AN INVESTIGATION OF ACRYLONITRILE BUTADIENE STYRENE (ABS) IMPACT PROPERTIES SUBJECTED TO THERMAL DEGRADATION

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DEDICATION

This report is dedicated to my beloved parents,

Encik Mohidin Bin Musa and Puan Rabiah Binti Mohamed.

Siblings too.

APPROVAL

I hereby declare that I have read this report and in my opinion this report is sufficient in terms of scope and quality for the award of the degree of Bachelor of Mechanical Engineering (Structure and Material).

Signature : ………………………………

Name of Supervisor: DR MIZAH BINTI RAMLI

Date : 16 JUNE 2017

STUDENT'S DECLARATION

"I hereby declare that the work in this thesis is the results of my own except for summaries and quotations which have been duly acknowledged"

Signature: ………………………………….

Author : NUR AMIRA BINTI MOHIDIN

Date : 16 JUNE 2017

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ABSTRACT

Nowadays, ABS can be said as one of the material that keeps enlarging its applications field especially in electronics devices. ABS is used everywhere without being acknowledge by the consumers. Due to ABS was said as a hard and tough polymers and applications of ABS were at various environmental condition, this study is conducted to investigate the impact properties effect of pure ABS after being exposed at different temperatures and times by charpy impact test method. Exposing the ABS at different temperatures and times are best known as thermally degrading the material. Therefore, this study is aim to investigate the impact energy (absorbed energy) value of ABS subjected to thermal degradation method and also characterize the morphological surface of ABS after being thermally degrade. The samples was fabricated by hot press method and cut into desired shape by referring to ASTM charpy test standard dimension for polymers materials. Samples will be heated at different temperatures under condition defined as 50^{o}C and 80^{o}C and at different times defined as 10, 30 and 50 hours in an oven. Samples at room temperature are also prepared for this experimental investigation for a reference and comparison purpose. Then, the charpy test was conducted to obtain the impact energy value, resilience and percentage of absorbed energy of thermally degrade ABS samples under constant mass, speed, angle and height for the hammer to swing. Moreover, the morphological test was conducted by SEM machine to analyse the fracture behaviour of samples under same magnification. The samples exposed at 80^{o}C temperature absorbed less energy before it breaks into two pieces compared to samples that was exposed at 50^{o}C and the longer the time the samples were heated in the same temperature, the smaller energy it absorbed to fracture the specimen. The fractographic results from SEM recognised an obvious brittle failure mode only exist in samples at 80^{o}C temperature heated for 50 hours by the presence of flat surface structure while others are still behaving as ductile and respectively shows ABS are good and safe to be used at low temperature environmental condition.

ABSTRAK

Pada waktu kini, ABS boleh dikatakan sebagai salah satu bahan yang terus mengembangkan bidang applikasinya lebih-lebih lagi dalam peralatan elektroniks. ABS digunakan di mana-mana sahaja tanpa disedari oleh pihak pengguna. Oleh kerana ABS sering dikatakan sebagai polimer yang kuat dan teguh dan applikasi ABS digunakan pada pelbagai persekitaran, pembelajaran ini telah dijalankan untuk mengkaji sifat hentaman ABS yang asli setelah didedahkan pada suhu dan masa yang berlainan menggunakan kaedah ujian hentaman charpy. Mendedahkan ABS pada suhu dan masa yang berlainan sesuai ditakrifkan sebagai perlakuan degradasi terma terhadap bahan tersebut. Oleh itu, pembelajaran ini bertujuan untuk mengkaji nilai tenaga hentaman (tenaga serapan) ABS bersubjek kepada kaedah degradasi terma dan juga untuk menggambarkan sifat permukaan morfologi ABS setelah dikenakan tindakan degradasi terma. Sampel telah difabrikasi menggunakan kaedah tekanan berhaba dan dipotong kepada bentuk yang ditetapkan dengan berpandukan kepada ukuran piawaian ASTM untuk ujian charpy bagi bahan polimer. Sampel akan dipanaskan pada berlainan suhu yang disifatkan sebagai 50^{o}C dan 80^{o}C dan juga pada masa yang berlainan yang disifatkan sebagai 10, 30 dan 50 jam di dalam ketuhar. Sampel pada suhu bilik juga telah disediakan untuk kajian eksperimen ini bertujuan untuk membuat perbandingan dan sebagai rujukan. Kemudian, ujian charpy dijalankan bagi mendapatkan nilai tenaga hentaman, ketahanan dan peratusan tenaga yang diserap oleh sampel yang telah dikenakan degradasi terma apabila ditetapkan jisim, kelajuan, sudut dan tinggi untuk pemukul melakukan hayunan. Tambahan pula, ujian morfologi telah dijalankan oleh mesin SEM untuk menganalisa tindak laku retakan sampel pada magnifikasi yang sama. Sampel yang dikenakan suhu 80^{o}C meresap kurang tenaga dibandingkan dengan yang dikenakan suhu 50^{o}C sebelum ianya patah menjadi dua dan makin lama masa sampel dipanaskan pada suhu yang sama, makin kurang tenaga yang diserap untuk patahkan sampel. Keputusan fraktografi dari SEM menunjukkan penampakan ketara kegagalan yang bersifat rapuh wujud pada sampel bersuhu 80^{o}C yang dipanaskan selama 50 jam dengan melihat kehadiran permukaan struktur yang rata sedangkan sampel yang lain masih bersifat mulur dan sekaligus menujukkan ABS adalah selamat dan sesuai untuk digunakan pada kondisi persekitaran yang mempunyai suhu yang rendah.

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LIST OF ABBREVIATIONS

ABS	Acrylonitrile Butadiene Styrene
DTA	Differential Thermal Analysis
DSC	Differential Scanning Calorimetry
FDM	Fused Deposition Method
MWD	Molecular Weight Distribution
PBT	Polybutylene Terephthalate
PC	Polycarbonate
PP	Polypropylene
SEBS	Styrene Ethylene Butylene Styrene
SEM	Scanning Electron Machine

LIST OF SYMBOLS

E	=	Total absorbed energy by samples (J)
$m_{samples}$	=	Mass of samples used in one mould = 936 g
g	=	Gravity acceleration value = 9.81 ms^{-2}
h_i	=	Initial height for the pendulum to swing (m)
h_f	=	Final height for the pendulum to swing (m)
ρ_{abs}	=	Density of ABS = 1.04 g/cm^3
v	=	Volume dimension for mould = 900 cm^3
$t_{cooling}$	=	Cooling time for fabrication process = 15 minutes
$t_{preheat}$	=	Preheat time for fabrication process = 7 minutes
t_{press}	=	Pressing time for fabrication process = 10 minutes
P	=	Pressure on hot press machine = 50 kg/cm^2
m_{hammer}	=	Mass of hammer = 23 kg
θ_{hammer}	=	Angle to swing the hammer = 150°
L_{span}	=	Span length = 42 mm
$\sum X$	=	Sum of data set
N	=	Total number of set
x_i	=	Sample value
$\bar{x}$	=	Mean value

CHAPTER 1

INTRODUCTION

1.1 BACKGROUND OF STUDY

Materials are important in the development of civilization where engineers keep them improved day by day. Material selection is a process of designing an object with a main goal to minimize the cost while meeting material performance. Systematic selection of the best material for a specified applications begins with analysing its properties. Properties can be described by how the material respond to the environment. Thus, in this case, an Acrylonitrile Butadiene Styrene (ABS) is selected to study its properties.

Generally, an ABS is a thermoplastic polymers that are hard and tough. ABS is started to be used since year 1950 (Desrousseaux, 2015) and widely applied in different field such as on electronic devices packaging, toys, automotive industries, hospitals furniture (James,1985) and much more as shown in Figure 1.1. Different applications of ABS also indicates the different environmental condition. This shows that application of ABS will experience a different environmental temperature until it has a major failure. Therefore, it is important to test ABS performance under different temperature to determine its ability.

Figure 1.1: Product made up of ABS material (James, 1985)

1.1.1 Polymers

Polymers material is most frequently used in the manufacturing process for industrial productions (Gan, 2009). It is widely used as a based material for most daily appliances. Polymers are constructed with relatively small molecular fragments called monomers. Polymers can be classified into two, which are synthetic polymer and natural polymer (Rich, 2011). Synthetic polymers are human made polymers that are prepared synthetically from low molecular weight compounds while natural polymers are generally obtained from nature (Anonymous, 2015). Figure 1.2 shows the classification of a polymer and its product example.

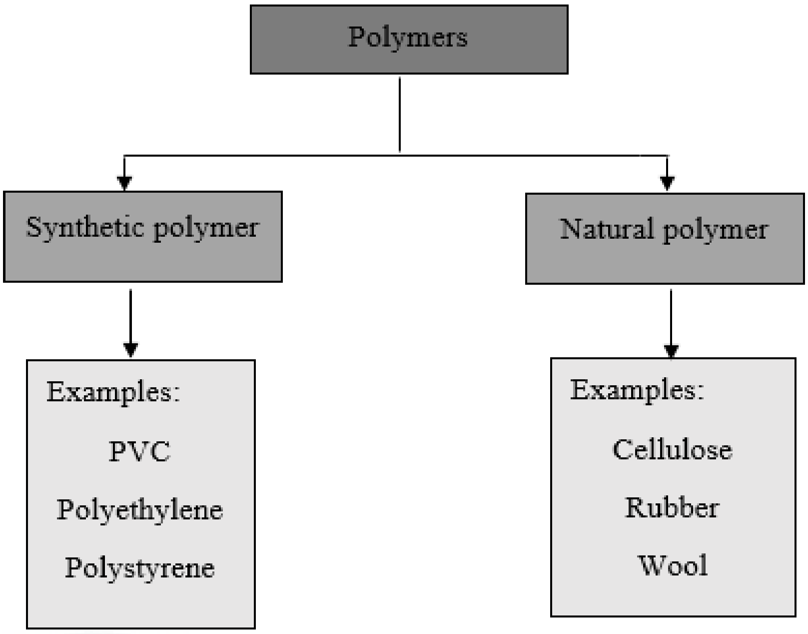


Figure 1.2: Classification of a polymer (Rich, 2011)

Polymers are widely used as adhesive in coatings, foams and packaging material in different industries. It is also used as fibres, composite, biomedical devices and electronic devices for new high technology purpose (James, 1985). The physical properties of a polymer in term of its strength and flexibility depends on its chain length, side groups, branching and cross linking. Furthermore, types of a polymers can be divided into thermoplastics and thermosetting plastic. The uses of plastic over metal material can give more advantages where plastic material is mouldable (Chanda, 1993). In addition to that, a plastic is an insulator, it will not lead to an adverse impact on material in the same way a metal would. The developments of materials that called polymer began with Rayon in 1981, Bakelite in 1907, Polyethylene in 1933, Nylon and Teflon in 1938, Polypropylene in 1954, Kevlar in 1965 (Sameer, 2012) and still continuing.

1.1.2 Thermoplastic

Thermoplastic can be define as materials that get soften while heating and can be remoulded in many shapes and pattern. After cooled down, it becomes solid again. This type of polymers can exist in amorphous and crystalline form. The amorphous structure acquired a bundle structure while crystalline structures of polymers contain ordered and compact arrangement (Dolgov, 2007). An Acrylonitrile Butadiene Styrene (ABS), Acrylic Plastic, Polypropylene (PP), Polyester and Polybutylene Terephthalate (PBT) are the examples of thermoplastics polymer (James, 1985).

Even though thermoplastic material has high impact towards resistance, capabilities to remoulding and reshaping, but they still higher in cost and ease to melt. Figure 1.3 shows the properties of ABS type Polylac PA-757. An ABS is on considered as a focused material in this research to study about its behaviour on impact testing.

Table 1.1: Physical properties of ABS (General ABS Polylac Characteristics PA-757, 2013)

PROPERTIES	ASTM METHOD	TEST CONDITION	UNIT	ABS (PA-757)
Tensile Strength	D-638	6mm/min	kg/cm^2 (lb/in^2)	460 (6 520)
Tensile Elongation	D-638	6mm/min	%	25
Flexural Modulus	D-790	2.8mm/min	$10^4 kg/cm^2$ ($10^5 lb/in^2$)	2.7 (3.8)
Flexural Strength	D-790	2.8mm/min	kg/cm^2 (lb/in^2)	790 (11 660)
Rockwell Hardness	D-785	-	R-Scale	R-116
Izod Izod Impact Strength (Notched)	D-256	1/8’’ 1/4’’	kg-cm/cm (ft-lb/in) kg-cm/cm (ft-lb/in)	21 (3.9) 18 (3.3)
Vicat Softening Temperature	D-1525	50°C/hour	°C (°F)	105 (221)
Heat Distortion Temperature	D-648	Annealed Unannealed	°C(°F) °C(°F)	95(203) 85(186)
Specific Gravity	D-792	23°C	-	1.05
Flammability	Fil No E56070 UL&C-UL	-	-	1.6mm HB

1.1.3 ABS

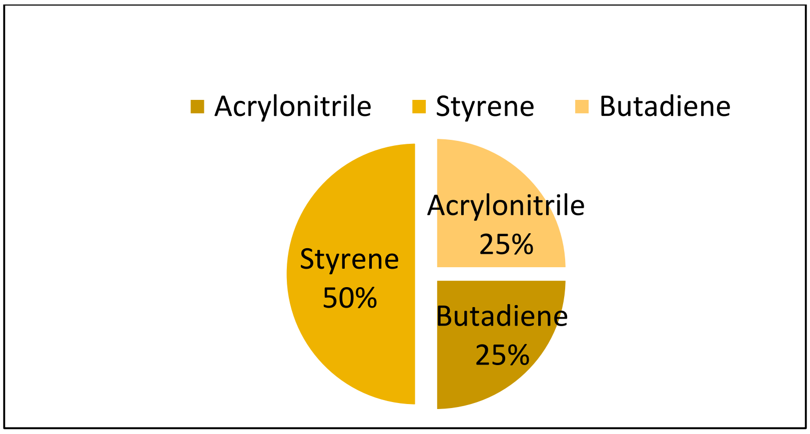


Figure 1.3: Composition of an ABS (Hashim, 2013)

Figure 1.4: Pellets of ABS

ABS is an oil based filament that is opaque and translucent. As shown in Figure 1.3, an ABS is a copolymer comprised of polymerized styrene and acrylonitrile with polybutadiene (Hashim, 2013). Based on application, half styrene with balance divided equally between butadiene and acrylonitrile are generally used in industries. Figure 1.4 shows the ABS pellets used in this study. This is a low cost engineering products that is easy to machine and fabricate. ABS can be fabricated by injection moulding or hot press technique (Jose, 2001). A virgin ABS seems to be expensive, thus the virgin ABS can be blended with recycled ABS which is economically attractive, while preserving high quality. Because of its non-toxic and recyclability characteristics, ABS is recommended compared to acrylic plastic where it is also a lightweight material and have high impact resistance (Perez, 2010).

1.2 PROBLEM STATEMENT

ABS is widely used in daily life. Application of ABS such as toys, car parts and on electrical device are used in different environmental condition either hot or cold, indoor or outdoor and days or night. Changes in temperature always influence the material performance in toughness properties because temperature effect may change the microstructure of the material as well as the ability to absorb energy. Therefore, it is significant to study the impact force at pure ABS material subjected to thermal degradation.

For better understanding, a modern refrigerator is one of the major applications of ABS where it is used in the making of the door liners of this device (ABS- Acrylonitrile Butadiene Styrene, 2013). This device can be used as an example of cases. The door liners is expected to receive an extreme force during opening and closing of the device. Moreover, the door liners of the refrigerator will also experience a heat transfer from the device to its surrounding. Therefore, it is significant to study the impact force of ABS material subjected to thermal degradation.

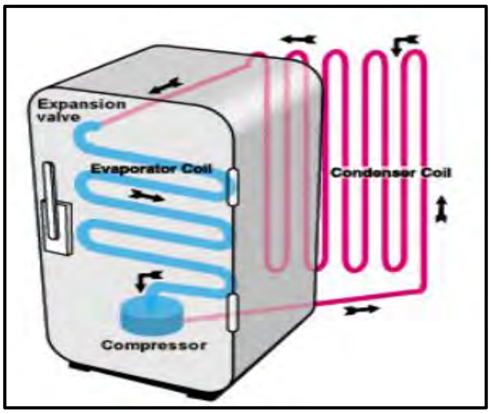


Figure 1.5: Illustration of heat transfer in refrigerator
(source from http://refrigeratorillustration)

1.3 OBJECTIVES

This study is aim to investigate the impact properties of ABS subjected to thermal degradation. Thus, the objectives of this project are:

i. To investigate the absorbed energy (absorbed energy) of ABS subjected to thermal degradation.

ii. To characterize the morphological surface of ABS subjected to thermal degradation.

1.4 SCOPE

A proper guideline need to be construct to ensure this project can be finished smoothly and satisfied the scope. The scopes of this project are to conduct literature on ABS impact properties subjected to thermal degradation. Journals, articles or any materials regarding this project were reviewed to assist the studies. The plates are prepared using hot press machine. Next, conduct experimental test under different condition by varying its temperatures and times in oven. Each sample will be give an impact test on it. Then, undergoes a morphological study of ABS by using SEM (Scanning Electron Microscope). All results gain from experiments in laboratory will be recorded and the morphological surface structure of an ABS that undergoes thermal degradation and impact test will also be analysed. After that, data analysis will be done and interpret in the form of figures, tables and graphs. Finally, a complete report writing will be conducted to accomplish this study.

CHAPTER 2

LITERATURE REVIEW

2.1 ABS

ABS has a big molecular mass with its formula $(C_8H_8{\cdot}C_4H_6{\cdot}C_3H_3N)_n$ shows a long carbon chain that consist of monomers acrylonitrile, butadiene and styrene. The atomic components includes carbon, hydrogen and nitrogen where carbon is the dominant atom in this structure. With the presence of two double bond (C=C) in butadiene monomers, the butadiene structure can be very reactive. Butadiene will contributes to the toughness and impact resistance in ABS compound. ABS loss its strength due to loosen in butadiene carbon-carbon double bond. The double bonds in the elastic rubber phase in butadiene monomers will decrease the toughness of ABS in response to long term heat effect (Joseph, 1986).

Campo et. al, in this study described an Acrylonitrile Butadiene Styrene (ABS) as a polymeric material. Chemical structures of ABS made up of three substances as shown in Figure 2.1 below. This journal stated that an ABS is tough and good impact resistance material through the contribution of butadiene monomers. Because of its individuality towards morphological analysis, more products have been produced in industries. ABS performance are stated to be well in usage of alloys and blends because the combination of plastics enhanced a positive features. Table 2.1 shows the typical applications of ABS that is used by humans (Campo, 2007).

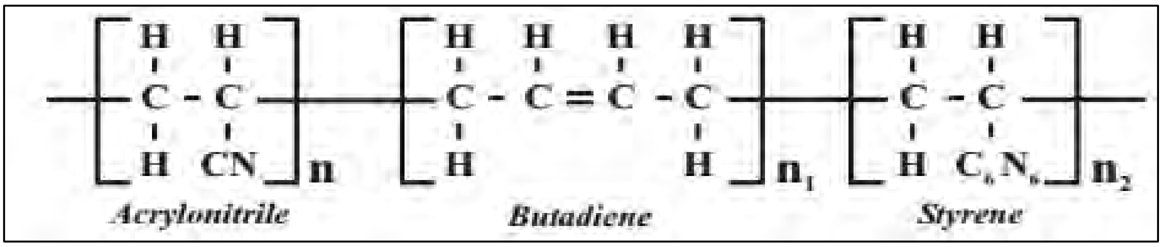


Figure 2.1: Chemical structure of ABS (Joseph, 1986).

Table 2.1: Typical application of ABS (Eric, 2016)

APPLICATION	DESCRIPTION
Refrigerators	Doors and food liners for the interior wall, shelves, evaporator part trays and breaker strips.
Automotive Appliances	Seat belt retainers, headlight, mirror housing and armrest.
Home appliances	Hair dryers, blenders, vacuum cleaners and coffee makers.
Recreational	Motorcycles moulding, sailboats, airplanes, campers and picnic cooler liners,
Other applications	Briefcase, cosmetic cases, toys, photographic equipment and household packaging

Gorski et. al, study on utilizing an Acrylonitrile Butadiene Styrene (ABS) as the tested material define that different angle of orientation in fabricating samples gives a different strength results. The fabrication of the ABS specimen has been carried out by using fused deposition modelling (FDM) and injection moulding method in order to determine its mechanical strength ability and will presents the results of impact strength test. Samples are manufactured under different orientation at angle from 0^o to 75^o with difference of 15^o angle each. As a results, the samples of ABS fabricated using FDM method is weaker than injection moulding method. Effect of weak bond between layers in FDM parts and volume error that is defined not monolithic are the main reasons FDM will never be as strong as the injection moulded parts out of the same material. All 30°C orientation and only certain 15°C orientation in y-axis experiencing brittle behaviour on the specimen that shows low elongation, failure at disjoint layer and no yield point. For the impact strength test, parts with orientation of angle higher than 45°C have no impact strength at all and assumed that it were lower than the sensitivity of the measuring equipment (Gorski, 2015).

Krache et. al, in this study used Acrylonitrile Butadiene Styrene (ABS) and Polycarbonate (PC) to determine its thermal and mechanical properties. It has been determined by the results of blend ABS/PC to test its impact strength by Izod impact test. Both polymer are prepared to dry in vacuum at 100°C and 70°C for PC and ABS respectively about 24 hours before processed. The izod impact test was performed on notched specimen according to ASTM D 256-73 using CEAST pendulum with 7.5J hammer. The results shows that materials blends with lower ABS content gives high impact strength (Krache, 2011).

Peydro et. al, in this research studies the mechanical properties of recycled Acrylonitrile Butadiene Styrene (ABS) mixed with Styrene Ethylene Butylene Styrene (SEBS). Charpy axial impact pendulum test is conducted on mixed ABS/SEBS. The samples were prepared by degradation process at two injection moulding temperature 220°C and 260°C and repeated for five cycles. The mixing of ABS and SEBS were obtained using twin screw extruder via varying the percentage of SEBS by 0, 2.5, 5 and 10% in weight. As a results, mixing of SEBS more than 5% at higher temperature (260^oC) gives high impact strength because presence of SEBS in degraded ABS allowed the recovery of the lost ductility (Peydro, 2014).

2.2 Thermal Degradation

Madorsky et. al, study about thermal degradation effect of molecular structure on chains and side groups of polymers when heated in vacuum condition at certain temperatures. Each polymers have its own molecular weight which was determined cryoscopically in suitable solvent. The rates of degradation were define as the loss of weight in polymer samples by a high sensitivity tungsten helical-spring balance. Polymers are used to describe the mechanism of this type of degradation. It is observed that a polymer chain tends to break its carbon-carbon (C-C) bond at its weakest points. Figure 2.2 illustrates that, the breaks in polymers material will happened easily in the bonds which are adjacent to a tertiary or quaternary carbon in the chain structure compared to the (C-C) structure in series position. The bonding between carbon atom and side group atoms such as carbon-fluorine (C-F) structure shows better strength than atoms bonding in carbon-hydrogen (C-H) structure. Thus, from this study the pattern of thermal degradation of products are a function of their molecular structure that will effects its stability (Madorsky, 1954).

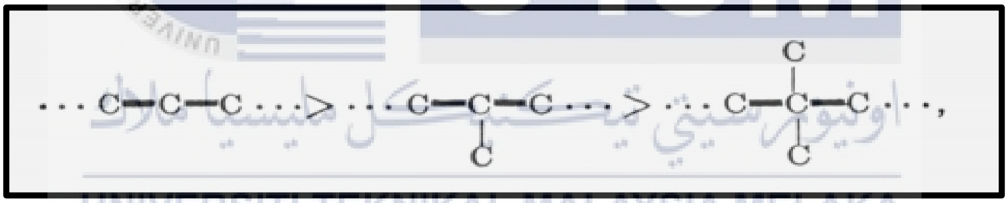


Figure 2.2: Increasing strength of C-C bond (Madorsky, 1954)

Wachik, study on thermal degradation of polymers reveals that thermal degradation of a sample refers to condition where the samples are placed at elavated temperatures. The samples will starts to undergoes a chemical changes to change its material properties. Polymers are basically cassified into two natural and synthetic that shows a synthetic polymers are man-made molecules that have longer chains containing carbon atoms. In polymers materials, at certain point when its reached a certain temperatures that sufficient to react with the monomers, the strength of the polymers will becomes greater. Mechanically, this effect may be viewed macroscopically under the influence of shear force. The bond will seems to always ruptures in the polymer main-chains to eventually shows its decreasing ability in strength. Analytical test method to determine polymer’s thermal degradation effects may be done via differential thermal analysis (DTA) method, differential scanning calorimetry (DSC) method or by calculating its molecular weight distribution (MWD) to characterize a polymer (Wachik, 2013).

2.3 Impact

In a research about impact testing of advanced material stated that polymers is frequently used material because it withstand impact damage. Impact testing involve high and low velocity impact where charpy fits the low velocity impact testing category. From the impact testing, the impact toughness properties of various material can be test. In pendulum test, the pendulum will strikes the specimen at fixed height and rise to a certain height. The changes in height directly provide the amount of energy lost to fracture the specimen (Plastic Determination of Charpy Impact Properties, 1997). From that, the total energy of fracture can be determine based on Equation 2.1.

$$Energy_{total} = mg\,(h_i - h_f) \qquad (2.1)$$

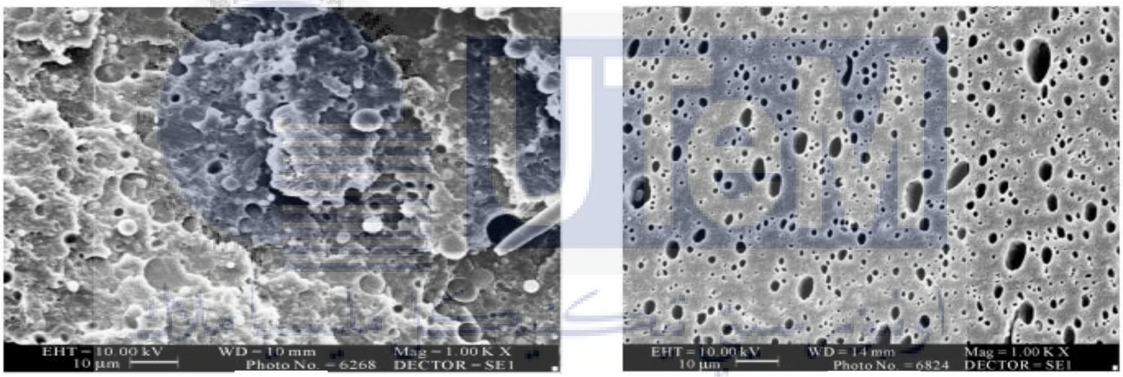
where,

m = *mass (g)*
g = *gravity acceleration (ms^{-2})*
h_i = *initial height*
h_f = *final height*

Brostow et. al, study on the brittleness of material related to the impact strength define that brittleness shows the dimensional stability of a material. Thermoplastic materials such as ABS, PC, PP and PS was chosen and conducted mechanical properties. The specimen was run at temperature -15°C to 60°C for 5°C/minutes to test its impact resistance and ABS resulting to be one of the materials that have middle-range brittleness compared to PC, PP and PS. From this, it can be said that the lower the brittleness, the higher the dimensional stability in cyclic loading (Brostow, 2009).

2.4 Morphology Study

Krache et. al, on a study to determine the mechanical and thermal properties of PC/ABS blends had revealed the morphological results under SEM observations. The surface characterization of this blends are complex and depends on the composition. Figure 2.3(a) shows a (90/10) PC/ABS blends micrographs that contains a spherical inclusions at the ABS phase and resulting for a uniform blend look when viewed under SEM. Moreover, Figure 2.3(b) that shows micrographs view for the (40/60) PC/ABS blends was characterized by the presence of nodules in ABS matrix with an irregular dispersion. From this, it can be conclude that PC is a very good heat resistant material. Between PC and ABS there are no chemical reaction that might messed its structure. Thus, a partially miscibility between PC and ABS can be attribute (Krache, 2011).



(a) (b)

Figure 2.3: SEM images for PC/ABS blends (a) (90/10) PC/ABS blends (b) (40/60) PC/ABS blends

Lu et. al study on the accelerated life testing of structural polymers under cyclic loading revealed the fractographic images viewed under SEM machine. Carbon particles filled with PC was used to determine its microstructure behaviour after all specimens are annealed at 100°C for 3 hours and 140°C for 6 hours and then applied an un-notched thin fatigue test. When the fracture surface of all fatigue test specimens viewed under SEM, it was shown that at room temperature, a ductile fracture appears dominant and after the temperature are increased to 60°C still the surface shows a ductile failure mode. At temperature of 80°C and 100°C, all fracture behaviour look ductile and a high plastic deformation zones are well developed (Lu, 2006).

CHAPTER 3

METHODOLOGY

3.1 Introduction

This chapter discuss about the methodology that was used in order to complete this project. This project involved specimen fabricating, thermal degradation of specimen at different temperatures and proceed with charpy pendulum impact test. After fulfil all the steps, the specimen fracture surface behaviour were analyse by using Scanning Electron Microscope (SEM). The standard test method of ASTM D-6110 (Standard Test Method for Determining the Charpy Impact Resistance of Notched Specimens of Plastic, 2002) was used as a reference in determining the charpy impact resistance of notched specimen. The dimensions of tested samples are:

Notch type	*:V-notched*
Thickness	*: 10mm*
Width	*: 10mm*
Length	*: 55mm*

Furthermore, in every steps taken to complete this project, a good health and safety practices had been followed at every workplace. A proactive approach to protect own safety had been strictly practiced to make sure everyone are not exposed to greater risk or any danger that may harm users and lab belongings. Every lab work was assist by technician and also, the faculty rules and regulations are followed all the times.

3.2 Preparation of Samples

3.2.1 Fabrication Process

The procedures of fabrication process is started by the mould preparation method. Then, the mould will be used to form an ABS samples by hot press technique.

The moulds used based on Figure 3.1 are made from a steel type material which can withstand a very high temperature during hot press. The mould should be clean thoroughly before been used because it can easily get rust when exposed to wet environment.

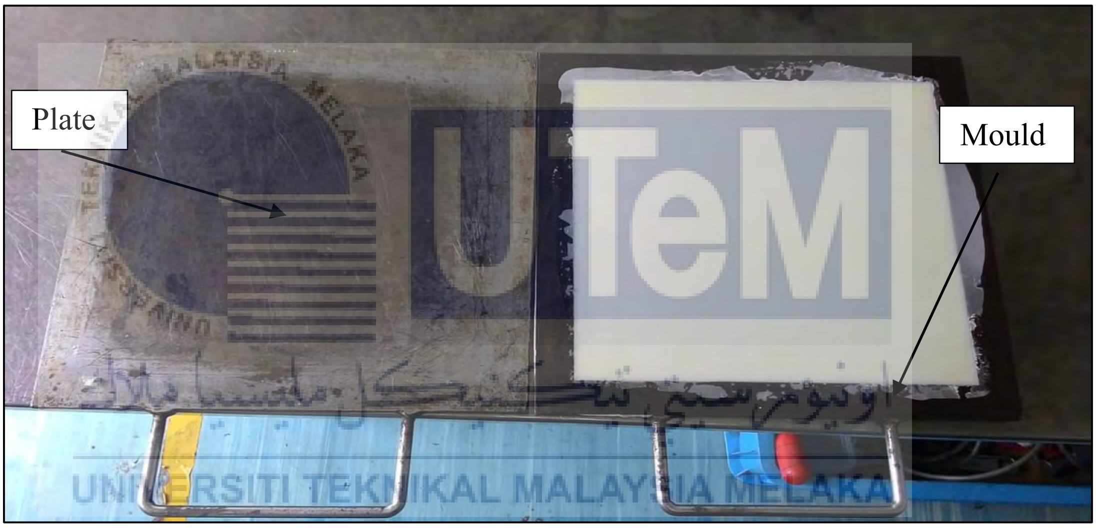


Figure 3.1: Mould used to fabricate ABS pellets

Acetone as shown in Figure 3.2 is the cleaning agents that been used to remove dirt and any contaminations. Firstly, the mould was soaked in acetone liquid to remove any leftover impurities to ensure a smooth surface and clean samples are produced. Then a thin layer of wax agent is applied all over the mould to ease the removing process of the samples from the mould at cooling process later. Then the mould is ready to be used for next process. This pre-cleaning process may took longer time and need to be handle properly because contaminated moulds will effects the samples surfaces and leads to defects.

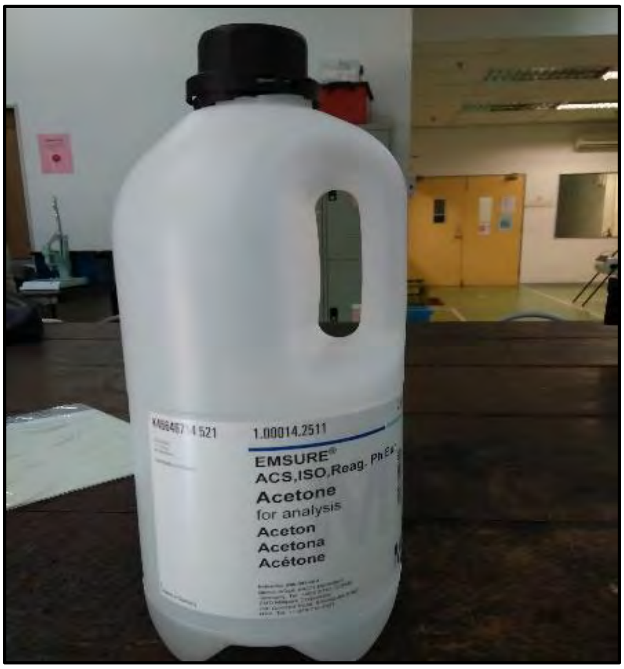


Figure 3.2: Acetone liquid

As the mould is prepared, the next steps is to proceed with the fabrication part. An exact amount of ABS pellets are in need so that it will not spilled or overflow from the mould when melted during hot press process. In order to estimate the amount of ABS used, the density of ABS is required. Based on Equation 3.1 shown below, the amount of ABS pellets used to fabricate one specimen is calculated from the product of ABS density with volume of mould used. ABS pellets were weighed to 940g and poured into the mould.

Mould volume = 300mm×300mm×10mm = 900000 mm^3 @ 900cm^3

Density of ABS = 1.04 g/cm^3

$$\rho = \frac{m}{v} \text{.................................(Equation 3.1)}$$

$$1.04 \text{ g/cm}^3 = \frac{mass}{900cm^3}$$

$$\text{mass} = 936\text{g} \approx 940\text{g}$$

where,

p= density of ABS (g/cm^3)

m= mass of ABS needed (g)

v= volume of mould (cm^3)

The pellets of ABS is poured into the mould and covered by mylar sheet at top and bottom as shown in Figure 3.3 below. Mylar sheets helps to produce a shiny and flat surface of specimens without bubbles. When the preparation of mould is complete, then the power source of machine is switched on and let to be reached the temperature of 180°celcius where at this temperature ABS starts to melt. Parameters such as the pressure value, preheat time, pressing time and cooling time was set. The preheat time was set to 10 minutes to ensure within that term the temperature of the hot press machine with mould temperature will get balanced. The pressure value was fixed at 50 kg/cm^{2}and material is pressed about 10 minutes.

Figure 3.3: Mylar sheet covering method

A Hydraulic Molding Test Press machine by GoTech as shown in Figure 3.4 was used to conduct hot press technique. The operation procedure of using this machine is started by preheating process where the mould with raw material was placed between upper and lower heating die (hot press area) without being pressed yet. As stated above, it is important to get a thermally equilibrium temperature between upper and lower heating die so that it will compress the material at same temperature. Then the compress button is pushed upwards to move the lower heating die (cooling process area). Stop button is used to stop the loading when the upper and lower heating dies grip the mould. Table 3.1 shows the parameters set up in fabrication process. Then, cooling process occur by water quenching from Souwa Electric Water Pump as shown in Figure 3.5. This machine pump water to cool the mould for 15 minutes before it was removed. Then a clean and smooth surfaced specimens are produced as shown in Figure 3.6.

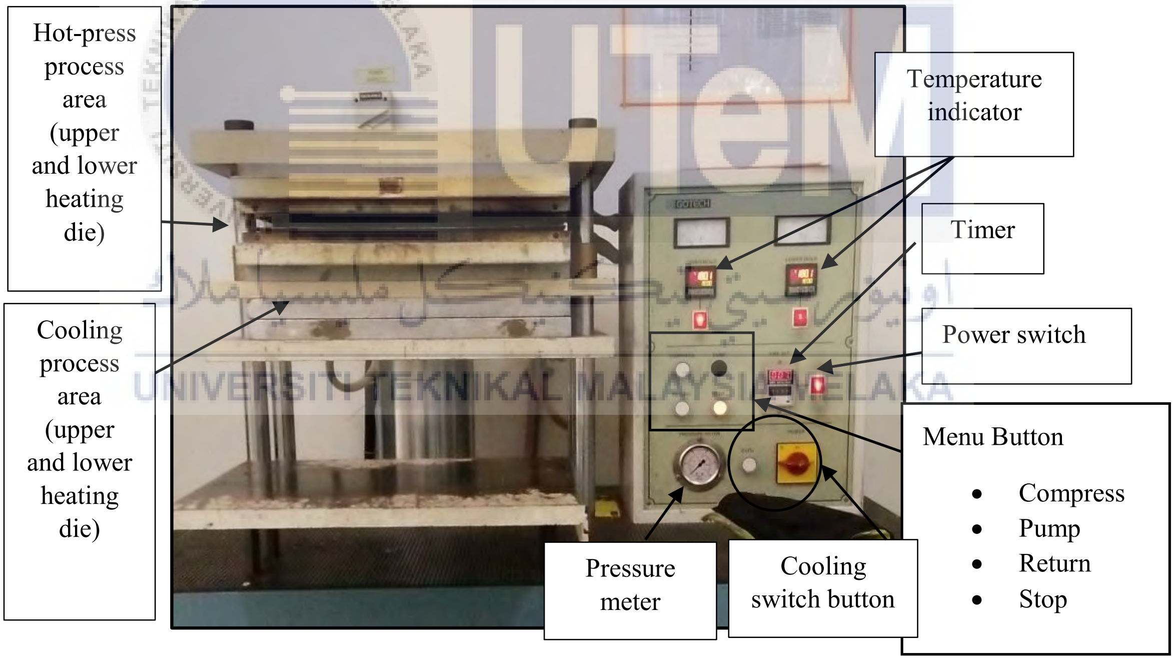


Figure 3.4: Hot press machine

Figure 3.5: Water quenching machine

Table 3.1: Parameters set up for hot press method

PARAMETERS	**VALUE**
Pressure, P	50kg/ cm^2
Temperature, T_m	180°C
Preheat time, $t_{preheat}$	7 minutes
Pressing time, t_{press}	10 minutes
Curing time/ cooling time, $t_{cooling}$	15 minutes

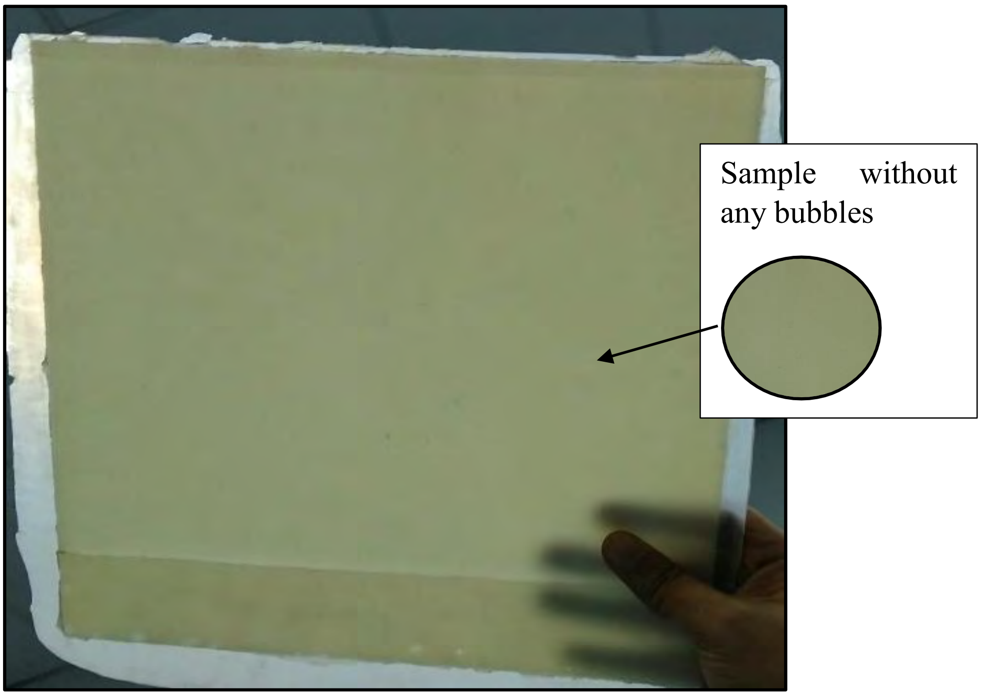


Figure 3.6: Sample produced by hot press method

3.2.2 Cutting Process

3.2.2.1 Waterjet Machine

The first stage cutting process is conducted by using Flow Waterjet machine as shown in Figure 3.7. This machine will help to cut a rectangular size shape as drawn in Solidwork software. The default speed of water flow that has been set by technician was used to run the machine. While operating with this machine, the emergency button should always kept to be turned on to ease the machine to be stop on the spot if there is any unexpected situation occurs. The most beneficial about using waterjet is that there will be no heat affected zone compared to when using a laser cutting machine. If the specimen is cut with laser cutting machine, it will be burn out. This is because the specimen was too thick and it need a higher power of projected flame spark.

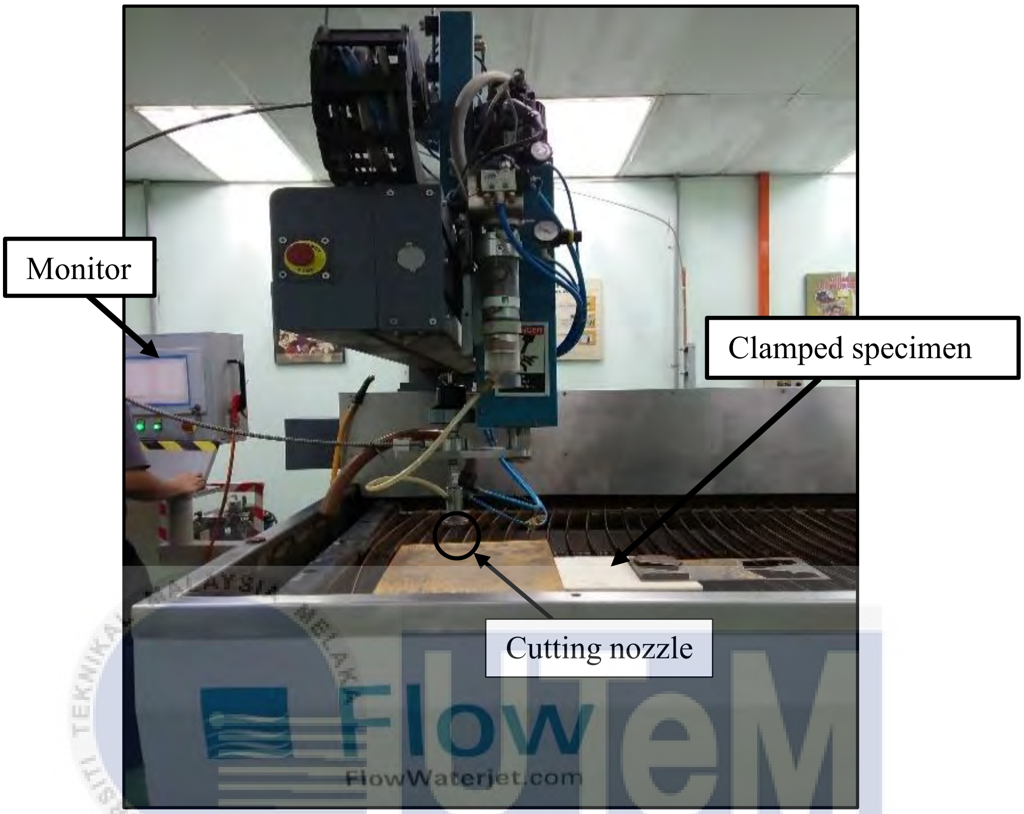


Figure 3.7: Waterjet machine set-up

The procedure start with releasing all the emergency button at the monitor, front of machine and the right side of machine. Then the switchboard, isolator, air compressor and water tank pipe was turned on. Before run the machine the abrasive tank is checked and filled if it is not fully occupied. The Garnet mesh type-80 as shown in Figure 3.8 is required as an abrasive material that will cut the specimen with high velocity flow of water.

Next, the specimen that is ready to be cut was clamped. Then, the drawing that has been save in dxf-type format was opened. The drawing is done by exceed the real dimension at the start and ending point. This is to prevent the samples from falls in the water tank immediate after it have been cut. After all connection had been checked, the program is run and cutting process start. The produced samples from waterjet machine cutting is shown in Figure 3.9.

Figure 3.8: Abrasive material type garnet mesh 80

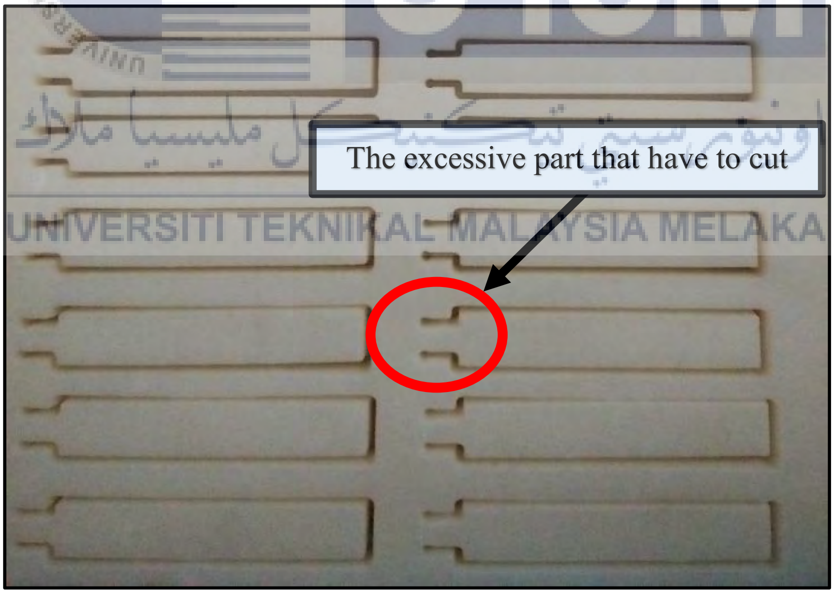


Figure 3.9: Produced specimen from waterjet cutting process

3.2.2.2 Professional Mitre Saw Tools

This mitre saw machine as shown in Figure 3.10 is used to remove the excessive part from the waterjet cutting process. This machine is used manually and able to cut any straight line. This machine is not recommended to cut curve shaped object.

Firstly, the markings is done on the specimen to ease the cutting process. Then, the power switch was opened and the specimens was placed on the stage. Next, the saw are adjusted straight to the line that has been mark. Then the specimen is move towards the saw when its machine starts running. The produced samples from this process was then been get to the laboratory again for creating notches.

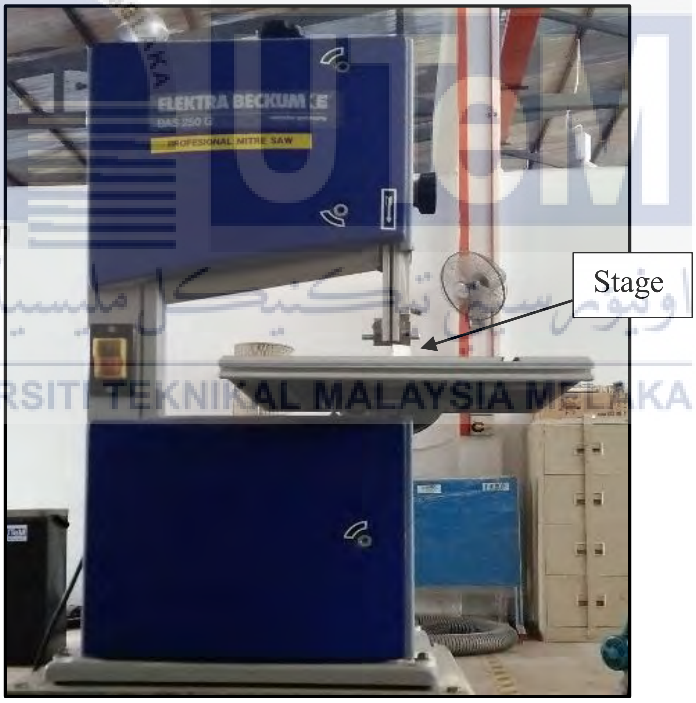


Figure 3.10: Professional mitre saw machine

3.2.2.3 Flat File Tools

The specimen that fits into the charpy impact tester is a rectangular bar with a notch cut in one side. The notch serves as a stress concentration zone and predetermined crack initiation location. The notch depth is fixed for 2mm at an angle of 45°. A sharper and accurate notches are required in all specimens to distinguish its behaviour after experienced certain heat treatment. Notches should be smoothly made to ensure its sharp tip is not damaged. In this project the notches making is done manually due to the lack of facilities.

The process of making notches was started with marking one straight line at the centre of specimen as a guidance point to place the file when to start filing as shown in Figure 3.11. Then, the file was tilt at an angle of 45° and filing was begin up to 2mm depth. The most accurate specimen is chosen by looking of the accuracy towards notches depth and notches angle. Finally, the specimens as shown in Figure 3.12 are prepared and ready to be used for heat treatment.

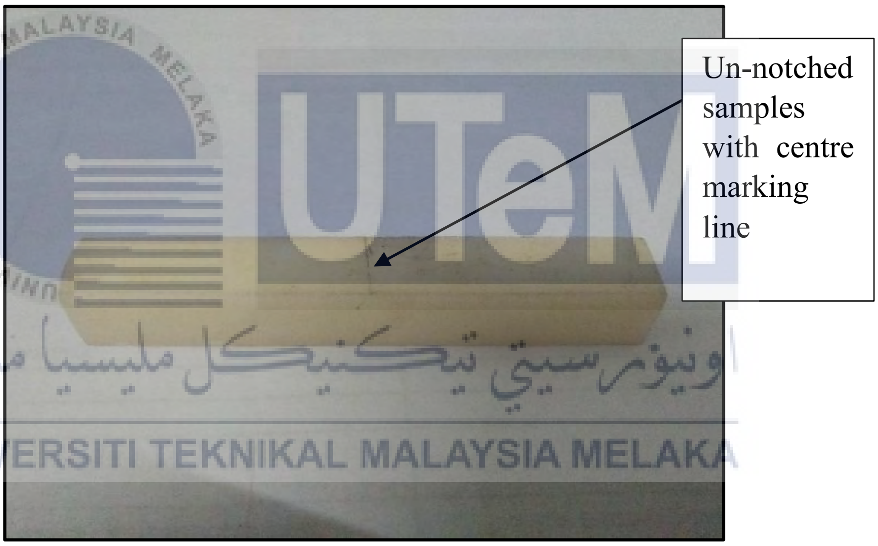


Figure 3.11: Un-notched samples

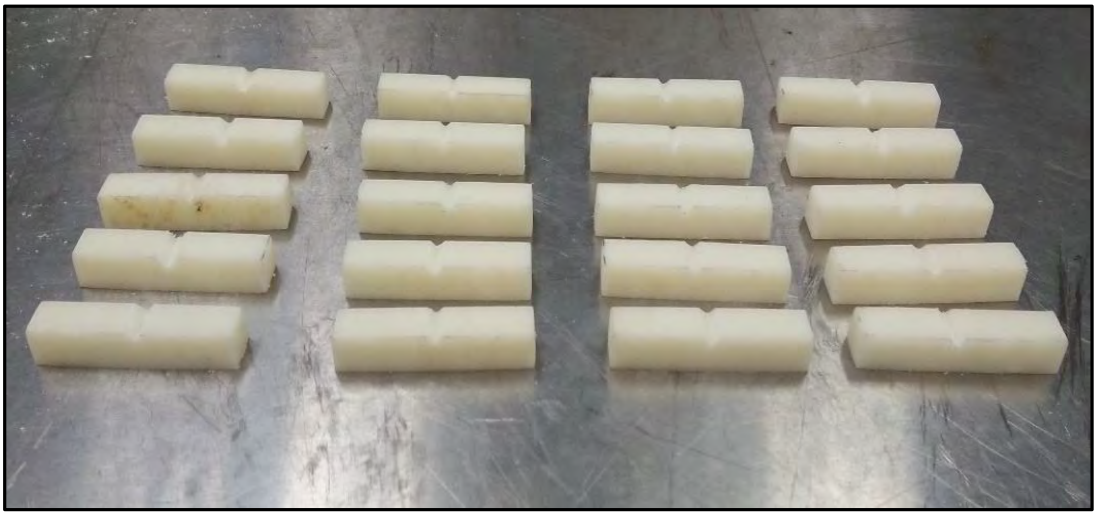


Figure 3.12: V-notched samples

3.3 Thermal Degradation using Oven

Thermal degradation is an enclosure used to test the effects of specified environmental condition on material. Exposed the samples with varying the temperatures values at different time (in unit hours) on this oven is expected to give a different result during impact test. The specimen are left to be exposed in constant temperature value at 50°C and 80°C for 10, 30 and 50 hours. An overview of this process is roughly shown in Table 3.2. From ABS material data sheet given by the supplier, the glass transition temperature of ABS are at 105°C (Chimei Corporation, 2013). Therefore, according to JEDEC standard, in condition-J (JEDEC, 2009), the temperature treated on samples should be in between 0°C - 80°C so that it will not exceed the glass transition temperature value. This is the due to having a completely solid samples even tough had been heated in different level.

Table 3.2: Tabulation of data by charpy pendulum impact test

TEMP. (°C)	SAMPLES	**TIME (Hours)**											
		10 Hours				**30 Hours**				**50 Hours**			
50 °C		1	2	3	**Ave**	1	2	3	**Ave**	1	2	3	**Ave**
80 °C		1	2	3	**Ave**	1	2	3	**Ave**	1	2	3	**Ave**

Figure 3.13: Oven machine

The Memmert brand oven as shown in Figure 3.13 above is used for this heat treatment method. By referring to the graph in Figure 3.14, two ovens is used to ease the heat treatment process. Both oven hold different temperature that has been set which is Oven 1 has conducted the heat treatment at temperature of 80°C while Oven 2 conducted for 50°C temperature. Both oven have been start operate at the same time. Firstly, the power source is switched on and all parameters was set. The time was set for 7 minutes (which is equal to 0.1167 in unit hours) for the temperature to rise up from 0°C to 80°C in Oven 1 and 50°C in Oven 2 respectively. Then, the timing for the constant temperature was set to 10 hours. Finally, cooling process will occur at the end of this process where the temperature is same as the room temperature at 23°C.

After setting all the parameters and the oven starts to operate, all samples were placed in the oven. After 10 hours in the oven, three samples were removed from the oven. That sample will be named as ABSI-50-10 where the first part shows that this is a sample using ABS material and will be conducting an impact test at temperature 50°C for 10 hours. After been cooled, the samples were immediately sealed to avoid any heat transfer to the environment. The samples are also been protect by inserting a silica gel. Silica gel is functioned to absorb any moisture in the system. After reached 30 hours of heating, another three samples were taken out and finally the samples left for 50 hour was taken out. All of this samples will be used to proceed with testing and samples at room temperature condition was prepared too.

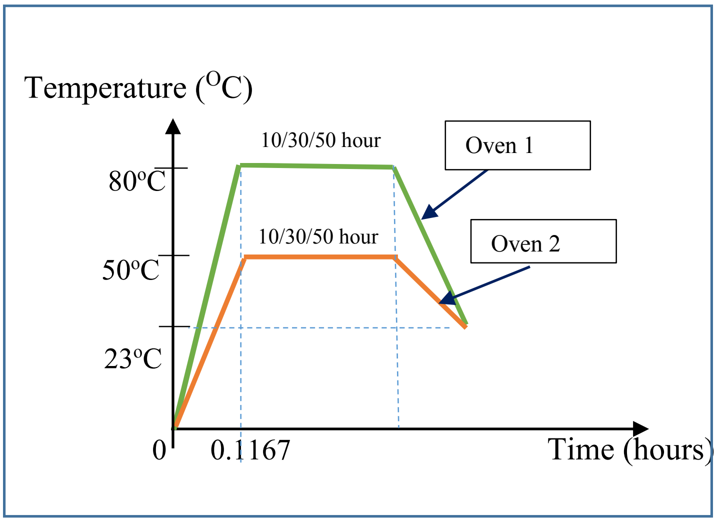


Figure 3.14: Flow of thermal degradation process

3.4 Impact Test

Charpy pendulum impact test is conducted after performing conditional test in oven. The pendulum impact system used an apparatus from Instron Ceast 9050 as shown in Figure 3.15. This machine will give out a digital value at the end of every swing of hammer. The details of machine are shown below in Table 3.3.

The impact test methods is discussed based on the use of pendulum. The importance of impact study is to apply impact force to determine material toughness characterization. Charpy test consist of two types of notches which are sharp notches and round notches. At this notch, crack starts to propagate when extreme force is applied until it is broken or failed. Most of failures in industrial application caused catastrophic accidents without any warning (Makani, 2016). Defect will become critical when concentrated around v-notch area because of the decreasing in load in charpy specimen (Ashraf, 2011). The fracture and surface of the specimen involved were analysed to see the crack. Thus, this is the way to evaluate the performance of any material by such damage (Toth, 1901).

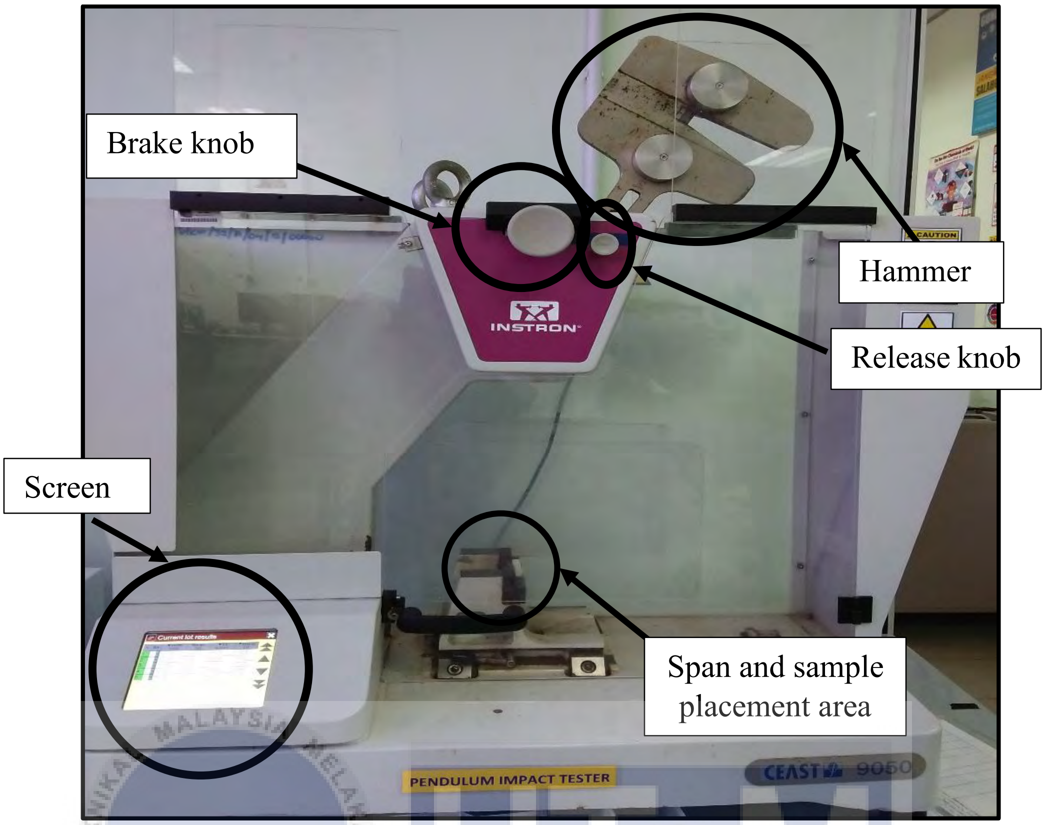


Figure 3.15: Apparatus set up for charpy impact test

Table 3.3: Pendulum impact test machine specification

Speed of swing, v	3.8m/s
Mass hammer, m_{hammer}	23kg
Span length, L_{span}	42mm
Angle of hammer, θ_{hammer}	150°
Calibration readings	0.097J

In handling this machine in laboratory, it is advised to make a calibration first before start the experiment. The calibration process is done by selecting the calibration button in the menu appeared on the screen. Then release the hammer from fixed angle to run the calibration without hitting the specimen which is known as free swing reading. This process shows the loss energy value in unit Joule (J). If the digitally measured value is less than maximum value allowed by the standard, then experiment can be proceed. The loss energy value get from the free swing reading are 0.097J. Theoretically, this value should be less than 2.5% of pendulum mass on free swing. The experiment continued with that calibration results when 2.5% from 23kg of pendulum mass is equal to 0.575 which are significantly lower. Therefore, it can be said that this machine has high sensitivity.

After finished the calibration process, the first specimen is stored inside the shelf. During placing the specimen, the notch was placed by facing to the opposite direction where the hammer should hit at opposite side of the notches. Then the hammer was rotated upward and hanged at 150^{o}. Next, the parameter value such as the test type, specimen dimension and span length was set. Start button was touched and release knob was pressed. The hammer starts swing and hit the specimen. Calculation of lost energy was shown in the screen. The brake knob was pressed to stop the hammer before open the shelf. The same steps was repeated for all samples with the same default parameters. This experiment give out a tabulation of data as an example that is shown in Figure 3.16 consist of breaking type (complete broke, hinge, partial or not broken), absorbed energy (%), resilience value (kJ/m^2) and loss energy value (J). The example of sample after completely break is shown in Figure 3.17. The complete tabulation of results will be shown by writings in Chapter 4.

Results

N	Brk	▼Width [mm]	Abs.en. [%]	▼Re [kJ/m²]	▼Energy [J]
2	C	10.00	3.22	16.13	1.613
3	C	10.00	3.95	19.80	1.980
4	C	10.00	3.78	18.94	1.894
5	C	10.00	3.56	17.81	1.781
6	C	10.00	3.77	18.89	1.889
7	C	10.00	2.76	13.77	1.377
X̄		10.00	3.73	18.65	1.865

Figure 3.16: Tabulated results from charpy test

(a) (b)

Figure 3.17: Experimental material: (a) The v-notched bar specimen, (b) overview on before and after fracture specimen

3.5 Morphological Analysis using SEM

If the severity of a specimen is significant, then a Scanning Electron Microscope (SEM) is used. Basically, SEM is used in order to observe the microstructure for topographical of the corrosion product for the specimen's surface. In SEM process, it utilizes electrons instead of light to form an image. SEM is an electron microscope that enables a better image of a specimen by scanning it with a focused beam of electrons (Moser, 1987). The electrons interact with atoms in the specimen producing various signals that contain information about the surface topography and composition. All samples must be in appropriate size to fit in the specimen chamber and are generally mounted rigidly on a specimen holder called specimen tub (Moser, 2007).

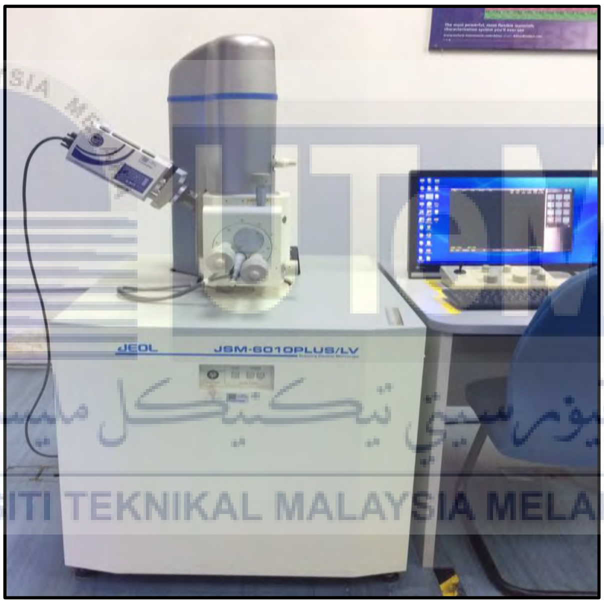


Figure 3.18: SEM machine

By referring to Figure 3.18, the SEM machine used is a JEOL JSM 6010plus/lv brand. This machine can magnify an object about 10 times up to 300 000 times greater from its original shape. Firstly, the samples were cut to 10 mm length. Then it is bind together to be put in the Joel Auto Fine Coater machine as shown in Figure 3.19 for coating process. To be add on, polymers material is a non-conductive material. A non-conductive material will tends to rebound the electrons that is projected to the specimen if it is not coated (Kulkarni, 2016). Therefore, coating is used to absorb the electrons so that the image can be viewed through monitor. Coating that can be used are like platinum and gold. In this project, a platinum coating were used.

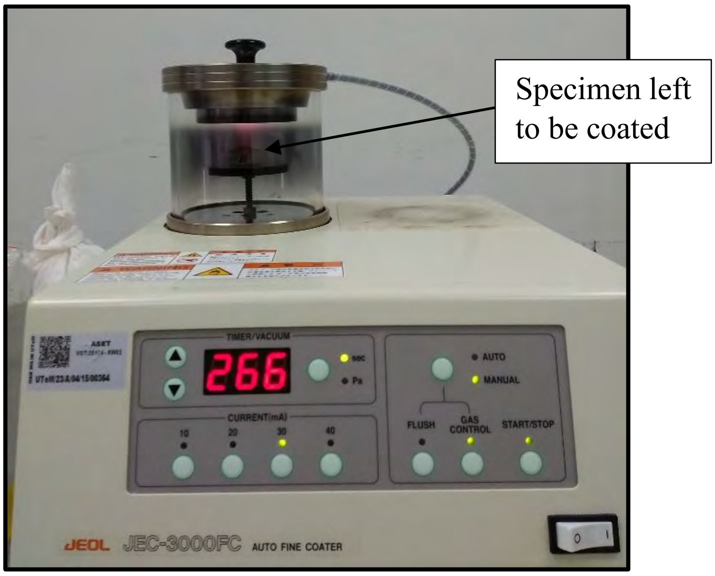


Figure3.19: Auto fine coater machine

Figure 3.20: Platinum coated samples

The coated samples as shown in Figure 3.20 above is then placed in the machine and the surface analysis been done. Only five sample is viewed under the SEM. The samples to be tested was chosen randomly except for the samples that had been left for 30 hours in oven at every condition. This is due to expectation that among 10 hours, 30 hours and 50 hours period of heat treatment, it is expected there will be more difference when comparing the results between the longest and shortest period time. In addition to that, this is majorly due to too much request to use this machine, so the faculty decide to minimize the number of samples that is allowed for one student when using this machine. Therefore, this decision is taken during the discussion session with supervisors and technician. Figure 3.21 shown the example of image viewed on the screen. The results of SEM morphological study is shown in Chapter 4 and Appendix.

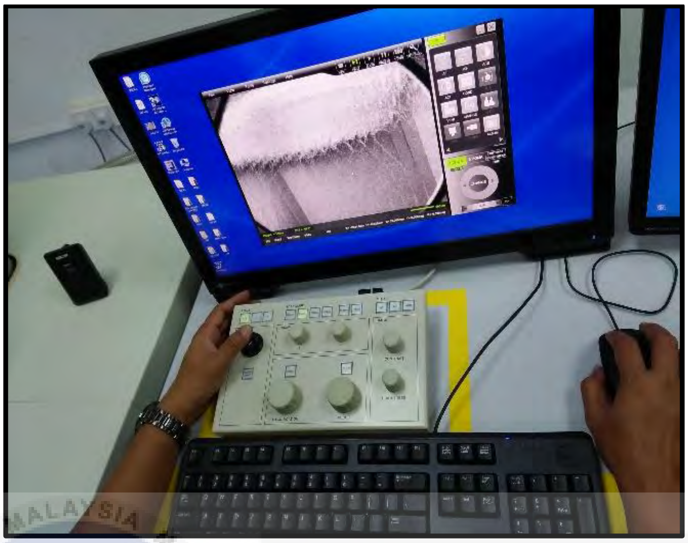


Figure 3.21: Monitoring and adjusting the image on SEM screen

CHAPTER 4

RESULTS AND DISCUSSION

This section will discuss on the results obtained from the charpy pendulum impact test and images viewed by SEM machine. All information that related to this study will be shown, stated and included in this part to prove the relevance of this study. These type of test are repeated for three samples to get an average reading.

4.1 Charpy test results

The ABS samples for every condition experience a completely breakage when been hit by the pendulum. All those breakage is observed being separated into two pieces in response to the notches that act as the crack initiator. Generally, the most important element that need to be considered in this study is to analyse the behaviour of the impact energy at different heat level. Table 4.1 shows the summary results obtained by charpy impact test. The results at room temperature act as a reference results to do comparison.

Table 4.1: Summary results on charpy test

SAMPLES	ABSORBED ENERGY (%)	RESILIENCE (kJ/m^2)	IMPACT ENERGY (J)
ABSI-RT	3.65	18.28	1.828
ABSI-50-10	3.86	19.33	1.933
ABSI-50-30	3.86	19.38	1.938
ABSI-50-50	3.71	18.56	1.856
ABSI-80-10	3.65	18.29	1.829
ABSI-80-30	3.63	16.82	1.682
ABSI-80-50	3.33	16.64	1.664

From Figure 4.1, it is clearly shown that by comparing the impact energy at 50°C and 80°C, the higher temperature use smaller energy to break a sample. This is due to at high temperature, the chemical bond of the material starts to weaken and leads to break. But however, this hypothesis will be depends on the type of that material itself. At temperature 50°C in graph above, fluctuation occurs. By starting with the impact energy value at room temperature which shows 1.828 J, the results keep increasing at the 10 hours of heating while at 30 hours heating for the same temperature used higher energy value to break a sample which are at 1.933 J and 1.938 J respectively. Finally, the energy value need to break a sample decrease to 1.856 J after 50 hours of heating time in the oven. This can be said that at 10 hours and 30 hours heating, the ABS samples were having a same characteristics because these results have only small difference at the third decimal value. It can be said that the grain structures of samples at this temperature value did not effected much by the continuous heat for 30 hours' time. Then only it start to get weaker after been heated for 50 hours. Therefore it is easily break with only small energy value applied.

While by referring to the line graph at 80ºC, the trend shows that the energy value decrease as the time increases. By starting with the energy value to break the samples at room which are at 1.828 J, it seems to see that after 10 hours of heating the samples, the impact energy value is almost same with room temperature condition which means that this both also share the same characteristics at that point. However, at this temperature, there is a big difference in energy value to break a samples that was heated for 10 hours long to 30 hours long time. From this, it can be assume that after 10 hours heating time on ABS sample, the carbon-carbon bond is still difficult to be break and need higher energy in order to loosen the bond whereas at 30 hours heating time, the bond is already weak and just use small energy value to be absorbed by the sample to break.

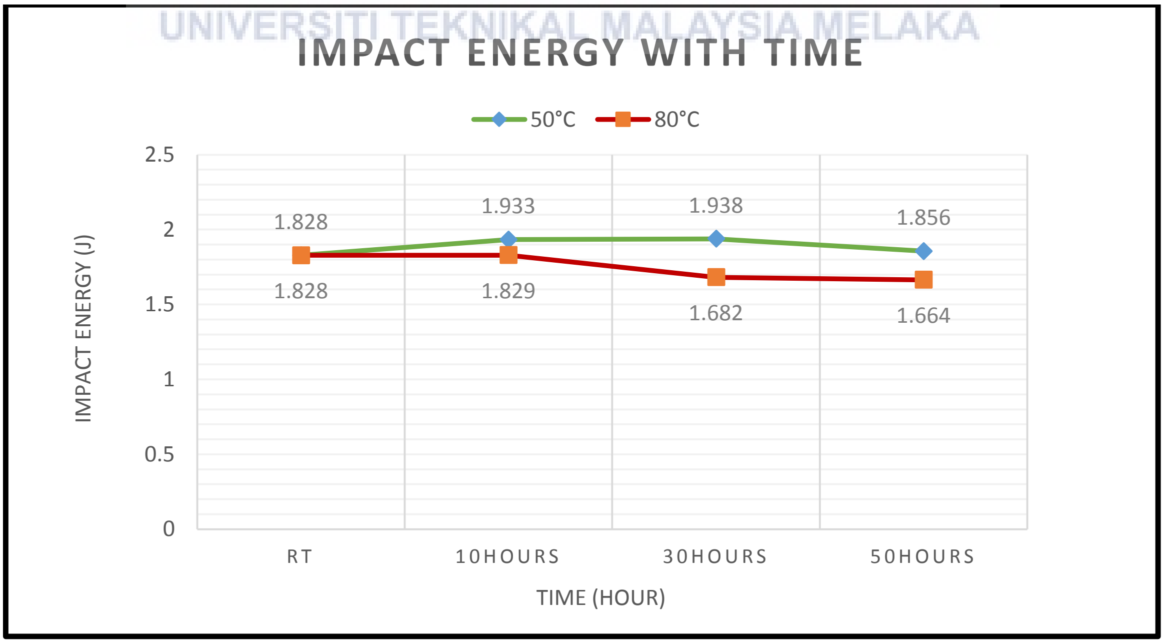


Figure 4.1: Graph of impact energy versus time

Resilience can be define as the ability of material to absorb energy by the body up to elastic limit. The sample under elastic limit zone will return to its original shape once the applied load is released which means that sample will not deform permanently at this evaluation point. Resilience energy is taken digitally by the measurements of energy per cross sectional area.

Both line graphs in Figure 4.2 shows the same trend as the impact energy versus time graph. The resilience value is decreasing with increasing of time. At temperature 50°C, the ABS sample stored more energy before fracture occurs compared to samples at temperature 80°C. This shows that the lower temperature needs higher resilience value before it fractures. This graph proved that, ABS is tougher at lower temperature.

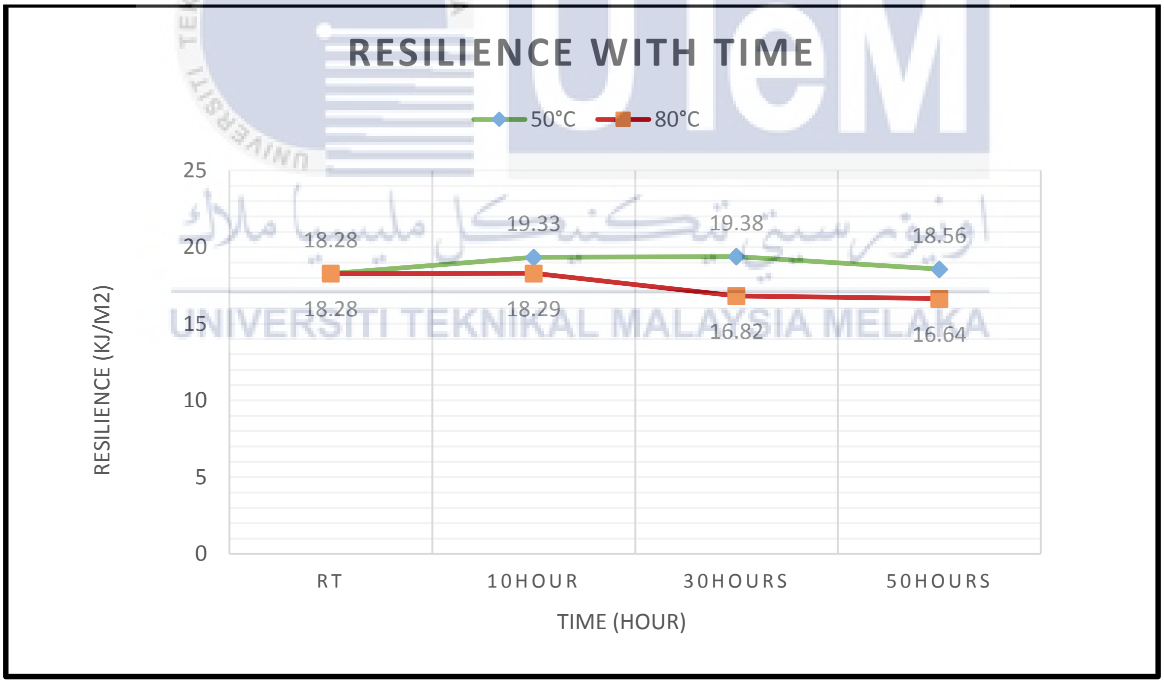


Figure 4.2: Graph of resilience versus time

From Figure 4.3, the trend of both line graphs is still the same. This figure reveals out the percentage of absorbed energy at that particular impact energy used. The higher the percentage used to break the sample, the better its toughness.

At both temperatures, the lowest percentage of absorbed energy were shown after being heated for 50 hours in the oven. Whereas, at 10 and 30 hours heating time, it shows the highest percentage of absorbed energy by ABS sample. From the other hand, the reason of such behaviour towards ABS sample can be reveal by the carbon-carbon bonding. The carbon-carbon bond in ABS structure becomes stronger after exposed to some heat level. Then it drops drastically and tends to have lower ability to absorbed energy for the period of 50 hours heating in the oven because the bond getting weaker. From this, it can be conclude that the ABS behaviour at both temperatures after being heated at 10 and 30 hours in the oven increase their toughness and directly shows that they are brittle.

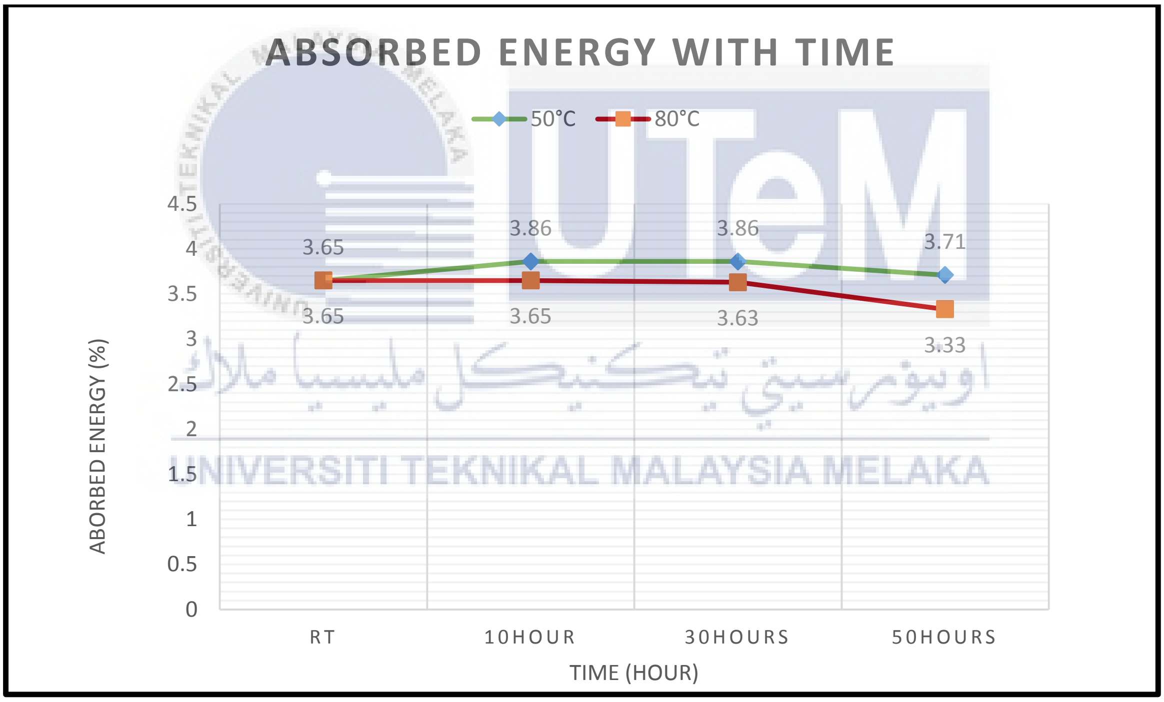


Figure 4.3: Graph of absorbed energy versus time

By analysing all of the results above, a simple conclusion can be made where in dominant, at lower temperature value, ABS can be characterized as tough material. There are significant difference in impact energy, resilience and absorbed energy value between samples at 50ºC and 80ºC. Furthermore, samples at lower temperature shows that it is tougher than the samples at higher temperature value by increasing in impact energy value, absorbing more energy before failure occurs and usage of higher percentage of absorbed energy value across the time.

4.1.1 Standard Errors

To be add on, in order to clarify the precision of data obtained from the testing done in lab, the standard deviation value is calculated. An analysis had been done also under an intentions to describe the data spread in impact energy value subjected to time (in unit hours). The average impact energy values for three samples is taken from the conducted charpy impact test that had been tabulated in Appendix A. The time is the independent variable that is manipulated and the amount of impact energy absorbed by a sample is the dependent variable. At specified time, the average are calculated to get the standard deviation value and this standard deviation value will describe uncertainty in measurements.

Two figures were presented to show the variations on standard deviation results at temperature 50^{o}C and 80^{o}C respectively as shown in Figure 4.4 and Figure 4.5 each. Then, discussion on the results is made. The sample calculation in order to find the standard deviation values are shown below. All the mean and standard deviation results are shown in Appendix A.

It is necessary to calculate the standard deviation value and plot the error bars to measure how well the data are concentrated around the average value. The lower the standard deviation, the more concentrated the results are which means, a smaller standard deviation value shows a set of data which are close to each other. By referring at Figure 4.4 which are at temperature 50^{o}C, it can be said that impact energy value at 10 hours and 50 hours have a significant greater standard error value than 30 hours. While by referring at Figure 4.5 which are at temperature 80^{o}C, the impact energy value at 10 and 30 hours have a significant greater standard deviation value than the 50 hours. However, in overall the impact energy value at temperature 80^{o}C has a less standard error which directly shows that it is more precise. Moreover, by referring to Figure 4.6, it can be said that in this study, ABS samples at temperature 50^{o}C that have been exposed for 30 hours in the oven had absorbed highest energy by 1.938 J compare to all other condition. At temperature 80^{o}C, the samples absorb less energy before break into two pieces. From this, it was noticed that ABS are good at temperature 50^{o}C compared to temperature of 80^{o}C.

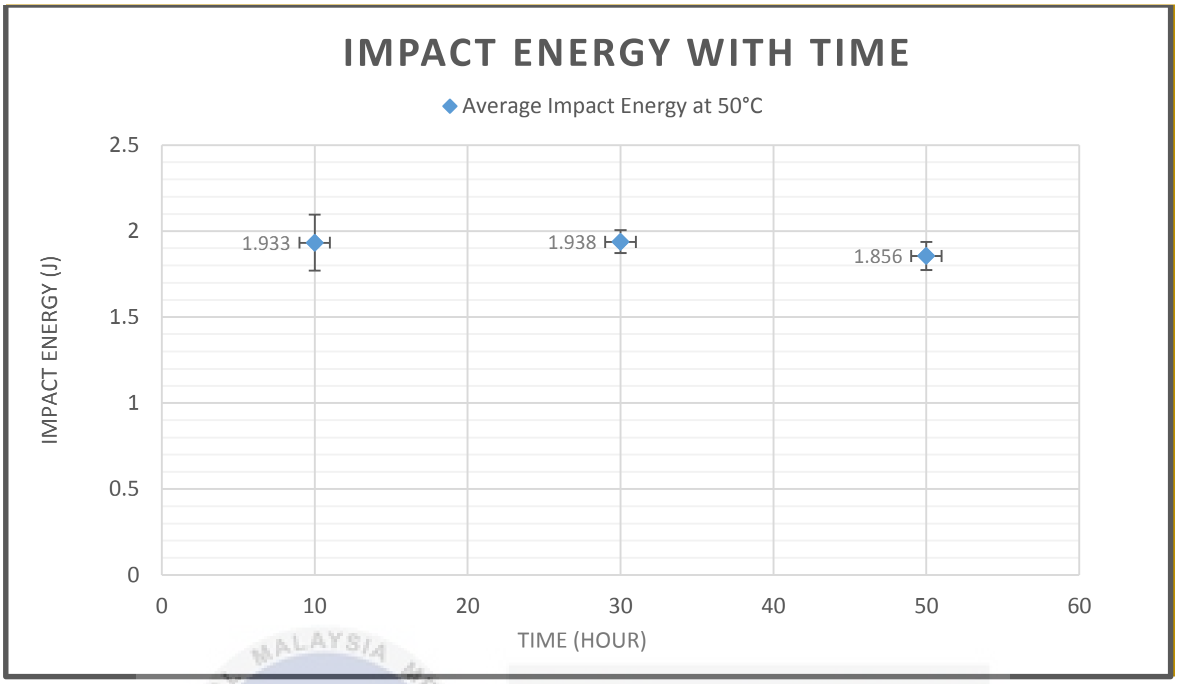


Figure 4.4: Standard deviation at 50^{o}C temperature

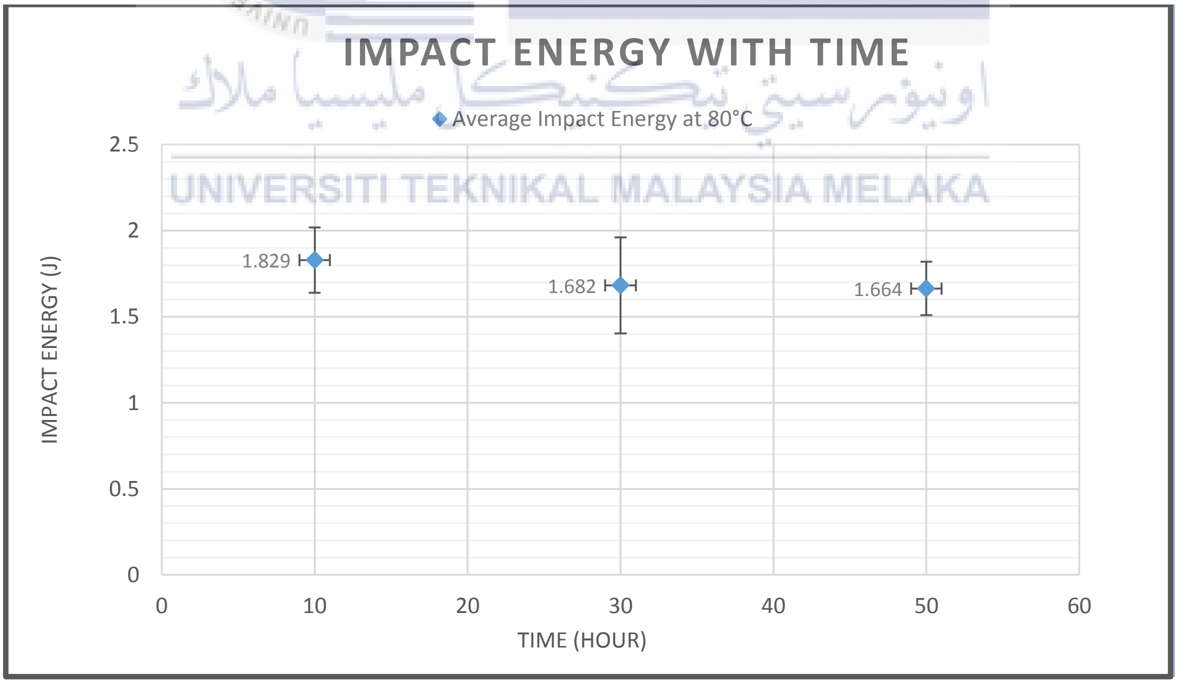


Figure 4.5: Standard deviation at 80^{o}C temperature

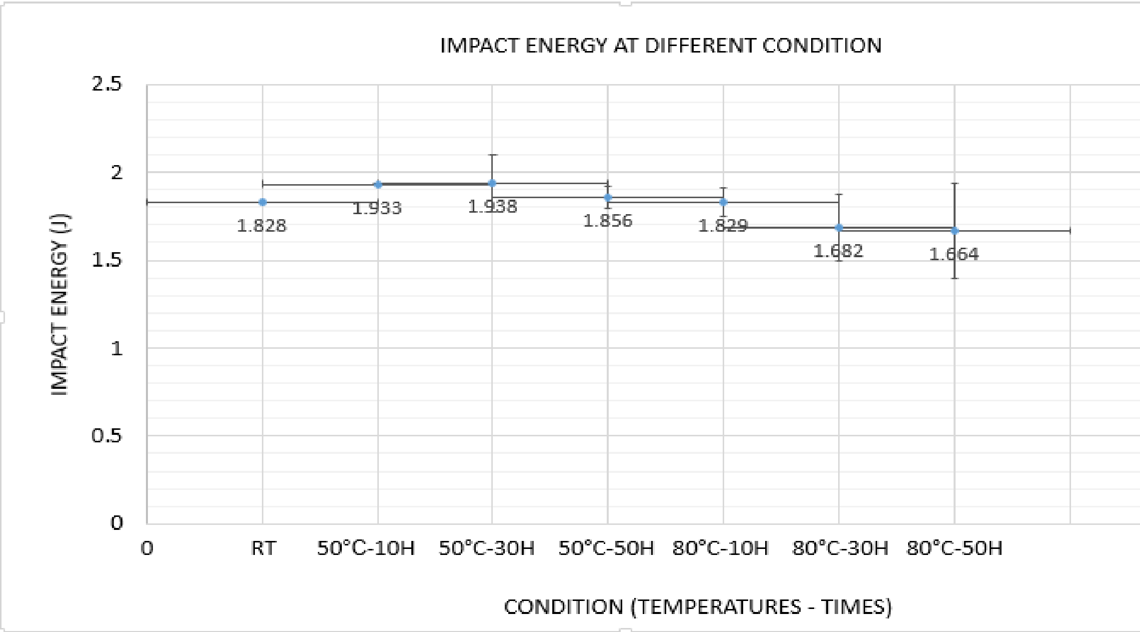


Figure 4.6: Summarise standard deviation graph

Sample standard deviation calculation at:

Temperature: 50°C

Time: 10 hours

Average Value, $\bar{x} = \sum x/N$

$$= \frac{1.928+1.772+2.098}{3}$$

$$= 1.933$$

x_i	$\bar{x}$	$(x_i - \bar{x})^2$
1.928	1.933	2.5×10^{-5}
1.772	1.933	0.026
2.098	1.933	0.027
		SUM 0.053

$$\text{Standard Deviation} = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_{i-}\overline{x})^2}$$

$$= \sqrt{\frac{1}{3-1}(0.053\,)}$$

$$= 0.163$$

where, $\sum X$: Sum

N : Total numbers

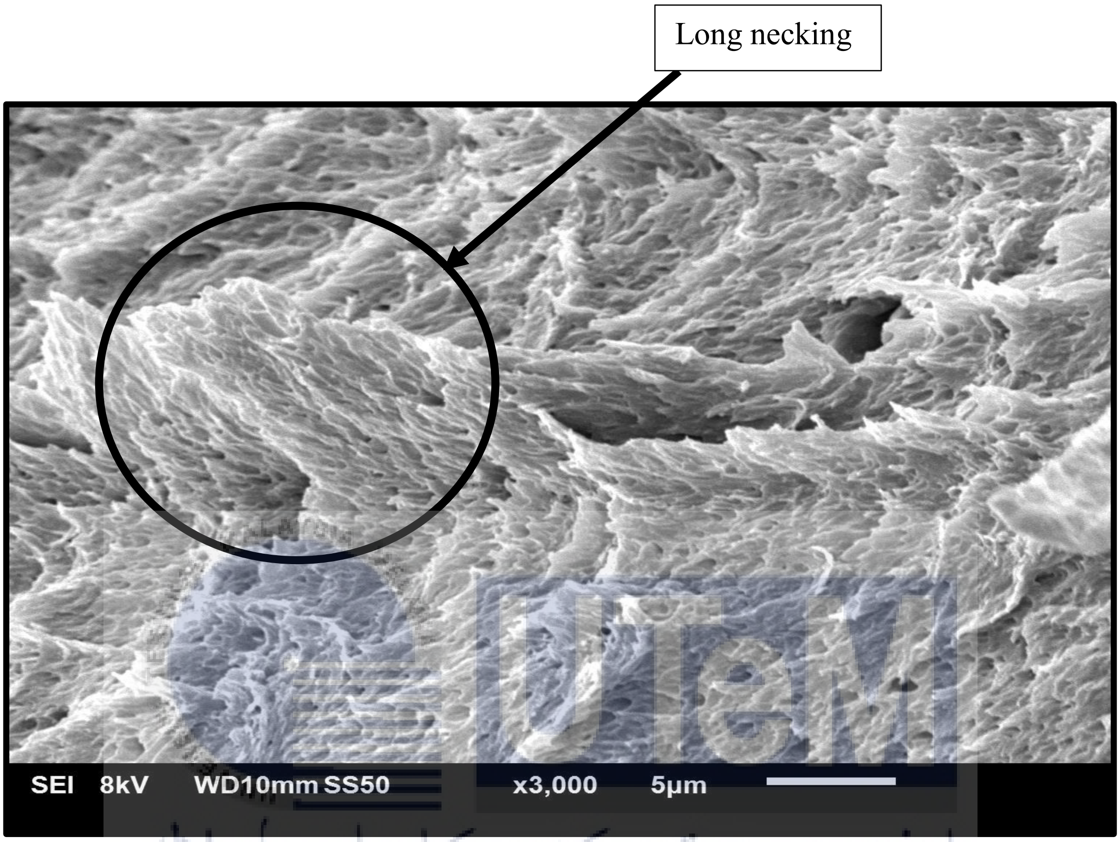
x_i : One sample value

$\bar{x}$: Mean

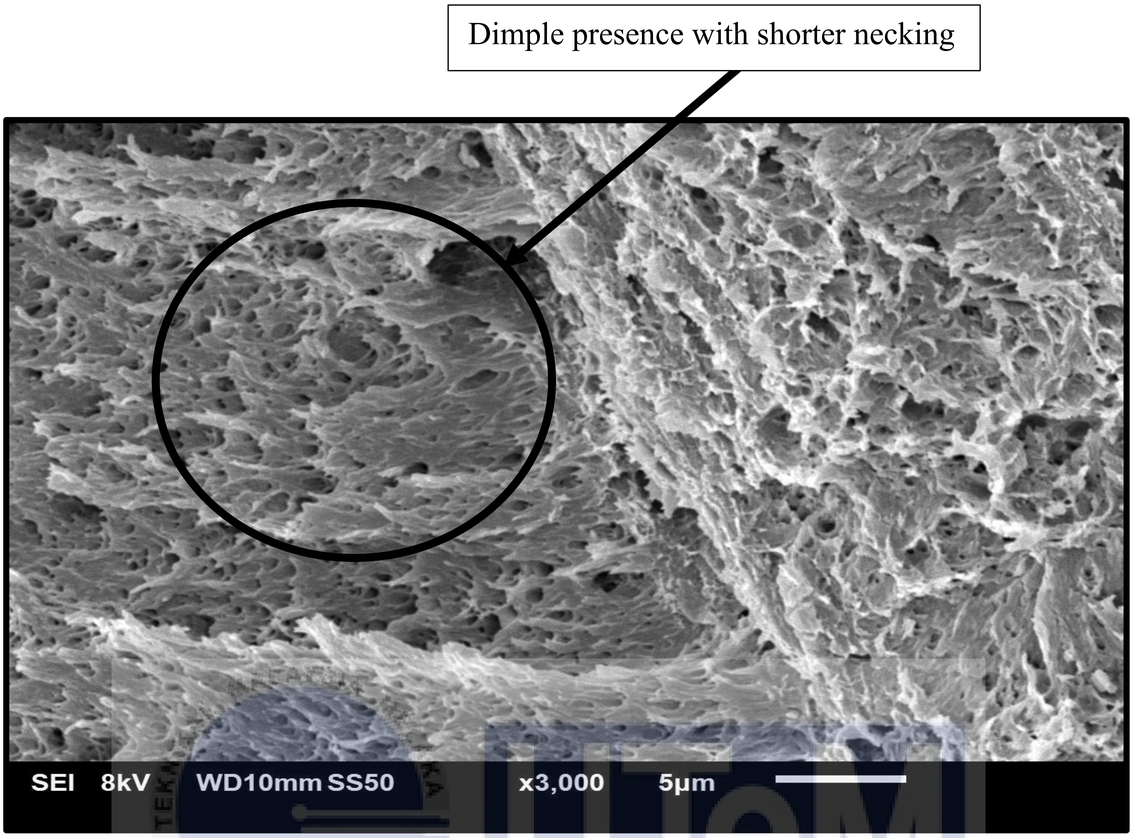
4.2 SEM Results

Fractures of material is a type of observation that can be seen with naked eyes. Fractures analysis with SEM also revealed new insights into fracture mechanism. To define the nature of specific failure, SEM can be used with the help of the magnifier in the machine. By viewing the microstructure at 3000 macroscopic level of magnifier, the difference can be seen clearly between samples. The observed results will be discussed in this part to characterized the morphological surface of heated ABS samples.

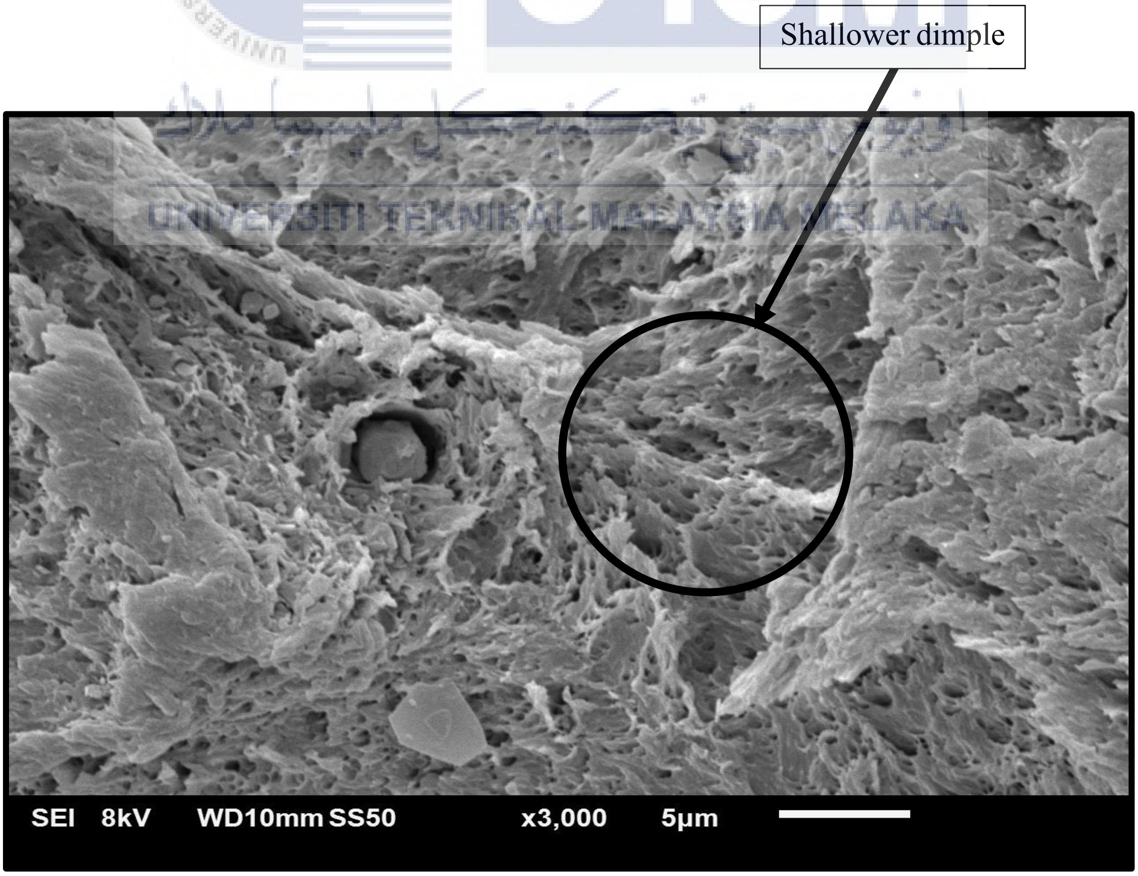
At the macroscopic level, the brittle and ductile behaviour of samples can be identified. From Figure 4.7a, it is shown that the ABS sample in room temperature condition were dominant by ductile failure mode. This is characterize by the presence of a longer necking structure when samples are viewed under SEM. Due to the samples was placed in room temperature condition, its chains had not loosen yet. Thus, it is harder to break the samples and resulting for a long necking compared to samples in other condition. For the samples at 50^{o}C temperature, the dimple structure starts to presence along with shorter necking as the time increases. This can be measured as decreasing in ductility by the samples. At the highest temperature of 80^{o}C and longest time of 50 hours, the samples were completely dominant by brittle failure mode when the microstructure shows the existence of a flat surface with no any necking viewed. As a conclusion, at the longer time heated at highest temperature, the sample will behave and shows a complete brittle mode failure.



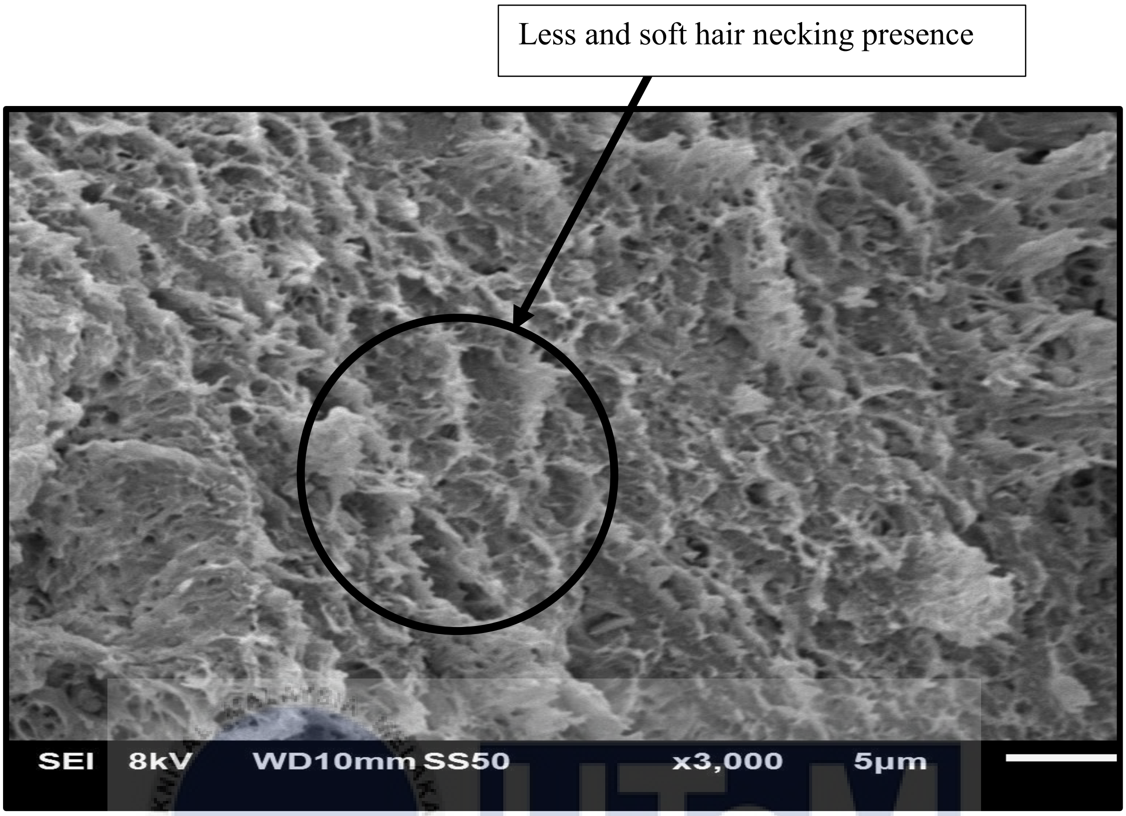
[a]


Dimple presence with shorter necking
SEI 8kV WD10mm SS50 x3,000 5μm

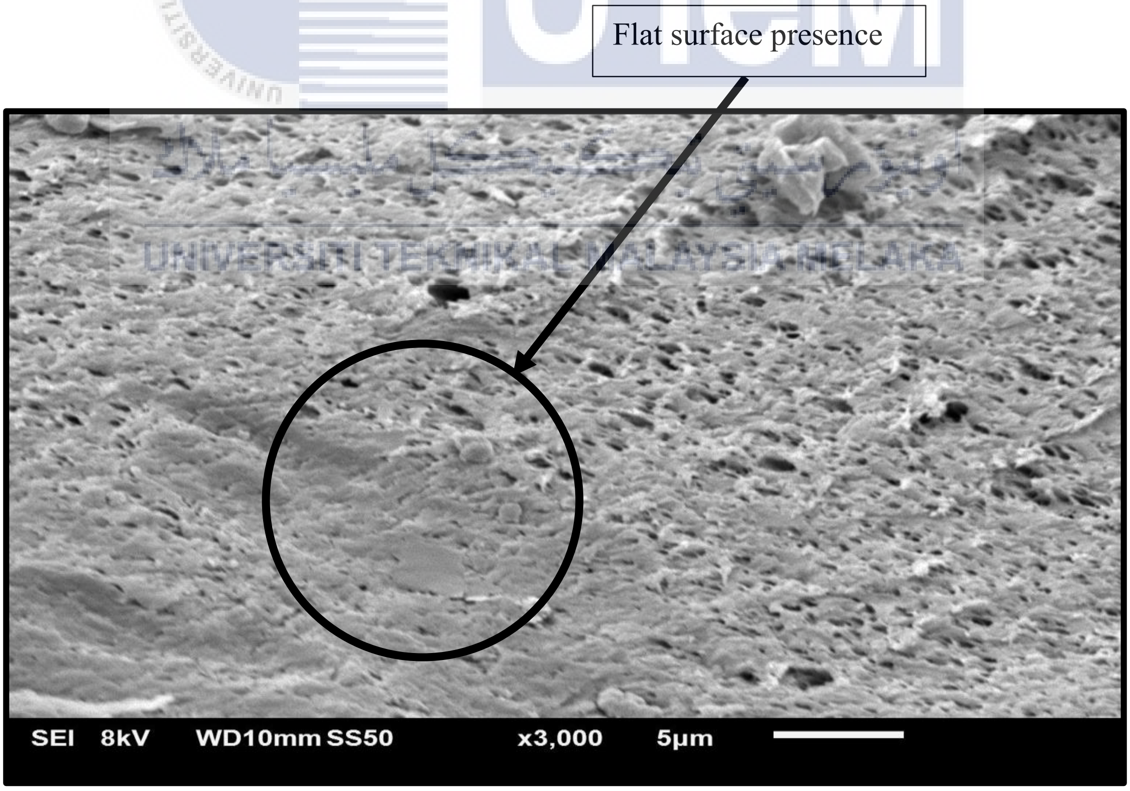
[b]


Shallower dimple
SEI 8kV WD10mm SS50 x3,000 5μm

[c]



[d]



[e]

Figure 4.7: Fractographic image under SEM a) room temperature b) at 50ºC in 10 hours c) at 50ºC in 50 hours d) at 80ºC in 10 hours e) at 80ºC in 50 hours

CHAPTER 5

CONCLUSION AND RECOMMENDATIONS

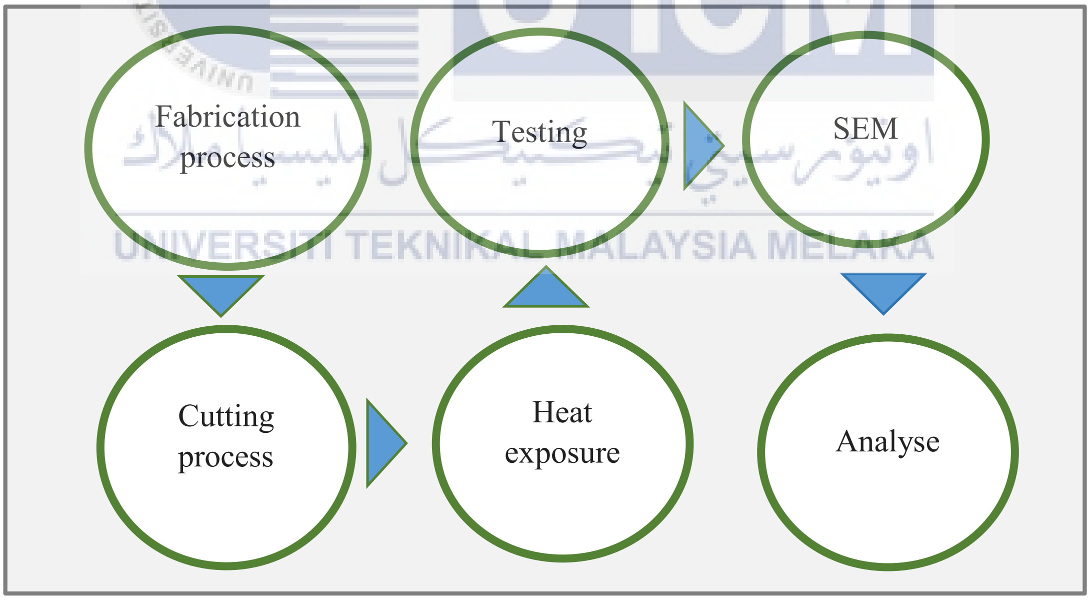


Figure 3.1: Summary of process

This project is completed by following the sequences as shown in Figure 5.1. All results that is presented in previous chapter is summarise and will be propose recommendation for future investigation purpose in this chapter.

5.1 Conclusion

As a conclusion, from the results obtained and discussed in previous chapter, it is said that ABS performed well in lower temperature which are at 50°C compared to temperature 80°C. Perhaps, after heated continuously at 80°C temperature, the carbon-carbon bond getting very weak. Therefore, it is easier to break the samples. As the temperature and the time increases, the absorbed energy values will be decrease. This means that the longer the time a samples is treated by high temperature, the lower the energy absorbed by the samples until fracture occurs. This will also affect the toughness of that sample where it will be easily break due to a weak bond.

From the SEM results obtained, the second objectives in this study are achieved. By the morphological studies conducted via SEM machine, it can be conclude that ABS sample are ductile at room temperature. This results is changed when the ABS tends to behaving as a brittle material after those sample is subjected to elevated temperature. The longer the samples is placed in high temperature, the more it seems to change its properties in becoming brittle. From this, it just can be said that, due to exposing at a higher temperature, a small energy may break ABS samples by brittle behaviour because of the weak bond in ABS microstructure.

As per pointed about cases involving a refrigerator in the problem statement, it can be conclude that after ABS parts have been thermally degrade, the microstructure are eventually loosen and have reduce in its strength. Therefore, ABS can be stated as safe and good in low temperature condition. To look further about this study, few recommendations are suggested.

5.2 Recommendations

To future researcher that interested in improving this results, below are few suggestions that can be taken in order to get better results: Firstly, it is suggested to increase the number of samples in order to get precise and trusted results. Testing on un-notched samples can also be done to do comparison which may give more reliable results in considering the toughness of ABS.

Next, in order to save time, while preparing the notched samples, use specific machine that may cut all the samples in consistent and high accuracy measurements. For the sake of saving time, this method is really important. If it is possible, find a machine that can cut the rectangular shaped samples and prepare the notch at one time process. This may also reduce the errors due to consistency in specimen measurements.

Then, it is suggested to the next researcher, while conducting the reliability test by using oven, make sure the oven is not being reopened again in between the experimental hours. Keep the heat trapped in the oven so that it can change the microstructure of those samples. For that, plan an ample time to done the reliability test where the oven is run for one specified experimental time only. This steps might take few days depends on the respective setting time used according in next project.

Furthermore, for the sake to save the cost, try to find materials in powder form compared to pellets. Because at fabricating the ABS material using hot press machine either for thick or thin dimensions, it needs the aid of mylar sheets to produce a smooth and shiny plate without air bubbles or defects. This mylar sheets is expensive and it can just be recycled to be used for maximum 2 times after placed in hot press machine. Perhaps if it is in powder form, mylar sheets is unnecessary.

At last, it is important to study about the impact energy in designing any structure because it will shows the plasticity of the material which reveals the ability of that materials to absorb energy when changes in plasticity occur. The results from the charpy testing itself can used to evaluate how much impact is afford by some structure until it lost its toughness. Therefore, this report is considered to achieve its target.

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APPENDIXES

APPENDIX A: RESULTS OF CHARPY TEST

Temperature = 50^{O}C
Time = 10 Hours

	Samples			
	1st	2nd	3rd	Average
Absorbed Energy (%)	*3.85*	*3.54*	*4.19*	3.86
Resilience (kJ/m^2)	*19.28*	*17.72*	*20.98*	19.33
Impact Energy (J)	*1.928*	*1.772*	*2.098*	1.933
Average impact energy: 1.933 **Standard deviation: 0.163**				

Temperature = 50^{O}C
Time = 30 Hours

	Samples			
	1st	2nd	3rd	Average
Absorbed Energy (%)	*3.83*	*3.76*	*4.01*	3.86
Resilience (kJ/m^2)	*19.17*	*18.84*	*20.12*	19.38
Impact Energy (J)	*1.917*	*1.884*	*2.012*	1.938
Average impact energy: 1.938 **Standard deviation: 0.066**				

Temperature = 50^{O}C
Time = 50 Hours

	Samples			
	1st	2nd	3rd	Average
Absorbed Energy (%)	*3.80*	*3.80*	*3.52*	3.71
Resilience (kJ/m^2)	*19.03*	*19.03*	*17.62*	18.56
Impact Energy (J)	*1.903*	*1.903*	*1.762*	1.856
Average impact energy: 1.856 **Standard deviation: 0.082**				

Temperature = 80^{O}C
Time = 10 Hours

	Samples			
	1st	2nd	3rd	Average
Absorbed Energy (%)	*3.22*	*3.95*	*3.78*	3.65
Resilience (kJ/m^2)	*16.13*	*19.80*	*18.94*	18.29
Impact Energy (J)	*1.613*	*1.980*	*1.894*	1.829
Average impact energy: 1.829 **Standard deviation: 0.190**				

Temperature = 80^{O}C
Time = 30 Hours

	Samples			
	1st	2nd	3rd	Average
Absorbed Energy (%)	*3.56*	*3.77*	*2.76*	3.63
Resilience (kJ/m^2)	*17.81*	*18.89*	*13.77*	16.82
Impact Energy (J)	*1.781*	*1.889*	*1.377*	1.682
Average impact energy: 1.682 **Standard deviation: 0.270**				

Temperature = 80^{O}C
Time = 50 Hours

	Samples			
	1st	2nd	3rd	Average
Absorbed Energy (%)	*3.11*	*3.45*	*3.42*	3.33
Resilience (kJ/m^2)	*15.57*	*17.25*	*17.11*	16.64
Impact Energy (J)	*1.557*	*1.725*	*1.711*	1.664
Average impact energy: 1.664 **Standard deviation: 0.155**				

Room Temperature = 23^{o}C

	Samples			
	1st	2nd	3rd	Average
Absorbed Energy (%)	*3.56*	*3.63*	*3.77*	3.65
Resilience (kJ/m^2)	*18.23*	*18.26*	*18.34*	18.28
Impact Energy (J)	*1.823*	*1.826*	*1.834*	1.828
Average impact energy: 1.828 **Standard deviation: 0.00711**				

Summary of Charpy Test Impact Energy Results Table

TEMPERATURE	IMPACT ENERGY (J)		
	10 HOURS	30 HOURS	50 HOURS
$50^{o}C$	1.993	1.938	1.856
$80^{o}C$	1.829	1.682	1.664
Average impact energy value at room temperature = 1.828 J			

Summary of Charpy Test Resilience Results Table

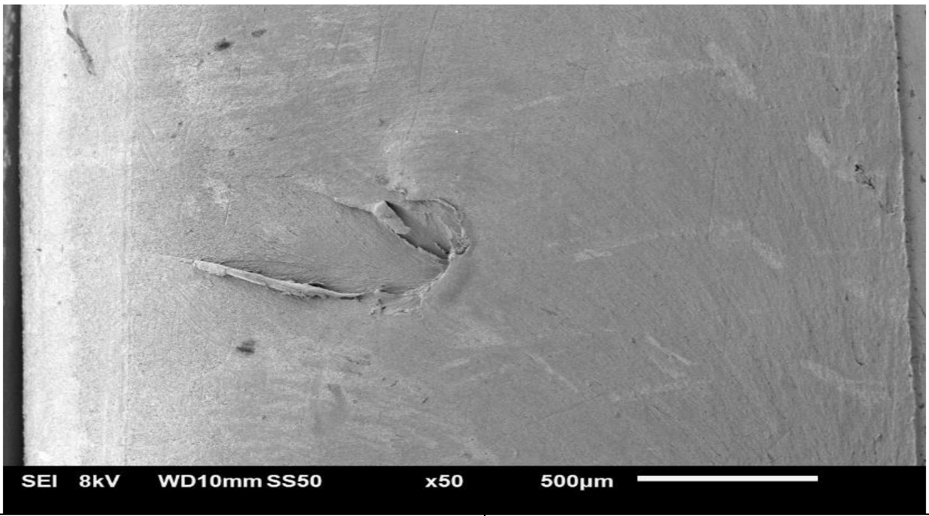
TEMPERATURE	RESILIENCE (kJ/m^2)		
	10 HOURS	30 HOURS	50 HOURS
$50^{o}C$	19.33	19.38	18.56
$80^{o}C$	18.29	16.82	16.64
Average resilience value at room temperature = 18.28 kJ/m^2			

Summary of Charpy Test Absorbed Energy Percentage Results

TEMPERATURE	ABSORBED ENERGY (%)		
	10 HOURS	30 HOURS	50 HOURS
$50^{o}C$	3.85	3.83	3.80
$80^{o}C$	3.22	3.56	3.11
Average percentage absorbed energy value at room temperature = 3.65%			

APPENDIX B: SEM RESULTS

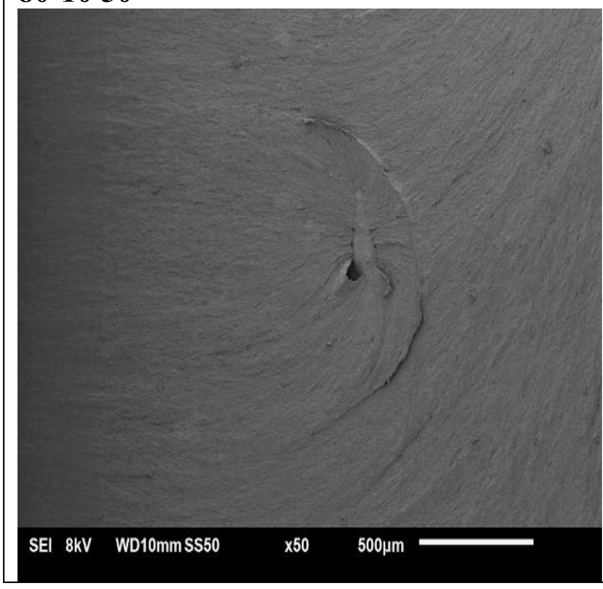
RT-50



50-10 50

50-50 50

80-10 50



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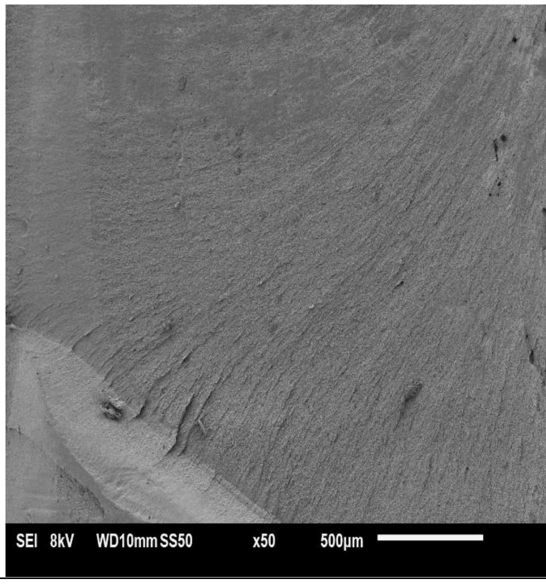

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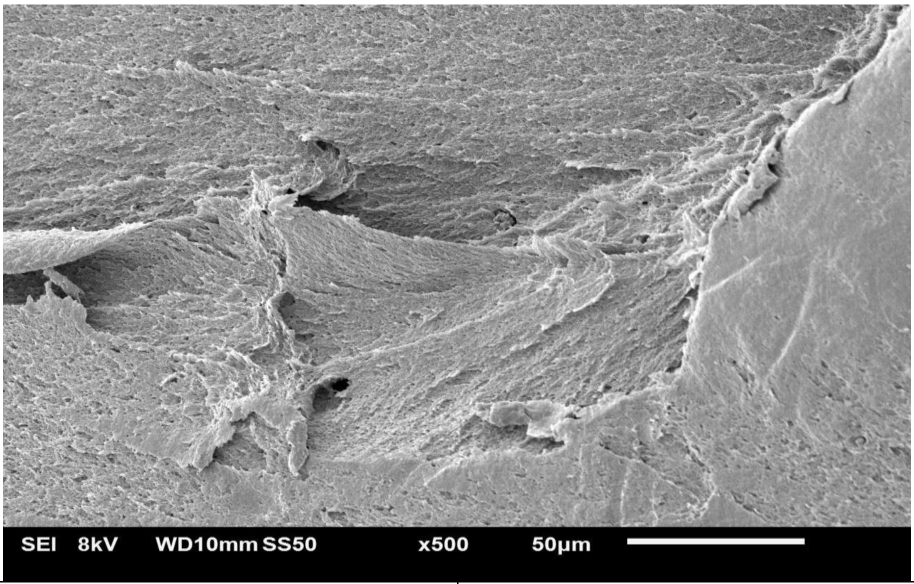

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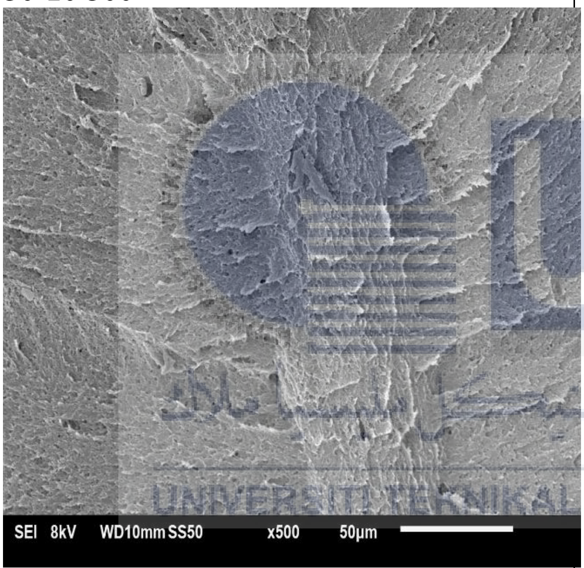

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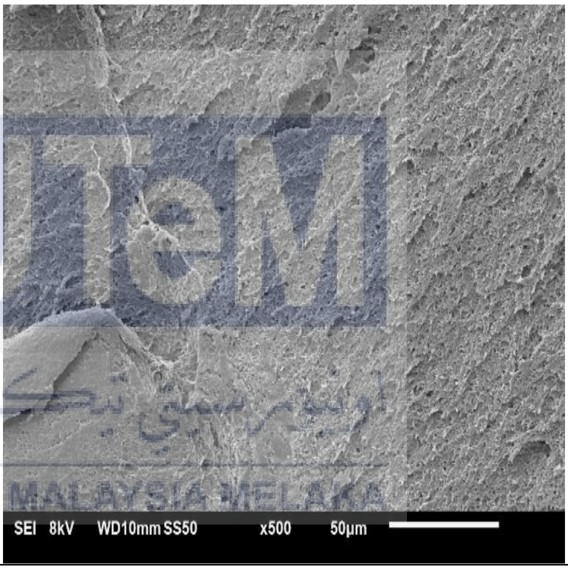

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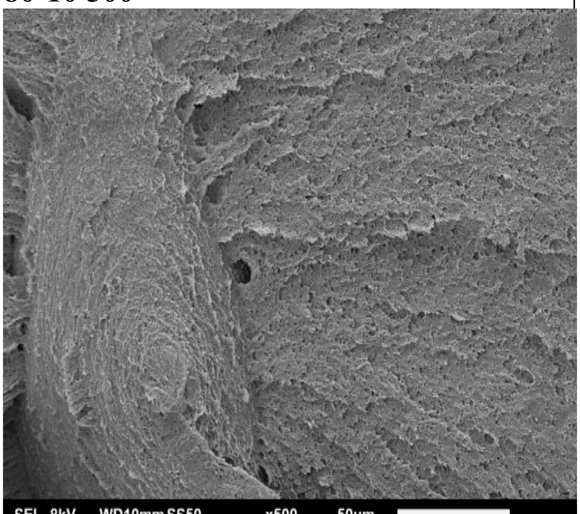

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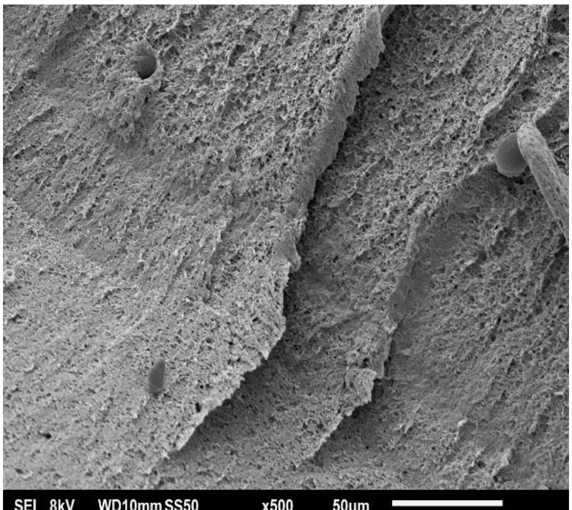

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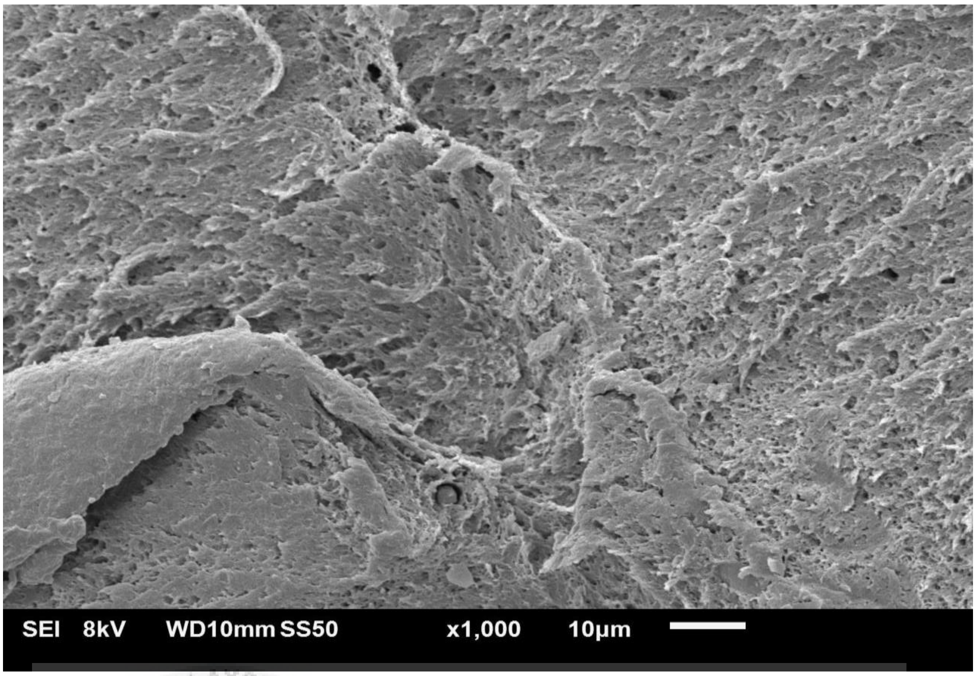

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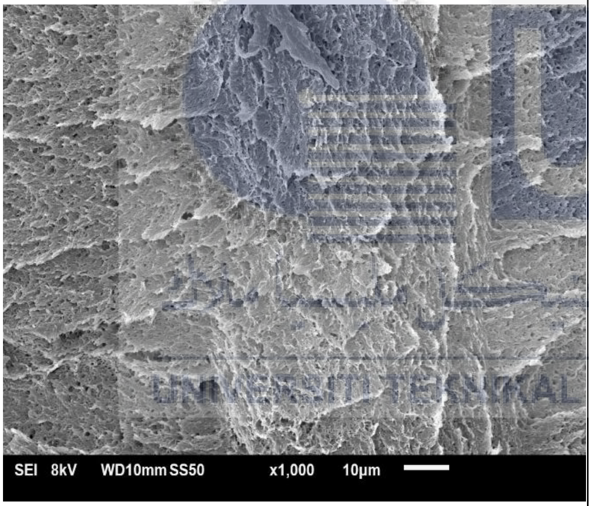

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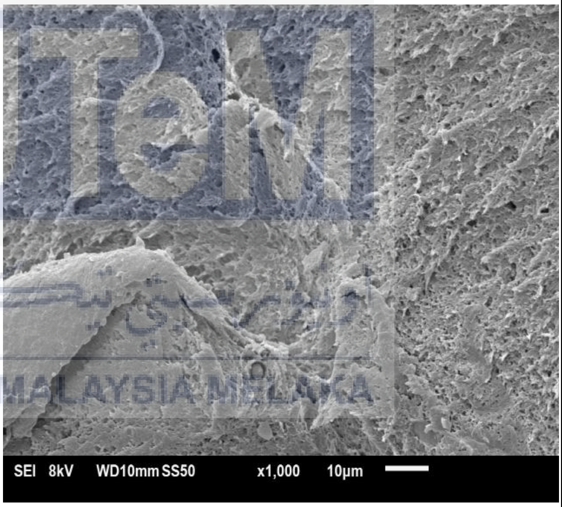

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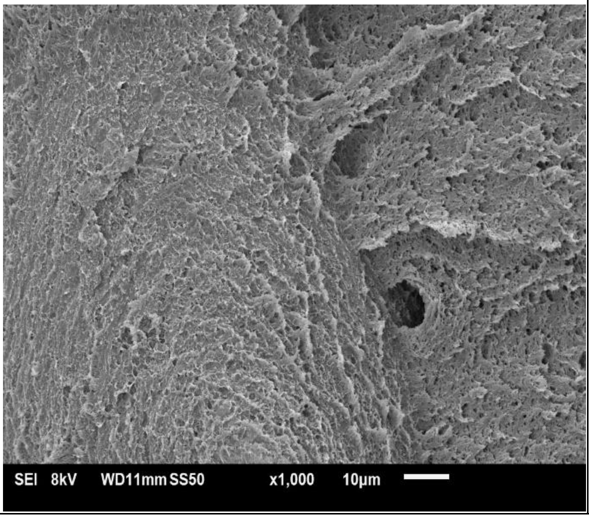

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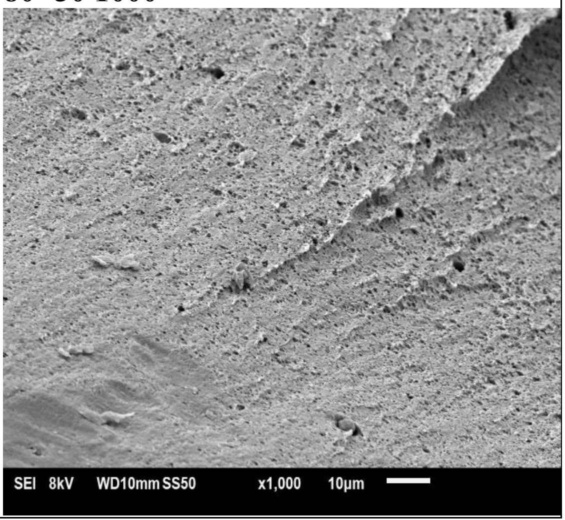
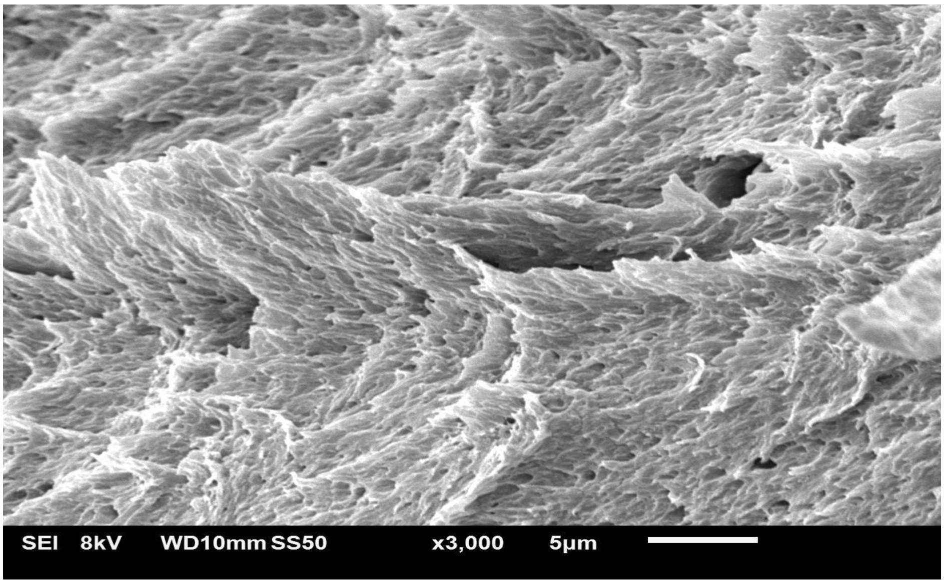


RT-3000



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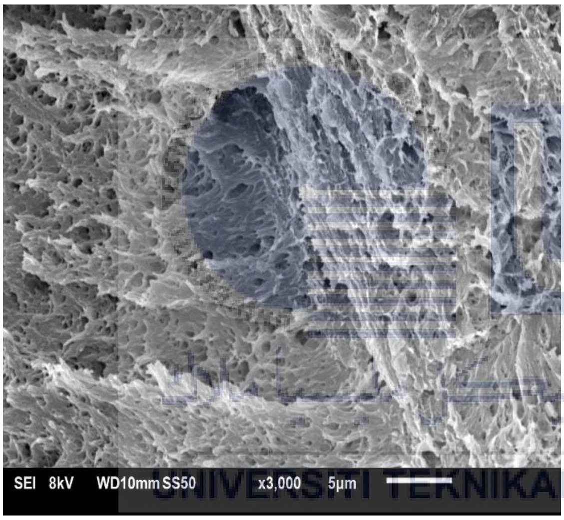

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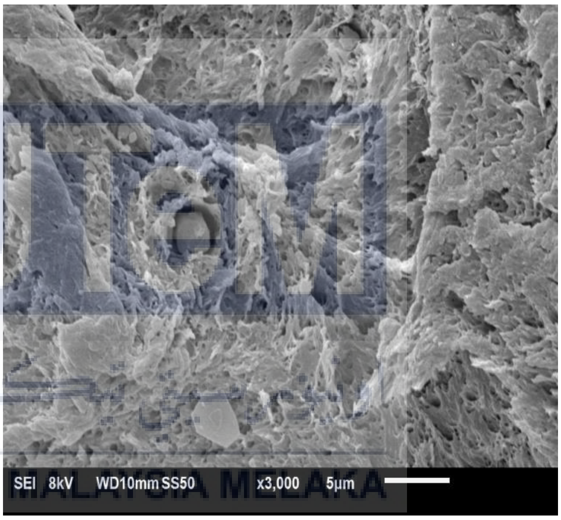

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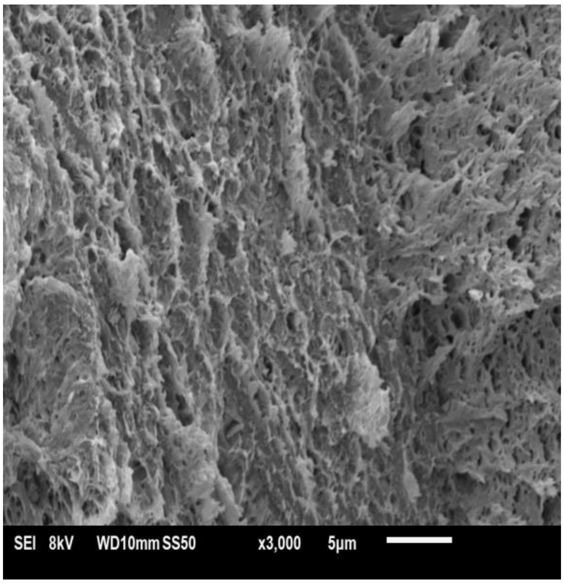

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