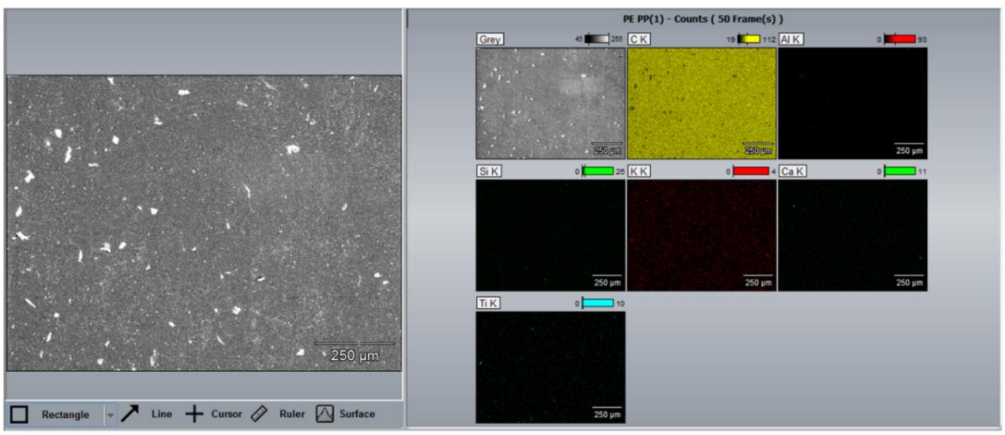

Figure 40: Distribution and relative intensity of elements over the scanned area of PE-PP foils

Table 15: Elements present in PP boxes

Element	PP Boxes		
	Line Type	**Weight %**	**Weight % error**
Carbon	k	99,06	0,22
Magnesium	k	0,03	0,01
Aluminum	k	0,30	0,01
Calcium	k	0,22	0,01
Titanium	k	0,13	0,03
Barium	L	0,26	0,07

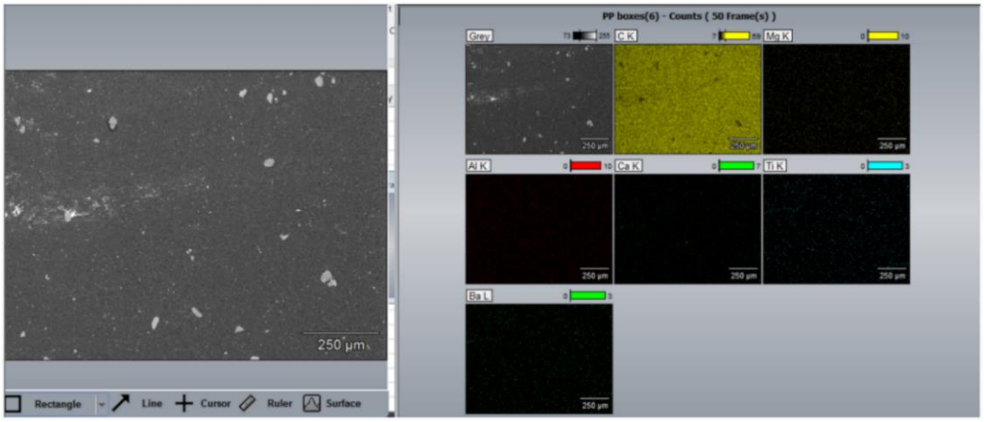

Figure 41: Distribution and relative intensity of elements over the scanned area of PP boxes

Table 16: Elements present in PP bottles

Element	PP Bottles		
	Line Type	**Weight %**	**Weight % error**
Carbon	k	99,11	0,22
Magnesium	k	0,05	0,01
Aluminum	k	0,62	0,01
Silicon	k	0,11	0,01
Calcium	k	0,11	0,01

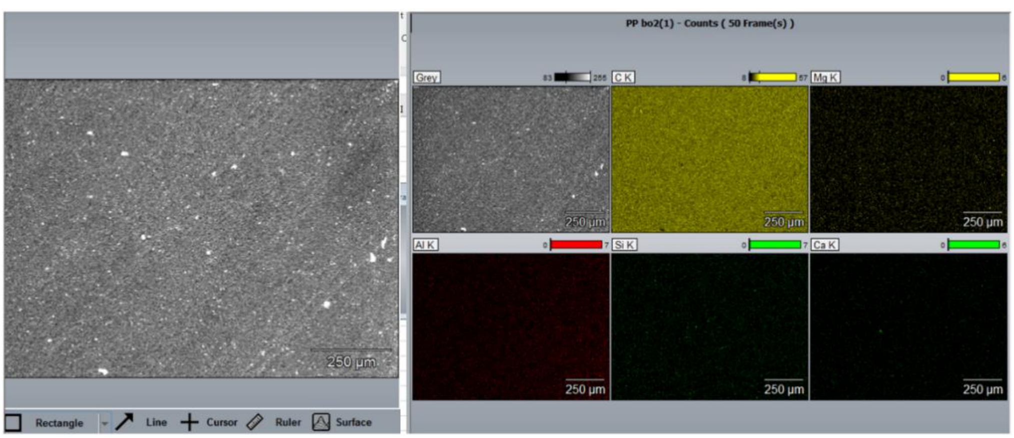

Figure 42: Distribution and relative intensity of elements over the scanned area of PP bottles

4 DISCUSSION

The experimental work shows that waste stream consisted of different polymer groups used for various purposes in the form of slide boxes, foils and bottles as shown in Figure *22*. The results obtained after sorting the waste stream shows large volume of multilayer materials with unknown polymer groups used for the purpose of packaging. It was difficult task to identify and characterize multilayer materials based on its content. Mieth, et al. (2016) conducted a research to identify and characterize the composition of multilayer film which provided information in details about the general composition of multilayer matrials and its characterization process. The reaseach showed the presence of various forign elements and different plastic groups in multilayer materials.

Another research made by Kaiser, et al (2017) investigated about the possible recycling method of polymer based multilayer packaging. They concluded with the result that there are two possible options to recycle multilayered packages.The first option is to delaminate all the layers and recycle them in separated recycling streams. The other option is to process them together in one compatibilization step. Practically, the proposed delamination process is suitable only for limited groups of multilayer materials and is not economic recycling method. On the other hand, compatibilization method is also not effective as there are fluctuations in the composition of post consumer which cannot gurantee the quality of recycled product.

However, until today, there has not been any research made on the processing of multilayer materials obtained from post-consumer packaging waste. In this experiment the waste stream was sorted into 7 different groups as shown in Table 7. The shredded granules from the waste were then utilized to carry out further processing methods. With the precise measurement and considerable care, the melt flow index test, tensile test and SEM-EDS was carried out. As group 7 plastics doesn’t have available reference to compare its mechanical properties, it’s properties will be compared with the reference from other groups of plastics (PP and PE).

The results of MFI test as shown in Table 9 was performed with the test condition mentioned in Table 8. Plastics with higher viscosity will increase the flow per unit time and have lower melt flow index value and vice versa (Baijal & Sturm, 1970). The result shows that PET and group 7 slide boxes has relatively higher MFI values whereas PP boxes has the least MFI values. This means PP boxes consist of the most viscous materials and PET consist of less viscous materials in comparison with other groups. The melting point of PET was higher than the standard melt flow temperature used (230°C), so for PET and group 7 plastics the temperature was increased to 275°C. Elamr, et al., (2015) investigated about the effective recycling condition of PET. The result from the research suggested that for effective MFI result it is necessary to remove all the moisture content of PET and should not exceed 0,005%. In case of group 7 plastics, the melt flow rate is higher than PE and PP whereas it's lower than PET. This suggest that multilayer materials have average viscosity as compared with other groups of plastics.

In the next step granules of each plastic groups were molded with the injection molding machine to create the specimen for further analysis. The machining parameters of the injection molding machine was optimized to ensure high quality and productivity. The standard parameter as shown in Table 5 was used to perform the process. Except for PET, molding of all other groups of plastics were performed successfully. PET has relatively higher melting point as compared with another group (around 260°C). Considering this fact into account the temperature of injection molding machine was set to 275°C. However, the outcome was not as expected, and molding of PET was a failure. Further study helped to figure out two possible reason for the failure of PET molding process.

1. The barrel temperature of injection molding machine might not be uniformly heated to meet the required melting point. PET melts at 260°C and cools quickly to pour in a mold. This means PET can get cooled down during the hold time and can block the nozzle.
2. PET is hygroscopic so it is easily attacked by water molecules at melt processing temperature. In this experiment water bottles were used to prepare the PET granules. Awaja & Pavel (2005) made a research about PET recycling and came with the conclusion that PET with moisture content when processed at high temperature can get aggressively hydrolyzed into tar blocking the nozzle. Pre drying of hygroscopic material stored outside is needed to keep moisture level low in the injection molding system. It is recommended that PET should be dried at the temperature of 120°C -130°C for 4 hours before performing the injection molding process. It is necessary to have less than 0,02% of moisture content to successively perform the injection molding of PET. Hydrolysis of PET due to the

moisture reduces the IV (*Intrinsic Viscosity*) that can tend to fail at injection point or produce product that are brittle (Haynie, 2019).

The specimen prepared was used to perform the tensile test to evaluate the mechanical properties of all groups of plastics. The results obtained from the tensile test are shown in Table 10. In this experiment tensile test of four main groups were performed which are PP, PE, PP-PE and Group 7 plastics. From the stress-strain curve shown in Figure 20 it suggests that increase in strength will decrease the elongation at break and vice-versa. The properties comparison of recycled PP and PE with their respective virgin plastic is shown in Table 17 below.

Table 17: Properties comparison of recycled plastic with virgin plastic

Physical Properties	**PP**			**PE**	
	Virgin PP (Yin, et al., 2013)	**PP boxes**	**PP bottles**	**Virgin PE** (Ashby, 2013)	**PE bottles**
Density (g/cm^3)	0,90-0,91	0,835	0,81	0,91-0,94	0,83
σ_M [MPa]	25-33	9,76	24,62	21-45	29,16
E_0 [MPa]	1103-1600	1602,50	1364,2	620-860	890,21
Elongation at break (%)	100-600	64,2	10,03	200-800	16,73

In case of recycled PP boxes, the tensile strength is lower than virgin PP, but young's modulus is almost equal with virgin PP. Whereas for recycled PP bottles the tensile strength and young's modulus both are slightly less than that of virgin PP. In a research made by Yin, et al. (2013) , the mechanical properties of virgin and recycled PP were studied. It also concluded that recycled PP had lower tensile strength and Youngs modulus than virgin PP. However, slight improvement in the mechanical properties can be enhanced with mixed 50% recycled PP and 50% virgin PP.

Physical properties data of virgin PE published by Ashby (2013) was used to compare the physical properties of our recycled PE bottles. The result shows that tensile strength of recycled PE bottles was almost equal as virgin PP with slight increase in the Youngs modulus meaning there was very less deterioration in its mechanical properties.

In case of PP-PE, results from tensile test showed it has a poor tensile strength of 19,15 MPa, Young's modulus of 428,58Mpa and elongation at break of 150,92%. In an investigation made by Turku, et al. (2017) it was found that the tensile strength of PP-PE composites can be remarkably improved by increasing PP content. Tai, et al. (2000) also studied about the impact behavior of PP-PE blends and its result suggested that both PP/LDPE and PP/HDPE blends have similar impact strengths which is lower than that of PP homopolymer. They also concluded with the remarks that impact fracture behavior depends upon the impact test employed.

Group 7 materials consisting of multilayer materials were divided into two groups as foils and slide boxes. The tensile test result showed big difference in the physical properties between them. In case of group 7 foils it has poor tensile strength of 9,76 MPa and Young's modulus of 358,55 MPa. Tensile strength of group 7 slide boxes was 26,69 MPa, almost three times that of group 7 foils and is equal to that of virgin PP and PE. However, it very large Young's modulus of 2402,69 MPa as compared with all other groups of plastic included in this research. The elongation at break values of both foils and slide boxes were 12,53% and 2,35% respectively, which is very low in comparison with other groups. This suggest that recycled multilayer material results in very ductile and brittle product. However, the tensile strength seems quite satisfying. Mechanical properties of multilayer material are dependent on the miscibility of the system. As multiple plastics do not mix spontaneously at the melt state, the end product mechanical properties is directly proportional to the dominant polymer present in the blend (Ragaert, 2017).

Maja, et al (2016) researched about the effect of molding temperature on the morphology of PP-PET blends and microfibrillar composites. The researcher stated that mechanical properties of mixed blend is dependent upon adhesion between matrix and reinforcement and length/thickness ratio of reinforcing element.

The result from SEM-EDS test was used to study surface morphology and chemical composition of the specimen. The surface morphologies of all plastic groups were investigated using scanning electron microscopy. SEM results showed that there was presence of impurities on the surface of all groups of plastics. This suggest that thorough cleaning of granules is very necessary to avoid any kind of contamination before processing it. The solution to avoid this problem can be such that granulated flakes can be passed through caustic hot wash process in order to remove impurities such as surface dirt, paper labels and its adhesives (Forrest, 2016).

The SEM result in Figure 31 and Figure 32 shows that group 7 plastics has cracks and fractures on its surface. and Group 7 plastics might consist of multiple polymer blend including hygroscopic plastics such as Nylon, Polycarbonate (PC) and PET which is responsible to change the physical characteristics of it while processing and results in the surface cracks and fracture (Bozzelli, 2010). So, drying of every specimen is necessary to avoid change in physical characteristics. Also, the processing temperature is responsible to change the physical characteristics and morphology of group 7 plastics (Maja, et al., 2016). Multiple plastics with different melting temperature are complex to blend together. So differential scanning calorimetry (DSC) testing can be carried out to study the behavior of group 7 plastics as a function of time or temperature. The result from DSC analysis can help to evaluate the melting temperature of group 7 plastics, which can be effective while performing the injecting molding process.

The result from EDS result for group 7 showed the presence of different elements as compared with other groups. Interestingly there was presence of chlorine in both slide boxes and foils of group 7. PVC (Polyvinyl chloride) contains chlorine (Petrovic & Hamer, 2017). This concludes that PVC was used to manufacture those multilayer packages. Other than group 7 all other groups of polymers have carbon as the main elements (more than 99%). Presence of some other elements can be from the additives and stickers used in the packages. According to research of Mieth, et al (2016), Sodium chloride (NaCl), Calcium carbonate ($CaCO_3$), Silicon oxide (SiO_2) and Wollastonite minerals ($CaSiO_3$) are the major additives that can be used in packages which resulted in presence of calcium, silicon, oxygen and chloride in the specimen. This suggest that the recycled polymer of all groups of plastics must be cleaned and dried properly before processing to eliminate presence of foreign elements. Especially for multilayer materials proper recycling strategy must be adopted to get the best results after processing it.

5 CONCLUSION

The studies have been carried out in academic which have demonstrated that processing of all groups of plastics can be carried out. According to the current state of the art, multilayer packages are not allocated to distinct sorting stream. Decent sorting of waste stream is an important task to produce high quality recycled products. The experiment shows that it is time consuming and complex process to separate multilayer packages from the waste stream. The NIR spectroscopy seems helpful to separate specific groups of plastic packages that were without RIC labelled on it. However, in large scale recycling purpose it is not economic and reliable method to separate multilayer packages from other groups of plastics. In addition, limited studies have been performed to study the behavior of multilayer materials under different environmental conditions.

The test performed in this research concludes that temperature is an important factor affecting the mechanical properties and morphology of the product. An investigation to find suitable processing temperature will also undoubtedly improve its mechanical properties. The result showed that recycled group 7 polymer has good tensile strength and modulus of elasticity as compared with other recycled mono materials. However, it has poor elongation at break values which concludes that it is hardly deformed and breaks at low strain. This is due to filler and matrix adhesion at the interface which can be seen from the SEM results. During the mechanical processing of multilayer material complex immiscible blends is formed and it is challenging to predict the precise composition of the blend. The matrix is most likely formed by the dominant polymer, so mechanical properties is reliant on the miscibility of final blend.

Finally, there is still room for further improvement in future. Thorough cleaning and proper drying of multilayer waste will help to remove impurities. Study about multilayer materials behavior as a function of temperature using DSC analysis can help to find suitable processing temperature. Proper investigation for the mitigation of the immiscibility problem can also lead to improved recycled product. Nonetheless, under a scientific approach, recycling of multilayer materials was found to be achievable.

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