PREPARATION AND CHARACTERIZATION OF r-PP/PLA BIODEGRADABLE THERMOPLASTIC BLEND

This report is submitted in accordance with requirement of the University Teknikal Malaysia Melaka (UTeM) for Bachelor Degree of Manufacturing Engineering (Hons.)

by

NURUL SHAFFIQA BINTI MOHD NAZILAH

FACULTY OF MANUFACTURING ENGINEERING

2022

DECLARATION

I hereby, declared this report entitled "Preparation and Characterization of r-PP/PLA Biodegradable Thermoplastic Blend" is the result of my own research except as cited in references.

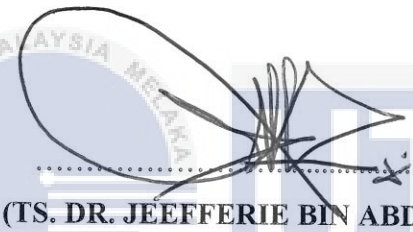
Signature : .....

Author's Name : NURUL SHAFFIQA BINTI MOHD NAZILAH

Date : 30/06/2022

APPROVAL

This report is submitted to the Faculty of Manufacturing Engineering of Universiti Teknikal Malaysia Melaka as a partial fulfilment of the requirement for Degree of Manufacturing Engineering (Hons). The member of the supervisory committee is as follow:



19/7/2022

(TS. DR. JEEFFERIE BIN ABD. RAZAK)

ASSOCIATE PROFESSOR TS. DR. JEEFFERIE BIN ABD. RAZAK
CEng IMechE ; P.Tech MBOT
Faculty of Manufacturing Engineering
Universiti Teknikal Malaysia Melaka (UTeM)
Hang Tuah Jaya,
76100 Durian Tunggal,
Melaka, Malaysia.

ABSTRAK

Pada masa kini, produk mesra alam dan biodegradasi mendapat permintaan tinggi. Walau bagaimanapun, masalah pencemaran plastik yang semakin meningkat akibat pembuangan yang meluas tidak akan berakhir tanpa penyelesaian jangka panjang. Oleh itu, adalah layak untuk mengembangkan bahan canggih baru yang dapat menyumbang kepada pembangunan lestari dengan menggunakan campuran termoplastik biodegradasi r-PP / PLA. Lebih-lebih lagi, plastik yang terbuat dari pati jagung, yang dikenali sebagai asid polylactic (PLA), juga 100 peratus terbiodegradasi. Sementara itu, polipropilena kitar semula dibuat dari polipropilena dara dan dikitar semula. Polipropilena kitar semula (r-PP) dan asid polylactic (PLA) diadun bersama menggunakan kaedah pengadun dalaman (campuran. Campuran termasuk campuran berasaskan termoplastik akan mendapat banyak manfaat daripada kemasukan kompatibilizer kerana ia akan meningkatkan sifat mekanikal dan fizikal dengan berkesan. Reka bentuk eksperimen (DOE) - faktorial penuh dua tahap digunakan sebagai pendekatan eksperimen untuk mengoptimumkan parameter pemprosesan untuk ujian eksperimen. Nisbah campuran (r-PP: PLA), suhu (° C), masa pencampuran (mins), dan kelajuan pemutar (rpm) adalah beberapa pemboleh ubah (rpm). Nilai R2 hampir 1.00, yang cukup untuk mewakili model regresi linier yang dicadangkan untuk meramalkan parameter interaksi optimum tindak balas kekuatan tegangan dan tindak balas lenturan rPP/Campuran PLA. Seterusnya, Hasil morfologi fasa campuran r-PP / PLA untuk keserasian dan sebahagiannya dapat dilihat diperhatikan oleh Scanning Electron Microscope (SEM). Gabungan optimum parameter pencampuran dan nisbah campuran didapati dapat mempengaruhi morfologi fasa kecil dan meningkatkan ketidakcocokan separa antara polimer rPP dan PLA, untuk sifat kekuatan tegangan dan lenturan maksimum.

ABSTRACT

Nowadays, environmental friendly and biodegradable products are in high demand. However, the growing problem of plastic pollution as a result of widespread disposal has no end without any long-term solution. Therefore, it was feasible to develop a new sustainable advanced material that can contribute to sustainable development by using the r-PP/PLA biodegradable thermoplastic blends. Moreover, plastic made from corn starch, known as polylactic acid (PLA), is also 100 percent biodegradable. In the meantime, recycled polypropylene is made from virgin polypropylene and recycled. Recycled polypropylene (r-PP) and polylactic acid (PLA) were blended together utilising the melt blending (internal mixer) method. The mixture including thermoplastic-based blends would benefit greatly from the inclusion of the compatibilizer because it would effectively improve mechanical and physical properties. Design of experiment (DOE) - two level full factorial was used as the experimental approach to optimise the processing parameter for the experimental test. Blend ratio (r-PP: PLA), temperature (°C), mixing time (mins), and rotor speed (rpm) are some of the variables (rpm). The value of R^2 was almost 1.00, which was sufficient to represent the proposed linear regression model for forecasting the optimal interacting parameters of the tensile strength response and flexural response of rPP/PLA blends. Next, The result of r-PP/PLA blend's phase morphology for compatibility and partially miscible was observed by the Scanning Electron Microscope (SEM). The optimum combination of mixing parameter and the blend ratio was found able to effect the morphology of minor phase and improve the partial miscibility between the rPP and PLA polymer, for maximum tensile and flexural strength properties.

DEDICATION

my beloved father, Mohd Nazilah bin Ibrahim

my appreciated mother, Radziah binti Bardan

my adored sister, Nurul Shazwani Adha and Husnul Hidayah

for giving me moral support, money, cooperation, encouragement and also understandings

Thank You So Much & Love You All Forever

ACKNOWLEDGEMENT

In the name of ALLAH, the most merciful and gracious. I am grateful to God for all the possibilities, tribulations, and courage that have been Bestowed upon me as I work through the difficulties of completing the thesis. I pray that I am able to successfully complete this final year assignment with flying colour result.

Next, I also want to give special thanks to my respected supervisor, Ts. Dr. Jeefferie Bin Abd. Razak for the great mentoring and guidance that was given to me throughout the study. He has encouraged me positively and with a kind heart to complete this study. It had been an incredible opportunity to have him as my supervisor.

Finally, I want to express my appreciation to supportive and wonderful family that give a good moral support for me while undergoing this study. I am thankful for everyone for the kindness and help during the process for completing this study. I really appreciate it.

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

DOE	-	Design of Experiment
SOP	-	Standard operating procedure
r-PP	-	Recycle Polypropylene
PLA	-	Polylactic acid
PP-g-MAH	-	Maleic anhydride-grafted polypropylene
SEM	-	Scanning Electron Microscope
ASTM	-	American Society for Testing and Materials
Tg	-	Glass of transition temperature
Tm	-	Melting point
AMTES	-	N-(6-aminohexyl) aminomethyltriethoxysilane
FTIR	-	Fourier transform infared

LIST OF SYMBOLS

cm	-	Centimetre
m	-	Metre
%	-	Percent
g/cm^3	-	Grams per centimetre cube
wt. %	-	Weight percent
mm	-	Millimetre
MPa	-	Mega Pascal
GPa	-	Giga Pascal
°C	-	Degree Celsius
kg.cm3	-	Kilogram centimetre cube
kg	-	Kilograms
mm/min.	-	Millimetre per minute
rpm	-	Revolution per minute
kN	-	Kilo newton
W	-	Sample width
y	-	Geometry correction factor
S	-	Span length
a	-	Notch length
B	-	Sample thickness
Wt	-	weight
CO2	-	Carbon dioxide

CHAPTER 1
INTRODUCTION

This chapter had briefly explained related background on the study of preparation and characterization of r-PP/PLA biodegradable thermoplastic blends. From this chapter, a special attention has been given to the background of study, objectives, problem statement, scope of study, significance and importance of study, organization of the report, and an overall summary of the research work. The motivation of conducting this study also was fully explained and several novelty statements related to this research work have also been emphasized.

1.1 Background of Study

Global attention has been given towards ecological sustainability on reducing and mitigating environmental pollution. Plastic waste generation and massive disposal have become a critical phenomenon. Yearly, about 400 million tons of plastic-based products are manufactured globally, and 79% of all massive plastic disposal has ever made ends up in landfills or as litter in the municipal area (Sandrine Ceurstemont, 2020). Therefore, various efforts have been taken to preserve the environment by increasing global awareness toward saving mother-earth. In 1983, Canada has launched the Blue Box Recycling system to encourage citizens' awareness to recycle plastic wastes (Hintons, 2018). Till now, this approach has been widely utilized on a global basis. Meanwhile, England has begun charging for the use of plastic bags starting in the year 2015. As a result, plastic bag utilization had overwhelmingly decreased by almost 80% in England over that period of time (Hintons, 2018). Next, around 23% of the approximately five billion tonnes of waste plastic in our world are estimated to be polypropylene as shown in Figure 1.1. Recycling is the only option

available to mitigate this never-ending issue. Therefore, this approach has been extensively practiced worldwide and had certainly proven in enhancing sustainability by reducing carbon emissions and waste generation by minimizing the use of plastics.

Figure 1.1: Plastic waste retrieved (Gwyn D'Mello, 2019)

Polymers combines synthetic organic chemicals of extremely large macromolecules built from multiples of basic chemical units called monomers (Britannica, 2021). The two primary polymer classifications are thermoplastic and thermoset. In this study, plastic under the category of thermoplastic was utilized. Thermoplastic is obtained from various sources, including petroleum and plant-based products such as plants, fruits, and animals. Along with thermoplastics, biopolymers are also being employed as a matrix material for composites that are entirely biodegradable in the natural environment (Manral et al., 2021). There is various type of thermoplastic material, including polypropylene, polystyrene, polycarbonate, polymethylmethacrylate, and many others. In this study, thermoplastic polypropylene was used.

The r-PP is an abbreviation for recycled polypropylene, and this is a recyclable thermoplastic material. According to Doug Smith, (2017), in the year 2014 itself, more than $80 billion polypropylene worth was manufactured. Meanwhile, for the year 2023, the market value is expected to be overshoot into $133.3 billion. In addition, the strategic collaboration between Procter and Gamble and Pure Cycle Technologies has been made in July 2017. This collaboration was directly attributed to the one billion pounds demand of r-PP yearly, which amounted to about 720 million pounds (Rick Leblanc, 2019). As a natural by-product, the raw material needed, and the energy consumption is minimized for safer

environment. Hence, the amount of waste polypropylene that was dumped at landfills can be controlled (Matei et al., 2017). Therefore, the r-PP is widely being used for many applications such as food containers, industrial fibers, and many others.

The degradation of plastic materials is highly dependent to the exact environmental conditions to which they are subjected. When a polymeric material exhibits a considerable loss of characteristics over time due to environmental influences such as light, heat, and moisture, it is referred to as degradable polymer (Chi Wang et al., 2018). Thus, biodegradable material contributes to waste reduction, and it was environmentally friendly. Several examples of degradable polymers, that are available in the market are likes PLA, PHBV, and etc.

The PLA is an abbreviation for polylactic acid. PLA is one of the most promising bioabsorbable polymers. The monomers of PLA can be manufactured from a non-toxic and naturally occurring organic acid (Shady Farah, 2016). Wallace Carothers had discovered it in 1932, by heating the lactic acid under the vacuum and extracting condensed water. Initially, only low-density PLA was manufactured (Joseph Flynt, 2017). Finally, by using lactide as raw material and the ring-opening polymerization process, a higher density form of PLA was synthesized (Joseph Flynt, 2017). Additionally, PLA is widely used renewable and biodegradable polyester. PLA has demonstrated the potential to exchange the standard petrochemical-derived polymers in industrial applications and could act as biomaterial-based for various medical applications (Shady Farah, 2016). It is also reported that the PLA also are among the most consumed bioplastic material worldwide in the year 2010 (Hintons, 2018).

Polymer modification through blending is being developed to improve the polymer properties while also minimizing the cost of synthesizing a new type of polymer. Various approaches of polymer modification are possible, as illustrated in Figure 1.2.

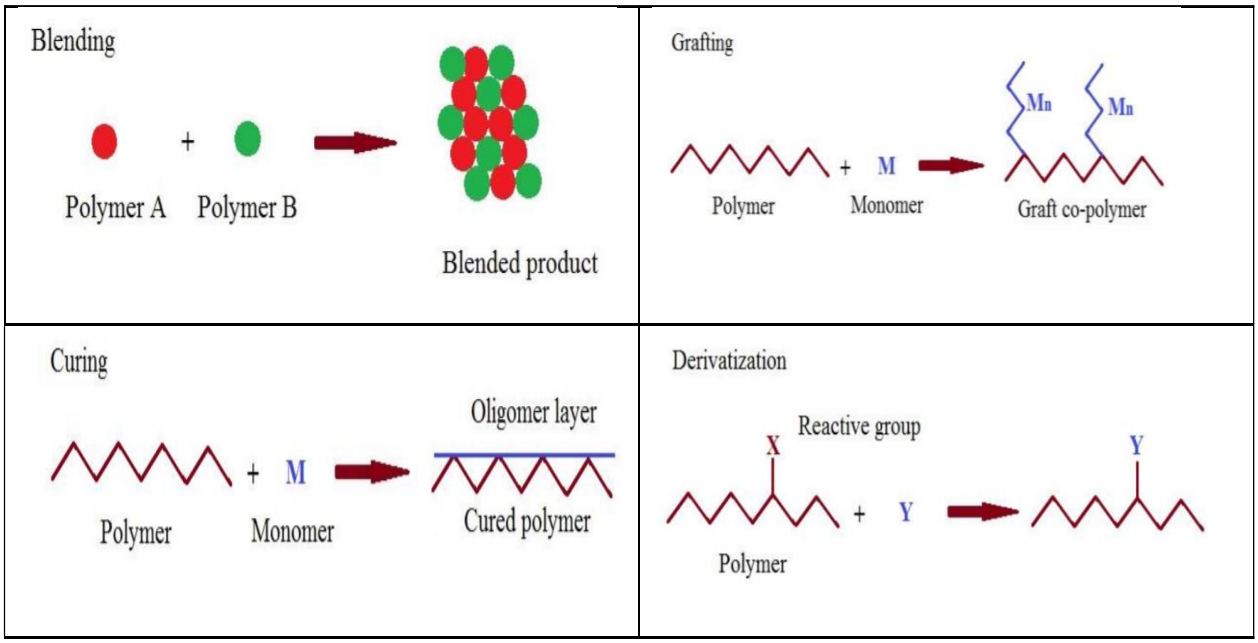


Figure 1.2: Polymer modification approach (Tosh and Routray, 2014)

The difference between these polymer approaches, a polymer blend is a combination of two or more polymers in order to generate a new advanced material (Sabzi, 2018). Next, polymer grafting is a method that involves covalently bonding monomers and polymerizing them as side chains to the main polymer chain and acting as a backbone (Sherazi, 2016). Next, polymerization is a process of linking molecules, and curing agents that are typically chosen to provide the optimal mix of temperature and time to dissolve completely for the specific product. Last but not least, derivatization is widely utilized when gas chromatography (GC) is used to analyse compounds which have low volatility, poor thermal stability, contains "active" groups which can occur in sample loss (Wang et al., 2020). Therefore, the blending approach is highly recommended for polymer modification, considering its sampling and practicability. Hence, this was further applied in this study.

The polymer blending method is used to induce the properties changes. Polymer blending is developed by the physical blending of two or more polymers with or without chemical interaction (Chi Wang et al., 2018). Alexander Parkes has claimed the first patent of polymer blend composed of gutta-percha and natural rubber in 1846 (Khan et al., 2019). The polymer blend is a well-developed technique that was frequently utilized in the industrial area to manufacture many functional polymer-based products. They have highlighted that the modification of PLA material has been accomplished throughout the last decades using polymer blending techniques such as solution blending and melt blending to

achieve the desired qualities for various possible applications (Lin et al., 2020). Furthermore, the polymer blending approach has a number of advantages that make it an ideal technique. First advantage is sustainable material. Various lignocellulosic materials are indeed being researched for use as reinforcing fillers in polymer matrices with the intention of boosting overall characteristics and limiting environmental effect (Balart et al., 2020). Next is improving the material's properties, strength, resistance, and etc (Kruger, 2021). After that, cost effectiveness. Which reducing 80% of chemical cost and can minimize the cost of development with improvising the efficiency of the material properties (Randy McIff, 2017). In addition, polymer blends can be categorized into three types, which are immiscible, compatible, and miscible blends. The immiscible blend is the standard type of polymer blend. Two glass transition temperatures will be recorded if the blend contains two types of immiscible phase. Next, the compatible polymer blend types are incompressible blend polymers that have macroscopically homogeneous physical characteristics. Generally, the macroscopically uniform properties are the result of sufficiently strong interactions between the component polymers. Last but not least, the miscible blends are the single-phase polymer mixtures which having a single glass transition temperature that will be appeared in the scanned thermogram (Khan et al., 2019).

This study explores the efforts in formulating a new advanced material by developing a degradable thermoplastic blend from recycled polypropylene (r-pp) and polylactic acid (PLA). This study is conducted to develop a sustainable material with high-strength properties for a future potential application. In addition, the preparation and characterization of thermoplastic blends are being investigated and explored further to enhance the understanding of this new advanced material characteristics. To summarize, the preparation and characterization of thermoplastic blends r-PP/PLA was performed to observe and optimize the formulation, in order to suggest the best ratio of r-PP/PLA, as well as the optimum melt blending processing parameters using an internal mixer as a blending tool.

1.2 Problem Statement

Nowadays, plastic is indeed the most commonly used commercial at large. Massive disposal of plastic waste possessed a significant risk to the environment, and it contains

substantial amounts of harmful chemicals. It can be negatively impacted the ecosystem through the air, water, and land contamination (Nur Imani Abdullah, 2018). Recent report from The star, 2021, indicate that Malaysia has severe issue with plastic pollution. This was occurred because, by 2020 itself, people had already consumed 148,000 tons of plastic for food packaging. Our annual consumption of plastic packaging per capita is 16.78 kg. Furthermore, this plastic consumption had been increasing sky-rocketing yearly, despite initiatives has been taken to educate people about the dangers of using single-use plastics (The Star, 2021).

Additionally, in today's society, plastic pollution has increased this year due to the covid-19 pandemic. This is because people have ordered their meal either by delivery or take-away method, which increases the consumption of plastic packaging, tremendously. Therefore, development of biodegradable plastics is in needs. This can be done through synthesizing new polymer or by doing so, this could enhance the sustainability of green materials produced by industry. In this study, the r-PP was blended with degradable PLA polymer for r-PP/PLA blends development of new potential materials for green and sustainable environment.

Various research experiments have been undertaken on combining blend with other thermoplastic materials. However, no study has been conducted on optimizing the r-PP/PLA blending approach. Thus, special consideration is needed to be taken to observe the polymer chain's compatibility through optimization blending process. Thus, the DOE approach is implemented in the experiment to optimize the experimental variable and results. Furthermore, the new advanced material should be easily disposed of and environmentally friendly to make it as sustainable plastic material. The blending material must have sufficient characteristics to ensure that it can be used for its intended purpose in the future.

Polymer incompatibility is another difficulty that occurs during the development of polymer blends. As a result, the choice of polymer material has an effect to the material's polymer structure during testing and application. When performing mechanical tests such as tensile tests, the incompatibility of the polymer blend will cause phase separation. Following that, compatibilizer selection is key to ensuring that the compatibilizer can enhance the bonding of polymer structure between two polymer phases which enabling that the blending material is strong, has great attributes, and is applicable.

Moreover, the complexity of the experiment in determining the appropriate blend ratio and its corresponding melt blending process variables and required for reliable blend development. Additionally, there are various components that must be considered while conducting an effective polymer blend experiment. As a result, employing the Design of Experiment (DOE) technique can also boost productivity spent to the methodology for the development of polymer blends. This technique has the potential to increase the reliability of data results. It also minimizes the number of tests required to identify the variables that mostly effecting the resulted blend properties. Then, it also can optimize the experiment to have optimal response.

To summarize, there are no research has been conducted on preparing and characterizing the r-PP/PLA biodegradable thermoplastic blends. As a consequence, this study possessed a great challenge in terms of ensuring proper blending methodology, optimization and characterization. Hence, this study aims to develop a new advanced material by blending the thermoplastics between the r-PP and biodegradable PLA, in ensuring the sustainability in terms of materials and green environment.

1.3 Objectives

The goals of these studies are as listed in the following: -

I. To optimize the r-PP/PLA blend formulation and processing parameters by melt blending process using response surface methodology (RSM) through the tensile strength (R1).
II. To optimize the r-PP/PLA blend formulation and processing parameters by melt blending process using response surface methodology (RSM) through the Flexural strength (R2).
III. To observe the r-PP/PLA blend compatibility and miscibility through the Scanning Electron Microscope (SEM) observation.

1.4 Scope of Work

To accomplish the stated objectives, involving preparing and characterizing r-PP/PLA biodegradable thermoplastic blends. Hence, various study boundaries and limitations must be carefully considered as part of completing this final year project research work.

In this study, investigation is focused to the development of thermoplastic-based blend material. The material selection is limited into the recycled Polypropylene (r-PP) and Polylactic acid (PLA) only due to its availability and practicability. Therefore, the specimen of the experiment is only developed based on these two material powders. The specimen is prepared and characterized at FKP UTeM's Lab facility. The process of producing the specimen is by using an internal mixer and hot-press set-up for compression moulding.

Next, r-PP/PLA formulation and processing parameter optimization is performed by using the melt blending process through the response surface methodology (RSM). Additionally, the response surface methodology (RSM) uses two level-full factorial methods by considering four variables which are the material ratio, temperature (T), time (t), and speed (rpm); which are at the end yielded 19 different samples in total, including the control samples.

Last but not least, the compatibility and miscibility of produced blends are observed and evaluated by using a Scanning Electron Microscope (SEM) machine.

1.5 Significant of the Study

Plastic is a material that is extensively used in the community. Thus, this study can establish deep understanding to the importance of sustainability material development which benefited to the environment. For instance, the usage of plastic bags and food packaging leads to plastic waste disposal and can be detrimental to the environment and living organisms.

Next, development of new advanced material by establishing new knowledges on the biodegradable thermoplastic blends process. The blend material is consisting of recycled polypropylene material and biodegradable thermoplastic material, PLA. Hence, this new advanced material should be environmentally friendly. Still, the compatibility of the blend material must be studied in detail to observe in order to understand its characteristic for suitable potential future applications. This study can be beneficial to the industry and community to reduce plastic disposal waste and proposing several new candidates of degradable material that can be environmentally friendly.

To summarize, this study focuses on formulating new sustainable advanced material for future application. Besides that, the new advanced material has higher-quality properties and characteristics, which enabling it to be a sustainable material without compromising the plastic's primary function.

1.6 Thesis Organization

This thesis is segmented into five major chapters, starting with Chapter 1. This is the introduction chapter, and it consists of the background of the study and an overview of the selected topic. Next, followed with the problem statement. This section identifies the arising problem related to the chosen topic, the preparation and characterization of r-PP/PLA biodegradable thermoplastic blends. The problem is established from several resources such as previous journals, articles, and recent news. Then followed by the objectives that need to be accomplished under the scope of study. Several scope issues concerning the study are being clearly stated.

Chapter 2 is the literature review. This chapter explained in detail the preparation and characterization of r-PP/PLA biodegradable thermoplastic blends. The resource for the literature review is retrieved from the website, e-book, journal, article, news, and related sustainable sources.

Chapter 3 describes and justifies the preparation and characterization of r-PP/PLA biodegradable thermoplastic blends in methodological approaches and blending process procedures. Response surface methodology (including two level-full factorial statistical design was implemented) to accomplish the study's intended goals. The materials and techniques adopted for the study were explained further to ensure the understanding of the methodological development of the study.

Chapter 4 is the result and discussion part which discussing the results and experimental data collected throughout the research period. The raw material characterization, followed by the mechanical and physical testing of the blends with and without PP-g-MAH compatibilizer, were further discussed. Additionally, the morphological fracture was observed using Scanning Electron Microscope (SEM) and the compatibility between phases, was commented further.

Chapter 5 is the conclusion and recommendations. This chapter is vital since it highlights the study's referancy and emphasizes the facts from which a conclusion is drawn to accomplish the objectives listed in the Chapter 1.

1.7 Summary

To summarize, for this introduction part, it involves the preparation and characterization of r-PP/PLA biodegradable thermoplastic blends. The background of the study was briefly explained, followed by the list of research objectives and the scope of the study. This chapter also includes the organizational setting of the whole thesis. Besides, the importance of conducting this research was also described. In overall, this study is vital for understanding in detail about the characteristic of new degradable blend materials of r-PP/PLA blends. The formulation and processing were systematically optimized through the utilization of Design of Experiment (DOE) approach.

CHAPTER 2
LITERATURE REVIEW

This chapter organizes a critical and systematic study of the literature on the preparation and characterization of r-PP/PLA biodegradable thermoplastic blends. After that, this chapter has described knowledges regarding the thermoplastic biodegradable materials and related products. Not only that, the literature review will also explain the fundamentals of thermoplastic blending processes and their compatibilizers. Additionally, this section also provides a comprehensive overview on the selected topic. Hence, for this chapter, a detailed review of new materials, r-PP/PLA blend, a brief review of the material, properties, related fabrication such as blending process and their compatibilizer, and their final applications had extensively reviewed.

2.1 Polymer Blend

The polymer blend is the mixture of two or more polymer, which have different macromolecular chains (Nyamweya, 2021). Polymer blends are mostly composed of common polymers and are extensively used to overcome the limitations of single polymers (Niaounakis, 2015). Additionally, polymer blends can be applied for various applications, including the creation of nanocomposites with enhanced chemical and mechanical characteristics, and medical applications (Khan et al., 2019). Figure 2.1 depicts illustration on polymer blend development for polymer A and polymer B which undergoing blending process to mix the polymer chain, that leads into blend categories, which are the miscible blend and immiscible blend (Toh et al., 2021).

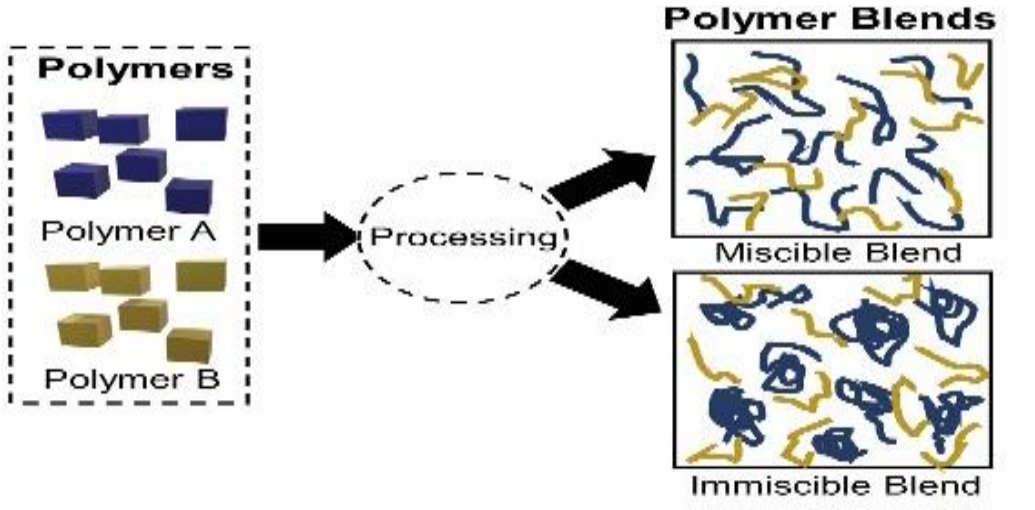


Figure 2.1: Illustration on polymer blend development retrieved from (Toh et al., 2021)

2.1.1 Fundamental of Polymer

A polymer is a group of natural or synthetic compounds composed of massive molecules called macromolecules multiples of basic chemical units called monomers (Britannica, 2021). Additionally, polymer materials exhibit a wide variety of properties, depending on the type of molecules bound and the form in which they are connected. Hence, certain polymers, such as rubber and polyester, are flex and stretch. Meanwhile, other types such as epoxies and glass are extremely strong and durable (Alina Bradford, 2017). Furthermore, the polymer is divided into three (3) main categories: thermoplastic, thermoset, and elastomer. A brief explanation of the mentioned categories was described in the following table 2.1 (Tanzi et al., 2019).

Table 2.1: Type of polymers (Tanzi et al., 2019)

Type	Description	Example of the Polymer
Thermoplastic	A thermoplastic is a form of polymer resins that soften when heated and harden when cooled. These materials are easily recyclable and exhibit no chemical changes when heated or cooled repeatedly.	1. Polypropylene 2. Polystyrene 3. Polyethene
Thermoset	Thermosets are a subclass of polymers that form well-defined, irreversible chemical networks that tend to grow in three-dimensional directions during the curing process, which can be induced by heating or adding a curing agent, resulting in crosslinks between the thermoset's chemical components.	1. Epoxy 2. Phenolics 3. Bismaleimide
Elastomer	Elastomers are typically amorphous with little cross-linkage, soft and flexible, and capable of withstanding a high amount of stress that would normally result in deformation and resuming their previous shape.	1. Butyl Elastomer 2. Nitrile Elastomer 3. Acrylic Elastomer

2.1.2 Types of Polymer Blend

This study provides an important opportunity to enrich understanding on types of polymer blend. The academic literature on polymer blend has revealed the emergence of several contrasting themes on the classification of the polymer blend. As said by Parameswaranpillai et al., (2015), there are five (5) different types of polymer blend which is rubber–thermosetting blends, thermoplastic–rubber blends, thermoplastic–thermosetting blends, thermoplastic–thermoplastic blends, and polymer–filler blends. Furthermore, according to the Khan et al., (2019), there are three (3) types of polymer blends; miscible polymer blends, immiscible polymer blends, and partially miscible. Meanwhile, according to Ali, (2016) there are six (6) type of polymer blends; miscible polymer blends, immiscible polymer blends, homologous polymer blend, compatible polymer blend, and isomorphic polymer blend. The types of polymer blends are further clarified as follow.

1. Miscible polymer blend

Miscible is the potential of mixture to convert into a single phase throughout a particular factor such as temperature, pressure, and composition. This concept also refers to homogeneity of polymer mixtures at certain temperature that have variety factor affect such as crystal phase, shape, intermolecular interaction, and surface tension (Kruger, 2021). According to Khan et al., (2019), miscibility of polymer blend also can be determined by various criterion such as molecular weight distribution, chemical structure, and molecular architecture. These properties can be evaluated in detail using neutron scattering, light scattering, and X-ray scattering method. The concept idea of a miscible polymer blend is shown in Figure 2.2. The polymer chains in the polymer mixture are entirely connected. This polymer mixture has great amount of rigidity (Martins et al., 2019).

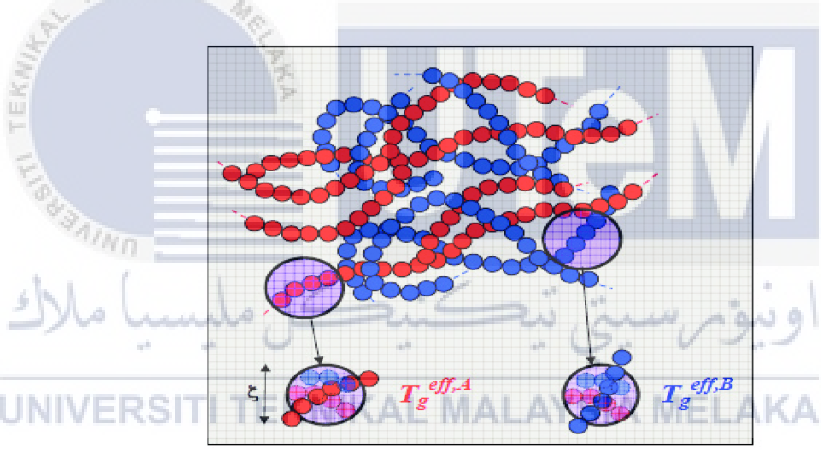


Figure 2.2: Miscible polymer blend (Martins et al., 2019)

Additionally, Parameswaranpillai et al., (2015) and Khan et al., (2019) indicates that the miscible blend can be analysed by using the second law of thermodynamic. The miscible blend is mostly optically clear and homogeneous at the segmental level of macromolecular. Thus, Niaounakis, (2015) indicate that the observation on the single composition which depended to the glass transition temperature (Tg) can be suggested in the by Gordon-Taylor equation related to the analysis of polymer blend as shown in the following Equation 2.1. The glass transition temperature (Tg) will be determined by using the differential scanning calorimetry (DSC) machine or dynamic mechanical analysis

(DMA) machine. The glass transition temperature (Tg) between the homopolymers component in the blend can be calculated as follows:

$$T_g = T_{g1}(W_1) + T_{g2}(W_2) \quad \text{Equation 2.1}$$

where T_g is glass transition temperature of the polymer blend, whiles T_{g1} and T_{g2} are the glass transition temperature of the homopolymers, and W_1 and W_2 are weight percentages (wt%) of each component in the polymer blend. Additionally, study done by Parameswaranpillai et al., (2015) has indicates that the free energy consume by the mixing element can be determined by applying the following Equation 2.2.

$$\Delta G_m = \Delta H_m - T\Delta S_m \quad \text{Equation 2.2}$$

where ΔG_m is change in free energy, ΔH_m is change in enthalpy, T is absolute temperature, ΔS_m is change in entropy, and m is the mixing element. Furthermore, the requirement that must be fulfilled for the miscible polymer blend is ΔG_m value need to be less than 0, $\Delta G_m < 0$. Additionally, there is another importance requirement that need to be considered which is Gibbs free energy of mixing (ΔG_m) with respect to the volume fraction (φ) which must be greater than zero as shown in the following Equation 2.3.

$$\left(\frac{\partial^2(\Delta G_m)}{\partial \emptyset_i^2}\right)_{T,p} > 0 \quad \text{Equation 2.3}$$

where ΔG_m is the Gibbs energy of mixing, and $\emptyset$ is the composition of the polymer blend. Therefore, if the mixing polymer is exothermally generated, then it will consider as the polymer blend is miscible. Additionally, the effectiveness of miscible polymer blend technique has been exemplified in a report by Parameswaranpillai et al., (2015) which combining between polystyrene with poly (phenylene oxide), and poly(styrene-acrylonitrile) with poly(methyl methacrylate). Meanwhile, according to the (Khan et al., 2019), poly(ethylene terephthalate) with poly(butylene terephthalate), and poly(methyl methacrylate) with poly(vinylidene fluoride) also one of the examples for miscible polymer blend system. Moreover, several studies have shown that miscible polymer blend is the mixture of polymer material that result in single-phase structure of polymer blend. Then,

the concept of thermodynamic laws is used to analyse the glass transition temperature (Tg) of the polymer blend (Malek et al., 2021; Mandal et al., 2021; Suthapakti et al., 2018; Zhang et al., 2021).

2. Immiscible polymer blends

Immiscible polymer blend is the phase separation of two polymer material to mix, then establish a homogenous mixture (Anne Marie Helmenstine, 2019). The immiscible consist of heterogeneous morphology and the characteristic properties is opposite of miscible polymer blend (Ajitha and Thomas, 2019). Furthermore, according to Niaounakis, (2015) research and experiment found that the immiscible polymer blend will show multiple glass transition temperature (Tg) and melting point (Tm) value. Moreover, the element requirement for immiscible polymer blend is ΔG_m value need to be more than 0, $\Delta G_m > 0$. Next, the concept idea of an immiscible polymer blend is shown in Figure 2.3 (Khan et al., 2019).

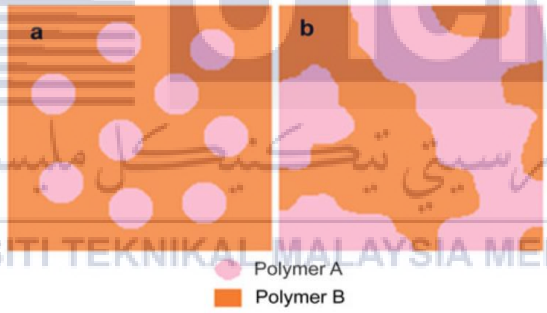


Figure 2.3: Immiscible polymer blend; a. polymer before blending process b. polymer after mixing process retrieved (Khan et al., 2019)

Additionally, the effectiveness of immiscible polymer blend technique has been exemplified in a report by Kruger, (2021) which is poly(propylene) with poly(ethylene). Next, polybutadiene with polystyrene and poly(propylene) with polystyrene (Ajitha & Thomas, 2019).

3. Partially miscible

The partially miscible addition is when two or more substances are just partially mixed, and it is described to as partial miscibility. When the two substances are combined,

two layers form, each layer holding some of each liquid (Sujay Mistry, 2021). Additionally, Figure 2.4 illustrates the behaviour of partially miscible polymer blends by representing two phases. These regions represent a miscible intermediate phase, referred to as the partially miscible polymer blend region (Khan et al., 2019).

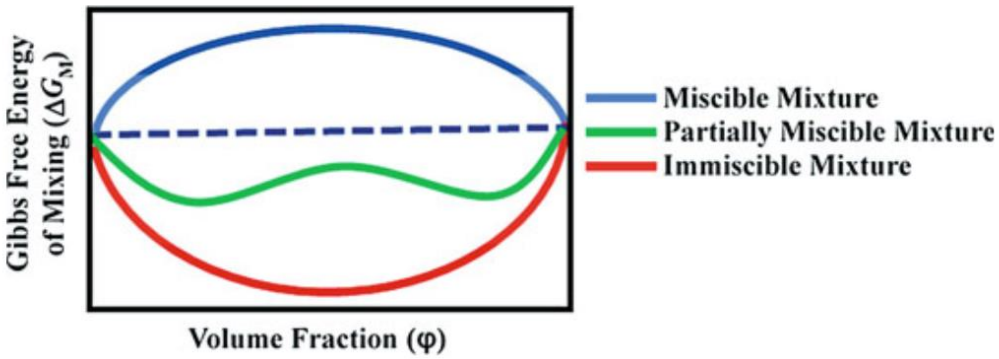


Figure 2.4: Gibs Free Energy of polymer blend (Khan et al., 2019)

4. Homologous polymer blend

The homologous polymer blend is a blend of two or more fractions of the same polymer with varying molecular weight ratios (Ali, 2016). Moreover, the mixture of polymer is the same type of polymer material that have different ratio of molecular weight. Then the observation will be analysed based on the miscible and immiscible state of the polymer blending.

5. Compatible polymer blend

The compatible blend is the capability of the blend to improvise their properties and establish fine-phase morphology (Ajitha & Thomas, 2019). An example of this is reported in the study carried out by Manias & Utracki, (2014), in which process of modifying the interphase in immiscible polymer blends. As results in a decrease in interfacial energy, and stability of a desirable morphology, and the formation of polymer alloy with increased performance. Based on the appropriate study, the compatible blend is indeed an immiscible polymer mixture with macroscopically equivalent physical features (Niaounakis, 2015).

Figure 2.5 is illustrating the conceptual of compatible polymer blend. The compatible polymer blend is on improving the cross links of polymer macromolecules to have a good characteristic of the polymer blend (Erlin Widjaja, 2019).

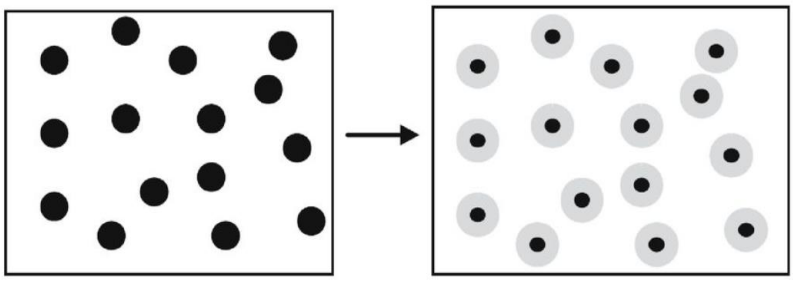


Figure 2.5: Polymer matrix A is black, and phase B is white. The modification on the immiscible polymer is complete by implemented the compatibilization; grey (Erlin Widjaja, 2019)

Furthermore, according to study develop by Ajitha and Thomas, (2019), the polycarbonate with acrylonitrile-butadiene-styrene blend is of partially miscible blend. The miscible blend is the polymer blend that have multiple glass transition temperature (Tg) and the Tg value is shifted from the blend element in the polymer blend. Furthermore, the outcome of compatible polymer blend is on the reduction of particle size, improve the stability stage of the polymer and the mechanical properties of the polymer material (Parameswaranpillai et al., 2015). In addition, the functionalization by using reactive compatibilizer agent possessed an ability to minimize the interfacial tension between the polymer phases, which affecting the emulsification and producing adhesion among the phases. This is exemplified in the work undertaken by Khan et al., (2019)

6. Isomorphic polymer blend

A polymer blend consisting of two or more distinct semi-crystalline polymers is miscible in both the crystalline and molten states (Ali, 2016). This type of polymer blend is known as semi-crystalline polymer. The example of semi-crystalline polymer is linear polyethylene (PE), isotactic polypropylene (PP) or polyethylene terephthalate (PET).

2.1.3 Preparation of Polymer Blend

Different methodologies exist for compounding and preparing the polymer blend mixtures. Each technique has its own advantages as well as disadvantages. The polymer blend has been divided into five (5) common strategies including the melt blending, mill mixing, solution mixing, freeze drying, and latex blending. However, in this study, the utilization of melt blending approach was utilized. Therefore, the preparation of melt blending process will be clarified further in detail.

Melt blending is the main alternative technique for developing thermoplastic polymer blend (Sanjay Kumar, 2020). This method is particularly useful in industry considering its cost - effectiveness and environmentally friendly (Ajitha and Thomas, 2019). Additionally, extruders or batch mixers are used to compound the blend materials while they are still in molten state (Kulkarni, 2018). Generally, the melt blender includes utilizes on internal mixer, extruder and injection molding machineries. Thus, the melt blender technique used for this study is Haake internal mixer as shown in Figure 2.6.

Figure 2.6: Haake internal mixer machine (Banu et al., 2009)

The polymers are melted in this process, and mixing happens under strong shear forces (Ajitha and Thomas, 2019). Many researchers have utilised melt blending technique to mix between two polymer phases. This method is particularly useful in improving the mechanical properties and sustainability of the material itself. Next, a case-study approach by Zailan et al., (2019) was utilizing the melt blending approach for their study. Schematic

diagram on Figure 2.7 was based on the conceptual framework proposed by (Zailan et al., 2019). The preparation of polymer blend is using polyaniline (PANI) and thermoplastic natural rubber (TPNR) material. The material of polyaniline (PANI) is pre-mixed with liquid natural rubber (LNR) by utilising a chemical technique of oxidation photodegradation. Next, the internal mixer (HAAKE Rheomix 600P) is used for melt blending operation. The composition ratio of natural rubber (NR)/ linear low-density polyethylene (LLDPE)/ liquid natural rubber (LNR) is 50:40:10. Then the polyaniline (PANI) powder is 1–5 wt %. The mixing temperature were mixed by first loaded the natural rubber (NR) to the mixer, followed by the linear low-density polyethylene (LLDPE) resin after 3 minutes, and then the liquid natural rubber (LNR)/ polyaniline (PANI) premixture after 5 minutes. Following that, blend materials were then being fabricated via compression moulding employing a hot and cold pressing machine (LP 50; Labtech Engineering Company Ltd.) at 6.9 MPa pressure and 130 ℃ temperature. Then, the stabilization of the sample panels was left overnight for 24 hours (Zailan et al., 2019).

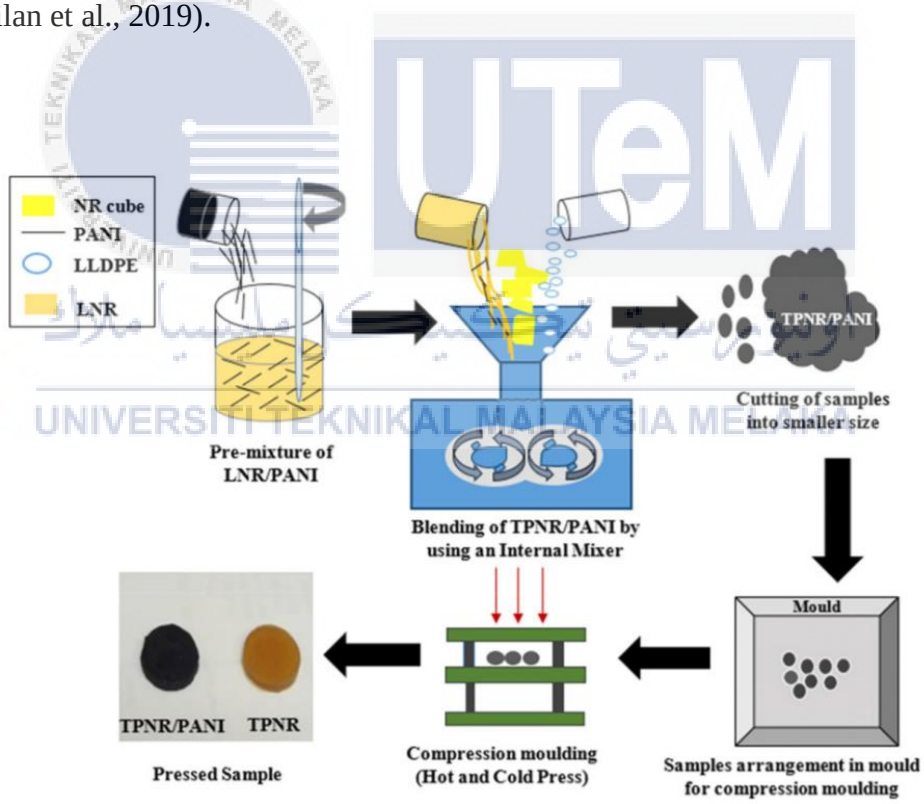


Figure 2.7: Schematic diagram of TPNR/PANI blend method retrived by (Zailan et al., 2019)

In summary, the preparation of polymer blend can be described by selecting an appropriate solvent for polymer materials and blend the materials under certain ratios. Then, the raw material is produced by an injection moulding in order to ensure an even distribution

of raw materials (Salehiyan and Sinha Ray, 2018). After that, the rotating screw is used to produce a consistent of blend mixture (Ajitha and Thomas, 2019). Therefore, Khan et al., (2019) study indicate that this approach is generally recognized to be a great technique for the polymer mixture but sometimes it looks to be cost prohibitive. Meanwhile, Salehiyan and Sinha Ray, (2018) study indicates that melt blending technique is economical as it suitable for rapid large-scale production. Additionally, the preparation of polymer blend is quite straightforward, and an internal mixer is utilised for the melt blending process.

2.1.4 Advantages and disadvantages of Polymer Blend

Polymer blend is widely used in the industry to improvise the polymer properties. Therefore, the advantages and disadvantages of the polymer blend has summarized as in the following Table 2.2 and Table 2.3.

Table 2.2: Advantage polymer blend

Source	Advantage
(Ali, 2016)	Polymer blend: • Enhance the performance of the resin or product with low cost. • Improve the brittleness of the polymer properties by reduce the additive element, low molecular weight. • Stabilize the modulus and dimension element. • Maximize resistant to solvents and chemicals • Improved processability
(Sanjay Kumar J Pai, 2020)	Melt blending: • Cost effective on process • Minimizes solvent removal, contamination, and water removal.
(*Polymer Blends and Alloys*, n.d.)	Polymer blend: • To produce materials that possess a comprehensive set of desirable qualities. • Reduced research and development costs and time spent generating new monomers and polymers.

Table 2.3: Disadvantage polymer blend

Disadvantage	Source
Polymer blend: • High cost of equipment. • Risk towards degradation • Process of cleaning the mixer is time consume.	(Sanjay Kumar J Pai, 2020)
Polymer blend: • Incompatible with thermally reactive chemicals. • Various methods are essential.	(Casalini et al., 2019)

2.2 Biodegradable Polymer

For several years, production of biodegradable polymers has been growing due to their potential of solving current issues as they were utilized in tissue engineering and medicine applications (Haider et al., 2019). The deterioration of polymer materials is highly reliant on the particular environmental conditions to which they are treated (Chi Wang et al., 2018) . Additionally, biodegradable polymers can be added in significant quantities (less than 5% by weight) to the recycled PP process without impairing the effectiveness of the resulting blending which ideal for a variety purposed uses, including food packaging and agricultural films for farming. Example of the biodegradable polymer such as polylactic acid (PLA) (Anja Krieger, 2019) .

Table 2.4 outlines the many classifications biodegradable polymer used in the various kinds of source and manufacturing processes. Bio polyesters are biodegradable due to their hydrolysable ester linkages, whereas natural polymers are often degraded via hydrolysis. Then, the fabrication methods are classified into three broad categories which is chemical polymerization of monomers derived from biological activity, chemosynthesis of polymers in microorganisms and modifying of natural sources polymers. Additionally, representative examples of each category are provided, with their primary characteristics emphasized.

Table 2.4: Classification of biodegradable polymer (Fouad & Farag, 2019)

Example	Types	Category	Sources	Sources type	Method of production
PLA	Bio-polyesters	Synthetic	Bio-derived	Renewable	Chemical polymerization
Starch	Agropolymer	Natural	Biomass products	Renewable	Fragmentation of biomass
PHA	Bio-polyesters	Synthetic	Bio-chemosynthetic monomer	Renewable	Biosynthesis of polymers in microorganisms
PLA	Bio-polyesters	Synthetic	Synthetic monomer	Non-renewable	Polymerization of lactide
PCL	Bio-polyesters	Synthetic	Synthetic monomer	Non-renewable	Enzymatic catalysed polymerization

2.2.1 Polylactic Acid (PLA)

Wallace Carothers had discovered it in 1932 by heating lactic acid under a vacuum and extracting condensed water. Initially, only low-density PLA was manufactured (Farah et al., 2016). Finally, high-density form of PLA was produced by using lactide as raw material and the ring-opening polymerization technique (Joseph Flynt, 2017). PLA is a biodegradable material that sustainable to environment. Next, this PLA material is categorized as a triangle symbol with the number 7 inside. These plastics are not often recycled. However, it may be transformed to plastic timber or certain custom products (Rick LeBlanc, 2019).

Figure 2.8: Triangle symbol of PLA retrieved by (Rick LeBlanc, 2019a)

Furthermore, polylactic acid is a hydrophobic polymer that is a part of biomaterial family. It is also known as poly—hydroxy acids, poly—esters, and aliphatic polyesters (Casalini et al., 2019). If was synthesized from lactic acid (LA; 2-hydroxypropanoic acid), a water-soluble monomer that exists in two enantiomeric forms, L-(+)-LA and D-(-)-LA, which can be seen in Figure 2.9. Meanwhile, the chemical structure of the PLA is shown in Figure 2.10.

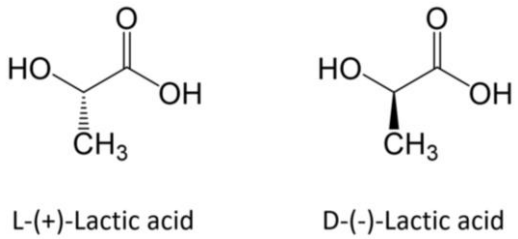


Figure 2.9: Water soluble monomer form (Casalini et al., 2019)

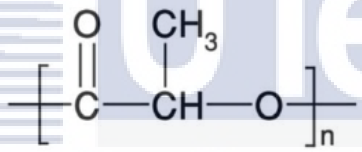


Figure 2.10: Chemical structure for PLA (Naser et al., 2021)

Furthermore, PLA is suitable material that can be used as an alternative for mixture blending with biodegradable material itself or non-biodegradable based such as thermoplastic material to produce new kind of material (Saini et al., 2016) and it also can be used as composite material (Murariu and Dubois, 2016). The advantage and disadvantage of the PLA material is being detail has been pointed out by Farah et al., (2016). The advantage is PLA was eco-friendly material as it produces by corn starch, PLA also biocompatible material as it sustainable to the environment. However, among the most common drawbacks of that PLA is on its brittle characteristic, and it also weak in term of reactive side chain group. Furthermore, the PLA properties is being clarify in the Table 2.5 (Ghomi et al., 2021).

Table 2.5: Properties of PLA (Ghomi et al., 2021)

Properties	PLA value
Polymer density (g/cm3)	1.21–1.30
Tensile strength (MPa)	15.5–150
Tensile modulus (GPa)	2.7–16
Ultimate strain (%)	2–10
Specific tensile strength (Nm/g)	16.8–66.8
Specific tensile modulus (kNm/g)	0.28–3.85
Glass transition temperature (◦C)	60–65
Melting temperature (◦C)	130–180

In addition, the life cycle of PLA is shown in the following Figure 2.11. The life cycle of PLA is explained as the material produce from bio-based material which is corn starch. It utilised the biomass for photosynthesis (Murariu and Dubois, 2016). Next, the processing involves for PLA are include of injection moulding, extrusion, and blending (Ghomi et al., 2021). Then, the end products of the PLA are familiar to our daily life. The product includes feedstock for 3D printing and desktop fused filament fabrication for three dimensional printers (Joseph Flynt, 2017b), water bottle (Naser et al., 2021), and tissue engineering in modern medicine (DeStefano et al., 2020). Additionally, PLA's excellent features are often employed to boost the performance of other polymers in blends (Saini et al., 2016). To conclude, this study is using the PLA as an alternative to be blended with r-PP material to produce a new sustainable advance material that can be high excellent in their end-product application with good end of life characteristics. Furthermore, the effect of PLA material in the polymer blending properties has been discussed in the study conducted by Saini et al., (2016). The polymer blend morphology, process parameters, and phase separation all have a substantial effect to the outcome new material's degradation, and thermomechanical characteristics (Saini et al., 2016).

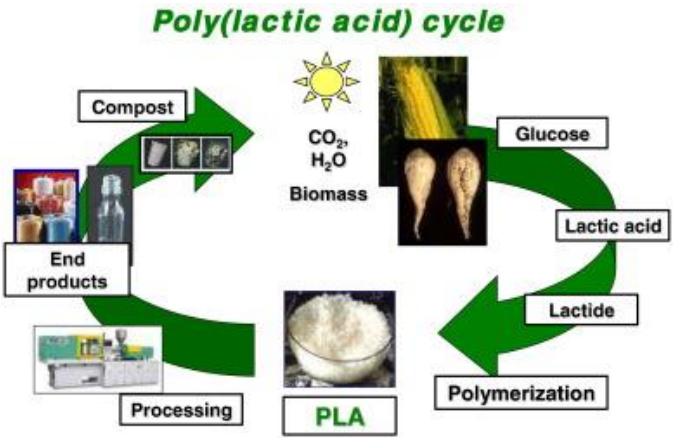


Figure 2.11: PLA life cycle (Murariu & Dubois, 2016)

2.3 Commercial Thermoplastic for Consumer Application

Thermoplastic is widely used for many applications. The thermoplastic material has various category. The thermoplastic materials can be classified according to their economic value and performance as shown in Figure 2.12. Amorphous and semicrystalline polymers are categorized (Alexander H. Tullo, 2016). High-performance polymer engineering is required at elevated temperatures. The higher the price, the higher the performance of the material itself (Kruger, 2021).

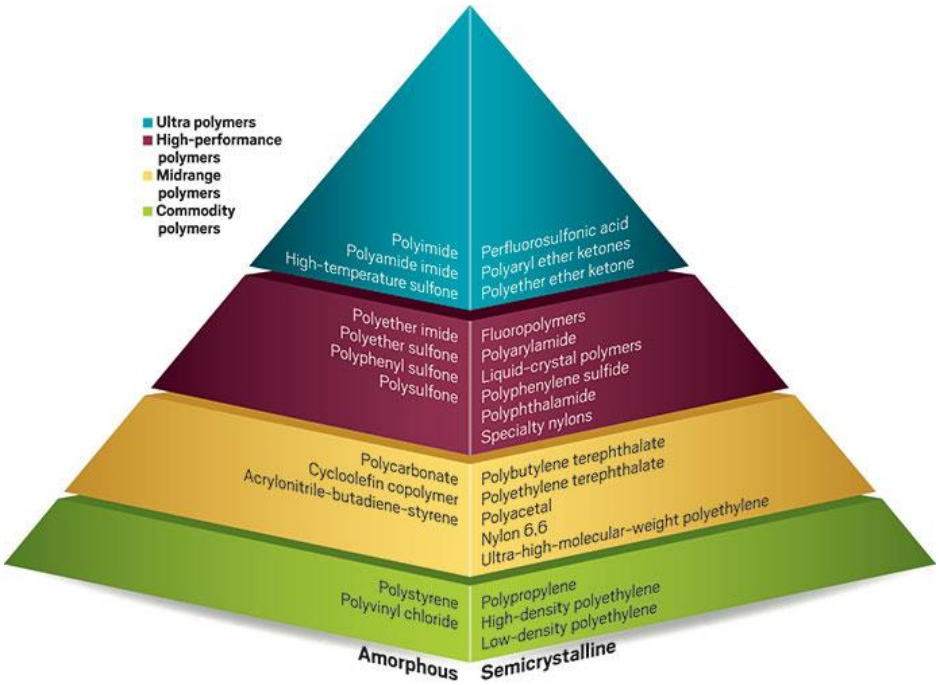


Figure 2. 12: Thermoplastic category (Alexander H. Tullo, 2016)

Furthermore, according to Saini et al., (2016), the market desired for bio-based biodegradable polymers has risen significantly as sustainability material and demand on finite petrochemical resources had increased tremendously increased. The global market for PLA blends in biomedical applications has proactively involved for bioplastics to commercialize pre-formed PLA blends. Then, the data is shown in the Table 2.6 is the Agricultural Utilization Research Institute research finding which highlighting point that PLA manufacturers is the world's leading since year 2013 and their estimated market by year 2020 (Saini et al., 2016).

Table 2. 6: World's market capability of PLA retrieved from (Saini et al., 2016)

Chosen company	Country	Capacity on 2013 (tons)	capacity on 2020 (tons)
NatureWorks LLC	USA or Thailand	150000	450000
Pyramid	Germany	3000	60000
Purac/Carbion	Europe or Thailand	75000	150000
Zhejiang Hisun	China	5000	20000
Teijin	Japan	1200	5000

2.3.1 Polypropylene (PP)

Polypropylene (PP) is a non-biodegradable and recyclable thermoplastic polymer which commonly found in variety of commercial products. PP is a rigid material which resistant to various chemical solvents, acids, and bases (Rick Leblanc, 2019). In 1988, the Plastics Industry Association has developed the symbols, now known as the Plastics Industry Association, then known as the Resin Identification Code (RIC). ASTM International oversees the symbols, officially referred to as the ASTM International Resin Identification Coding System (Rick LeBlanc, 2019). It is important to note that the recycling symbol at the bottom of a plastic product does not necessarily indicate that the plastic can be recycled or not. But the purpose is to tell the users what kind of plastic the product use (Maureenwise, 2020). Therefore, this polypropylene material is categorized as a triangle symbol with the number five (5) inside. The number inside the triangle indicates that the product is from polypropylene material. This type of material can rarely recycle and possessed high melting point. Hence, the material is widely used in the production of bottles and containers. The Figure 2.13 depicts the triangle symbol for the PP. Table 2.7 show the mechanical and thermal properties of the PP material. These features will have an influence on the result product's development.

Figure 2.13: Triangle symbol of PP (Maureenwise, 2020)

Table 2.7: Mechanical and thermal properties of PP (Anonymous, 2022)

Properties	**PP value**
Melting Point (℃)	160 - 163
Density (g mL^{-1})	0.905
Elongation, Break %	50 - 145
Processing Temperature ℃	200 - 280

2.3.2 Recycle-polypropylene (r-PP)

Recycled polypropylene is originated from the thermoplastic virgin polypropylene. Rick Leblanc, (2019), indicated that UK-based plastic development has been invented the recycled innovation process to be used in food packing application. Additionally, recycling polypropylene is critical to reducing trash at landfills and ensuring the material's sustainability to the environment. Meanwhile, the r-PP is extremely cost effective and sustainable. Figure 2.14 is shown the polymer chain structure for the recycled polypropylene, which basically still retaining the basic structure of virgin polypropylene.

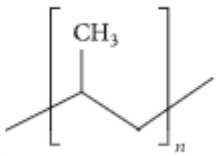


Figure 2.14: Polymer chain recycle-polypropylene (r-PP) (Ecaterina Matei, 2017)

Additionally, to better understand on r-PP, Doug Smith, (2017) in his research paper indicates the application of r-PP that can minimizing the natural sources petroleum gas. This is due to about 8% of oil consumption all around the world is employed in the manufacturing production of 4% 'feedstock' in order to produce plastic end-product. Therefore, the plastic is environmentally friendly due to the recyclability of their product into other useful product includes food and beverage container. In addition, the mechanical properties of 100% recycle polypropylene has been studied by Jose M. Kenny, (2003). Hence, for further clarification of r-PP properties, the mechanical properties data is being clarified in the Table 2.8.

Table 2.8: Mechanical properties of r-PP (Jose M. Kenny, 2003)

Properties	r-PP value
Young's Modulus (MPa)	1245
Max strength (MPa)	27.4
Strength at break point (mm)	27.3

2.3.3 Plastic Pollution and Environmental Issue

This shows a need to be explicit about exactly what is meant by the word ‘plastic’. Plastics are composed of synthetic organic polymers and are extensively utilized in a variety of applications includes food packaging, water bottles, medical supplies, electrical goods, and so on (Alabi et al., 2019). Figure 2.15 show a plastic waste pollution. The globally plastic waste contamination is escalating at an astounding level, and it is quite disturbing to learn that a significant amount of plastic trash is almost never disposed (Raudhah et al., 2020). According to the Kimberly Amadeo, (2020), since year 1950, globally more than 8 billion million tonnes of plastic production have been manufactured. This activity gives approximately 6.3 billion tonnes of plastic to be dumped into landfill. About 9% were recycled, and 12% was burnt. Therefore, the degradation of the plastic itself takes 100 - 1000 of years.

Figure 2.15: Plastic waste (Kimberly Amadeo, 2020)

Plastic pollution has characteristics including diversity, persistent, and possible dangers (Alabi et al., 2019). The characteristic that has been mentioned will be detail after this. First and foremost, diversity. Plastics in the environment were diverse in terms of colour, size, and shape (Alabi et al., 2019). According to Tom Bond, (2018), this is the pollution caused by today's extensively used plastic. The example includes Polypropylene (PP), Polystyrene (PS), Polyvinylchloride (PVC) and Polyethylene (PE). Second is persistent. The ability of a material to be environmentally friendly is extremely important. The economically beneficial aspects of plastic that can be degrade into the environment through a variety of method include biodegradation, thermal oxidation, photodegradation,

and hydrolysis (Liqi Cai, 2018). Therefore, the plastic that cannot be degrade to the atmosphere will give a hug impact to the environment include living organism. Thirdly is Considering the endurance and sustainability of plastic waste in the environment, those molecules may persist for an extended duration, likely contributing to the global impact of plastics (Alabi et al., 2019). According to the study by Zeynep Akdogan, 2(019), Figure 2.16 is a data collection from various of study. Regardless of diversity of plastic size, the study has largely concentrated on fundamental of microplastics. The microplastic is plastic with size of <5 mm (diameter). Meanwhile, macroplastic is plastic with size of >20 mm (diameter) (Alabi et al., 2019). However, the study on the nano plastics is insufficient. Due to the fact that the microplastic give a hug impact to the environment compared to nano plastics and macroplastics.

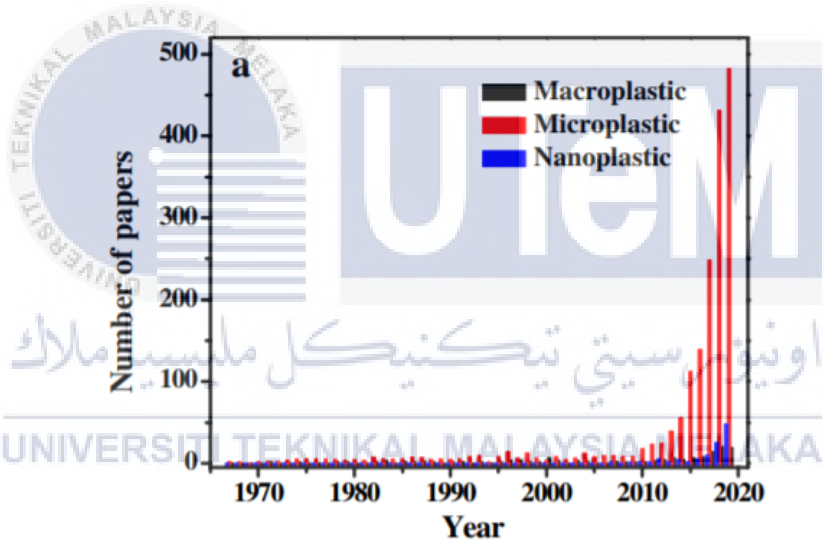


Figure 2. 16: Plastic population (Zeynep Akdogan, 2019)

2.3.4 Plastic Sustainability

Nowadays, sustainable material is really vital to the society and environment effect. Therefore, the plastic needs to be sustainable in order to degrade properly to be a green material for the environment purpose. According to the development of global goals for sustainable serve as a road map for achieving a more just and sustainable world for everyone.

They target worldwide issues such as poverty, inequality, global warming, environmental degradation, as well as peace and freedom.

Additionally, Figure 2.17 is the development of sustainable global goal that being utilize worldwide. The development that relates to the plastic sustainable development will be detail. First goal development, more than 700 million people continue live with poor life surviving. Thus, donating unwanted items is an activity that can assist the needy in mitigating the impact of disposal. For example, donating unwanted cloth to the poor people including homeless. Second goal development, zero hunger. Reduce the waste of food and help the local farms. Food is a major component of sustainable development since it is necessary for hunger and eradicate poverty. For example, the PLA is utilizing the corn starch for their development, therefore the supporting farm's business can help to produce a sustainable material for the green environment. Ninth goal development, industry, innovation and infrastructure. Invest in the development of projects and infrastructure that will contribute to the country's long-term growth. Twelfth goal development, responsible consumption and production. The activity on recycle plastic is vital in order to have a good impact on sustainable material. The process of recycle plastic need to be consider ensuring the safety for the environment. Thirteenth goal development, climate action. Since year 1990, there is 50% of global emission of CO^2. Meanwhile for the fourteenth goal development is life below water. The oceans must be kept clean in order to protect the underwater life, which includes fish. Therefore, the plastic life cycle must be environmentally sustainable in order to assist in minimizing global emissions and thereby save the world. In addition, reducing the use of plastic can give a beneficial impact to the environment. For example, use the recycle bag for grocery instead of plastic bag. As a result, the plastic pollution can be reduced effectively.

Figure 2.17: Global goal for sustainable development

2.4 Biodegradable Plastic

Biodegradable plastic is a manufactured material that degrades over time when it comes into contact with the surrounding living environment (Anja Krieger, 2019). The process of plastic biodegradation is accomplished when environmental microorganisms decompose and degrade the polymer structure, usually with other degradative elements such as temperature, light, moisture, and oxygen (Suthapakti et al., 2018). According to the Kruger, (2021), the biodegradable material is an ability of material to overcome the recyclable problem and also development of weed in agriculture industry. In addition, Kruger, (2021) commented in his study that the polymer blending method does not give a bad environmental effect after their process due to the dissolution of polymer powder during the biodegradation.

PLA is biodegradable polymer (Rick LeBlanc, 2019a). Therefore, the utilization of PLA is widely used as a beneficial due to their biodegradable properties include medical

field and packaging industry (Saini et al., 2016). Furthermore, according to Saini et al., (2016) has indicated that the PLA blend will be producing an excellent degradation formula, but it depends to the quantity of the blend's portion and resulted morphology.

2.4.1 Thermoplastic/PLA Blends

Numerous studies have attempted to explain thermoplastic/PLA blend. Details on the selected study was further explained at the subsequence paragraph.

According to the study conducted by Saini et al., (2016), the experiment on polymer blend can be conducted using melt-blending method. PLA blends are made using melt blending processes. The miscibility of the polymers would significantly affect the physical properties and mechanical behaviour and final product quality of PLA bends. PLA blends are further processed into various structures, such as fibres, films, and porous structures. This process to depending on the final product specifications (Saini et al., 2016).

According to the (Mohammed Ajmal et al., 2019), the PLA/HDPE blend preparation is discussed. As everyone already knowing that the PLA material is currently expensive and brittle but it also biodegradable material. As a result, blending is used to compensate for this limitation. The function of HDPE is to stabilize the crystalline structure. This procedure was carried out at a fixed temperature of 170 degrees Celsius. After that, the blended mixture was fed throughout the two-roll mill.

Table 2.9 depicts the blending of PLA and other polymer materials to produce new advanced materials. Two studies have been conducted on r-PP/PLA blends. Further, the results obtained from the investigation via SEM or TGA observation show the presence of immiscible blends. As a result, these factors will influence the polymer material's mechanical strength. Tensile strength results show incompatibility with the blend. Next, there are three blend materials that combine PLA with another material other than r-PP which is PP,

Poly(meth)acrylates, and Poly(meth)acrylates (ethylene glycol). The mixture of pp and poly (ethylene glycol) indicates that the two polymers are incompatible. Poly(meth)acrylates, on the other hand, are miscible. This is because the PLA and Poly(meth)acrylates are highly compatible and have a high mechanical strength.

Table 2.9: Blend material of PLA

Blend material	Findings	Source
r-PP/PLA	The properties of r-PP are affected by presence of PLA material. Thus, loss of mechanical strength due to the incompatibility of the blend. The result is observed during tensile test. Then, the SEM observes showing the immiscibility of r-PP/PLA blend due to presence of two-phase separation.	(Samper et al., 2018)
r-PP/PLA	AHAMTES is utilize as coupling agent for the r-PP/PLA blend. The PLA/r-PP were shown to be immiscible using DMA and DSC analyses. Next, SEM analysis revealed that AHAMTES is an effective adhesion enhancer for PLA/rPP blends. The presence of rPP enhances the thermal stability of PLA throughout the blend, as shown by TGA. Then it also reduces the tensile strength and modulus of PLA while increasing the impact strength of the blends.	(Abay et al., 2016)
PP/PLA	The presence of PLA into the blended sample lowered the thermal stability of PP. Due to the radical aspect of degraded PLA polymers, the durability of experimental examples reduces dramatically as the temperature rises.	(Mandal et al., 2019)
PLA/ Poly(meth)acrylates	PLA/ Poly(meth)acrylates are miscible blend. In numerous PLA/PMMA mixes, just one Tg was identified. PMMA increases the Tg of the blend but decreases PLA's crystallisation rate, that harmful towards high productivity in crystallised components. At a concentration of 1-5 percent in PLA, high molecular weight acrylate resins have been demonstrated to greatly impact the rheology and melt extensibility of PLA.	(eknuth, 2007)
PLA/Poly (ethylene glycol)	By melt mixing the PLA, a flexible material might be obtained. The addition of Poly (ethylene glycol) by 2.5–10wt%. plasticizer resulted in a reduction in the strength, stiffness, and impact strength of the PLA material. The Poly (ethylene glycol) was dispersed in the PLA as droplets with a distinct boundary between the PLA/ Poly(ethylene glycol) phases. Then it indicates the immiscible of polymer blend	(Bijarimi et al., 2016)

2.5 A Testing Related to Thermoplastic/PLA Blend

This section has been including several testings that need to be considered for the researcher to analyse the mechanical and thermal properties of the polymer blend. According

to the experimental research done by (Abay et al., 2016), (Suthapakti et al., 2018), (Mandal et al., 2021), (Mandal et al., 2019), and several other research utilised these mechanical and thermal testing for their experimental observation and testing to analyse the mechanical and thermal behavior of the polymer blend. The mechanical testing that mention is tensile test. Meanwhile, for the thermal test is using differential scanning calorimetry (DSC).

2.5.1 Mechanical Testing

According to the (Saini et al., 2016), PLA is a material that have low toughness and brittle mechanical properties. Thus, the purpose to blend the PLA material is to improve their strength in term of tensile and modulus of the polymer properties itself.

There is a large volume of published studies describing the role of polymer blend in the behaviour of the material. Therefore, the study by (Abay et al., 2016) utilised tensile testing as an appropriate way to determine the strength of the polymer blend material. The study mention before is using PLA/r-PP blend for their study. The mechanical behaviour of a blend is determined by a variety of aspects, including the blend's material, composition, compatibility, the existing of coupling agents, and the natural mechanical properties of the material. Figure 2.19 show a stress-strain curve for the PLA/rPP bends. The natural PLA is poor ductility. In comparison to PLA, r-PP displayed a lower tensile strength with a greater flexibility. Additionally, those blends demonstrated elongation at break (7.2 %), which is significantly less than the pure PLA and dramatically less than rPP (67 %). The blends reduced elongation at break is most likely owing to poor interface connecting between the blend structure and have phase separation of the polymer structure.

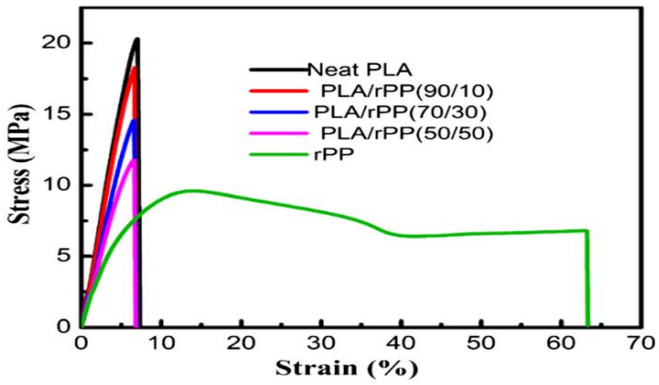


Figure 2.18: Graph stress strain PLA/r-PP blend with various weight retrieved from (Abay et al., 2016)

Additionally, using this Universal Testing Machine (UTM) that complies with the ASTM D-638 Standard approach, researchers of (Zhang et al., 2021), (Suthapakti et al., 2018), and (Abay et al., 2016) have performed tensile testing on the specimen material in order to characterise its mechanical strength behaviour. In Figure 2.20, a tensile testing machine is shown being utilised in a variety of tensile tests on plastic materials. Meanwhile, Figure 2.21 illustrates a specimen sample for the tensile test technique.

Figure 2.19: Tensile test machine

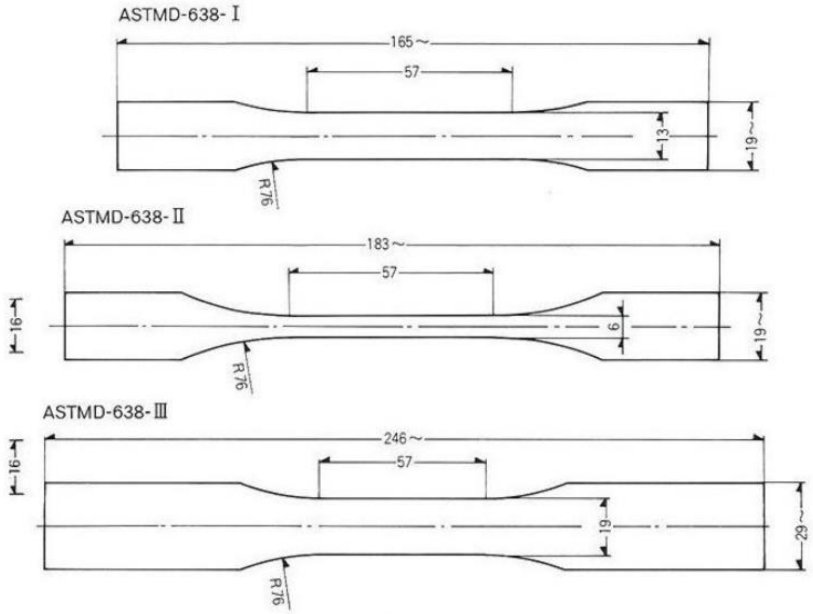


Figure 2.20: Specimen for tensile test (Anas et al., 2013)

In conclude, the mechanical testing that has been utilised in the previous study relate to the thermoplastic/PLA bends is tensile test. The tensile test is to observe the strength and elongation required for the material to break on job. In order to have a better test for the mechanical behaviour properties. This study utilised the hardness test to observe the resistance of the test piece to local deformation against the standard rigid ball indenter was assessed using the SHORE-A hardness scale.

2.5.2 Morphological Blend Testing

Surface Morphology is a part of Analytical Imaging, a complex high spatial resolution imaging that use sophisticated microscopes to generate images of objects that are invisible to the naked eye. These photos originate from the sample that exposed surface (Anonymous, 2018). Numerous studies include (Bijarimi et al., 2016; Chen et al., 2015; Suthapakti et al., 2018; Wen-Dong et al., 2021, and Yanc et al., 1996) have utilised the SEM methodology to observe the surface morphology and fracture of the polymer blend material.

The data observation of the surface morphology of the previous study by (Abay et al., 2016) on rPP/PLA will be discussed. The pure PLA is having the smooth surface roughness. Meanwhile for the rPP, it has a rough surface compared to the PLA as it has defect on their semi crystalline morphology. Meanwhile, for the blend ratio of 90:10, and 70:30 of rPP/PLA blends displayed an extremely diverse fracture surface with a distinctive two-phase structure and gaps. The characteristic two-phase structure visible in the SEM scans are caused by material immiscibility showing a lack of interfacial bonding between both the nonpolar rPP and polar PLA portions. This result implies that the two polymers are incompatible and tend to create immiscible mixtures.

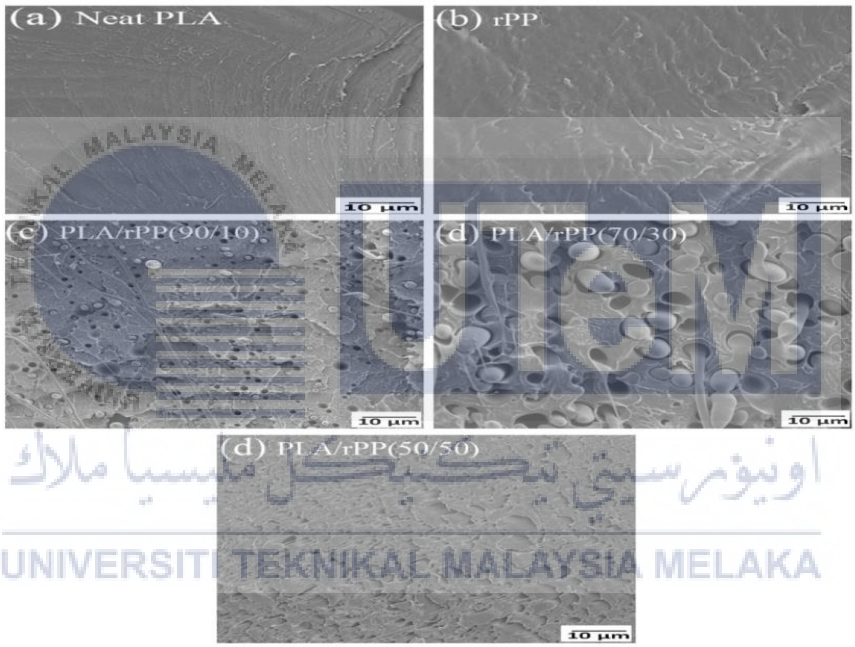


Figure 2. 21: SEM micrographs of the morphology surfaces of pure PLA, rPP, and PLA/rPP blends in a variety of compositions: (a) pure PLA, (b) rPP, (c) blend of 90:10 ratio of PLA/rPP, (d) combination of 70:30 ratio of PLA/rPP, and (e) blend of 50:50 ratio of PLA/rPP (Abay et al., 2016)

2.6 Design of Experiment (DOE)

Design of experiment (DOE) is being used to discover variability in outcomes due to variations in the response or process output caused by varying or changing the input parameter or variable defined as a quantitative or qualitative factor (Suksaeree et al., 2021). According to the (Martins Coelho et al., 2012), design of experiment (DOE) is a method to

overcome the problem of determine the suitable variable that influence the experiment with suitable value include. This method also can optimize the factor needed for the experiment.

For this study, the implementation of DOE is utilized to optimize the parameter needed for the experiment. Moreover, there is no study utilize the DOE two-level full factorial in their study. Thus, this study optimises the parameter through the use of the DOE approach in order to improve the experimental factor and obtain a desirable outcome for the experimental research study.

2.7 Research Gap and Summary

Various facts about this study have been gathered from plenty of sources for this literature review. In general, there is an author who conducted an experiment on r-PP/PLA blend, but the result of the experimental study was immiscible. Therefore, the design of experiment (DOE) was used in this study to optimize the important four (4) processes parameters required for manufacturing industries. According to earlier research summarise in table 2.11, the rPP/PLA blends are immiscible. Thus, the DOE approach is used to optimize the parameters required for the experiment in order to achieve an exceptional result with high mechanical strength.

Table 2. 10: Previous research study in rPP/PLA blends.

Blend material	Properties	Source
r-PP/PLA	Immiscible	Marina Patricia, 2018
r-PP/PLA	Immiscible (with coupling agent)	Po Chun Lin, 2016

CHAPTER 3
METHODOLOGY

This chapter summarised the overall experimental flow of this study. All steps taken are integrated into the systematic flow or procedure. First, the methodology parts had discussed the preparation and characterization of raw material used which are the recycled polypropylene (r-PP) and polylactic acid (PLA). Next followed with the Design of Experiment (DOE) for blend sample preparations. Sample preparation, design and fabrication, and related experimental testing and procedure are all explained. All procedure used are in accordance with the American Society for Testing and Materials (ASTM) standard operating procedures.

3.1 Overview of Methodology

The following Figure 3.1 has described the flow chart which illustrates the general flow of an overall study. Basically, there are three (3) objectives were involved in this study. The study process has begun with the selection, preparation, and characterization of all significant raw materials that employed in the study. Then, sample preparation stage according to the systematic design of experiment was conducted. Next, the melt blending process was undertaken by using an internal mixer approach and there are about four (4) variables was varied accordingly, which are the blend ratio, temperature, speed, and mixing time. After that, the DOE approach was used to identify the overall number of experiments for this thermoplastic blending. Next, several tests should be performed. All the testing was performed in accordance with the ASTM standard and particular SOP of the testing apparatus and machine. Finally, the SEM is used to observe the blend miscibility and compatibility, based on the fracture morphologies.

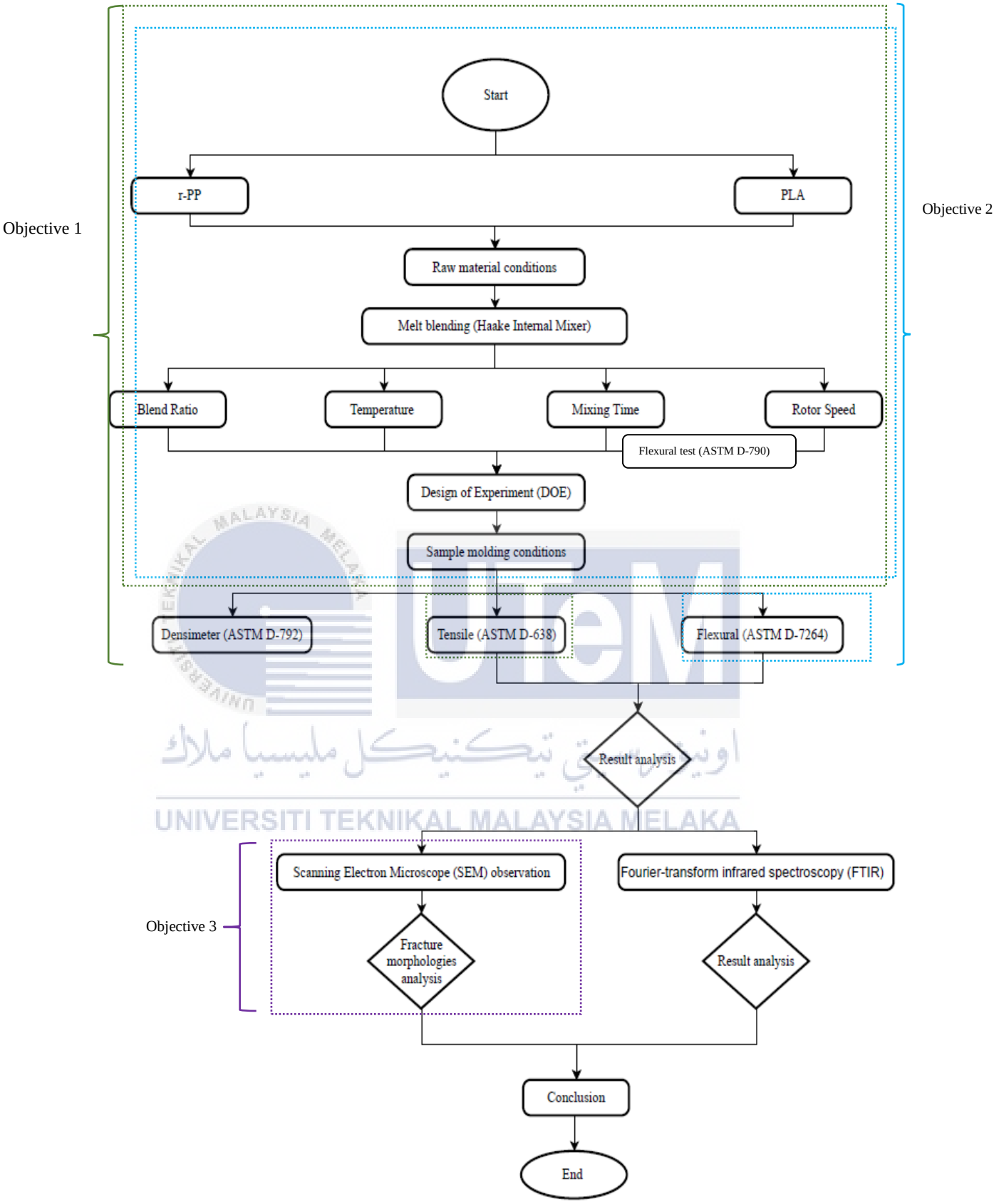


Figure 3.1: Flowchart of methodology

3.2 Materials Preparation for The Melt Blending

Raw material of the study is recycled polypropylene (r-PP) and polylactic acid (PLA). The classification of raw material is being discussed in detail. The methodological approach is established from the previous researcher.

The r-PP is a recycle polypropylene thermoplastic material that widely being used at many applications. Therefore, the new material is produced by mixture the r-PP with PLA to have a good quality property that sustainable to the environment without minimizing the limitation properties of the material itself. The r-PP material is generated from the waste develop at the teaching and learning activity in polymer engineering lab associated in Faculty of Manufacturing Engineering, UTeM. All those wastes are generated from the injection moulding process during teaching and learning. The Figure 3.2 depicts the pallet shape of the r-PP raw material.

Figure 3.-:The r-PP pallet form

PLA is biodegradable material that used in this study to improve the material properties of the recycled polypropylene to have a sustainable material that can degrade in the environment when it being dispossessed. The PLA was producing with density of 1.24 g/cm^3, and Tm of 175℃ by NatureWorks LLC company at Minnetonka MM, USA. The Figure 3.3 depicts the pallet shape of the PLA raw material.

Figure 3.2: PLA pallet form

Blends were created by combining recycled polypropylene and a biodegradable polymer, PLA. The weight percent required for these two materials is presented in Table 3.1, along with the percentage of r-PP and PLA in each blend ratios.

Table 3.1: Sample acronym

Blend	Composition	
	r-PP (wt%)	PLA (wt%)
r-PP/30%PLA	70	30
r-PP/50%PLA	50	50
r-PP/70%PLA	30	70

3.2.1 Raw material conditioning

The pallets are dried at a drying oven for 8 hours at 80 ℃ to eliminate the moisture. This procedure is needed to minimize the crack or any physical defect on the sample due to miscible trapped. This procedure is called as conditioning. Figure 3.4 show the drying oven that used for this study.

Figure 3. s: Drying oven

3.3 Design of experiment (DOE)

For rPP/PLA thermoplastic blend samples preparation, pre-experimental planning was designed by using a statistical software namely as Design Expert® Software. To optimize the parameter used in this study the DOE strategy is implemented with two level full factorial methodology. The variable that needs to be considered in this experimental procedure is involving four (4) factors which are blend ratio, temperature, mixing time, and rotor speed. Furthermore, the sample needed for this experiment is 19 samples. The explanation of the total 19 sample; 2^4 factorial design for four (4) type of variables with 3 repetitions at centre point. Then, one (1) block is used to perform 19 experimental sample sets. Table 3.2 is clarifying the parameter needed for this experiment. Table 3.3 is shown the experimental layout for the DOE layout in the software.

$2^4 = 2x2x2x2$

= 16 + 3 test at centre point

= total sample 19 samples

Table 3.2: Parameters for r-PP/PLA blends

Factors	Min (-1)	Centre Point (0)	Max (+1)
Blend Ratio (rPP/PLA)	30	50	70
Temperature (°C)	165	175	185
Mixing time (mins)	6	9	12
Rotor speed (rpm)	60	70	80

Table 3.3: Experimental layout of the DOE

			Factor 1	Factor 2	Factor 3	Factor 4	Response 1	Response 2
Std	**Run**	**Block**	**A:Blend Ratio Percent (%)**	**B:Temperature deg Celcius (°C)**	**C:Time mins**	**D:Rotor Speed rpm**	**Tensile Strength MPa**	**Flexural Stregth MPa**
1	15	Block 1	30	165	6	60		
2	4	Block 1	70	165	6	60		
3	18	Block 1	30	185	6	60		
4	14	Block 1	70	185	6	60		
5	7	Block 1	30	165	12	60		
6	2	Block 1	70	165	12	60		
7	8	Block 1	30	185	12	60		
8	13	Block 1	70	185	12	60		
9	10	Block 1	30	165	6	80		
10	17	Block 1	70	165	6	80		
11	12	Block 1	30	185	6	80		
12	11	Block 1	70	185	6	80		
13	5	Block 1	30	165	12	80		
14	6	Block 1	70	165	12	80		
15	9	Block 1	30	185	12	80		
16	1	Block 1	70	185	12	80		
17	3	Block 1	50	175	9	70		
18	16	Block 1	50	175	9	70		

Std	Run	Block	Factor 1 A:Blend Ratio Percent (%)	Factor 2 B:Temperature deg Celcius (°C)	Factor 3 C:Time mins	Factor 4 D:Rotor Speed rpm	Response 1 Tensile Strength MPa	Response 2 Flexural Stregth MPa
19	19	Block 1	50	175	9	70		

3.4 Melt blending

The composition of rPP/PLA blends at different concentrations is shown in Table 1. Melt blending was performed by Haake rheomix os LAB (Internal Mixer) as shown in Figure 3.5. Materials were weighed and manually mixed before being loaded into the mixer. The different compositions of PP/PLA blend with ratio 70:30, 30:70, and 50:50 was prepared. The blend ratio and their mixing parameter is conducted by implement the optimization of DOE in Table 3.5.

Figure 3. 3: Haake internal mixer's machine

3.5 Sample molding condition

The sample for the testing is prepared by hot compress technique by using mould that fit with the testing specimen's size as shown in Figure 3.6. This procedure is used to prepare an ASTM-compliant sample specimen for tensile and flexural testing. Figure 3.7 depicts the hot press machine utilised in this method.

Figure 3. 4: mould for the specimen

Figure 3. 5: Hot compress machine

3.6 Testing and characterization for the r-PP/PLA blends

The properties of the r-PP/PLA blends are analysing by using several tests include tensile test, and flexural test. Then the scanning electron microscope (SEM) is used to analyse the morphological structure of r-PP/PLA polymer blend samples. In addition, the Fourier transform infrared (FTIR) test is used to analyse the peak and chemical bonding of the blend material. Meanwhile, the densimeter is used to identify the physical properties of the rPP/PLA blend. The testing in this study was conducted in compliance with the ASTM standard, which can be seen in Table 3.4.

Table 3.4: ASTM standard of testing

Testing	Standard
Tensile test	ASTM D-638
Flexural test	ASTM D-790

3.6.1 Tensile test

Tensile test is used to evaluate the strength and elongation required for the r-PP/PLA to break. Tensile testing was performed utilising a Universal Testing Machine (UTM) that compliance to the ASTM D-638 standard. The sample is undergoing the molding procedure using hot compression molding, Figure 3.8 show a geometry ‘dumbbell’ shape for tensile test procedure. The speed is 5 mm/min. The sample is clamped to the machine, and force will be applied until it breaks. Following that, the data collection is to determine each sample's tensile stress, maximum elongation, and modulus of elasticity. Figure 3.9 shown machine used for ASTM D-638 standard’s tensile test.

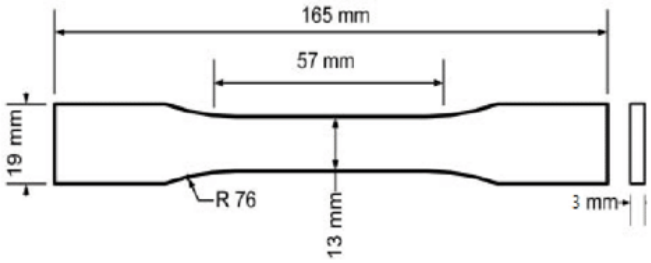


Figure 3.6: Geometry ' dumbbell' shape sample

Figure 3.7: Machine for tensile test

3.6.2 Flexural test

The flexural test is a three-point bending test utilising a Shimadzu Autograph 100 KN UTM Machine from Japan. The flexural test was performed in accordance with ASTM D-790 standard. The mission of this test is to measure the sample's flexural strength. The sample is undergoing the molding procedure using hot compression molding. During the test, the load was delivered to the sample's centre at a crosshead speed of 2 mm per minute. Figure 3.11 depicts the flexural testing machine.

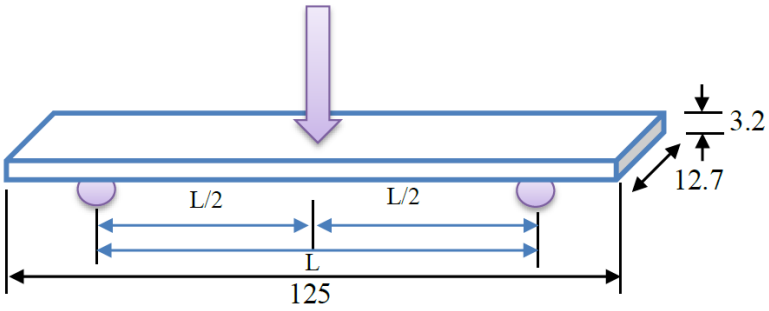


Figure 3. 8: Specimen's size for tensile test

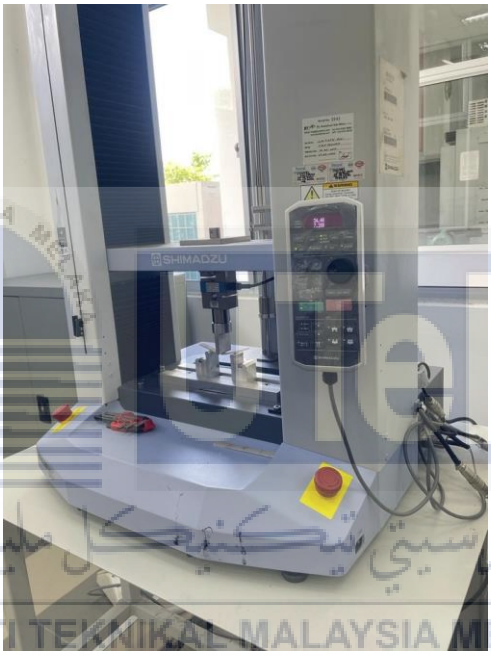


Figure 3.9: Machine for flexural test

3.6.3 Density Test

In accordance with ASTM D792, the mass per unit volume of the test sample was determined by conducting a density test. The sample was prepared as shown in Figure 3.12. All the data is recorded. Density experiments were conducted on the 19 samples. Each sample was weighed and placed in the densimeter to obtain a reading of its density. Figure 3.13 depicts the density metre utilised in this research.

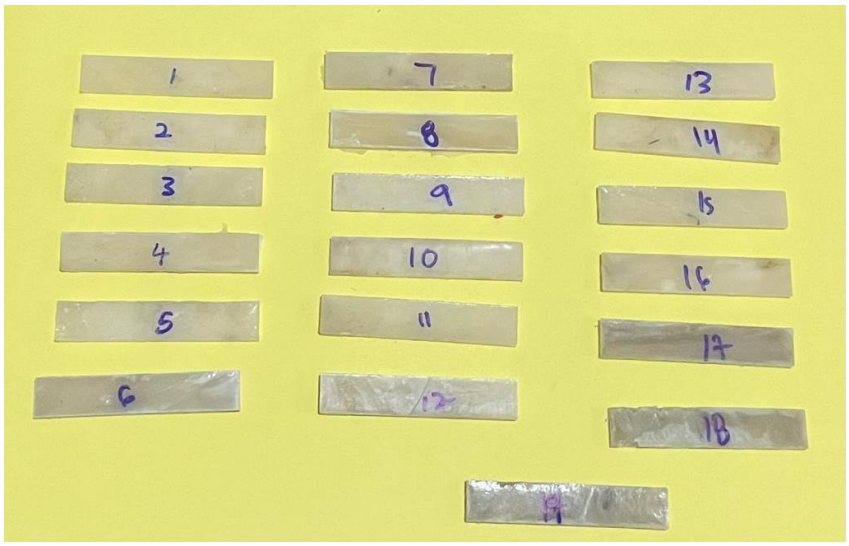


Figure 3. 10: Sample for density

Figure 3. 11: Densimeter machine

3.6.4 Fourier transform infrared (FTIR)

The Fourier transform is used in infrared spectroscopy. The FTIR was utilised as a dependable and low-cost analytical instrument for identifying polymers and evaluating the quality of plastics products. The purpose of FTIR was to determine the chemical composition of polymer (rPP/PLA) functional groups. Figure 3.14 is type of FTIR spectrophotometer machine for this experiment.

Figure 3.12: FTIR spectrophotometer

3.6.5 Scanning Electron Microscope (SEM)

The morphological structural of the three (3) sample from the previous step was observed under the scanning electron microscope (SEM). The scanning electron microscope is used to evaluate the surface feature of the sample to analyse the surface defect and failure structure of the r-PP/PLA blends sample. Before scanning electron microscopy (SEM), all sample was shape with dimension of 15 mm long, 15 mm wide, and 10 mm thick. Figure 3.15 is type of scanning electron microscopy which is ZEISS EVO 50. The experiment is at an accelerating voltage of 30 kV. Following that, the samples were placed inside the vacuum chamber and the computer screen image was presented. The image was magnified 50X, 130X, 300X and 500X. All morphology results were preserved for future analysis.

Figure 3.13: SEM machine set-up

3.7 Summary

To conclude, the r-PP/PLA is conducted using melt blending method with implementation of design of experiment (DOE) concept to optimize the variable of the experiment. The factor that considers in this experiment include; blend ratio, temperature, mixing time, and rotor speed. Then, the sample of r-PP/PLA blend is observed and analyse using several tests which are the tensile testing and flexural test for mechanical behaviour. Meanwhile, Fourier transform infrared (FTIR) to determine functional group of the polymer with their chemical composition. Last but not least, the scanning electron microscope (SEM) is used to observe the miscibility and compatibility of the r-PP/PLA blend which is important for the end-product application.

CHAPTER 4
RESULT AND DISCUSSION

This chapter provides a summary of the corresponding tests and their analyses. To improve the explanation and develop relationships between the results and important theoretical frameworks, the analysis of research findings was analysed in depth, with support from additional relevant literature.

4.1 Overview

The fundamental goal of this work is to develop a new sustainable material using a melt mixing process. Then, the Design of experiment (DOE) with two (2) responses, tensile strength and flexural strength, is utilised to optimise the experiment's parameters. This outcomes were discussed in detail. In addition, this chapter was covered the results of density testing, scanning electron microscopy (SEM), and the Fourier transform infrared spectroscopy (FTIR).

4.2 Design of experiment (DOE)

Design experiment (DOE) technique is utilized in this study. This method was performed using design expert software with screening utilization of two-level full factorial design experiment. Table 4.1 tabulates approximately nineteen (19) sets of experimental designs with various parametric combinations of Blend ratio (rPP/PLA)

[A], Temperature (°C) [C], Mixing time (mins) [C], and Rotor speed (rpm) [D], for the preparation of rPP/PLA polymer blends utilising 2^4 two-level full factorial design strategies. The experimental design was produced with the software Design-Expert 6.0.8. The experimental design was analysed by focusing on the tensile strength and flexural strength of the rPP/PLA polymer blend obtained. The actual values of coded factor are provided in Table 4.1 below. Negative one (-1) represents the smallest range, zero (0) represents the centre point, and positive one (+1) represents the maximum range for each parameter. Next. According to this design experiment, there were nineteen (19) set of experiments need to be performed as tabulated in Table 4.2.

Table 4. 1: Selected level of variables for rPP/PLA polymer blends preparation

Blend Ratio (rPP/PLA) [A]	Temperature (°C) [B]	Mixing time (mins) [C]	Rotor speed (rpm) [D]
30 (-1)	165 (-1)	6 (-1)	60 (-1)
50 (0)	175 (0)	9 (0)	70 (0)
70 (+1)	185 (+1)	12 (+1)	80 (+1)

Table 4. 2: Parametric combination for rPP/PLA polymer blends preparation and their responses values

Std	Run	Block	Factor 1 A:Blend Ratio Percent (%)	r-PP Grams (g)	PLA Grams (g)	Factor 2 B:Temperature deg Celcius (°C)	Factor 3 C:Time (mins)	Factor 4 D:Rotor Speed (rpm)	Response 1 Tensile Strength MPa	Response 2 Flexural Stregth MPa
1	15	Block 1	30	12	28	165	6	60	14.3535	33.9715
2	4	Block 1	70	28	12	165	6	60	16.9161	37.0068
3	18	Block 1	30	12	28	185	6	60	14.6229	24.9163
4	14	Block 1	70	28	12	185	6	60	15.1274	34.337
5	7	Block 1	30	12	28	165	12	60	10.4292	29.618
6	2	Block 1	70	28	12	165	12	60	14.0905	33.3882
7	8	Block 1	30	12	28	185	12	60	13.6616	19.7506
8	13	Block 1	70	28	12	185	12	60	14.2595	34.2608
9	10	Block 1	30	12	28	165	6	80	12.1568	23.516
10	17	Block 1	70	28	12	165	6	80	14.2959	33.2864
11	12	Block 1	30	12	28	185	6	80	14.9494	28.6102
12	11	Block 1	70	28	12	185	6	80	15.2567	34.4674

Std	Run	Block	Factor 1 A:Blend Ratio Percent (%)	r-PP Grams (g)	PLA Grams (g)	Factor 2 B:Temperature deg Celcius (°C)	Factor 3 C:Time (mins)	Factor 4 D:Rotor Speed (rpm)	Response 1 Tensile Strength MPa	Response 2 Flexural Stregth MPa
13	5	Block 1	30	12	28	165	12	80	10.1191	21.1573
14	6	Block 1	70	28	12	165	12	80	15.2663	34.0478
15	9	Block 1	30	12	28	185	12	80	15.2198	22.7245
16	1	Block 1	70	28	12	185	12	80	15.1829	28.4529
17	3	Block 1	50	20	20	175	9	70	12.3943	30.4636
18	16	Block 1	50	20	20	175	9	70	12.4049	29.7626
19	19	Block 1	50	20	20	175	9	70	12.141	29.9407

Optimization strategy that are recommended by the DOE software were tabulated in the following Table 4.3. The goal of this optimization was fixed into “is in range” for blend ratio and rotor speed independent variable factors, “minimize” for temperature and time and “is maximum” for the tensile strength dependent response and flexural strength dependent response. Meanwhile in Table 4.4, there are about nine possible optimization suggestion were recommended with higher desirability of the corresponding tensile strength response.

First recommendation with desirability of one (unity) was chosen for additional validation testing, as it represents the most desirable solution for achieving maximum tensile strength response and flexural strength response. The selected solution was 70 % of blend ratio, 165 °C for temperature, 6.01 mins for time, 60 rpm of rotor speed, 16.9093 MPa for tensile strength, and 36.9981 MPa for flexural strength. The desirability result neared the value of one, indicating that all evaluated elements are totally relevant and should not be disregarded. Other recommendation solutions may also be used to achieve the same outcome, although with a lower attractiveness value and the presence of residue. In this analysis, the first solution proposed by the software was validated further.

Table 4. 3: Optimization results of RSM on rPP/PLA polymer blends

Parameter	Units	Goal	Level		Optimization result
			Lower	upper	
Blend Ratio	(%)	is in range	30	70	69.98
Temperature	(°C)	minimize	165	185	165.12

Time	(mins)	minimize	6	12	6
Rotor Speed	(rpm)	is in range	60	80	60
Tensile Strength	(MPa)	maximize	10.1191	16.9161	16.9037
Flexural Strength	(MPa)	maximize	19.7506	37.0068	36.9887

Table 4. 4: Optimization recommendation of rPP/PLA polymer blends solution

Number	Blend Ratio	Temperature	Time	Rotor Speed	Tensile Strength	Flexural Strength	Desirability	
1	70.00	165.00	6.01	60.00	16.9093	36.9981	0.999046	Selected
2	64.55	165.00	6.00	60.00	16.5667	36.593	0.980924	
3	69.87	165.00	6.00	63.47	16.4534	36.3476	0.973007	
4	69.88	165.00	6.45	60.00	16.6973	36.7275	0.968857	
5	57.46	165.00	6.00	60.00	16.1124	36.0549	0.955381	
6	69.98	165.18	6.00	66.14	16.1024	35.8494	0.949832	
7	70.00	165.00	6.00	68.78	15.7664	35.3743	0.931301	
8	70.00	165.00	7.82	60.00	16.057	35.9066	0.868603	
9	70.00	165.00	6.00	78.52	14.4892	33.5608	0.846943	

Figure 4.1 depicts the optimization result for rPP/PLA polymer blends in ramps view, while Figure 4.2 depicts the desirability result for rPP/PLA polymer blends in histogram view. Described in Figure 4.1, the ramps revealed that the best parameters for temperature and time were in the lowest range, whereas the blend ratio, rotor speed, tensile strength response, and flexural strength response were in the highest range (shown by the red bullet). Figure 4.2 histogram depicts the desirability of each factor, tensile strength response and flexural strength, separately. The bottom histogram bar illustrates the combined attractiveness of all parameters for the tensile and flexural strength responses. 70 percent of blend ratio, 165 °C for temperature, 6.01 minutes for duration time, 60 rpm of rotor speed, 16.9093 MPa for tensile strength, and 36.9981 MPa for flexural strength where the results of the proposed solution of DOE that are capable of producing a desirability value of unity, indicating a perfect interaction between the involved parameters.

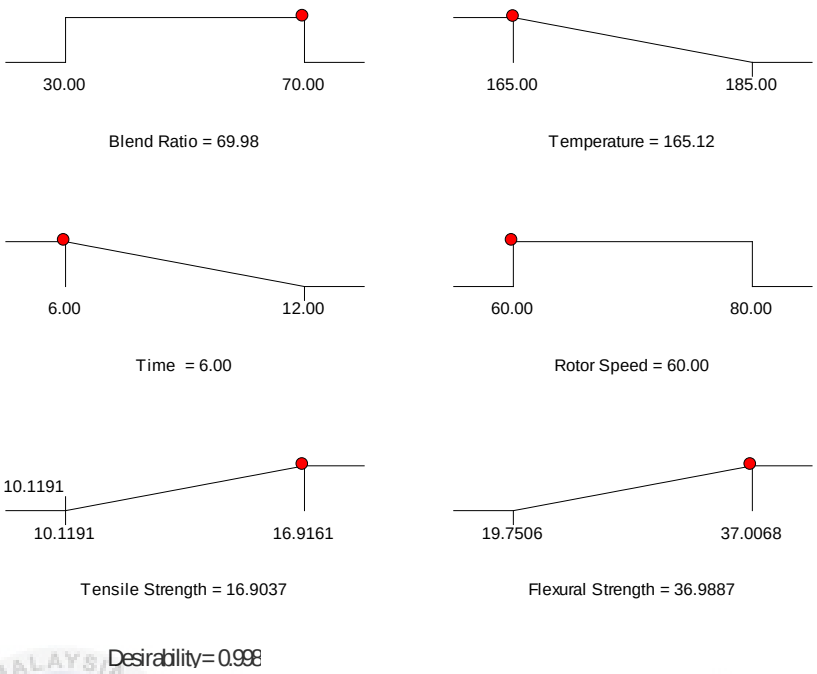


Figure 4. 1: Optimization result of rPP/PLA polymer blend in ramps graphical view

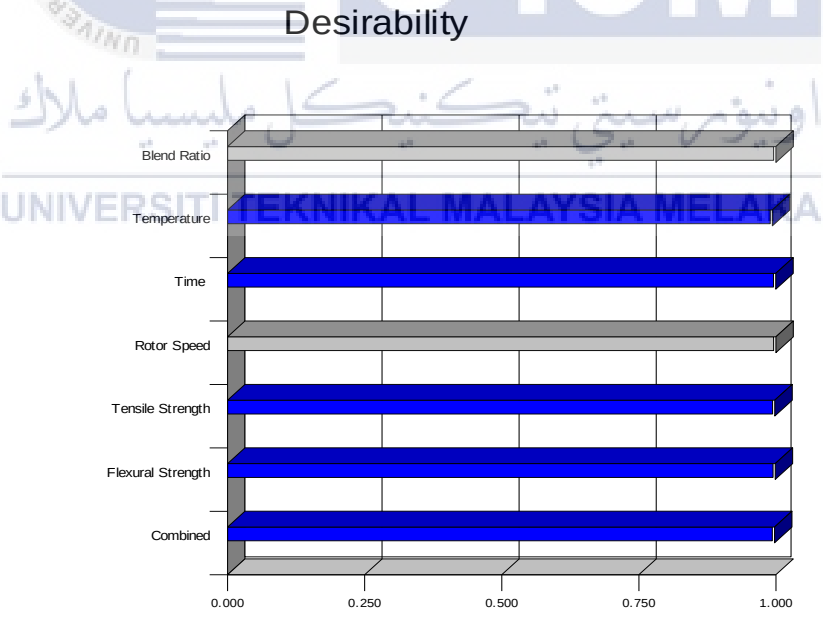


Figure 4. 2: Optimization result of rPP/PLA polymer blend in histogram graphical view

4.2.1 Tensile Strength Analysis of rPP/PLA

Table 4.5 tabulates approximately nineteen (19) sets of experimental designs with various parametric combinations of Blend ratio (rPP/PLA) [A], Temperature (°C) [C], Mixing time (mins) [C], and Rotor speed (rpm) [D], for the preparation of rPP/PLA polymer blends utilising 2^4 two-level full factorial design strategies. The experimental design was produced with the software Design-Expert 6.0.8. The experimental design was analysed by focusing on the tensile strength and flexural strength of the rPP/PLA polymer blend obtained. The actual values of coded factor are provided in Table 4 below. Negative one (-1) represents the smallest range, zero (0) represents the centre point, and positive one (+1) represents the maximum range for each parameter.

Table 4. 5: Parametric combination for rPP/PLA polymer blend preparation by using 2^4 two-level full factorials

Experiment	Blend Ratio (rPP/PLA) [A]	Temperature (°C) [B]	Mixing time (mins) [C]	Rotor speed (rpm) [D]
1	-1	-1	-1	-1
2	+1	-1	-1	-1
3	-1	+1	-1	-1
4	+1	+1	-1	-1
5	-1	-1	+1	-1
6	+1	-1	+1	-1
7	-1	+1	+1	-1
8	+1	+1	+1	-1
9	-1	-1	-1	+1
10	+1	-1	-1	+1
11	-1	+1	-1	+1
12	+1	+1	-1	+1
13	-1	-1	+1	+1
14	+1	-1	+1	+1
15	-1	+1	+1	+1
16	+1	+1	+1	+1
17	0	0	0	0
18	0	0	0	0
19	0	0	0	0

The results were averaged from four (4) tested samples of each respective experimental design at different parametric combination. The results had revealed that, at the highest rPP content of 70 wt. %, lowest temperature at 165 °C, slowest time taken at 6 mins, and minimum speed of rotor at 60 rpm, the tensile strength respond had higher value compare the other. This event has proven by the experiment 2 which has 16.9161 MPa value of tensile strength. Meanwhile, the tensile strength of experiment

5 and 13 was about 10.11915 MPa and 10.42922 MPa which considerably lowest as compared to the highest tensile strength response from experiment 2. The result shows that, the higher rPP content in the blending lead to higher tensile strength value. It has been proven by Kk et al., (2019) that tensile characteristics increase with increasing polypropylene concentration. Meanwhile, the result is contrast with the study done by Pivsa-Art et al., (2016) which is the highest of PLA content in the blending has increased the tensile strength.

Half normal plot of tensile strength response generated from two-level full factorial design of experimental approach was depicted in the following Figure 4.1. From the effects (factorials) result, it can be seen that Blend ratio (rPP/PLA) [A], Temperature (°C) [C], Mixing time (mins) [C], and Rotor speed (rpm) [D] as well as the interaction term between AB, BC, CD, BD, AC, and AD were positioned away from the straight line, indicating the significant terms of this experiment. The farther the individual term or interaction term from the half normal plot, the higher the contribution of the term or interaction term towards the response studied. Next, all model terms were chosen to be analysed through analysis of variance (ANOVA) test.

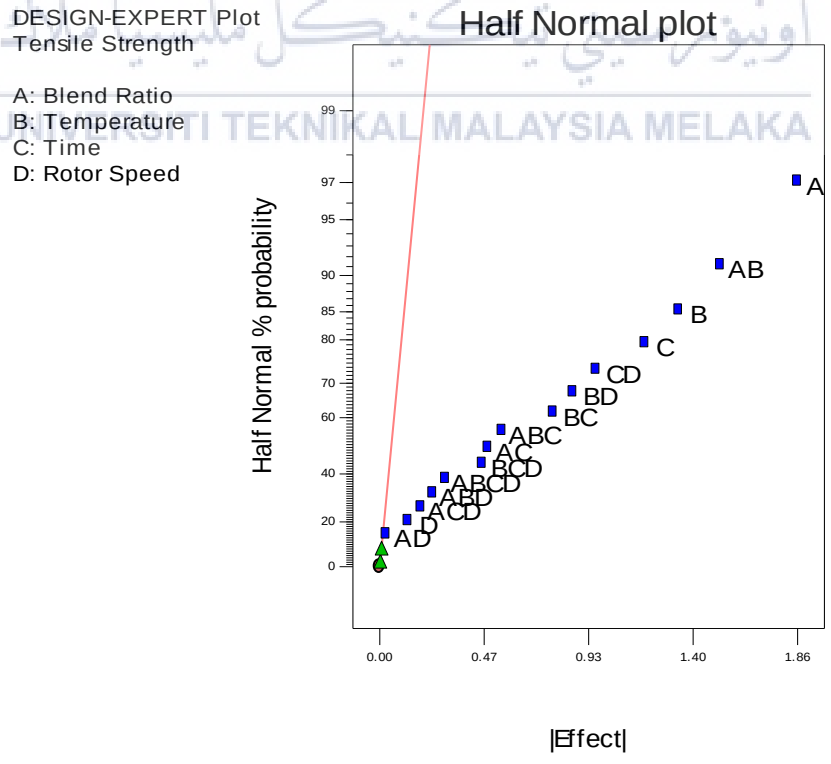


Figure 4. 3: Half normal plot of rPP/PLA blend tensile strength response

The details on effects list of all model and interaction terms were listed as in Table 4.6. From the effects list, it was noticed that the highest percentage of contribution on tensile strength response was contributed by the blend ratio (factor A) of variable parameter. This result has revealed that the factor A was the most significance factor with 24.3734 % of contribution on the studied response with 13.8442 of sum of squares (SS). The individual factor D shows lower contribution on the response with only about 0 %. The individual factor C and D as well as interacted factor between AB, ABC, ABD, BCD and ABCD had exhibited a negative Studentized effects.

Table 4. 6: The effect list of model terms for rPP/PLA for Tensile Strength

Term	Studentized Effects	Sum of squares	% Contributed
A	1.86039	13.8442	24.3734
B	1.33156	7.09223	12.4862
C	-1.18119	5.58085	9.82537
D	-0.126713	0.0642247	0.
AB	-1.51719	9.20743	16.2101
AC	0.481983	0.92923	1.63596
AD	0.0287879	0.00331498	0.00583618
BC	0.77307	2.39055	4.20868
BD	0.861059	2.96569	5.22124
CD	0.963545	3.71368	6.53812
ABC	-0.54467	1.18666	2.08918
ABD	-0.236825	0.224345	0.394971
ACD	0.183955	0.135357	0.238303
BCD	-0.457108	0.835791	1.47145
ABCD	-0.293384	0.344296	0.60615

Table 4. 7: ANOVA of experimental data for rPP/PLA for Tensile Strength

Source of variation	Sum of squares	DF	Mean Square	F Value (F_0)	Prob>F (P-Value)
Model	48.52	15	3.23	144.86	0.0069
A	13.84	1	13.84	620.04	0.0016
B	7.09	1	7.09	317.64	0.0031
C	5.58	1	5.58	249.95	0.004
D	0.064	1	0.064	2.88	0.232
AB	9.21	1	9.21	412.37	0.0024
AC	0.93	1	0.93	41.62	0.0232
AD	3.32E-03	1	3.32E-03	0.15	0.7371
BC	2.39	1	2.39	107.07	0.0092

Source of variation	Sum of squares	DF	Mean Square	F Value (F_0)	Prob>F (P-Value)
BD	2.97	1	2.97	132.82	0.0074
CD	3.71	1	3.71	166.32	0.006
ABC	1.19	1	1.19	53.15	0.0183
ABD	0.22	1	0.22	10.05	0.0868
ACD	0.14	1	0.14	6.06	0.1329
BCD	0.84	1	0.84	37.43	0.0257
ABCD	0.34	1	0.34	15.42	0.0592
Curvature	8.24	1	8.24	368.95	0.0027
Pure Error	0.045	2	0.022		
Cor Total	56.8	18			

Table 4. 8: Statistical model summary of the Tensile Strength response for rPP/PLA

Stastistical Result	Value
Standard Deviation	0.15
R-Squared	0.9991
Adjusted R-Squared	0.9922
Adequate Precision	48.088

Analysis of variance (ANOVA) was performed to establish the statistical validity of processing parameters and to analyze the influence of input parameter on output response (Abd Razak et al., 2020). In this context, it was conducted to determine the relevance of each variable's effect and contribution to the tensile strength response of the rPP/PLA blend that was tested. A variable with a considerable value will have a greater percentage of contribution relative to other findings. This occurrence indicates that the parameter has a greater effect on the investigated response.

The statistical ANOVA findings for the tensile strength response (R1) of rPP/PLA blend are shown in Table 4.7Model F-value (Fo) of 144.86 indicated that the model was statistically significant. There was only a 0.69% possibility that the model's F-Value could have been affected by noise. Prob > F or P-values that were <0.05 suggest that the model terms were significant in which model terms A, B, C, AB, AC, AD, BC, BD, CD, ABC, ABD, ACD, BCD and ABCD are all significant. A curvature F-value of 368.95 indicated that design space had significant curvature (as assessed by the difference between the average of the centre points and the average of the factorial points). There was only a 0.27 % chance that the Curvature F-value may have been caused by noise. This study has no Lack-of-Fit values. This result implied that the experiment was done successfully, with no errors reported by the DOE software.

Three-dimensional response surface contour plot was utilized to interpret and evaluate the produced statistical model as depicted in Figure 4.4 (a), (b), (c), (d), (e) and (f). The surface plot of the tensile strength response was based on the regresses of Blend ratio (rPP/PLA) [A], Temperature (°C) [C], Mixing time (mins) [C], and Rotor speed (rpm) [D]. The interaction of four (4) factors through response surface plot has helped to understand and to locate the optimum level between of the results. From the response surface plot, the tensile strength response value was escalated to the highest of 15.1422 MPa at decrease of factor A. Tensile strength decrease with the increase of Factor C and D.

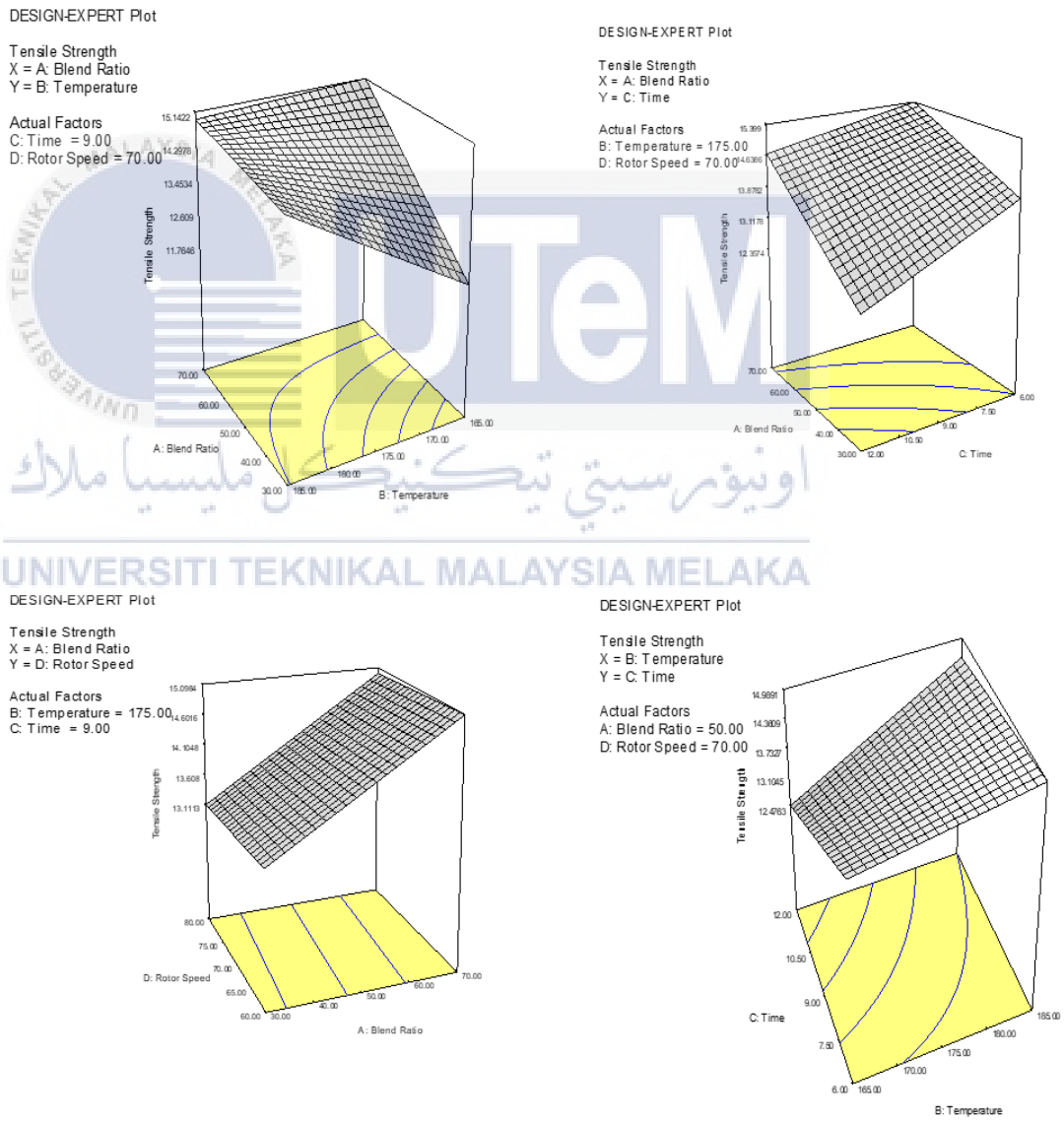


Figure 4. 4: Response surface plots of tensile strength response of rPP/PLA blend with AB interaction; AC interaction; AD interaction; and BC interaction

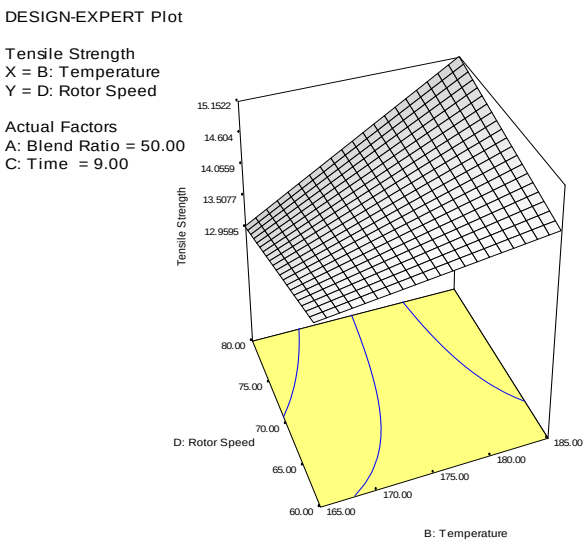


Figure 4. 5: Response surface plots of tensile strength response of rPP/PLA blend with BD interaction

The most essential qualities of materials are tensile properties such as tensile strength, modulus, and elongation, which assess a material's resistance to forces that tend to tear it apart and measure how far a material can stretch before breaking (Mandal et al., 2019). The graph demonstrates that the greater the rPP value in the blend ratio, the more flexible the deformed rPP. Moreover, there is a rise in tensile strength. This is because RPP has a higher tensile strength than other materials (32.5 MPa).

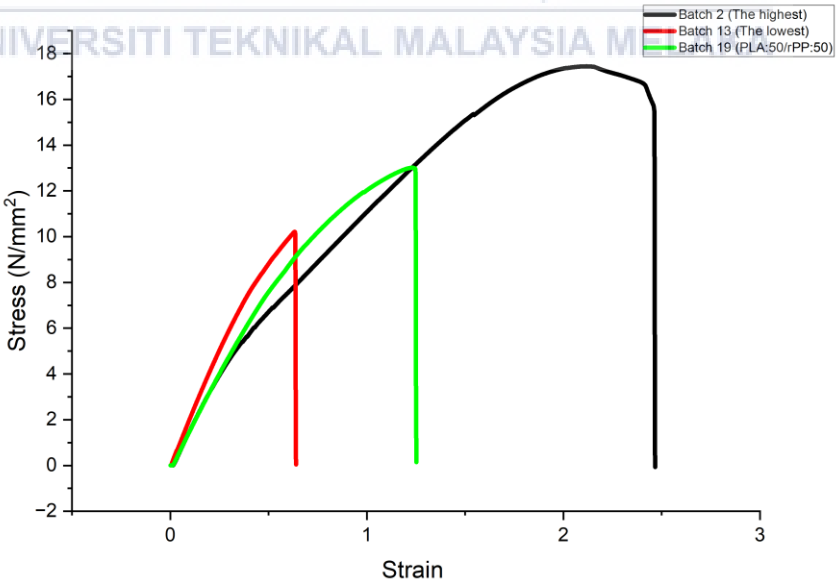


Figure 4. 6: Tensile strength curve for stress-strain graph of rPP/PLA blend

4.2.2 Flexural Strength Analysis of rPP/PLA

Half normal plot of tensile strength response generated from two-level full factorial design of experimental approach was depicted in the following Figure 4.6. From the effects (factorials) result, it can be seen that Blend ratio (rPP/PLA) [A], Temperature (°C) [C], Mixing time (mins) [C], and Rotor speed (rpm) [D] as well as the interaction term between AB, BC, CD, BD, AC, and AD were positioned away from the straight line, indicating the significant terms of this experiment. The farther the individual term or interaction term from the half normal plot, the higher the contribution of the term or interaction term towards the response studied. Next, all model terms were chosen to be analysed through analysis of variance (ANOVA) test.

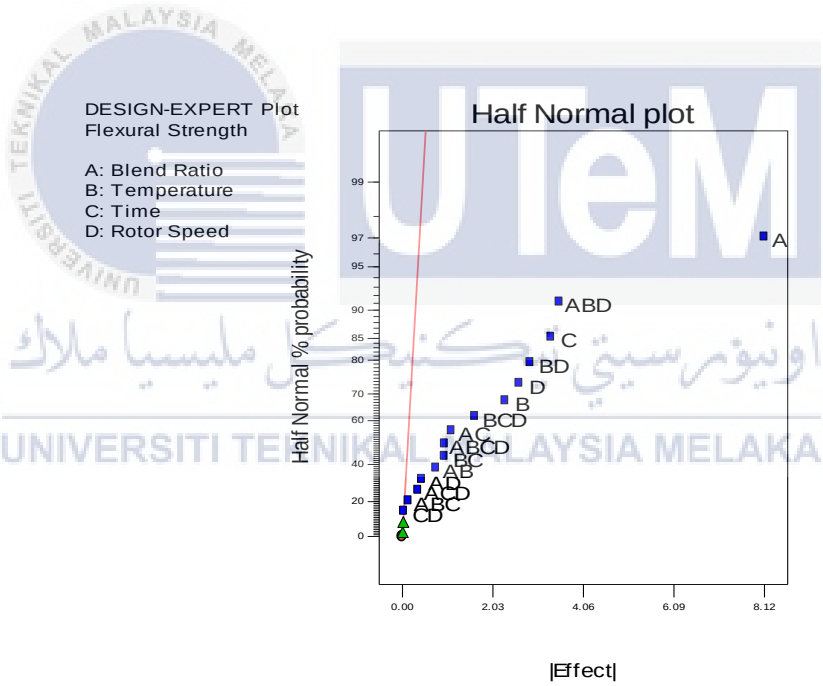


Figure 4. 7: Half normal plot of rPP/PLA blend flexural strength response

The details on effects list of all model and interaction terms were listed as in Table 4.9. From the effects list, it was noticed that the highest percentage of contribution on flexural strength response was contributed by the blend ratio (factor A) of variable parameter. This result has revealed that the factor A was the most significance factor with 56.4954% of contribution on the studied response with 263.924 of sum of squares (SS). The individual factor B shows lower contribution on the

response with only about 4.56504 %. The factor B, C and D as well as interacted factor between BC, CD, ABD, ACD, BCD, and ABCD had exhibited a negative Studentized effects.

Table 4. 9: The effect list of model terms for rPP/PLA for Flexural Strength

Term	Studentized Effects	Sum of squares	% Contributed
A	8.12287	263.924	56.4954
B	-2.30901	21.326	4.56504
C	-3.33897	44.5948	9.54594
D	-2.62334	27.5277	5.89256
AB	0.756269	2.28777	0.489718
AC	1.10196	4.85723	1.03973
AD	0.438756	0.770028	0.164832
BC	-0.946569	3.58397	0.767182
BD	2.87091	32.9684	7.05719
CD	-0.0354312	0.00502149	0.0010749
ABC	0.138206	0.0764039	0.016355
ABD	-3.52509	49.7051	10.6398
ACD	-0.354131	0.501636	0.10738
BCD	-1.62913	10.6163	2.27251
ABCD	-0.950431	3.61328	0.773456

Table 4. 10: ANOVA of experimental data for rPP/PLA for Flexural Strength

Source of variation	Sum of squares	DF	Mean Square	F Value (F_0)	Prob>F (P-Value)
Model	466.36	15	31.09	234.22	0.0043
A	263.92	1	263.92	1988.24	0.0005
B	21.33	1	21.33	160.66	0.0062
C	44.59	1	44.59	335.95	0.0030
D	27.53	1	27.53	207.38	0.0048
AB	2.29	1	2.29	17.23	0.0534
AC	4.86	1	4.86	36.59	0.0263
AD	0.77	1	0.77	5.80	0.1377
BC	3.58	1	3.58	27.00	0.0351
BD	32.97	1	32.97	248.36	0.0040
CD	0.005021	1	0.005021	0.038	0.8638
ABC	0.076	1	0.076	0.58	0.5273
ABD	49.71	1	49.71	374.45	0.0027
ACD	0.50	1	0.50	3.78	0.1913
BCD	10.62	1	10.62	79.98	0.0123
ABCD	3.61	1	3.61	27.22	0.0348
Curvature	0.54	1	0.54	4.05	0.1819
Pure Error	0.27	2	0.13		
Cor Total	467.16	18			

Table 4. 11: Statistical model summary of the Flexural Strength response for rPP/PLA

Stastistical Result	Value
Standard Deviation	0.36
R-Squared	0.9994
Adjusted R-Squared	0.9952
Adequate Precision	50.072

Analysis of variance (ANOVA) was performed to establish the statistical validity of processing parameters and to analyze the influence of input parameter on output response. In this context, it was conducted to determine the relevance of each variable's effect and contribution to the tensile strength response of the rPP/PLA blend that was tested. A variable with a considerable value will have a greater percentage of contribution relative to other findings. This occurrence indicates that the parameter has a greater effect on the investigated response.

The statistical ANOVA findings for the tensile strength response (R1) of rPP/PLA blend are shown in Table 4.10 Model F-value (Fo) of 234.22 indicated that the model was statistically significant. There was only a 0.43% possibility that the model's F-Value could have been affected by noise. Prob > F or P-values that were <0.05 suggest that the model terms were significant in which model terms A, B, C, AB, AC, AD, BC, BD, CD, ABC, ABD, ACD, BCD and ABCD are all significant. A curvature F-value of 4.05 indicated that design space had significant curvature (as assessed by the difference between the average of the centre points and the average of the factorial points). There was only a 0.18 % chance that the Curvature F-value may have been caused by noise. This study has no Lack-of-Fit values. This result implied that the experiment was done successfully, with no errors reported by the DOE software.

Three-dimensional response surface contour plot was utilized to interpret and evaluate the produced statistical model as depicted in Figure 4.7 (a), (b), (c), (d), (e) and (f). The surface plot of the tensile strength response was based on the regresses of Blend ratio (rPP/PLA) [A], Temperature (°C) [C], Mixing time (mins) [C], and Rotor speed (rpm) [D]. The interaction of four (4) factors through response surface plot has helped to understand and to locate the optimum level between of the results. From the response surface plot, the flexural strength response value was decrese dramatically with highest of Factor A.

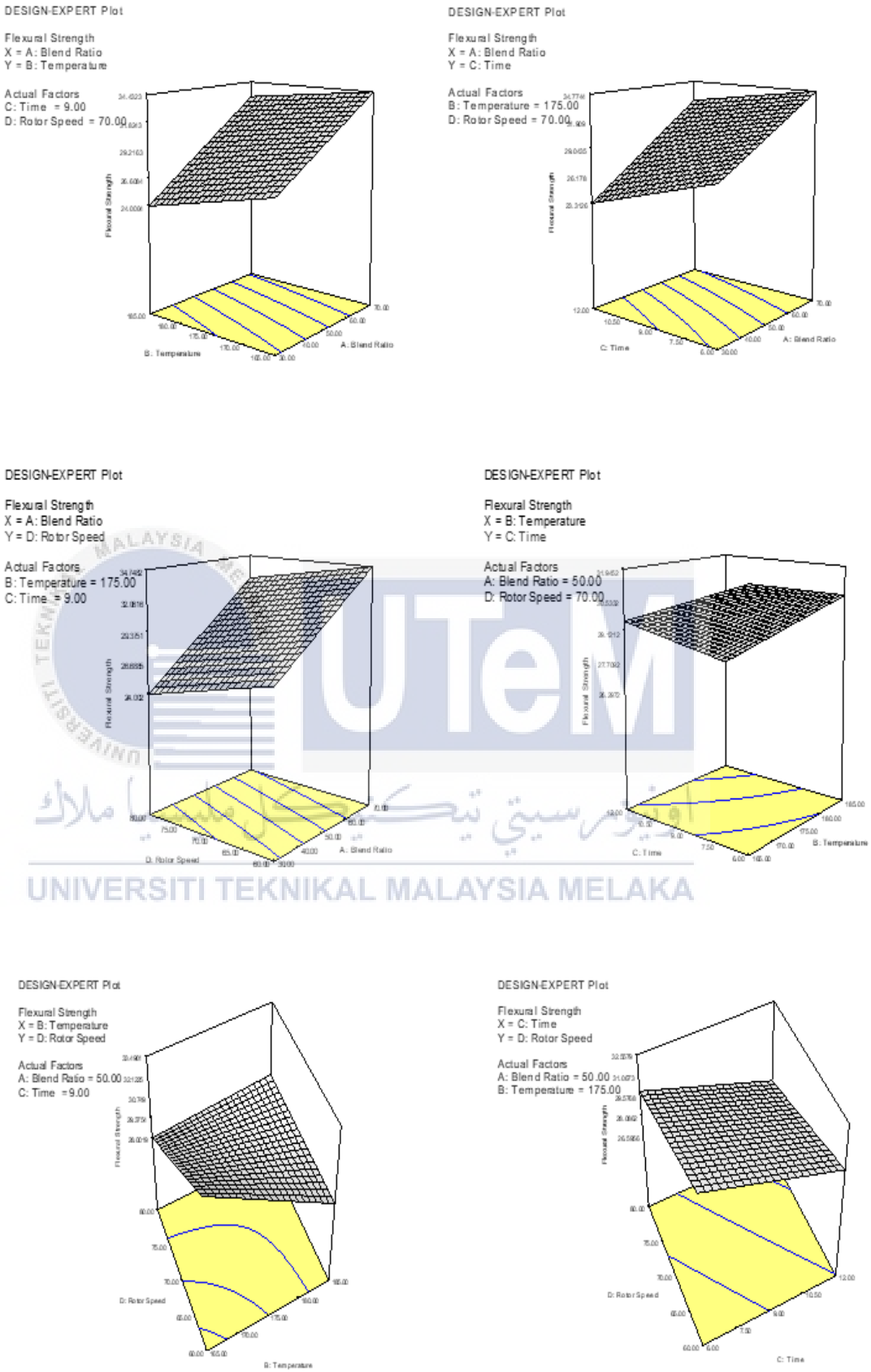


Figure 4. 8: Response surface plots of tensile strength response of rPP/PLA blend with (A) AB interaction; (B) AC interaction; (C) AD interaction; (D) BC interaction; (E) BD interaction; and CD interaction

The flexural strengths of a material are useful for a specification purposes, as well as for classifying the material properties based on its bending strength and stiffness (Mohammed Ajmal et al., 2019). From the graph in Figure 4.8 indicate that the highest value of rpp given the higher stiffness. this result also include the other factor in DOE.

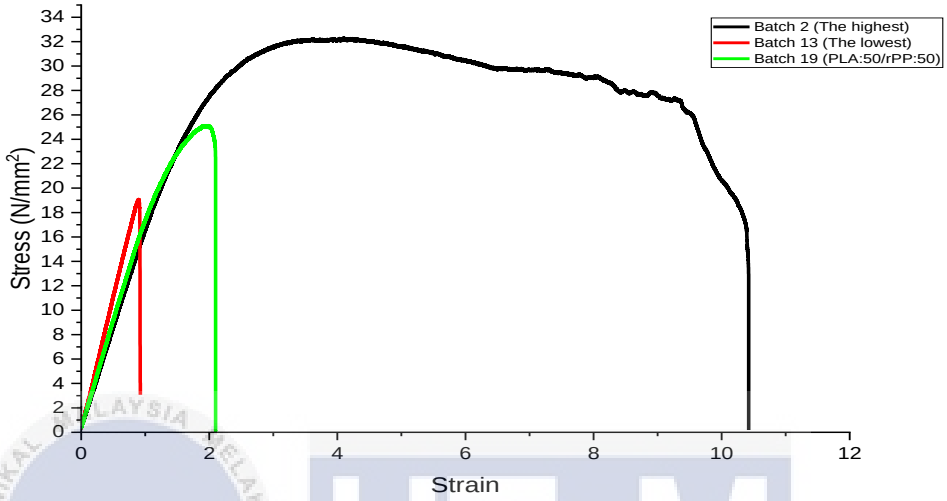


Figure 4. 9: Flexural strength curve for stress-strain graph of rPP/PLA

4.3 Scanning of electron microscopy (SEM)

The fractured morphologies in Figures 4.7, 4.8, and 4.9 displays the SEM observation of fractured surface morphologies of rPP/PLA polymer blend being used evaluate the fracture characteristic under tensile loading at 50X, 130X, and 500X magnifications, respectively. As demonstrated in Figure 4.7, 4.8, and 4.9, the high tensile strength of PP results in the occurrence of ductile fracture. Thus, the ductile fracture proved that PLA and rPP are compatible (Pivsa-Art et al., 2016). From the observation, The rPP was dispersed as a spherical dispersion phase in the PLA matrix. In addition, the mixing ratio also has a significant effect on the shape of the dispersed phase. The interface tension between PLA and PP was decreased, and PP tends to form small droplets with a smaller specific surface area; hence, it is more difficult for PP dispersed phases to collide and merge with larger size dispersed phases (Wen-Dong et al., 2021). To conclude, ductile fracture confirmed the compatibility of PLA and rPP. Then, the phase morphology shows that the graph was partially miscible

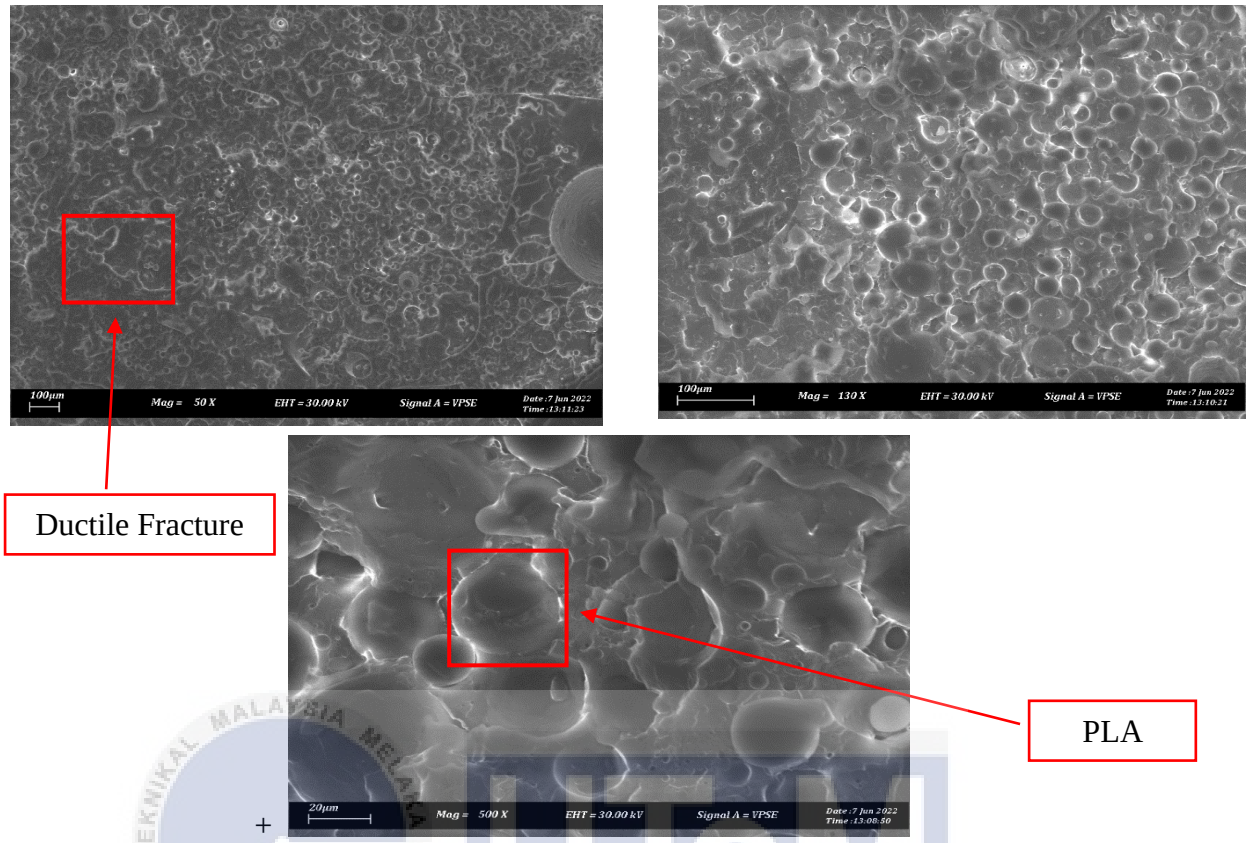


Figure 4. 10: Phase morphology of batch 19 (control sample)

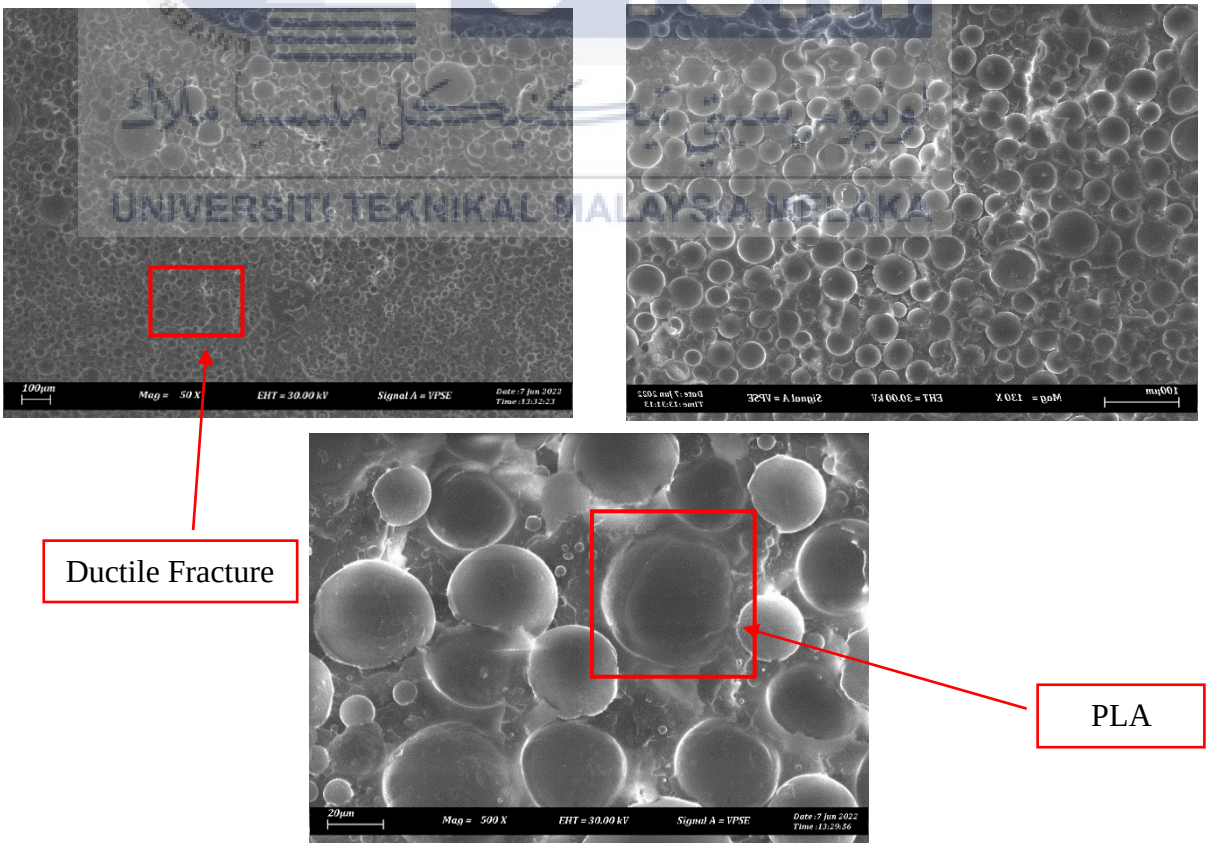


Figure 4. 11: Phase morphology of batch 13 (The worst)

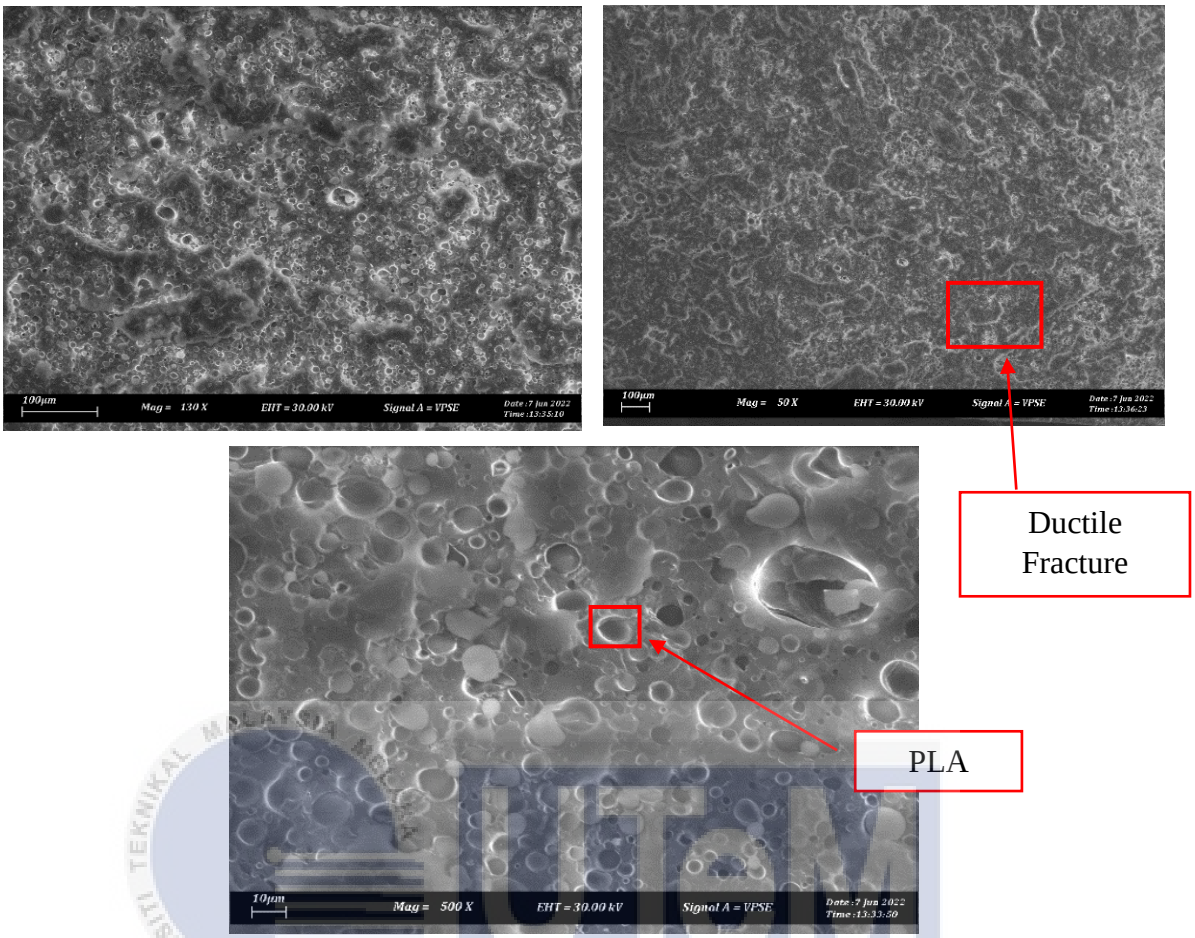


Figure 4. 12: Phase morphology of batch 2 (The best)

4.4 Fourier transform infrared (FTIR)

Fourier transform infrared (FTIR) study show nature of functional groups present in the structural foam. From the graph. It shows that the transmittance bands corresponding to PP are at 2950-2838, 1455-1453, and 1376 cm-1referred to CH stretching, CH3bends, and C-H bending, respectively. Same as study done by (Mandal et al., 2019). meanwhile for the transmittance bands corresponding to PLA are at 1749, 1181, and 1080 cm-1referred to C=O stretching, symmetric C-O-C stretching, and asymmetric CH3, respectively. Same as study done by (Manral et al., 2021; Pivsa-Art et al., 2016)

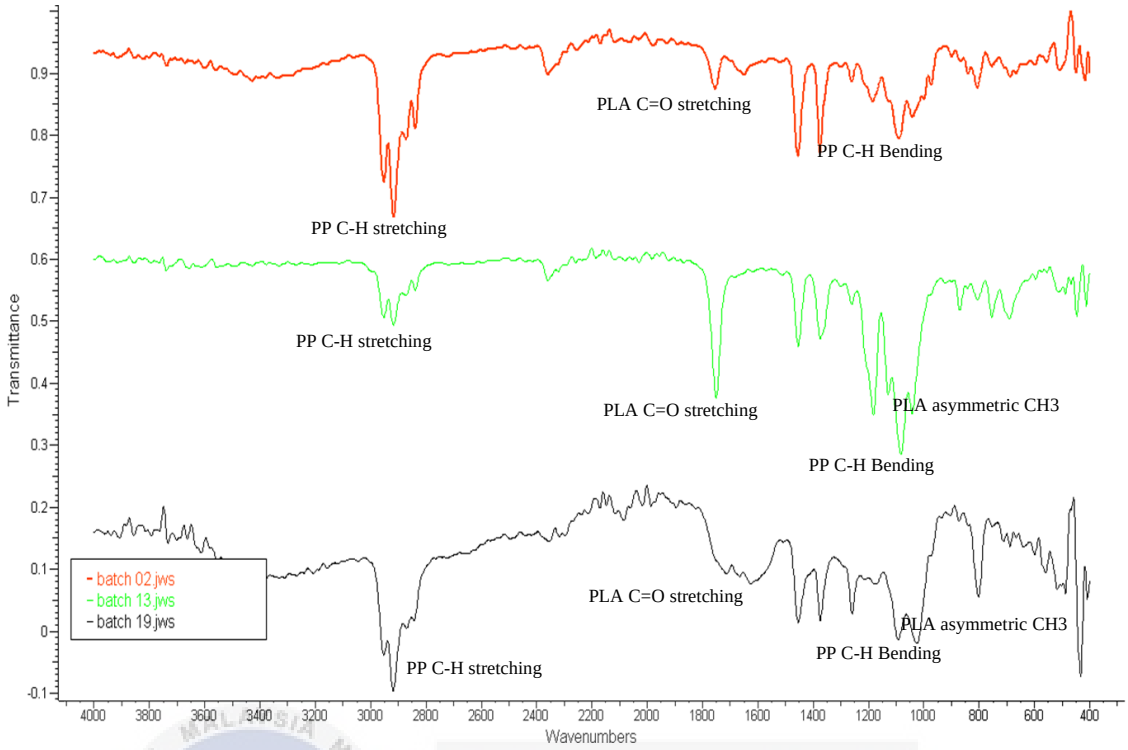


Figure 4. 13: FTIR's graph for the rPP/PLA blend

4.5 Density

The density of the rPP/PLA is shown in bar chart on the Figure 4.6. From the bar chart observation, when the portion of PLA is higher, the density of blending was also increase.

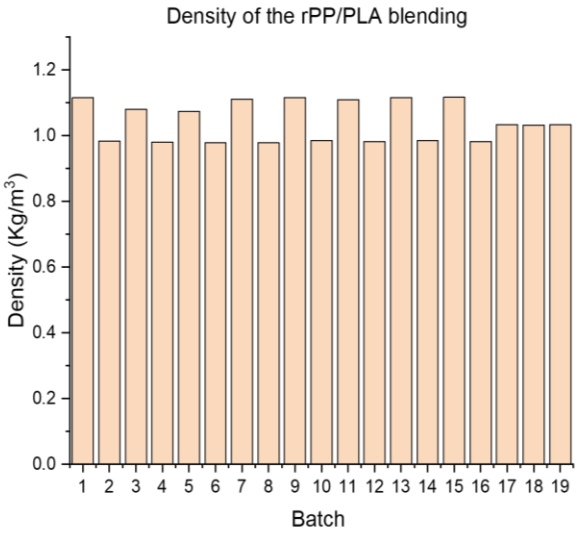


Figure 4. 14: Bar chart on density of the rPP/PLA blends

4.6 Summary

In conclusion, r-PP/PLA blend was successfully made by utilizing the melt blending approach and the design of experiments (DOE) concept to optimise the experiment's variables. In this experiment, the following variables are considered: blend ratio, temperature, mixing duration, and rotor speed. Consequently, tensile strength and flexural strength are experimental design responses (DOE). 70 % of blend ratio, 165 °C for temperature, 6.01 minutes for duration time, 60 revolutions per minute (rpm) of rotor speed, 16.9093 MPa for tensile strength, and 36.9981 MPa for flexural strength are the optimal conditions for the experiment was determined through the design of experiment (DOE). In the meantime, Fourier transform infrared (FTIR) is used to determine the chemical composition and functional group of polymers. Last but not least, the scanning electron microscope (SEM) was utilised to observe the miscibility and compatibility of the r-PP/PLA blend, which is crucial for the application of the final product. Then, the result of the polymer blend was partially miscible with improved compatibility due to the accurate and optimize selection of the mixing parameters.

CHAPTER 5
CONCLUSION AND RECOMMENDATION

This chapter focuses on the conclusion drawn from the discussion of the results in Chapter 4. In addition, this conclusion can be carried out to analyse whether the Chapter 1 objectives are realistically achievable. Last but not least, the chapter include brief summarize on lifelong learning element, complexity element, and sustainability.

5.1 Conclusion

In conclusion, the objective one (1) and two (2) of this study for optimization the formulation and processing parameters of r-PP/PLA blend by melt blending process using response surface methodology (RSM) through tensile strength (R1) and flexural strength (R2) has been effectively identified using a two-level, full-factorial statistical optimization technique. The tensile strength and flexural strength properties were referred to as response for the purpose of optimization. This study determined the optimal combination of interacting factors (70 percent of blend ratio, 165 °C for temperature, 6.01 minutes for duration time, 60 rpm of rotor speed, 16.9093 MPa for tensile strength, and 36.9981 MPa for flexural strength) for achieving the best performance (tensile strength and flexural strength) of the rPP/PLA blend. In addition, the value of R^2 was nearing 1.00, which was sufficient to reflect the proposed linear regression model for forecasting the optimal interacting parameters for the tensile strength response and flexural response of rPP/PLA blends. Next, the objective three (3) is to analyse the phase morphology of the rPP/PLA blend using a scanning electron microscope (SEM) to evaluate the polymer blend's miscibility. The polymer blend is partially miscible. In addition, rPP/PLA blend compatibility has been confirmed due to the blend's ductile fracture.

5.2 Recommendations

This research could be improved with the development and execution of process effectiveness. Such as the addition of PP-g-MAH as a compatibilizer for the rPP/PLA polymer blend. This compatibilizer could improve the miscibility of the blending material and give a high strength of the final product. The strong connection of the polymer blend can improve the performance of their goods.

5.3 Sustainability Element

Yearly, about 400 million tons of plastic-based products are manufactured globally, and 79% of all massive plastic disposal has ever made ends up in landfills or as litter in the municipal area (Sandrine Ceurstemont, 2020). 23% of the approximately five billion tonnes of waste plastic in our world are estimated to be polypropylene (Gwyn D'Mello, 2019). Therefore, the polymer blending method is one of good alternative to produce a biodegradable thermoplastic blend that sustainable to the environment. This is due to the fact that recycling polymer blends is desirable not only for environmental reasons, but also from a circular economy one.

5.4 Lifelong Learning Element and basic entrepreneurship

Lifelong learning is also defined as the development of human potential through a strategy that continuously supports and develop the learning of all the facts, ideas, skills, and comprehension required throughout life and beneficial to all tasks. Therefore, through the rPP/PLA polymer blend study, there will be a greater opportunities for an action on this research topic. Several initiatives could be considered while conducting this topic throughout the lifelong learning experience of this topic is develop effective strategy for retaining information to repeatedly expose the brain to it at regular intervals while conducting a literature review. This new advanced material will also contribute to the future sustainability of the environment. To acquire a deeper

grasp of this novel material and its benefits, the material and its properties should be widely researched. This new advance material can be used as an application of packaging in the society include food and groceries. This type of plastic can reduce the massive plastic disposal in the environment and protect the environment.

5.5 Complexity Element

The limited availability of laboratories during the Covid-19 pandemic epidemic and the limited equipment and machinery at laboratories contributed to the complexity of the results. The miscibility and compatibility of the polymer blend has to be determined using the Differential Scanning Calorimetry (DSC) method. This method is ideal for identifying these features as part of objective 3. However, the machine is under maintenance and cannot be utilised. In addition, the sample preparation process is time-consuming due to restricted resources and machine breakdown. The intricacy of the investigation is reflected in the difficulty of sample preparation.

Understanding the deterioration of the polymer blend material is also a challenging aspect of this investigation. This characteristic must be studied in depth and on a regular basis so that it is more understandable and environmentally sustainable and socially beneficial in the future.

REFERENCES

Abay, A. K., Gebeyehu, M. B., Lin, H. K., Lin, P. C., Lee, J. Y., Wu, C. M., Murakami, R. I., & Chiang, T. C. (2016). Preparation and characterization of poly(lactic acid)/recycled polypropylene blends with and without the coupling agent, n-(6-aminohexyl)aminomethyltriethoxysilane. Journal of Polymer Research, 23(9). https://doi.org/10.1007/S10965-016-1091-5

Abd Razak, J., Mat Noor, N. A., Mohamad, N., Jaafar, R., Ismail, M. M., Junid, R., & Puspitasari, P. (2020). Process Parameter Interaction Study for Epoxy/Kenaf Composites Preparation via Two-Level Full Factorial Approach. Malaysian Journal on Composites Science and Manufacturing, 1(1), 11–26. https://doi.org/10.37934/mjcsm.1.1.1126

Ajitha, A. R., & Thomas, S. (2019). Introduction: Polymer blends, thermodynamics, miscibility, phase separation, and compatibilization. In Compatibilization of Polymer Blends: Micro and Nano Scale Phase Morphologies, Interphase Characterization, and Properties (pp. 1–29). Elsevier. https://doi.org/10.1016/B978-0-12-816006-0.00001-3

Alabi, O. A., Ologbonjaye, K. I., Awosolu, O., & Alalade, O. E. (2019). Public and Environmental Health Effects of Plastic Wastes Disposal: A Review. J Toxicol Risk Assess, 5, 21. https://doi.org/10.23937/2572

Alexander H. Tullo. (2016). Why chemical companies are investing in high-end polymers. https://cen.acs.org/articles/94/i9/chemical-companies-investing-high-end.html

Ali. (2016). Introduction to Polymer Blend.

Alina Bradford. (2017, October 14). What Is a Polymer? https://www.livescience.com/60682-polymers.html

Anas, S., Rehman, G., Khan, Z., Khan, M., Alam, S. F., Ul-Haq, N., Nauman, S., & Nasir, M. A. (2013, January). Influence of MWCNTs as Secondary Reinforcement Material in Glass Fiber/Epoxy Composites Fabricated using VARTM.

Anja Krieger. (2019, July 16). are bioplastics better for the environment than conventional plastics? https://ensia.com/features/bioplastics-bio-based-biodegradable-environment/

Anne Marie Helmenstine. (2019). What Does Immiscible Mean in Chemistry? https://www.thoughtco.com/definition-of-immiscible-and-example-605237

Anonymous. (2018, August 23). Surface Morphology. Nanolab Technology.

Anonymous. (2022). PP. https://polymerdatabase.com/Commercial%20Polymers/PP.html

Balart, R., Montanes, N., Dominici, F., Boronat, T., & Torres-Giner, S. (2020). Environmentally friendly polymers and polymer composites. In Materials (Vol. 13, Issue 21, pp. 1–6). MDPI AG. https://doi.org/10.3390/ma13214892

Banu, I., Doriana Banu, N., Bernard, C., Lyon, U., Bozga, G., Banu, I., Stanciu, N. D., & Puaux, J. P. (2009). A study of L-lactide ring-opening polymerization in molten state Project View project Ring-opening cationic polymerization of cyclic acetals View project a study of l-lactide ring-opening polymerization in molten state. Bull., Series B, 71(2). https://www.researchgate.net/publication/266322083

Bijarimi, M., Ahmad, S., Rasid, R., Khushairi, M. A., & Zakir, M. (2016). Poly(lactic acid)/Poly(ethylene glycol) blends: Mechanical, thermal and morphological properties. AIP Conference Proceedings, 1727. https://doi.org/10.1063/1.4945957

Britannica. (2021a, October 22). polymer. https://www.britannica.com/science/polymer

Britannica, T. (2021b, October 22). polymer | Description, Examples, Types, Material, Uses, & Facts | Britannica. https://www.britannica.com/science/polymer

Casalini, T., Rossi, F., Castrovinci, A., & Perale, G. (2019). A Perspective on Polylactic Acid-Based Polymers Use for Nanoparticles Synthesis and Applications. In Frontiers in Bioengineering and Biotechnology (Vol. 7). Frontiers Media S.A. https://doi.org/10.3389/fbioe.2019.00259

Chen, R., Zou, W., Zhang, H., Zhang, G., Yang, Z., & Qu, J. (2015). Poly(lactic acid)/polypropylene and compatibilized poly(lactic acid)/polypropylene blends prepared by a vane extruder: analysis of the mechanical properties, morphology and thermal behavior. Journal of Polymer Engineering, 35(8), 753–764. https://doi.org/10.1515/POLYENG-2014-0312

Chi Wang, A., Wu, C., Pisignano, D., Lin Wang, Z., Persano, L., Wagner, A. M., Spencer, D. S., Peppas, N. A., Appl Polym Sci, J., Muthuraj, R., Misra, M., Kumar Mohanty, A., Appl, J., Sarkar, P., Bhowmick, A. K., Stratton, S., Manoukian, O. S., Patel, R., Wentworth, A., … Soucek, M. D. (2018). Biodegradable compatibilized polymer blends for packaging applications: A literature review. Journal of Applied Polymer Science, 135(24), 45726. https://doi.org/10.1002/APP.45726

DeStefano, V., Khan, S., & Tabada, A. (2020). Applications of PLA in modern medicine. Engineered Regeneration, 1, 76–87. https://doi.org/10.1016/J.ENGREG.2020.08.002

Doug Smith. (2017, December 7). An introduction to the Polypropylene Recycling Process. https://www.cadybag.com/polypropylene-recycling-process-introduction/

Ecaterina Matei, 1 Maria Râps, 2 Árpád Andor Andras,2 Andra Mihaela Predescu,1 Cristian Pantilimon,1 Alexandra Pica,3 and Cristian Predescu1. (2017). Recycled Polypropylene Improved with Thermoplastic Elastomers.

eknuth. (2007). Technology Focus Report: Blends of PLA with Other Thermoplastics*.

Erlin Widjaja. (2019). Polymer blends. Institute of Applied Chemistry of NCTU.

Farah, S., Anderson, D. G., & Langer, R. (2016). Physical and Mechanical Properties of PLA, and Their Functions in Widespread Applications-A Comprehensive Review. Advanced Drug Delivery Reviews, 107, 367–392. https://doi.org/10.1016/J.ADDR.2016.06.012

Fouad, D., & Farag, M. (2019). Design for Sustainability with Biodegradable Composites. Design and Manufacturing. https://doi.org/10.5772/INTECHOPEN.88425

Ghomi, E. R., Khosravi, F., Ardahaei, A. S., Dai, Y., Neisiany, R. E., Foroughi, F., Wu, M., Das, O., & Ramakrishna, S. (2021). The Life Cycle Assessment for Polylactic Acid (PLA) to Make It a Low-Carbon Material. Polymers 2021, Vol. 13, Page 1854, 13(11), 1854. https://doi.org/10.3390/POLYM13111854

Gwyn D'Mello. (2019, February 13). Scientists Turn Plastic Waste Into 100% Clean Fuel For Cars, And It Will Help Reduce Pollution. https://www.indiatimes.com/technology/science-and-future/scientists-turn-plastic-waste-into-100-clean-fuel-for-cars-and-it-will-help-reduce-pollution-362096.html

Haider, T. P., Völker, C., Kramm, J., Landfester, K., & Wurm, F. R. (2019). Plastics of the Future? The Impact of Biodegradable Polymers on the Environment and on Society. Angewandte Chemie - International Edition, 58(1), 50–62. https://doi.org/10.1002/ANIE.201805766

Hintons. (2018, September 25). History of Recycling [Timeline] | Who & When Invented Recycling? https://www.hintonswaste.co.uk/news/history-of-recycling-timeline/

Jose M. Kenny, L. T. A. J. (2003). Processing and properties of recycled polypropylene modified with elastomers.

Joseph Flynt. (2017a, November 9). Polylactic Acid (PLA): The Environment-friendly Plastic. https://3dinsider.com/what-is-pla/

Joseph Flynt. (2017b, November 9). What is PLA? Polylactic acid properties, uses, & melting point - 3D Insider. https://3dinsider.com/what-is-pla/

Khan, I., Mansha, M., Abu, M., & Mazumder, J. (2019). Polymer Blends. 513–549. https://doi.org/10.1007/978-3-319-95987-0_16

Kimberly Amadeo. (2020). How Air, Water, and Plastic Pollution Affect the Economy. https://www.thebalance.com/pollution-facts-economic-effect-4161042

Kruger. (2021). Polymer Blends . https://kruger.industries/polymer-blends/

Kulkarni, G. S. (2018). Introduction to Polymer and Their Recycling Techniques. Recycling of Polyurethane Foams, 1–16.

Lin, T. A., Lin, J.-H., & Bao, L. (2020). Polypropylene/thermoplastic polyurethane blends: mechanical characterizations, recyclability and sustainable development of thermoplastic materials. Journal of Materials Research and Technology, 9(3), 5304–5312. https://doi.org/https://doi.org/10.1016/j.jmrt.2020.03.056

Liqi Cai, J. W. J. P. 2, Z. W. X. T. (2018). Observation of the degradation of three types of plastic pellets exposed to UV irradiation in three different environments. Sci Total Environment, 628–629.

Malek, N. S. A., Faizuwan, M., Khusaimi, Z., Bonnia, N. N., Rusop, M., & Asli, N. A. (2021). Preparation and Characterization of Biodegradable Polylactic Acid (PLA) Film for Food Packaging Application: A Review. J. Phys, 12037. https://doi.org/10.1088/1742-6596/1892/1/012037

Mandal, D. K., Bhunia, H., & Bajpai, P. K. (2019). Thermal degradation kinetics of PP/PLA nanocomposite blends. Journal of Thermoplastic Composite Materials, 32(12), 1714–1730. https://doi.org/10.1177/0892705718805130

Mandal, D. K., Bhunia, H., Bajpai, P. K., Chaudhari, C. v, Dubey, K. A., Varshney, L., & Kumar, A. (2021). Preparation and characterization of polypropylene/polylactide blends and nanocomposites and their biodegradation study. Journal of Thermoplastic Composite Materials, 34(6), 725–744. https://doi.org/10.1177/0892705719850601

Manias, E., & Utracki, L. A. (2014). Thermodynamics of polymer blends. In Polymer Blends Handbook (pp. 171–289). Springer Netherlands. https://doi.org/10.1007/978-94-007-6064-6_4

Manral, A., Kumar Bajpai, P., Ahmad, F., & Joshi, R. (2021). Processing of sustainable thermoplastic based biocomposites: A comprehensive review on performance enhancement. Journal of Cleaner Production, 316, 128068. https://doi.org/10.1016/j.jclepro.2021.128068

Martins, A. R., Bernard, C., & Lyon, U. (2019). Effect of intermolecular interactions on the viscoelastic behavior of polyamides. https://www.researchgate.net/publication/334119356

Martins Coelho, A., Vieira Estrela, V., Teixeira De Assis, J., & Carvalho, G. de. (2012). Methodology for Optimization of Polymer Blends Composition. www.intechopen.com

Matei, E., Râpă, M., Andras, Á. A., Predescu, A. M., Pantilimon, C., Pica, A., & Predescu, C. (2017). Recycled Polypropylene Improved with Thermoplastic Elastomers. International Journal of Polymer Science, 2017. https://doi.org/10.1155/2017/7525923

Maureenwise. (2020, December 24). Can you recycle number 5 plastics? https://earth911.com/home-garden/recycle-plastic-number-5/

Mohammed Ajmal, Vijayakumar, V., & John, N. (2019). Advanced Structural Foams Based on PLA/ PP and PLA /HDPE Blends. International Journal of Innovative Science and Research Technology, 4. www.ijisrt.com

Murariu, M., & Dubois, P. (2016). PLA composites: From production to properties. Advanced Drug Delivery Reviews, 107, 17–46. https://doi.org/10.1016/j.addr.2016.04.003

Naser, A. Z., Deiab, I., & Darras, B. M. (2021). Poly(lactic acid) (PLA) and polyhydroxyalkanoates (PHAs), green alternatives to petroleum-based plastics: a review. In RSC Advances (Vol. 11, Issue 28, pp. 17151–17196). Royal Society of Chemistry. https://doi.org/10.1039/d1ra02390j

Niaounakis, M. (2015). Blending. In Biopolymers: Processing and Products (pp. 117–185). Elsevier. https://doi.org/10.1016/B978-0-323-26698-7.00003-9

Nur Imani Abdullah. (2018, June 6). The huge problem of plastic waste in M'sia. https://www.malaysiakini.com/letters/428508

Nyamweya, N. N. (2021). Applications of polymer blends in drug delivery. Future Journal of Pharmaceutical Sciences, 7(1). https://doi.org/10.1186/S43094-020-00167-2

Parameswaranpillai, J., Thomas, S., & Grohens, Y. (2015). Polymer Blends: State of the Art, New Challenges, and Opportunities. Characterization of Polymer Blends: Miscibility, Morphology and Interfaces, 9783527331536, 1–6. https://doi.org/10.1002/9783527645602.CH01

Pivsa-Art, S., Kord-Sa-Ard, J., Pivsa-Art, W., Wongpajan, R., O-Charoen, N., Pavasupree, S., & Hamada, H. (2016). Effect of Compatibilizer on PLA/PP Blend for Injection Molding. Energy Procedia, 89, 353–360. https://doi.org/10.1016/j.egypro.2016.05.046

Randy McIff. (2017, April 4). What are the Advantages to Using a Polymer Blend? https://atsinnovawatertreatment.com/blog/advantages-of-polymer-blends/

Raudhah, N., Nirwandy, I. N., & Noordin, M. (2020). Understanding the Issue of Plastic Waste Pollution in Malaysia: A Case for Human Security. In Journal Of Media And Information Warfare (Vol. 13, Issue 1).

Rick Leblanc. (2019, May 9). An Introduction to Polypropylene Recycling. https://www.thebalancesmb.com/an-overview-of-polypropylene-recycling-2877863

Rick LeBlanc. (2019a, November 20). The Meaning of Recycle Symbols on Plastics. The Balance Small Business.

Rick LeBlanc. (2019b, November 20). The Meaning of Recycle Symbols on Plastics.

Sabzi, F. (2018). Gas Transport Through Polymer Blends. In Transport Properties of Polymeric Membranes (pp. 517–532). Elsevier. https://doi.org/10.1016/B978-0-12-809884-4.00024-0

Saini, P., Arora, M., & Kumar, M. N. V. R. (2016). Poly(lactic acid) blends in biomedical applications. Advanced Drug Delivery Reviews, 107, 47–59. https://doi.org/10.1016/J.ADDR.2016.06.014

Salehiyan, R., & Sinha Ray, S. (2018). Processing of Polymer Blends, Emphasizing: Melt Compounding; Influence of Nanoparticles on Blend Morphology and Rheology; Reactive Processing in Ternary Systems; Morphology–Property Relationships; Performance and Application Challenges; and Opportunities and Future Trends. Springer Series in Materials Science, 278, 167–197. https://doi.org/10.1007/978-3-319-97792-8_6

Samper, M. D., Bertomeu, D., Arrieta, M. P., Ferri, J. M., & López-Martínez, J. (2018). Interference of biodegradable plastics in the polypropylene recycling process. Materials, 11(10). https://doi.org/10.3390/ma11101886

Sandrine Ceurstemont. (2020, June 14). Bio-based? Recyclable? Biodegradable? Your guide to sustainable plastics | Journey to Zero. https://journeytozerostories.neste.com/plastics/bio-based-recyclable-biodegradable-your-guide-sustainable-plastics#b974548d

Sanjay Kumar J Pai. (2020, April 15). Melt Blending/ Internal Mixing. https://www.linkedin.com/pulse/melt-blending-internal-mixing-sanjaykumar-j-pai#:~:text=In%20melt%20blending%2C%20the%20properties,and%20high%20cost%20of%20equipment.

Shady Farah, D. G. A. L. (2016). Physical and mechanical properties of PLA, and their functions in widespread applications — A comprehensive review. Advanced Drug Delivery Reviews, 107, 367–392. https://dspace.mit.edu/bitstream/handle/1721.1/112940/Anderson_Physical%20and%20mechanical%20properties.pdf?sequence=1&isAllowed=y

Sherazi, T. A. (2016). Graft Polymerization. In L. Drioli Enrico and Giorno (Ed.), Encyclopedia of Membranes (pp. 886–887). Springer Berlin Heidelberg. https://doi.org/10.1007/978-3-662-44324-8_274

Sujay Mistry. (2021, July 22). Partially Miscible Liquids. https://solutionpharmacy.in/partially-miscible-liquids/

Suksaeree, J., Chaichawawut, B., Srichan, M., Tanaboonsuthi, N., Monton, C., Maneewattanapinyo, P., & Pichayakorn, W. (2021). Applying design of experiments (DoE) on the properties of buccal film for nicotine delivery. E-Polymers, 21(1), 566–574. https://doi.org/10.1515/epoly-2021-0064

Suthapakti, K., Molloy, R., Punyodom, W., Nalampang, K., Leejarkpai, T., Topham, P. D., & Tighe, B. J. (2018). Biodegradable Compatibilized Poly(l-lactide)/Thermoplastic Polyurethane Blends: Design, Preparation and Property Testing. Journal of Polymers and the Environment, 26(5), 1818–1830. https://doi.org/10.1007/s10924-017-1082-6

Tackling increasing plastics pollution in Malaysia | The Star. (n.d.). Retrieved December 18, 2021, from https://www.thestar.com.my/opinion/letters/2021/03/16/tackling-increasing-plastics-pollution-in-malaysia

Tanzi, M. C., Farè, S., & Candiani, G. (2019). Organization, Structure, and Properties of Materials. In Foundations of Biomaterials Engineering (pp. 3–103). Elsevier. https://doi.org/10.1016/b978-0-08-101034-1.00001-3

Toh, H. W., Toong, D. W. Y., Ng, J. C. K., Ow, V., Lu, S., Tan, L. P., Wong, P. E. H., Venkatraman, S., Huang, Y., & Ang, H. Y. (2021). Polymer blends and polymer composites for cardiovascular implants. European Polymer Journal, 146, 110249. https://doi.org/10.1016/J.EURPOLYMJ.2020.110249

Tom Bond, V. F.-M. M. F.-S. & E. van S. (2018). The occurrence and degradation of aquatic plastic litter based on polymer physicochemical properties: A review. Critical Reviews in Environmental Science and Technology , 48(7–9), 685–722. https://doi.org/https://doi.org/10.1080/10643389.2018.1483155

Tosh, B., & Routray, C. (2014). Grafting of Cellulose Based Materials: A Review Chitosan Derivatives for Drug Delivery Applications View project Synthesis and Characterization of Vinyl grafted copolymers of Cellulose and Cellulose Acetate in Homogeneous media View project. https://www.researchgate.net/publication/286931783

Wang, X.-Y., Xiong, C.-F., Ye, T.-T., Ding, J., & Feng, Y.-Q. (2020). Online polymer monolith microextraction with in-situ derivatization for sensitive detection of endogenous brassinosteroids by LC-MS. Microchemical Journal, 158, 105061. https://doi.org/https://doi.org/10.1016/j.microc.2020.105061

Wen-Dong, T., Guang-Jian, H., Wei-Tao, H., Xin-Liang, Z., Xian-Wu, C., & Xiao-Chun, Y. (2021). The reactive compatibilization of PLA/PP blends and improvement of PLA crystallization properties induced byin situUV irradiation. CrystEngComm, 23(4), 864–875. https://doi.org/10.1039/d0ce01445a

Yanc, 11-Ying, Smith,', T. C., & Blglo, D. (1996). Melt Blending of linear low-Density Polyethylene and Polystyrene in a Haake Internal Mixer. I. Compatibilization and Morphology Development.

Zailan, F. D., Chen, R. S., Shahdan, D., & Ahmad, S. (2019). Effect of conductive polyaniline in thermoplastic natural rubber blends on the mechanical, thermal stability, and electrical conductivity properties. Journal of Applied Polymer Science, 136(20), 47527. https://doi.org/10.1002/APP.47527

Zeynep Akdogan, B. G. (2019). Microplastics in the environment: A critical review of current understanding and identification of future research needs. Natural Library of Medicine. https://doi.org/10.1016/j.envpol.2019.113011

Zhang, Y., Jia, S., Pan, H., Wang, L., Zhang, H., Yang, H., & Dong, L. (2021). Preparation, characterization and properties of biodegradable poly(butylene adipate-co-butylene terephthalate)/thermoplastic poly(propylene carbonate) polyurethane blend films. Polymers for Advanced Technologies, 32(2), 613–629. https://doi.org/10.1002/PAT.5115