A STUDY ON THE EFFECT OF INJECTION MOULDING PROCESS PARAMETERS TO THE PROPERTIES OF INJECTED PARTS.

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A report submitted in fulfillment of the requirement for the award of the Degree of Bachelor of Mechanical Engineering with Manufacturing Engineering

Faculty of Mechanical Engineering
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DECEMBER 2010

SUPERVISOR DECLARATION

I hereby declare that I have checked this project and in my opinion this project is adequate in terms of scope and quality for the award of the Degree of Bachelor of Mechanical Engineering with Manufacturing Engineering.

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STUDENT DECLARATION

I hereby declare that the work in this report entitled "A study on the effect of injection moulding process parameters to the properties of the injected parts" is my own except for the quotations and summaries which have been duly acknowledged. The report has not been accepted for any degree and is not concurrently submitted for award of any other degree.

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DEDICATION

Encik Syed Hamid Bin Syed Ahmad

Puan Azlah Dalilah Binti Mohamad

and

beloved sisters and brother

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ABSTRACT

Plastic has, quite literally, become the cornerstone of our society. We make so many things from plastic that it is hard to imagine what our lives would be like if it was never invented. The value of parameters should be correct and exact so that the good and quality of product can be produced. The objective for this project is to study the effects of injection parameters which are temperature, pressure and volume to the mechanical properties of the injected parts. Besides that, it also to determine the optimum amount of pressure, temperature and volume at the injection machine in producing document tray. In order to achieve the objectives, the scopes of studies are performed which is the study will be using a polymer material which is Samsung Starex® SD-0150GP High Impact Grade ABS. Besides that, only pressure, temperature and volume will be varied in this study while other parameter for instant clamping unit is fixed constant. The project can be divided into 4 stages. Firstly, is the preparation of the material. Then, injection moulding machine is used to produce document tray with the parameter that control the process which is temperature (220 ^{o}C, 230 ^{o}C, 240 ^{o}C), pressure (1675 bar, 1700 bar, 1725 bar) and volume (340 cm^3, 350 cm^3, 360 cm^3). There are 27 samples produced by using full factorial method. After the samples are produced, there will be some testing for the samples such as mechanical testing such as tensile test and hardness test and physical testing such as density test. Lastly, analysis to determine the best and high quality of the samples was done. All the data obtained can be analyze and evaluate to produce the best optimum parameter for the injected part produce. As a result, the best injected part produced is sample number 10 which has good properties and optimum parameter is temperature at 230 ^{o}C, pressure at 1675 bar and volume at 340 cm^3. It gives the low value of mass, low value of density, high of strength-to-weight ratio, high value of maximum strength and high value of hardness.

ABSTRAK

Plastik secara amnya telah menjadi landasan dalam masyarakat hari ini. Pelbagai jenis barangan yang dihasilkan daripada plastik hari ini sehingga tidak dapat digambarkan kehidupan seharian tanpa barangan daripada plastik jika plastik tidak diciptakan. Nilai-nilai parameter perlulah betul dan tepat supaya produk yang akan dihasilkan akan mempunyai kualiti yang tinggi dan bagus. Tujuan projek ini adalah untuk mempelajari pengaruh parameter injeksi terhadap suhu, tekanan dan isipadu terhadap sifat mekanikal dari produk yang disuntik. Selain itu, ia juga untuk menentukan jumlah optimum suhu, tekanan dan isipadu pada mesin injeksi dalam menghasilkan bekas simpanan dokumen. Dalam rangka mencapai tujuan, ruang lingkup kajian yang dilakukan dalam kajian ini akan menggunakan bahan polimer yang sama iaitu Samsung starex ® SD-0150GP Grade High Impact ABS. Selain itu hanya nilai suhu, tekanan dan isipadu akan divariasikan dalam kajian ini sedangkan parameter lain seperti unit klem adalah pada nilai yang tetap. Penghasilan projek ini dapat dibagi kepada 4 tahap. Pertama, adalah persiapan bahan mentah untuk produk suntikan. Kemudian, mesin suntikan acuan plastik digunakan untuk menghasilkan bekas simpanan dokumen dengan parameter yang diuji iaitu suhu (220 ^{o}C, 230 ^{o}C, 240 ^{o}C), tekanan (1675 bar, 1700 bar, 1725 bar) dan isipadu (340 cm^{3}, 350 cm^{3}, 360 cm^{3}). Sebanyak 27 sampel dihasilkan dengan menggunakan kaedah pengfaktoran lengkap. Setelah sampel dapat dihasilkan, akan ada beberapa ujian untuk sampel seperti ujian mekanikal seperti ujian tarik dan ujian kekerasan dan ujian fizikal seperti ujian kepadatan. Selepas itu, analisis untuk menentukan kualiti terbaik dan bagus dari sampel dilakukan. Semua data yang diperolehi boleh dianalisi dan dinilai untuk menghasilkan parameter optimum yang terbaik untuk produk suntikan yang dihasilkan. Sebagai keputusannya, bahagian disuntik terbaik yang dihasilkan adalah sampel nombor 10 yang memiliki kulaiti yang baik dan parameter yang optimum iaitu pada suhu pada 230 ^{o}C, tekanan pada 1675 bar dan isipadu 340 cm^{3}. Ia memberikan nilai jisim yang rendah, nilai kepadatan yang rendah, nilai nisbah yang tinggi dalam kekuatan terhadap berat, nilai kekuatan maksimum yang tinggi dan nilai kekerasan yang tinggi.

UNIVERSITI MALAYSIA PAHANG

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We certify that the project entitled "A study on the effect of injection moulding process parameters to the properties of the injected part" is written by Sharifah Rafidah Binti Syed Hamid. We have examined the final copy of this project and in our opinion; it is fully adequate in terms of scope and quality for the award of the degree of Bachelor of Engineering. We herewith recommend that it be accepted in partial fulfillment of the requirements for the degree of Bachelor of Mechanical Engineering with Manufacturing Engineering.

(Mr. Jasri Bin Mohamad) ……………………………

Examiner Signature

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LIST OF EQUATION

LIST OF SYMBOLS

^{o}C	degree Celsius
cm^3	centi meter cube
m^3	meter cube
HV	hardness Vickers
g	gram
kg	kilogram
gf	gram force
MPa	mega Pascal
kN	kilo Newton
L	litre
mL	mililitre

LIST OF ABBREVIATIONS

ABS	Acrylonitrile-Butadiene-Styrene

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Injection is the most important plastics manufacturing process. Injection moulding can be used to form a wide variety of products. It produces such small products as bottle tops, children's toys and containers. It is also used to manufacture larger items such as dustbins, and milk crates. Complexity is virtually unlimited, sizes may range from very small to very large, and excellent control of tolerances is also possible. The developing of injection moulding becomes a competition from day to day. The process now integrated with computer control make the production better in quality and better quality.

In producing product by injection moulding process, the quality of the product is very important. The product should be good in physical and mechanical properties in order to have a good performance for consumer. Clearly, more manufacturers only care about appearance of the product, but to have long usage in term of life of that product, the mechanical properties such as tensile strength, hardness also important. Nowadays, there are lots methods for manufacturers to test their product so that they will improve and produce a better and good quality of product. It is important because of customer needs, requirements and expectations change over time besides, the manufacturer also have t o win market shares that it will hang longer in the industry.

1.2 PROBLEM STATEMENTS

Numerous variables affect the injection moulding process. In fact, a recent study itemized more than 200 different parameters that had direct or indirect effect on the process. So there is no preliminary study is conducted prior to the production of injection process based on certain parameter which is pressure, temperature and volume.

For every parameter that will be change, there were always producing a different quality of product in terms of properties. Different value of mechanical or physical properties found in producing part by using injection machine with different value of each parameter. Hence, the result is variety to investigate using a few types of testing method by manual calculation or automatically generate by the software. The best sample is chosen to determine the optimum parameter which is has high quality in its properties.

1.3 OBJECTIVES OF STUDIES

The main objectives for this project are:

i. To study the effects of injection parameters which are temperature, pressure and volume to the mechanical properties of the injected parts.
ii. To determine the optimum amount of pressure, temperature and volume at the injection machine in producing document tray.

1.4 SCOPE OF STUDIES

In order to achieve the objectives, the following scopes of studies are performed:

i. The study will be using a polymer material which is Samsung Starex® SD-0150GP High Impact Grade ABS.
ii. Only pressure, temperature and volume will be varied in this study while other parameter for instant clamping unit is fixed constant.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This chapter provides a review of the concept of injected parts and methods of parts developments. This chapter also relates how parts were produced by using specific tools that provided in the laboratory. Besides that, this chapter also includes the information about parameter involves and the material that used in this project. The injected parts also are chosen so that the sample can be taken nicely to do some analysis.

2.2 HISTORY OF INJECTION MOULDING

Injection is a manufacturing process for producing parts from both thermoplastic and thermosetting plastic materials. Material is fed into a heated barrel, mixed, and forced into a mold cavity where it cools and hardens to the configuration of the mold cavity. After a product is designed, usually by an industrial designer or an engineer, molds are made by a mould maker or toolmaker from metal, usually either steel or aluminium, and precision-machined to form the features of the desired part. Injection moulding is widely used for manufacturing a variety of parts, from the smallest component to entire body panels of cars. (Todd, 1994)

An Injection moulding machine, also known as an injection press, is a machine for manufacturing plastic products by the injection moulding process. It consists of two main parts, an injection unit and a clamping unit. Injection moulding machines can fasten the molds in either a horizontal or vertical position. The majority of machines are horizontally oriented, but vertical machines are used in some niche applications such as insert moulding, allowing the machine to take advantage of gravity.

The first man-made plastic was invented in Britain in 1851 by Alexander Parkes. He publicly demonstrated it at the 1862 International Exhibition in London; calling the material he produced "Parkesine." Derived from cellulose, Parkesine could be heated, molded, and retain its shape when cooled. It was, however, expensive to produce, prone to cracking, and highly flammable.

In 1868, American inventor John Wesley Hyatt developed a plastic material he named Celluloid, improving on Parkes' invention so that it could be processed into finished form. Together with his brother Isaiah, Hyatt patented the first injection moulding machine in 1872. This machine was relatively simple compared to machines in use today. It worked like a large hypodermic needle, using a plunger to inject plastic through a heated cylinder into a mold. The industry progressed slowly over the years, producing products such as collar stays, buttons, and hair combs. (U.S. patent, 1872)

The industry expanded rapidly in the 1940s because World War II created a huge demand for inexpensive, mass-produced products. In 1946, American inventor James Watson Hendry built the first screw injection machine, which allowed much more precise control over the speed of injection and the quality of articles produced. This machine also allowed material to be mixed before injection, so that colored or recycled plastic could be added to virgin material and mixed thoroughly before being injected. Today screw injection machines account for the vast majority of all injection machines. In the 1970s, Hendry went on to develop the first gas-assisted injection moulding process, which permitted the production of complex, hollow articles that cooled quickly. This greatly improved design flexibility as well as the strength and finish of manufactured parts while reducing production time, cost, weight and waste.

The plastic injection moulding industry has evolved over the years from producing combs and buttons to producing a vast array of products for many industries including automotive, medical, aerospace and consumer products. (Douglas, 1996)

2.3 INJECTION MOULDING MACHINE

For thermoplastics, the injection moulding machine converts granular or pelleted raw plastic into final molded parts via a melt, inject, pack, and cool cycle. A typical injection moulding machine consists of the following major components:

i. Injection system
ii. Hydraulic system
iii. Mold system
iv. Clamping system
v. Control system

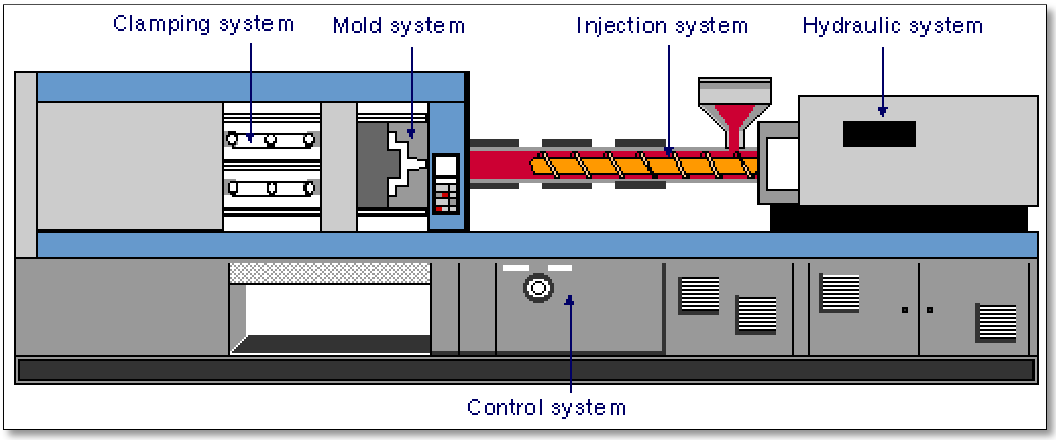

Figure 2.1: Injection moulding machine for thermoplastics.

For the machine specification, the clamping tonnage and shot size are commonly used to quickly identify the size of the injection moulding machine for thermoplastics. Other parameters include injection rate, injection pressure, screw design, mold thickness, and the distance between tie bars. The major equipment auxiliary to an injection moulding machine includes resin dryers, materials-handling equipment, granulators, mold-temperature controllers and chillers, part-removal robots, and part-handling equipment. Injection moulding machines can be generally classified into three categories, based on machine function which are:

i. General-purpose machines
ii. Precision, tight-tolerance machines
iii. High-speed, thin-wall machines

2.3.1 Injection system

The injection system consists of a hopper, a reciprocating screw and barrel assembly, and an injection nozzle, as shown in Figure 2.2. This system confines and transports the plastic as it progresses through the feeding, compressing, degassing, melting, injection, and packing stages.

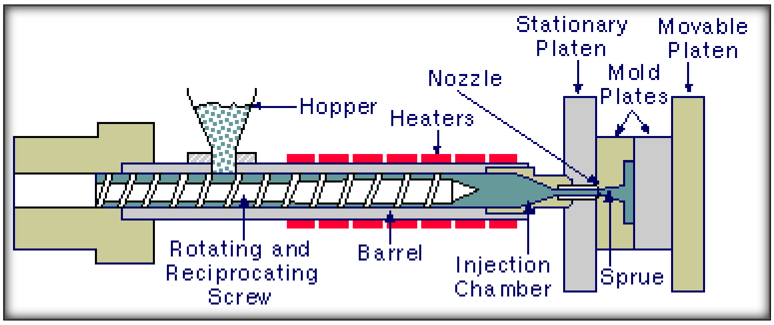

Figure 2.2: A single screw injection moulding machine

i. The hopper

Thermoplastic material is supplied to molders in the form of small pellets. The hopper on the injection moulding machine holds these pellets. The pellets are gravity-fed from the hopper through the hopper throat into the barrel and screw assembly.

ii. The barrel

As shown in Figure 2.2, the barrel of the injection moulding machine supports the reciprocating plasticizing screw. It is heated by the electric heater bands.

iii. The reciprocating screw

It is used to compress, melt, and convey the material. While the outside diameter of the screw remains constant, the depth of the flights on the reciprocating screw decreases from the feed zone to the beginning of the metering zone. These flights compress the material against the inside diameter of the barrel, which creates viscous heat. This shear heat is mainly responsible for melting the material. The heater bands outside the barrel help maintain the material in the molten state. Typically, a moulding machine can have three or more heater bands or zones with different temperature settings.

iv. The reciprocating screw consist of three zones which are:

- the feeding zone
- the compressing or transition zone
- the metering zone

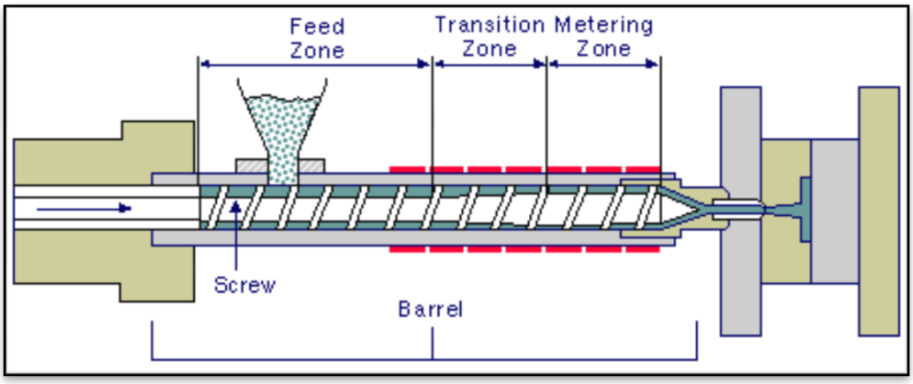

Figure 2.3: A reciprocating screw

v. The nozzle

It connects the barrel to the sprue bushing of the mold and forms a seal between the barrel and the mold. The temperature of the nozzle should be set to the material's melt temperature or just below it, depending on the recommendation of the material supplier. When the barrel is in its full forward processing position, the radius of the nozzle should nest and seal in the concave radius in the sprue bushing with a locating ring. During purging of the barrel, the barrel backs out from the sprue, so the purging compounds can free fall from the nozzle. These two barrel positions are illustrated below.

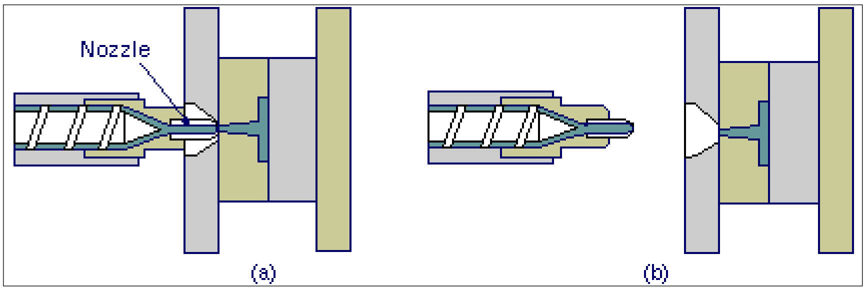

Figure 2.4: Nozzle with barrel in processing position (a) and nozzle with barrel backed out for purging (b).

Source: Capetronics (2009)

2.3.2 Mold system

The mold system consists of tie bars, stationary and moving platens, as well as moulding plates that house the cavity, sprue and runner systems, ejector pins, and cooling channels, as shown in Figure 2.5. The mold is essentially a heat exchanger in which the molten thermoplastic solidifies to the desired shape and dimensional details defined by the cavity.

A mold system is an assembly of platens and moulding plates typically made of tool steel. The mold system shapes the plastics inside the mold cavity (or matrix of cavities) and ejects the molded part. The stationary platen is attached to the barrel side of the machine and is connected to the moving platen by the tie bars. The cavity plate is generally mounted on the stationary platen and houses the injection nozzle. The core plate moves with the moving platen guided by the tie bars. Occasionally, the cavity plate is mounted to the moving platen and the core plate and a hydraulic knock-out (ejector) system is mounted to the stationary platen. (Capetronics, 2009)

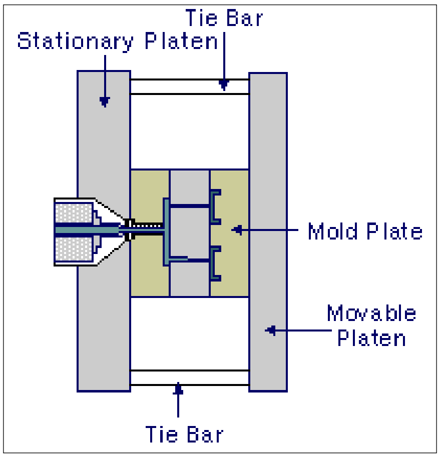

Figure 2.5: A typical (three-plate) moulding system.

i. Two plate mold

The vast majority of molds consist essentially of two halves, as shown below. This kind of mold is used for parts that are typically gated on or around their edge, with the runner in the same mold plate as the cavity.

ii. Three plate mold

The three-plate mold is typically used for parts that are gated away from their edge. The runner is in two plates, separate from the cavity and core, as shown in Figure 2.6 below.

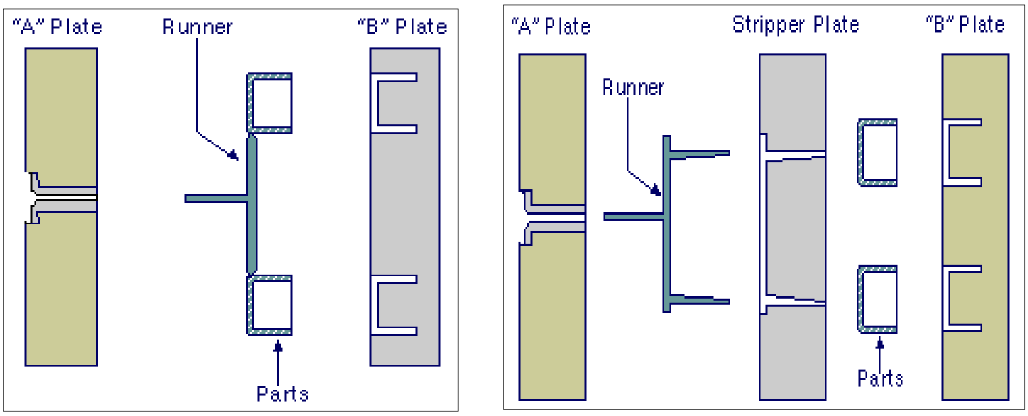

Figure 2.6: (Left) A two-plate mold. (Right) A three-plate mold.

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Source: Capetronics (2009)

2.3.3 Molded system

A typical molded system consists of the delivery system and the molded parts as shown in Figure 2.7**.**

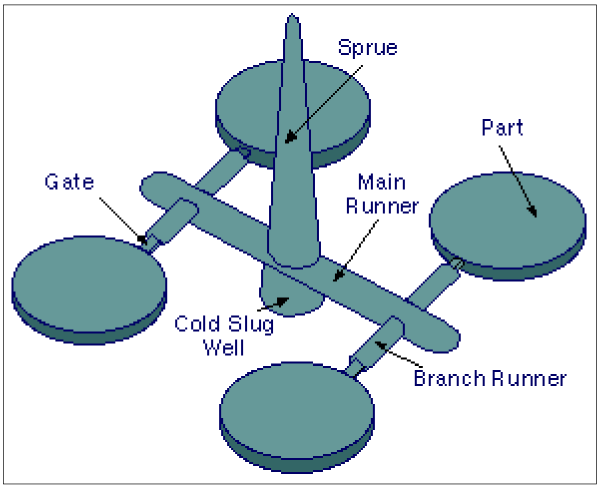

Figure 2.7: The molded system includes a delivery system and molded parts.

The delivery system design has a great influence on the filling pattern and thus the quality of the molded part. The delivery system, which provides passage for the molten plastic from the machine nozzle to the part cavity, generally includes:

i. a sprue
ii. cold slug wells
iii. a main runner
iv. branch runners
v. gates

2.3.3.1 Cold runners

After moulding, the cold-runner delivery system is trimmed off and recycled. Therefore, the delivery system is normally designed to consume minimum material, while maintaining the function of delivering molten plastic to the cavity in a desirable pattern.

2.3.3.2 Hot runners

The hot-runner or runnerless moulding process keeps the runners hot in order to maintain the plastic in a molten state at all times. Since the hot-runner system is not removed from the mold with the molded part, it saves material and eliminates the secondary trimming process.

2.3.4 Cooling channels

Cooling channels are passageways located within the body of a mold, through which a cooling medium (typically water, steam, or oil) circulates. Their function is the regulation of temperature on the mold surface. Cooling channels can also be combined with other temperature control devices, like bafflers, bubblers, and thermal pins or heat pipes.

2.3.5 Hydraulic system

The hydraulic system on the injection moulding machine provides the power to open and close the mold, build and hold the clamping tonnage, turn the reciprocating screw, drive the reciprocating screw, and energize ejector pins and moving mold cores. A number of hydraulic components are required to provide these powers, which include pumps, valves, hydraulic motors, hydraulic fittings, hydraulic tubing, and hydraulic reservoirs.

2.3.6 Control system

The control system provides consistency and repeatability in machine operation. It monitors and controls the processing parameters, including the temperature, pressure, injection speed, screw speed and position, and hydraulic position. The process control has a direct impact on the final part quality and the economics of the process. Process control systems can range from a simple relay on/off control to an extremely sophisticated microprocessor-based, closed-loop control.

2.3.7 Clamping system

The clamping system opens and closes the mold, supports and carries the constituent parts of the mold, and generates sufficient force to prevent the mold from opening. Clamping force can be generated by a mechanical (toggle) lock, hydraulic lock, or a combination of the two basic types. (Capetronics, 2009)

2.4 INJECTION MOULDING PROCESS

Before using the injection machine directly, the student should master and know how to handle the machine well. The student did some appointment with the Lab Instructor that incharge for the injection moulding machine which is Encik Khairul Aziha. He will explain and teach the student how to operate and handle the injection machine.

2.4.1 Safety Equipment

The most important part of operating an injection machine is safety. The equipment manufacturer should provide safety rules and requirements pertaining to specific piece of equipment, including a comprehensive safety checklist. This checklist is usually found in the operating manual of the injection machine. Safety rules, requirements, operation conditions and practices set forth by the equipment manufacturer should take precedence over all recommendations in this document.

There are many items that must be inspected prior to running the injection process. First, make a visual inspection to determine that all safety guards are in place and have not been tampered with or bypassed. Perform a physical check of all safety circuits, safety doors, emergency stops, limit switch safeties and overrides. In most cases, it is recommended that a prestart checklist be developed to assure that all the safety equipment has been inspected.

It is important that the machine and surrounding area is kept clean and free of clutter; housekeeping is often overlooked as a safety item. It is also recommended that a good preventive maintenance program be established and followed to keep the equipment in safe and proper working order and all checks are properly documented.

2.4.2 Powering up

Before the machine can be run, the machine needs to be on correctly so that no damages occur to the injection machine. Firstly, when turning on electrical power to the machine, set the temperature controllers to the operating conditions shown on the machine run sheet. If the machine does not have a run sheet, follow the instructions in the extruder section of this guide. Temperature controllers should be periodically checked for proper performance during both the power up and operation stages. At this point, ensure that the cooling water is on and that it is flowing to the feed throat.

Never allow the extruder to come up to temperature without cooling to the feed throat. Without cooling, the material at the feed throat could melt and cause an obstruction (bridging). Insure that all zones are coming up to temperature and that no zones are overriding. Once the machine has reached its set temperatures, then it should be allowed to come to equilibrium before any material is introduced into the extruder.

Never start up an extruder until temperatures have reached their set points and the system is allowed to soak until the melt or stock temperature is well above the melting point for the selected material.

2.4.3 Process cycle

The injection process has normally six steps that basically done to run the injection machine. Here are the steps that can be cycle to produce the samples.

i. The machine has three parts which is the mold, the clamp and the injection unit. Firstly, for the clamping units, it holds the mold at a certain pressure. This will ensure uniformity in the units that are outputted. Molds are normally made from two parts.

ii. Then, for the injection unit, the plastic pellets are loaded into a hopper at the top of the injection unit. The pellets are fed into the main cylinder where they are heated until they are liquefied. Inside the injection unit there is a screw which turns and mixes the plastic. Once this liquid plastic has reached the optimum for this product the injection process starts. The plastic is forced through a sprue and the pressure and speed are controlled by the screw or sometimes a ram depending on the type of machine.

iii. Next is dwelling. This is a pause in the process while some pressure is applied to ensure all the mold cavities have been completely filled. This is very important within the process as it will result in scrap of units if the mold is not filled correctly.

iv. Next, it is cooling process. This part of the process lets the mold cool for the required period. If it is done too quickly the units can stick or become deformed once out of the machine.

v. For the mold opens section, the clamping unit is opened to separate the mold. Molds are used over and over again and they are often the most important single part in the whole process. The tooling of mold can be very expensive.

vi. Lastly for the ejection section, the finished product is ejected from the injection mold machine. Often the finished product will continue on a production line or be stacked to go to a production line as parts for larger products. (Douglas, 1996)

2.5 PARAMETERS IN INJECTION MOULDING PROCESS

There are few parameters that involve in injection moulding process such as temperature, pressure and volume. These parameters will used to determine the optimum value to produce a high quality of product.

2.5.1 Temperature

A variety of temperature affect the injection process ranging from melt temperature to mold temperature and including the ambient temperature.

i. Melt temperature is the temperature at which plastic material is maintained throughout the flow path. This path begins where the plastic material is transferred from the machine hopper into the heating cylinder of the injection unit. Then the material is augered through the heating cylinder and into the machine nozzle. From there it is injected into the mold where it must travel along a runner system through the gates, and into the cavities that are machined into the mold. The temperature of the melt must be controlled all along the path starting with the heating cylinder.

ii. Mold temperature is when the plastic material is now ready to flow into the mold. First, it must travel through the machine nozzle which is the last heating zone provide by the machine. After the material exits the nozzle and enters the mold, it immediately begins to cool down as the mold absorbs heat from it. The rate at which this heat is absorbed determines how far the plastic will flow before it begins to solidify and stop moving. Each product depending on its design and plastic material, demands specific cooling rates and this rate of cooling is critical to product quality. Therefore, the mold temperature must be regulated in order to regulate the cooling rate of the plastic. This is done by connecting the mold to a temperature control unit that normally utilizes water as medium. The water is circulated through the mold and held at preset temperature by heating or cooling in cycles.

iii. Ambient temperature is also a concern. A particular job may be running perfectly well until someone opens a loading dock door or turns a cooling fan in the vicinity of the press. This causes a change in the temperature of the air surrounding the machine and this, in turn, results in fluctuations in the readings provided by the various temperature control units of the machine. The injection process then becomes unstable for a period of approximately 2 hours, assuming the ambient conditions. If more changes do occur, the process is unstable for longer periods of time. (Douglas, 1996)

2.5.2 Pressure

There are two areas in the injection machine that requires pressure and pressure control; the injection unit and the clamping unit. They are closely related in that they are opposing pressures which is the clamp unit must develop enough clamp pressure to overcome the pressure developed by the injection unit during the process.

i. Initial injection pressure

This is the first pressure that is applied to the molten plastic. It develops as the result of main system hydraulic pressure pushing against the back end of the injection screw.

The amount pressure developed by the main system is on the order of 2000 psi (13,789 kPa). Some systems are capable of producing more than that but 2000 psi is the most common line pressure. This pressure is converted to a maximum of 20, 000 psi at the nozzle of the injection unit where the plastic first enters the mould by the design and the shape on the injection screw. In most cases, the full 20,000 psi is not required for filling a mould, and most products can be moulded in range of from 5000 psi to 15,000 psi. The pressure actually required depends on the plastic being moulded, the viscosity and the flow rate of the plastic and the temperatures of the plastic and the mould.

The ideal solution is to be able to fill the mould initially with the highest practical pressure in the shortest practical time. Normally, the initial fill can be accomplished in less than 3 second. Note than even though the highest practical should be used, a constant effort should be made to keep that practical pressure requirement low so molded in stresses are minimized.

To summarized, initial injection pressure is used to create the initial filling of the mould. It should be set at the highest practical value to fill the mould with the fastest practical speed.

ii. Holding pressure

This pressure is applied at the end of the initial injection stroke and is intended to complete the final filling of the mould and hold pressure against the plastic that was injected so it can solidify while staying dense and packed. As a rule, the mount of the pressure used here can be half the initial injection pressure or less. So if initial pressure was 12,000 psi, the holding pressure can be approximately 6000 psi. The holding pressure is actually applied against a cushion or pad of material. To summarize, holding pressure is used to finish the filling of the mold and pack the plastic material into the cavity image.

iii. Back pressure

Back pressure is applied after the injection phases mentioned above. When the hold pressure phase is completed, a signal is sent to the machine to start turning the screw to bring new material to the front of the barrel in preparation for the next cycle or shot. The screw is not pulled back. Instead the churning or augering action of the screw brings new material forward and as the material fills up in front of the screw, the material itself begins to push the screw backward.

The back pressure as small compared to the injection pressure. A minimum of 50 psi and maximum of 500 psi pressure is required. The proper method of determining the amount of back pressure is to begin 50 psi and increase, only if necessary, in increment of 10 psi until the proper mix and density are achieved. Use of back pressure helps ensure consistency in part weight, density and material appearance. It also helps to squeeze out any trapped air or moisture not eliminate by predrying the material. This minimizes voids in the molded product, if less than 50 psi back pressure is attempted the controls and gages are neither consistent nor accurate enough to maintain or indicate the actual pressure being developed. Thus, faulty readings and setting can occur. If more than 500 psi back pressure is attempted, the screw may not return at all or it will stay forward much too long and the plastic material will degrade under the extreme shear imparted to it from the continue churning action the screw. In the case of reinforced plastics, the reinforcement material will break down and this result in much less strength than is required in the molded product. (Douglas, 1996)

2.5.3 Injection volume

The injection volume or shot capacity or stroke volume is the product of the feeding stroke multiplied by the cross sectional area of the piston. It is listed in the

European size indication and refers to the maximum possible design displacement of the reciprocating screw.

The injection volume is generally considered to be the most important performance indicator of an injection machine that listed in the machine data sheets, but it will be shown that this value needs to be critically analyzed.

If it is accepted that feeding strokes longer than 3 time diameter of the screw are impractical because of the substantial risk of quality impairment. It is possible to make consistent statements about the injection volume based solely on screw diameter and the strokes of 3 time diameter for all commercial machines (Douglas, 1996)

2.6 MATERIAL USED

In this project, the sample that will be used is Samsung Starex® ABS SD0150GP High Impact Grade. It is a subcategory of ABS Polymer, Polymer and Thermoplastic. The term ABS was originally used a general term to described various blends and copolymers containing acrylonitrile, butadiene and styrene. Although tough enough for many uses, styrene acrylonitrile copolymers are inadequate in this respect for other purpose. As a consequence, a range of materials popularly referred to as ABS polymers first became available in the early 1950s. The reasons for its widespread acceptance are stated below. (John, 2000)

i. High impact resistance
ii. Good stiffness
iii. Excellent surface quality
iv. High dimensional stability at elevated temperatures
v. Good chemical resistance
vi. Good stress cracking resistance

The properties table for Samsung Starex® ABS SD-0150GP is given at the appendix B.

2.7 PRODUCT

The product for this project is document tray. This product is usually is at the office or education purpose. The function of this product is as the storage for the papers, thin book or paper work. This product needs to look attractive for marketing purpose and it is usually located on the table. Figure 2.8 shows the product of this project which is document tray.

Figure 2.8: Injected part: Document tray

2.8 THERMOPLASTIC BEHAVIOUR

2.8.1 Ductile fracture

One of the most important and key concepts in the entire field of Materials Science and Engineering is fracture. In its simplest form, fracture can be described as a single body being separated into pieces by an imposed stress. For engineering materials there are only two possible modes of fracture, ductile and brittle. In general, the main difference between brittle and ductile fracture can be attributed to the amount of plastic deformation that the material undergoes before fracture occurs. Ductile materials demonstrate large amounts of plastic deformation. (Callister, 1994)

Ductility testing can be carried out on a range of materials testing machines together with data analysis software when more comprehensive testing results are required. Figure 2.9 shows the typical graph showing ductility test.

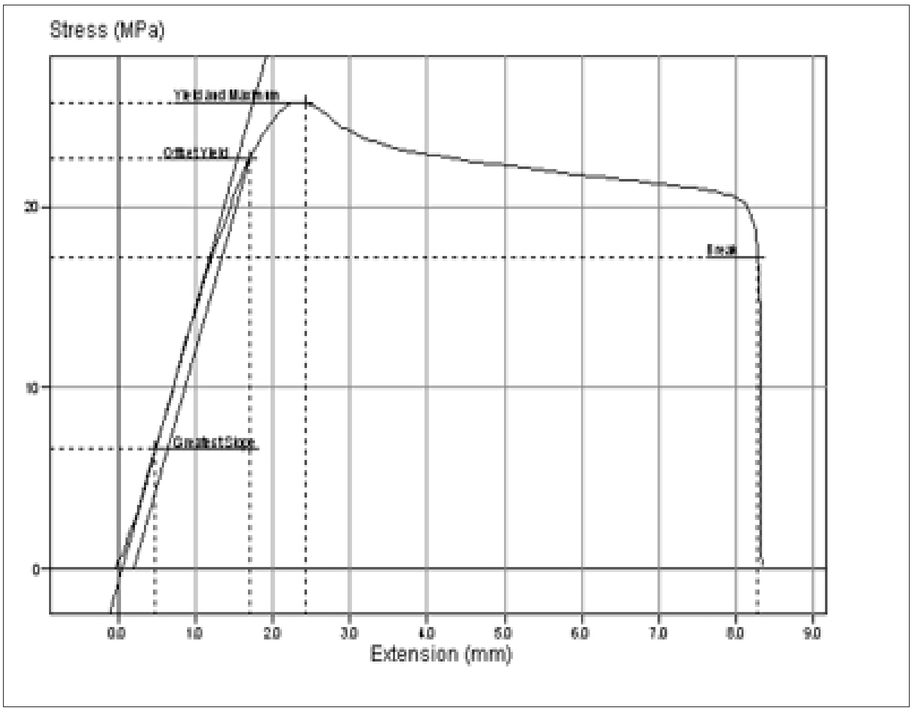

Figure 2.9: Graph of typical ductility test

Ductility involves determining the extent by which a material can withstand plastic deformation without rupture. With a ductile fracture, there is a considerable amount of plastic deformation prior to failure. In metals, for example, the fracture shows a typical cone and cup formation and the fracture surface appears rough and fibrous. Ductile materials show a measured amount of plastic deformation prior to fracture. (Iloyd-instruments, 2005)

2.9 THERMOPLASTIC TESTING

A thermoplastic, also known as thermo softening plastic is a polymer that turns to a liquid when heated and freezes to a very glassy state when cooled sufficiently. Testing of thermoplastics can take various forms. For this project, tensile and hardness testing will be done.

2.9.1 Tensile Testing

Tensile testing is one of the most common ways of measuring material strength. It generally involves the linear stretching of a material until failure or some critical value is achieved. Tensile testing can be performed on most types of materials, and can give information about yield strength, ultimate tensile strength, modulus of elasticity (stiffness), elongation, and other important properties.

2.9.1.1 Ultimate Tensile Strength

The ability of a material to resist breaking under tensile stress is one of the most important and widely measured properties of materials used in structural applications. The force per unit area (MPa or psi) required to break a material in such a manner is the ultimate tensile strength or tensile strength at break. The rate at which a sample is pulled apart in the test can range from 0.2 to 20 inches per minute and will influence the results. The analogous test to measure tensile properties in the ISO system is ISO 527.

2.9.1.2 Tensile Elongation

The ultimate elongation of an engineering material is the percentage increase in length that occurs before it breaks under tension. Ultimate elongation values of several hundred percent are common for elastomers and film/packaging polyolefins. Rigid plastics, especially fiber reinforced ones, often exhibit values under 5%. The combination of high ultimate tensile strength and high elongation leads to materials of high toughness.

2.9.1.3 Tensile Modulus of Elasticity

The tensile modulus is the ratio of stress to elastic strain in tension. A high tensile modulus means that the material is rigid - more stress is required to produce a given amount of strain. In polymers, the tensile modulus and compressive modulus can be close or may vary widely. This variation may be 50% or more, depending on resin type, reinforcing agents, and processing methods. The tensile and compressive moduli are often very close for metals. (Matweb, 2010)

2.9.2 Vickers Hardness Test

It is the standard method for measuring the hardness of metals, particularly those with extremely hard surfaces: the surface is subjected to a standard pressure for a standard length of time by means of a pyramid-shaped diamond. The diagonal of the resulting indention is measured under a microscope and the Vickers Hardness value read from a conversion table.

Vickers hardness is a measure of the hardness of a material, calculated from the size of an impression produced under load by a pyramid-shaped diamond indenter. Devised in the 1920s by engineers at Vickers, Ltd., in the United Kingdom, the diamond pyramid hardness test, as it also became known, permitted the establishment of a continuous scale of comparable numbers that accurately reflected the wide range of hardnesses found in steels.

The indenter employed in the Vickers test is a square-based pyramid whose opposite sides meet at the apex at an angle of 136º. The diamond is pressed into the surface of the material at loads ranging up to approximately 120 kilograms-force, and the size of the impression (usually no more than 0.5 mm) is measured with the aid of a calibrated microscope. The Vickers number (HV) is calculated using the following formula:

$$HV = 1.854(F/D2) \quad (2.1)$$

with F being the applied load (measured in kilograms-force) and D2 the area of the indentation (measured in square millimetres). The applied load is usually specified when HV is cited.

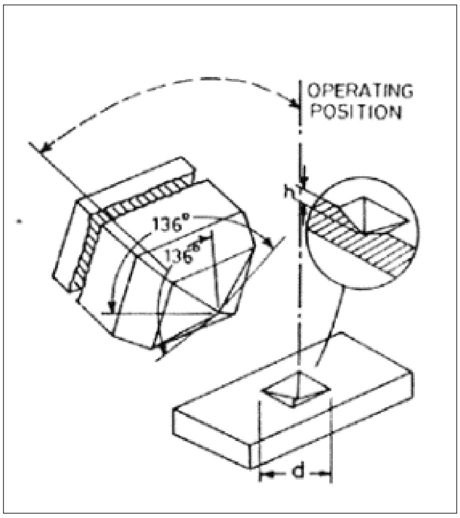

Figure 2.10: Diamond indenter for Vickers hardness test

Source: Calce (2001)

Figure 2.10 shows the diamond indenter that used for Vickers hardness test. To perform the Vickers test, the specimen is placed on an anvil that has a screw threaded base. The anvil is turned raising it by the screw threads until it is close to the point of the indenter. With start lever activated, the load is slowly applied to the indenter. The load is released and the anvil with the specimen is lowered. The operation of applying and removing the load is controlled automatically.

The advantages of the Vickers hardness test are that extremely accurate readings can be taken, and just one type of indenter is used for all types of metals and surface treatments. Although thoroughly adaptable and very precise for testing the softest and hardest of materials, under varying loads, the Vickers machine is a floor standing unit that is rather more expensive than the Brinell or Rockwell machines.

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

In this chapter, the flow of the process to produce the document tray and the samples are explained. To produce the samples, there are some preparation and flow that should be followed so that the process will run smoothly.

Firstly, is the preparation of the material. Then, injection moulding machine is used to produce document tray. After the samples are produced, there will be some testing for the samples such as mechanical testing and physical testing. Lastly, analysis to determine the best and high quality of the samples was done.

3.2 PREPARATION OF THE MATERIAL

In this project, the material used is Samsung Starex® SD-0150GP High Impact Grade ABS. ABS or Acrylonitrile Butadiene Styrene has been chosen as the material because of its properties that suitable for the product criteria. This material has high rigidity that can produce better quality product. This material was supplied by Polymer Technology and Services, LLC. Figure 3.1 shows the material that used to produced the document tray.

Figure 3.1: Samsung Starex® SD-0150GP High Impact Grade ABS

Before the material can be used, there is a property table of the ABS material must be refer to. Firstly, it should undergo the drying temperature which is about 70 ^{o}C to 80 ^{o}C about 2 hours. This is to ensure the material is completely dry before entering the hopper.

Then, by the properties table given at the appendix B, set the rear barrel temperature is about 190 ^{o}C to 210 ^{o}C. Then for the middle barrel temperature is about 200 ^{o}C to 220 ^{o}C. Next for the front barrel is 210 ^{o}C to 230 ^{o}C. This temperature should be set correctly so that when the material enters the barrel, this material will not melted over the required temperature or become too sticky. If the barrel temperature was set lower than that, it will cause the material will not properly melt or still hard.

3.3 PRODUCING DOCUMENT TRAY

3.3.1 Injection moulding machine

Before using the injection moulding machine directly, the student should master and know how to handle the machine well.

For this experiment, Arbug Injection Moluding Machine was used and it is located at Foundry Laboratory at Faculty of Mechanical Engineering. This machine manufactured by a Germany construction company, ARBURG, is one of the leading international manufacturers of injection machines that weighted 200 tons with clamping forces of between 1600 kN and 2000 kN. This machine is suitable enough for producing the document tray samples since the mould size is compatible for this machine. Figure 3.2 shows the Arbug Injection moluding machine provided by the faculty.

Figure 3.2: Arbug Injection Moluding Machine

3.3.2 Determine the parameter

From the readings and hands on practice using the injection machine during the class, the parameters involve in injection machine are determined. Those parameters should be controlled are temperature, pressure and volume.

For the temperature, since there is lot of temperature that should be controlled, the temperature chosen to be varied in this project is melting temperature and the other type of temperature should be kept constant. This is because it is the first stage the material will undergo. The quality of material is important for this stage. The average value is taken at the properties table of the material. During the injection process, the temperature value will be from the average value. Besides, for the pressure and volume value, the starting value can be determined during the injection process by doing try and error process during the class lesson. When the samples are produced, the physical of the product can be analyzes. If there is enough volume and pressure for the samples, that value was taken as the first reference value.

For the process, the samples are divided into nine categories according to the parameter. For the first series samples called A, the temperature (T1) and pressure (P1) value will remained constant and the volume value will be changed into another value (x, y, and z). This process was repeated for several times (A1, A2, A3).

Next, for the second group samples called B, the temperature (T1) is still constant value but pressure (P2) value will be increased and the volume value will be change into another value (x, y, and z). This process was also repeated for several times (B1, B2, B3).

Next, for the third group samples called C, the temperature (T1) is still constant value but pressure (P3) value will be increase and the volume value will be changed into another value (x, y, and z). This process was repeated for several times (C1, C2, C3) as well.

The process was repeated by changing the value of pressure from T1 to T2 and T3. Then it wills stops until 27 samples were produced.

3.3.3 Samples discrepancies

These 27 samples were produced by using the full factorial method using the Minitab Software. Figure 3.3 shows the data generated from Minitab Software and Figure 3.4 shows the 27 parts produce.

Table 3.1 shows the samples discrepancies for this project. T symbol is represent of the temperature while P symbol is represent the pressure and V is represent of volume. The temperature value is taken from the property table which is 230 ^{o}C, the pressure value is 1700 bar and volume value is 350cm^{3}.

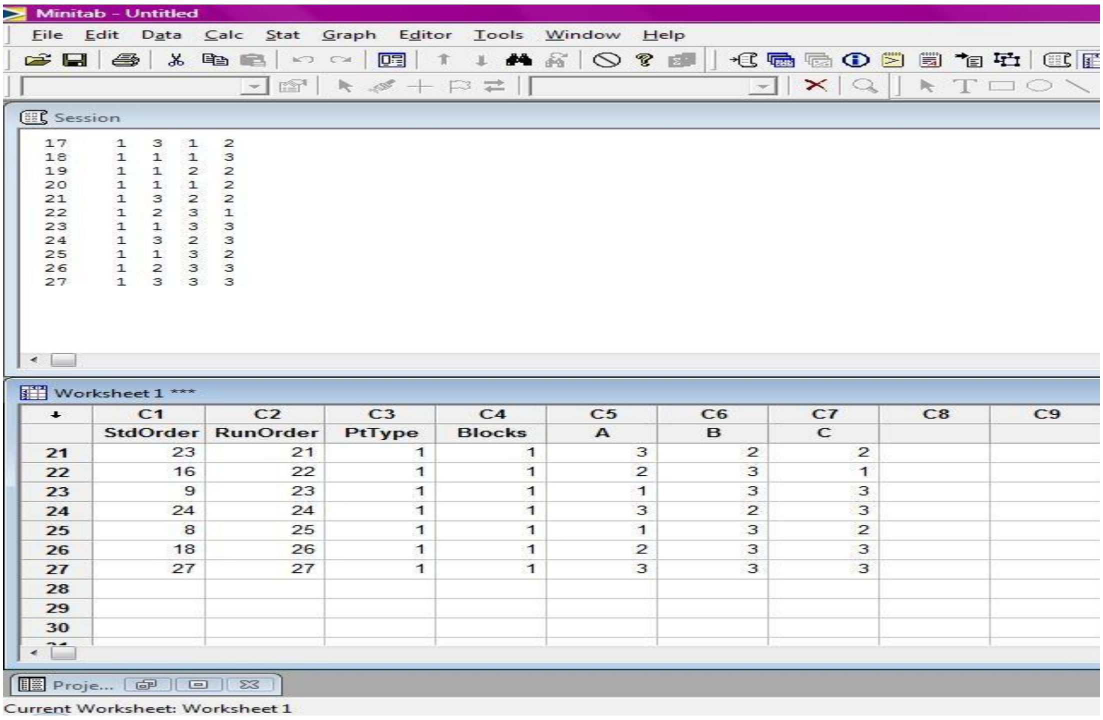

Figure 3.3: Data generated by Minitab Software

Figure 3.4: Injected part produced

Table 3.1: Samples discrepancies

Sample	Temperature (^oC)	Pressure (bar)	Volume (cm^3)
A1	T1= 220	P1= 1675	V1= 340
A2	T1= 220	P1= 1675	V2= 350
A3	T1= 220	P1= 1675	V3= 360
B1	T1= 220	P2= 1700	V1= 340
B2	T1= 220	P2= 1700	V2= 350
B3	T1= 220	P2= 1700	V3= 360
C1	T1= 220	P3= 1725	V1= 340
C2	T1= 220	P3= 1725	V2= 350
C3	T1= 220	P3= 1725	V3= 360
D1	T2=230	P1= 1675	V1= 340
D2	T2= 230	P1= 1675	V2= 350
D3	T2= 230	P1= 1675	V3= 360
E1	T2= 230	P2= 1700	V1= 340
E2	T2= 230	P2= 1700	V2= 350
E3	T2= 230	P2= 1700	V3= 360
F1	T2= 230	P3= 1725	V1= 340
F2	T2= 230	P3= 1725	V2= 350
F3	T2= 230	P3= 1725	V3= 360
G1	T3= 240	P1= 1675	V1= 340
G2	T3= 240	P1= 1675	V2= 350
G3	T3= 240	P1= 1675	V3= 360
H1	T3= 240	P2= 1700	V1= 340
H2	T3= 240	P2= 1700	V2= 350
H3	T3= 240	P2= 1700	V3= 360
I1	T3= 240	P3= 1725	V1= 340
I2	T3= 240	P3= 1725	V2= 350
I3	T3= 240	P3= 1725	V3= 360

3.4 TESTING METHOD

After the samples has been produced, the samples should undergo some analysis which are physical testing and mechanical testing to select that the best sample that can determine the optimum parameter for the injection machine.

3.4.1 Physical testing

Physical testing is developed to see the effect at those parameters to the density at the injected parts. Some problems can occur to the samples and it can be analyzed in terms of appearance of the samples.

3.4.1.1 Density test

Density test was carried out in order to study the physical properties of the samples produced with the parameter that have been varied. There is no any standard American Standard Test Method (ASTM) that follows to perform this test. This test was conducted by using basic knowledge of Archimedes Principal where value of displacement water represents the volume of the material that immersed in the water. Thus, the density of samples can be determined.

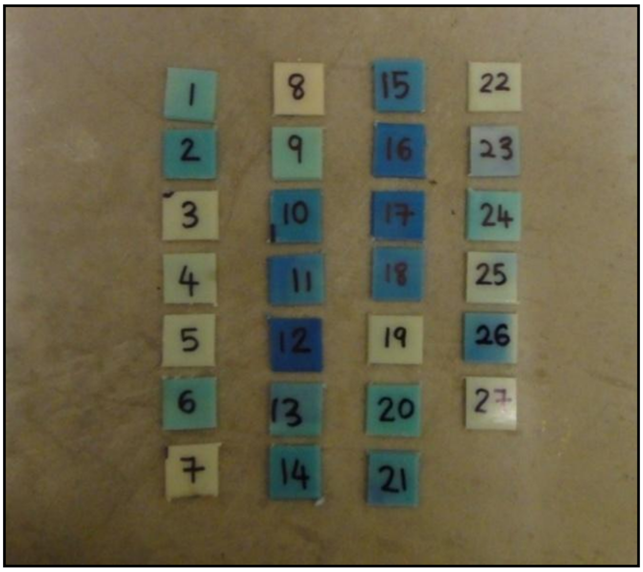

Figure 3.5: Samples for density test

The procedures of density test:

i. All the injected parts were cut into pieces in rectangular shape. The size is 20mm in width and 20mm in length.

ii. Weights of all samples were measured by using weigher to determine the mass. The value is recorded as M.

Figure 3.6: Taking the mass reading

iii. Put some water in the cylinder and the reading of water was recorded as initial volume, V_i

iv. Each sample was immersed in the cylinder and the water reading is recorded as final volume, V_f

v. The difference between the V_i and V_f was calculated and recorded as V

vi. The density for each sample was calculated by using the formula.

$$Density,\ p = \frac{Mass\ (M)}{Volume\ (V)} \qquad (3.1)$$

where mass must be in kg (kilogram) and volume must be in m^3(meter cube)

Figure 3.7: Taking the volume reading

3.4.2 Mechanical testing

Mechanical testing is the first step in putting samples into practice. Mechanical testing reveals the true mechanical properties of the samples using real samples. Testing were carried out under environmentally controlled conditions to ensure that the samples meet specifications and fit their intended purpose. Besides, mechanical testing needs some equipment to perform the test.

3.4.2.1 Tensile strength test

The tensile test was conducted according to ASTM Standard D638 which is Standard Test Method for Tensile Properties of Plastics. The machine used is Instron Testing Machine which is located at the Material Laboratory at Faculty of Mechanical Engineering.

Figure 3.8: Instron Testing Machine

Tensile tests measure the force required to break a plastic sample specimen and the extent to which the specimen stretches or elongates to that breaking point. This test method covers the determination of the tensile properties of unreinforced and reinforced plastics in the form of standard shaped test specimens when tested under defined conditions of pretreatment, temperature, humidity, and testing machine speed. This test method can be used for testing materials of any thickness up to 14 mm (0.55 in.).

The tensile test measure the strength of a material in resting being pulled apart. The tensile test pulls on both ends of a 8-1/2 inch long rectangular shape that resembles a dog bone. A specimen is typically 1/8 inch thick with a 3/4 inch width on both ends with a 1/2 inch wide in the middle. Test specimens of half this size are molded when smaller tensile machine are used. Since the specimen looks like a "dog bone", this term is used to refer to them.

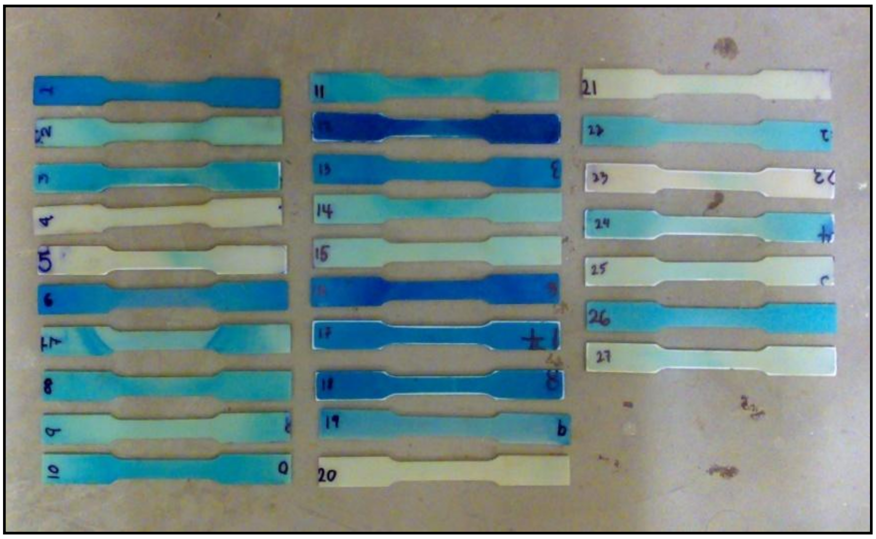

Figure 3.9: Tensile test samples

The procedures for tensile strength test:

i. Both ends of the specimen are firmly clamped in the jaws of the testing machine.
ii. A force (stress) in pounds is applied at one of four rates, 0.2, 0.5, 2, or 20 inches a minute, pulling the sample from both ends.
iii. Gauge marks, small lines or points drawn one inch apart at the center of the specimen are used to measure the elongation of the specimen.
iv. The more accurate elongation of the specimen is measured by the use of an extensometer (strain gauge) attached to the center of the specimen that electronically graphs change in length in relation to force applied.
v. The value is reported in pounds per square inch (PSI) and calculated from the cross section area of the center of the test specimen. The value is generated by dividing the cross section area into the stress in pounds to get PSI.
vi. Strain is a value measured in change in the length of the specimen and reported in inches per inch. Both are plotted on graph paper reflecting a stress-strain diagram. Normally this procedure is completed automatically by the tensile testing machine.

3.4.2.2 Hardness test

For this hardness test, the procedure is according to the correct procedure of Vickers Hardness Test. The machine is located at the Material Laboratory at Faculty of Mechanical Engineering.

Figure 3.10: Hardness test machine

The Vickers hardness test method consists of indenting the test material with a diamond indenter, in the form of a right pyramid with a square base and an angle of 136 degrees between opposite faces subjected to a load of 1 to 100 kgf. The full load is normally applied for 10 to 15 seconds. The two diagonals of the indentation left on the surface of the material after removal of the load are measured using by a microscope and their average were calculated**.**

The procedures of Vickers Hardness test:

i. The diamond ball acts as the indenter while a minor load is applied to the surface of the specimen.
ii. The minor load indents the diamond slightly to assure that contact is made.

iii. The machine gauge is set at zero and the lever at the top of the machine is flipped. This application is last 15 seconds.

iv. After the major load is removed the original minor load is left in place. The indentation remaining after 10 seconds is read directly off the dial.

v. This value is recorded as the Vickers hardness values and is preceded by the Vickers hardness letter scale which designates the type of ball and procedures used.

3.4 FLOW CHART OF EXPERIMENTAL METHODOLOGY

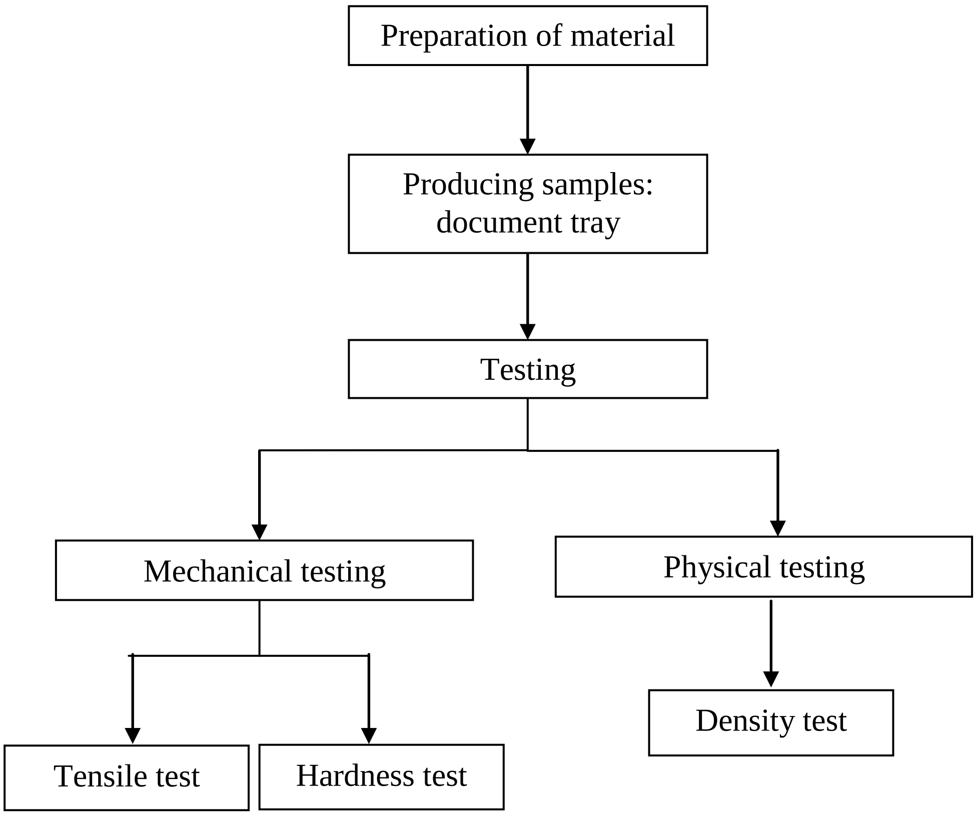

Figure 3.11: Flow chart of the experimental methodology.

CHAPTER 4

RESULT DAN DISCUSSION

4.1 INTRODUCTION

This chapter is the process to gather all the data from the testing and discuss about the result. The analysis method that used in this project is by using Microsoft Excel to do some basic calculation and Minitab Software to create the graph to evaluate the data. The chapter also discusses and decides the optimum parameter that will give the best properties of the injected part which has lowest density value, high of maximum strength, high of strength-to-weight ratio and high of hardness value. Most of the discussion based on the figure and the data that have been collected.

4.2 PRELIMINARY STUDY

Preliminary study is done to get the reference value for temperature, pressure and volume for starting to produce samples. All the parameter below is remain constant in order to get the preliminary value for the samples.

Table 4.1: Data of preliminary study for injection moulding process

PARAMETER	VALUE
Real barrel temperature	200 (^{o}C)
Middle barrel temperature	210 (^{o}C)
Front barrel temperature	220 (^{o}C)
Melting temperature	230 (^{o}C)
Back pressure	13 bar
Clamping force	2000 kN
Screw speed	70 rpm

This study is done before the sample of the document tray is produced. Table 4.1 shows the data that used in injection moulding process by using the Arbug Injection Moulding Machine. Other parameters are automatically generated by the computer according to the machine specification that attaches at appendix C.

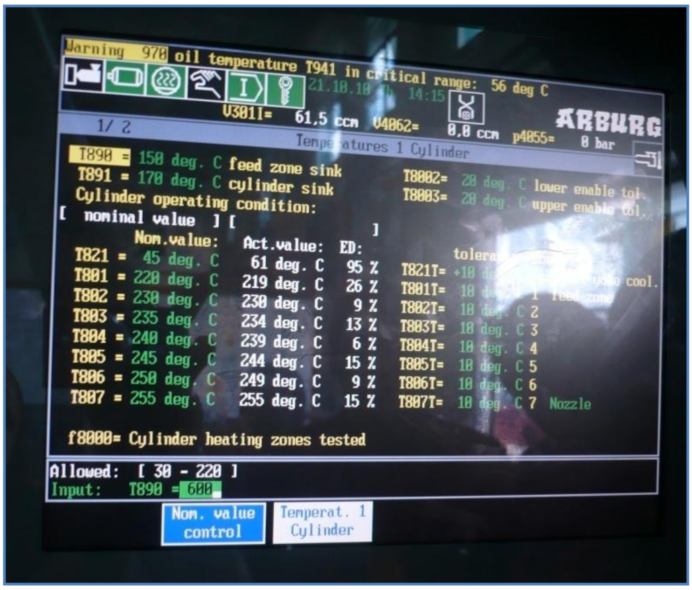

Figure 4.1: Parameter generated by the injection moulding machine

4.3 DATA COLLECTION

Data that collected from the experiment of density test, tensile test and hardness test is transfer into table so that analysis can be done systematically.

4.3.1 Sample labeling

Sample labeling is used to label the sample from 1 to 27 according to their parameter and this is the easy way to recognize each samples.

Table 4.2 shows the sample numbering for each parameter used. There are twenty seven samples that produced from three different parameters and three different values. From the table, the lowest and highest temperature value is 220 ^{o}C and 240 ^{o}C. For the pressure, the lowest and highest value is 1675 bar and 1725 bar and for the volume the lowest and highest value is 340 cm^3 and 360 cm^3. Each sample will give their own properties that will discuss in this chapter.

Table 4.2: Sample labeling according to the parameter used

Temperature (^oC)	Pressure (bar)	Volume (cm^3)	Sample number
220	1675	340	1
	1675	350	2
	1675	360	3
220	1700	340	4
	1700	350	5
	1700	360	6
220	1725	340	7
	1725	350	8
	1725	360	9
230	1675	340	10
	1675	350	11
	1675	360	12
230	1700	340	13
	1700	350	14
	1700	360	15
230	1725	340	16
	1725	350	17
	1725	360	18
240	1675	340	19
	1675	350	20
	1675	360	21
240	1700	340	22
	1700	350	23
	1700	360	24
240	1725	340	25
	1725	350	26
	1725	360	27

4.3.2 Density test result

For density test, mass and volume are measured. The mass value is taken from the weigher brand of Shimadzu (UW620H). For volume value, since the sample is too light, 6 samples are tested in the cylinder together to get the volume. The total volume is obtained by differences of final value from the initial value of the water displacement. The value obtained is divided by total samples that are tested together in order to get the average value for the volume of each sample.

Calculation

Each sample volume $= \frac{\text{total volume}}{\text{total samples}}$

$= \frac{10ml}{6}$

= 1.667ml (1.667×10^{-3}L)

(The unit from L is converted to m^3)

1000 L = $1m^3$

So, each sample volume = $\frac{1.667\ \text{mL}}{1000}$

= **1.667×10^{-6} m^3**

and according to equation 3.1,

Density, $p = \frac{\text{Mass (M)}}{\text{Volume (V)}}$

Example calculation of density for Sample number 1

Density sample 1= $\frac{\text{mass (in kg)}}{\text{volume (in m\^3)}}$

Density sample 1 = $\frac{1.268 \text{ x } 10 \text{ \^{}}{-3}}{1.667 \text{ x } 10\text{\^{}}{-6}}$

Density sample 1 = **760.648 kg/m^3**

Table 4.3 shows the result for density test. The density value is taken from the formula given. From the table, the lowest value of density is sample number 10 which has density value of 700.660kg/m^3. This is because of the contribution of small value of mass since density is directly proportional to mass.

Table 4.3: Density test result

Sample number	Mass (g)	Volume (m^3)	Density(kg/m^3)
1	1.268	1.667x10^{-6}	760.648
2	1.296	1.667x10^{-6}	777.445
3	1.339	1.667x10^{-6}	803.239
4	1.260	1.667x10^{-6}	755.849
5	1.279	1.667x10^{-6}	767.247
6	1.298	1.667x10^{-6}	778.644
7	1.261	1.667x10^{-6}	756.449
8	1.323	1.667x10^{-6}	793.641
9	1.335	1.667x10^{-6}	800.840
10	1.168	1.667x10^{-6}	700.660
11	1.194	1.667x10^{-6}	716.257
12	1.310	1.667x10^{-6}	785.843
13	1.266	1.667x10^{-6}	759.448
14	1.290	1.667x10^{-6}	773.845
15	1.291	1.667x10^{-6}	774.445
16	1.299	1.667x10^{-6}	779.244
17	1.292	1.667x10^{-6}	775.045
18	1.300	1.667x10^{-6}	779.844
19	1.283	1.667x10^{-6}	769.646
20	1.264	1.667x10^{-6}	758.248
21	1.268	1.667x10^{-6}	760.648
22	1.289	1.667x10^{-6}	773.245
23	1.271	1.667x10^{-6}	762.448
24	1.319	1.667x10^{-6}	791.242
25	1.284	1.667x10^{-6}	770.246
26	1.284	1.667x10^{-6}	770.246
27	1.272	1.667x10^{-6}	763.047

Figure 4.2 shows the plotted data for density versus sample number. There are different values of density for each sample. This is due the variety value for the mass even the value for volume is constant. The value of mass will give impact to the density value since the density is directly proportional to mass. From the Figure 4.2, the lowest value of density is sample number 10. This density is used as a measure of the compactness of a substance. It is a physical property of matter, as each element and

compound has a unique density associated with it. Density defined in a qualitative manner as the measure of the relative "heaviness" of objects with a constant volume. High density will give high compactness to the sample because the entire atoms in the sample are stick closely together.

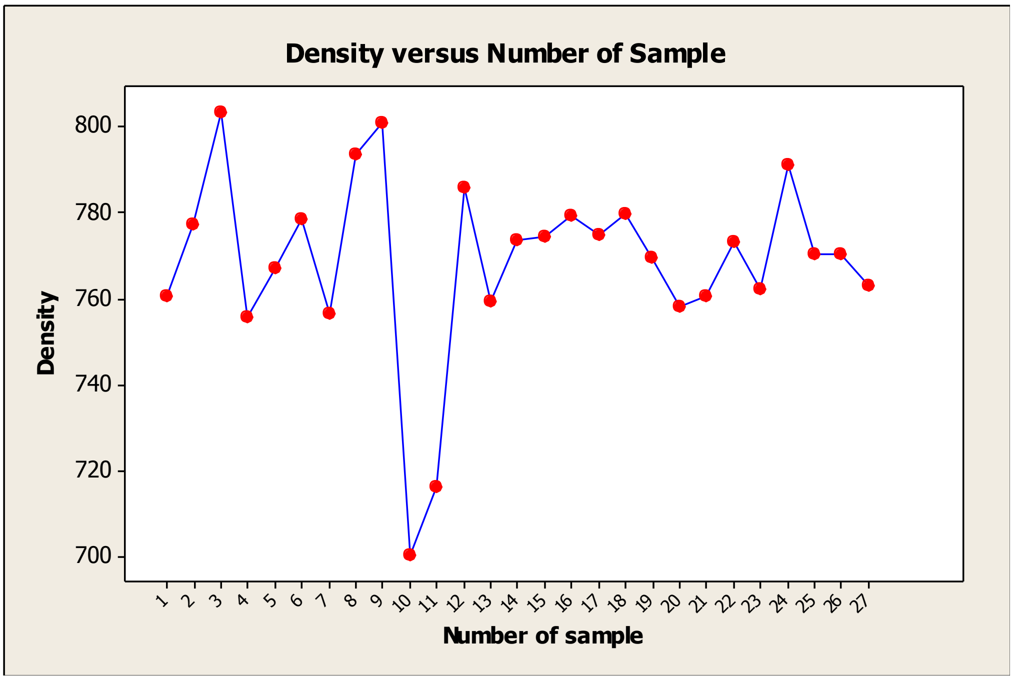

Figure 4.2: Graph of density value of each sample.

4.3.3 Tensile test result

Tensile test is the piece is gripped at either end by suitable apparatus in a testing machine which slowly exerts an axial pull so that the steel is stretched until it breaks. For this project, the Instron Testing Machine is used to conduct the experiment. The result at Table 4.4 shows the data that taken during the testing that generate automatically by the software used. The value of yield strength, maximum strength, young modulus and toughness is stated in the table. The graphs of stress versus strain of each sample are attached to the appendix G.

Table 4.4: Tensile test result

Sample number	Yield strength (MPa)	Maximum strength (MPa)	Young modulus (MPa)	Toughness (MPa)
1	31.84	35.65	490.3	1.611
2	32.99	38.61	280.1	1.425
3	28.46	41.03	167.0	1.010
4	26.64	36.21	64.87	3.111
5	26.63	37.66	50.45	1.210
6	29.53	36.93	162.0	1.067
7	24.31	36.12	161.1	1.597
8	25.18	36.20	35.49	1.829
9	32.47	41.95	283.9	2.647
10	24.79	37.64	91.51	1.274
11	23.54	37.40	83.63	1.106
12	26.40	37.34	162.7	1.266
13	29.43	36.98	146.9	0.8952
14	24.57	36.82	140.6	1.813
15	30.14	37.99	123.4	1.204
16	28.11	37.01	188.9	0.9087
17	28.42	37.14	194.4	1.011
18	26.76	37.32	261.2	1.238
19	27.12	36.09	179.2	1.457
20	28.51	37.01	117.9	1.632
21	33.20	39.57	502.8	1.810
22	27.03	36.53	132.6	1.290
23	28.31	36.55	714.3	2.004
24	28.35	36.47	227.5	1.204
25	27.25	36.48	536.6	2.207
26	29.51	36.80	309.9	2.055
27	29.29	35.24	333.8	0.8139

4.3.3.1 Maximum strength (Ultimate Tensile Strength analysis)

Below are the graphs of the effect of volume to the maximum strength for each sample according to the category of filled volume with constant temperature and pressure. The value of maximum strength obtains from the table.

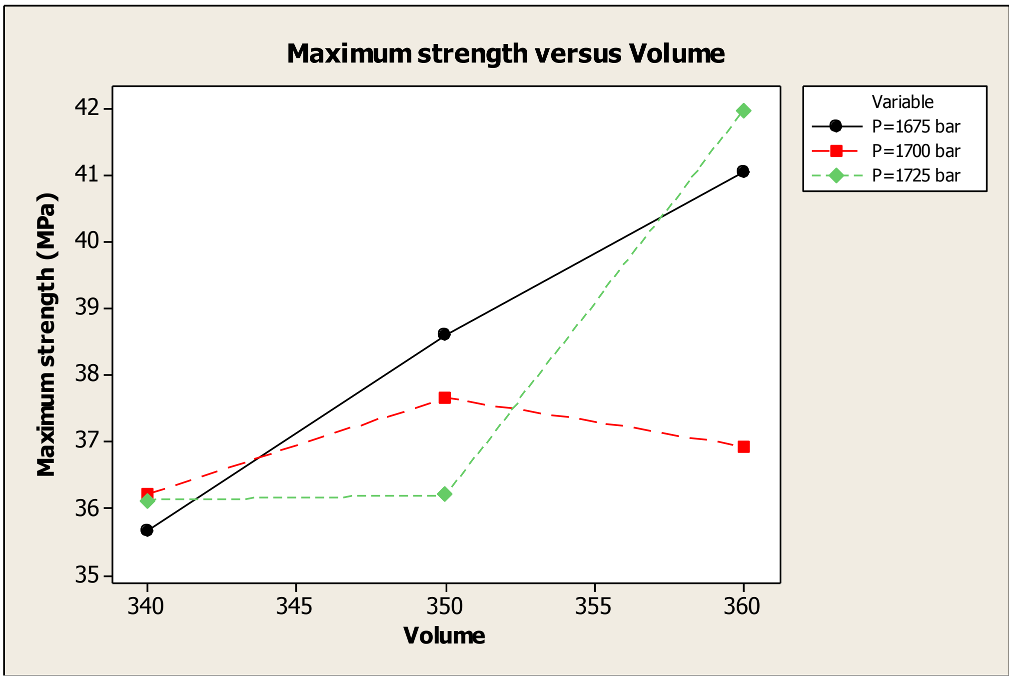

Figure 4.3: Effect of maximum strength at constant temperature (T=220 ^{o}C)

Figure 4.3 shows the effect of volume to the maximum strength according to the pressure with constant temperature of 220 ^{o}C. This graph is representing sample number from number 1 to number 9. For volume at 340 cm^3, the highest maximum strength is pressure at 1700 bar which is sample number 4. For volume at 350 cm^3, the highest maximum strength is pressure at 1675 bar which is sample number 2. For volume at 360 cm^3, the highest maximum strength is pressure at 1725 bar which is sample number 9.

Figure 4.4 shows the effect of volume to the maximum strength according to the pressure with constant temperature of 230 ^{o}C. This graph is representing sample number from number 10 to number 18. For volume at 340 cm^3, the highest maximum strength is pressure at 1675 bar which is sample number 10. For volume at 350 cm^3, the highest maximum strength is pressure at 1675 bar which is sample number 11. For volume at 360 cm^3, the highest maximum strength is pressure at 1700 bar which is sample number 15.

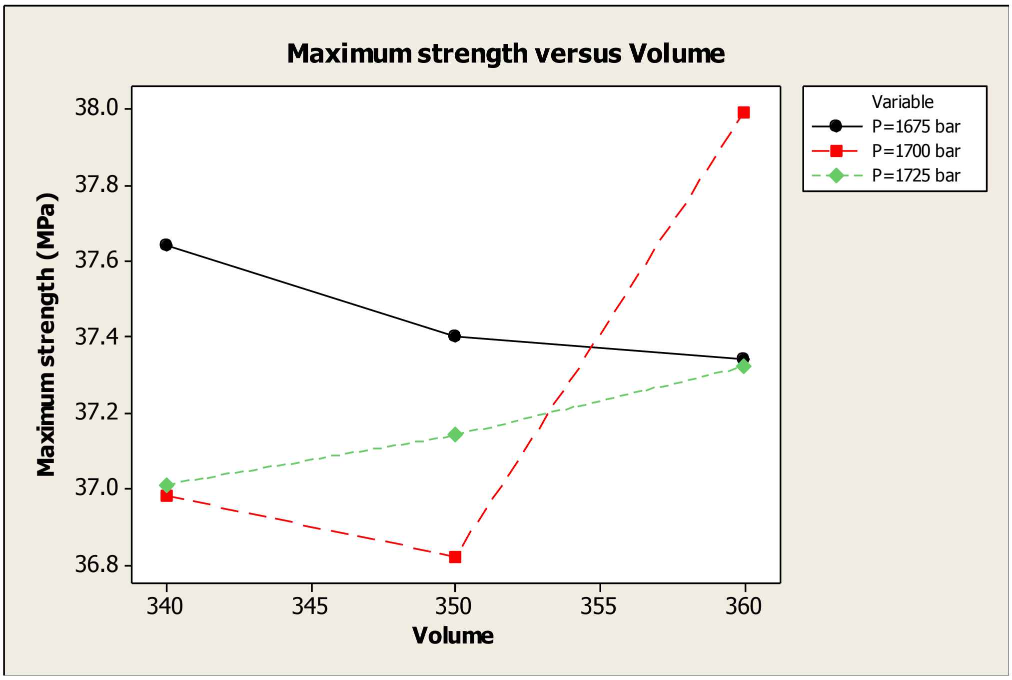

Figure 4.4: Effect of maximum strength at constant temperature (T=230 ^{o}C)

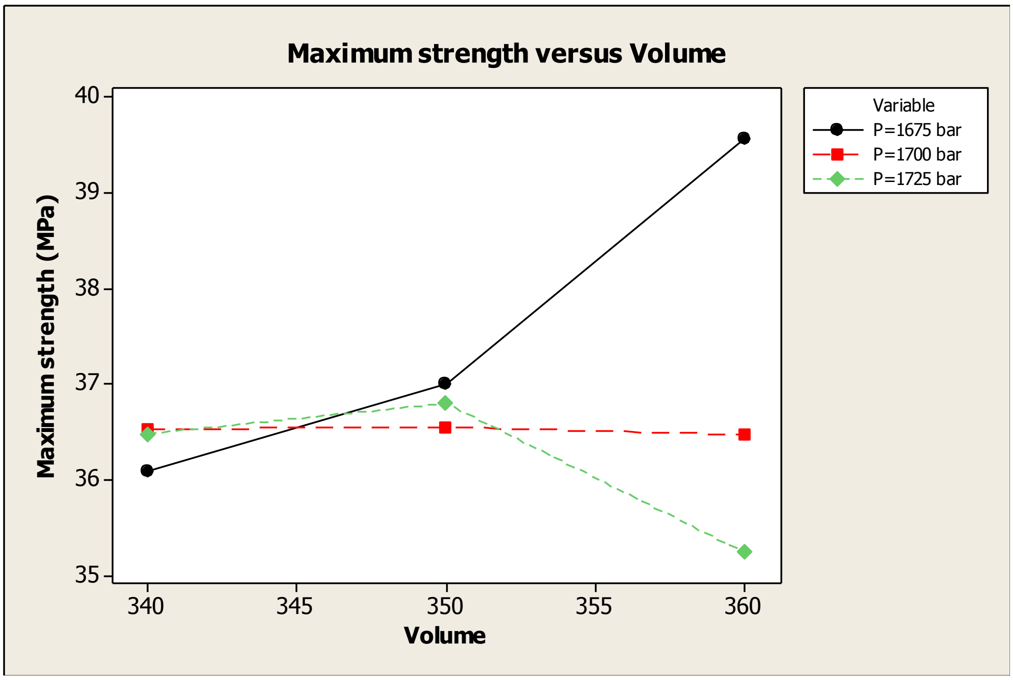

Figure 4.5: Effect of maximum strength at constant temperature (T=240 ^{o}C)

Figure 4.5 shows the effect of volume to the maximum strength according to the pressure with constant temperature of 240 ^{o}C. This graph is representing sample number from number 19 to number 27. For volume at 340 cm^3, the highest maximum strength is pressure at 1700 bar which is sample number 22. For volume at 350 cm^3, the highest maximum strength is pressure at 1675 bar which is sample number 20. For volume at 360 cm^3, the highest maximum strength is pressure at 1675 bar which is sample number 21.

From all these 3 figures, there are comparison of maximum strength between the volume and pressure to constant temperature. These 9 samples give high value of maximum strength. This wide range of useful engineering properties exhibit by ABS is due to the contributing properties of each components. Acrynitrile contributes heat and chemical resistance and toughness. Butadiene provides impact strength and low property retention and styrene provide surface gloss, rigidity and ease processing. (Smith, Hashemi, 2006)

4.3.3.2 Strength-to-weight ratio

Strength-to-weight ratio or known as specific strength is a material's strength (force per unit area at failure) divided by its density. **Table 4.5** shows the specific strength for each sample. This ratio is taken from the formula.

Example calculation for Sample number 1

$$\text{Strength-to-weight ratio} = \frac{\text{maximum strength}}{\text{density}} \tag{4.1}$$

Example calculation of strength-to weight ratio for Sample number 1

Ratio sample 1= $\frac{\text{maximum strength}}{\text{density}}$

Ratio sample 1 = $\frac{35.56}{760.648}$

Ratio sample 1 = **0.0469**

Table 4.5: Strength to weight ratio

Sample	Maximum strength (MPa)	Density(kg/m^3)	Strength-to-weight ratio
1	35.65	760.648	0.0469
2	38.61	777.445	0.0497
3	41.03	803.239	0.0511
4	36.21	755.849	0.0479
5	37.66	767.247	0.0491
6	36.93	778.644	0.0474
7	36.12	756.449	0.0477
8	36.20	793.641	0.0456
9	41.95	800.840	0.0524
10	37.64	700.660	0.0537
11	37.40	716.257	0.0522
12	37.34	785.843	0.0475
13	36.98	759.448	0.0487
14	36.82	773.845	0.0476
15	37.99	774.445	0.0491
16	37.01	779.244	0.0475
17	37.14	775.045	0.0479
18	37.32	779.844	0.0479
19	36.09	769.646	0.0469
20	37.01	758.248	0.0488
21	39.57	760.648	0.0520
22	36.53	773.245	0.0472
23	36.55	762.448	0.0479
24	36.47	791.242	0.0461
25	36.48	770.246	0.0474
26	36.80	770.246	0.0478
27	35.24	763.047	0.0462

Figure 4.6 shows the plotted data for strength-to-weight ratio versus number of sample. From the graph, the sample that has high ratio is sample number 10 which the ratio is 0.0537. This is because contribution of low value of mass in density value. The highest number of ratio will give the best properties to the sample.

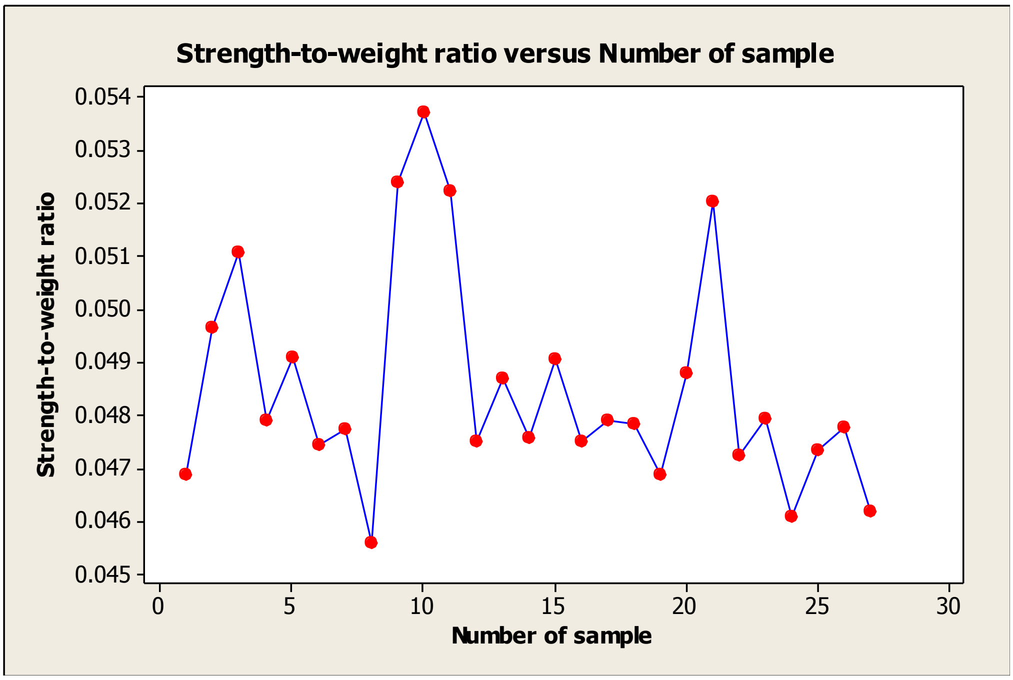

Figure 4.6: Graph of strength-to-weight ratio for each sample.

4.3.4 Hardness test result

The Vickers hardness test method consists of indenting the test material with a diamond indenter, in the form of a pyramid with a square base and an angle of 136 degrees between opposite faces subjected to a test force. For hardness test in this project, each sample is tested three times at different places using Matsuzawa MMT X-7 Hardness Machine to find the average hardness value. The time taken to penetrate the sample is 10 seconds and the load used is 500gf.

The Table 4.6 shows the result for Vickers hardness test. From the table the highest value of hardness test is sample number 13 which is 13.00 HV. The advantage of the Vickers hardness test is that extremely accurate readings can be taken and just one type of indenter is used for all samples.

Table 4.6: Hardness test result

Sample number	Test 1 (HV)	Test 2 (HV)	Test 3 (HV)	Average (HV)
1	10.7	11.1	10.9	10.90
2	11.6	11.5	11.8	11.63
3	11.4	10.1	10.3	10.60
4	11.4	10.4	11.0	10.83
5	10.8	12.5	11.1	11.47
6	11.7	11.4	12.0	11.70
7	13.0	11.2	12.6	12.27
8	10.2	11.5	11.0	10.90
9	10.9	11.2	12.2	11.43
10	10.9	11.2	11.2	11.10
11	11.3	12.4	11.4	11.70
12	9.6	11.9	11.2	10.90
13	13.3	13.3	12.4	13.00
14	11.1	11.9	11.9	11.63
15	11.1	11.5	12.3	11.63
16	10.7	10.9	10.8	10.80
17	12.3	12.2	10.8	11.77
18	10.6	11.2	12.0	11.27
19	13.0	11.0	11.3	11.77
20	12.2	11.6	11.3	11.70
21	11.4	12.6	11.7	11.90
22	11.6	12.0	11.6	11.73
23	10.8	11.6	11.6	11.33
24	10.6	10.5	10.5	10.53
25	10.7	10.9	10.9	10.83
26	11.3	11.4	11.2	11.30
27	11.6	11.7	11.4	11.57

Figure 4.7 shows the plotted data for hardness value versus sample number. There are different values of hardness for each sample. This hardness measurement based on the net increase in depth of impression as a load is applied to the sample. Sample number 13 has the highest value of hardness which is 13.00 HV means that the sample is hardest from others. Hardness is the resistance of a material to localized deformation. The term can apply to deformation from indentation, scratching, cutting or bending. This is because of the arrangement of atoms itself that closely pack together.

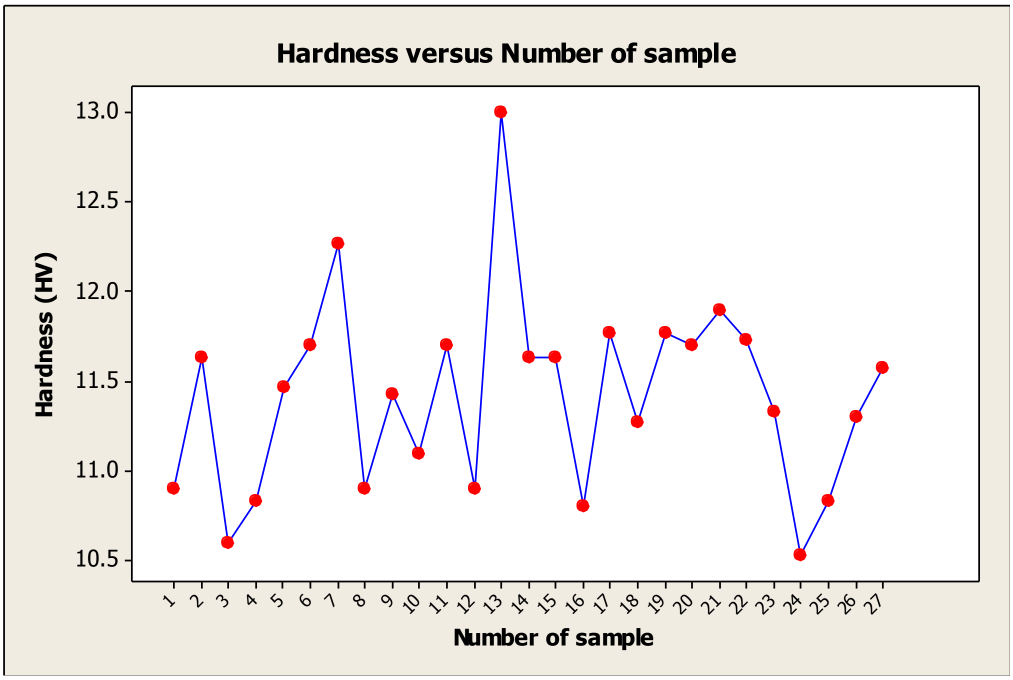

Figure 4.7: Graph of hardness value of each sample

Hardness tests serve an important need in industry even though they do not measure a unique quality that can be termed hardness. The tests are empirical, based on experiments and observation, rather than fundamental theory. Its chief value is as an inspection device, able to detect certain differences in material when they arise even though these differences may be indefinable. The higher the number in each of the scales means the harder the material.

Besides, ABS material is one of the thermoplastics. During the injection process, the increased temperature weakens the secondary bonds through the thermal vibration of the long molecules and the adjacent chains thus can move more easily when subjected to external shaping forces. When the polymer is cooled, it returns to its original hardness and strength. (Kalpakijan, 2006)

4.4 OPTIMUM PARAMETER

From the result and analysis done in this chapter, the best injected part produced is sample number 10 which has good properties and optimum parameter is temperature at 230 ^{o}C, pressure at 1675 bar and volume at 340 cm^3. The properties are shows at Table 4.7.

Table 4.7: Properties of best sample

Sample	Mass (g)	Density (kg/m^3)	Maximum strength (MPa)	Strength to weight ratio	Hardness (HV)
10	1.168	700.660	37.64	0.0537	11.10

From all the samples, sample number 10 has the lightest mass which is 1.168 gram. Reducing mass is important particularly in consumer products such as document tray where material can be saved and more products can be produced. This is very important in manufacturing because budget for the material can be reduced.

Besides, sample number 10 has the lowest density which is 700.600 kg/m^3. Lower value of density sample is particularly important in choosing the injected part for the sake of mass saving and economy is a major factor in the design both equipment and machinery and consumer products.

Other than that, the maximum strength of sample number 10 is not the highest value which is only 37.64 MPa compared to the highest value which is 41.95 MPa. This is because during the tensile specimen produced (dog bone shape) by using the stamping machine, there is notch that create of stress concentration in the middle of the sample causing the necking activity occur earlier at 24.79 MPa. Since the sample is ductile behavior, it sustain very long until it fracture at 37.64 MPa compared to the sample number 9, it is fracture at 32.47 MPa. But as refer to Figure 4.3, sample number 10 also has highest maximum strength for temperature at 230 ^{o}C and volume at 340 cm^3. There are some methods are available to reduce stress concentration are as follows:

i. Provide a fillet radius so that the cross-section may change gradually.
ii. Sometimes an elliptical fillet is also used.
iii. If a notch is unavoidable it is better to provide a number of small notches rather than a long one. This reduces the stress concentration to a large extent.
iv. If a projection is unavoidable from design considerations it is preferable to provide a narrow notch than a wide notch.
v. Stress relieving groove are sometimes provided.

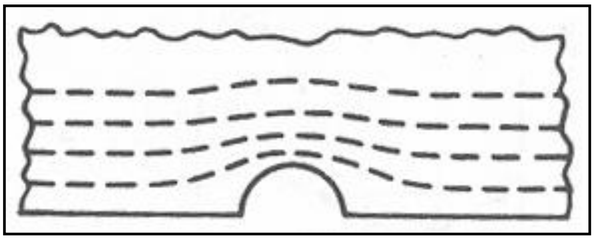

Figure 4.8: Force flow around a large notch force

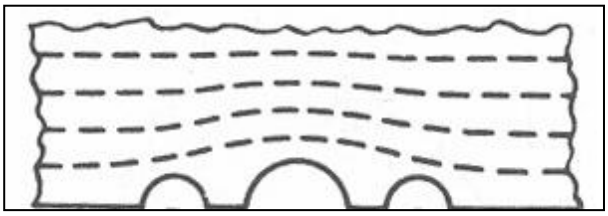

Figure 4.9: Flow around a number of small notches that effect low stress concentration.

Source: Kharagpur (2008)

The most important is sample number 10 has the highest strength-to-weight ratio value which is 0.0537. This is a relationship between a sample's strength and its weight. Sample that are light but also very strong have a high strength-to-weight ratio. This means that it has the ability to resist relatively high loads compared to their own weight.

Lastly, the hardness value of sample number 10 is not the highest value which is only 11.10 HV compared to the highest value which is 13.00 HV. This differences occur because the sample size taken only 1/10 from the overall size. Unfortunately the sample for number 10 is taken at the parts that have crystalline imperfection. There is defect which is vacancy; an atom is missing from the arrangement.

Vacancies may produced during solidification that created by atomic arrangement in an existing crystal due to atomic mobility. Additional vacancies can be introduced by plastic deformation, rapid cooling from higher temperature to lower ones to entrap the vacancies. (Smith, Hashemi, 2006)

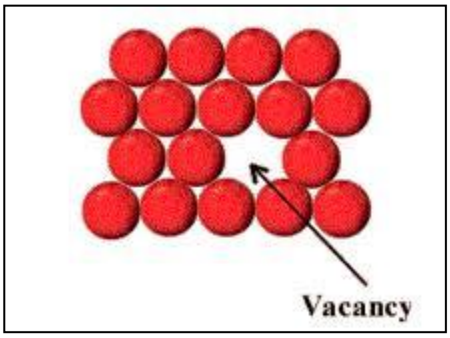

Figure 4.10: Vacancies of atomic arrangement

Since the injection moulding process is the rapid cooling process during the injection, these vacancies will occur to the sample. Besides that, air trap also occur in all samples. It is one kind of common defect found in any injection process. Generally, it is happened due to the air compacted inside the mold and cannot escape to environment. Figure 4.11 shows the air traps microstructure analysis using microscope.

Based on the analysis result, it shows that are some little air trap inside the parts. However, this problem can be eliminated by adjusting the machining setting like injection pressure, volumetric flow rate and etc. Thus, the design is means to be acceptable since the parts produce is totally complete in shape.

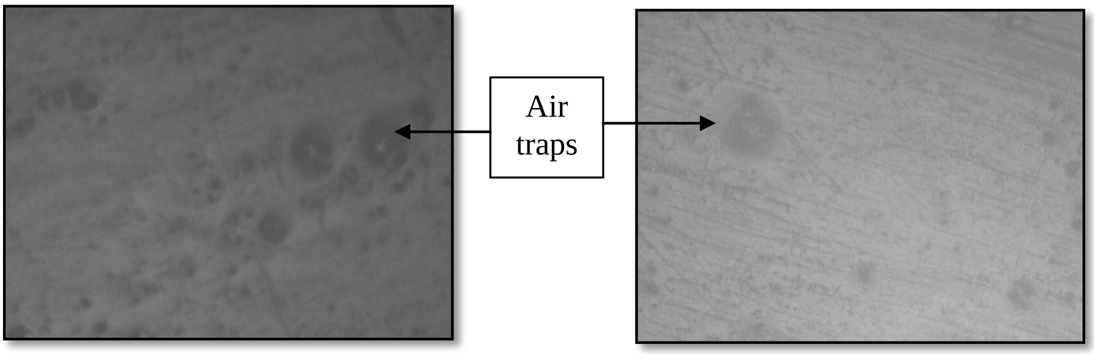

Figure 4.11: Air traps occur in sample 10 (right and sample 13 (left))

4.5 SUMMARY

This chapter discussed the result of the project which based on the parameter involve which is temperature, pressure and volume to produced injected parts. All this part will undergo some of mechanical and physical testing to analysis the properties. The optimum parameter will gives the best properties for the injected part. For all the parts produced, the optimum parameter chosen in sample number 10 which has temperature value at 230 ^{o}C, pressure at 1675 bar and volume at 340 cm^3.

CHAPTER 5

CONCLUSION AND FUTURE RECOMMENDATION

5.1 INTRODUCTION

The project was successfully done and achieving the objectives of the project. However during the project completion, there were a few problems that occur and need a solution in a way to solve the problem. It is because the limitation time to done the project. But the project can be continued based on future recommendation in a way to achieve excellent result. The project that has better result can be significant to the next researcher and as references.

5.2 CONCLUSION

As conclusion, at the end of analysis all the project objective was achieve. The problem had been occur also can be solve by alternative method in way to done the project. From analysis, the optimum parameter was selected for producing document tray product is sample 10 which has temperature value at 230^{o}C, pressure at 1675 bar and volume at 340cm^3. This sample is selected because the value gives the best properties such as low of density value, low of mass value, high of strength-to-weight ratio, high of maximum strength and high of hardness value.

5.3 RECOMMENDATION

In order to get better future result in future, there some recommendations could be implemented in future.

i. Prove the optimum parameter by doing analysis in Moldflow Software and compare between the samples produced by injection moulding process.
ii. There are 3 stages shown at auto controller to control the parameter for the injection moulding machine. For this project, only 1 stage parameter is used. In future, 3 stages can be used in order to get more accurate data.

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APPENDIX A

GANTT CHART

A1 Gantt Chart/ Project Schedule for FYP 1

A2 Gantt Chart/ Project Schedule for FYP 2

APPENDIX B

PROPERTIES OF ABS POLYMER

Table B.1: Property table of ABS polymer

PolymerTechnology & Services, LLC

Samsung Starex® ABS SD-0150GP High Impact Grade

Subcategory: ABS Polymer; Polymer; Thermoplastic

Physical Properties	**Metric**	**English**	**Comments**
Density	1.04 g/cc	0.0376 lb/in³	ASTM D792
Linear Mold Shrinkage	0.003 - 0.006 cm/cm	0.003 - 0.006 in/in	ASTM D955
Melt Flow	2.3 g/10 min	2.3 g/10 min	200°C/5kg
Mechanical Properties			
Hardness, Rockwell R	104	104	ASTM D785
Tensile Strength @ Break	40.7 MPa	5900 psi	5mm/min; ASTM D638
Elongation at Break	40 %	40 %	5mm/min; ASTM D638
Flexural Modulus	2.05 GPa	298 ksi	2.8 mm/min; ASTM D790
Flexural Strength	58.6 MPa	8500 psi	2.8 mm/min; ASTM D790
Izod Impact, Notched	4.11 J/cm	7.7 ft-lb/in	0.125"; ASTM D256
Thermal Properties			
Deflection Temperature at 1.8 MPa (264 psi)	85 °C	185 °F	0.250"; ASTM D648
Vicat Softening Point	97 °C	207 °F	5 kg, 50°C/hr; ISO R 306
Flammability, UL94*	HB	HB	1.5 mm
Processing Properties			
Rear Barrel Temperature	190 - 210 °C	374 - 410 °F	
Middle Barrel Temperature	200 - 220 °C	392 - 428 °F	
Front Barrel Temperature	210 - 230 °C	410 - 446 °F	
Melt Temperature	220 - 240 °C	428 - 464 °F	
Mold Temperature	40 - 80 °C	104 - 176 °F	
Drying Temperature	80 - 85 °C	176 - 185 °F	
Dry Time	2 - 4 hour	2 - 4 hour	
Injection Pressure	68.6 - 108 MPa	9950 - 15635 psi	
Back Pressure	0.689 - 1.38 MPa	100 - 200 psi	
Screw Speed	60 - 80 rpm	60 - 80 rpm	

APPENDIX C

SPECIFICATION OF ARBUG INJECTION MOULDING MACHINE

Table C.1: Specification of Arbug injection moulding machine

Technical data ALLROUNDER 470/520 C

ARBURG

Technical data 520 C - Europe

Technical data 520 C			
Machine model		**520 C 1600-800**	**520 C 2000-800**
EUROMAP size [1]		1600-800	2000-800
Clamping unit			
Clamping force	max. kN	1600	2000
Closing force	max. kN	70	70
Opening force / increased	max. kN	50/520	50/520
Opening stroke	max. mm	650	650
Mould height	min. mm	250	250
Daylight between platens	max. mm	900	900
Tie-bar clearance	mm	520 x 520	520 x 520
Mould platen size (hor x vert)	mm	728 x 728	728 x 728
Weight of mov. mould half	max. kg	1250	1250
Ejector force	max. kN	66	66
Ejector stroke	max. mm	225	225
Hydraulics, drive, general			
Drive power of hydraulic pump	kW	1 x 30	1 x 30
Dry cycle time for opening stroke	[3] s-mm	2.8-364	2.9-364
Total connected load	[2] kW	46.3	46.3
Colour: plastic coated, structure light grey / mint green / canary yellow			
Control cabinet			
Safety standard		DIN EN 60204	DIN EN 60204
Socket combination (1 single phase, 1 three-phase)		1 x 16 A	1 x 16 A
Injection unit		**800**	**800**
Screw diameter	mm	45/50/55	45/50/55
Effective screw length	L/D	22/20/18	22/20/18
Screw stroke	max. mm	200	200
Calculated injection volume	max. cm^3	318/39[illegible]/474	318/392/474
Shot capacity	max g/PS	291/359/434	291/359/434
Injection pressure	[5] max bar	2470/2000/1650	2470/2000/1650
Injection flow	[5] max cm^3/s	174/214/260	174/214/260
Injection flow with accumulator	max. cm^3/s	530/656/792	530/656/792
Back pressure positive/negative	max. bar	350/190	350/190
Circumferential screw speed	max. m/min.	56/62/69	56/62/69
Screw torque	max. Nm	880	880
Nozzle contact force	max. kN	70	70
Nozzle retraction stroke	max. mm	400	400
Installed cylinder heating power	W	6 x 2200	6 x 2200
Installed nozzle heating power	W	600	600
Material hopper capacity	l	50	50
Horizontal injection position	[4] max. mm	220 (160)	220 (160)
Machine dimensions and weights, basic machine			
Oil capacity	l	290	290
Net weight	kg	6950	7150
Electrical connection (pre-fused)	[2] A	125	125

1) 1st figure: clamping force (kN);
2nd figure: max. dosage volume (cm3) x max. injection pressure (kbar)

2) Values apply to 400 V/50 Hz. The load is symmetrically distributed over the 3 phases. The value applies to the basic machine version. Additional optional equipment can increase the connected load, so that 2 separate supply lines may be required (motor + controller / heating).

3) according to EUROMAP for basic machine

4) dimensions in brackets valid in connection with MULTILIFT H

5) a combination of max. injection pressure and max. injection flow (max. injection capacity) can be mutually exclusive, depending on the equipment-related motor output.

The technical data correspond to the current level when going to print. We reserve the right to modify specifications in the interest of further development.

APPENDIX D

TYPICAL TENSILE STRENGTH, ELONGATION, AND TENSILE MODULUS OF POLYMERS

Table D.1: Tensile test of polymer

Polymer Type	Ultimate Tensile Strength (MPa)	Elongation (%)	Tensile Modulus (GPa)
ABS	40	30	2.3
ABS + 30% Glass Fiber	60	2	9
Acetal Copolymer	60	45	2.7
Acetal Copolymer + 30% Glass Fiber	110	3	9.5
Acrylic	70	5	3.2
Nylon 6	70	90	1.8
Polyamide-Imide	110	6	4.5
Polycarbonate	70	100	2.6
Polyethylene, HDPE	15	500	0.8
Polyethylene Terephthalate (PET)	55	125	2.7
Polyimide	85	7	2.5
Polyimide + Glass Fiber	150	2	12
Polypropylene	40	100	1.9
Polystyrene	40	7	3

APPENDIX E

GRAPH OF STRESS-STRAIN FOR DUCTILE MATERIAL

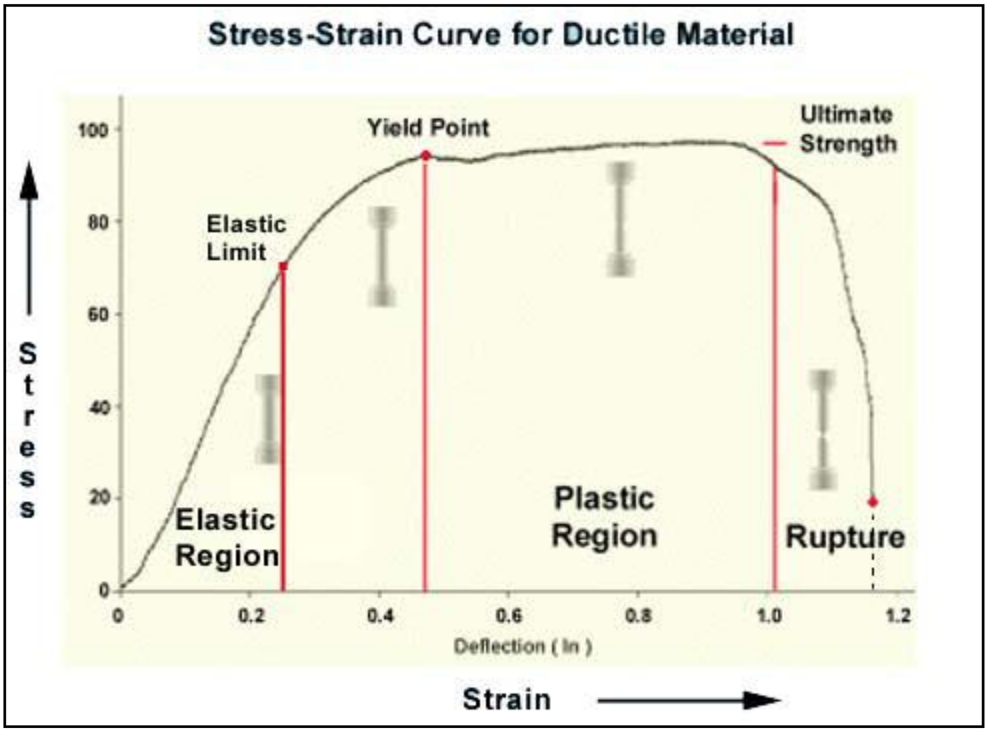

Figure E.1: Stress versus strain curve

APPENDIX F

HARDNESS INDENTER BALL

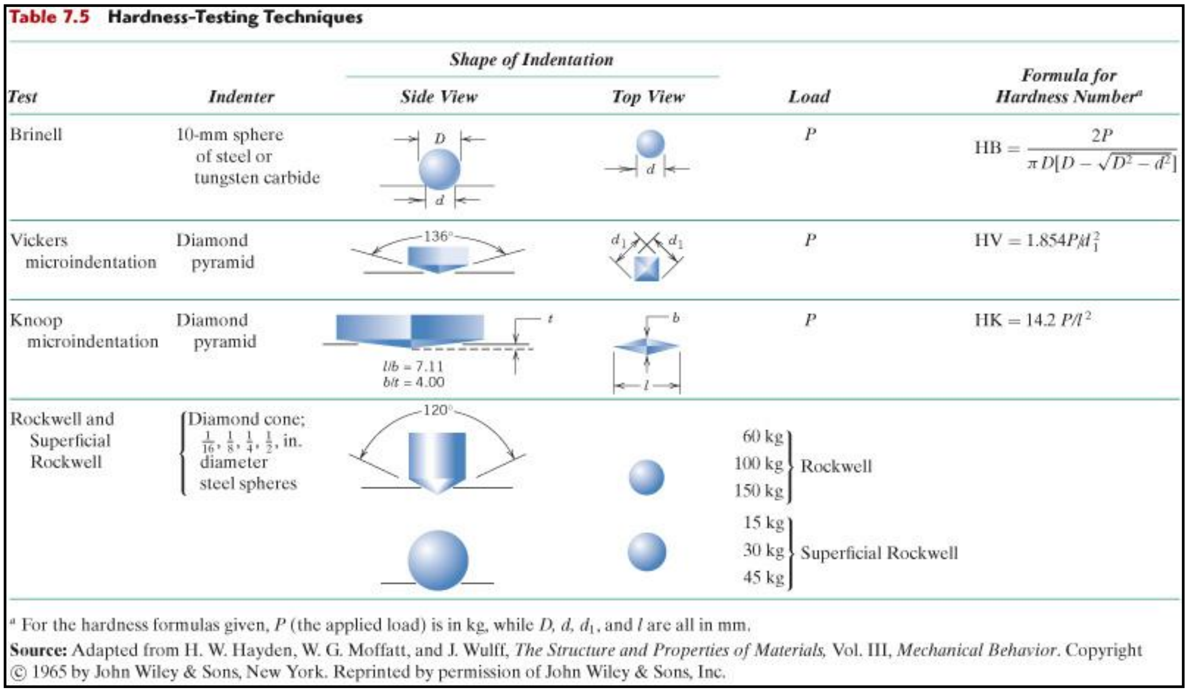

Table 7.5 Hardness-Testing Techniques

Test	Indenter	Shape of Indentation: Side View	Shape of Indentation: Top View	Load	Formula for Hardness Number[a]
Brinell	10-mm sphere of steel or tungsten carbide	D; d	d	P	$HB = \frac{2P}{\pi D[D - \sqrt{D^2 - d^2}]}$
Vickers microindentation	Diamond pyramid	136°	d_1; d_1	P	$HV = 1.854P/d_1^2$
Knoop microindentation	Diamond pyramid	t; $l/b = 7.11$; $b/t = 4.00$	b; l	P	$HK = 14.2\ P/l^2$
Rockwell and Superficial Rockwell	Diamond cone; $\frac{1}{16}, \frac{1}{8}, \frac{1}{4}, \frac{1}{2}$ in. diameter steel spheres	120°		60 kg, 100 kg, 150 kg: Rockwell	
				15 kg, 30 kg, 45 kg: Superficial Rockwell	

[a] For the hardness formulas given, P (the applied load) is in kg, while D, d, d_1, and l are all in mm.

Source: Adapted from H. W. Hayden, W. G. Moffatt, and J. Wulff, *The Structure and Properties of Materials,* Vol. III, *Mechanical Behavior*. Copyright © 1965 by John Wiley & Sons, New York. Reprinted by permission of John Wiley & Sons, Inc.

Figure F.1: Indenter balls for hardness test

APPENDIX G

STRESS STRAIN CURVE FOR EACH SAMPLE

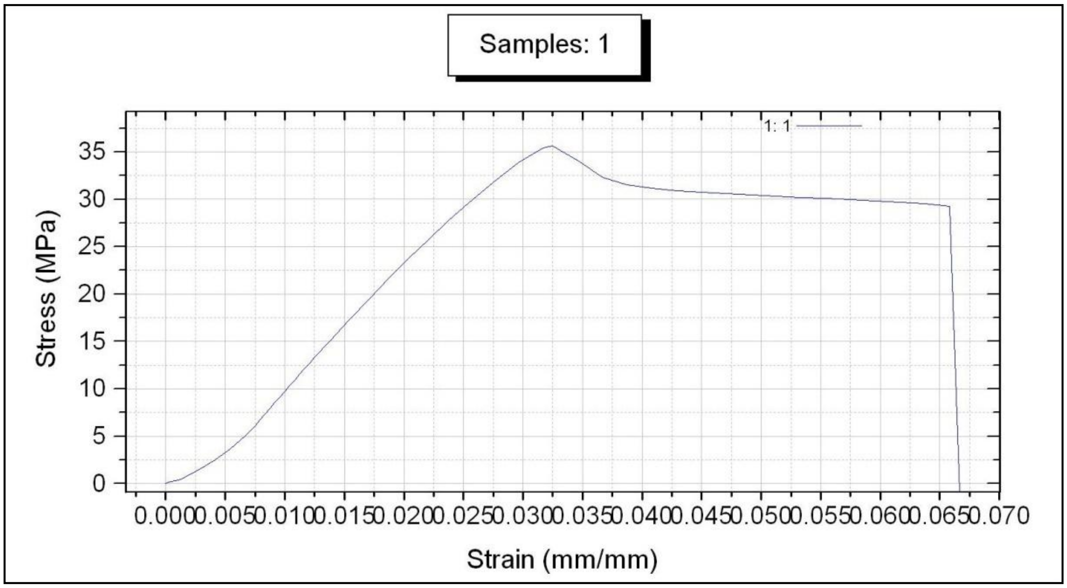

Figure G.1: Stress strain curve for sample 1

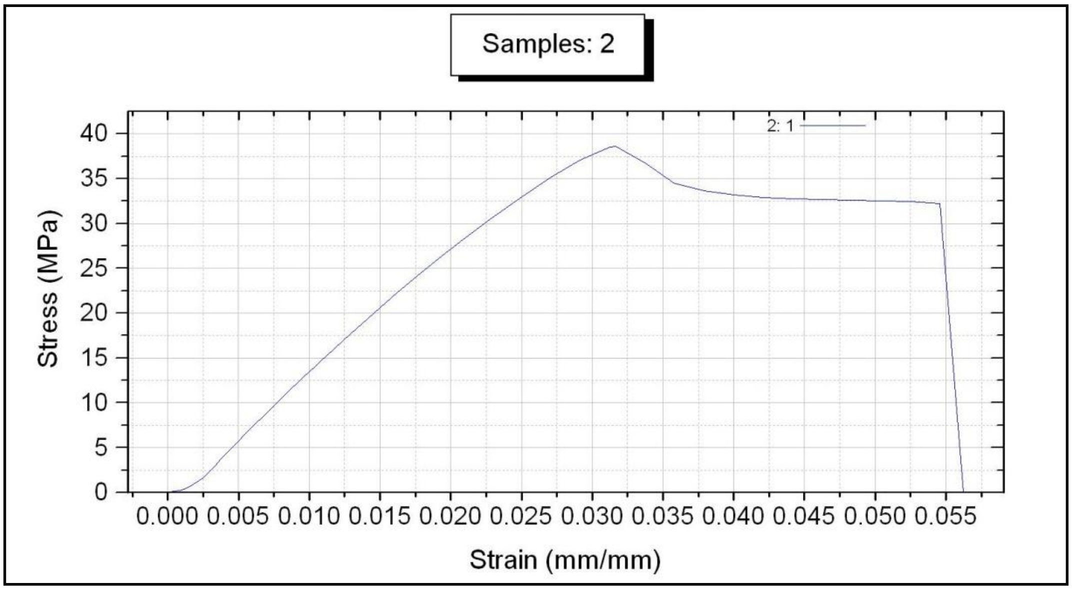

Figure G.2: Stress strain curve for sample 2

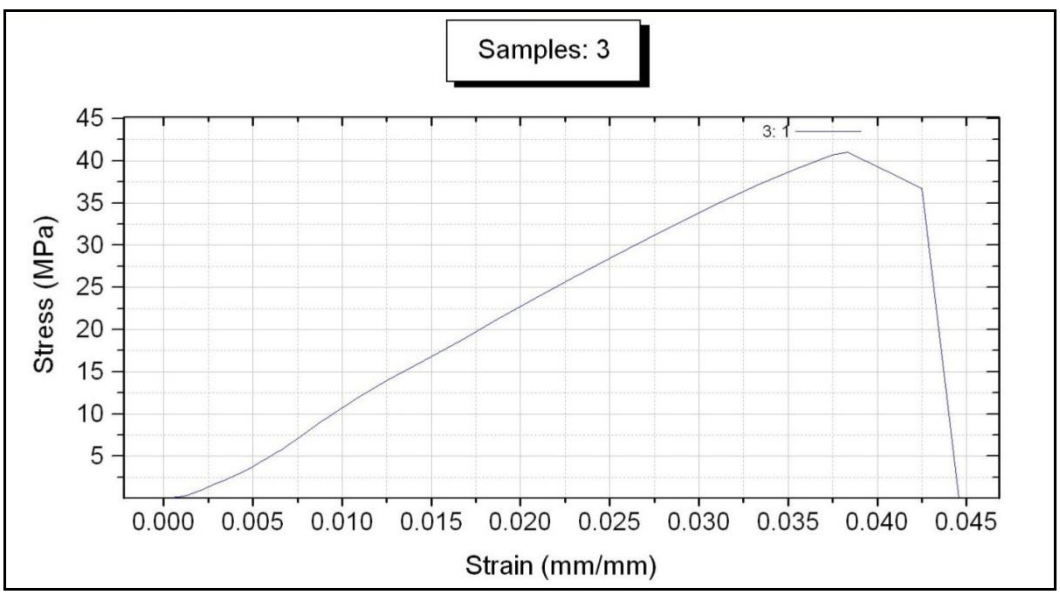

Figure G.3: Stress strain curve for sample 3

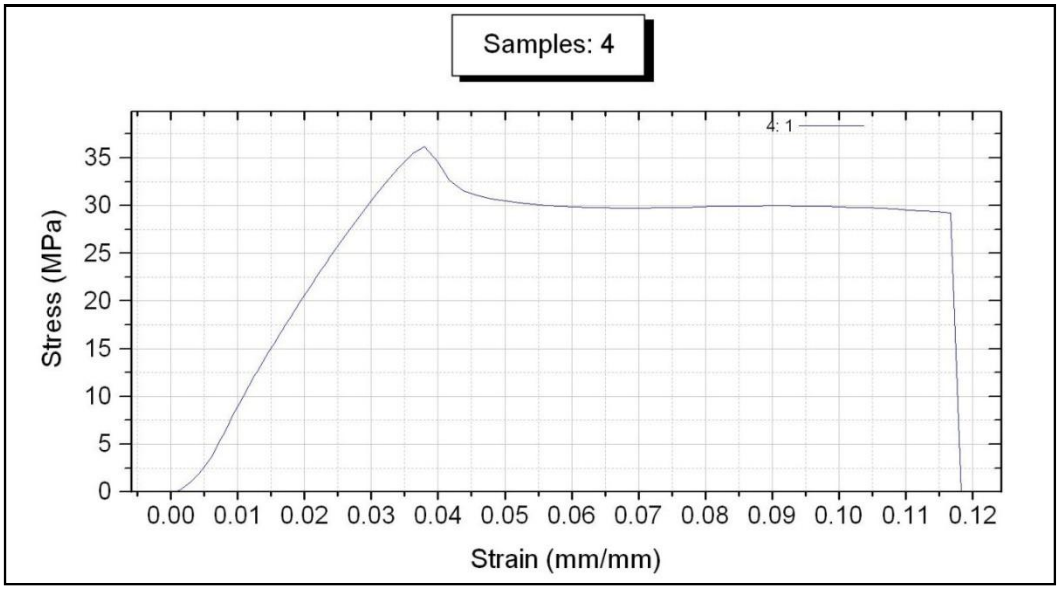

Figure G.4: Stress strain curve for sample 4

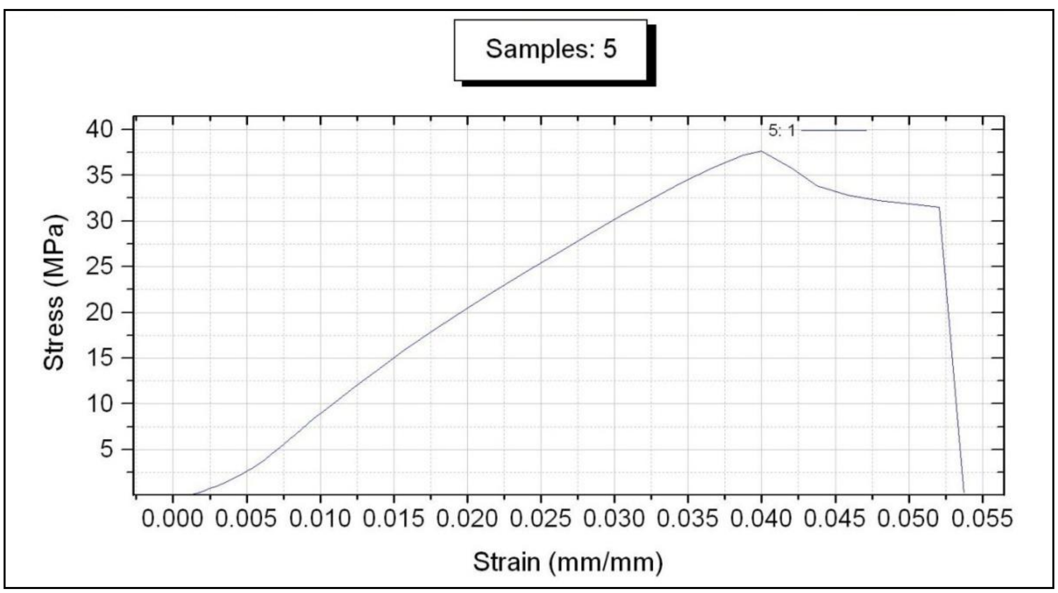

Figure 6.7: Stress strain curve for sample 5

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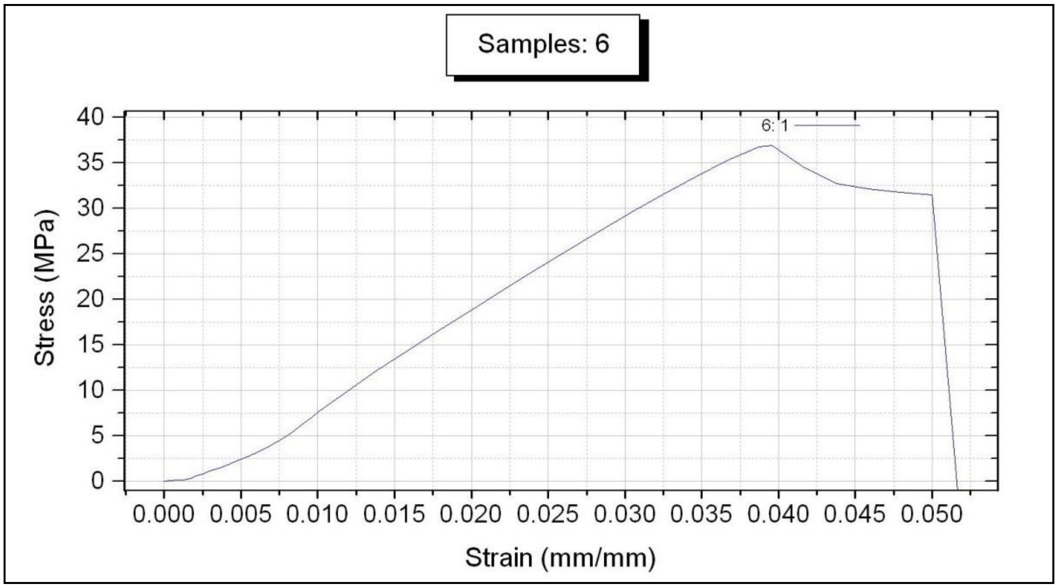

Figure G.5: Stress strain curve for sample 6

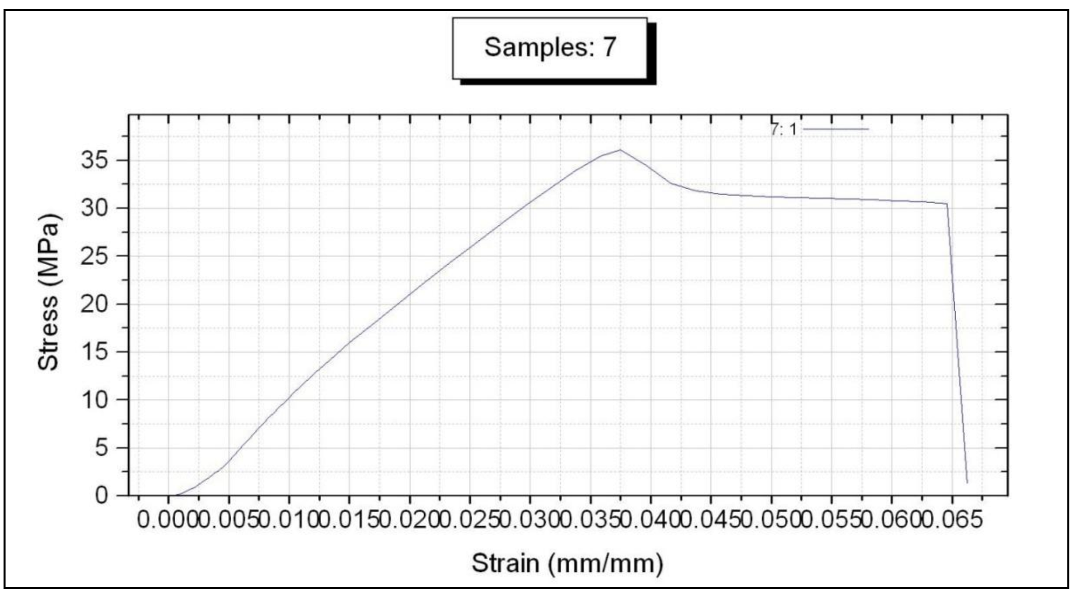

Figure G.6: Stress strain curve for sample 7

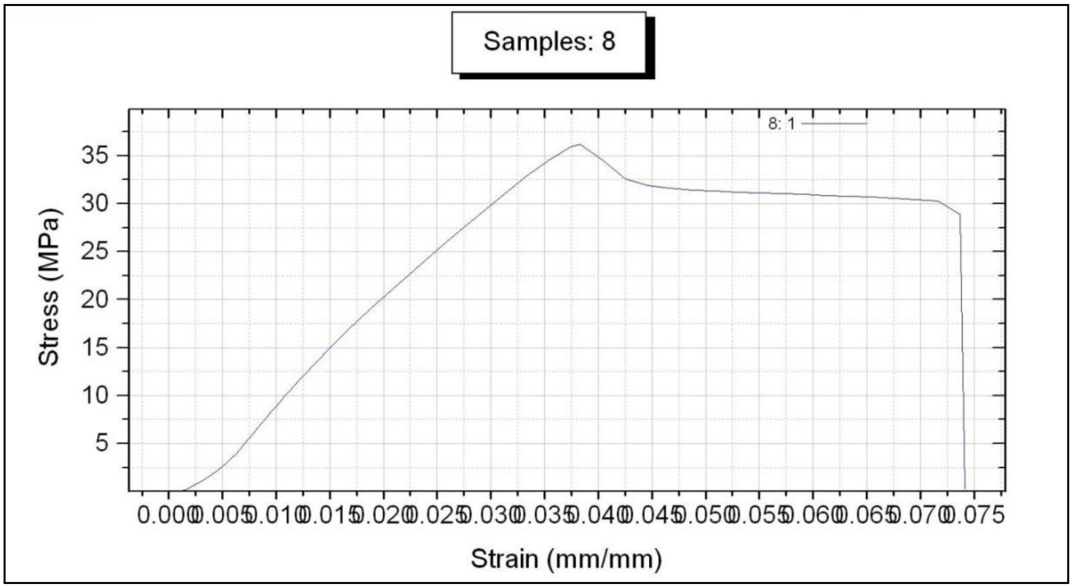

Figure G.8: Stress strain curve for sample 8

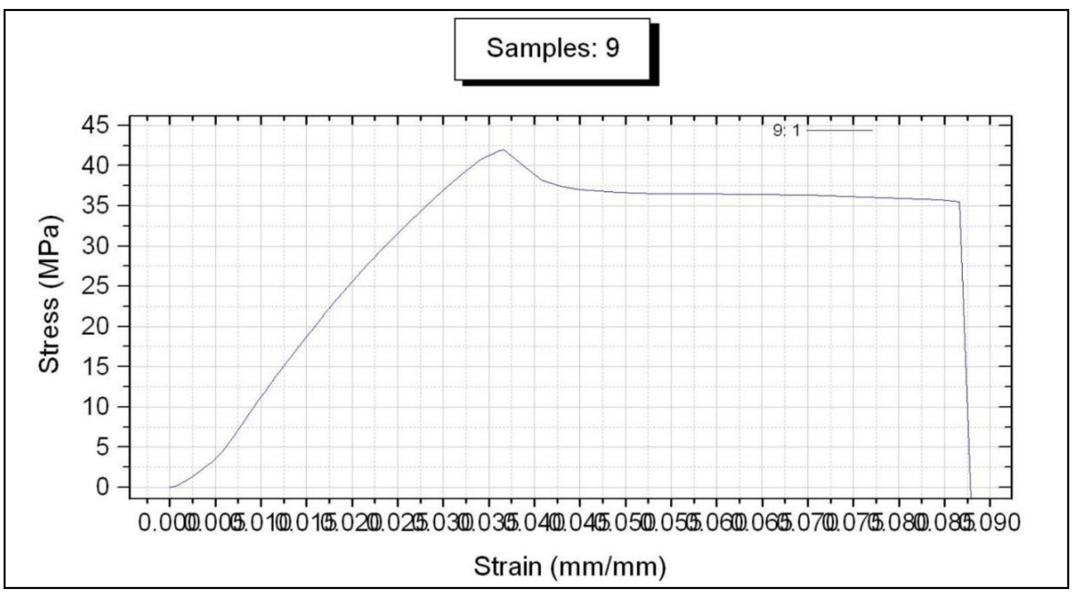

Figure G.9: Stress strain curve for sample 9

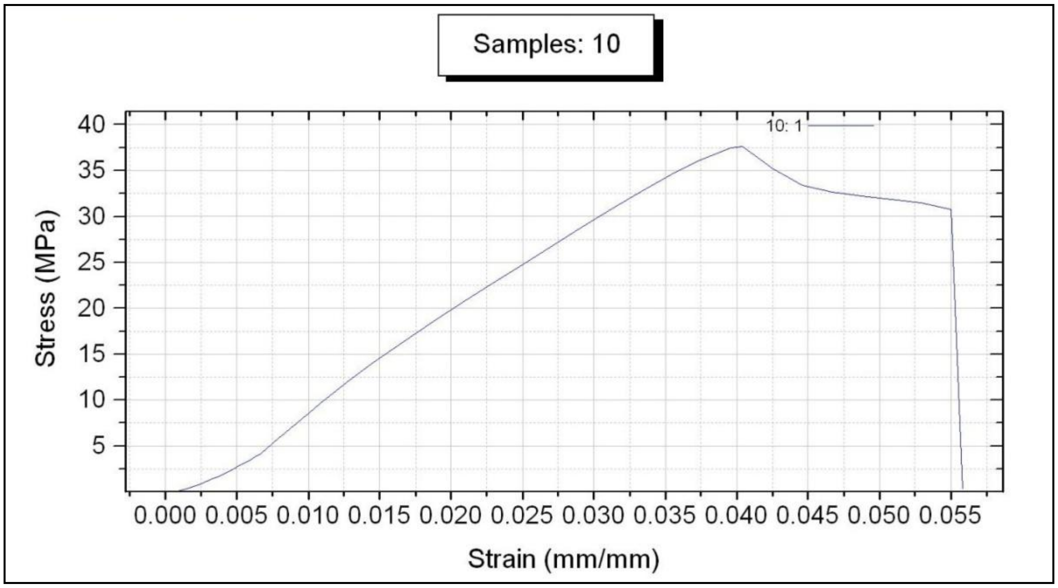

Figure G.10: Stress strain curve for sample 10

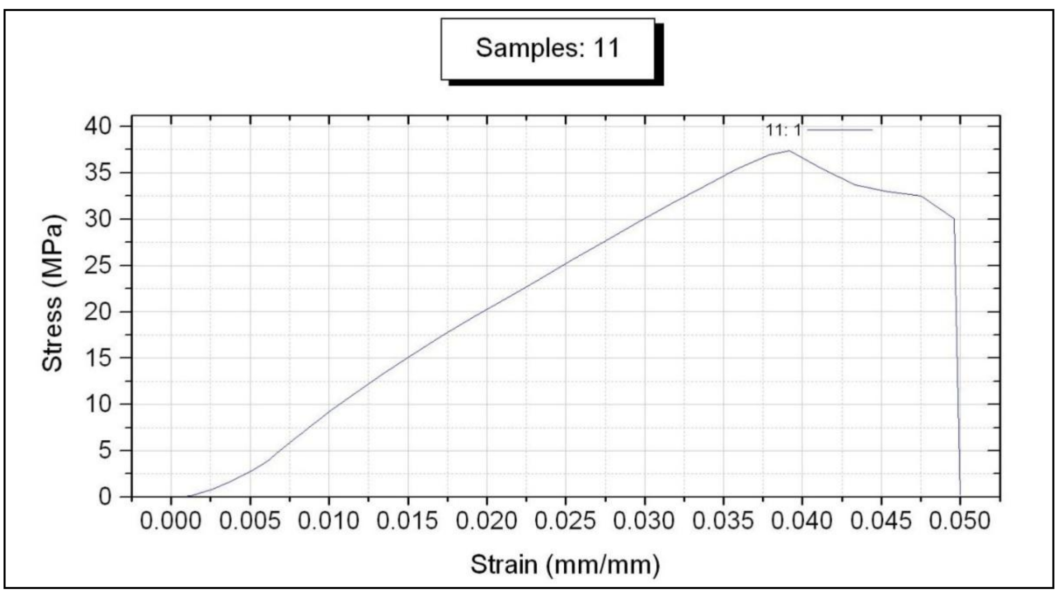

Figure G.11: Stress strain curve for sample 11

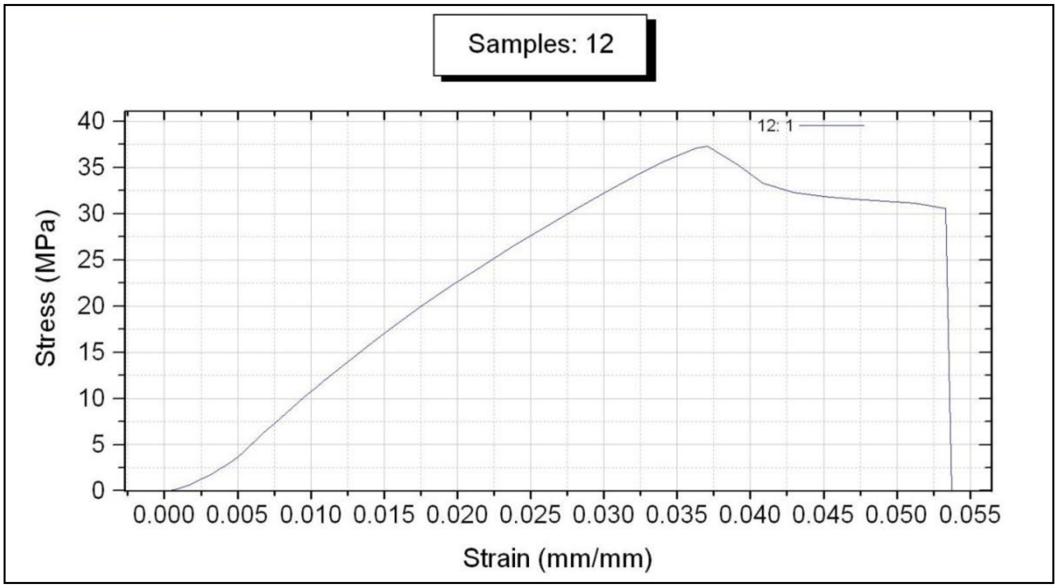

Figure G.12: Stress strain curve for sample 12

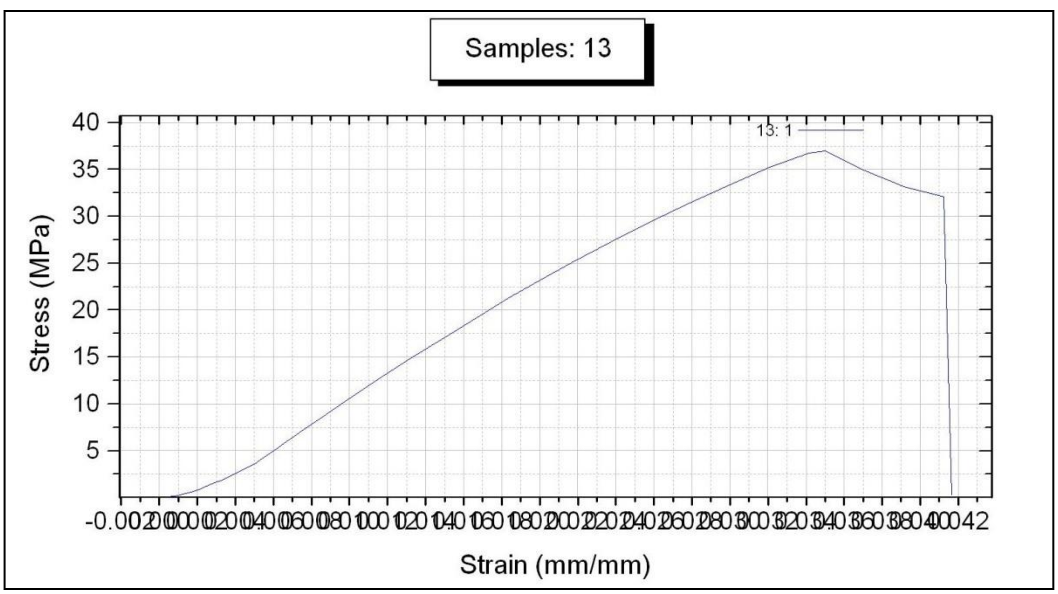

Figure G.13: Stress strain curve for sample 13

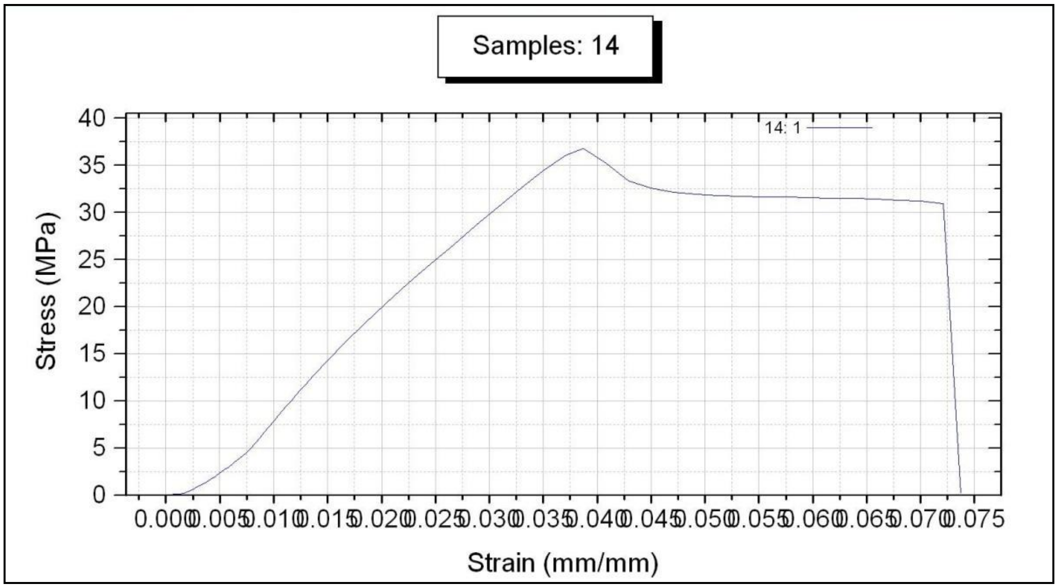

Figure G.14: Stress strain curve for sample 14

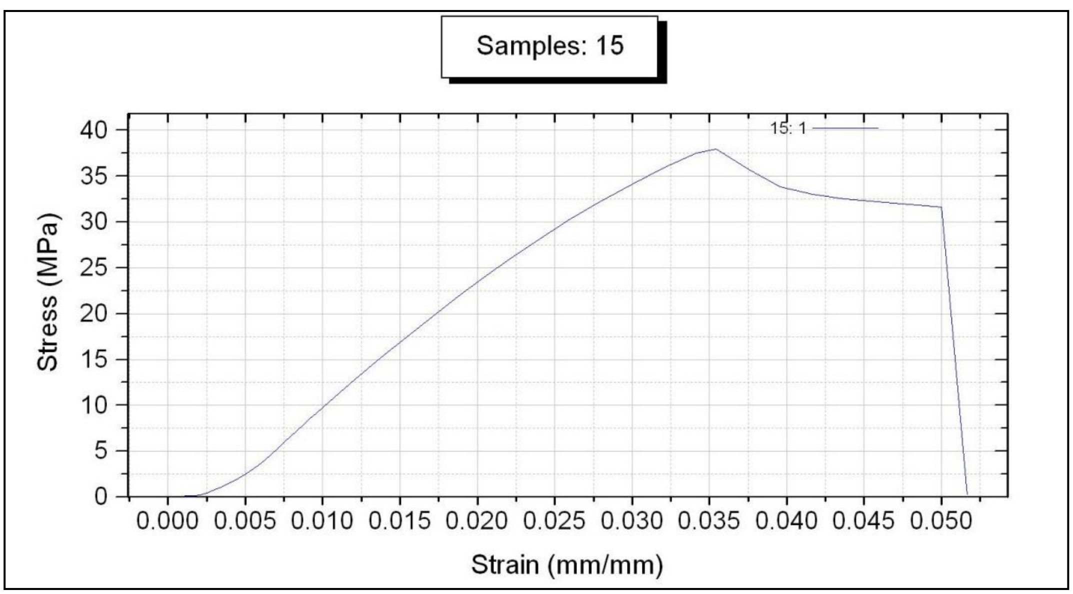

Figure G.15: Stress strain curve for sample 15

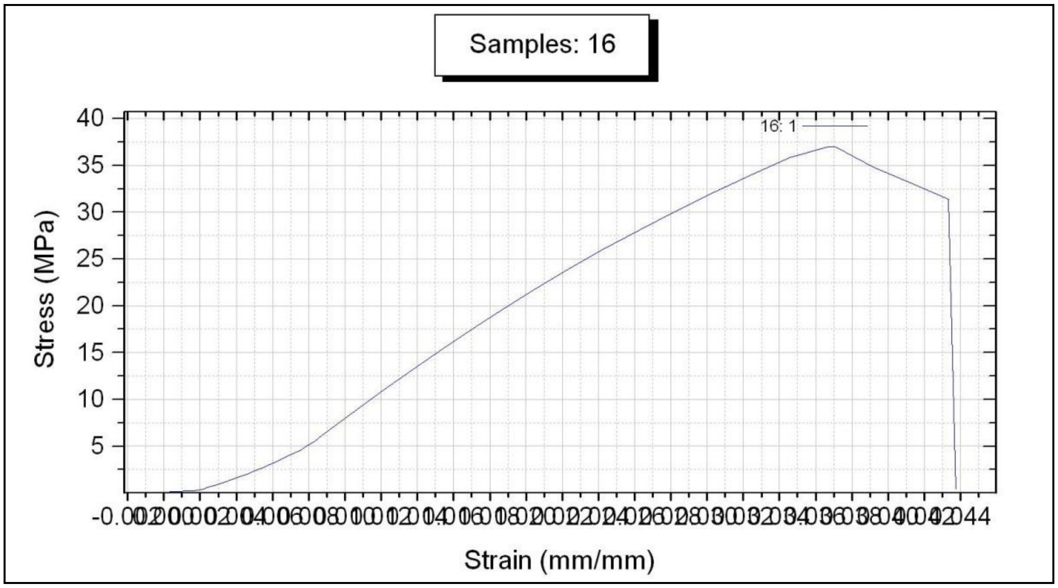

Figure G.16: Stress strain curve for sample 16

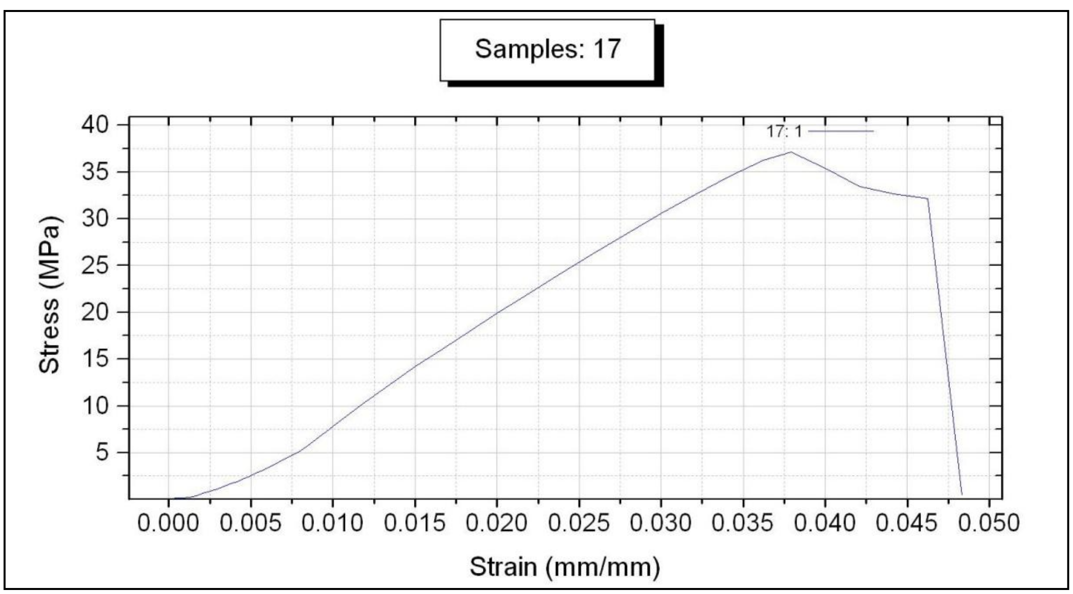

Figure G.17: Stress strain curve for sample 17

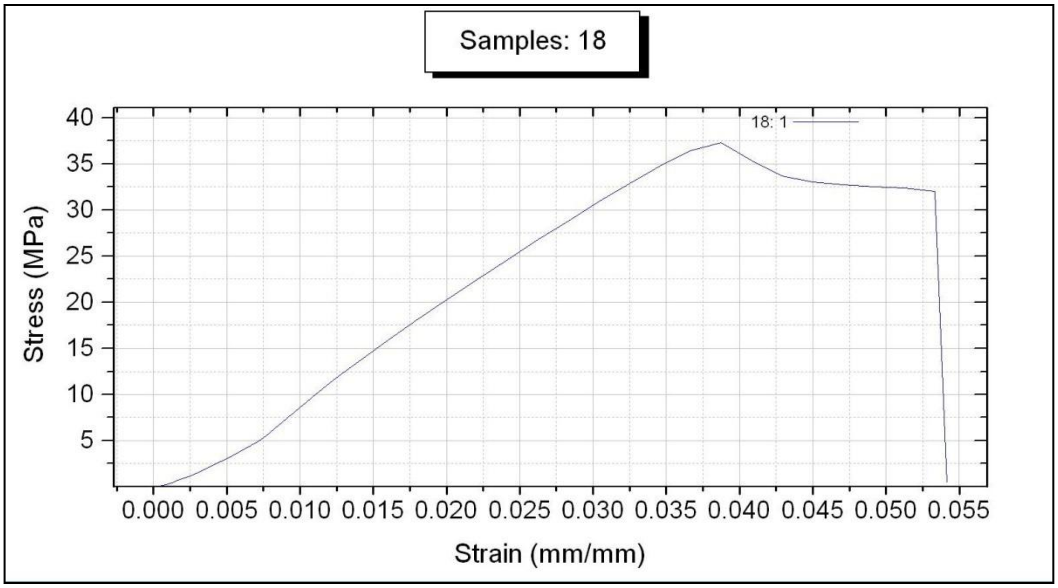

Figure G.18: Stress strain curve for sample 18

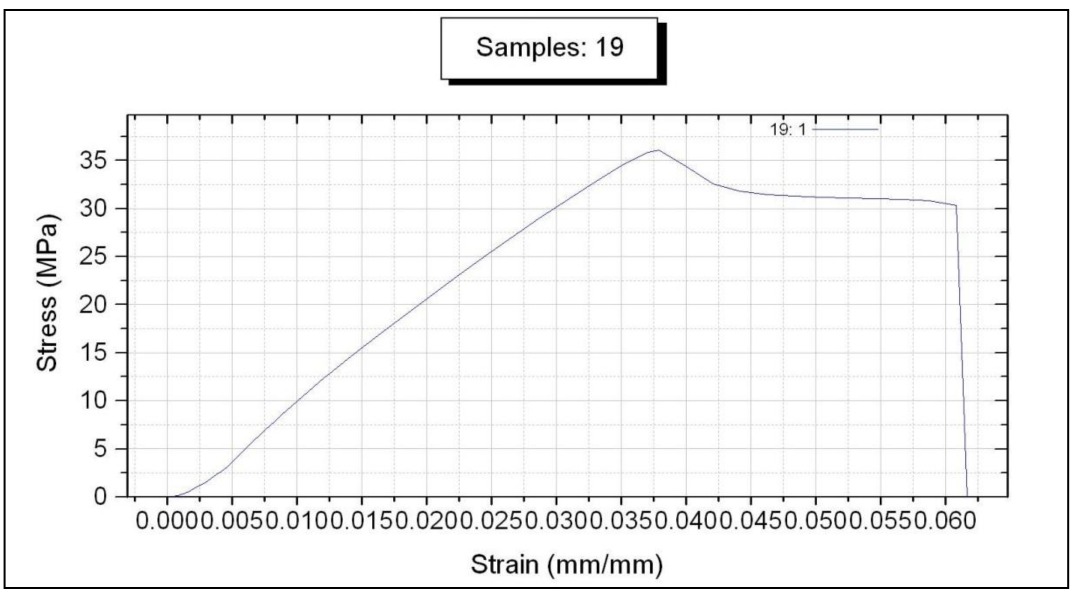

Figure G.19: Stress strain curve for sample 19

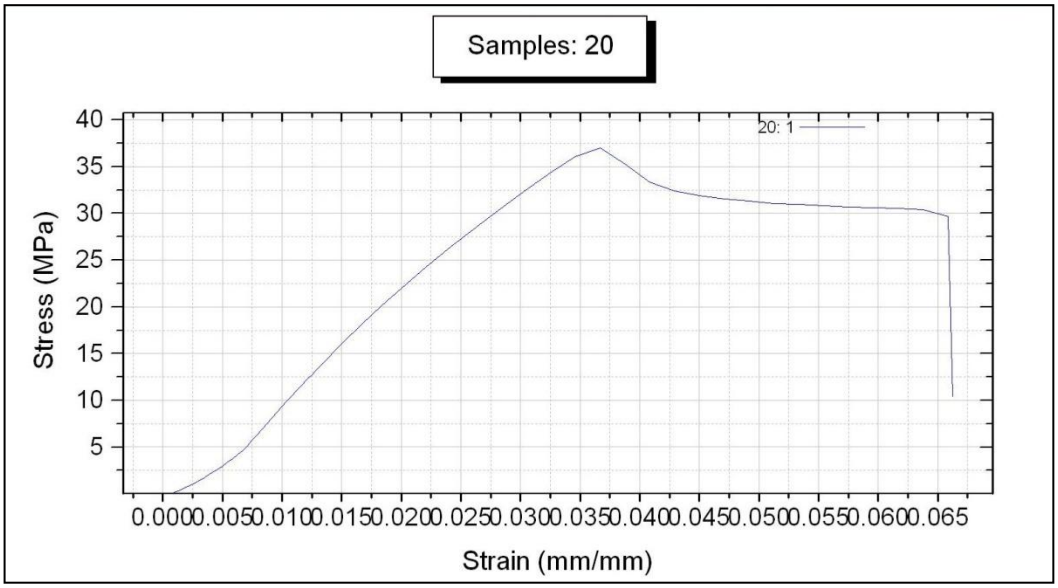

Figure G.20: Stress strain curve for sample 20

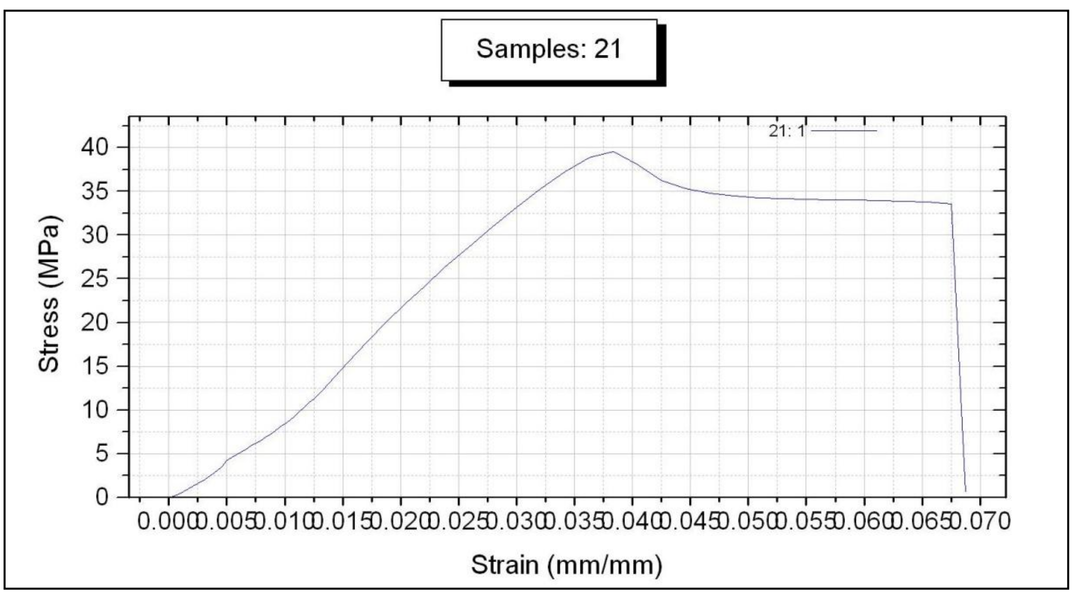

Figure G.21: Stress strain curve for sample 21

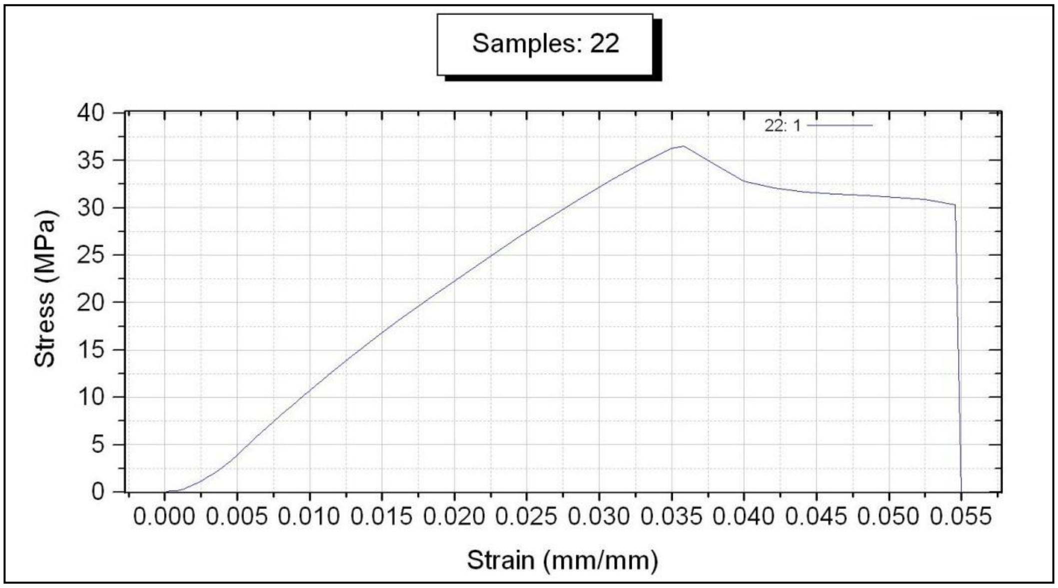

Figure G.22: Stress strain curve for sample 22

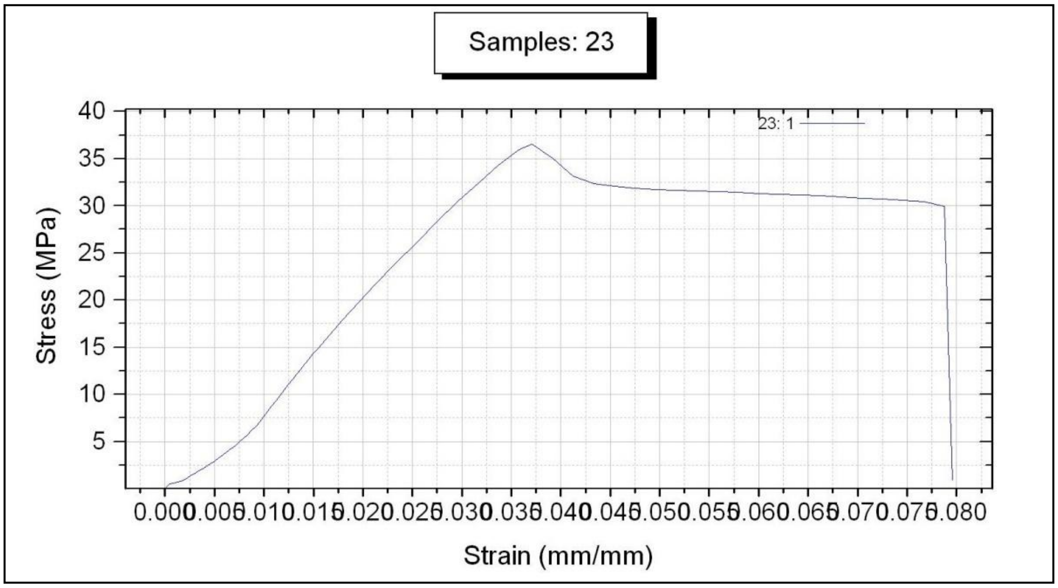

Figure G.23: Stress strain curve for sample 23

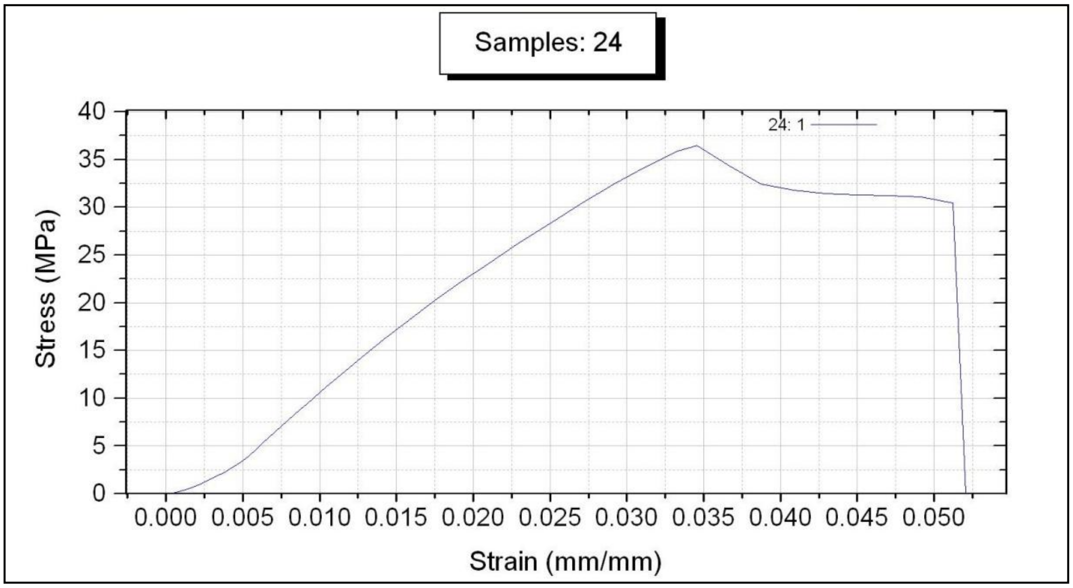

Figure G.24: Stress strain curve for sample 24

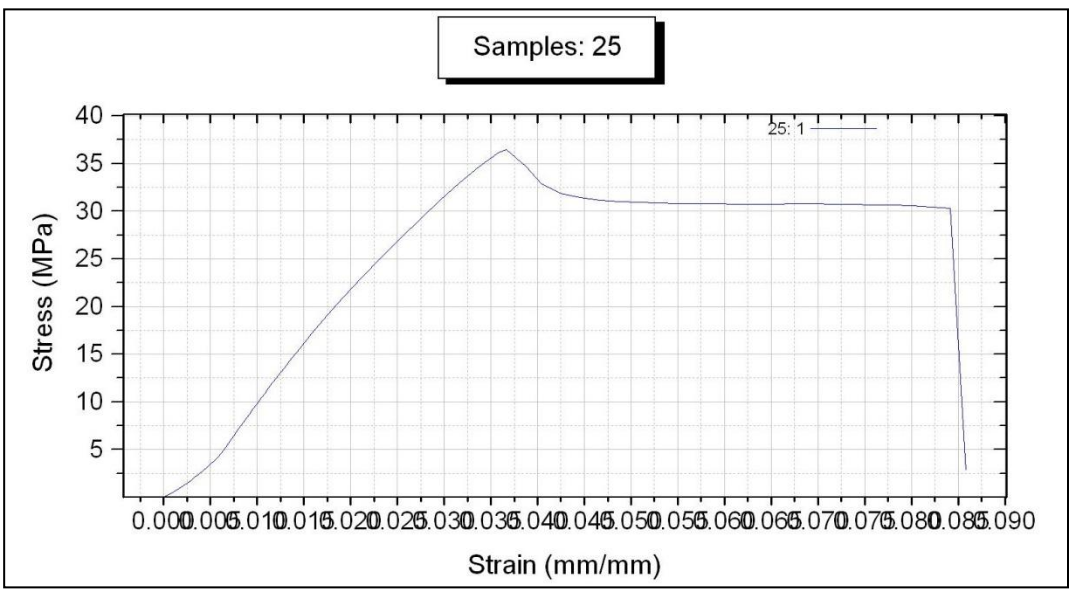

Figure G.25: Stress strain curve for sample 25

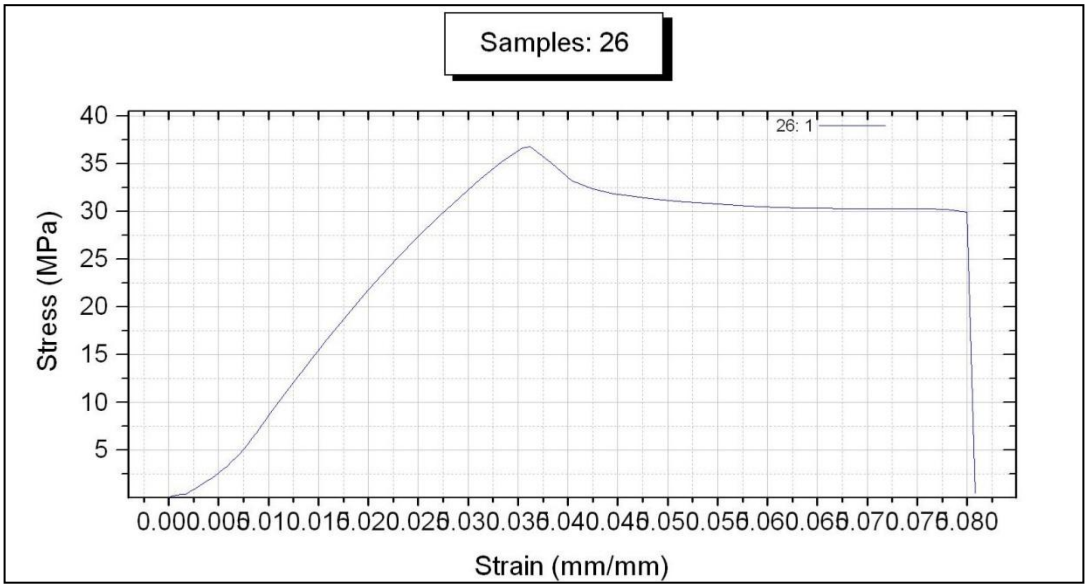

Figure G.26: Stress strain curve for sample 26

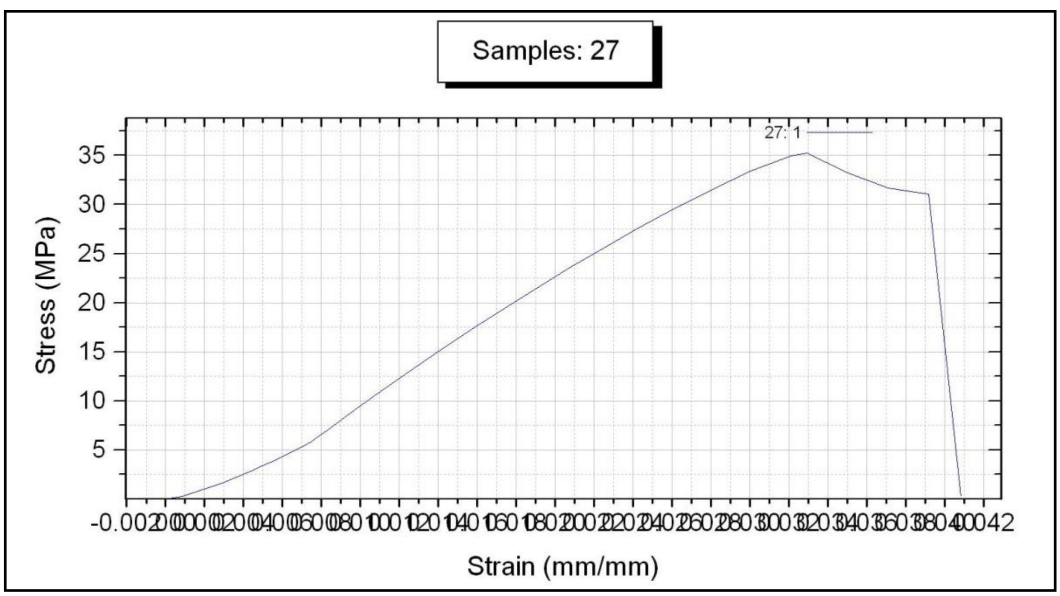

Figure G.27: Stress strain curve for sample 27

APPENDIX A1: Gantt chart/ Project schedule for FYP 1

No.			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Project progress																	
1	Receive PSM title from supervisor.	Planning																
		Actual																
2	Briefing with supervisor to get information.	Planning																
		Actual																
3	Gather and collect information through journals, books, internet and etc.	Planning																
		Actual																
4	Working on the introduction and literature review.	Planning																
		Actual																
5	Working on the methodology.	Planning																
		Actual																
6	Preparation for presentation	Planning																
		Actual																
7	Draft submission to supervisor	Planning																
		Actual																

APPENDIX A2: Gantt chart/ project schedule for FYP 2

No.			1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16
	Project progress																	
1	Current progresses discuss to continue PSM 2.	Planning																
		Actual																
2	Running the injection moulding machine	Planning																
		Actual																
3	Sample produced	Planning																
		Actual																
4	Testing and analysis	Planning																
		Actual																
5	Draft 1 submission to supervisor	Planning																
		Actual																
6	Report correction, and slide submission to supervisor	Planning																
		Actual																
7	Draft 2 submission to Faculty	Planning																
		Actual																
8	Report correction, presentation and final draft submission.	Planning																
		Actual																