

# OPTIMIZATION OF INJECTION MOLDING PARAMETERS FOR 70:30 VIRGIN-REGRIND (PP) PLASTIC MATERIAL



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#### OPTIMIZATION OF INJECTION MOLDING PROCESS PARAMETERS FOR 70:30 VIRGIN-REGRIND (PP) PLASTIC MATERIAL

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#### A thesis submitted

in fulfillment of the requirements for the degree of Bachelor of Manufacturing Engineering Technology (Process & Technology) with



#### UNIVERSITI TEKNIKAL MALAYSIA MELAKA

2022

#### DECLEARATION

I declare that this Choose an item. entitled "OPTIMIZATION OF INJECTION MOLDING PARAMETERS FOR 70:30 VIRGIN-REGRIND (PP) PLASTIC MATERIAL" is the result of my own research except as cited in the references. The Choose an item. has not been accepted for any degree and is not concurrently submitted in candidature of any other degree.



#### APPROVAL

I hereby declare that I have checked this thesis and in my opinion, this thesis is adequate in terms of scope and quality for the award of the Bachelor of Manufacturing Engineering Technology (Process & Technology) with Honours



#### **DEDICATION**

#### Alhamdulillah

Praise to Allah for the strength, guidance and knowledge that was given by Allah for me to complete this study.

#### &

To my beloved parents and families for every support that was given to me.

#### &

To my supervisor, Mr. Salleh Bin Aboo Hassan for his guidance and advice in completing



#### ABSTRACT

Plastic has been a widely used as the material for most of the products in the human life. However, the rate of plastic product waste is much faster than the rate of the plastic recycling which is resulting the plastic pollution to the world environment. Plastic recycling is a common raw material used in plastic industry especially for environment preservation purposed and more importantly due to cost saving. Polypropylene (PP) is one of commonly plastic type used for bottle caps, packaging tape, cereal liners, straw and as the material of filament for 3D printings, household products such as kitchen appliances and pipes, due to its toughness and high impact resistance. Injection molding is the most common plastic shaping process for PP thermoplastic material. To optimize the injection molding parameter in 70:30 virgin regrind blended Polypropylene (PP) plastic material, five (5) process control parameters namely cooling time, packing time, injection speed, mold temperature and packing pressure each at two levels is tabulated using the L'8 orthogonal array as recommended in Taguchi Design of Experiment method. Type I specimen according to STM D638-14 speciment industry standard is produced by using the injection molding machine. Eight (8) experiments were conducted according to OA table. Three (3) speciments of each experiment trial were collected and tested to obtain the ultimate tensile strength. In total there are (24) have been tested for tensile strength reading. The results were analyzed using the S/N ratio and ANOVA approched method. Significant factors and the optimum combination of process factors setting for achieving the optimum UTS of the Polypropylene (PP) blends 70:30 virgin-regrind material were determined. Cooling time and packing time have demostrated the most significant factors while others factors are insignificant. Cooling time at 10 second, packing time at 5 second, injection speed at 10mm/s, mold temperature at 30°C and packing pressure at 110MPa have resulted the optimum combination factors level according to Taguchi analysis result. The predicted tensile strength based on this optimum value is 34.46 MPa which is not much different commpared to virgin 100% material tensile strength 33.06 MPa. As a conclusion Polypropylene (PP) 70:30 virgin-regrind material is highly recommended to be used for replacing virgin material for material cost savng project.



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#### **Chapter 1: Introduction**

#### 1.0 Introduction

In this chapter, we will get to know a clear overview of this research and the aim of this research, in addition to the Scope of Study. All this is based on multiple readings related to the same topic, which will be the basis from which we will proceed to complete and understand the rest of the research.

#### 1.1 Background of Study

After plastic has become one of the most important materials used in the industry, this material has entered many fields, such as consumer products, medical products, electrical appliances, aerospace, packaging, building and construction, and many more fields that cannot be counted. More than 360 million tons of plastic have been produced in 2019. Plastics are manufactured through various processes, including injection molding, which is one of the most common and diverse plastic processes due to its ability to produce a complex design product at high production rates. In this process, the polymer heated and injected into the cavity of the mold, and it is cooled and solidified into the shape of the mold.

Year after year the demand for plastic material product globally has tremendously increases. Hence low-cost good quality plastic products have become a huge challenge for plastic industries nowadays to sustain. To remain competitive in plastic market industries, research study in application of blend plastic recycle material with virgin material is vital. This topic has attracted many plastics researcher worldwide in plastic manufacturing companies to investigate and publish their research study in several reputation plastic journal magazines. Injection molding process is a very complex plastic sharping process. Knowledgeable in plastic polymer properties, injection molding machine, product mold, injection process and application of Design of Experiment (DOE) are essential for a plastic engineer to be competent with. These could help and accelerate their daily job task in improving and achieving their objectives to produce good quality product and yet at lower cost while meeting customer expectation.

Taguchi method is deployed in this final year project study. This Taguchi optimization method is become most simples and cost effective in design of experiment approach compared to other method such as full factorial and response surface. It is one of the most popular methods in manufacturing industries application in twenties centuries during process optimization project study, in which orthogonal array is generated based on experimental parameter design. Mold temperatures, packing pressure, packing time, cooling time and injection speed are the process parameters factors understudy while the mechanical tensile strength of blended Polypropylene (PP) is a response. Under Taguchi method, the higher the better-quality characteristic has been selected since the maximum tensile strength is desirable in this case study.

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### **1.2 Problem Statement**

Polypropylene is one of the most common commodity plastics processed by injection molding machine and it is used in a variety of applications including packaging for consumer products, and plastic parts for various industries including the automotive industry. Compared to many other plastics, Polypropylene has good tensile strength - about 4800 psi. This allows products made of Polypropylene to withstand heavy loads, despite their light weight.

With the rising costs of raw materials and in order to reduce the cost of production, we can use composites of virgin Polypropylene and regrind Polypropylene. Thus, getting the final products at a cheaper price for the customers. But on the other hand, when we blend regrind plastic with

virgin plastic, the mechanical properties of the part deteriorate. Therefore, it is necessary to conduct studies and experiments to achieve the maximum tensile strength for 70:30 virgin-regrind (PP) Polypropylene products by controlling the various parameters of the plastic injection process. Mold temperature, cooling time, injection speed, packing pressure, and packing time are all parameters that must be properly under study to obtain the best quality.

#### 1.3 Objectives

The objectives that we should achieve in this research are:

- To determine the most significant factor that affect the tensile strength in 70:30 virginregrind Polypropylene (PP) plastic products.
- 2- To rank the process factors that influence tensile strength.
- 3- To establish the optimum process setting to achieve the maximum tensile strength using
   70:30 virgin-regrind Polypropylene (PP) plastic products.
- 4- To predict optimum value of tensile strength at optimum parameters using MiniTab software.
- 5- To compare between the tensile strength of 70:30 virgin-regrind Polypropylene (PP) and virgin Polypropylene (PP).

#### **1.4 Scope of Project**

To achieve the objectives, following scopes are formed.

- 1- The study will focus on the injection moulding process and its related parameters to reach high tensile strength products.
- 2- The material used in the research is 70:30 virgin-regrind (PP) Polypropylene.
- 3- Study using the Taguchi method to find out the most important parameters that affect the tensile strength.

#### **1.5** Significant/Importance of Study

The importance of this research is summarized in several points:

- Reduce the cost of some plastic products by blending recycled materials with virgin materials.
- 2- Providing useful information about the injection molding process and about the different types of plastics, especially Polypropylene (PP).
- 3- Studying and finding the most important parameter in improving the injection molding process, which gives better results in the industry.
- 4- Learn about one of the quality control methods, the Taguchi method, which can be used in many fiel



#### **Chapter 2: Literature Review**

#### 2.0 Introduction

This chapter includes an overview of the injection molding process from its inception and development, details of the injection machine, its working mechanism, related parameters, the resulting defects, the causes of these defects, and how to avoid them.

In addition, this chapter will include a discussion about plastics and their applications, the different classifications of plastics and their uses, including thermoplastics and thermosetting plastics. This will be followed by a focus on Polypropylene, waste plastic recycling, and the impact of recycling on mechanical properties. Finally, we will address one of the ways to improve quality, which is the Taguchi method, which we will apply in this research.

#### 2.1 Plastic Injection Molding Machine

In theory, the injection molding process is straightforward. Melt the plastic, inject it into a mold, allow it to cool, and then release the finished product, but this is a more complicated process. The injection unit and clamping unit are the two main sections of a typical injection molding machine, and their parts are explained below. Figure 2.1.



Figure 2. 1 Plastic Injection Molding Machine.

#### 2.1.1 Injection Unit

The injection unit in the injection molding machine is responsible for melting the plastic granules and converting them into a semi liquid material ready for injection in the mold. The injection unit consists of several parts. Starting with the Hopper that is used to feed plastic granules, the process may be done manually or automatically. Also, the Hopper Dryer that is used to get rid of the moisture contained in the raw materials, as it must be dry to avoid deflects. Another important part of the injection unit is the Barrel that contains the Screw, which is rotated by a Hydraulic Motor, as this screw rotates and pushes the plastic forward. Surrounding the barrel, heaters gradually heat the plastic until it melts. At the front of the barrel there is the Nozzle which the melted plastic passes through, and the mold is injected.

#### 2.1.2 Clamping Unit

The clamping unit supports the mold, keeps it closed during injection, opens, and closes the mold as quickly as possible, allows for part ejection, and protects the mold from damage. Hydraulic clamps, hydraulically actuated toggle (mechanical), electrically actuated toggle, and hydromechanical clamps are the four types of clamps. Every clamp has a stationary platen as well as a movable platen. The stationary platen has a hole through which the nozzle contacts the sprue bushing because it supports the mold's core or A side. The sprue bushing is typically surrounded by a locating ring that aligns the mold with the nozzle. When the mold has a hot manifold, the stationary platen is frequently water cooled. While supporting the B side of the mold, the moving platen moves horizontally to open and close the mold, applies clamping force to the mold, and houses the ejector system. The two platens align the mold's two halves, minimizing wear on contacting surfaces. Four tie bars usually support and align these platens. When the moving platen travels to open or close the mold, it is also guided by these tie bars. As the forces that hold the mold closed also stretch the tie bars, tie-bar adjustments are used to realign the platens on a regular basis (Tzy-Cherng, 1992).

#### 2.1.3 History of Injection Molding Machine

In 1860s the game of billiard was widespread in America, and billiard balls were made from elephant ivory, and therefore it was necessary to kill a lot of elephants to get ivory and make billiard balls, which caused the killing of large numbers of elephants and this animal became endangered. The billiard makers then felt this was so dangerous and it was imperative that elephant ivory be replaced with other materials .After several years of research and experiments, brothers John and Isaiah Hayat succeeded in discovering an alternative material, which is celluloid, and thy built first injection molding machine. (Figure 2.2)



Figure 2. 2 Hyatt Brothers' First Injection Molding Machine 1872.

From the beginning of the twentieth century, various plastics such as Bakelite, vinyl, and others were discovered, and the plastics industry began to develop. In the 1930s, the German engineer Eichengrun developed the Hayat brothers' machine and introduced a newer model of injection molding machines (Figure 2.3).



Figure 2. 3 Eichengrun Buchholz Injection Molder 1931.

Then, during the Second World War, the plastics industry became more popular, and more plastic materials were discovered. In 1946, the American inventor James Hendry made a revolution in the world of the plastics industry by inventing the first screw injection molding machine with an auger design which is like the injection molding machines that exist today. (Figure 2.4)



Figure 2. 4 First Screw Injection Molding Machine 1946.

Today's version of the plastic injection molding machine is controlled by a computer. It injects hot plastic into a mold, cool the plastic, and eject automatically. Today's injection molding machines make the mass production of plastic components easy and cost-effective.



# 2.1.4 Injection Molding Process

The process begins from the injection unit by placing the plastic pellets in the hopper and then proceeds to the barrel where it is carried forward by the screw. Inside the barrel, the screw rotates by a hydraulic motor, this screw pushes the plastic pellets forward while it is heated by Heating bands in addition to the frictional heat, which cause the plastic to gradually heat up until it melts when it reaches the front of the barrel. When the plastic totally melts in front of the screw, the screw stop rotating and it pushes the plastic through the nozzle like a syringe piston, and within seconds the empty part of the mold (cavity) is injected. Then the plastic solidifies in less than a minute, the mold opens, and the part is ejected. The mold closes again, and the process is repeated (Figure 2.6).



Figure 2. 6 Injection Molding Process

The screw has flights which have different diameters along the shaft, it pushes the plastic forward and helps to have homogeneous material, in addition to generate frictional heat.

In the head of the screw there is a non-return valve to prevent backflow of the plastic material to maintain the effectiveness of the injection pressure. (Figure 2.7)



Figure 2. 7 Non-Return Valve of The Screw

#### 2.1.5 Process Parameter Factors

To control the quality of the final products, there are several parameters related to the injection process that must be known and controlled in an optimal way. These parameters are adjustable during the injection molding process and directly influence the quality of the products. These parameters are categorized into groups as follow: temperatures (melting temperature, mould temperature), pressures (injection pressure, holding pressure, clamping force), times (injection

time, holding time, cooling time). It is very necessary to have good knowledge on the process parameters in order to minimize the defects.

#### 2.1.5.1 Melting Temperature

Melting temperature is the temperature inside the barrel and the nozzle that controls the change of the plastic from the solid phase to the melt, it is also reflected in the viscosity of the molten material. Temperature is a major factor in the process of melting and solidification, and any temperature imbalance leads to the occurrence of defects. Lack of sufficient temperature inside the barrel and the nozzle will lead to incomplete melting and high viscosity during the injection step, causing defects such as, pit, short shots, sink marks. On the contrary, too high temperature leads to excessive heating of the material and a decrease in viscosity during the injection step, and then hardening of solidification during the cooling process. This leads to the appearance of defects such as, flash, warpage, splay marks.

#### 2.1.5.2 Injection Pressure

Injection pressure affects the flow rate of the molten material during the injection phase, as the flow rate increases with increasing injection pressure and the flow rate decreases as the injection pressure decreases. The injection pressure must be sufficient to fill the mold. High injection pressure leads to high flow rate causing defects such as flashing and splay marks. And the lower injection pressure causes a lower molten flow rate, and this leads to the possibility of this molten to solidify before filling the mold cavity. In addition to air retention and high surface temperature inside the cavity, which leads to the appearance of defects such as short shots, sink marks and voids.

#### 2.1.5.3 Injection Speed

The injection speed is the forward speed of the screw during the injection process. For most engineering resins, the injection speed should be set as fast as the part design and process allow for technical and economic reasons. To minimize turbulent flow and jetting when the material passes through the restricted sections, a slower injection speed may be necessary at the commencement of the injection (e.g. gates). The injection speed should be reduced again at the end of the injection to avoid flashing at the end of the stroke and to improve the development of homogeneous weld lines following a divided flow. You can expect decreased flow resistance, longer flow length, and increased weld line strength with the greatest injection speed achievable within shear rate restrictions. However, once you've done this, you may need to add extra vents.

#### 2.1.5.4 Holding Pressure

A sufficient holding pressure prevents the melt from flowing backwards toward the nozzle. It also adds material to prevent the part from shrinking. The molten plastic will flow back toward the nozzle if the holding pressure is insufficient. As a result, the plastic at the nozzle droops, causing the splay marks. It also causes the mold cavity to be insufficiently filled.

#### 2.1.5.5 Cooling Time

The cooling time mainly controls the cooling rate. Failure to cool enough time causes the **UNIVERSITIEEXAMPLAKA** solidification process not to take place completely, causing defects in the molded part such as warpage and distortion. In addition, it causes the parts not to eject out properly. Cooling time also control the rate of plasticization. Failure to cool enough time affects the molten material not completely plasticizing, causing surface defects such as short shots, pit marks, sink marks, splay marks, and voids.

#### 2.1.5.6 Mold Temperature

The temperature of the mould affects the solidification of the molten material, insufficient mould temperature leads to a decrease in the viscosity of the melt in the cavity resulting in defects such as splay marks, short shots, surface ripples, pit marks, and sink marks. On the

other hand, if the mould temperature is too high, the viscosity of the melt in the cavity is too high, which is a major cause for warpage, distortion, voids, and flashing.

#### 2.1.6 Plastic Defects

The primary goal of every production process is to assure high product quality. The same is true for the injection molding process. It is, however, a little more difficult to do with the injection molding procedure. This is due to the complexities of the injection molding process and the unstable qualities of plastics. Defects can, of course, arise at any moment and at any location throughout the injection molding process. Three basic keys exist to eliminate or reduce defects. To begin, it is vital to comprehend the complete injection molding process. Second, it is vital to understand how to identify defects. Furthermore, the causes of the defects must be identified. Defects can finally be eliminated or decreased if these fundamental guidelines are followed. To completely understand the process, it is necessary to trace the origins of defects, adjust the influencing variables, and rectify the errors. To recognize a fault, the source of the fault must be known. To identify and eradicate the source of the faults, one must first comprehend the influence variables involved in the deviations. Recognizing the defects is a huge problem. Some discrepancies can be identified using a specific indication. For example, the cavity pressure transducer can determine whether or not short shots are produced by insufficient injection pressure.

However, there is a subset of defects that cannot be detected by sensors. Typically, these variances are only discovered after the process has been completed. There are no warpage sensors, for example, to detect warpage during the procedure. Once the defect is identified, the reasons of the defect can be eliminated to resolve the issue.

#### 2.1.6.1 Warpage

Warpage is a distortion that occurs when the surfaces of a molded object do not correspond to the intended shape of the design. Part warpage is induced by molded-in residual strains, which are created by the material of the molded part shrinking differentially. The molding will not distort or warp if the shrinkage is homogeneous throughout the portion; it will simply shrink. However, obtaining low and uniform shrinkage is a tough challenge due to the existence and interplay of various elements such as molecule and fiber orientations, mold cooling, part and mold designs, and process conditions (Kurtaran, H. Kurtaran, B. Ozcelik, T. Erzurumlu, 2005; Dong, B.B. Dong, C.Y. Shen, C.T. Liu, 2005).

Rapid cooling is one of the most common causes of warping in injection-molded plastic and related materials. High temperatures or low thermal conductivity of the molten material usually worsen injection molding defects. If the walls of the mold are not equally thick, shrinkage rises with wall thickness, which can contribute to warping. To prevent warping in molded parts many steps must be done as following: (1) Make certain that the cooling process is gradual and long enough to avoid uneven stresses on the material. (2) reduce the material's or mold's temperature. Consider using a material that shrinks less during cooling, (e.g. particle-filled thermoplastics shrink much less than semi-crystalline materials). (3) redesign the mold to have uniform wall thickness and part symmetry to ensure greater part stability during cooling.



Figure 2. 8 Warpage Defect

#### 2.1.6.2 Shrinkage

When measured at the processing temperature and the ambient temperature, shrinkage of molded plastic parts can be as much as 20% by volume. Thermal shrinkage is more common in crystalline and semi-crystalline materials, while amorphous materials shrink less. When crystalline materials are cooled below their transition temperature, they become crystalline, Crystallites are formed when molecules arrange themselves in a more orderly manner. The microstructure of amorphous materials, on the other hand, does not change with phase change. Because of this difference, crystalline and semi-crystalline materials have a larger difference in specific volume between their melt and solid (crystalline) phases.



Figure 2. 9 Shrinkage Defect

#### 2.1.6.3 Sink Marks

Sink marks are small recesses or depressions in a molded part's otherwise flat and consistent surface. These can happen when the inside of a molded component shrinks, pulling material in from the outside.

Sink marks, like other surface flaws, cause poor surface quality and severe internal stresses to concentrate in one place. As a result, the product loses its value, and its functional performance suffers. Sink marks are caused primarily by uneven shrinkage of the part.



Figure 2. 10 Sink Marks Defect

#### 2.1.6.4 Flash

Flashing is the surplus material adhering to the parting line's edge. In general, lashing occurs only when the "A" plate and the "B" plate come together. Installing a cavity pressure transducer to detect flashing is one way to do so. An abnormally high cavity pressure distribution shows the presence of flashing in the molded pieces.

Flashing must be removed for two reasons. First and foremost, the flashing is an unexpected component. It can occasionally render the part inoperable. For example, flashing in gear teeth indicates that this gear cannot mesh with other gear teeth. Flashing can also be utilized to eliminate some sorts of secondary operations. It will, however, increase the cost of the part. It is due to the additional labor required for the part to be acceptable. Second, the flashing may become adhered to the mold surface. When the mold closes, the flashing component will harm and eventually wear down the mold surface.



Figure 2. 11 Flash Defect

#### 2.1.7 Applications of Injection Molding

Injection molding is the preferred method for mass production of plastic products, due to the many advantages of this process, where multiple types of plastic can be used and colored at will, and the ability to design and manufacture complex shapes with high accuracy. It is also characterized by fast production rates and high efficiency. In addition, this process is considered somewhat environmentally friendly as some of the manufactured plastic can be recycled and therefore less waste. Products manufactured by the injection molding process include, but are not limited to:

Plastic injection molding is used in many industries, such as packaging, bottle caps, auto parts, toys, some musical instruments, and the list goes on. This is due to the ability to produce large quantities and in different forms, the fields in which the plastic injection molding process is applied have varied, in addition to the diversity of plastic materials and the diversity of their properties, which enables us to find the right material for almost every function.

Plastic injection molds are ideal for producing high volumes of plastic parts due to their ability to produce multi-cavity injection molded parts, which allow multiple parts to be produced in a single cycle. High tolerances, repeatability, a wide range of material selection, low labor cost, minimal scrap losses, and little need to finish parts after molding are just a few of the benefits of injection molding.

#### 2.2 Plastic as Material

Plastics are a necessary part of everyday life; we can find plastic in many products, in our clothes, homes, transportation, games, electronic devices, and medical devices. The term "plastic" comes from the Greek word "plastikos", meaning moldable material. Plastic is defined as any organic, synthetic, or semi-synthetic polymer that is permanently composed of carbon and hydrogen and may contain elements other than both. One of the distinguishing

characteristics of plastic is light weight, long life, and its electrical and heat insulation. Also, there are many plastics materials, and they are varied in properties, so the plastic can be used in almost all fields and meet the requirements and the standards.

The tremendous range of properties exhibited by plastics and their ease of processing are two of the reasons for their widespread use in a wide range of industrial applications. Plastic properties can be tailored to meet specific needs by varying the atomic makeup of the repeat structure, molecular weight and molecular weight distribution, and flexibility as governed by the presence of side chain branching as well as the lengths and polarities of the side chains. and by tailoring the degree of crystallinity, the amount of orientation imparted to the plastic during processing, copolymerization, blending with other plastics, and modification with a vast array of additives (fillers, fibers, plasticizers, stabilizers). Given all the options for tailoring any given polymer, it is not surprising that we have such a wide range of options today.

Most of the plastics in use today are manufactured by following a set of steps and processes, including the following. (1) Extraction: During this process, the raw materials from which the plastic is made is extracted, which include crude oil, natural gas, and coal as well. These materials need to be processed. (2) Refining Process: Converting crude oil into various petroleum products such as monomers that are processed to manufacture polymers. The refining process goes through several stages, where the oil is heated and then distilled, separating the heavy crude oil into lighter components, including naphtha, which is the main compound for plastic manufacturing. It should be noted that other methods are used if natural gas is used to produce plastics. (3) Polymerization: The polymerization process refers to chemically combining small molecules called monomers to produce a very large mesh molecule called a polymer. Molecules of monomers consist of one or more types of compounds.

#### **2.2.1** Classification of Plastic

Plastics can be classified as thermoplastics or thermosets. A thermoplastic material is a noncross-linked polymer with a high molecular weight. A thermoplastic material can be linear or branched in structure. When a thermoplastic is heated, it transforms into a highly viscous liquid that can be shaped with plastics processing equipment. A thermoset has all of its chains linked together in a network by covalent bonds (cross-linked). Once cross-linked, a thermoset cannot be reprocessed, but a thermoplastic material can be reprocessed by heating to the appropriate temperature. Figure 2.12 depicts the various types of structures.



2.2.2 Thermosetting

Plastic materials that cannot be reshaped after being melted, formed, and hardened for the first time. Polymers in thermosetting plastics bind together during the curing process to form an irreversible chemical bond. Because the product cannot be reshaped by applying heat and melting it, it is best suited for high-temperature applications such as electronics and appliances. Thermosetting significantly improves the material's mechanical properties, which improves chemical resistance, heat resistance, and structural integrity. Because of their resistance to deformation, thermosetting plastics are frequently used in sealed products. However, this material has the disadvantage of being unable to be recycled or reshaped. With its combination of thermal stability, performance, and chemical resistance, thermoset plastics are widely applied in a wide range of sectors, including the aerospace industry, heavy duty construction equipment, the energy sector (including oil, gas, and solar), and automobile production. Thermoset plastics are commonly used in construction equipment panels, electrical housings and components, insulators, cell tower tops, heat shields, circuit breakers, agricultural feeding troughs, motor components, and disc brake pistons. Epoxy, silicone, polyurethane, and phenolic are common thermoset plastics and polymers. Furthermore, certain materials, such as polyester, can be found in both thermoplastic and thermoset forms. The components of thermoset polymers, unlike thermoplastic pellets, are held in liquid form, often in huge tanks or containers. When applied as a manufacturing material, different thermosets provide unique benefits. Epoxies, for example, are very elastic, strong, and chemically resistant, whereas phenolic is very flame resistant. See our post here for a more in-depth look at the advantages of one popular thermoset, polyurethane.

# 2.2.3 Thermoplastics

Thermoplastic pellets melt and become formable when heated, but no chemical bonding occurs. Because of this property, thermoplastics can be remodeled and recycled without affecting their physical properties. Many thermoplastic materials provide different performance benefits, but most materials provide easy bendability, shrink resistance, and high strength. Thermoplastics can be used in low-stress applications such as plastic bags or high-stress mechanical parts, depending on the material. Thermoplastics are not suitable for high-temperature-sensitive products because they may melt.

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Thermoplastics are commonly used in the injection molding process because they produce flexible and precise parts and have excellent aesthetically pleasing surface finishes. Thermoplastics are also valuable due to their recyclability as the manufactured products can be re-melted and shaped into different shapes through injection molding. This led to the adoption of thermoplastics in the toys, furniture and clothing industries, allowing parts to be recycled and repaired after they were damaged.

The different types of thermoplastics can be identified by following the rapid experimental method (that is for common plastics) and the required tools are simple only a match or a lighter, because the test is based on the principle of burning where the type of plastic material is identified by noting the color and smell of smoke, the color of the flame, the method of melting or from the lack of combustibility of the material.



Figure 2. 13 Recycling Numbers of Thermoplastics

Thermoplastics are a large variety of plastics and are divided into two main groups according to use, engineering plastics and commodity plastic.

#### 2.2.4 Engineering Plastic

Engineering plastics are plastics that have excellent performance in the areas of heat resistance, chemical resistance, shock resistance and mechanical strength, compared to commodity plastics, so they are the ideal choice when there are specific mechanical properties required to do a function. Natural materials such as metals and wood are replaced by engineering plastics,

Because of its strength, light weight, and ease of manufacture in complex shapes. Engineering plastics are used in a wide variety of applications, including electrical and electronic devices, construction, and automobiles.



Table 2. 1: Common Engineering Thermoplastics in Plastic Industry

#### 2.2.5 Commodity Plastic

Plastics are mass produced for applications that do not require exceptional properties, and unlike engineering plastics, commodity plastic is cheaper to produce and has poor mechanical properties. Common products made from Commodity Plastic include: disposable products (plates,cups,bags,gloves..etc), packaging, and toys.
Table 2. 2: Commodity Plastics



### 2.2.6 Polypropylene

Polypropylene, a thermoplastic polymer, has a linear molecular structure that allows it to soften when heated due to the polymer's weak molecular chains. When heated, intermolecular bonds break and molecules move in respect to one another; when cooled, these links or joints are rebuilt. Polypropylenes can thus be recycled endlessly until the polymers degrade to the point where the material loses structural integrity.

Polypropylene, being a polymer, is more complicated than metals and ceramics in terms of microstructure. On the contrary, it is inexpensive and simple to process. Polypropylenes have lower strength and modulus values, as well as lower temperature limitations, than metals or ceramics. Polypropylenes are usually poor conductors of heat and electricity because to their mainly covalent bonding. Polypropylenes are more chemically resistant than metals, however extended exposure to UV light and some solvents can cause Polypropylene characteristics to degrade.

Tensile strength and stiffness are two of Polypropylene's essential features as an affordable, lightweight engineering material. Its ability to crystallize is critical to this. This adds strength to the resin, allowing it to be used in molded shapes. Polypropylene, for example, has strong

chemical resistance, high shrinkage, high warpage, high tensile strength and tensile modulus, low elongation, high creep resistance, high in flow of the polymer, can sustain a high maximum exposure temperature, and has a high density.

As previously stated, Polypropylene is a thermoplastic polymer with linear molecular architectures. When Polypropylene is warmed, its molecular structure weakens, allowing the material to reshape or reform. This property of Polypropylene allows it to be recycled into new products after reforming or reshaping. The estimated outcomes of mechanical forces on Polypropylene are shown below.



Table 2. 3 Mechanical Properties of Polypropylene

# 2.2.7 Recycling plasticRSITI TEKNIKAL MALAYSIA MELAKA

Plastic recycling means the process of producing useful products from waste plastic after reprocessing and re-melting. This process is one of the most important ways to reduce the amount of plastic waste (Pivnenko & Jakobsen ,2015). Recycling thermoplastics has many benefits, including saving raw materials for industry and reducing environmental pollution because the plastic is not biodegradable (Dvorak & Kosior ,2009). The figure 2.14 shows the cycle of the thermoplastics recycling process. Recycled plastics are cheaper than virgin plastics but have lower mechanical properties (Azeez & Walter, 2018). Pollution and inadequacy remain a concern for the use of these materials, so blending technology is an appropriate solution to this issue as it achieves production costs and low technical risks in addition to

obtaining environmentally friendly products (Kukaleva, Simon, 2003). This is the approach that is followed in this research, where we mix virgin plastic with regrind plastic.



Figure 2. 14 The Cycle of The Thermoplastics Recycling Process

Plastic recycling begins by collecting waste plastic or unusable products including electronic devices, food containers, toys, and auto parts, in addition to quality rejected parts. It is difficult to recycle all types of plastic due to the different types of plastic mixtures, so the sorting process must be done first and then the grinding process.

According to Scott (2000), plastic recycling can be done in three different ways, mechanical recycling, chemical recycling, and energy recovery (Fortelng et al, 2004). Mechanical recycling is one of the most common methods and it is the method adopted in this research. Plastic waste is recycled and processed by a mechanical process and these recycled materials are used in various plastic processes such as injection molding, extrusion, bowing and vacuum (Achlias & Andriotis 2007).

Although plastic waste recycling is constantly improving and evolving, the amount of plastic that ends up in landfill is still increasing (European Environment Agency, 2005). Only a small percentage of plastic waste is re-melted and made into new products, due to the limited use of

recycled plastic. In 2015 only 20-25% of plastic waste was recycled (Mojtaba, Myriam & Woon-Hee, 2020)

#### 2.2.8 Restrictions of Recycled Plastic

Although recycling of plastics has reduced the use of virgin plastic, it is still limited in use. There is still concern about the poor performance of mechanical and physical parts produced. As stated by Scott (2000), in contrast to glass and metals that can be recycled and reproduced into products with properties similar to those of raw materials, each time the plastic is reprocessed, a change in its physical and mechanical properties occurs due to oxidation. The reason for this decline in the physical and mechanical properties of recycled plastics is due to changes in the chemical structure of the plastic material when it is processed (Kartalis et al, 2000, Bonelli et al, 2001). Another important reason for the limited use of recycled plastic is the deterioration of the material itself, which results from repeated processing of the material at high temperatures. Contaminants include the barrel remains of other thermoplastics, dirt particles, grease etc. This leads to thermal and mechanical deterioration and loss of the material's properties (Pawlak et al,2000). In addition, thermal degradation is another reason that limits the use of recycled plastics. Recycled plastics go through successive cycles of high and low temperatures (Navarro et al, 2003). Thermal degradation involves changes in the molecular weight of the plastic that affect the melt flow index (MFI) (Phuong, 2008). Thermal degradation has other effects on material properties such as reduced ductility, discoloration, cracking, and reduced thermal stability. Regardless of the mechanical and thermal deterioration caused by plastic reprocessing at high temperatures, the process of blending recycled plastic with virgin plastic to produce high quality products is not a simple and smooth process. This is due to the aerodynamic miscibility of most plastics (Zenkiewicz & Kurcok, 2008). For example, PE and LDPE are somewhat immiscible, the intermolecular adhesion of these

materials is very low, which has limited their applications of blending processes to produce parts (Ahano et al, 2000).

#### 2.2.9 Mechanical Properties of Plastic

The final performance of the product is primarily determined by its mechanical properties. However, during the injection molding process, these properties have no effect on the molten polymer's performance. These properties include tensile strength and modulus, compressive strength and modulus, flexural strength and modulus, impact strength, hardness.

Tensile strength is the ability to apply the maximum force or load per unit cross-sectional area within the gauge length of the test specimen in the pulling direction. Tensile modulus is defined as the normal stress to tensile stress ratio that is less than proportional stretching. The flexural strength of a material is the unit resistance to the maximum load before it fails by bending. It can be used to indicate the maximum stress that surface fibres in a beam can withstand while bending. Flexure modulus is defined as the ratio of the applied stress on a flexural test specimen to the corresponding strain in the outermost fibre of the test specimen within the elastic limit. Impact strength is the ability to withstand shock loading. The resistance to surface indentation is defined by hardness. It is commonly measured by the depth of penetration of a blunt point under a given load using a specific instrument and following a prescribed procedure (Tzy-Cherng, 1992).

#### 2.2.10 Preliminary Finding

Several studies have shown that in general the recycling of thermoplastics leads to a decrease in tensile strength due to lower molecular weight (Hamad & Kassem, 2001). For PC and PBT it was found that tensile strength is not significantly affected by reprocessing (Sanchez, 2007).

It is important when using recycled materials to ensure the required quality. Therefore, recycled materials are mixed with virgin materials in a ratio usually between 0-50% or sometimes more

(Lewis & Buser, 1997). Packing time is the most influential element on tensile strength for virgin Polypropylene, according to (Azhad 2022). And, according to his research, the expected average tensile strength at optimum settings is 33.064Mpa. (Moh Hakimi 2022) investigated the optimization of plastic injection moulding settings for 80:20 virgin-regrind Polypropylene. Hakimi discovered that there are no major factors influencing tensile strength for 80:20 virgin-regrind (PP), and the predicted value for optimum parameters is 33.94Mpa. According to these investigations, the tensile strength of blended Polypropylene differs slightly from that of virgin Polypropylene. (Maryam, Mojtaba & Won-Hee, 2020) conducted a study on the effect of Polypropylene recycling on mechanical properties by studying virgin Polypropylene with recycled Polypropylene, and they found that increasing the concentration of re-grinded Polypropylene in the compound leads to a decrease in mechanical properties, especially tensile strength, ductility, and impact strength. But on the other hand, the use of recycled materials reduces the crystallization rate and the melting temperature.



Figure 2. 15 The Trends of Elastic Modulus and Tensile Strength Alterations Against

**Recycled PP/virgin PP Ratios** 

#### 2.3 Taguchi Method

Taguchi's concept is an effective tool for developing high-quality manufacturing systems. Dr. Genichi Taguchi, a Japanese quality management consultant, has devised a method based on orthogonal array experiments that gives significantly reduced variance for the experiment with optimal process control parameter selection. Thus, the Taguchi technique integrates design of experiments (DOE) with process parametric optimization to produce desired outcomes. Traditional experimental design methods take a long time. When the number of control factors is large, many experiments must be carried out. Taguchi methods explore the entire factor space with a special design of orthogonal arrays and a minimal number of experiments. The Taguchi technique seeks to optimize a process or product design and is divided into three stages, which are as follows: (1) Concept Design or System Design. (2) Parameter Design. (3) Tolerance Design.

The concept design is regarded as the initial phase of the design strategy. This phase collects technical knowledge and experiences to assist the designer in selecting the best one for the planned product. The ideal setting of the control factors is found during parameter design. This is possibly the most significant phase because it has no effect on the product's unit manufacturing cost.

The third phase is used only after the parameter design stage has been completed, and it is used when further modifications to the optimal design are required. This stage focuses on the cost-quality trade-off. However, at this stage, designers consider only tightening tolerances, upgrading material standards, and components, if any, that have a substantial impact on quality through parameter design tests. The Taguchi approach, rather than the average, uses the signal-to-noise (S/N) ratio to translate trial result data into a value for the characteristic in the optimum setting analysis. The S/N ratio displays the quality characteristic's average as well as its fluctuation. The following are the standard S/N ratios that are commonly used: Nominal is the best (NB), lower is better (LB), and higher is better (HG) (HB). The parameter combination with the highest S/N ratio is the best configuration.

Туре	Definition	Formula
Nominal is the best (NB)	when a specified value is most desired.	$[S / N]_n = 10 . \log_{10} \frac{\mu^2}{\sigma^2}$
lower is better (LB)	The smaller the output, the better quality.	$[S / N]_{S} = -10 \cdot \log_{10} \frac{\Sigma \mu^{2}}{n}$
higher is better (HB)	The higher output, the better quality.	$[S/N]_{L} = -10 \cdot \log_{10} \frac{\Sigma \frac{1}{\mu^{2}}}{n}$
n: the number of trials/sam	ples. µ: the signal mean.	σ: standard deviation.

 Table 2. 4 The Different Types of Quality Characteristics



Figure 2. 16: Steps of Taguchi Methods

## **Chapter 3: Methodology**

# **3.0 Introduction**

This chapter will explain the method used in our study, starting from preparing materials, producing parts, making tests, obtaining, and analyzing results, and reaching the required conclusion. We will use the Taguchi method and ANOVA method using MINITAB software and will do a tensile test using the appropriate equipment.



# 3.1 Gantt Chart 1

PSM 1 GANTT CHART															
PSM 1 GANTT CHART		W 1	wo	<b>W/2</b>	14/4	W/5	MG	14/7	14/9	14/0	W10	M/11	W12	M/12	M/1/
Activities		~ 1	VV 2	vv3	VV4	005	~~~	~~/	***	003	VV 10	**11	VV 12		VV 14
TASK 1:	PLAN														
Finding Research Paper and Reading.	ACTUAL														
TASK 2:	PLAN														
Draft Chapter 1: Introduction	ACTUAL														
TASK 3:	PLAN														
Draft Chapter 2: Literature Review	ACTUAL														
TASK 4:	PLAN														
Check with The Supervisor	ACTUAL														
TASK 5:	PLAN		1												
Draft Chapter3: Methodology	ACTUAL														
TASK 6:	PLAN														
preliminary Submission	ACTUAL														
TASK 7:	PLAN														
Final Report LAYS	ACTUAL														
TASK 8:	PLAN														
Slide Presentation	ACTUAL														
TASK 9:	PLAN														
Video Presentation	ACTUAL								V	1					

Figure 3. 1 Gantt Chart PSM 1

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# 3.2 Gantt Chart 2

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PSM 2 GANTT CHART			1												
PSM 2 GANTT CHART		M/ 1	W 2	14/2	14/4	14/5	MG	14/7	14/9	14/0	W10	W11	W12	M/12	W14
Activities		~ 1	VV 2	003	VV4	005	~~~	•••	***	005	VV 10	**11	VV 12	VV15	VV 14
TASK 1:	PLAN														
Run the experiments and collect data	ACTUAL														
TASK 2:	PLAN														
Draft chapter 4 with analyses	ACTUAL														
TASK 3:	PLAN		1												
Draft chapter 5	ACTUAL														
TASK 4:	PLAN		-												
Make improvements	ACTUAL		1												
TASK 5:	PLAN														
Final Writing	ACTUAL		1												
TASK 6:	PLAN		1												
Final presentation	ACTUAL														
TASK 7:	PLAN														
Final submission	ACTUAL														

Figure 3. 2 Gantt Chart PSM 2

## 3.3 Laboratory Setting

The experiment is conducted in the Plastics Technology Laboratory in faculty of Mechanical and Manufacturing Engineering Technology (FTKMP) at UTeM University. This laboratory contains all the equipment required to conduct this experiment, such as a plastic injection molding machine (Figure 3.3), blender (Figure 3.4), and crusher (Figure 3.5).



Figure 3. 3 HAITIAN VE300 Injection Molding Machine

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Figure 3. 4 Plastic Material Blender



Figure 3. 5 Waste Plastic Crusher

### **3.4 Material Preparation:**

We have to prepare 15kg of the material under consideration which is a mixture of 70% (10.5kg) virgin Polypropylene (PP) and 30% (4.5kg) regrind Polypropylene (PP). The first step begins with preparing the raw materials. For the regrind Polypropylene, it must be prepared in the laboratory by grinding the waste Polypropylene. Waste Polypropylene can be obtained from the laboratory through parts that were previously produced and tested, or by collecting useless parts and checking the recycling number (Figure 3.6). After that, waste parts are prepared and grinded into small pieces by the crusher (Figure 3.5). The last step is to mix the regrind plastic with the virgin plastic pellet in a ratio of 70:30, which is done using the blender shown in the



Figure 3. 6 Polypropylene Recycling Number.

Figure 3. 7 Regrind Polypropylene.

### **3.5 Design of Experiment**

The design of experiment chosen is Taguchi method, it consists of five factors and two levels for each factor where an orthogonal array L8 is used to suit the inputs. Parameters to be considered are cooling time, packing time, injection speed, mold temperature, and packing pressure. Taguchi employs the S/N ratio to assess deviations in quality characteristics from the desired value. The quality characteristics of the S/N ratio that is applied in this study is thelarger-the-better (LB). The choice of which orthogonal array (OA) to use is primarily determined by the number of factors and interactions of interest, the number of levels for the factors of interest, and the desired experimental resolutions or cost constraints. Three samples are collected for each experiment.

Table 3.1 Injection Molding Parameters and Working Level of Design Factor

D I	T 11		TT 1
Parameters	Level 1	Leve 2	Units
Cooling Time	10	15	S
Packing Time	5	10	S
Injection Speed	lund 10		mm/s و دمو م
Mold Temperature	30	50	C
Packing Pressure	ERSITI 50EKNIKA	L MAL110SIA ME	<b>LAKA</b> Мра

Table 3. 2 Experimental Plot Using L8 Orthogonal Array

		Injection Molding Parameter Level							
	А	В	C	D	E				
	Colling Time	Packing	Injection	Mold	Packing				
Experiments		Time	Speed	Temperature	Pressure				
1	1	1	1	1	1				
2	1	1	1	2	2				
3	1	2	2	1	1				
4	1	2	2	2	2				
5	2	1	2	1	2				
6	2	1	2	2	1				
7	2	2	1	1	2				
8	2	2	1	2	1				

#### **3.6** Tensile Test

The purpose of this method is to determine the tensile properties of plastic materials. Tensile properties of reinforced and unreinforced plastics can be determined using standard dumbbell-shaped test specimens tested under defined pretreatment, temperature, humidity, and testing machine speed conditions. True Stress and Strain, Engineering Stress and Strain, Elastic Modulus, and Ultimate Tensile Strength are some of these properties. It entails linearly stretching a material until failure or a critical value is reached. Eight experiments are done, each one with three samples. The total number of the samples collected is 24 samples.



Figure 3. 8 Tensile Test Machine

#### **3.7** Data Analysis

In data analysis, Minitab software will be used for statistical evaluation of experimental observation. We enter the data of the 24 samples into the Minitab software, and then tables, graphs, and information will be generated by Minitab software, such as main effect plot for S/N ration, analysis variance for mean, response table for signal to noise ratios, and main effect plot for means. From these outputs we can analyse which parameter has the greatest influence on the tensile strength and we can know if the difference between the tensile strength of the blended material and the virgin material is significant or not.

Level	A	B	C	D	E
1	11.50	13.63	11.91	16.02	15.33
2	18.62	16.49	18.21	14.10	14.79
Delta	7.12	2.86	6.31	1.91	0.54
Rank	1	3	2	. 4	5

Table 3. 3 Response Table for Signal -to-Noise Ratios

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Table 3. 4 Response Table for Mean and S/N Ratio

Α	В	С	D	E	SNRA1	MEAN1
1	1	1	1	1	7.8967	0.4026
1	1	1	2	2	5.9389	0.5042
1	2	2	1	1	17.5654	0.1316
1	2	2	2	2	14.6116	0.1826
2	1	2	1	2	20.7153	0.0918
2	1	2	2	1	19.9657	0.0998
2	2	1	1	2	17.8895	0.1266
2	2	1	2	1	15.9027	0.1568
			2	· · · · · · · · · · · · · · · · · · ·		and the second second



Figure 3. 9 Main Effect Plot (data mean) for SN ratio from Minitab

# 3.8 Results and conclusion

As a result of this study and after conducting the tests and analyzing them, we will be able to:

- 1- Using the Taguchi method to find out the effect of different parameters on the mechanical properties of 70:30 virgin-regrind (PP).
- 2- Using the Taguchi method to determine the optimal parameters and using ANOVA method to get the significant degree of each parameter.
- 3- Determine the parameter most affecting the tensile strength of 70:30 virgin-regrind (PP).
- 4- To determine whether this blend material 70:30 virgin-regrind (PP) is suitable or not to replace virgin material will be concluded based on comparison study between blend tensile strength against virgin (PP) material.

#### **Chapter 4: Results and Discussion**

#### 4.0 Introduction

In this chapter, the results of tensile test of our 70:30 virgin-regrind Polypropylene (PP) samples helped us to study the effect of different parameters on the tensile strength. The total number of experiments is eight, each experiment with 3 samples. Taguchi method was applied and MiniTab software was used. In addition, samples were analyzed using S/N ratios and analysis of variance (ANOVA). Since our study aims to obtain the highest tensile strength, S/N ratios was computed based on the bigger the better quality characteristic. At the end of this study, we were able to identify the most significant factor that affect tensile strength in 70:30 virgin-regrind Polypropylene (PP) and we were able to set the optimum parameters to get highest tensile strength.

# 4.1 Tensile Test Results

The tensile strength refers to the behavior of the curve and its response to the applied force. UNIVERSITITEKNIKAL MALAYSIA MELAKA The highest tensile strength a specimen can withstand during a tensile test is called Ultimate Tensile Strength. The tensile test results for the samples of 70:30 virgin-regrind Polypropylene (PP) show the differences in tensile strength with different setting parameters.





Figure 4. 1: Tensile Strength Testing Results for Experiment 1

The figure 4.1 shows the tensile test results obtained from three samples of 70:30 virgin-regrind Polypropylene (PP) at the first experiment. The average value of the tensile strength is 33.083 MPa. The parameters setting for this experiment were at: cooling time (10s), packing time (5s), injection speed (10mm/s), mold temperature (30C), packing pressure (50Mpa).



4.1.2 Tensile Test for Experiment 2

Figure 4. 2: Tensile Strength Testing Results for Experiment 2

The figure 4.2 shows the tensile test results obtained from three samples of 70:30 virgin-regrind Polypropylene (PP) at the second experiment. The average value of the tensile strength is 34.077 MPa. The parameters setting for this experiment were at: cooling time (10s), packing time (5s), injection speed (10mm/s), mold temperature (50C), packing pressure (110Mpa).

## 4.1.3 Tensile Test for Experiment 3



Figure 4. 3: Tensile Strength Testing Results for Experiment 3

The figure 4.3 shows the tensile test results obtained from three samples of 70:30 virgin-regrind Polypropylene (PP) at the third experiment. The average value of the tensile strength is 32.74 MPa. The parameters setting for this experiment were at: cooling time (10s), packing time (10s), injection speed (50mm/s), mold temperature (30C), packing pressure (50Mpa).



### 4.1.4 Tensile Test for Experiment 4

Figure 4. 4: Tensile Strength Testing Results for Experiment 4

The figure 4.4 shows the tensile test results obtained from three samples of 70:30 virgin-regrind Polypropylene (PP) at the fourth experiment. The average value of the tensile strength is 33.641 MPa. The parameters setting for this experiment were at: cooling time (10s), packing time (10s), injection speed (50mm/s), mold temperature (50C), packing pressure (110Mpa).



4.1.5 Tensile Test for Experiment 5

Figure 4. 5: Tensile Strength Testing Results for Experiment 5

The figure 4.5 shows the tensile test results obtained from three samples of 70:30 virgin-regrind Polypropylene (PP) at the fifth experiment. The average value of the tensile strength is 33.322 MPa. The parameters setting for this experiment were at: cooling time (15s), packing time (5s), injection speed (50mm/s), mold temperature (30C), packing pressure (110Mpa).

# 4.1.6 Tensile Test for Experiment 6



**UNIVERSITITEE KNIKAL MALAY SIA MELAKA** Figure 4. 6: Tensile Strength Testing Results for Experiment 6

The figure 4.6 shows the tensile test results obtained from three samples of 70:30 virgin-regrind Polypropylene (PP) at the sixth experiment. The average value of the tensile strength is 33.705 MPa. The parameters setting for this experiment were at: cooling time (15s), packing time (5s), injection speed (50mm/s), mold temperature (50C), packing pressure (50Mpa).



### 4.1.7 Tensile Test for Experiment 7

Figure 4. 7: Tensile Strength Testing Results for Experiment 7

The figure 4.7 shows the tensile test results obtained from three samples of 70:30 virgin-regrind Polypropylene (PP) at the seventh experiment. The average value of the tensile strength is 33.377 MPa. The parameters setting for this experiment were at: cooling time (15s), packing time (10s), injection speed (10mm/s), mold temperature (30C), packing pressure (110Mpa).





Figure 4. 8: Tensile Strength Testing Results for Experiment 8

The figure 4.8 shows the tensile test results obtained from three samples of 70:30 virgin-regrind Polypropylene (PP) at the eighth experiment. The average value of the tensile strength is 34.595 MPa. The parameters setting for this experiment were at: cooling time (15s), packing time (10s), injection speed (10mm/s), mold temperature (50C), packing pressure (50Mpa).

#### 4.1.9 Data Summery

Table 4.1 shows the data summery of the whole experiments with three samples. From the table we can notice that experiment 8 comes out with the highest average tensile strength test result.

Experiment	Sample 1(Mpa)	Sample 2(Mpa)	Sample 3(Mpa)	Average(Mpa)
1	33.584	32.671	32.993	33.083
2	33.893	33.782	34.556	34.077
3	32.874	32.617	32.729	32.740
4	33.167	33.681	34.074	33.640
5	33.528	32.712	33.726	33.322
6	33.736	33.399	33.982	33.705
7	32.960	34.186	32.984	33.377
8	34.681	34.857	34.247	34.595

Table 4. 1: Data Summery for Eight Experiments

# 4.2 Finding and Data Analysis

In this study, the maxim "the greater the better" was used to determine the best parameter for higher tensile strength. The S/N ratio values proposed are large. A high S/N ratio value indicates that the signal is much stronger than the arbitrary impact of noise factors. The processing parameters with the highest S/N ratio consistently produce the best quality with the least amount of variation. As a result, in this study, the processing parameter values with the highest S/N ratio of tensile strength.

#### 4.2.1 Analyze Data Using Taguchi

The data in table 4.2 shows the results of S/N ratios and means of eight experiments. This data is analyzed using the Taguchi method to identify the factors ranking which affect the tensile strength. Lastly it helped us to set the optimal parameters and predict the highest possible tensile strength value.

Experiment	S/N Ratios(Mpa)	Means (Mpa)
1	30.390	33.083
2	30.650	34.077
3	30.301	32.740
4	30.536	33.640
5	30.452	33.322
6	30.553	33.705
7	30.465	33.377
8	30.780	34.595

Table 4. 2: Summery	of S/N	Ratios	and Means
---------------------	--------	--------	-----------

The table 4.3 is response table for signal to nose ratios. It shows the larger the better class performance which was adopted for our study. From the data shown in the table we can clearly conclude that the most influential factor on tensile strength based on S/N ratios are mold temperature, because it has the highest delta value which is 0.23.

Table 4. 3: Response Table for Signal to Nose Ratios

لاك Respons UNI Larger is b	ی ملیسیا ما e <b>Table for !</b> VERSITI TE etter	نيكر Signal to KNIKAL	ي نيڪ Noise Rat MALAYS	وفر سيخ tios SIA MELA	اوي KA
Level Coo	ling Time Pacl	ا king Time	njection Speed Ter	Mold F npateture P	Packing ressure
1	30.47	30.51	30.57	30.40	30.51
2	30.56	30.52	30.46	30.63	30.53
Delta	0.09	0.01	0.11	0.23	0.02
Rank	3	5	2	1	4

The table 4.4 is response table mean. It shows the larger the better class performance which was adopted for our study. From the data shown in the table we can clearly conclude that the most influential factor on tensile strength based on means are mold temperature, because it has the highest delta value which is 0.87.

Respons	e Table for I	Means			
		li	njection	Mold	Packing
Level Coo	ling Time Pack	king Time	Speed	Tempateture	Pressure
1	33.39	33.55	33.78	33.13	33.53
2	33.75	33.59	33.35	34.00	33.60
Delta	0.36	0.04	0.43	0.87	0.07
Rank	3	5	2	1	4

A high signal-to-noise ratios shows that the signal is much stronger than the erratic impact of noise elements. The part or process activity with the highest S/N ratios yields optimal quality attributes with the least variation.

In this analysis, the level of factor with the higher S/N ratios indicates that this level can result in a higher modulus and quality of tensile strength for the dogbone product. The arrangement of appropriate levels of processing parameters can be evaluated by selecting the level with the highest S/N ratios for each factor.



Figure 4. 10: Main Effects Plot for SN ratios

# 4.2.2 Analyze Data Using ANOVA

The purpose of ANOVA is to identify the main process parameters influencing the tensile strength of 70:30 virgin-regrind Polypropylene (PP) plastic material. The study allows us to determine which parameters are most significant in terms of tensile strength. As a result, these parameters should be closely controlled during the process of producing 70:30 virgin-regrind Polypropylene (PP) products with high tensile strength.

Source	DF	Seq SS	Adj SS	Adj MS	F	Р	Contribution %	Rank
Cooling Time	1	0.017581	0.0176	0.0176	3.05	0.223	12.1 %	3
Packing Time	1	0.000178	0.0002	0.0002	0.03	0.877	0.1 %	5
Injection Speed	MAL	0.02423	0.0242	0.0242	4.2	0.177	16.6 %	2
Mold Temperature	1	0.102881	0.1029	0.1029	17.84	0.052	70.7 %	1
Packing Pressure	1	0.000726	0.0007	0.0007	0.13	0.757	0.5 %	4
Residual Error	2	0.011532	0.0115	0.0058				
Total	7	0.157129						

The S/N ratios derived from ANOVA analysis are shown in table 4.5 above. If P value is equal to or less than 0.1, the factor is considered significant. However, if the P value is greater than 0.1, the factor is considered insignificant. According to the data, the most significant factor is Mold Temperature (P=0.052), which has the lowest P value.

Table 4. 6: Analysis of Variance for Means

Source	DF	Seq SS	Adj SS	Adj SS	F	Р	Contribution %	Rank
Cooling Time	1	0.26615	0.0176	0.2662	3.02	0.225	12.2 %	3
Packing Time	1	0.0034	0.0002	0.0034	0.04	0.863	0.2 %	5
Injection Speed	1	0.37154	0.0242	0.3715	4.21	0.177	17 %	2
Mold Temperature	1	1.52801	0.1029	1.528	17.31	0.053	70.1 %	1
Packing Pressure	1	0.01069	0.0007	0.0107	0.12	0.761	0.5 %	4
Residual Error	2	0.17654	0.0115	0.1765				
Total	7	2.35633						

The table 4.6 above shows the data analysis of variance for means. If P value is equal or less than 0.1, the factor is considered significant. However, if P value is greater than 0.1, the factor is considered insignificant. According to the data, the most significant factor is Mold Temperature (0.053), which has the lowest P value.

#### 4.2.3 Predicted Results

Based on both graphs S/N ratios and means and with choosing the characteristic the larger the better, the optimal processing parameters for 70:30 virgin-regrind Polypropylene (PP) which are predicted to give the highest tensile strength are identified as A2B2C1D2E2. Factor A (Cooling Time) should be set at level 2(15s), B (Packing Time) should be set at level 2(10s), C (Injection Speed) should be set at level 1(10mm/s), D (Mold temperature) should be set at level 2(50C), E (Packing Pressure) should be set at level 2(110Mpa). Figure 4.11 shows the predicted value of tensile strength at optimum parameters obtained using MiniTab software, which is 34.46Mpa.

Prediction	کل ملیہ	کنید	سيتي تيە	اونيوس
S/N Ratio N 30.7453 34.	4596 TEKNIK	CAL MA	LAYSIAN	IELAKA
Settings				
Settings		Injection	Mold	Packing
Settings Cooling Time	Packing Time	Injection Speed	Mold Tempateture	Packing Pressure
Settings Cooling Time	Packing Time	Injection Speed	Mold Tempateture 2	Packing Pressure 2

Figure 4. 11: Predicted Results

## 4.3 Taguchi VS ANOVA Results

The purpose of comparing Taguchi and ANOVA rank results is to see if both methods produce similar results. This is the experiment's final step. Both methods were utilized to find the most significant factor in optimizing the parameters of the plastic injection molding process. The ranking objective is to illustrate which factor has the greatest influence on the other elements. Following an examination of both methodologies discovered that Taguchi and ANOVA yielded the same rank. Furthermore, the optimal parameters for higher tensile strength are identified as A2B2C1D2E2. Factor A (Cooling Time) should be set on level 2(10s), C (Injection Speed) should be set on level 1(10mm/s), D (Mold temperature) should be set on level 2(50C), E (Packing Pressure) should be set on level 2(110Mpa

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#### **Chapter 5: Conclusion and Recommendations**

### 5.0 Introduction

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This chapter will summarize the findings in reaching the study's objectives and make recommendations for future study improvements.5.1 Conclusion

### 5.1 Conclusion

The tensile strength of 70:30 virgin-regrind Polypropylene (PP) was tested at various injection molding parameters. Cooling time (s), packing time (s), injection speed (mm/s), mold temperature (C), and packing pressure (Mpa) are the five parameters . Taguchi's orthogonal array was used to study them. Based on the experimental and analytical data, the following conclusions are reached:

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- 1- The ANOVA approach was applied to evaluate the effect of process parameters on tensile strength. The data show that the most significant factor is mold temperature; the other factors, injection speed, packing time, cooling time, packing pressure, and packing time, are insignificant.
- 2- According to Taguchi method and ANOVA, the ranking of process parameters based on the effect on tensile strength is mold temperature first, followed by injection speed, packing time, cooling time, packing pressure, and packing time.
- 3- The injection molding processing parameters that maximize the tensile strength of 70:30 virgin-regrind Polypropylene (PP) plastic have been determined. Cooling time at

level 2 which is 15s (A2), packing time at level 2 which is 10s (B2), injection speed at level 1 which is 10mm/s (C1), mold temperature at level 2 which is 50C (D2), and packing pressure at level 2 which is 110Mpa (E2) are the optimal process parameters.

4- The predicted value of tensile strength at optimum parameters (A2B2C1D2E2) is obtained using MiniTab software, and it is equal to 34.3596 Mpa.

## 5.2 Recommendation

At the end of this project, we can recommend that blended Polypropylene 70:30 virgin-regrind can be employed instead of virgin Polypropylene because the tensile strength of blended material was discovered to be greater than the tensile strength of virgin material. Furthermore, this contributes to environmental preservation and lowers production costs, resulting in products that are less expensive, more environmentally friendly, and stronger.



# Appendix 1: Gantt Chart 1

PSM 1 GANTT CHART																
PSM 1 GANTT CHART		VA/ 1	w 2	14/2	14/4		MIC	14/7	14/0	14/0	W10	14/11	W/13	14/12	N/1 /	
Activities		~ 1	VV 2	vv 5	VV4	005	VV O	VV /	vvð	vv9	VV 10	**11	VV 12	VV 13	VV 14	
TASK 1:	PLAN															
Finding Research Paper and Reading.	ACTUAL															
TASK 2:	PLAN		1													
Draft Chapter 1: Introduction	ACTUAL		1													
TASK 3:	PLAN		1													
Draft Chapter 2: Literature Review	ACTUAL		1													
TASK 4:	PLAN															
Check with The Supervisor	ACTUAL		1													
TASK 5:	PLAN															
Draft Chapter3: Methodology	ACTUAL		1													
TASK 6:	PLAN		1													
preliminary Submission	ACTUAL		     													
TASK 7:	PLAN		1													
Final Report	ACTUAL															
TASK 8:	PLAN															
Slide Presentation A S 3	ACTUAL															
TASK 9:	PLAN															
Video Presentation	ACTUAL									1						

# Figure 3. 10 Gantt Chart PSM 1

# **Appendix 2: Gantt Chart**

PSM 2 GANTT CHART	6		6		1. A.	- 44										
PSM 2 GANTT CHART		w1	W 2	W3	W4	W5	W6	W7	W8	W9	w10	w11	W12	W13	W14	
Activities						4.9										
UTASK1:/ERSITI TE	PLAN	ΔL	Μ	AL	A	'S	A	ME	Ξ.	٩K	A					
Run the experiments and collect data	ACTUAL															
TASK 2:	PLAN		1													
Draft chapter 4 with analyses	ACTUAL															
TASK 3:	PLAN		1													
Draft chapter 5	ACTUAL															
TASK 4:	PLAN		1													
Make improvements	ACTUAL															
TASK 5:	PLAN		1													
Final Writing	ACTUAL		1													
TASK 6:	PLAN		1													
Final presentation	ACTUAL		1													
TASK 7:	PLAN		1													
Final submission	ACTUAL		1													

Figure 3. 11 Gantt Chart PSM 2

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