MODELING AND MECHANICAL PROPERTIES OF GLASS FIBER REINFORCED NYLON

MUHAMMAD SYAFIQ BIN MOHD ZAMIL

B. ENG. (HONS.) MANUFACTURING ENGINEERING

UNIVERSITI MALAYSIA PAHANG

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MUHAMMAD SYAFIQ BIN MOHD ZAMIL

Report submitted in partial fulfilment of the requirements
For the award of degree of
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Dedicated to my beloved parents

MOHD ZAMIL BIN A. HAMID

SUTAITAH BINTI HJ. MAHMOOD

and

My supervisor, **ASSOC.PROF.DR.DEWAN MUHAMMAD NURUZZAMAN**

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ABSTRACT

Nylon is one of synthetic polymers known as polyamides. Although nylon has many advantages in terms of physical properties and mechanical properties. However the advantages of plastic nylon improvements need to be made to obtain better physical properties and mechanical properties. The combination of the two types of glass-reinforced nylon 6 and nylon fibers, generate of plastic composite materials. This study aims to analyze model and the properties of glass fiber reinforced nylon. This study used CATIA V5 software for producing modeling of dog bone shaped specimens according to ASTM D638 standard size. Modeling specimen are complete with feed system. Modeling the three different locations for injection of entrance door pin, the central door, and the door edge. Autodesk Moldflow Insight software is used to identify the appropriate process flow between the three different doors for the injection molding process. Then, the injection molding machine is used to produce specimens of glass fiber reinforced nylon in shaped of dog bone with different percentages of glass fiber. The percentage of glass fiber used is 5%, 10%, 15% and 20%. The temperature used to mix two materials (nylon and fiberglass) is between 230 ° C to 258 ° C. Lastly the process of studying physical properties and mechanical by using universal tensile machine and pendulum impactor machine. Universal tensile machine is used to generate the tensile stress-strain graphs for each specimen and the tensile strength for each of the tests were analyzed by using three different rates of 3mm / min, 5mm / min and 10mm / min. Pendulum impactor is used to perform impact tests. Specimens according to ASTM D4812 and the hammer 50 J used during the impact test. In conclusion, the percentage of glass fiber mixture higher achieve higher tensile stress at maximum temperature. This is because the total weight of glass fiber nylon reinforced increased as a percentage of glass fibers increases. The difference between the tensile strength of pure nylon and glass fiber reinforced scheduled and in plot in the graph.

ABSTRAK

Nilon adalah merupakan salah satu daripada polimer sintetik atau lebih dikenali sebagai *polyamides*. Walaupun nilon mempunyai banyak kelebihan dari segi sifat-sifat fizikal dan mekanikal. Namun kelebihan plastik nilon perlu dibuat penambahbaikan untuk meningkatkan sifat-sifat fizikal dan mekanikal. Gabungan dua jenis bahan iaitu nilon 6 dan kaca bertetulang gentian nilon, maka terhasilnya bahan komposit plastik. Kajian ini adalah bertujuan untuk menganalisis model dan sifat-sifat kaca bertetulang gentian nylon. Kajian ini menggunakan perisian CATIA V5 untuk menghasilkan lakaran spesimen berbentuk tulang anjing dengan mengikut saiz piawaian ASTM D638. Lakaran spesimen tersebut lengkap dengan lakaran sistem suapan. Lukisan yang dihasilkan adalah berbeza tiga lokasi suapan untuk suntikan iaitu pintu pin, pintu pusat, dan pintu tepi. Perisian *Autodesk Moldflow Insights* digunakan untuk mengenalpasti aliran proses yang sesuai antara tiga pintu yang berbeza bagi proses pengacuan suntikan. Kemudian, mesin pengacuan suntikan digunakan untuk menghasilkan spesimen kaca bertetulang gentian nilon yang berbentuk tulang anjing dengan peratusan gentian kaca yang berbeza. Peratusan gentian kaca yang digunakan adalah 5%, 10%, 15%, dan 20%. Suhu yang digunakan bagi campuran dua bahan (nilon dan gentian kaca) adalah diantara 230°C hingga 258°C. Akhir sekali adalah proses mengkaji sifat-sifat fizikal dan mekanikal dengan menggunakan mesin tegangan universal dan mesin instron. Mesin tegangan universal digunakan untuk menjana graf tegasan-terikan tegangan untuk setiap spesimen dan kekuatan tegangan untuk setiap satu bahagian ujian dianalisis dengan menggunakan 3 kadar yang berbeza iaitu 3mm/min, 5mm/min, dan 10mm/min. Mesin Instron pula digunakan untuk melakukan ujian hentaman. Spesimen mengikut piawaian ASTM D4812 dan tukul 50 J digunakan dalam ujian hentaman. Kesimpulannya, peratusan campuran gentian kaca yang lebih tinggi mencapai tegasan tegangan yang tinggi pada suhu maksimum. Ini kerana jumlah berat kaca bertelulang gentian nilon meningkat apabila peratusan campuran gentian kaca meningkat. Perbezaan kekuatan tegangan antara nilon tulen dan kaca bertetulang gentian dijadualkan dan di plot dalam graf.

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LIST OF ABBREVIATIONS

ASTM	American Society for Testing Materials
CAD	Computer Aided Design
CATIA	Computer Aided Three-dimensional Interactive Application
GF	Glass Fibre
GFRP	Glass Fibre-Reinforced Polymer
FKP	Fakulti Kejuruteraan Pembuatan
FRP	Fibre-Reinforced Plastic
OM	Optical Microscope
PA6	Nylon 6
PMC	Polymer Matrix Composites
PP	Polypropylene
UTM	Universal Testing Machine

CHAPTER 1

INTRODUCTION

1.1 INTRODUCTION

Composite material is a combination of two or more different materials and structure or chemical composition are bonded together to improve the properties. The other name for composite material is engineered materials. Composite materials is combination from various materials such as fibers, polymers, ceramics and metal. The properties, structure and proportion of the constituent materials are an important role to determine the properties of composite. Usually the matrix and reinforcements contained in a composite. Composite also can be classified as a fiber reinforced, particulate and laminates.

Fiber reinforced especially fiber reinforced polymer (FRP) which is often used in various applications. It is because fiber reinforced polymer (FRP) have good mechanical and physical properties. The matters affecting the mechanical properties of reinforced polymer is the percentage parameters of the reinforcing material. The fiber reinforced polymer (FRP) usually apply in aerospace equipment and automobile part. That because properties of fiber reinforced polymer (FRP) are light weight, high strength, and better durability.

Glass Fibre reinforced Polymers (GFRP) is also as a composite material by combination of three material like glass, fibre and polymers. The glass material be added in fibre to improve the mechanical properties, resistance to damage and maintain the fixed shape. The result of three combination of material between glass, fiber and polymers, the high tensile strength is supported. Besides that, in modern composite material requires several factors such as light weight, high strength, good thermal insulation, chemical resistance, corrosion resistance and easy to produce.

1.2 PROBLEM STATEMENT

Plastic is a material that has many advantages compared other materials. This is because plastic has properties such as corrosion resistant, low thermal conductivity, light weight, comparatively low cost and good electrical resistance compare with another's material such as steel, copper alloys, and aluminium. Plastic materials have to be improved to enhance the properties of existing ones. Therefore, reinforced plastic needs to be generated to further improve properties of plastics. Reinforced plastic can be produced through the process of adding materials such as nylon, fibres glass, ceramic and etc.

1.3 OBJECTIVES

- ✓ Design the plastic part modeling with 3 different of gate location by using CATIA V5 software.
- ✓ To analyze moldflow of plastic modeling for injection molding process by using Autodesk Moldflow Insights software.
- ✓ To fabricate the plastic modeling of glass fibre reinforced nylon by using injection molding machine.
- ✓ To study the mechanical properties of glass fibre reinforced nylon by using tensile and impact test.
- ✓ To characterize structure of glass fiber reinforced nylon for each different composition by using Optical Microscope machine.

1.4 PROCESSING TECHNIQUE

In this research, there are several software and machine to be use such as CATIA V5 software, Autodesk Moldflow Insights software, Injection Molding machine and Universal Tensile Machine (UTM).

Firstly, the plastic models need to be design by using CATIA V5 software. The design specifications must be follow the size that is already available in the mold

injection molding machine. The design is in the shape of specimen (dog bone shape) to tensile test.

After design process, the design must go through a process of analyzing. This process using Autodesk Moldflow Insights software. Before using this software, the design must be saved in STL file format. The software will be analyze Moldflow process, fulfill time analysis for each specimen and the temperature of the specimen during the injection process.

Then, the specimen is produced through injection process by using injection molding machine. The resulting specimen is composites different the plastic percentages polypropylene (PP), nylon and fibre. This process begins by entering the plastic mixture into the hopper. Then, the plastic mixture will enter the heater zone for preheating. When it is melted, screw will turn and give high rotation pressure to forced molten plastic into the nozzle. The nozzle will be inject molten plastic into the mold cavity. After injection, the mold will be cool for a while to ensure the specimen solidifies. After that, the mold is opened and the ejector will eject the specimen out of the mold cavity.

Finally, after producing specimen by using injection molding machine, the specimen will undergo tensile test and impact test. Universal Tensile Machine (UTM) will be used to identify the properties of the specimen. Properties that will be study is tensile strength, fracture stress, yield stress and other properties. INSTRON – CEAST 9050 machine will be used for impact test (IZOD) to identify the mechanical properties of the specimen.

1.5 SCOPE OF PROJECT

In this study focused on modeling and properties of glass fibre reinforced nylon. Glass fibre is a material consist of fine filaments of glass that are combined. Glass fibres have a high strength, chemical resistance and good electrical insulation. Nylon is a type thermoplastic. In addition it is also known nylon as polyamides. Nylon have good properties such has high tensile strength, resistant to corrosion and good insulator at low temperature. First of all, it is necessary to design a model specimen (dog bone shape) by using CATIA software. After that, it is necessary to analyze the design by

using Moldflow software for injection molding process. Injection molding machine used to produce the specimen. After producing specimen, Universal Testing Machine (UTM) and INSTRON – CEAST 9050 used to study the mechanical properties of each specimen.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

This literature review is intended to identify, analyze and summarize in previous research related to the focus of my studies. Nowadays there are a variety of materials have been produced, one of which is fiber-reinforced composite. This materials are widely used in automotive parts, aircraft, boat hulls, sports kits and pipeline industries. This is because the materials have very good mechanical properties and structures. In the scope of my research work includes modeling and study about the properties of glass fiber-reinforced nylon.

2.2 POLYMERS

Other names for polymers is plastic. Polymers have long-chain molecules same substances connected together. Characteristics of polymers is good chemical resistance, light weight, corrosion resistance, good electrical and thermal insulation. In addition, the polymer is also low coefficient of friction, stiffness, and low cost in the production. However, polymers have low operating temperature in range below 350°C. Polymers also can be classified as a thermoplastics, thermoset and elastomer. (G K Lal & S K Choudhury, Fundamentals of Manufacturing Processes, 2005)

2.3 THERMOPLASTIC POLYMER

Thermoplastic polymer is a soften material and easy to melt at high temperature and harden when cooled. Thermoplastic polymer also known as cold setting plastics.

Thermoplastic polymer like a wax can be reshaped at several times when melt at the high temperature. When the thermoplastic polymer are heated repeatedly, no change in the chemical properties but only change in physical properties. In addition, thermoplastic polymer have high viscosity compared to thermoset polymer. Thermoplastic polymer can be recycled and remolded after it is cured. (J.P. Kaushish, Manufacturing Processes, 2008)

2.4 THERMOSET POLYMER

Thermoset polymer is a harden material but can melt in once time. Thermoset polymer also known as heat setting plastics. Thermoset polymer cannot be remelted when shape already set. Thermoset polymer have high compression strength compare to thermoplastic polymer because of the strong bond molecules. Thermoset polymer also has good stiffness because of the cross-linked chain structure. (J.P. Kaushish, Manufacturing Processes, 2008)

2.5 POLYPROPYLENE

Polypropylene (PP) is a thermoplastic polymer. Polypropylene always used in production and engineering because have good dimensional stability, good mechanical properties, good resistance of fatigue failure, good creep resistance and low density. In addition, polypropylene also excellent in electrical insulator and inexpensive. Polypropylene always used in many application such as automotive parts, stationery, cutlery, and pipes. (Serope Kalpakjian & Steven R. Schmid, Manufacturing Engineering and Technology 6th edition, 2010)

2.6 NYLON

Nylon is a type of thermoplastic and another name for nylon is polyamides. Nylon have high tensile strength, corrosion resistance, and good insulator at low temperatures. In addition, nylon also tend to provide good resistance chemical and absorb moisture surface. There are also various types of nylon such as nylon 6, nylon

66, nylon 11, and nylon 12. Nylon that are used in many purposes such as in textile industry. Nylon has a high tensile strength, so that product made from nylon durable. Nylon also is a semi crystalline polymer suitable to use in the manufacture of automobile parts because of high mechanical, tensile strength and good processability. (Emel Kuram, 2013).

2.7 FIBRE-REINFORCED PLASTIC (FRP) COMPOSITES

Fibre reinforced plastics is a combination of two material between fibre and plastics. Reinforced plastic is known as polymer-matrix composite (PMC). Fibre are high strength and stiffness. Fibre have two type, synthetic and natural. Synthetic fiber is a carbon, glass, asbestos and aramid. While, natural fiber is a cotton, flax and wood fibre. Reinforced plastic have greater toughness, high creep resistance, fatigue resistance and relatively easy to design, fabricate and repair. When more than one type of fibre used in reinforced plastics, will improve properties but they are more expensive. That combination is called hybrid. Usually, glass or carbon will be used in fiber reinforced plastics because can developed for high temperature application. Fibre reinforced plastic always used in various industries such as aerospace, marine and construction industries. (Martin Alberto Masuelli, Introduction of Fibre-Reinforced Polymers,2013)

2.8 GLASS FIBER-REINFORCED POLYMER (GFRP)

Glass Fibre Reinforced Polymer is a composite material and glass fiber mostly used from all fibers because the cost cheaper than others. To improve wetting and bonding between fibre and matrix, glass fibre will be treated with silicon hydride. There are type of glass fibre, E type, S type and E-CR type. S type has high strength, stiffness but more expensive than E type. E type is a Calcium Aluminoborosilicate glass. E type also is a alkali free that will protect from corrosion and E type is the type commonly used. (Serope Kalpakjian & Steven R. Schmid, Manufacturing Engineering and Technology 6th edition, 2010)

2.9 ANALYSIS DESIGN METHODS

2.9.1 Software Autodesk Moldflow

Before injection molding process, the design need to analysed by using Autodesk Moldflow Insight 2011 software. Moldflow analysis is a function as the stimulation of injection molding process before the actual production process by using injection molding machine. There are many functions that can be used in Moldflow analysis. This analysis can calculate the filling time of the molten plastic flow to fulfill whole injection part design. This analysis will indicate the temperature difference in whole part design. Moreover, this analysis will also show the suitable position to put the gate. In this process can also detect defects during the process of filling until fulfill overall part design.

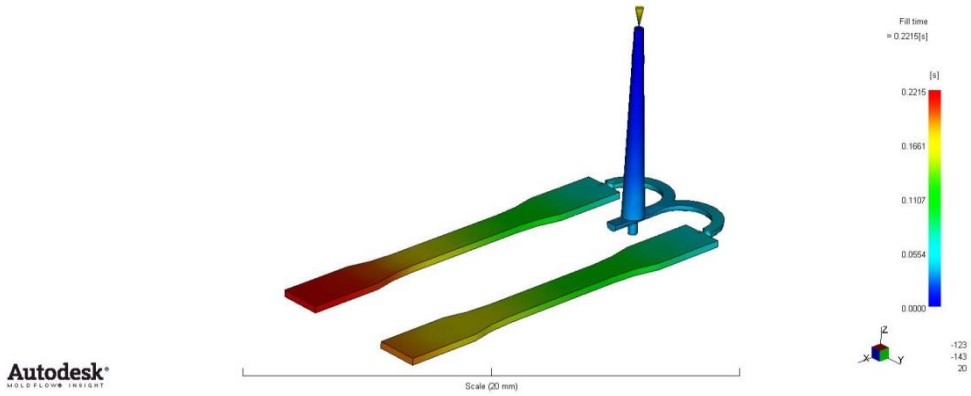


Figure 2.1: Example of fill time result

2.10 PROCESSING METHODS

There are many type of processing method to produce specimen of glass fibre reinforced nylon. The suitable process to use is injection molding process because low viscosity of material and high production rate.

2.10.1 Injection Molding

Injection molding is suitable to produce the plastic part with high production rate. There are 3 types of mold usually used in industries, three plate mold, two plate mold and hot runner mold. In this study, two plate mold that will be used to produce plastic specimen because at FKP machining lab only have two plate mold to produce part.

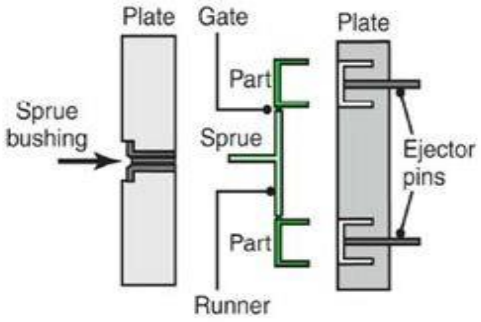


Figure 2.2: Two plate mold (Serope Kalpakjian , 2010)

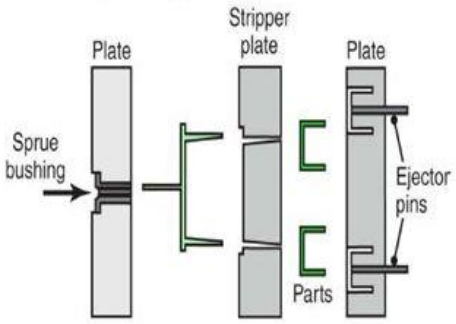


Figure 2.3: Three plate mold (Serope Kalpakjian, 2010)

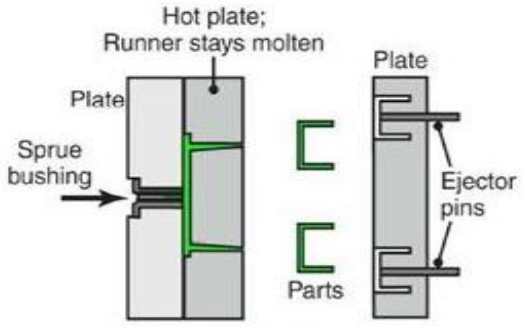


Figure 2.4: Hot runner mold. (Serope Kalpakjian , 2010)

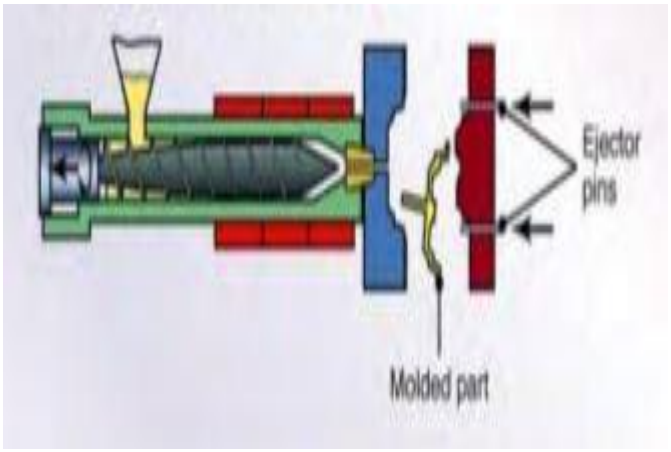


Figure 2.5: Operation in the injection molding. (Serope Kalpakjian , 2010)

CHAPTER 3

METHODOLOGY

3.1 INTRODUCTION

The methodology chapter is very importance in a study. This is because the methodology of this chapter will show all methods used in a study from beginning until achieving the result of research. In this study, the first thing is material selection to be used in the study. The next process is the production of plastic part design (dog bone specimen) by using CATIA V5 software and stored in STL file format. After that, going through the process of analyzing by using Autodesk Moldflow Insights software. The next stage is stage of producing the plastic part (dog bone specimen) using the Injection Molding Machine. In this process, the molten material to be injected into the mold and then will produce plastic part (dog bone specimen). The resulting specimen, going through the process of tensile test. Finally, after undergoing the test would make discussions and conclusions based on the analysis results obtained from these tests applied to each specimen.

3.2 PROCESS FLOW CHART

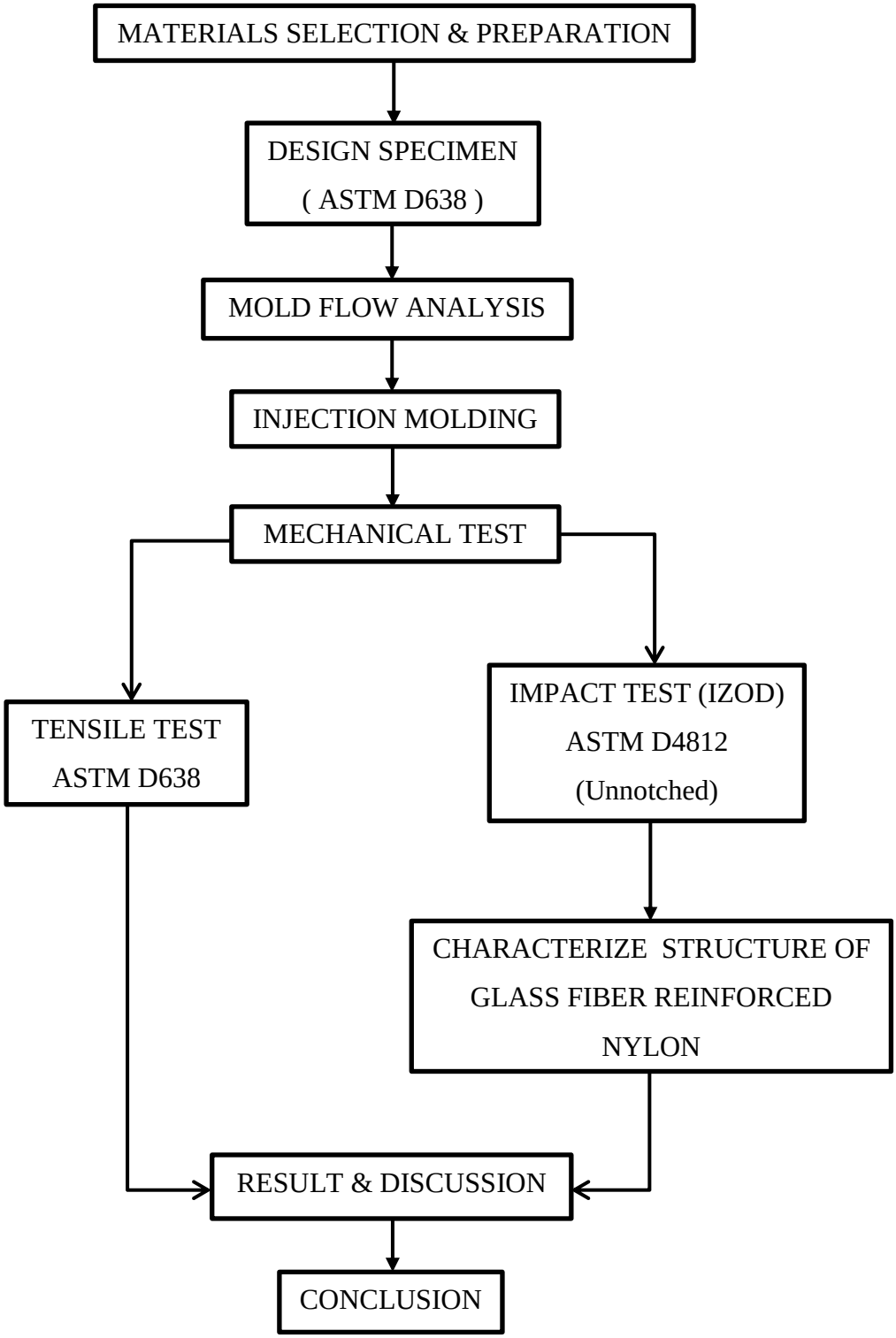


Figure 3.1 : Process flow chart

3.3 MATERIALS SELECTION

3.3.1 Nylon – 6

Nylon or other name is polyamides. Polyamides is a synthetic polymer. Nylon also have variety of type with different properties. In this study, nylon 6 will be used to produce the specimen. Nylon-6 fibre is tough, elastic and has high tensile strength.. Nylon is also suitable for use in the process of extrusion, injection molding, casting and cold forming. In this study, Nylon 6 will be mixed with Glass fibre to produce specimen Glass fibre reinforced Nylon. Nylon to be used must be in the form of pellets or granules shape.

3.3.2 Glass Fibre – reinforcement

Glass fibre reinforcement plastic is composed of strands of glass with very fine and small diameter (lightweight). There are properties of glass fibre reinforced plastic is good wear resistance, good impact resistance, very high tensile strength and stiffness. The mixture of glass fibre and polymer will produce strong composite material with good mechanical properties and light weight.

3.4 MATERIAL PREPARATION

In the production specimen process, the materials used are pure nylon (PA6) and glass fibre. The raw material (nylon and glass fibre) is in the form of pellets. Specimen that will be produced is composed of a mixture of nylon with glass fibre and pure nylon (PA6).

Sample Calculation :

3.4.1 95% Nylon (PA6) + 5% Glassfibre

100g GF (30% GF + 70% PA6) | 30g GF + 70g PA6

5 GF = 30

95 PA6 = X

X = 570g PA6

= 570g – 70g

= 500g Pure PA6

3.4.2 90% Nylon (PA6) + 10% Glassfibre

100g GF (30% GF + 70% PA6) | 30g GF + 70g PA6

10 GF = 30

90 PA6 = X

X = 270g PA6

= 270g – 70g

= 200g Pure PA6

3.4.3 85% Nylon (PA6) + 15% Glassfibre

320g GF (30% GF + 70% PA6) | 96g GF + 224g PA6

15 GF = 96

85 PA6 = X

X = 544g PA6

= 544g – 224g

= 320g Pure PA6

3.4.4 80% Nylon (PA6) + 20% Glassfibre

450g GF (30% GF + 70% PA6) | 135g GF + 315g PA6

20 GF = 135

80 PA6 = X

X = 540g PA6

= 540g – 315g

= 225g Pure PA6

3.5 DESIGN AND MOLDFLOW ANALYSIS

After the preparation of the material, the next process is to design specimen (modeling). Computer Aided Three-dimensional Interactive Application (CATIA) is the software that will be used to produce the specimen design. Design of specimen to be produced is in the form of dog bone shape and the size according to ASTM D 638 standard. In ASTM D 638, there are many kinds of size. That is Type I, II, III, IV, V. ASTM D 638 Type I to be used to produce a design specimen.

Figure 3.2 shows an example of ASTM D 638 Type I standard :

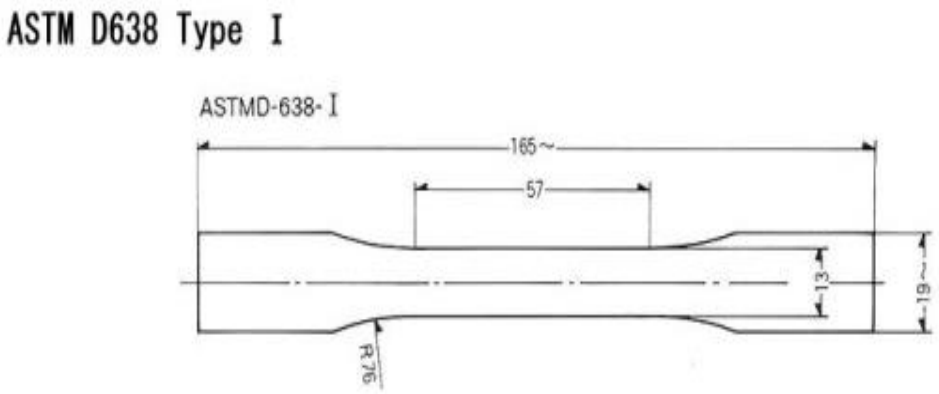


Figure 3.2 : ASTM D 638 Type I

After the design process, is the process of analyzing specimen design. In the process analyzing design, will use Autodesk Moldflow Insight 2011. This analysis will be used before the injection molding process. Moldflow analysis is a function as the stimulation of injection molding process before the actual production process by using injection molding machine. There are many functions that can be used in Moldflow analysis. This analysis can calculate the filling time of the molten plastic flow to fulfill whole injection part design. This analysis will indicate the temperature difference in whole part design. Moreover, this analysis will also show the suitable position to put the gate. In this process can also detect defects during the process of filling until fulfill overall part design. In conclusion, by using this moldflow analysis can define the suitable pressure can be use during fill process, identify the suitable gate location, estimate time to fulfill whole part design, can identify and control the temperature of part design during injection process by using cooling system, and also can detect defect after fulfill whole part design.

3.5.1 Procedure of Design and Moldflow Analysis

1) Open CATIA V5 software.
2) Click Start → Choose Mechanical Design → Part Design
3) Draw the design by follow the standard size ASTM D 638 Type I.
4) Design specimen complete with feed system design.
5) Save as type in “stl” format.
6) Open Autodesk Moldflow Insight 2011 software.
7) Import part (stl format) and open in Solid 3D
8) Duplicate an original file and rename to “Fill time” file.
9) Fill time : Select Material →Choose fill →Mesh→Set the injection location → Start analysis.
10) Duplicate the “Fill time” file and rename to “gate location” file.
11) Gate location : Choose the suitable gate location → Re mesh → Remove injection location → Start analysis.
12) Duplicate “gate location” file and rename to “full analysis” file
13) Select (Fill + Pack + Wrap) to do the full analysis.

14) Result will come out (fill time, pressure flow, gate location, defect and many more)
15) Analysis complete.

3.6 INJECTION MOLDING

In this process, the injection molding machine was used to produce a specimen. specimen mold to be used is in accordance with ASTM D638 standard. The specimen is in the form of a dog bone shape.

3.6.1 Part of Injection Molding Machine

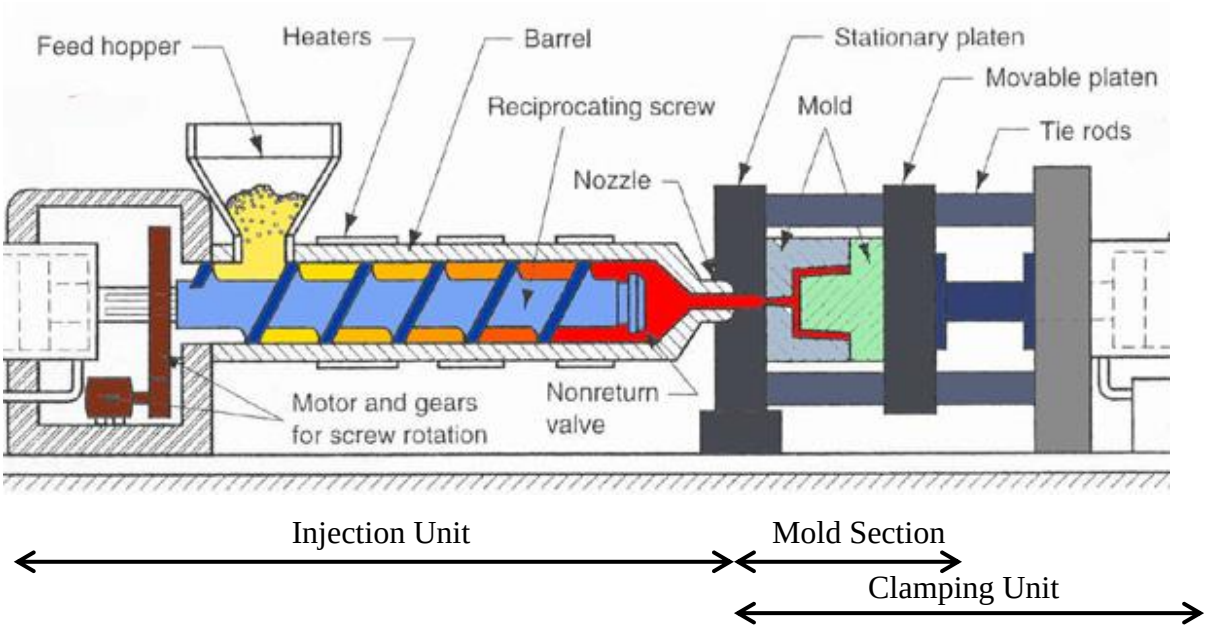


Figure 3.3: Injection Molding Machine

1) Injection Unit
    i. Motor and Gears
    ii. Rotation Screw
    iii. Hopper
    iv. Barrel
    v. Heater

vi. Nozzle

2) Mold Section
   i. Two-plate mold.
3) Clamping Unit
   i. Core
   ii. Cavity
   iii. Ejector Pin
   iv. Movable platen
   v. Tie rods
   vi. Clamping cylinder

3.6.2 Procedure Injection Molding Machine

1) Turn ON the machine
2) Pellets or granules of raw material (Nylon & Glassfibre) are fed into the hopper.
3) Preheat chamber (heater section) from 200°C until 300°C.
4) A motor will rotate the gear and indirectly, screw also will be rotate.
5) Usually rotation pressure will use range from 35 MPa to 140 MPa.
6) The rotation screw will move forward and push the molten plastic into the nozzle area.
7) The molten plastic will be injected into the mold through nozzle.
8) Wait for a while to cooling process and solidifies parts.
1) Open the mold section and the ejector pin will be ejected out the specimen from the cavity.
2) Finishing process, cut and remove the feed system (gate, runner, sprue) from the specimen.
3) Turn OFF the machine.

3.7 MECHANICAL TEST (TENSILE TEST)

After producing the specimen, the specimen will go through process of mechanical testing on it tensile strength and impact force. The mechanical properties of a material are directly related to the response of the material when it is subjected to mechanical stress. The basic mechanical properties of a material are found by determining the stresses and corresponding strains for various critical occurrences. This process will used a Universal Tensile Machine (UTM) for tensile test and INSTRON-CEAST 9050 for impact test. The unnotched specimen to be used is a standard size according to ASTM D 638. Standard size ASTM D638 used to test method for tensile and impact properties plastic material. During the tensile experiment, the specimen will be clamped both sections and will be pulled up until occur process of elongation and until its breakpoint. For the izod impact test, the unnotched specimen will be clamped on one side. The specimen must be in a vertical position at 90 degrees and the clamp force used is same for each specimen.

3.7.1 Software setup (Instron Bluehill)

1) Turn ON the Universal Testing Machine (UTM).
2) Wait until server connect the system.
3) Open Instron Bluehill software.
4) Select “Test” to start a new sample on the main page.
5) Choose method that will be used.
6) Create and save a new method

3.7.2 Machine setup

1) Select and install the load cell depends on size of specimen.
2) Calibrate the load cell by using Instron Bluehill (click calibrate icon) and make sure no loads or specimen on the load cell.
3) Clamp the specimen at load cell and make sure that clamp tight.

4) Calibrate the extensometer to zero coordination and clamp at the middle of specimen.
5) Final check, make sure that specimen is vertical position and tight clamp before start the testing.

3.7.3 Start tensile test

1) Click on the “start” button and the load cell and clamp will start move.
2) The clamp will pull up the specimen.
3) A plot of tensile stress against strain will be generated in real time during experiment.

3.7.4 End of tensile test

1) When specimen facture, machine will be stop automatically.
2) Press the “return” button at the machine to returned clamp and load cell to original position.
3) Remove the specimen by open the clamp and load cell.
4) Repeat the previous step for next specimen.
5) Save the file into PDF format and click finish.
6) Clean up the machine from any fragments fracture of specimen.
7) Turn OFF the Universal Testing Machine (UTM) and exit the program of Instron Bluehill.

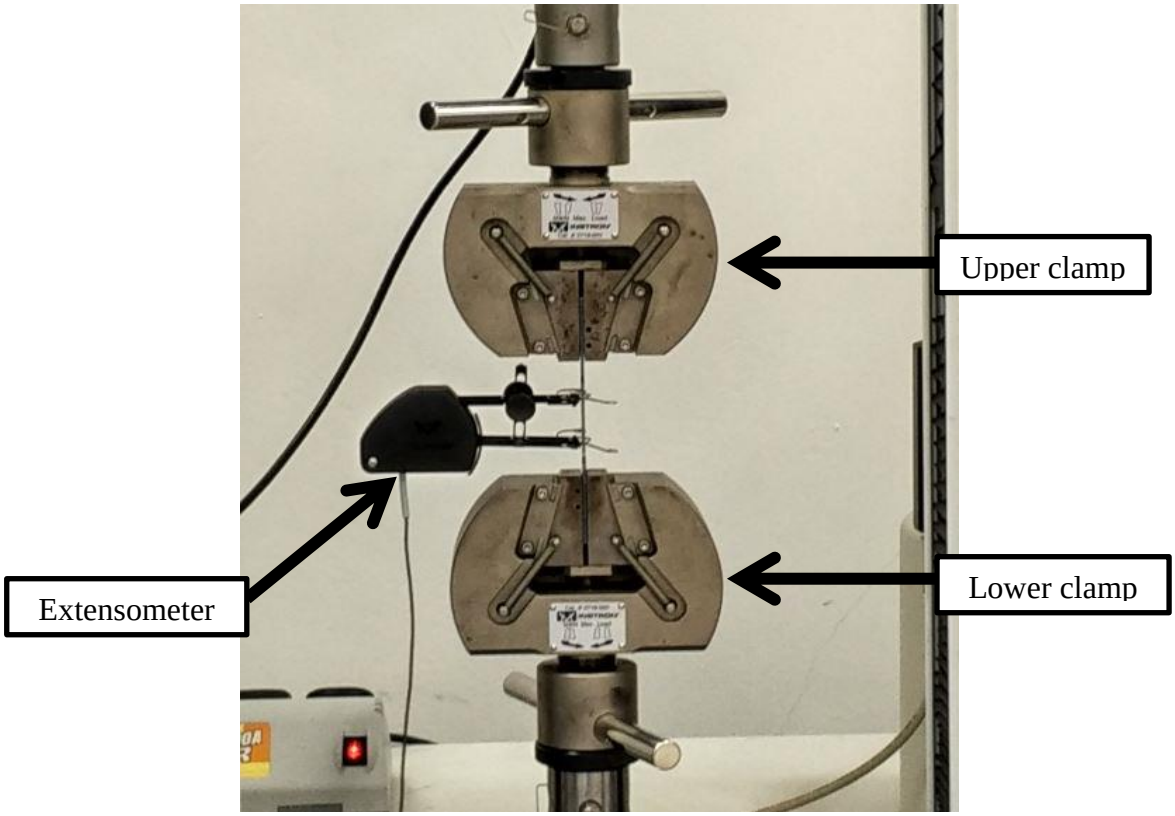


Figure 3.4 : Clamp section

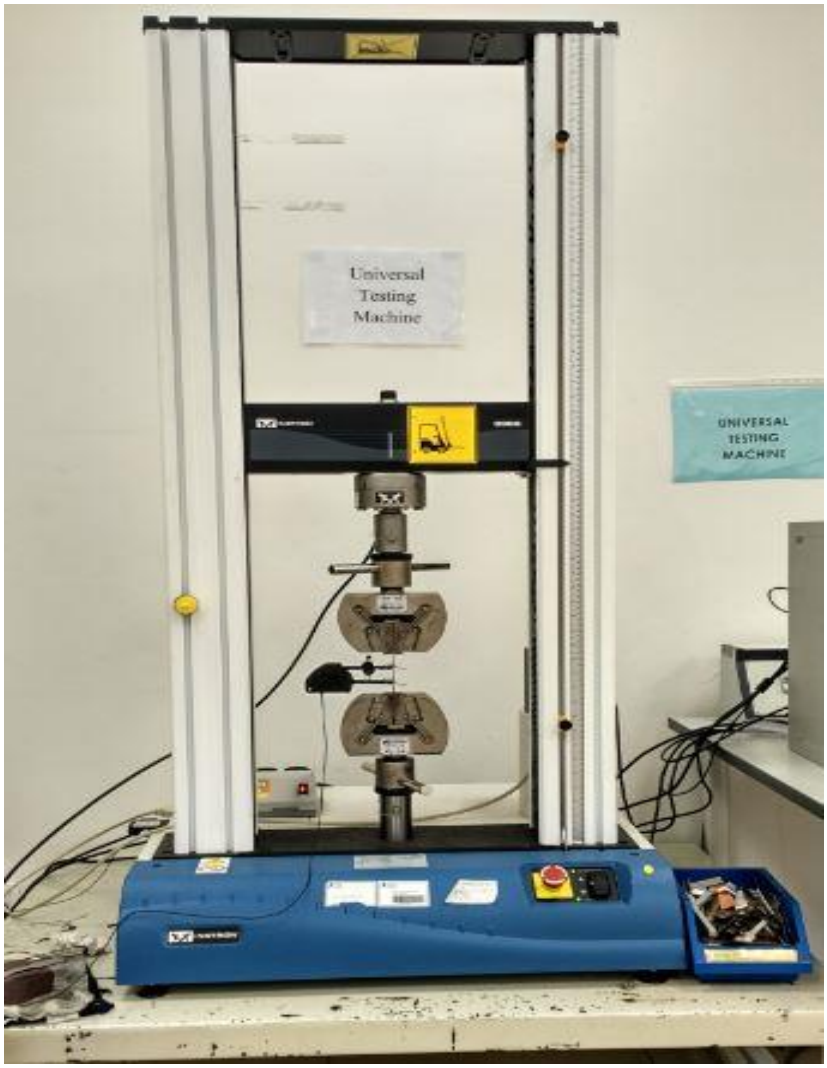


Figure 3.5 : Universal Testing Machine (UTM)

Figure 3.6 : Instron Bluehill software

3.8 MECHANICAL TEST (IMPACT TEST - IZOD)

Izod impact testing is an ASTM standard method of determining the impact resistance of materials. An arm held at a specific height (constant potential energy) is released. The arm hits the sample. The specimen either breaks or the weight rests on the specimen. From the energy absorbed by the sample, its impact energy is determined. A unnotched sample is used to determine impact energy. Unnotched specimen is held as a vertical cantilevered beam and is broken by a pendulum. In this impact test used 50(J) pendulum hammer to hits and break the sample.

Figure 3.7 : Impact Test (INSTRON – CEAST 9050)

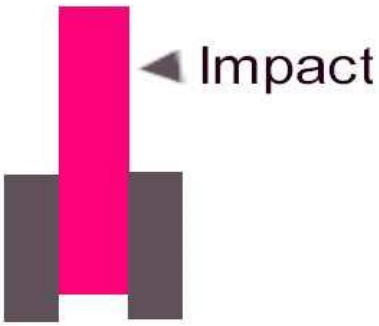


Figure 3.8 : Position of specimen for Impact Test (IZOD)

Figure 3.9 : Pendulum Hammer (50 J)

Figure 3.10 : Distance tighten of clamp

3.9 MICROSTRUCTURE ANALYSIS

The characteristics of glass fiber reinforced nylon can be seen through the process of microstructure analysis by using Optical Microscope machine (OM). Through the process of microstructure analysis, that will show the percentage difference of glass fiber for each specimen. The composition of glass fiber used to produce

specimen are 5%, 10%, 15% and 20%. In this method, it will show and define classification of each different composition.

Figure 3.11 : Optical Microscope Machine

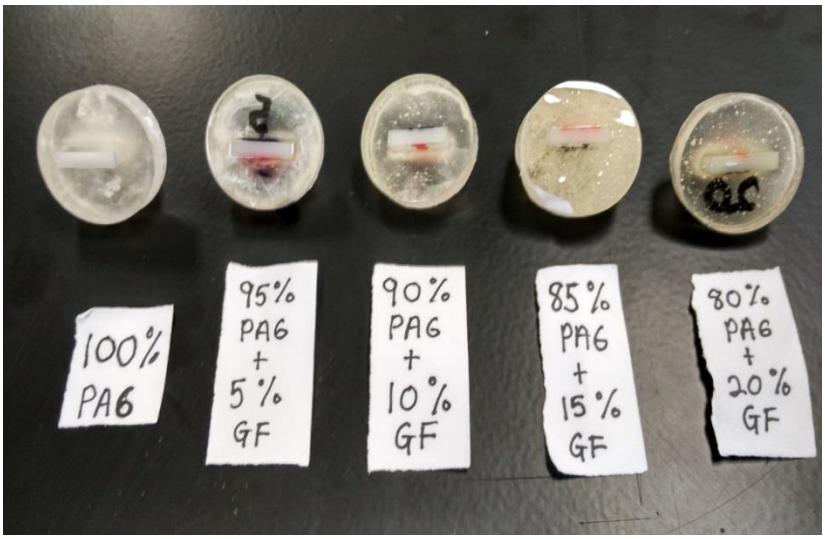


Figure 3.12 : Composition for Microstructure Analysis

CHAPTER 4

RESULTS AND DISCUSSIONS

4.1 INTRODUCTION

A plastic material is any of a wide range of synthetic or semi-synthetic organic solids that are moldable. A successfull plastics injection molded part is result when a well-designed concept, the right material and an appropriate manufacturing process are bought together. The strength of a part is defined as the maximum load that can be applied to a part without causing part failure under given conditions. The concept of strength is common in engineering design. The factor of consideration is take a big role in design a plastic part like design for compressive stress, in tension, design for a uniform cross-sectional area, in bending and consider worst case.

The CATIA V5 software that is intended to produce a 3D modeling in shaped dog bone and in accordance with ASTM D638. In Figure 4.1 shows the 3D modeling that followed ASTM D638 standard. This design of specimen is followed based on ASTM D638 standard and the dimension of specimen are as below :

Overall length : 165mm
Thickness : 3.2mm
Width : 12.70mm
Fillet radius : 76mm
Length of parallel narrow section : 57mm

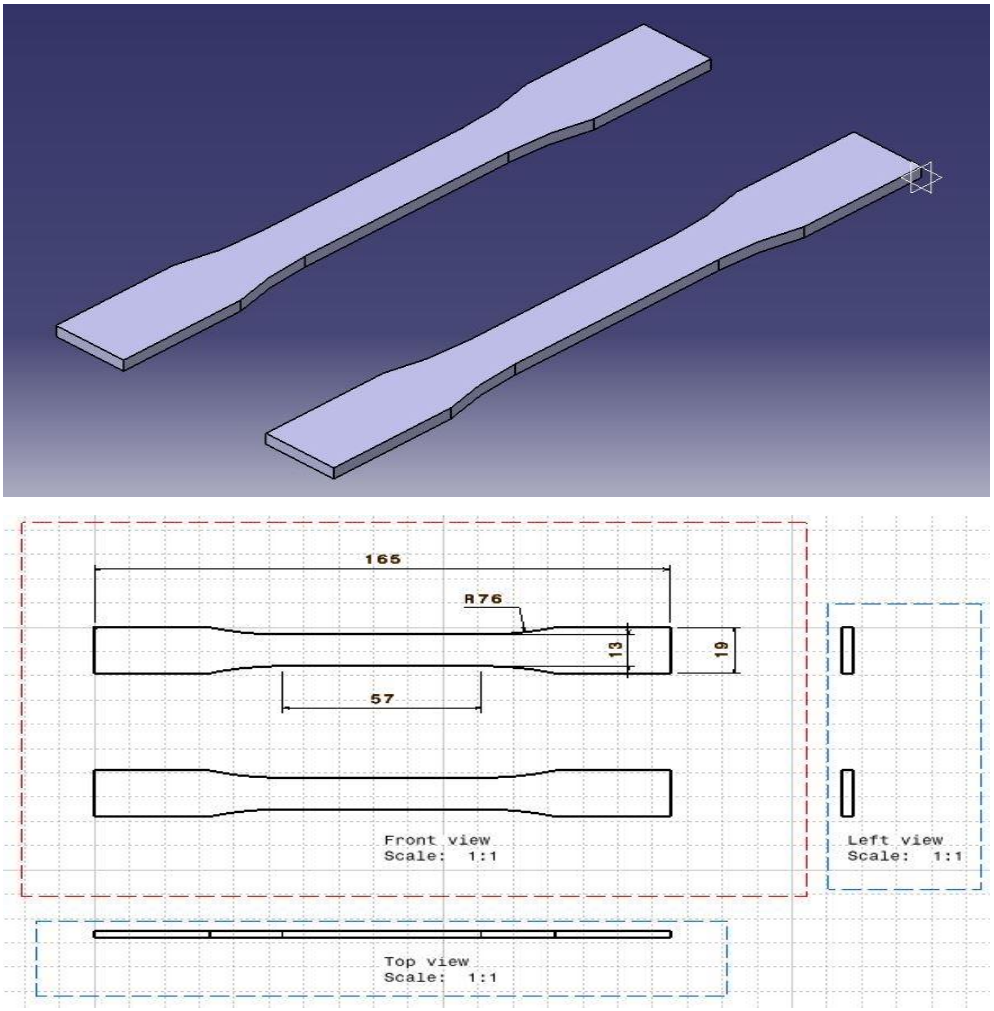


Figure 4.1 : 3D modeling of ASTM D638 specimen.

There are three different design of gate location it is Pin gate, Centre gate and Edge gate. All three designs of gate location will undergo a moldflow analysis to identify the best gate location for a dog bone (ASTM D638) specimen that will be produced in injection molding process. This figure 4.2 shows the different of gate location it is Pin gate, Centre gate and Edge gate.

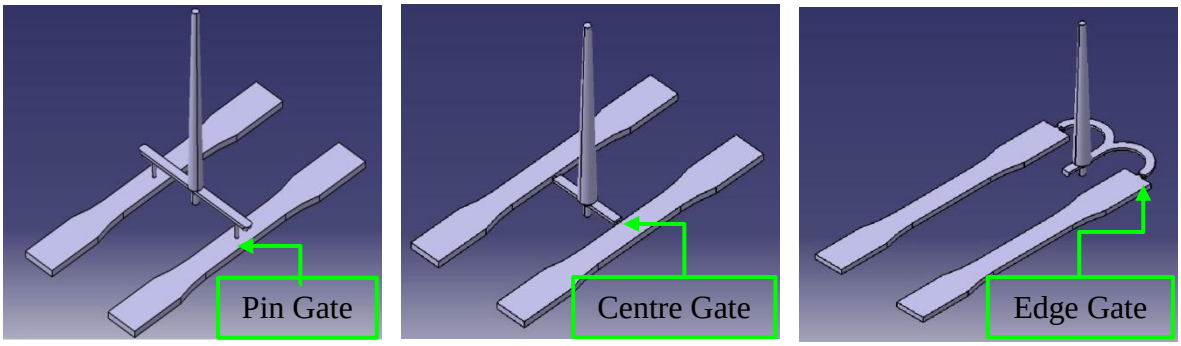


Figure 4.2 : Three different gate location of ASTM D638 specimen.

Autodesk Moldflow Insight 2011 software is a software that being used after the drawing 3D modeling. This software is used to identify the suitable process flow of the injection molding process. There are lots of characteristics process moldflow that can be identify in this software like prediction on fill time of molten plastic to fulfill injection of the part. This software also can analysis the temperature at flow front of the filling part. Besides, moldflow software can analysis pressure at fill end, time to reach ejection temperature, defect of injection part like air traps, weld lines and many more.

The best gate location design is chosen, that is Edge gate location of dog bone shaped specimen (ASTM D638). This is because the most common location gate design for dog bone shaped it is Edge gate. The edge gate is located on the edge of the specimen.

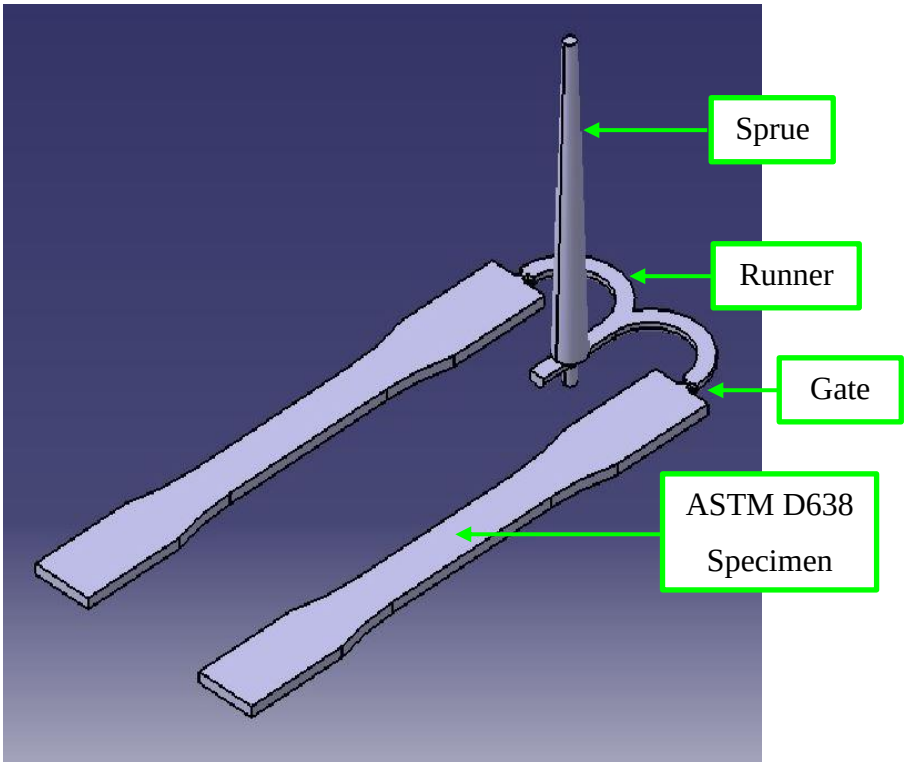
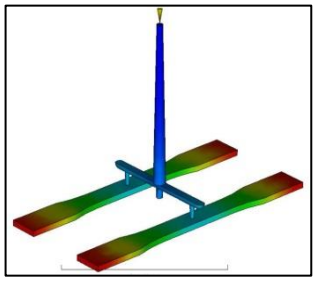
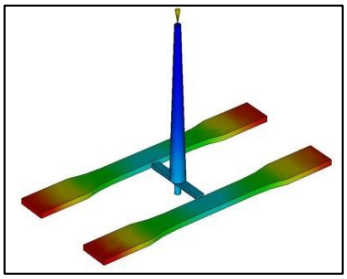
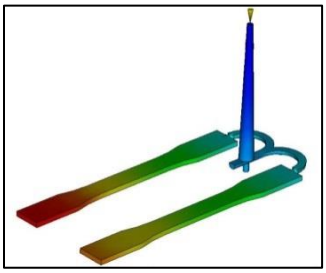
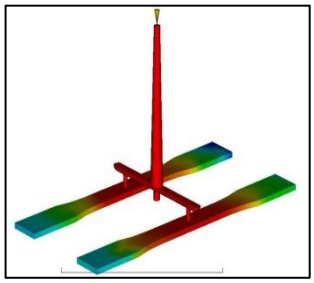
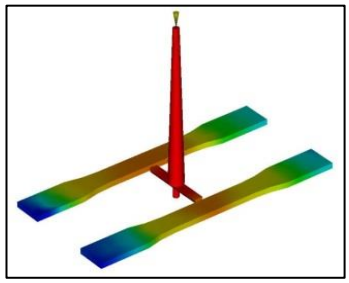
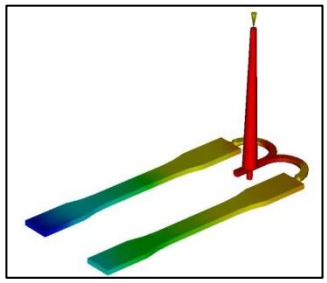
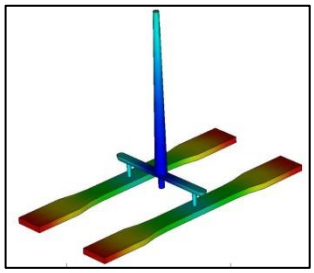
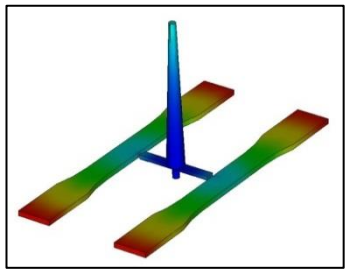
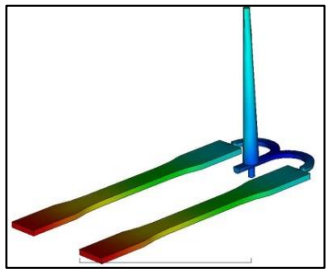
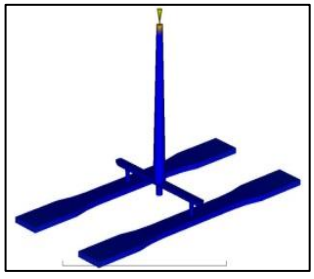
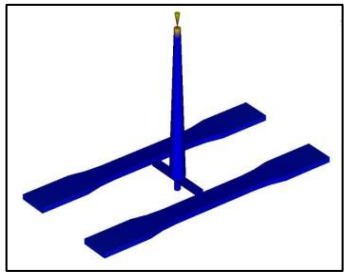
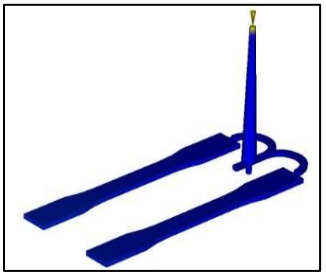


Figure 4.3 : Edge gate for ASTM D638 modeling.

In order for the molten plastic to flow into the mold cavities, several channels are integrated into this specimen design. Another name for that channels is feed system. In feed system have sprue, cold slug, runner and gate. Firstly, the molten plastic will enters the mold through the sprue. After that, the runner carry the molten plastic from sprue to all cavities. At the end of runner, the molten plastic will enter the cavity through a gate and finally the molten plastic will fulfill all part modeling.

4.2 MOLDFLOW ANALYSIS

Table 4.1 : Tabulated Moldflow Analysis

Moldflow Analysis	**Pin Gate**	**Centre Gate**	**Edge Gate**
Fill time	0.1056 (s) 	0.1058 (s) 	0.2215 (s) 
Temperature at Flow Front	250.2 (°C) 	250.2 (°C) 	250.2 (°C) 
Gating Suitability			
Time to Reach Ejection Temperature	2.078 (s) 	2.139 (s) 	2.958 (s) 

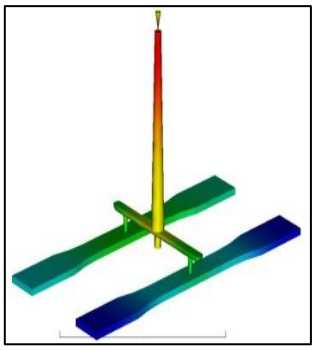
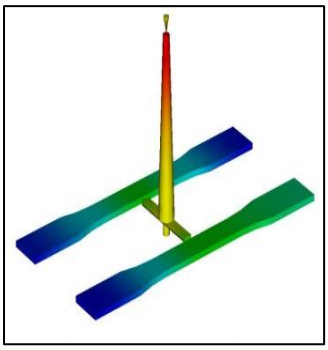
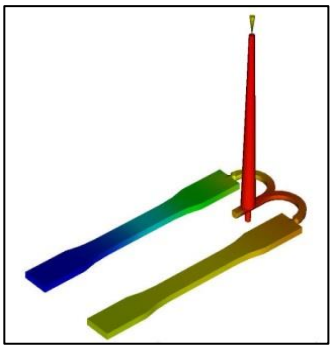
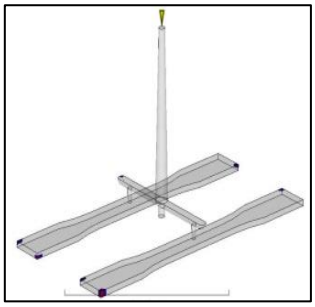
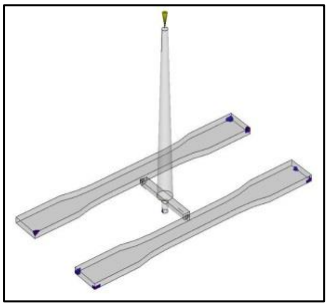
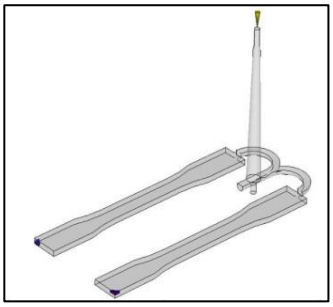
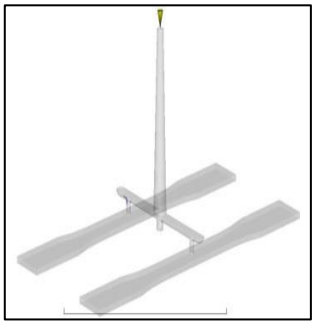
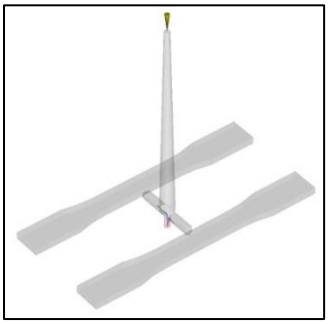
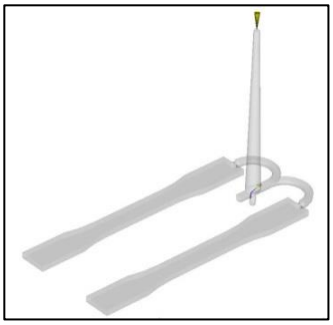
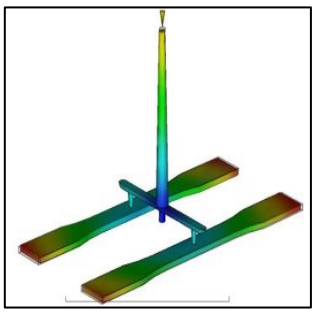
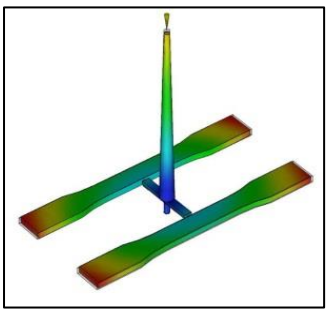
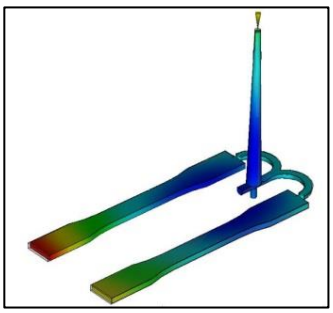
Moldflow Analysis	**Pin Gate**	**Centre Gate**	**Edge Gate**
Pressure at End of Fill	22.77 (MPa) 	17.40 (MPa) 	69.93 (MPa) 
Air Traps	0.1056 (s) 	0.1058 (s) 	0.2215 (s) 
Weld Lines	135.0 (deg) 	135.0 (deg) 	135.0 (deg) 
Warp			

Table 4.1 shows the differentiation of moldflow analysis for three different type of gate location it is Pin gate, Centre gate and Edge gate. The result of moldflow analysis for different gate location will be different value and different properties. Moldflow analysis has shown that the most suitable gate location to produce a specimen is edge gate. This is because the gate edge shows uniform parallel direction flow of molten plastic or parallel orientation across the whole width. Even fill time of edge gate take longer than pin gate and centre gate, but the gate edge less occurrence of defects such as air traps and weld lines compared to pin gate and centre gate that produce more defects. To produce a good specimen, should be less occurrence of defect, so the gate edge is the most suitable gate. Pin gate and centre gate are not suitable use to produce specimen. This is because the gate location are located in the middle of the specimen. When the gate are located in the middle, then the direction flow of molten plastic are not uniform or irregularly and possibility will occur defect such as air trap in the middle of specimen. The most important part of the specimen is in the middle. This is because the central part is used to perform mechanical tests such as tensile test and impact test.

4.2.1 Gating Suitability

Gating suitability analysis is a result that covers all the properties to determine the best injection location. The most suitable injection location will be in blue colour and unsuitable injection location will be in red colour. Based on the Figure 4.4 shows gating suitability for edge gate location. The blue color shows the most suitable locations for injection gate to molten plastic flow into the part.

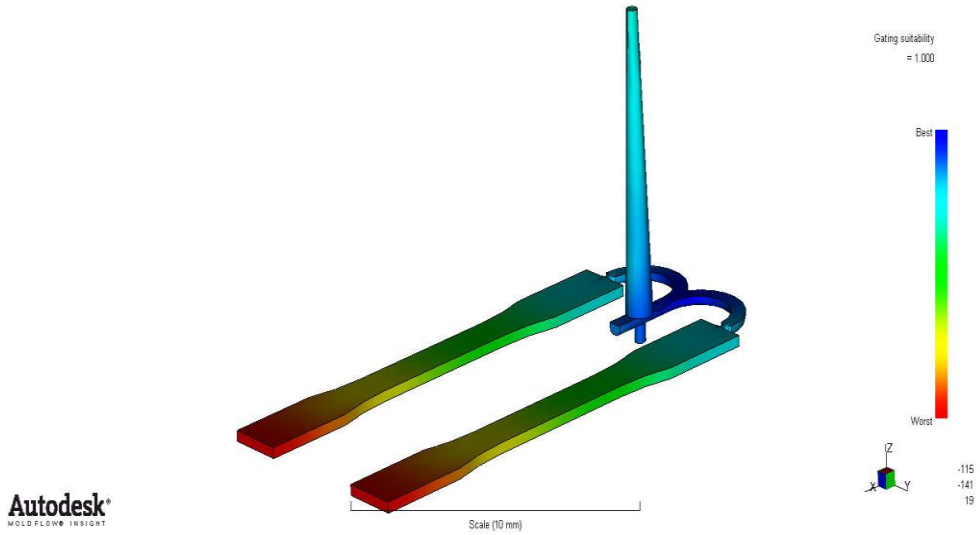


Figure 4.4 : Gating suitability.

4.2.2 Fill Time

A moldflow or mold filling analysis can help in predict short shots. Shorts shots are legitimate concern for those involved in creating plastic parts. It is important to run an analysis on a variable wall thickness like this dog bone modeling because to ensure these areas will fill out and the short shot in plastic part can be prevented. The result from figure 4.5 below show the plastic flow path thorough the part measured in seconds. The filling time is 0.2215s. These results indicate plastic material flow path thorough sections using contour connecting the area to fill the same time. The contours are shown in different colours from blue to indicate that the first areas to fill, to red to fill the show last region. Short shot is part of the model that does not fill, and appears as a translucent. By plotting the contours in the order of time, plastics canvas is actually flowing into the mold, is given.

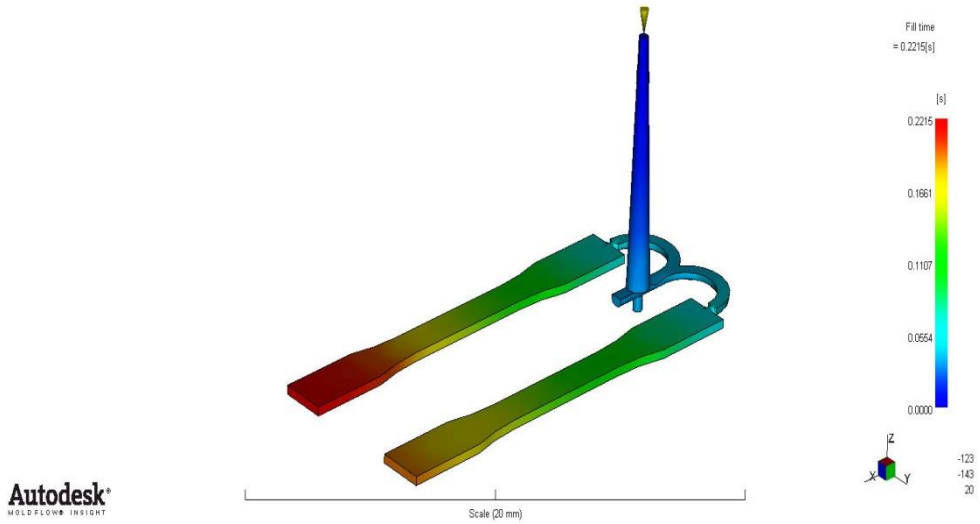


Figure 4.5 : Fill Time.

4.2.3 Temperature at Flow Front

Temperature distribution is generated from the results of the analysis of flow of saturation. It shows the presence of flow when the polymer temperature reached a certain point in the middle of the plastic cross-section. As show at the figure 4.6 below, the temperature at flow front result uses a range of colours to indicate the region of lowest temperature in blue through to the region of highest temperature in red. The colours represent the material temperature at each point was filled. The result shows the changes in the temperature of the flow front during filling. The flow front temperature should not drop more than 4°C to 9°C during the filling phase as this figure 4.6 shows that the filling phase just drop about 8°C only. The main changes are the areas that show the injection time is too low. If the flow front temperature is too low, we have to secure a short shot in the area of the thin section. In areas where the flow front temperature increases by several degrees, material degradation and surface defects may occurs.

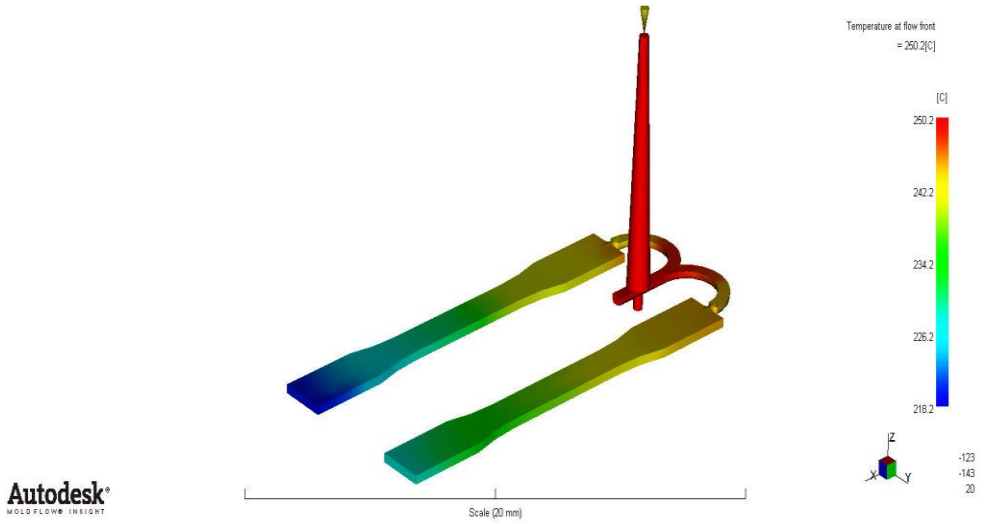


Figure 4.6 : Temperature at Flow Front.

4.2.4 Time to Reach Ejection Temperature

Time to reach ejection temperature shows what time is needed to cool the part to the ejection temperature. Determine throwing time to reach the temperature, I indicate the amount of time required to reach an ejection temperature mearsured from the start of fill. Portion, a predetermined cycle, when it is not frozen by the end of the freeze period is described in the decision. In the 3D moldflow analysis show the time taken the polymer reach ejection temperature is 2.958 s.

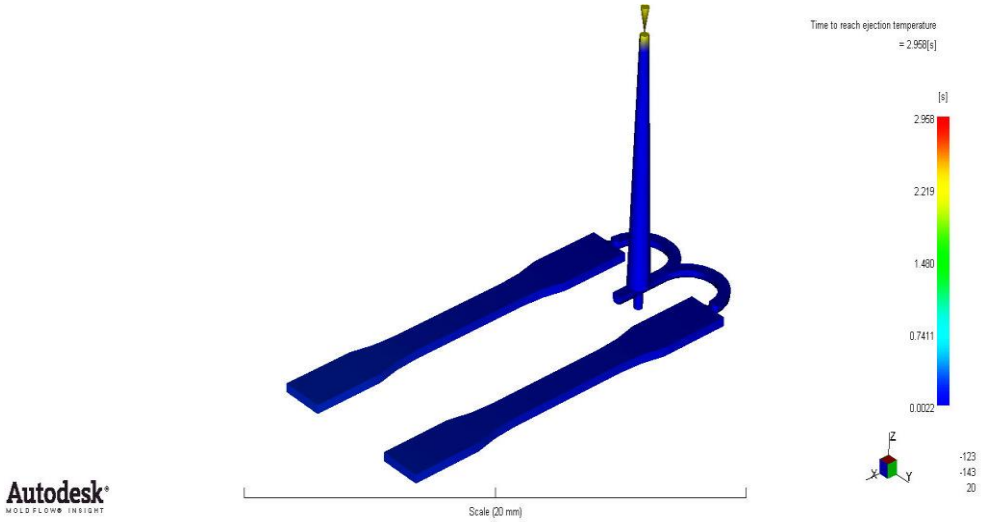


Figure 4.7 : Time to Reach Ejection Temperature.

4.2.5 Air Traps

Melt, converge at or fill at least two flow fields, as a result of stopping at the end point of the trapped bubble trap air show area. Highlight region on these results, the position of possible air trap. Air traps may be acceptable if they occur on surface that does not have to be visually perfect. A higher value indicates a higher probability that an air trap will occur while a lower value indicate a lower probability that an air trap will occur. The air traps result can reveal the following problem in our part:

i. Burn marks caused by air an air trap, which ignites under pressure and burns the plastic.

ii. Other surface blemishes caused by air traps.

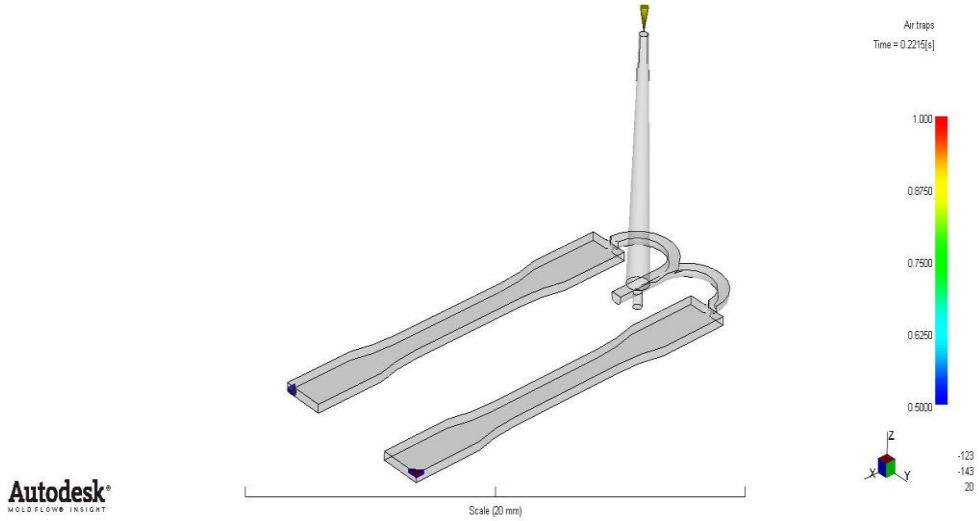


Figure 4.8 : Air Traps

4.2.6 Weld Lines

The weld lines must result displays the angle of convergence as two flow fronts meet. The presence of weld lines may indicate a structural weakness and a surface blemish. The term “weld line” is often used to mean both weld and meld lines. The only difference between them is the angle at which they are formed. The weld lines form at lower anglers than meld lines. From the figure 4.9, it shows that there are some weld lines occurs at the end of runner or other name is cold slug area. The plastic part does not affected by the weld lines. That means the dog bone shape is in good condition and have a smooth appearance. Weld lines can cause structural problems and make part visually unacceptable. Weld lines should be avoided, particularly weld lines in areas that require strength or a smooth appearance.

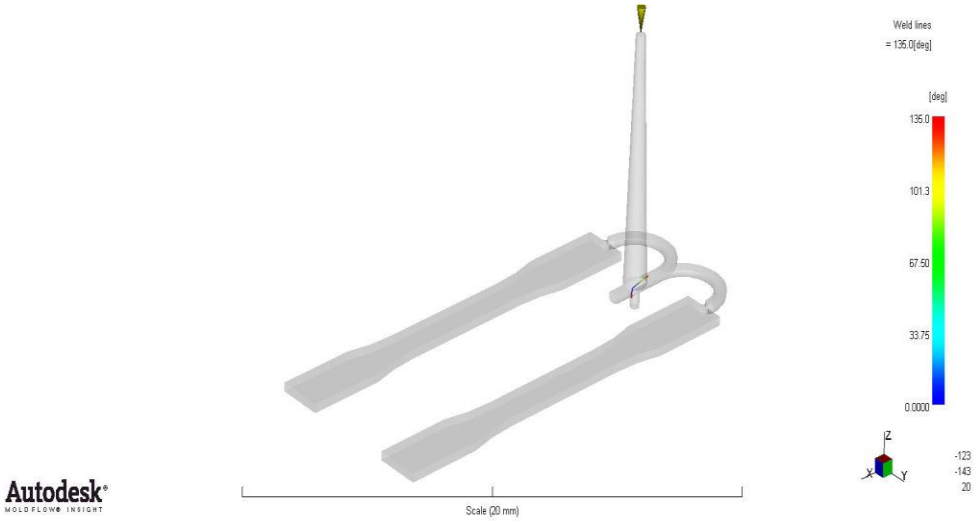


Figure 4.9 : Weld Lines.

4.2.7 Warp

A warp analysis is used to determine whether a part molded with a thermoplastic material will warp. Warp analysis facilities the understanding of the deflection in X, Y, and Z direction, effect of corrective actions to minimize warpage and final shape of the product. Warp analysis work as to predict the location warp and to determine the cause of the warp of the mold part occurs in part. As can be seen from the analysis, based on the cause of the warp, the warp of the part can be controlled by optimizing the design, the parameters of the materials and processing. Be addressed to the warping of the problem in the design stage itself, will help to avoid rework consuming mold and time delay cost. For a warp analysis, constraints are applied to the model nodes to prevent rigid body motion of the model, in response to the natural warpage of the part. This is automatic by default. Warp requires high dimensional stability and excellent visual appearance.

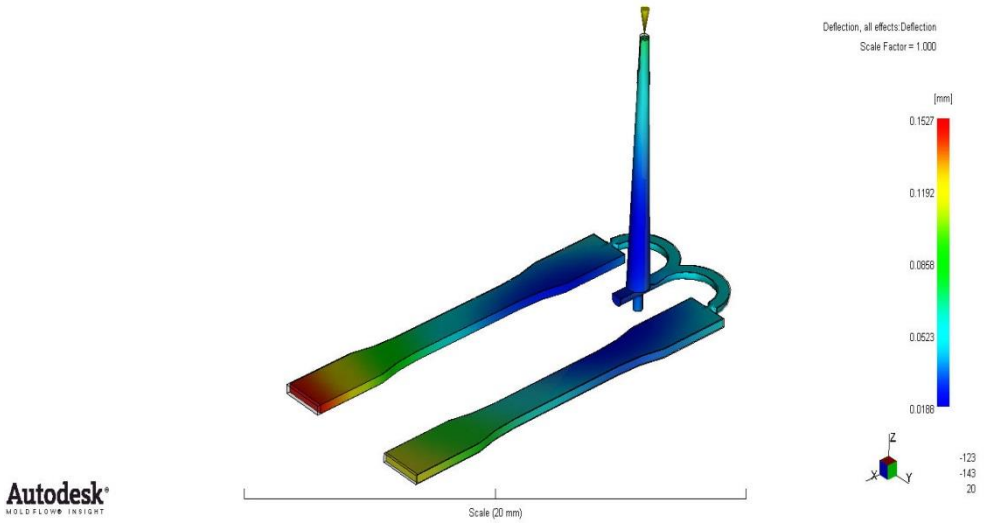


Figure 4.10 : Warp (Deflection, all effects: Deflection)

4.3 MAIN DATA OF INJECTION MOLDING

The important things during producing ASTM D638 specimen by using the injection molding machine is to determine the ideal temperature, cooling time and stroke material to produce specimens of different composition glass fiber. The table 4.2 and table 4.3 show the temperature, cooling time and stroke material used during producing ASTM D638 specimen by using injection molding machine.

Table 4.2 : Temperature used for different composition of glass fiber-reinforced nylon.

Material Composition	Temperature (°C)				
	Nozzle	Head	Front	Middle	Rear
Pure Nylon	229	226	223	220	217
95%PA6 + 5%GF	242	239	236	233	230
90%PA6 + 10%GF	245	242	239	236	233
85%PA6 + 15%GF	248	246	243	240	237
80%PA6 + 20%GF	258	255	252	249	246

Table 4.3 : Cooling time and stroke material used for different composition of glass fiber-reinforced nylon.

Material Composition	Cooling Time (s)	Stroke Material (mm)
Pure Nylon	43	67
95%PA6 + 5%GF	63	59
90%PA6 + 10%GF	80	65
85%PA6 + 15%GF	100	73
80%PA6 + 20%GF	120	83

The temperature used to producing pure nylon specimen is between 217°C until 229°C. The temperature used for composition 95% PA6 + 5%Glass Fiber is increased 13°C to 14°C. So, the temperature for composition 95%PA6 + 5%GF is 230°C until 242°C. The temperature for composition 90%PA6 + 10%GF is increased 3°C from the previous temperature used for composition 95%PA6 + 5%GF. The temperature used for composition 85%PA + 15%GF is 237°C until 248°C. the temperature used for composition 80%PA6 + 20%GF is 246°C until 258°C. Figure 4.12, 13, 14, 15, and 16 show the temperatures on monitor of injection molding machine.

In conclusion, increasing the temperature used to produce specimens of different glass fiber composition. The increment of temperature happened because of the percentage of glass fiber increase. Require a high temperature to reach the melting point of glass fiber. So, increasing the percentage of glass fiber mixture, the higher the temperature required for the process of producing specimen ASTM D638. Figure 4.11 show the successful ASTM D638 specimen in the shape of dog bone.

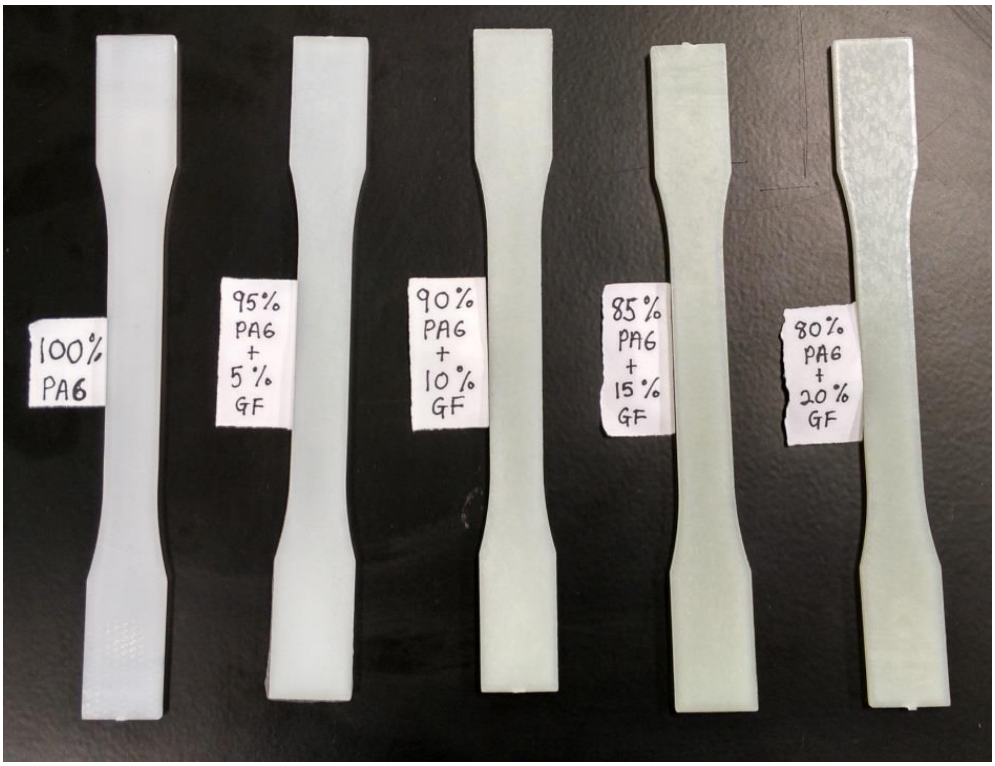


Figure 4.11 : Successful ASTM D638 specimen

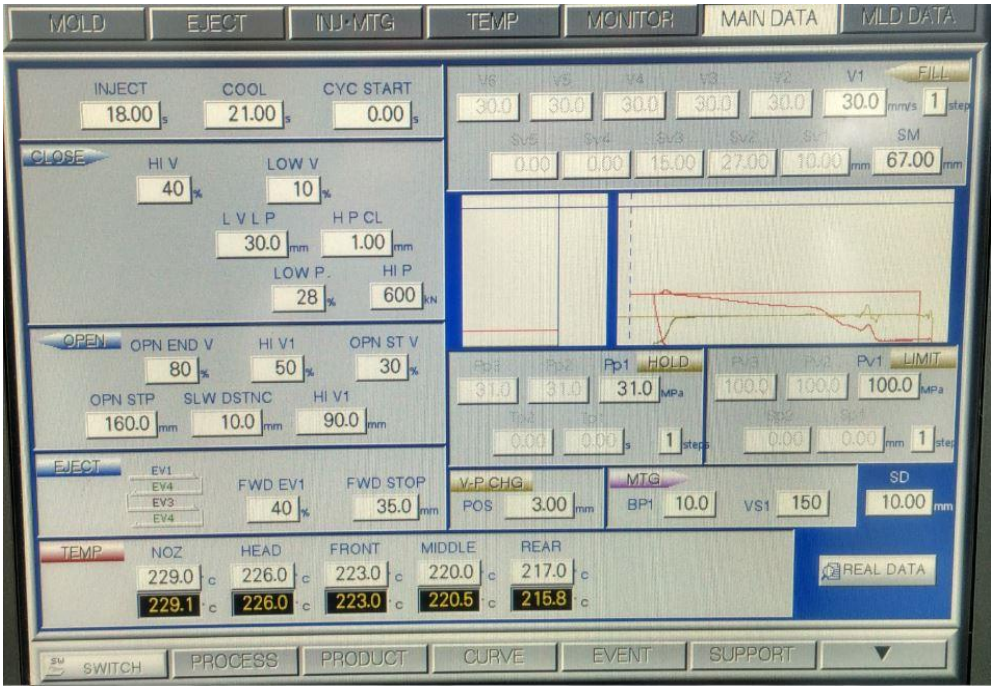


Figure 4.12 : Temperature used for Pure Nylon

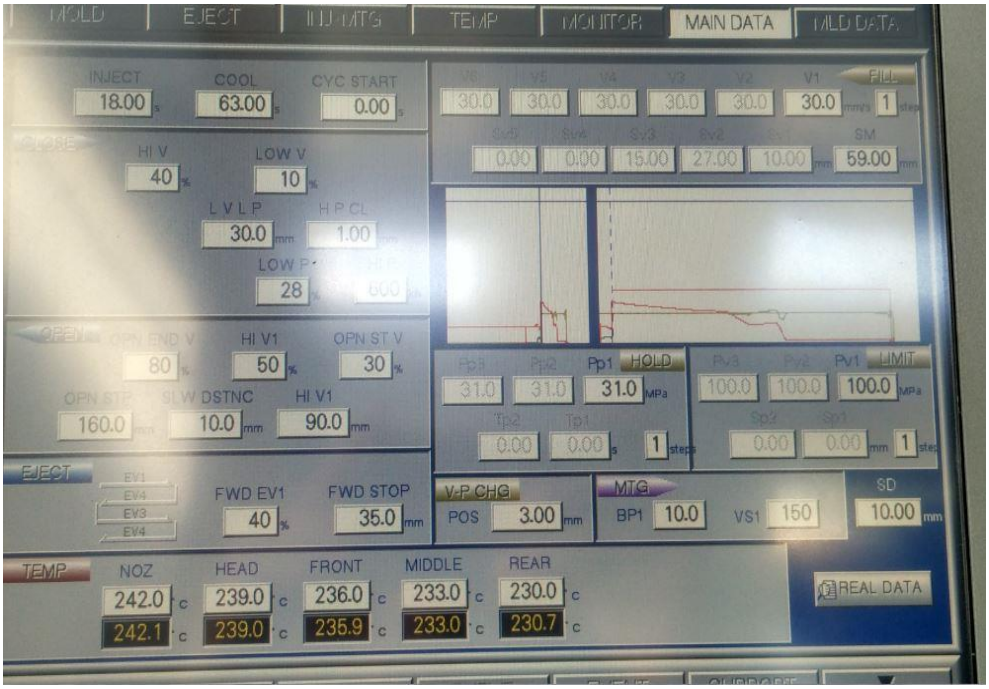


Figure 4.13 : Temperature used for 95%PA6 + 5%GF

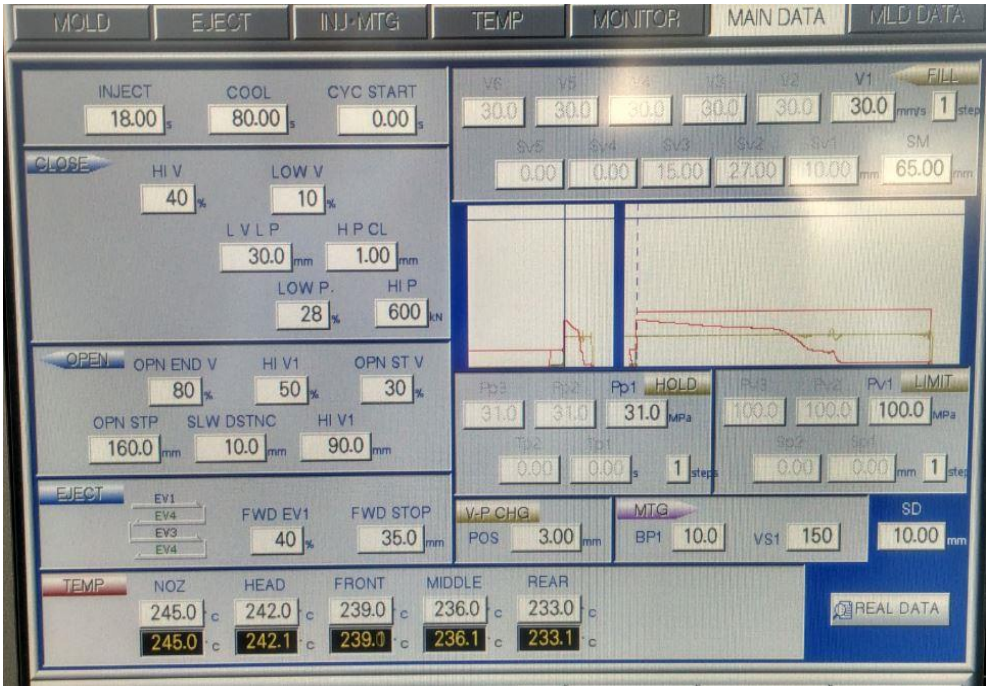


Figure 4.14 : Temperature used for 90%PA6 + 10%GF

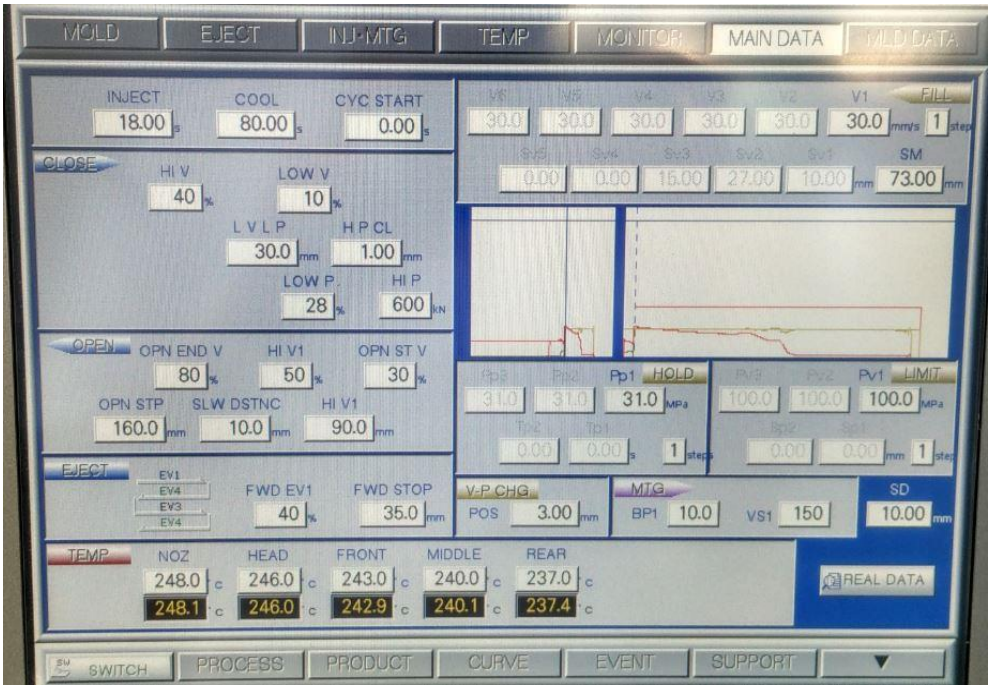


Figure 4.15 : Temperature used for 95%PA6 + 15%GF

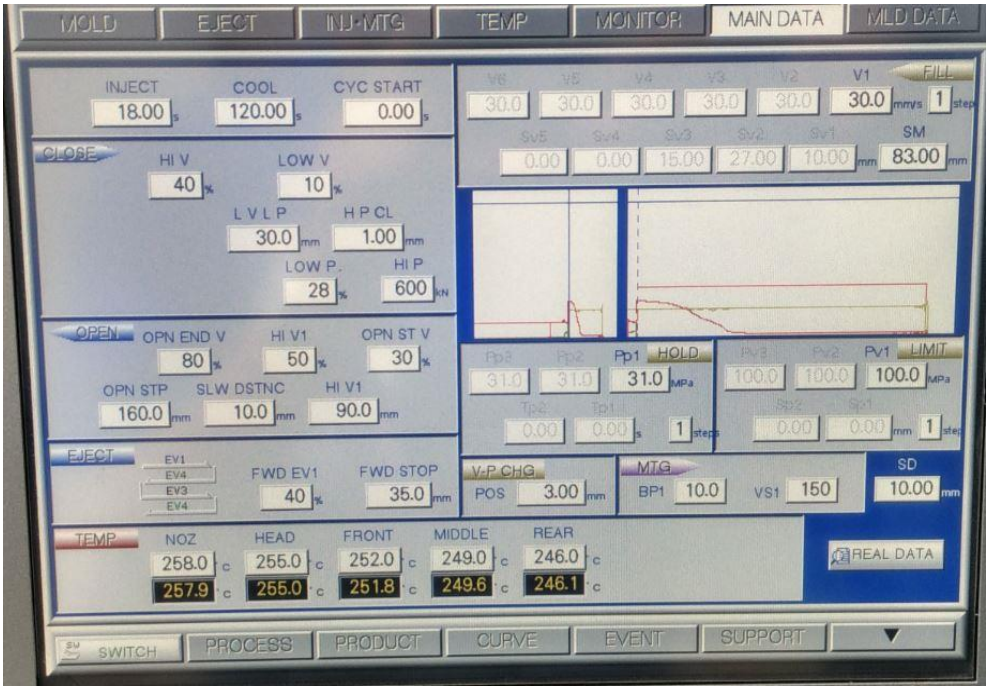


Figure 4.16 : Temperature used for 80%PA6 + 20%GF

4.4 TENSILE TEST RESULT ANALYSIS

4.4.1 Introduction

Mechanical testing is an important role in evaluating fundamental properties of engineering materials as well as in developing new materials and in controlling the quality of materials for use in design and construction. If a material is to be used as part of an engineering structure that will be subjected to a load, it is important to know that the material is strong enough and rigid enough to withstand the loads that it will experience in service.

The most common type of the test used to measure the mechanical properties of a material is the tension test. Tension test is widely used to provide basic design information on the strength of materials and is an acceptance test for the specification of materials. The major parameters that describe the stress-strain curve obtained during the tension test are the modulus (GPa), tensile stress at maximum load (MPa), tensile stress at break (MPa) and tensile stress at yield (MPa).

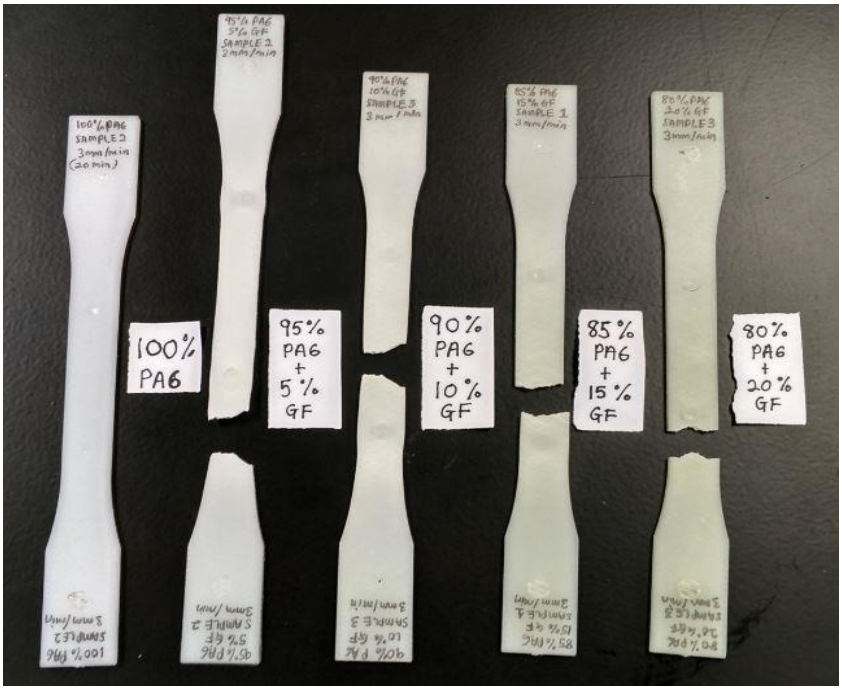


Figure 4.17 : Fractured specimens (3mm/min).

Figure 4.18 : Fractured specimens (5mm/min).

Figure 4.19 : Fractured specimens (10mm/min).

This tensile tests using different three rate condition that is 3mm/min, 5mm/min and 10mm/min. Through this tensile test will generate tensile stress-tensile strain curve. These stress-strain curve shows a result of mechanical test generate from the Bluehill software of tensile machine. The mechanical properties shown are Young's Modulus, Tensile Stress at Maximum Load, Tensile Stress at Break and Tensile Stress at Yield. The mechanical test result for five different percentage of glass fiber used is tabulated in the Table 4.4, 4.5, 4.6. From Table 4.4, 4.5, 4.6 show the increase of mechanical properties for each specimen when the percentage of glass fiber is increased.

Table 4.4 : Tensile Test (3mm/min)

Composition	Rate	Sample	Modulus (GPa)	Tensile Stress At Maximum Load (MPa)	Tensile Stress At Break (MPa)	Tensile Stress At Yield (MPa)
100% PA6	3mm	2	1.3345	39.7244	39.5526	18.2417
95% PA6 + 5% GF		2	1.4597	43.3632	38.3454	19.2248
90% PA6 + 10% GF		3	1.7627	47.2669	41.6508	21.3280
85% PA6 + 15% GF		1	3.2161	62.8394	57.6774	28.7130
80% PA6 + 20% GF		3	3.8425	74.6766	72.3036	35.9001

Table 4.5 : Tensile Test (5mm/min)

Composition	Rate	Sample	Modulus (GPa)	Tensile Stress At Maximum Load (MPa)	Tensile Stress At Break (MPa)	Tensile Stress At Yield (MPa)
100% PA6	5mm	1	1.5160	41.5628	40.5550	19.5639
95% PA6 + 5% GF		2	1.5334	44.7781	39.4827	17.1395
90% PA6 + 10% GF		2	2.2841	55.2321	49.4734	25.9714
85% PA6 + 15% GF		1	3.4585	64.6392	61.0433	31.2367
80% PA6 + 20% GF		2	4.4649	78.5932	76.1270	39.6654

Table 4.6 : Tensile Test (10mm/min)

Composition	Rate	Sample	Modulus (GPa)	Tensile Stress At Maximum Load (MPa)	Tensile Stress At Break (MPa)	Tensile Stress At Yield (MPa)
100% PA6	10mm	1	1.5039	41.9764	41.0444	21.5109
95% PA6 + 5% GF		1	2.0220	47.3320	41.1730	22.7052
90% PA6 + 10% GF		2	2.5116	56.1127	50.5835	28.6083
85% PA6 + 15% GF		2	3.5438	70.0149	67.5854	33.5922
80% PA6 + 20% GF		2	5.0388	82.6548	80.4761	37.9197

4.4.2 Pure Nylon

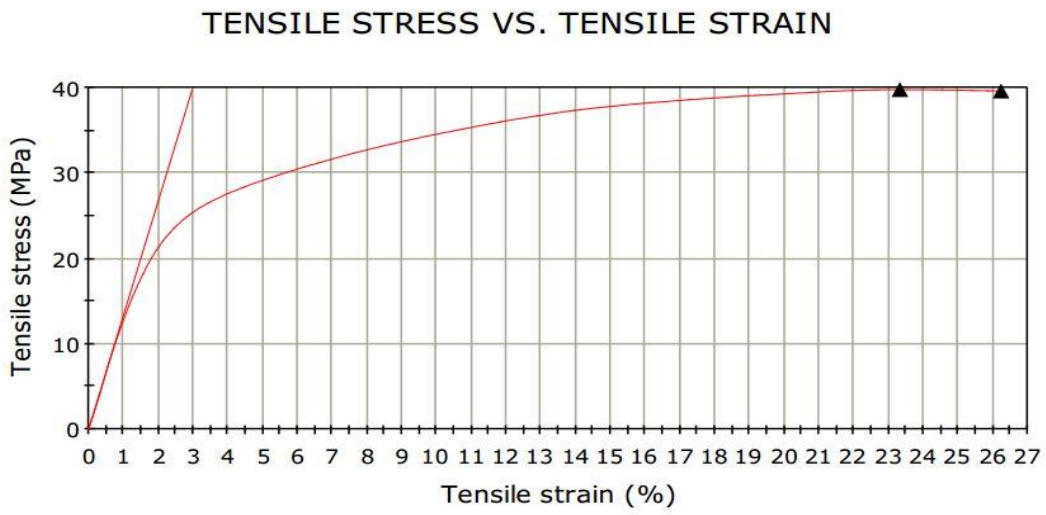


Figure 4.20 : Stress-strain curve of pure nylon (3mm/min).

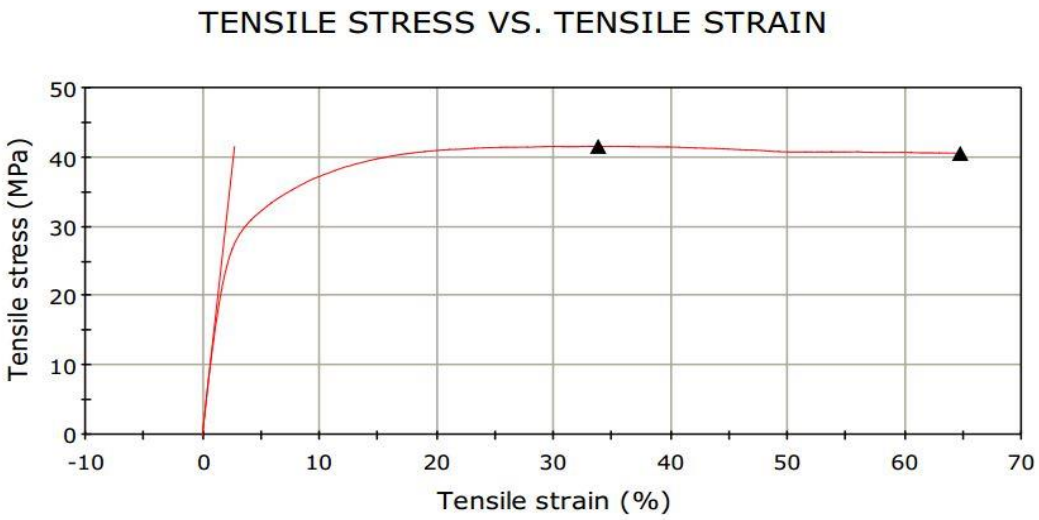


Figure 4.21 : Stress-strain curve of pure nylon (5mm/min).

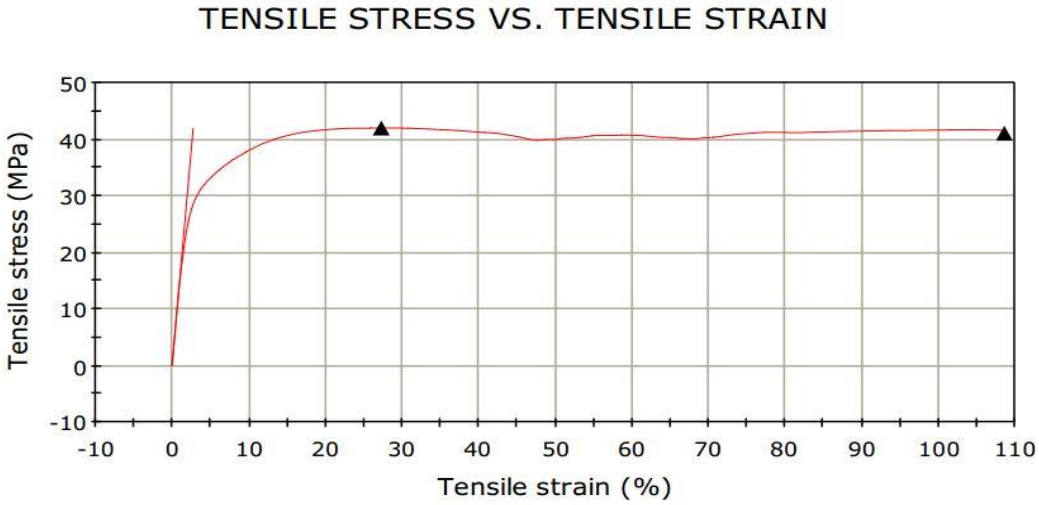


Figure 4.22 : Stress-strain curve of pure nylon (10mm/min).

4.4.3 95%PA6 + 5%GF

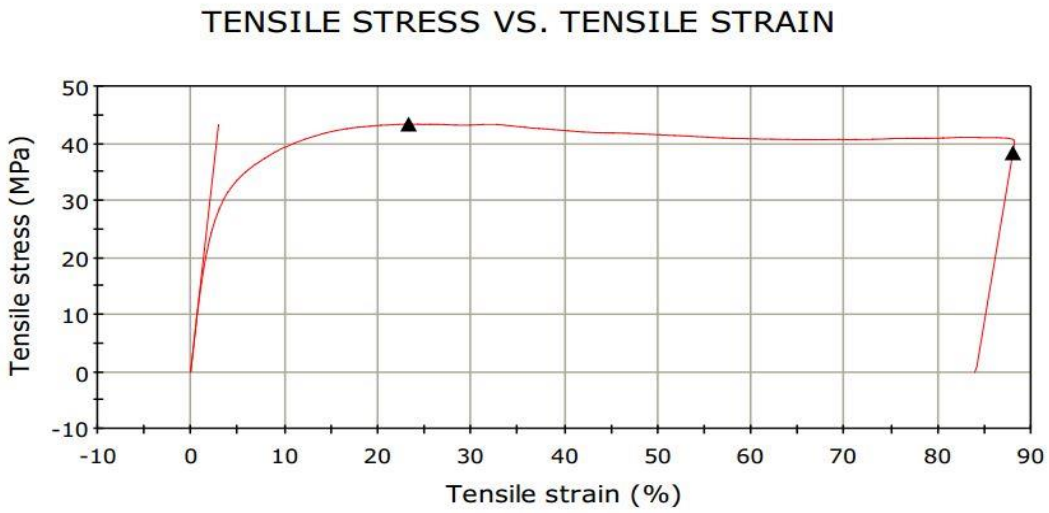


Figure 4.23 : Stress-strain curve of 95%PA6 + 5%GF (3mm/min).

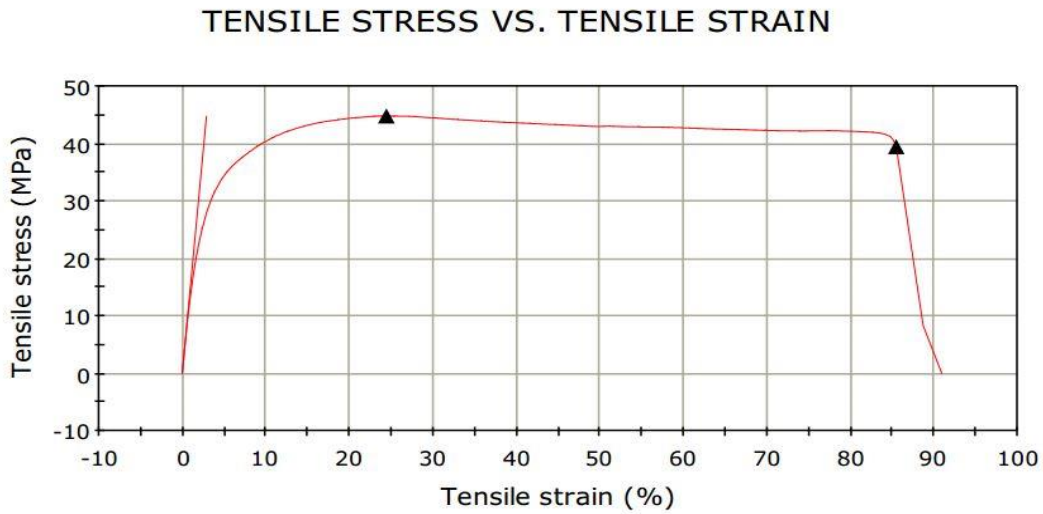


Figure 4.24 : Stress-strain curve of 95%PA6 + 5%GF (5mm/min).

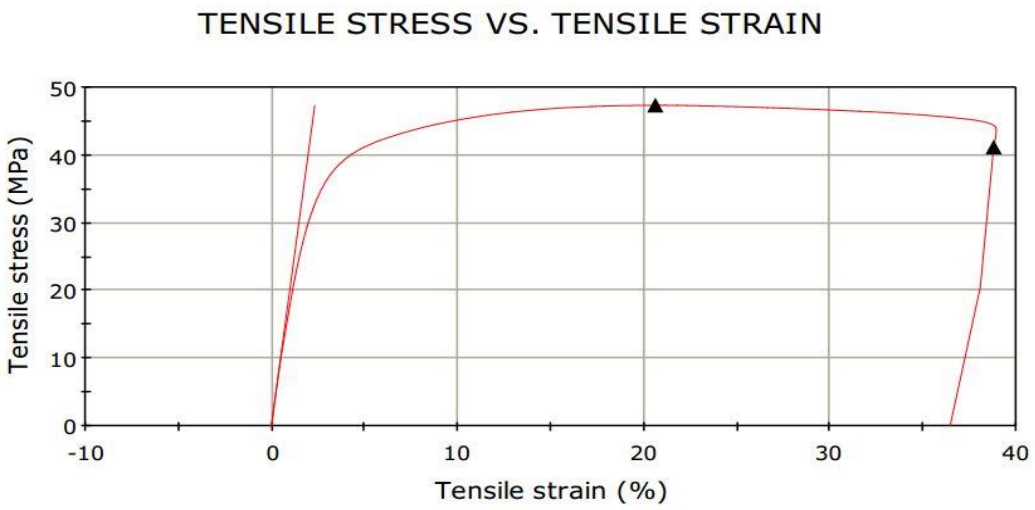


Figure 4.25 : Stress-strain curve of 95%PA6 + 5%GF (10mm/min).

4.4.4 90%PA6 + 10%GF

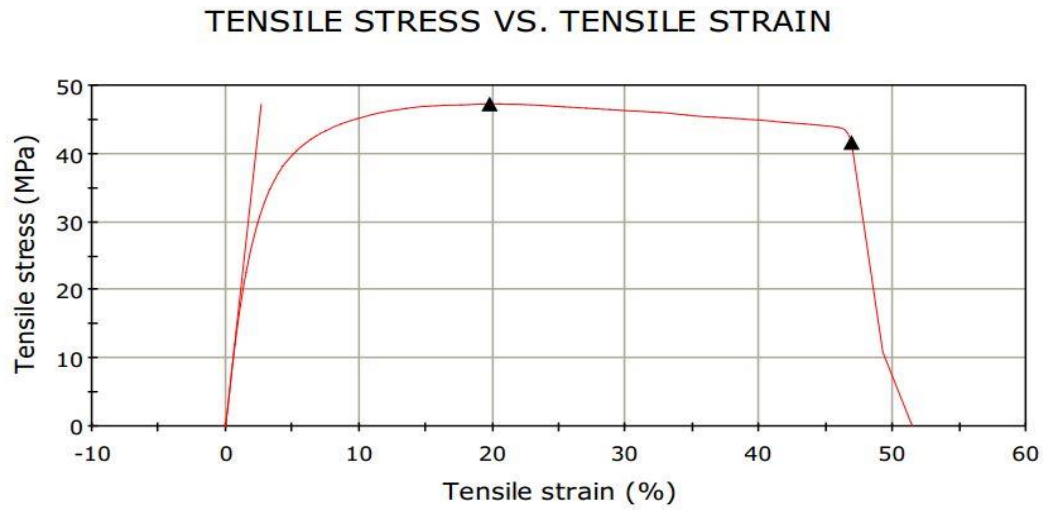


Figure 4.26 : Stress-strain curve of 90%PA6 + 10%GF (3mm/min).

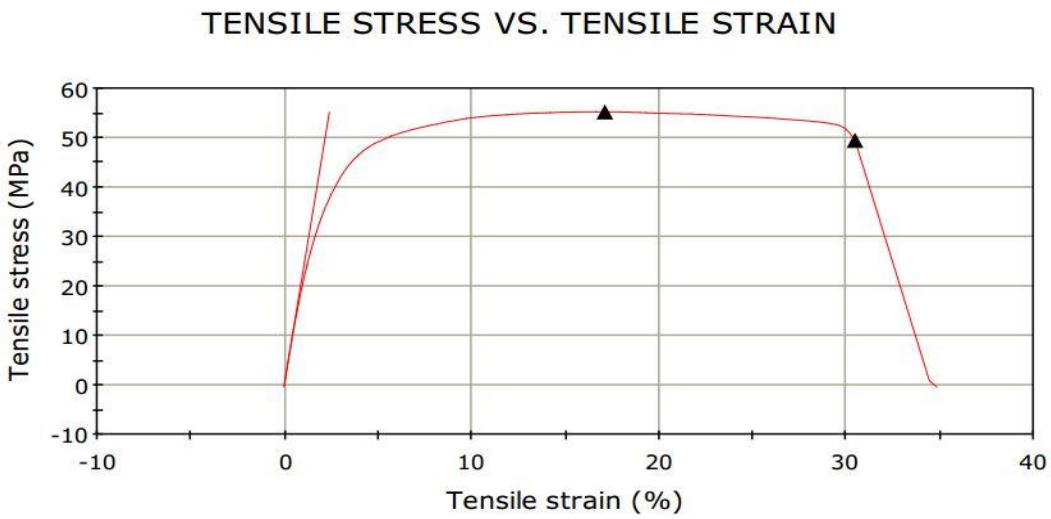


Figure 4.27 : Stress-strain curve of 90%PA6 + 10%GF (5mm/min).

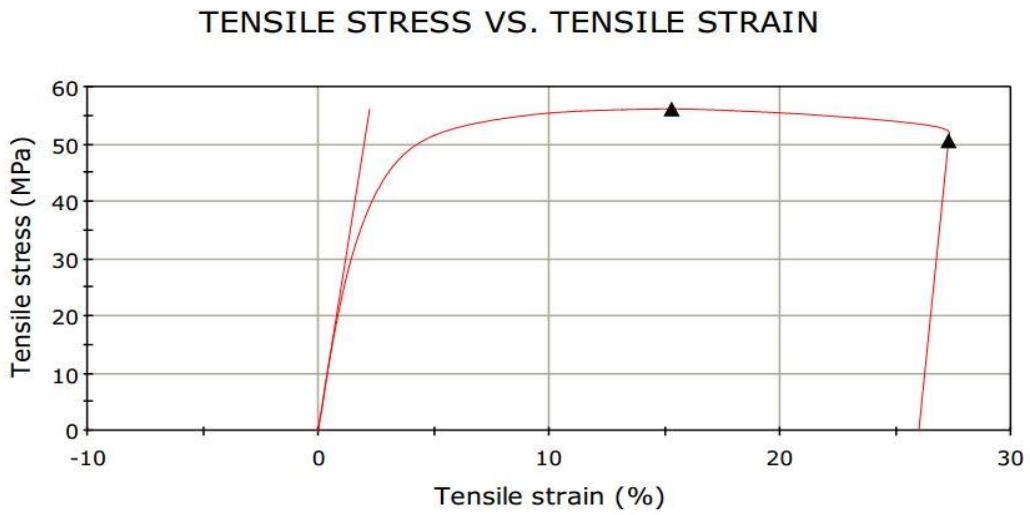


Figure 4.28 : Stress-strain curve of 90%PA6 + 10%GF (10mm/min).

4.4.5 85%PA6 + 15%GF

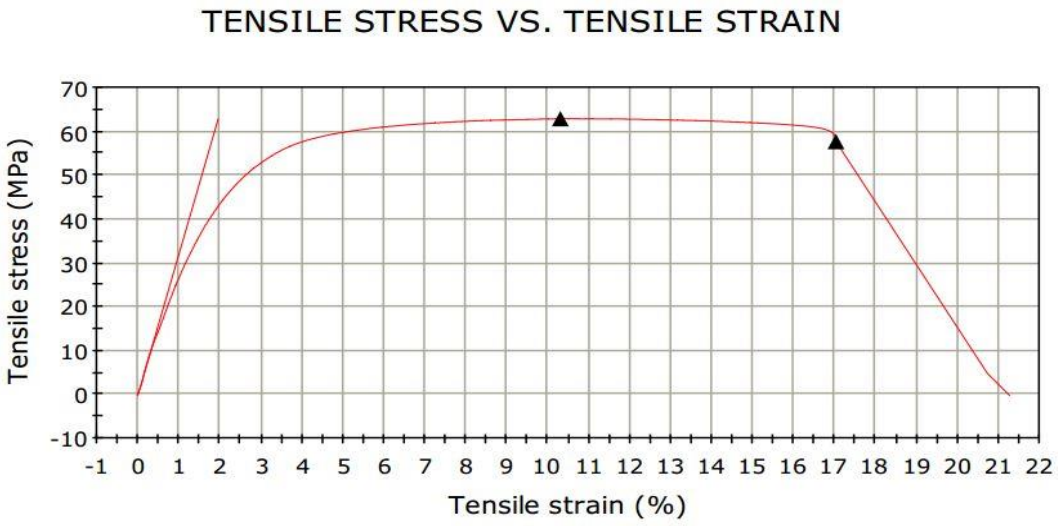


Figure 4.29 : Stress-strain curve of 85%PA6 + 15%GF (3mm/min).

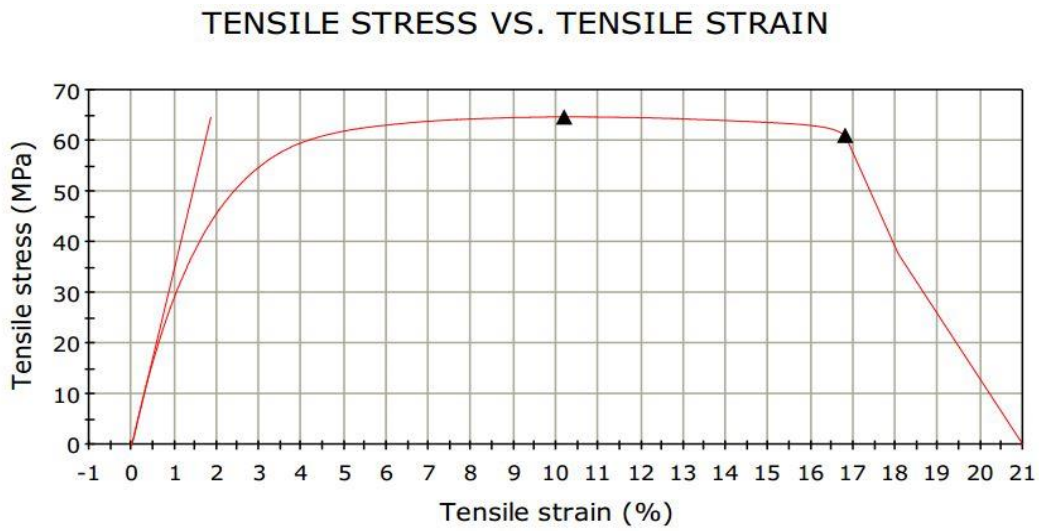


Figure 4.30 : Stress-strain curve of 85%PA6 + 15%GF (5mm/min).

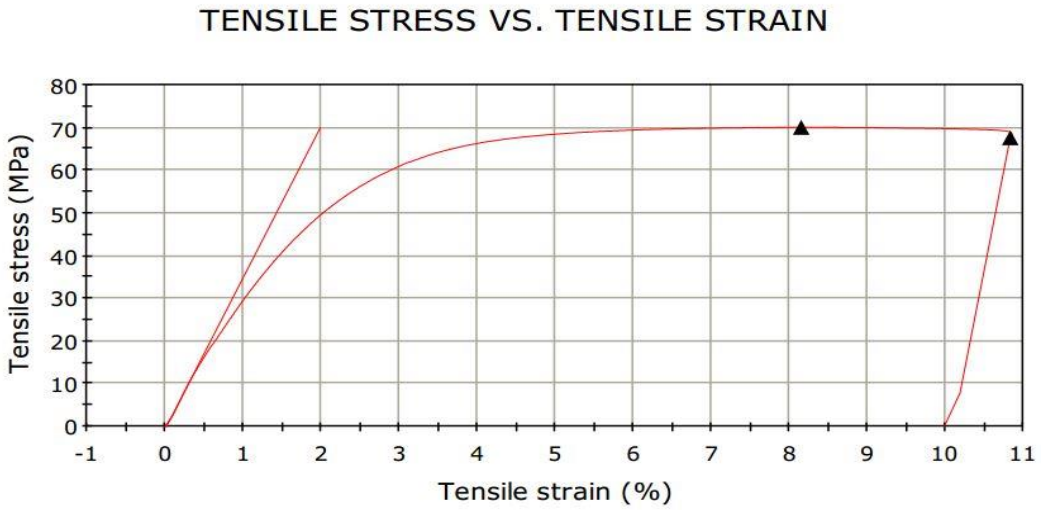


Figure 4.31 : Stress-strain curve of 85%PA6 + 15%GF (10mm/min).

4.4.6 80%PA6 + 20%GF

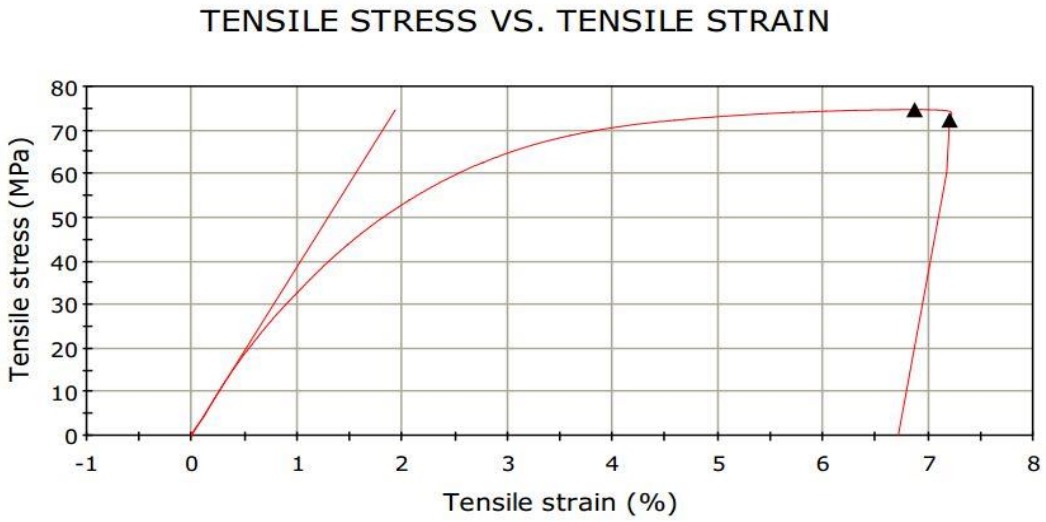


Figure 4.32 : Stress-strain curve of 80%PA6 + 20%GF (3mm/min).

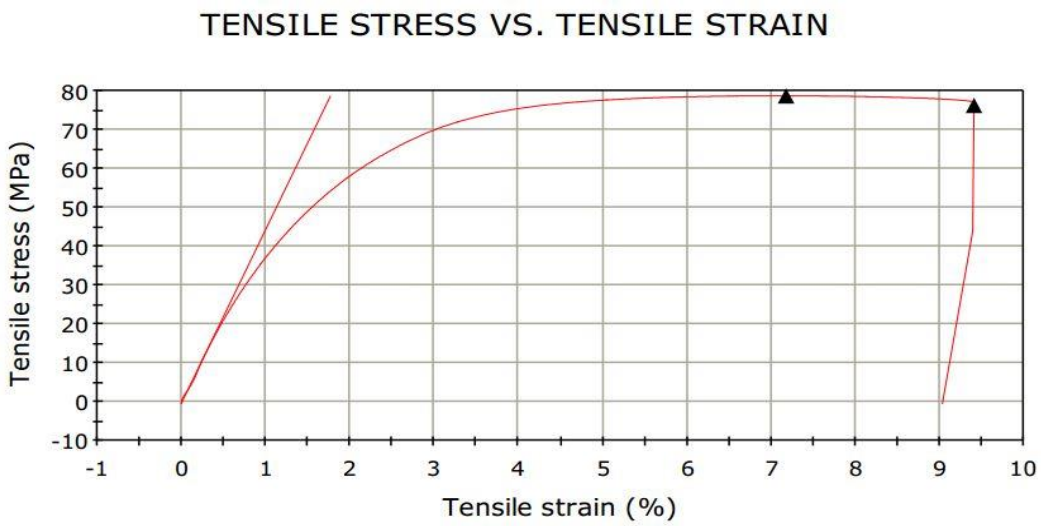


Figure 4.33 : Stress-strain curve of 80%PA6 + 20%GF (5mm/min).

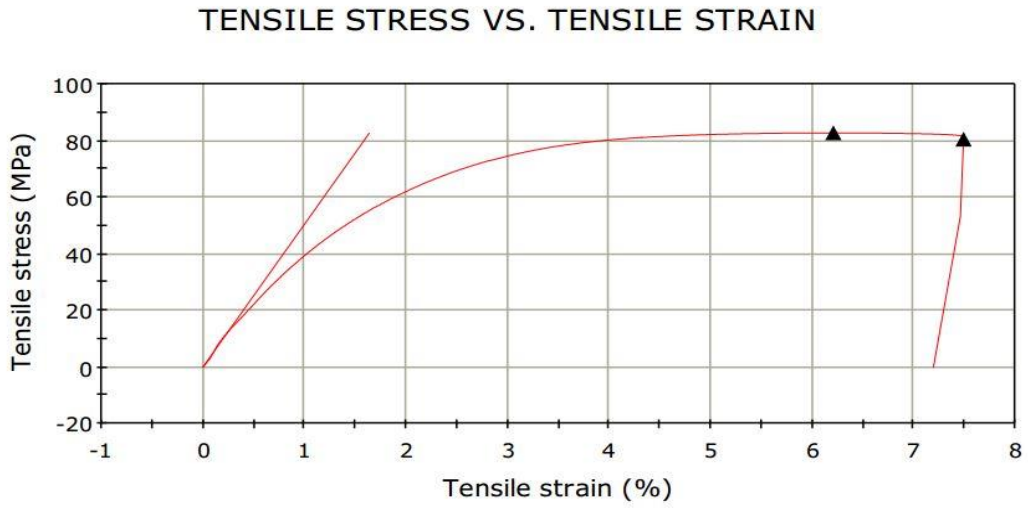


Figure 4.34 : Stress-strain curve of 80%PA6 + 20%GF (10mm/min).

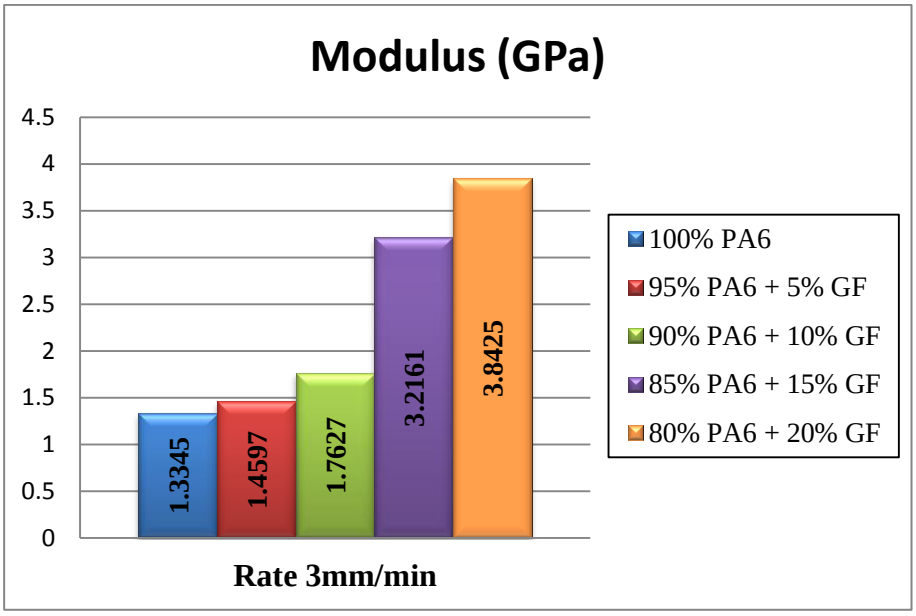


Figure 4.35 : Modulus (GPa), Rate 3mm/min.

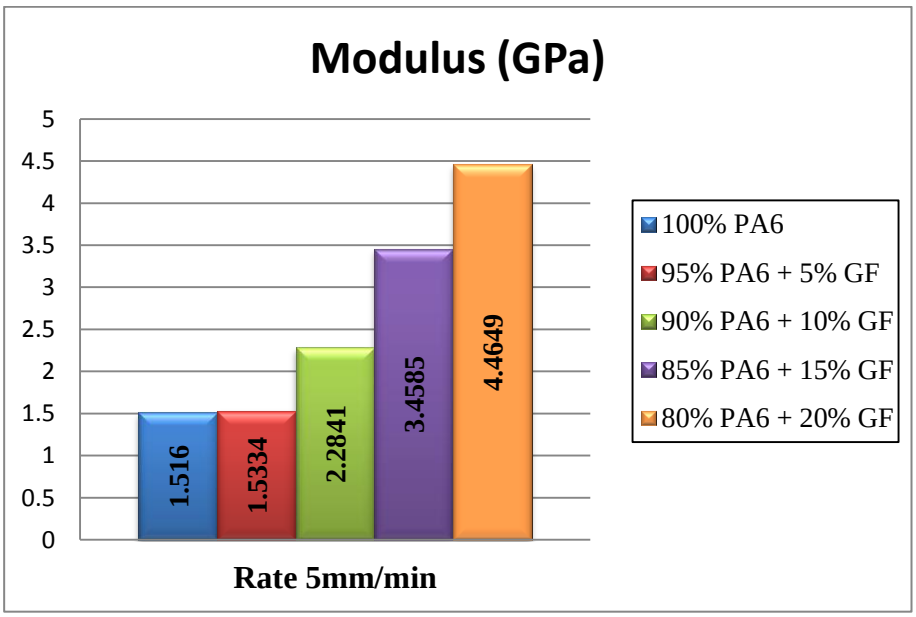


Figure 4.36 : Modulus (GPa), Rate 5mm/min.

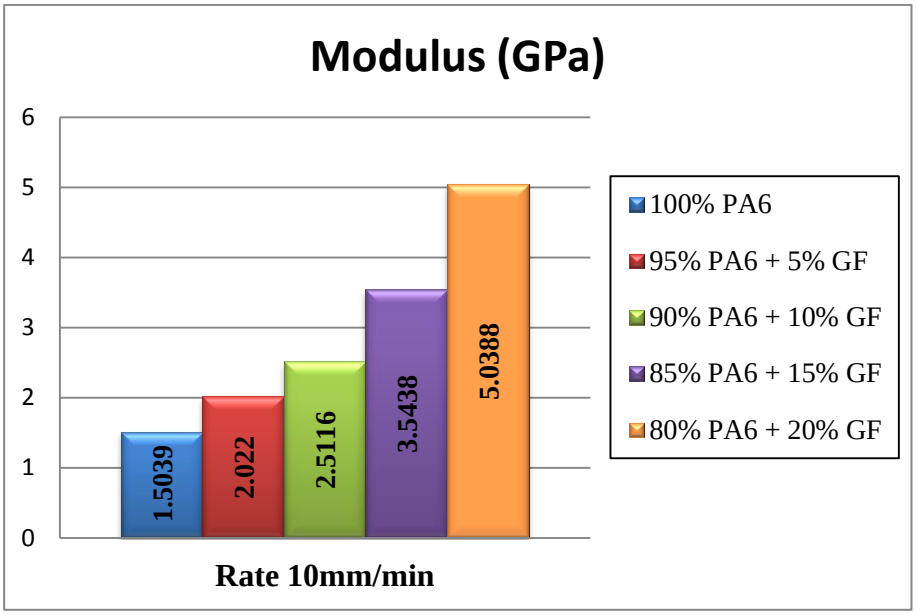


Figure 4.37 : Modulus (GPa), Rate 10mm/min.

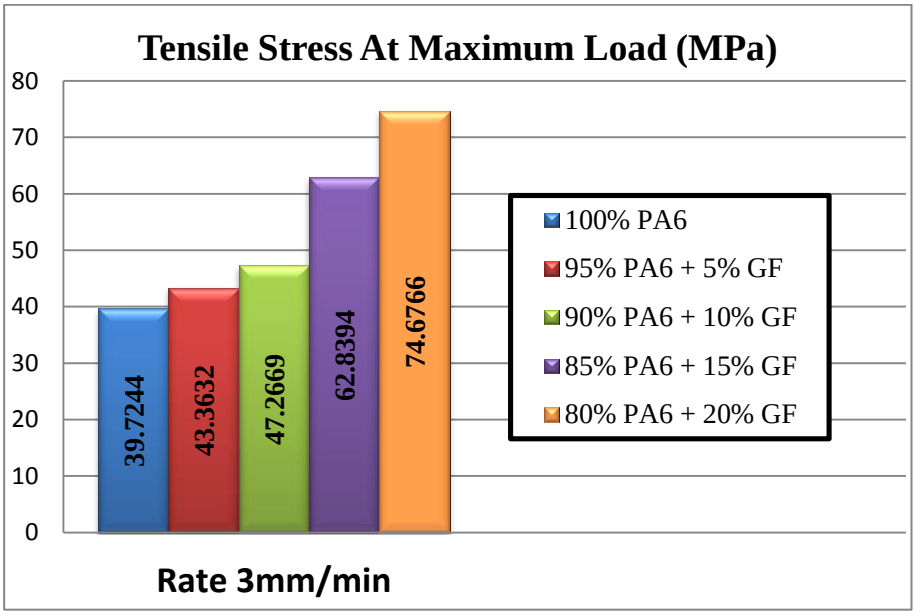


Figure 4.38 : Tensile Stress at Maximum Load (MPa), Rate 3mm/min.

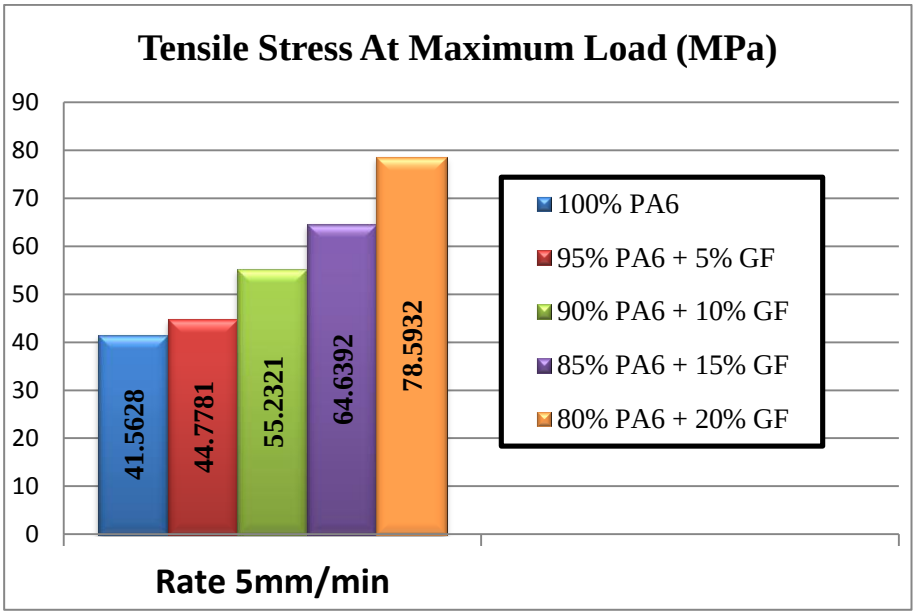


Figure 4.39 : Tensile Stress at Maximum Load (MPa), Rate 5mm/min.

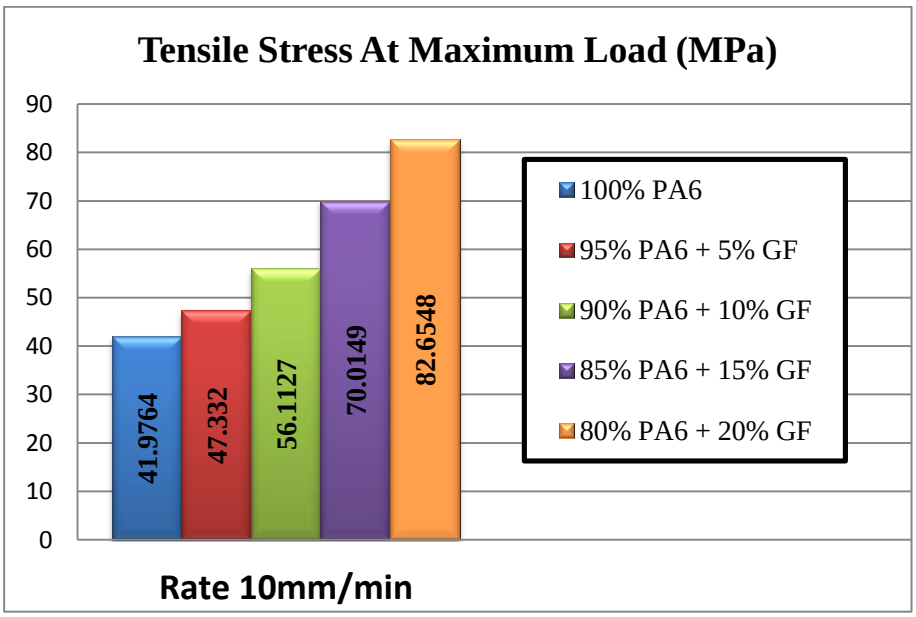


Figure 4.40 : Tensile Stress at Maximum Load (MPa), Rate 10mm/min.

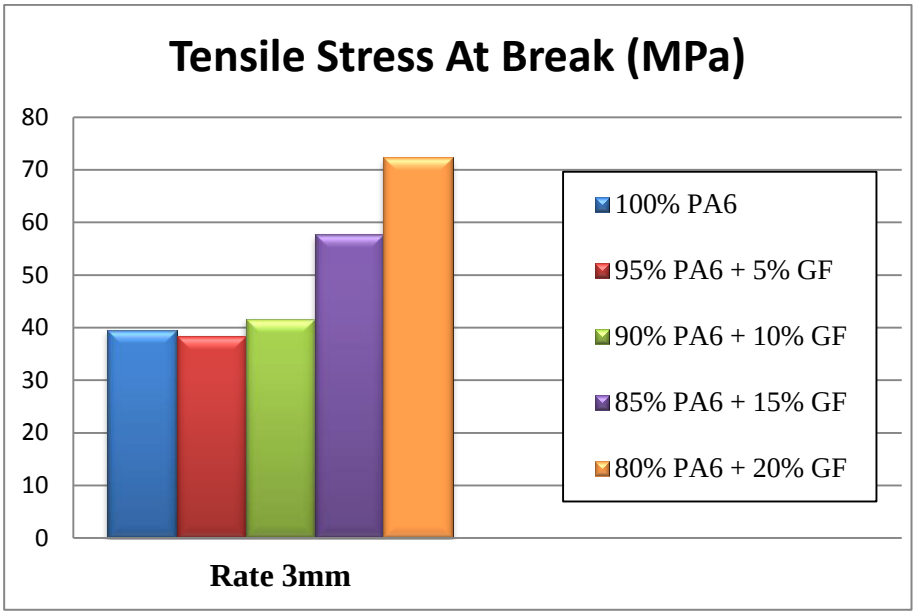


Figure 4.41 : Tensile Stress at Break (MPa), Rate 3mm/min.

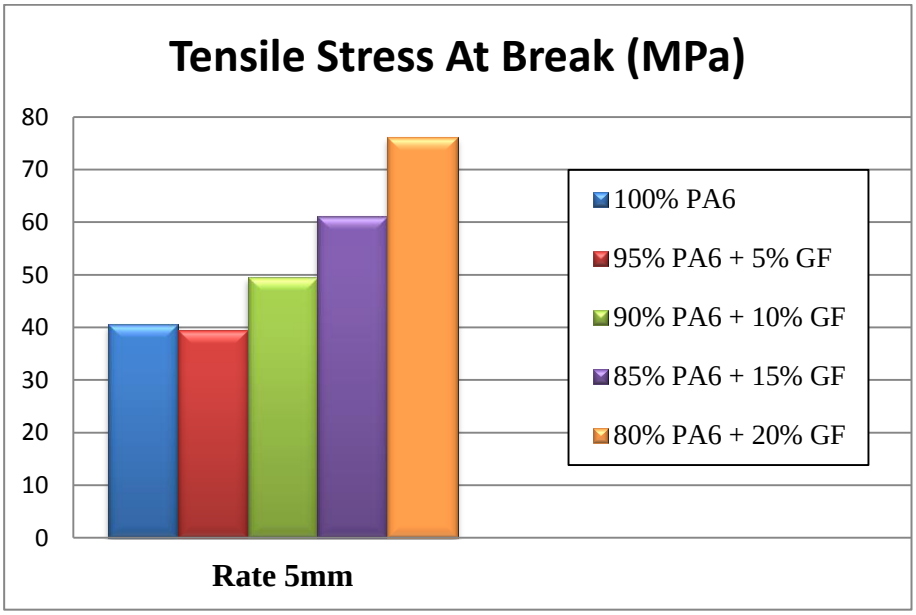


Figure 4.42 : Tensile Stress at Break (MPa), Rate 5mm/min.

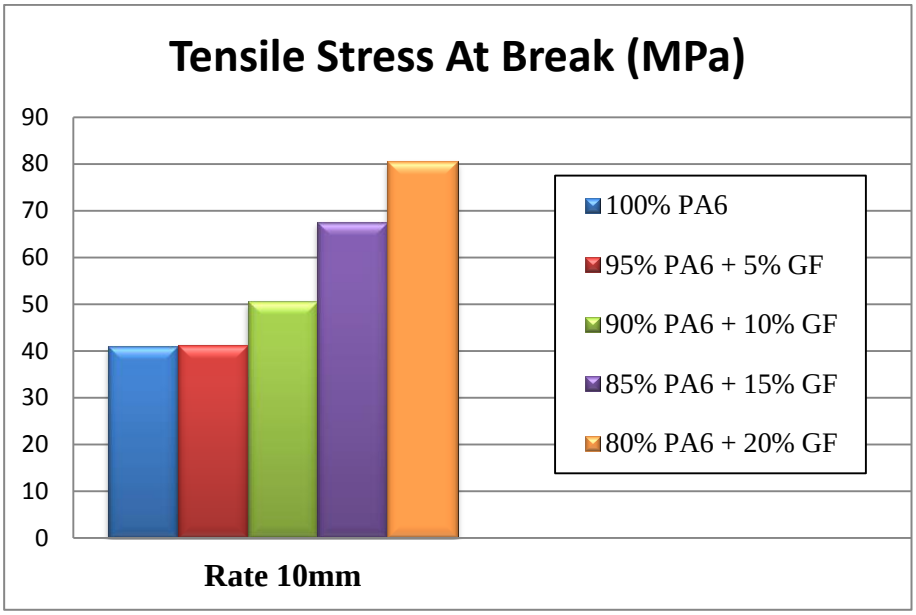


Figure 4.43 : Tensile Stress at Break (MPa), Rate 10mm/min.

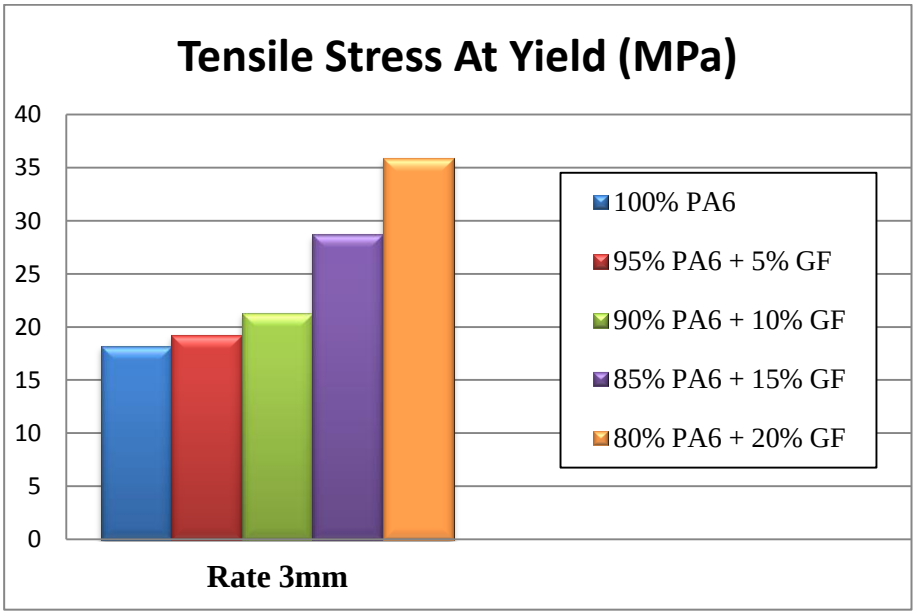


Figure 4.44 : Tensile Stress at Yield (MPa), Rate 3mm/min.

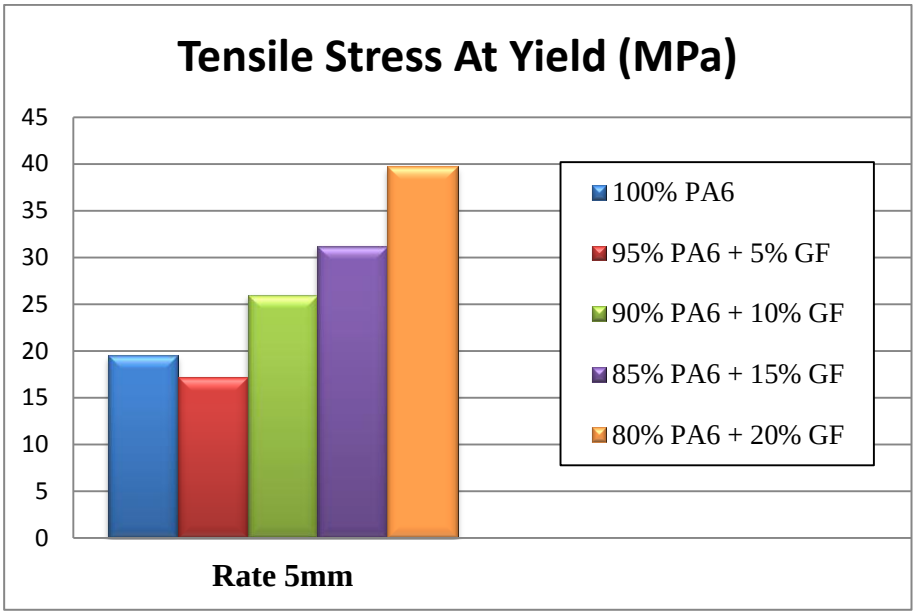


Figure 4.45 : Tensile Stress at Yield (MPa), Rate 5mm/min.

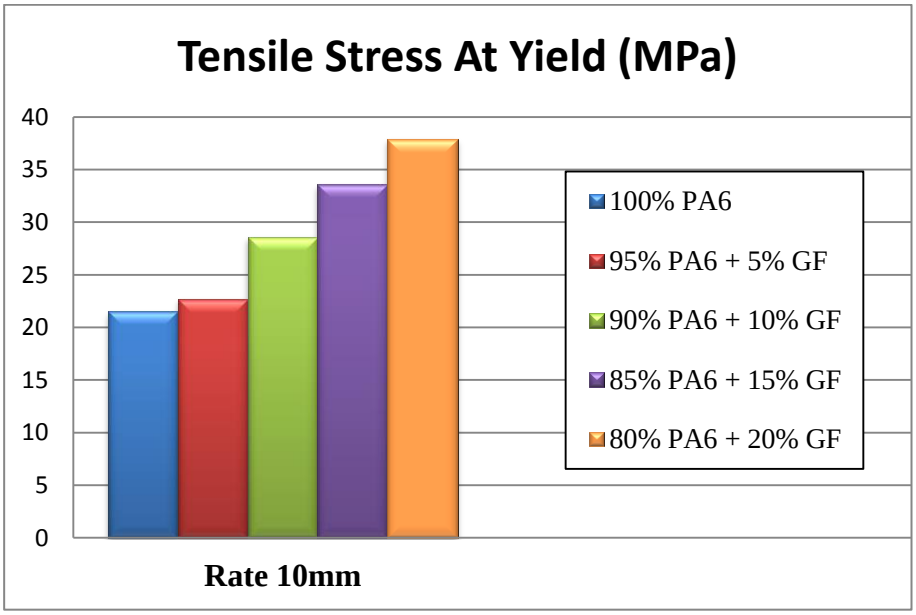


Figure 4.46 : Tensile Stress at Yield (MPa), Rate 10mm/min.

4.5 IMPACT TEST (IZOD) RESULT ANALYSIS

4.5.1 Introduction

One of the most common test of the physical characteristics of plastic materials is the unnotched izod impact test as specified by ASTM D4812 standard test method for determining the izod pendulum impact resistance of plastics. This test fixes one end of a unnotched specimen in a cantilever position by mean of vice. A striker on the arm of a pendulum or similar energy carrier then strikes the specimen. The energy absorbed by the specimen in the breaking process is known as the breaking energy. The breaking energy can be converted into an indication of a materials impact resistance using such unit as joules (J).

In this study used 50(J) pendulum hammer to hit the specimen and also used constant tightening clamp (11.20mm) for each sample testing. This study found the energy (J) from the material pure nylon is low compared to glass fiber-reinforced nylon. Increasing the composition of glass fiber, also increasing the energy of the material.

4.5.2 Pure Nylon

Table 4.7 : Impact Test Pure Nylon

Specimen No.	Composition	Width (mm)	Break	Absorb Energy (%)	Re (kJ/m²)	Energy (J)
2	100% PA6	12.70	No. Break	11.37	139.81	5.682

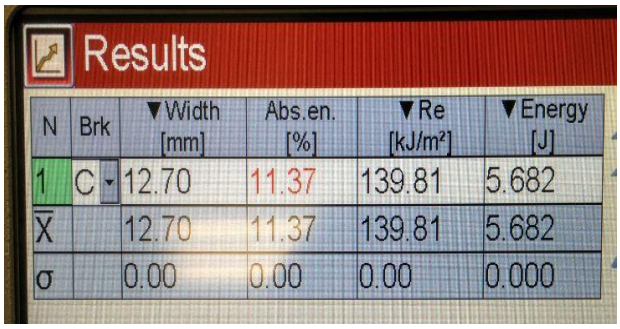


Figure 4.47 : Impact Test Pure Nylon

4.5.3 95%PA6 + 5%GF

Table 4.8 : Impact Test 95%PA6 + 5%GF

Specimen No.	Composition	Width (mm)	Break	Absorb Energy (%)	Re (kJ/m²)	Energy (J)
2	95% PA6 + 5% GF	12.70	Break in 1 time	3.32	40.86	1.661

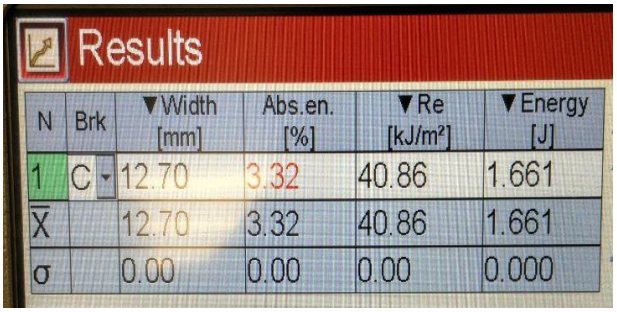


Figure 4.48 : Impact Test 95%PA6 + 5%GF

4.5.4 90%PA6 + 10%GF

Table 4.9 : Impact Test 90%PA6 + 10%GF

Specimen No.	Composition	Width (mm)	Break	Absorb Energy (%)	Re (kJ/m²)	Energy (J)
2	90% PA6 + 10% GF	12.70	Break in 1 time	4.82	59.34	2.411

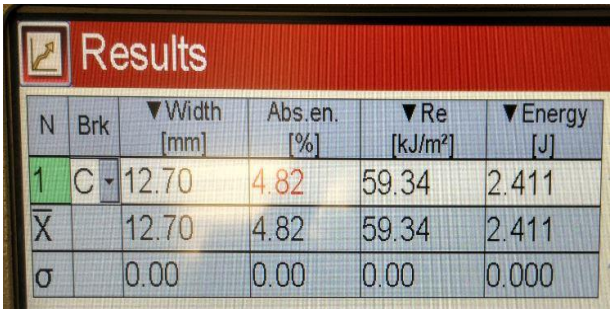


Figure 4.49 : Impact Test 90%PA6 + 10%GF

4.5.5 85%PA6 + 15%GF

Table 4.10 : Impact Test 85%PA6 + 15%GF

Specimen No.	Composition	Width (mm)	Break	Absorb Energy (%)	Re (kJ/m²)	Energy (J)
3	85% PA6 + 15% GF	12.70	Break in 2 time	10.56	129.84	5.277

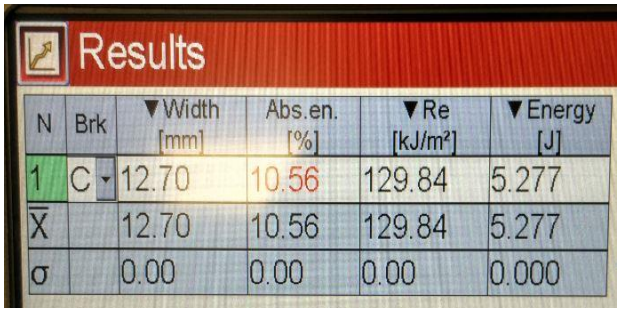


Figure 4.50 : Impact Test 85%PA6 + 15%GF

4.5.6 80%PA6 + 20%GF

Table 4.11 : Impact Test 80%PA6 + 20%GF

Specimen No.	Composition	Width (mm)	Break	Absorb Energy (%)	Re (kJ/m²)	Energy (J)
1	80% PA6 + 20% GF	12.70	Break in 1 time	9.56	117.54	4.777

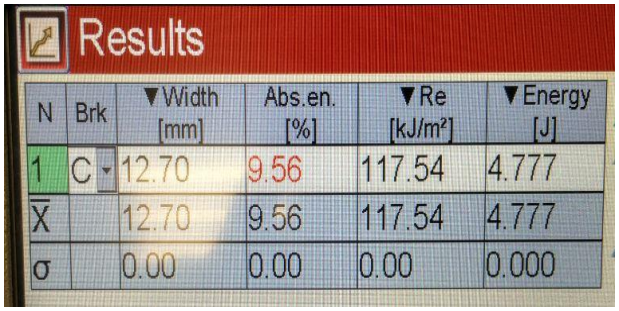


Figure 4.51 : Impact Test 80%PA6 + 20%GF

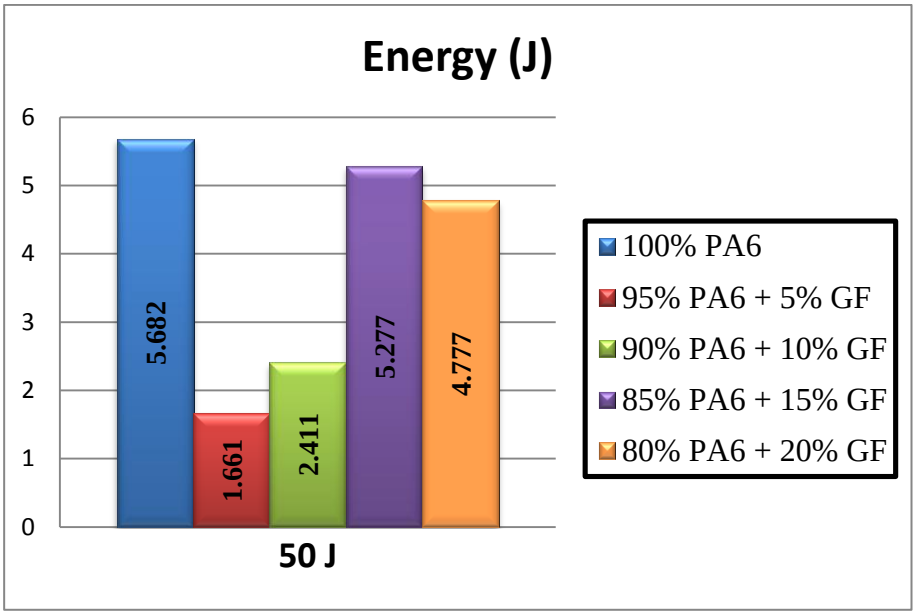


Figure 4.52 : Energy (J)

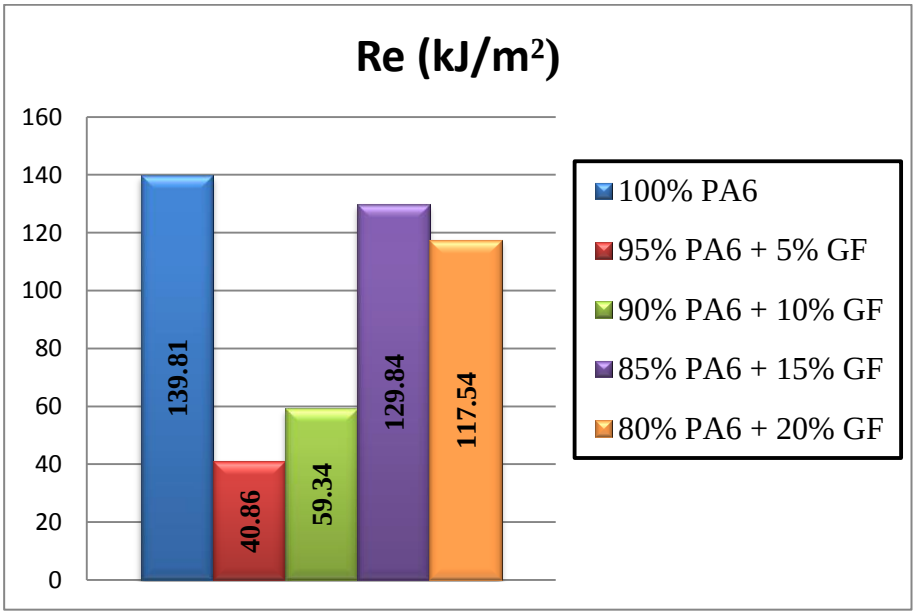


Figure 4.53 : Re (kJ/m²)

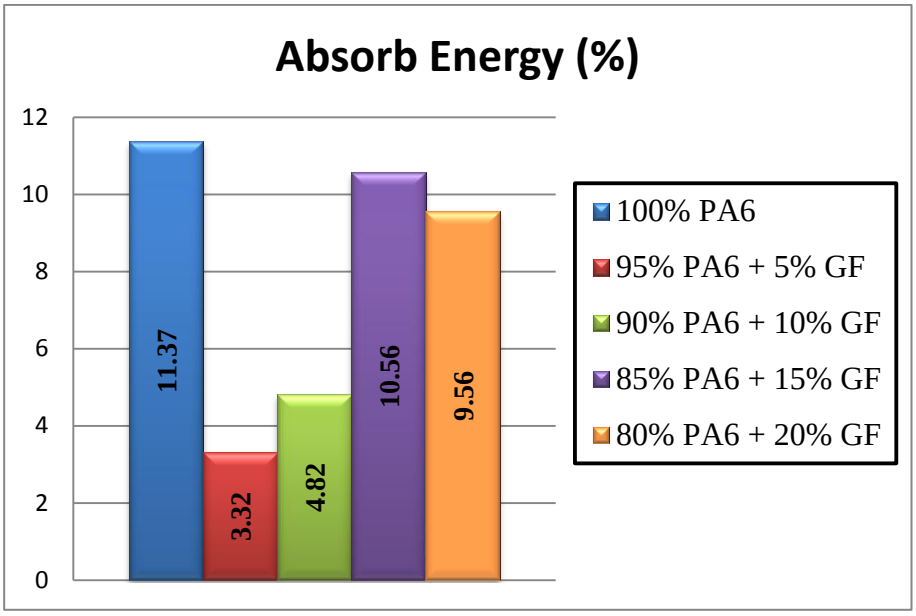


Figure 4.54 : Absorb Energy (%)

4.6 MICROSTRUCTURE ANALYSIS

4.6.1 Introduction

In this microstructure analysis will show percentage difference between glass fiber and pure nylon. Composition used in this study are 100%PA6, 95%PA + 5%GF, 90%PA6 + 10%GF, 85%PA6 +15%GF and 80%PA6 + 20%GF. The different of composition specimen will be cut at the center to use in cold mounting process. Optical Microscope (OM) machine has been used to conduct a study microstructure analysis. For starters, objective lens (5X) used to get a picture of the surface, then objective lens (10X) used to get more focus microstructure of glass fiber-reinforced nylon. This microstructure analysis showed that the glass fiber can be shaped and whiteness compared to nylon an invisible shape. This is because the temperature used during the production of specimen has reached the melting point of nylon compared to glass fiber does not reach the melting point. Glass fiber has high melting point compared to pure nylon.

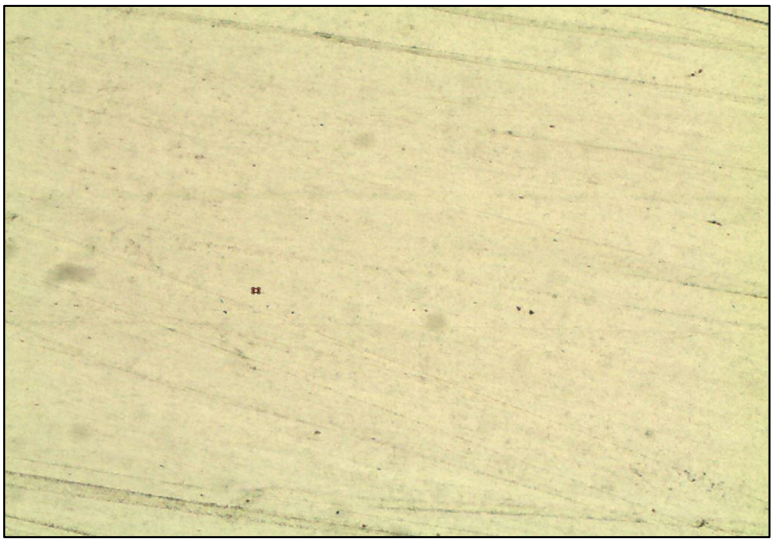


Figure 4.55 : Structure of Pure nylon

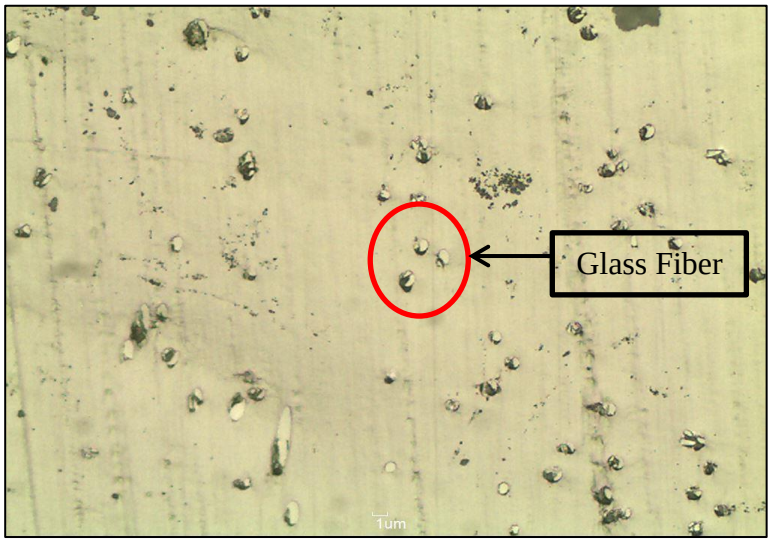


Figure 4.56 : Structure of 95%PA6 + 5%GF

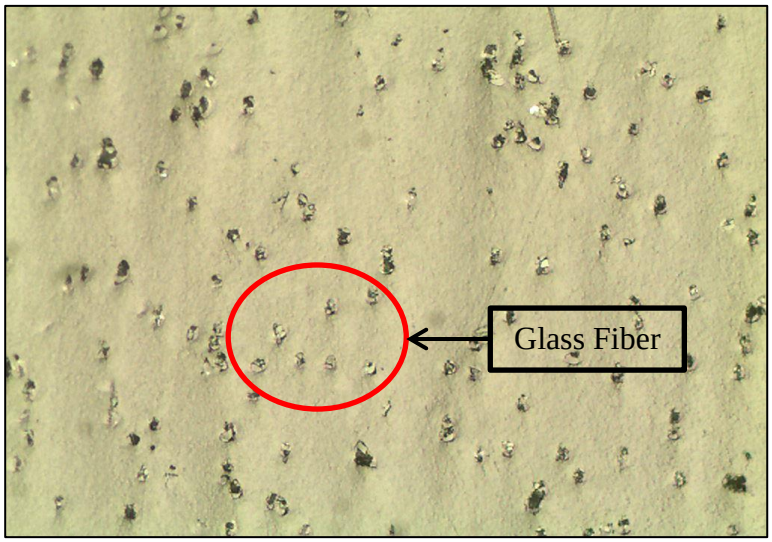


Figure 4.57 : Structure of 90%PA6 + 10%GF

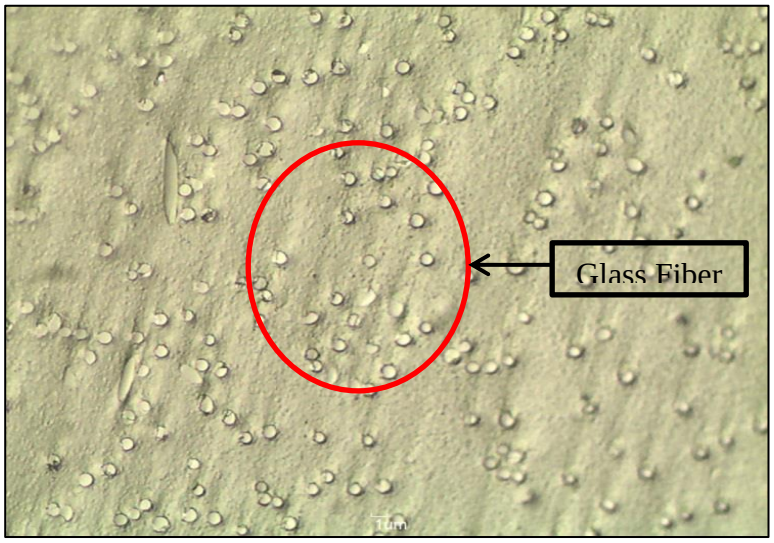


Figure 4.58 : Structure of 85%PA6 + 15%GF

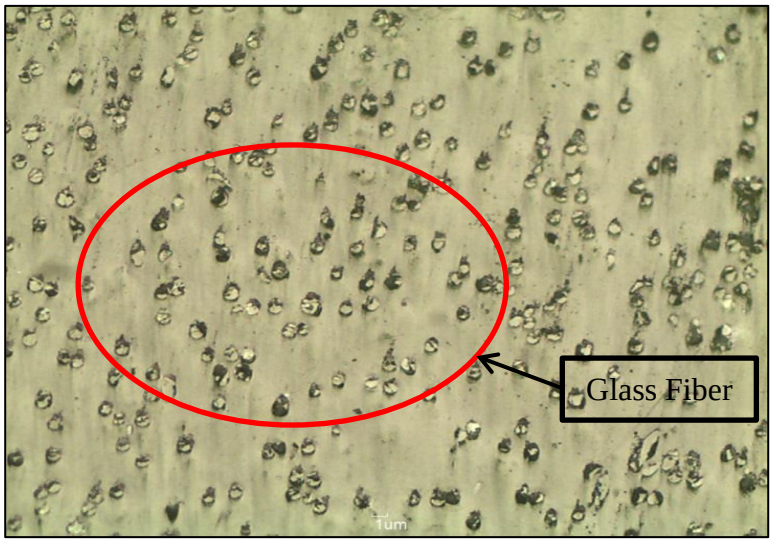


Figure 4.59 : Structure of 80%PA6 + 20%GF

CHAPTER 5

CONCLUSION AND RECOMMENDATION

5.1 INTRODUCTION

This chapter summarizes the whole research study and recommendation for improvement in this project. This chapter concludes all the observation results, outcomes, data analysis and discussion. The conclusion given is based on the results. Recommendation given to improve this research for future studies.

5.2 CONCLUSION

In this research CATIA and Moldflow software are used to determine the parameter that appropriate for during the production of real specimens by using injection molding machine. Moldflow analysis showed the edge gate is the most suitable gate position compared to pin gate and centre gate. Edge gate gave a uniform flow of molten plastic throughout the specimen. Moldflow analysis will analyze some data such as filling time, temperature at flow front and etc. These data can be used during the real situation production of specimen by using injection molding machine. Different compositions glass fiber have been used to identify differences in mechanical properties of the different compositions. Additional 5% composition of glass fiber are used to obtain more clear results. As a result, it is concluded that the specimen with higher percentage of glass fiber-reinforced that exceeds the percentage of pure nylon obtain high tensile stress at maximum load compare to the lower percentage of glass fiber-reinforced. When the percentage of glass fiber-reinforced increase, then the tensile stress and modulus increase, that is the composition become more brittle .

5.3 RECOMMENDATION

There are some recommendation for this research study :

i. Moldflow software have some limitation to analyze, so the suggestion is use ANSYS software to analyze the fibre orientation.

ii. The injection molding machine and mold should have routine service to produce better specimens and less occurrence of defect in the specimen.

iii. Apply more test for the experiments such as bending test, hardness test and Scanning Electron Microscope (SEM) to examine more detail the fracture surface.

REFERENCES

Asoke K. Ghosh. (2005). An Introduction to Engineering Material and Manufacturing Processes.

Autodesk Moldflow Insight, Flow Results, Autodesk website, Autodesk Moldflow. http://www.autodesk.com/products/moldflow/features/all/gallery-view

Copyright BASF Corporation 2003. An Advanced High Modulus (HMG) Short Glass Fiber Reinforced Nylon 6 : Part I – Role and Kinetic of Fiber-Glass Reinforcements.

Demeng Che, Ishan Saxena, Peidong Han, Ping Guo & Kornel F. Ehmann. (2014). Machining of Carbon Fiber Reinforced Plastics/Polymers: A Literature Review, Journal of Manufacturing Science and Engineering, Volume 136, Issue 3.

E. Paul DeGarmo, J. T. Black, Ronald A. Kohser & Barney E. Klamecki. (2003). Materials And Processes In Manufacturing, Ninth Edition.

G K Lal & S K Choudhury. (2008). Fundamentals of Manufacturing Processes.

Intertek website, Plastics Tensile Testing for ASTM D638, http://www.intertek.com/polymers/tensile-testing/astm-d638-iso-527/

J.P. Kaushish. (2008). Manufacturing Processes.

Mamco Precision Molding website, Moldflow Analysis, http://www.mamcomolding.com/engineering/mold-flow-analysis/

Prince Engineering website, Fiber Reinforced Polymers Characteristics and Behaviors http://www.build-on-prince.com/fiber-reinforced-polymers.html#sthash.me78JwiT.SDiJqAy6.dpbs

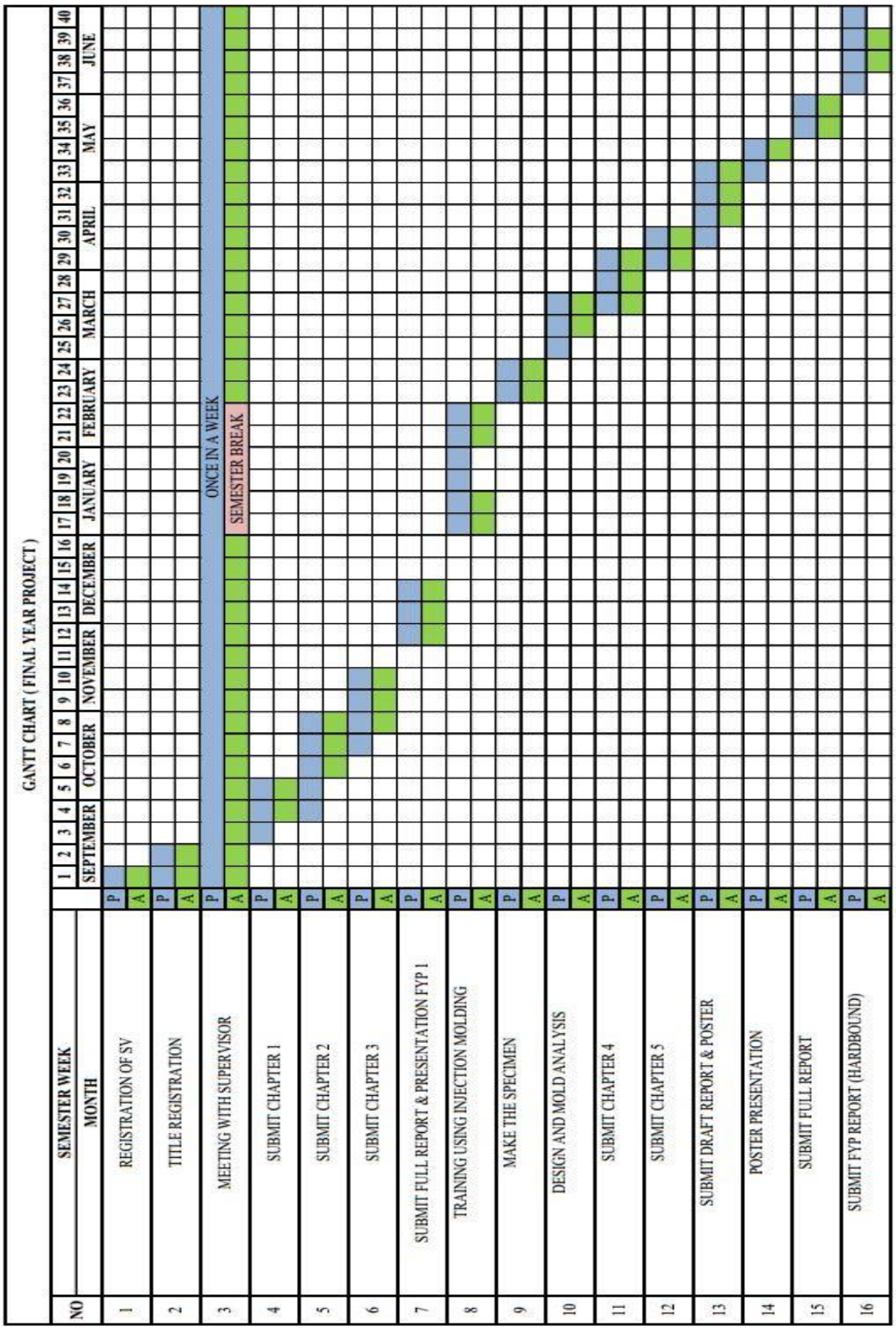
Serope Kalpakjian & Steven R. Schmid. (2010). Manufacturing Engineering and Technology, Sixth Edition in SI Units.

The Madison Group, Madison Group website, Moldflow Analysis http://www.madisongroup.com/moldflow-analysis.html

Qingzheng Cheng. (2012). Fibre-Reinforced Composites.

APPENDIX A

Gantt Chart FYP



APPENDIX B1

EDGE GATE MOLDFLOW ANALYSIS LOG

Filling parameters:

Maximum %volume to fill per time step	= 4.000 %
Maximum iterations per time step	= 50
Convergence tolerance (scaling factor)	= 1.000
Flow front scheme	= Level set

Packing parameters:

Maximum time step	= 2.000 s
Maximum iterations per time step	= 50
Convergence tolerance (scaling factor)	= 1.000

Intermediate results:

Intermediate results type	= Write at constant intervals
Number of intermediate results in filling phase	= 5
Number of intermediate results in packing phase	= 5
Number of intermediate results in cooling phase	= 3

Material Data:

Manufacturer	= DSM
Trade name	= Akulon K225-KS
Family name	= PA6
Specific heat (CP)	= 2904.0000 J/kg-C
Transition temperature	= 185.0000 C

Filling Control:

Filling control type	= Automatic
Fill time	= 0.20 s
Stroke volume determination	= Automatic

Velocity/pressure switch-over control:

Velocity/pressure switch-over control type	= Automatic

End of filling phase results summary :

Current time from start of cycle	= 0.2215 s
Total mass	= 0.0210 g
Frozen volume	= 53.2506 %
Injection pressure	=61.2627 MPa
Volumetric shrinkage - minimum	= -1.0700 %
Volumetric shrinkage - maximum	= 14.6826 %
Time at velocity/pressure switch-over	= 0.2153 s
Injection pressure at velocity/pressure switch-over	= 69.9302 MPa
Volume filled at velocity/pressure switch-over	= 97.5121 %

End of filling. Packing will now commence.

End of packing phase results summary :

Current time from start of cycle	= 30.2153 s
Total mass	= 0.0212 g
Frozen volume	= 100.0000 %
Injection pressure	= 0.0000 MPa
Volumetric shrinkage - minimum	= -1.0700 %
Volumetric shrinkage - maximum	= 14.6826 %
Maximum velocity	=25.6334 cm/s
Maximum shear rate	= 9.8812E+04 1/s

Warp Analysis:

Number of vertex nodes:	= 1865
Number of midside nodes:	= 10529
Total number of nodes in Warp analysis:	= 12394
Total number of elements in Warp analysis:	= 7627
Estimated memory requirement:	= 40 Mbytes.

Mapping warpage result :

Minimum/maximum displacements at last step (unit: mm):

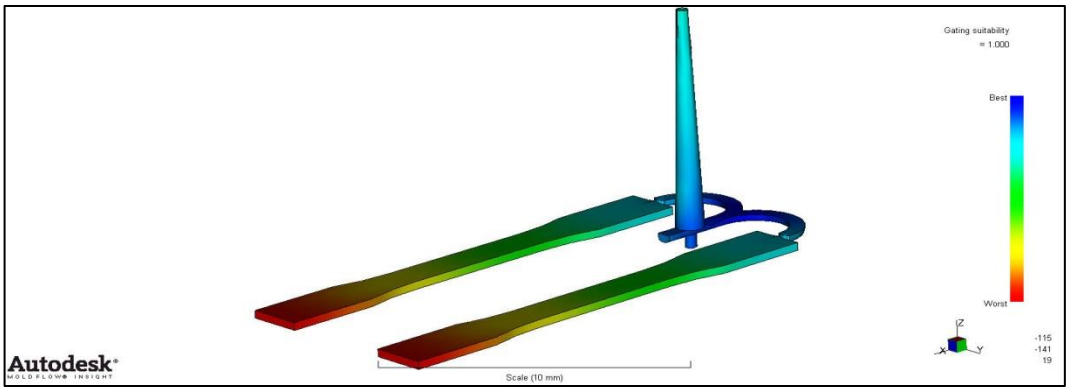
	Node	Min.	Node	Max.
Trans-X	428	-1.4728e-01	209	5.3863e-02
Trans-Y	148	-3.4893e-02	516	4.1191e-02
Trans-Z	244	-7.1724e-02	100	1.7415e-02

Warp analysis has completed successfully.

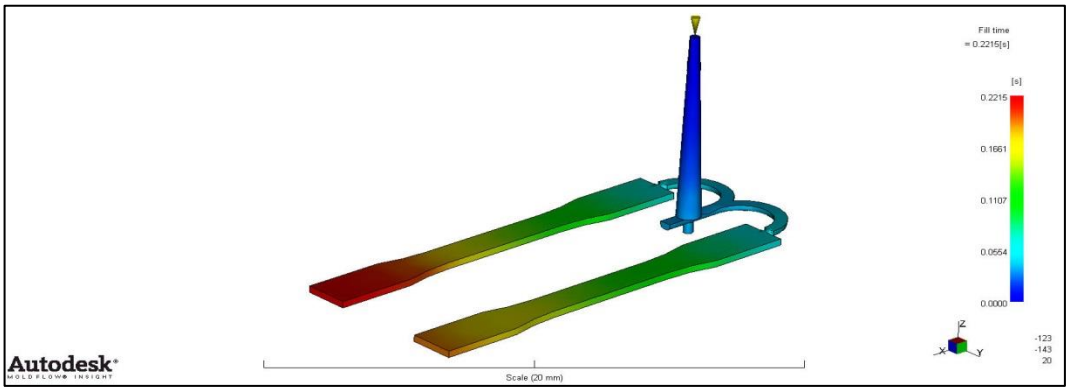
APPENDIX B2

EDGE GATE MOLDFLOW ANALYSIS RESULT

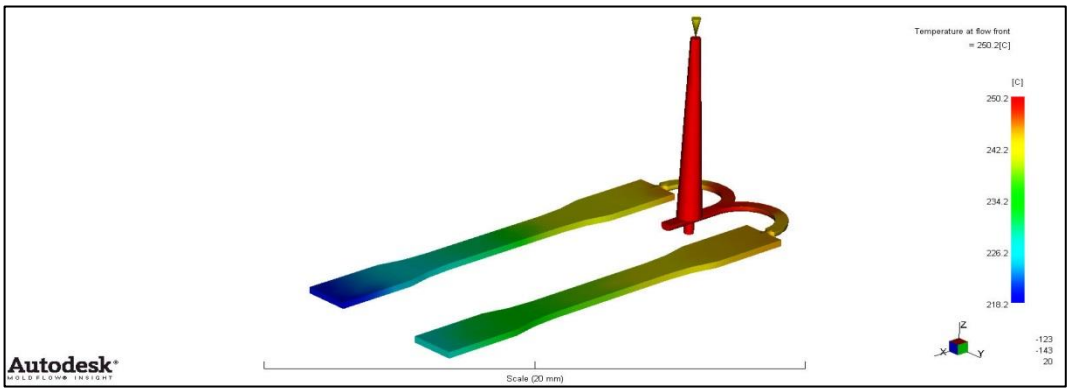
1) Gating suitability.



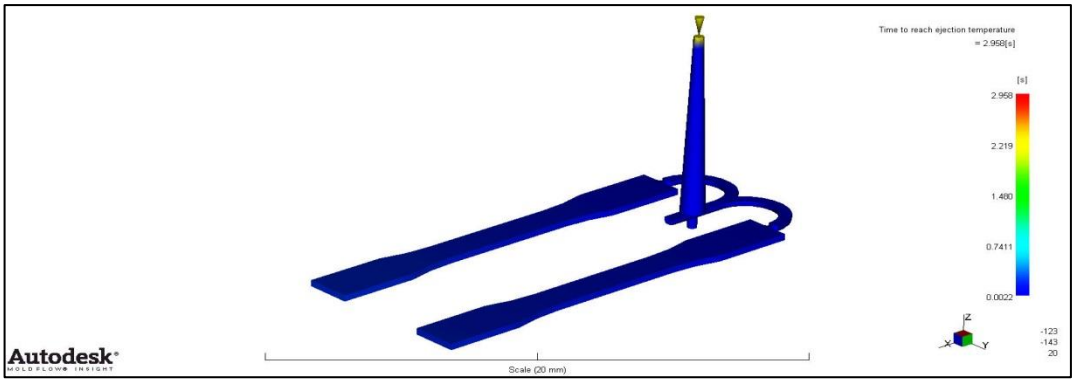
2) Fill time.



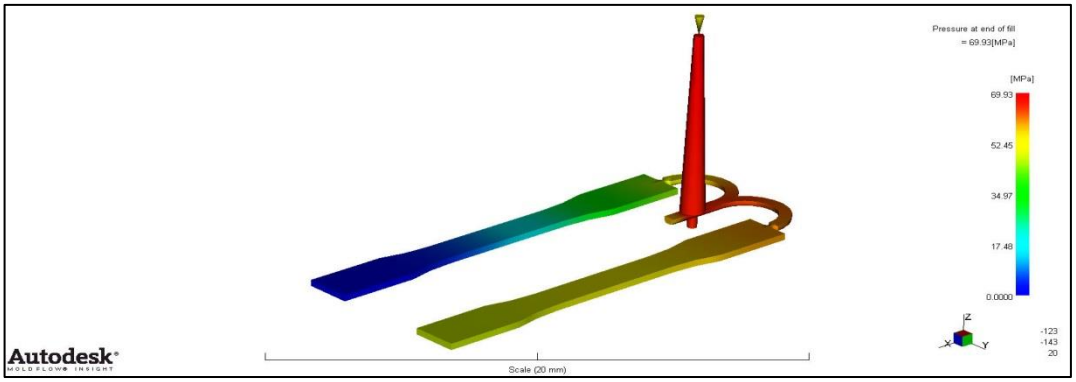
3) Temperature at flow front.



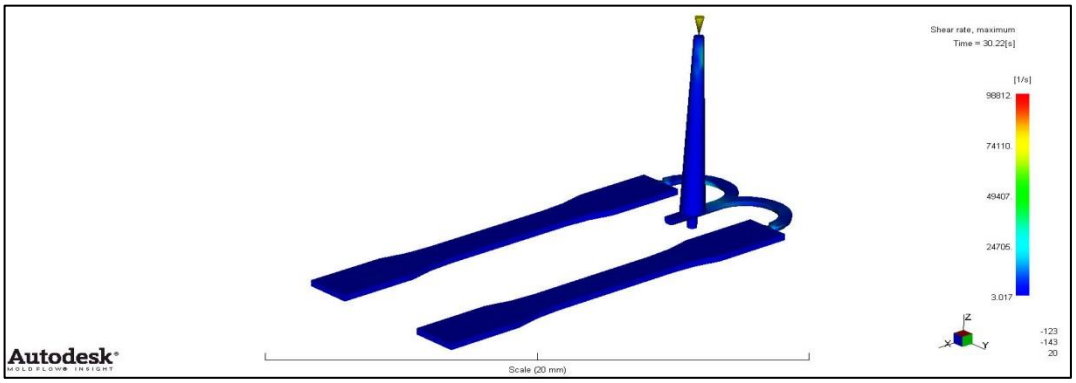
4) Time to reach ejection temperature.



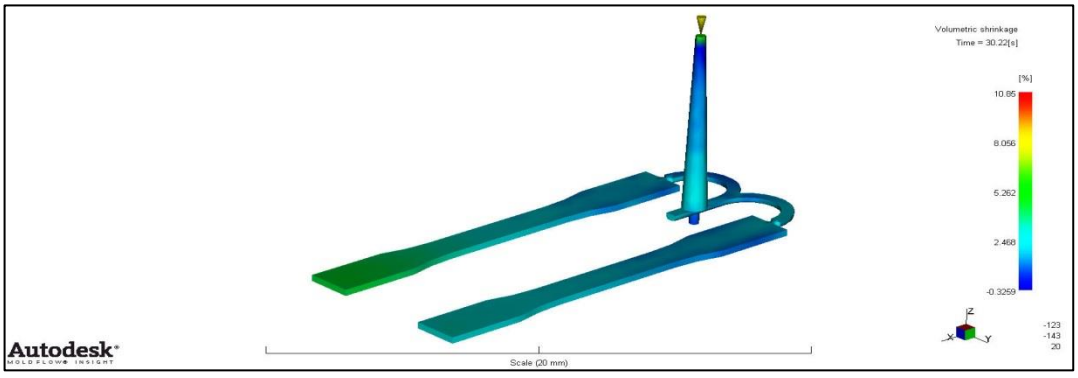
5) Pressure at end of fill.



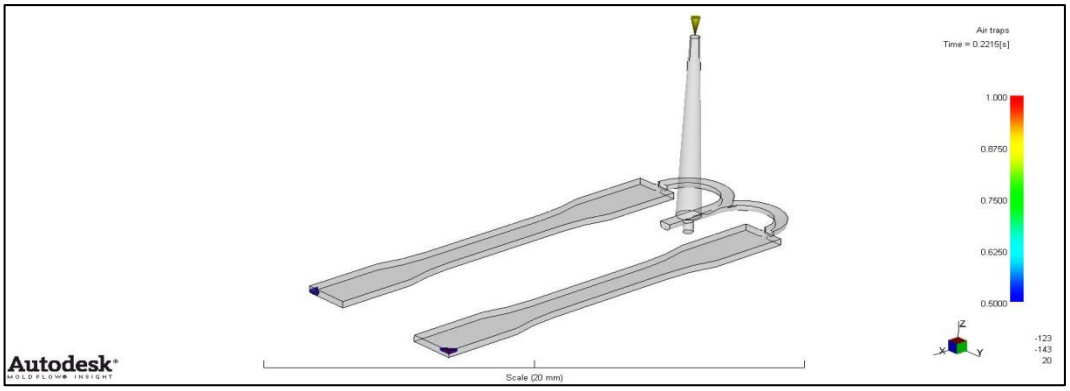
6) Shear rate, maximum.



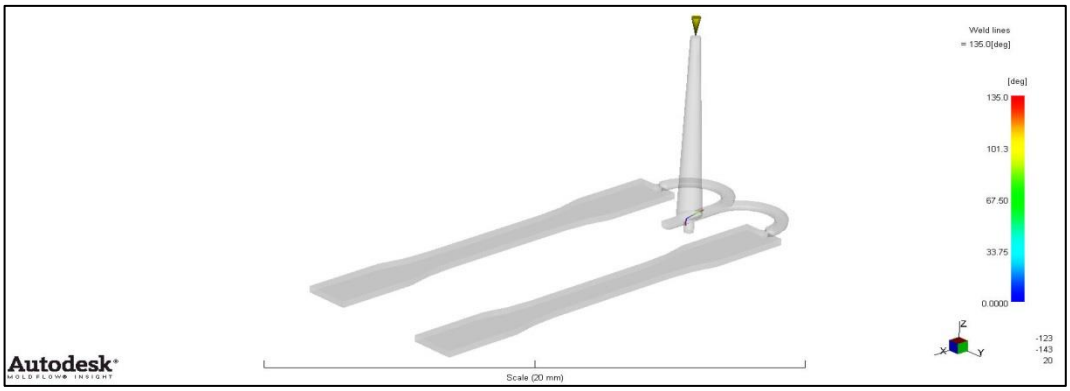
7) Volumetric shrinkage.



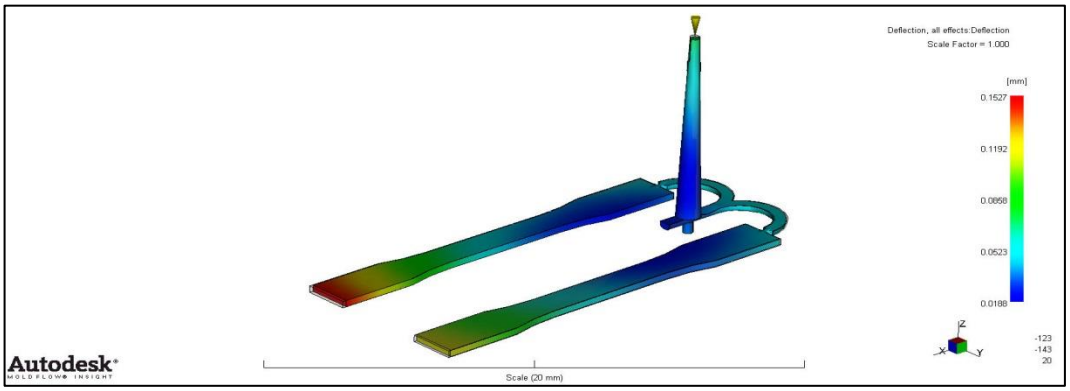
8) Air traps.



9) Weld lines.



10) Warp



APPENDIX C1

CENTRE GATE MOLDFLOW ANALYSIS LOG

Filling parameters:

Maximum %volume to fill per time step	= 4.000 %
Maximum iterations per time step	= 50
Convergence tolerance (scaling factor)	= 1.000
Flow front scheme	= Level set

Packing parameters:

Maximum time step	= 2.000 s
Maximum iterations per time step	= 50
Convergence tolerance (scaling factor)	= 1.000

Intermediate results:

Intermediate results type	= Write at constant intervals
Number of intermediate results in filling phase	= 5
Number of intermediate results in packing phase	= 5
Number of intermediate results in cooling phase	= 3

Material Data:

Manufacturer	= DSM
Trade name	= Akulon K225-KS
Family name	= PA6
Specific heat (CP)	= 2904.0000 J/kg-C
Transition temperature	= 185.0000 C

Filling Control:

Filling control type	= Automatic
Fill time	= 0.10 s
Stroke volume determination	= Automatic

Velocity/pressure switch-over control:

Velocity/pressure switch-over control type = Automatic

End of filling phase results summary :

Current time from start of cycle	= 0.1058 s
Total mass	= 0.0191 g
Frozen volume	= 28.4327 %
Injection pressure	= 17.0677 MPa
Volumetric shrinkage - minimum	= 1.0035 %
Volumetric shrinkage - maximum	= 14.6791 %
Time at velocity/pressure switch-over	= 0.1049 s
Injection pressure at velocity/pressure switch-over	= 17.4009 MPa
Volume filled at velocity/pressure switch-over	= 99.4532 %

End of filling. Packing will now commence.

End of packing phase results summary :

Current time from start of cycle	= 30.1049 s
Total mass	= 0.0196 g
Frozen volume	= 100.0000 %
Injection pressure	= 0.0000 MPa
Volumetric shrinkage - minimum	= 1.0035 %
Volumetric shrinkage - maximum	= 14.6791 %
Maximum velocity	=27.6563 cm/s
Maximum shear rate	= 1.3202E+05 1/s

Warp Analysis:

Number of vertex nodes:	= 1593
Number of midside nodes:	= 8958
Total number of nodes in Warp analysis:	= 10551
Total number of elements in Warp analysis:	= 6455
Estimated memory requirement:	= 40 Mbytes.

Mapping warpage result :

Minimum/maximum displacements at last step (unit: mm):

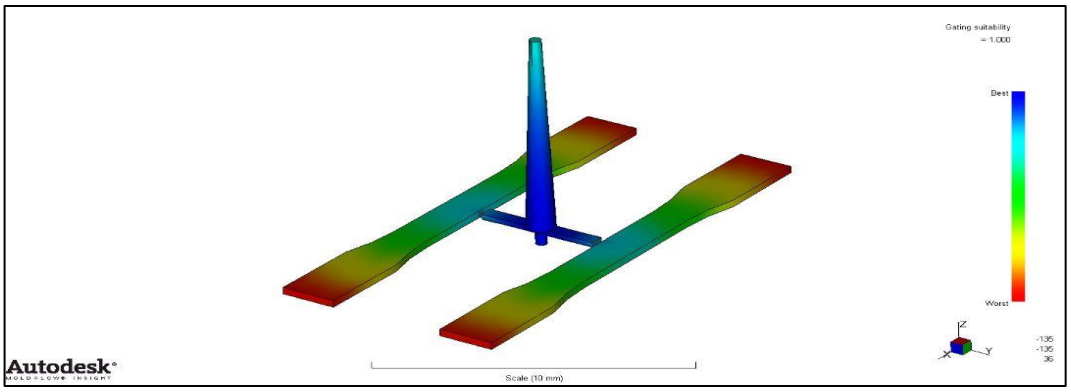
	Node	Min.	Node	Max.
Trans-X	155	-1.2884e-01	140	1.2897e-01
Trans-Y	334	-4.5334e-02	225	5.0064e-02
Trans-Z	92	-1.0735e-01	128	2.1356e-02

Warp analysis has completed successfully.

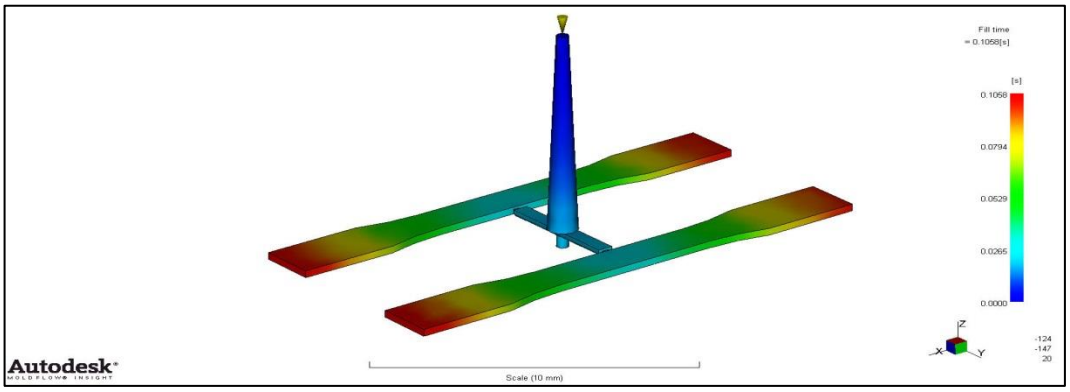
APPENDIX C2

CENTRE GATE MOLDFLOW ANALYSIS RESULT

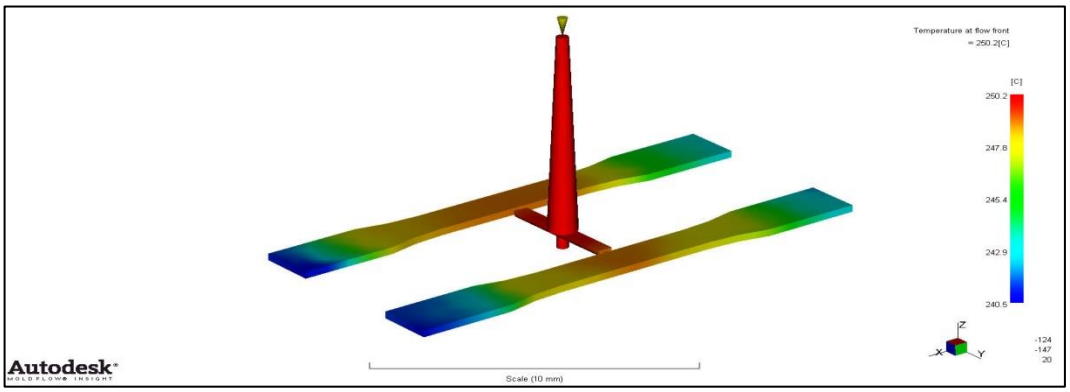
1) Gating suitability.



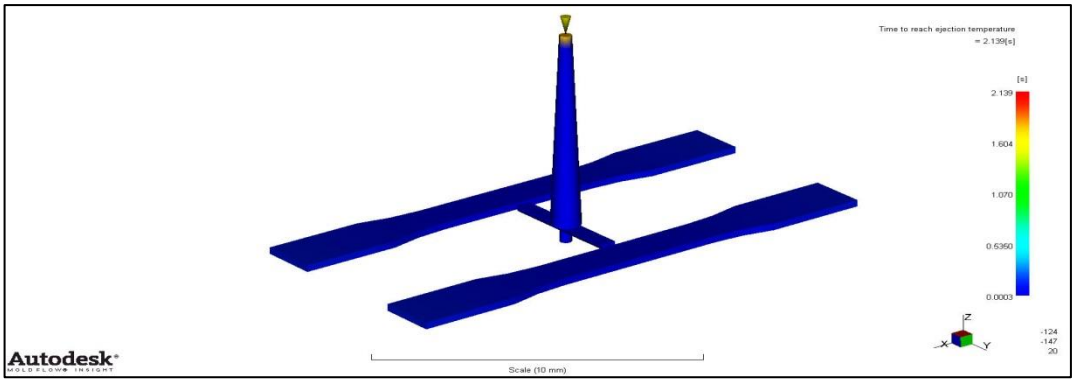
2) Fill time.



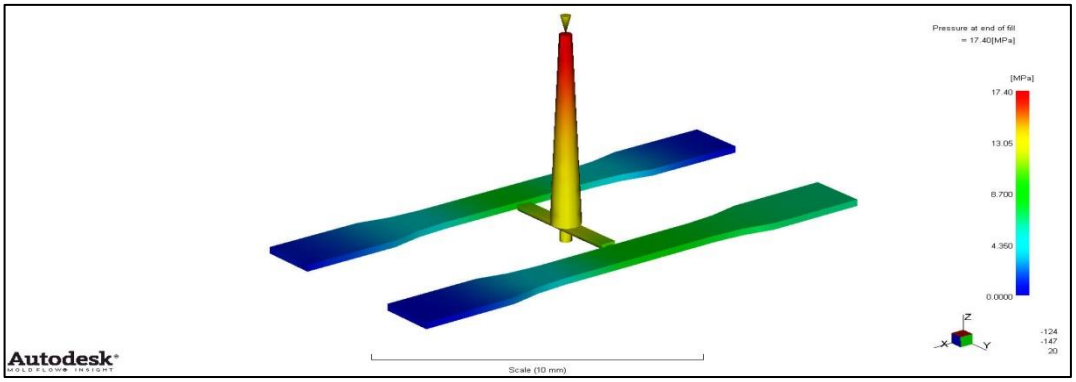
3) Temperature at flow front.



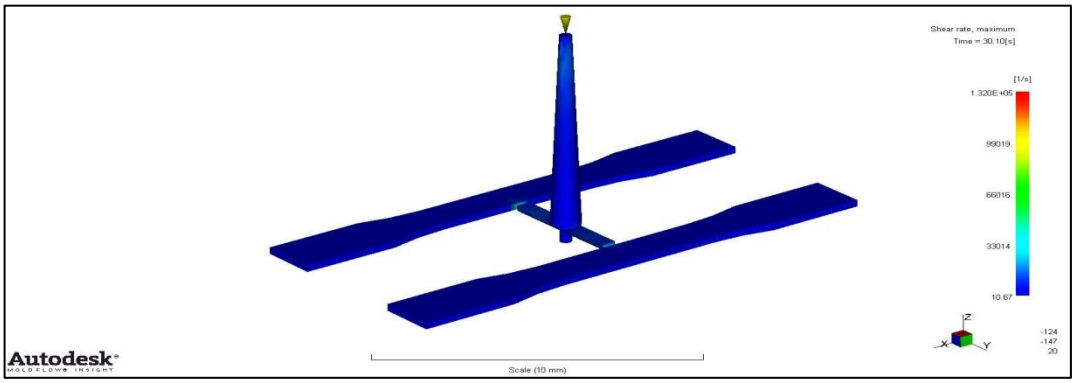
4) Time to reach ejection temperature.



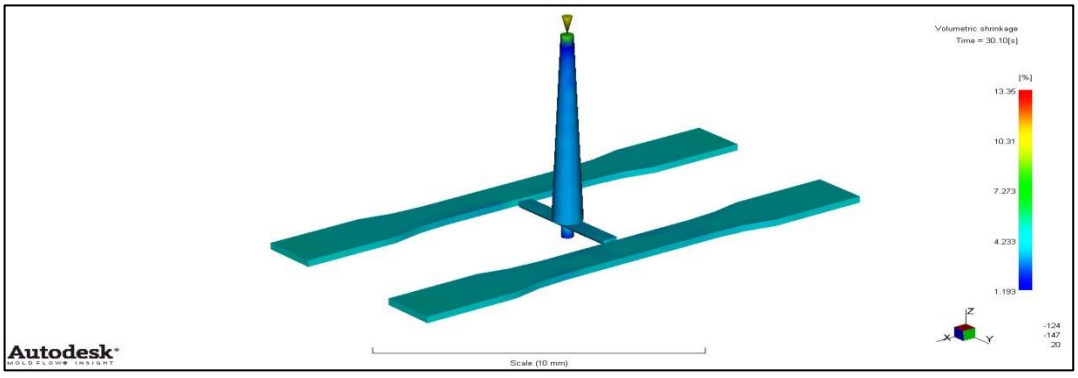
5) Pressure at end of fill.



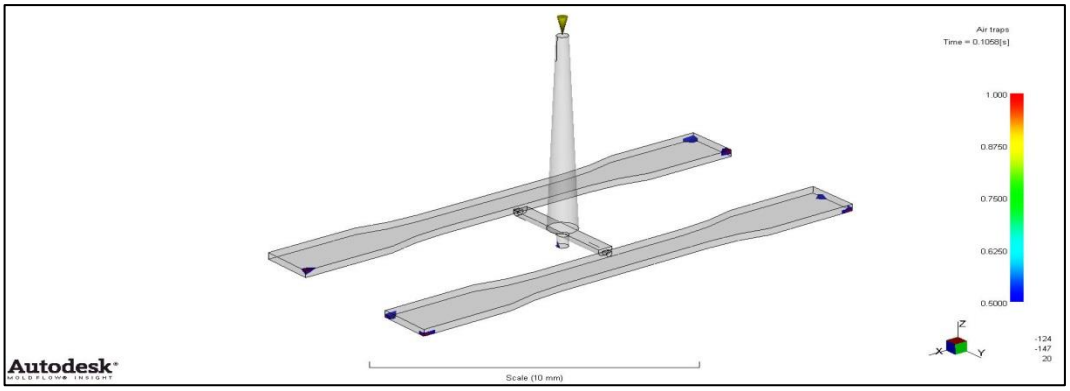
6) Shear rate, maximum.



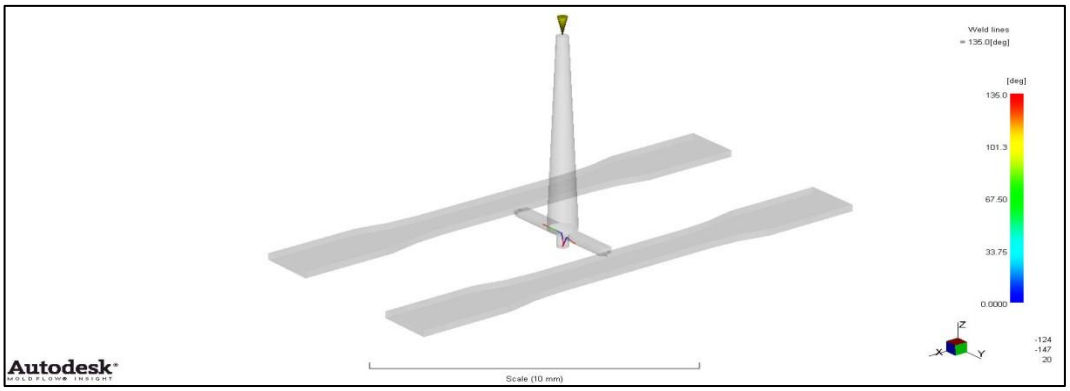
7) Volumetric shrinkage.



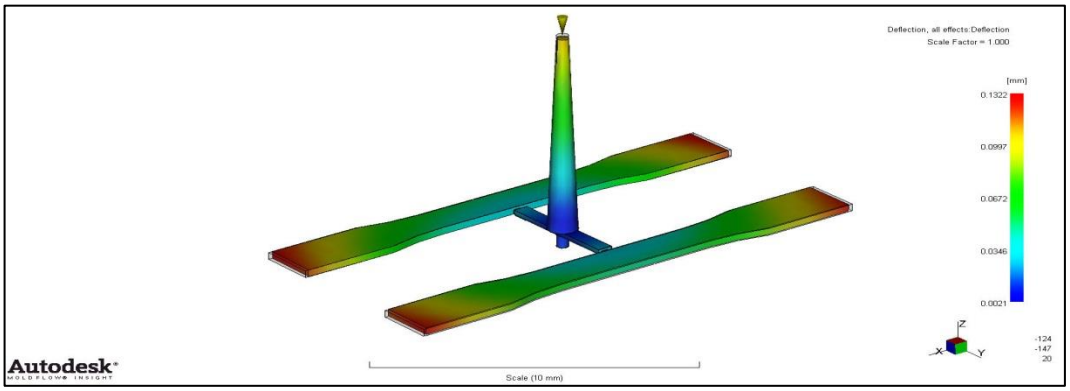
8) Air traps.



9) Weld lines.



10) Warp



APPENDIX D1

PIN GATE MOLDFLOW ANALYSIS LOG

Filling parameters:

Maximum %volume to fill per time step	= 4.000 %
Maximum iterations per time step	= 50
Convergence tolerance (scaling factor)	= 1.000
Flow front scheme	= Level set

Packing parameters:

Maximum time step	= 2.000 s
Maximum iterations per time step	= 50
Convergence tolerance (scaling factor)	= 1.000

Intermediate results:

Intermediate results type	= Write at constant intervals
Number of intermediate results in filling phase	= 5
Number of intermediate results in packing phase	= 5
Number of intermediate results in cooling phase	= 3

Material Data:

Manufacturer	= DSM
Trade name	= Akulon K225-KS
Family name	= PA6
Specific heat (CP)	= 2904.0000 J/kg-C
Transition temperature	= 185.0000 C

Filling Control:

Filling control type	= Automatic
Fill time	= 0.10 s
Stroke volume determination	= Automatic

Velocity/pressure switch-over control:

Velocity/pressure switch-over control type = Automatic

End of filling phase results summary :

Current time from start of cycle	= 0.1056 s
Total mass	= 0.0187 g
Frozen volume	= 26.1248 %
Injection pressure	= 20.3949 MPa
Volumetric shrinkage - minimum	= 0.8582 %
Volumetric shrinkage - maximum	= 14.6738 %
Time at velocity/pressure switch-over	= 0.1047 s
Injection pressure at velocity/pressure switch-over	= 20.7692 MPa
Volume filled at velocity/pressure switch-over	= 99.3731 %

End of filling. Packing will now commence.

End of packing phase results summary :

Current time from start of cycle	= 30.1047 s
Total mass	= 0.0191 g
Frozen volume	= 100.0000 %
Injection pressure	= 0.0000 MPa
Volumetric shrinkage - minimum	= 0.8582 %
Volumetric shrinkage - maximum	= 14.6738 %
Maximum velocity	= 36.8714 cm/s
Maximum shear rate	= 8.6803E+04 1/s

Warp Analysis:

Number of vertex nodes:	= 1871
Number of midside nodes:	= 10801
Total number of nodes in Warp analysis:	= 12672
Total number of elements in Warp analysis:	= 7945
Estimated memory requirement:	= 40 Mbytes.

Mapping warpage result :

Minimum/maximum displacements at last step (unit: mm):

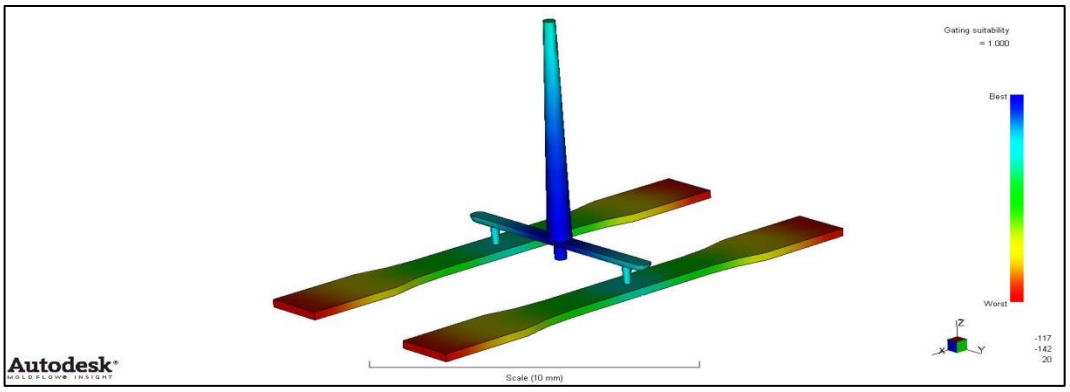
	Node	Min.	Node	Max.
Trans-X	194	-1.2746e-01	148	1.3114e-01
Trans-Y	149	-7.3253e-02	178	8.3554e-02
Trans-Z	174	-1.1755e-01	202	4.4898e-02

Warp analysis has completed successfully.

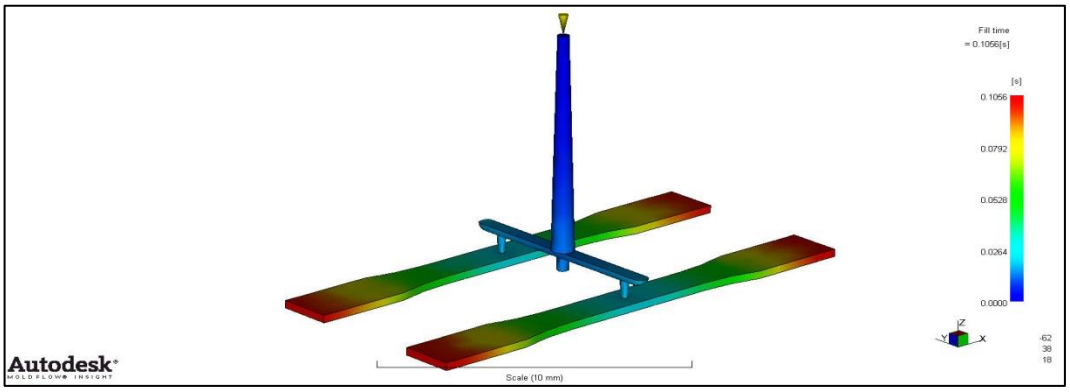
APPENDIX D2

PIN GATE MOLDFLOW ANALYSIS RESULT

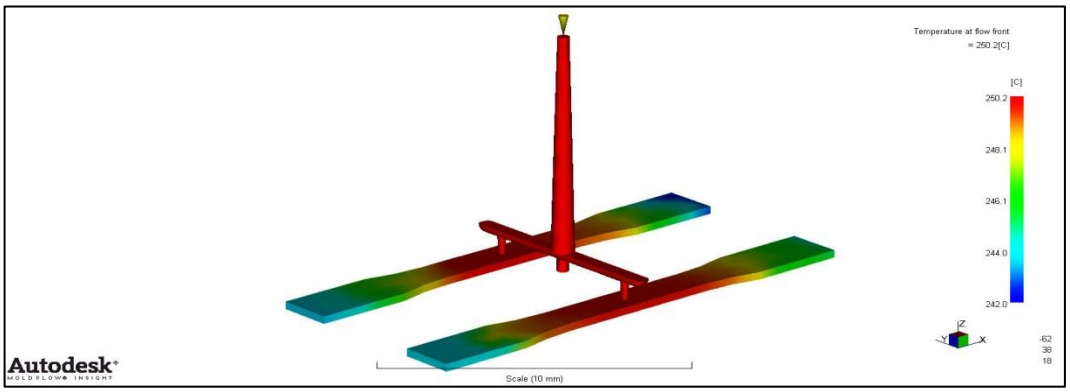
1) Gating suitability.



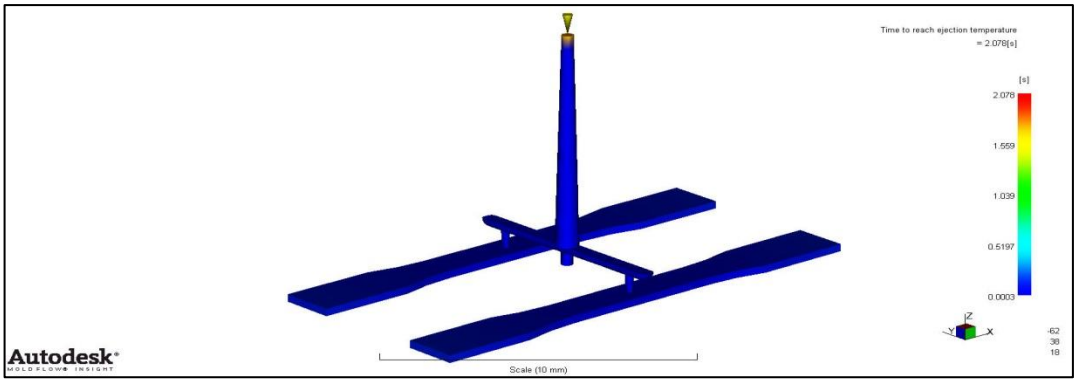
2) Fill time.



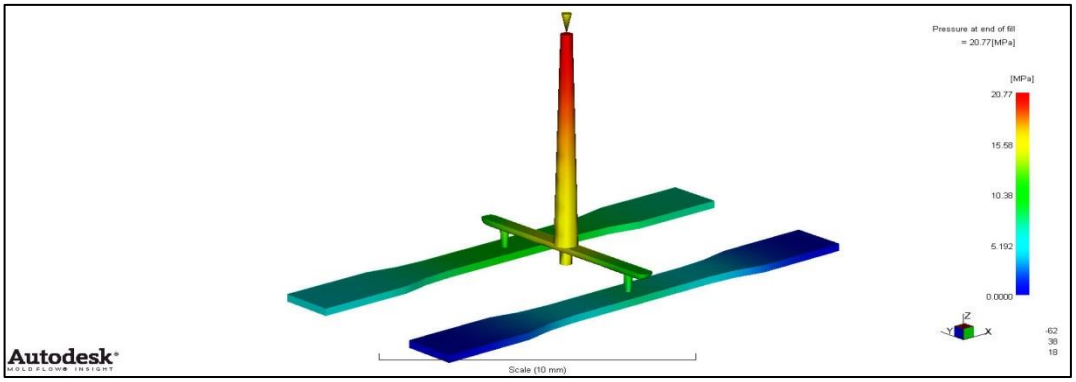
3) Temperature at flow front.



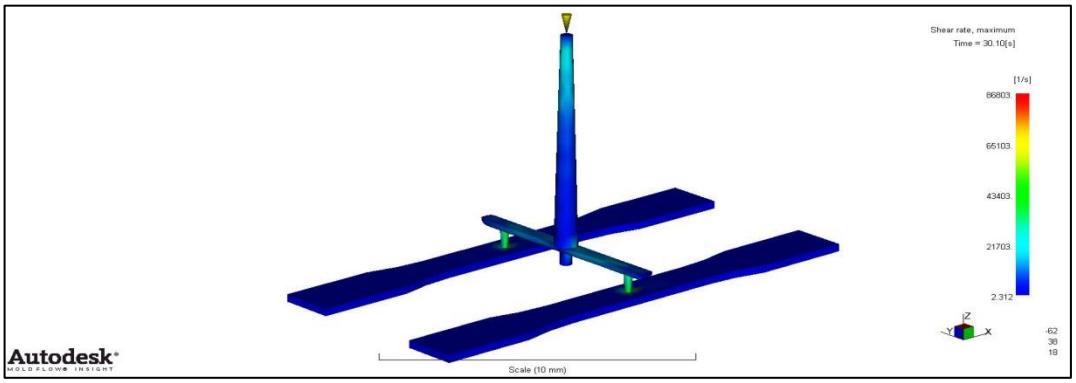
4) Time to reach ejection temperature.



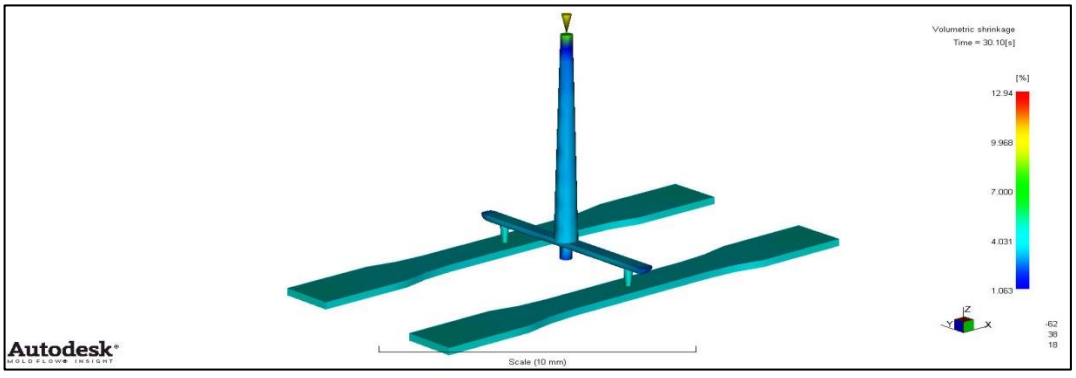
5) Pressure at end of fill.



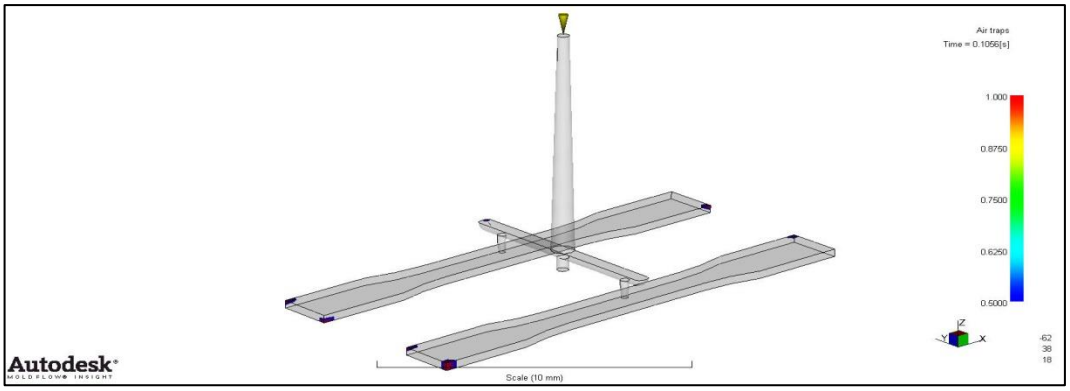
6) Shear rate, maximum.



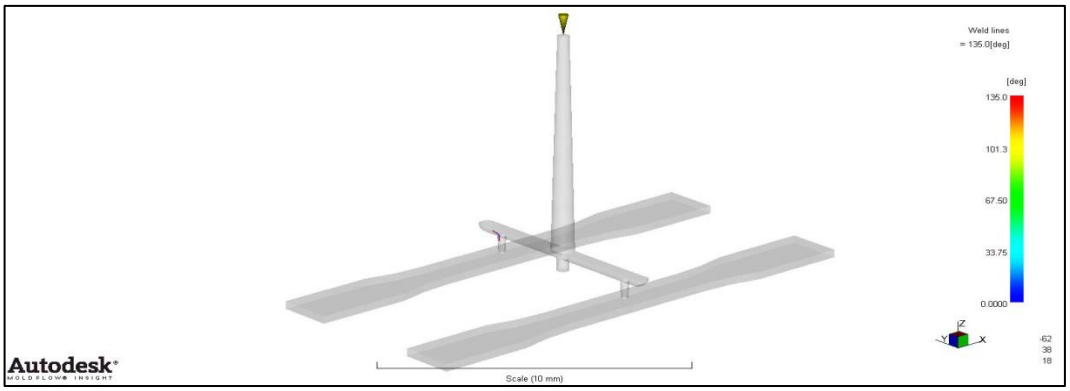
7) Volumetric shrinkage.



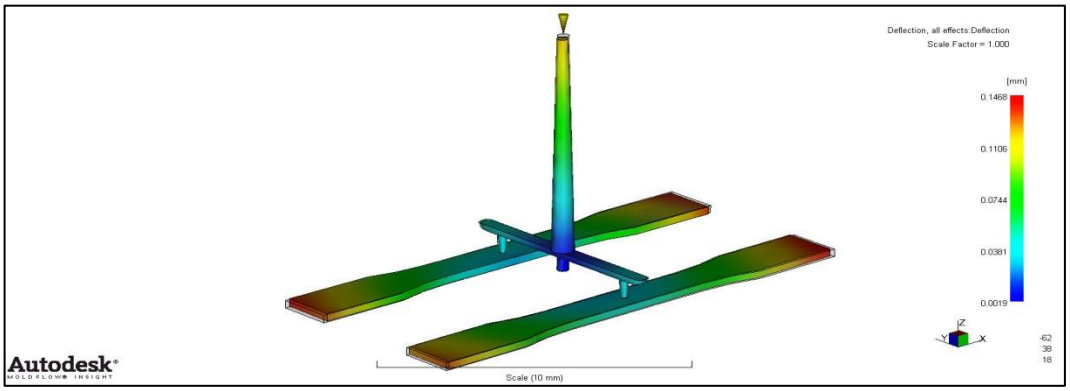
8) Air traps.



9) Weld lines.



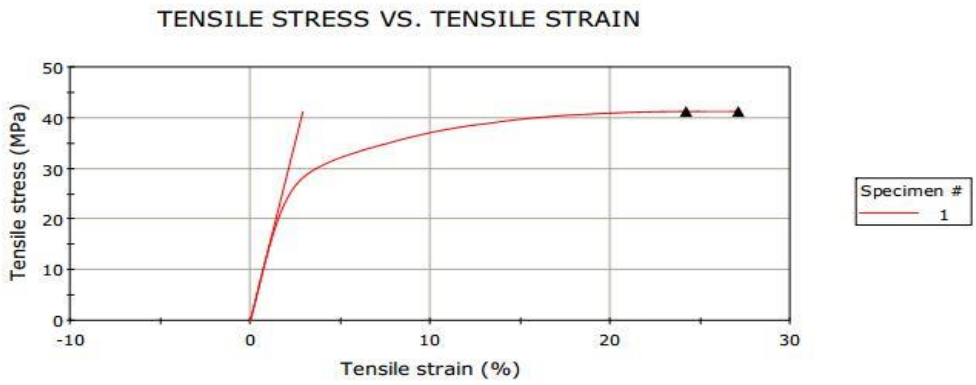
10) Warp



APPINDIX E1

TENSILE TEST RESULT – 3mm/min

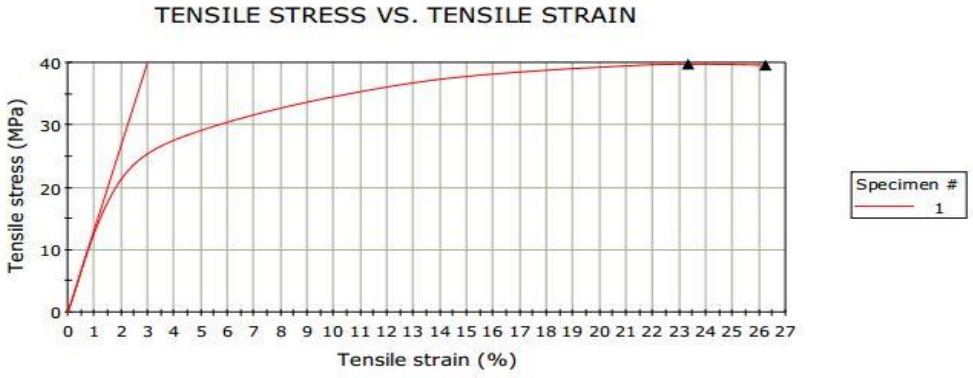
1. Pure Nylon, PA6 (Sample 1)



	Modulus (E-modulus) (GPa)	Load at Yield (Offset 0.2 %) (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Tensile stress at Maximum Load (MPa)	Tensile strain at Maximum Load (%)	Tensile stress at Break (Standard) (MPa)
1	1.4202	0.8263	21.6870	41.2611	24.1752	41.2553

	Tensile strain at Break (Standard) (%)	Strain 1 at Break (Standard) (mm/mm)
1	27.0706	0.2707

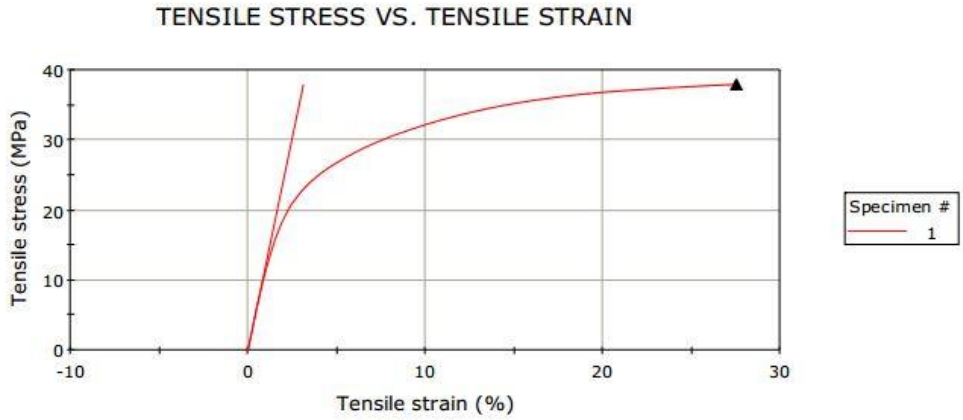
2. Pure Nylon, PA6 (Sample 2)



	Modulus (E-modulus) (GPa)	Load at Yield (Offset 0.2 %) (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Tensile stress at Maximum Load (MPa)	Tensile strain at Maximum Load (%)	Tensile stress at Break (Standard) (MPa)
1	1.3345	0.6950	18.2417	39.7244	23.2990	39.5526

	Tensile strain at Break (Standard) (%)	Strain 1 at Break (Standard) (mm/mm)
1	26.2106	0.2621

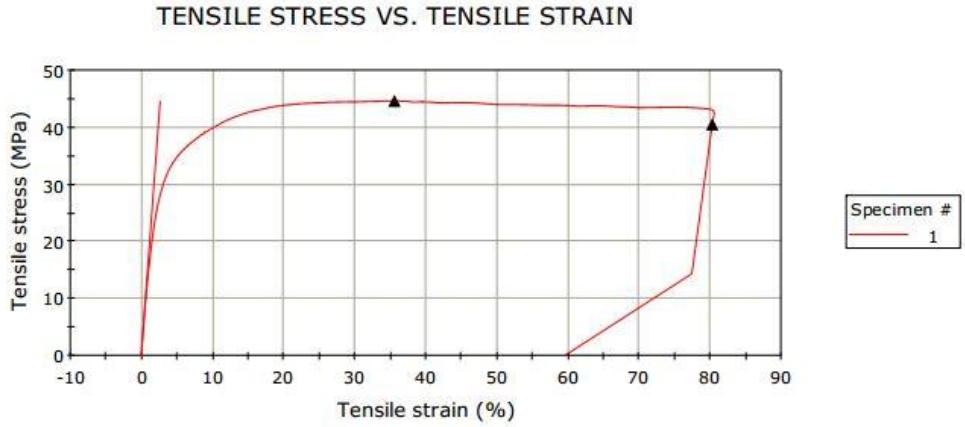
3. Pure Nylon, PA6 (Sample 3)



	Modulus (E-modulus) (GPa)	Load at Yield (Offset 0.2 %) (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Tensile stress at Maximum Load (MPa)	Tensile strain at Maximum Load (%)	Tensile stress at Break (Standard) (MPa)
1	1.2146	0.5766	15.1329	37.9086	27.4760	37.9061

	Tensile strain at Break (Standard) (%)	Strain 1 at Break (Standard) (mm/mm)
1	27.5263	0.2753

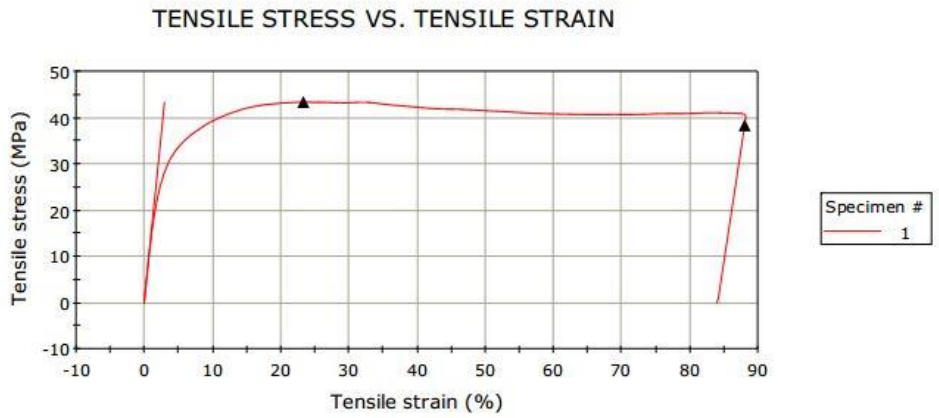
4. 95%PA6 + 5%GF (Sample 1)



	Modulus (E-modulus) (GPa)	Load at Yield (Offset 0.2 %) (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Tensile stress at Maximum Load (MPa)	Tensile strain at Maximum Load (%)	Tensile stress at Break (Standard) (MPa)
1	1.6754	0.6570	17.2447	44.6374	35.5129	40.5497

	Tensile strain at Break (Standard) (%)	Strain 1 at Break (Standard) (mm/mm)
1	80.1988	0.8020

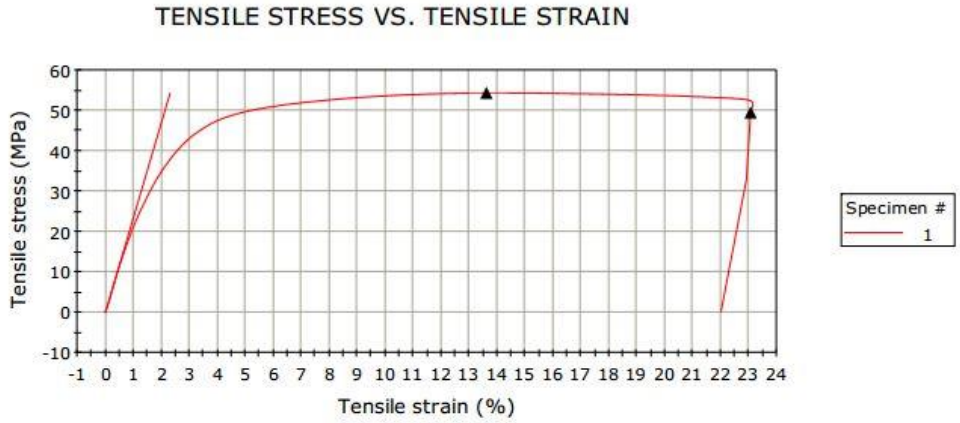
5. 95%PA6 + 5%GF (Sample 2)



	Modulus (E-modulus) (GPa)	Load at Yield (Offset 0.2 %) (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Tensile stress at Maximum Load (MPa)	Tensile strain at Maximum Load (%)	Tensile stress at Break (Standard) (MPa)
1	1.4597	0.7325	19.2248	43.3632	23.2918	38.3454

	Tensile strain at Break (Standard) (%)	Strain 1 at Break (Standard) (mm/mm)
1	87.9306	0.8793

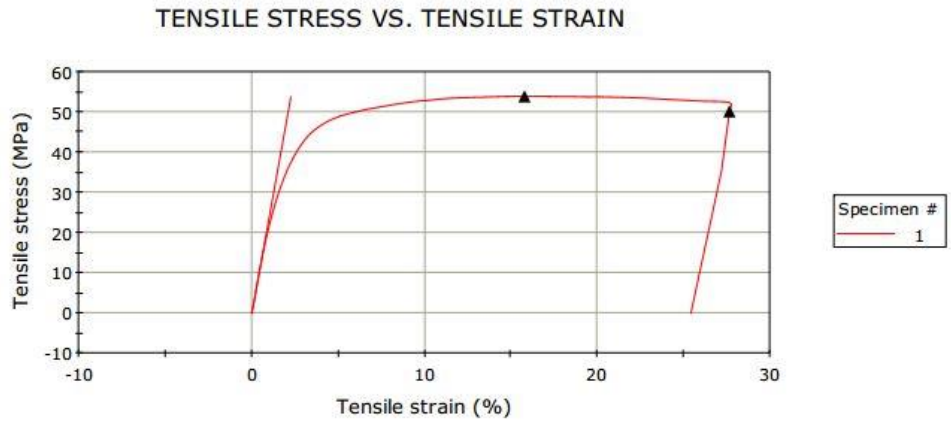
6. 90%PA6 + 10%GF (Sample 1)



	Modulus (E-modulus) (GPa)	Load at Yield (Offset 0.2 %) (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Tensile stress at Maximum Load (MPa)	Tensile strain at Maximum Load (%)	Tensile stress at Break (Standard) (MPa)
1	2.3499	0.9996	26.2361	54.3050	13.6129	49.5041

	Tensile strain at Break (Standard) (%)	Strain 1 at Break (Standard) (mm/mm)
1	23.0432	0.2304

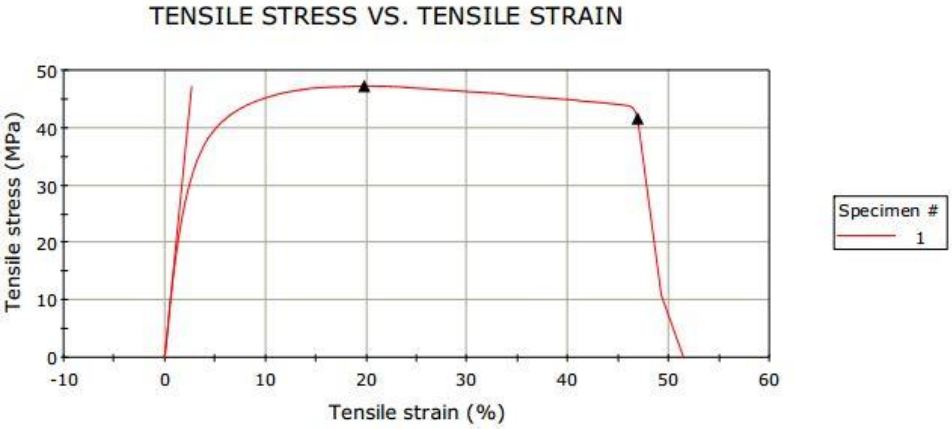
7. 90%PA6 + 10%GF (Sample 2)



	Modulus (E-modulus) (GPa)	Load at Yield (Offset 0.2 %) (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Tensile stress at Maximum Load (MPa)	Tensile strain at Maximum Load (%)	Tensile stress at Break (Standard) (MPa)
1	2.3708	1.0308	27.0547	53.8748	15.7628	50.1206

	Tensile strain at Break (Standard) (%)	Strain 1 at Break (Standard) (mm/mm)
1	27.6120	0.2761

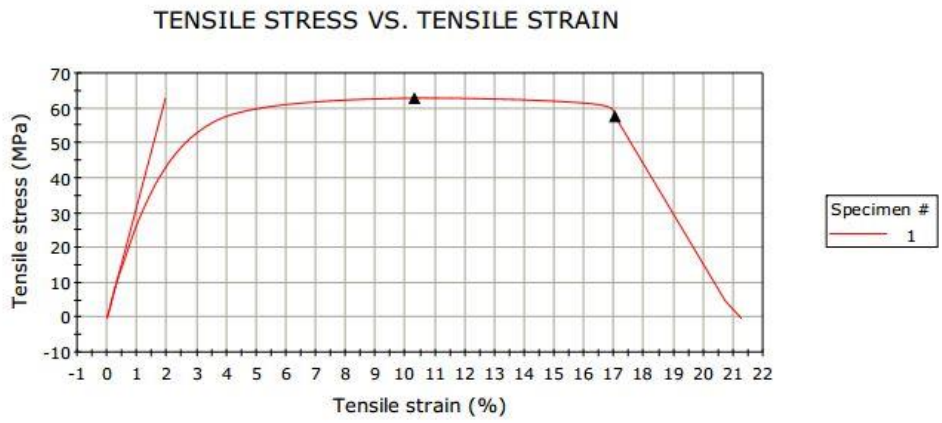
8. 90%PA6 + 10%GF (Sample 3)



	Modulus (E-modulus) (GPa)	Load at Yield (Offset 0.2 %) (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Tensile stress at Maximum Load (MPa)	Tensile strain at Maximum Load (%)	Tensile stress at Break (Standard) (MPa)
1	1.7627	0.8126	21.3280	47.2669	19.7675	41.6508

	Tensile strain at Break (Standard) (%)	Strain 1 at Break (Standard) (mm/mm)
1	46.8625	0.4686

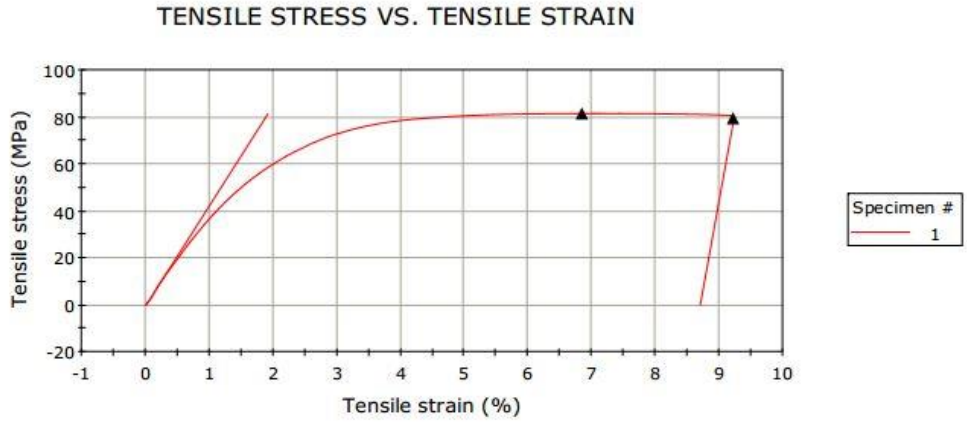
9. 85%PA6 + 15%GF (Sample 1)



	Modulus (E-modulus) (GPa)	Load at Yield (Offset 0.2 %) (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Tensile stress at Maximum Load (MPa)	Tensile strain at Maximum Load (%)	Tensile stress at Break (Standard) (MPa)
1	3.2161	1.0940	28.7130	62.8394	10.2964	57.6774

	Tensile strain at Break (Standard) (%)	Strain 1 at Break (Standard) (mm/mm)
1	17.0110	0.1701

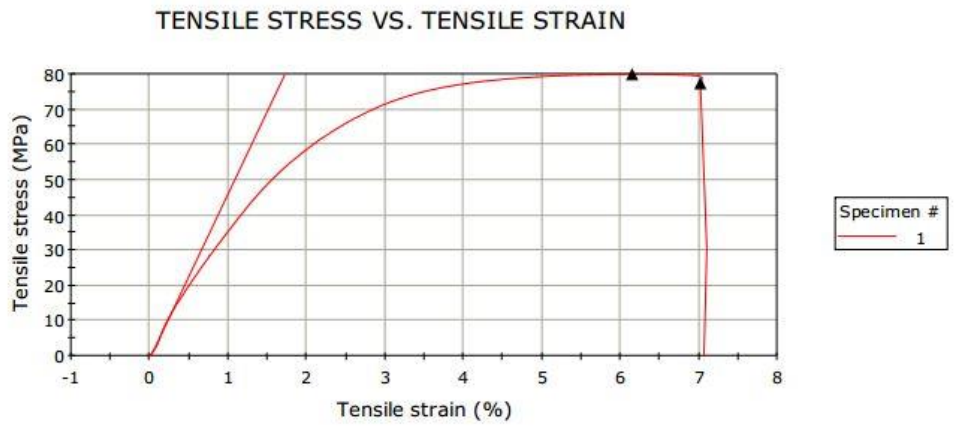
10. 80%PA6 + 20%GF (Sample 1)



	Modulus (E-modulus) (GPa)	Load at Yield (Offset 0.2 %) (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Tensile stress at Maximum Load (MPa)	Tensile strain at Maximum Load (%)	Tensile stress at Break (Standard) (MPa)
1	4.2518	1.6387	43.0097	81.4452	6.8373	79.4221

	Tensile strain at Break (Standard) (%)	Strain 1 at Break (Standard) (mm/mm)
1	9.2074	0.0921

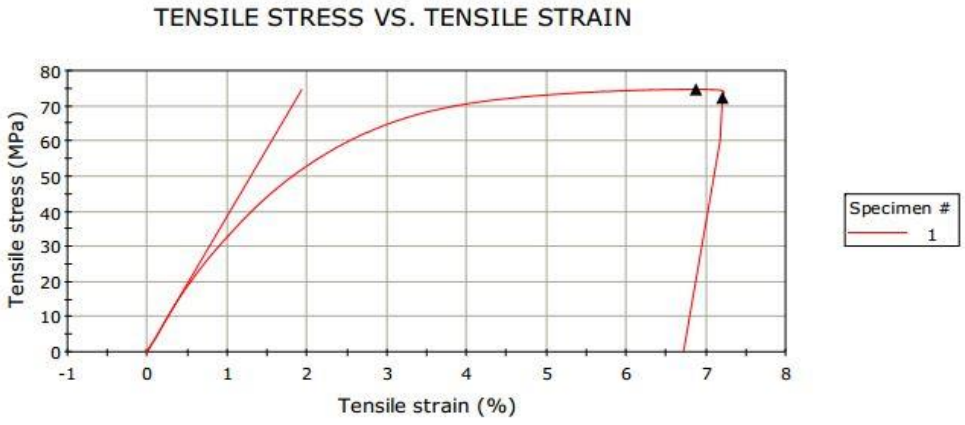
11. 80%PA6 + 20%GF (Sample 2)



	Modulus (E-modulus) (GPa)	Load at Yield (Offset 0.2 %) (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Tensile stress at Maximum Load (MPa)	Tensile strain at Maximum Load (%)	Tensile stress at Break (Standard) (MPa)
1	4.6749	1.2698	33.3270	79.8762	6.1454	77.2830

	Tensile strain at Break (Standard) (%)	Strain 1 at Break (Standard) (mm/mm)
1	7.0111	0.0701

12. 80%PA6 + 20%GF (Sample 3)



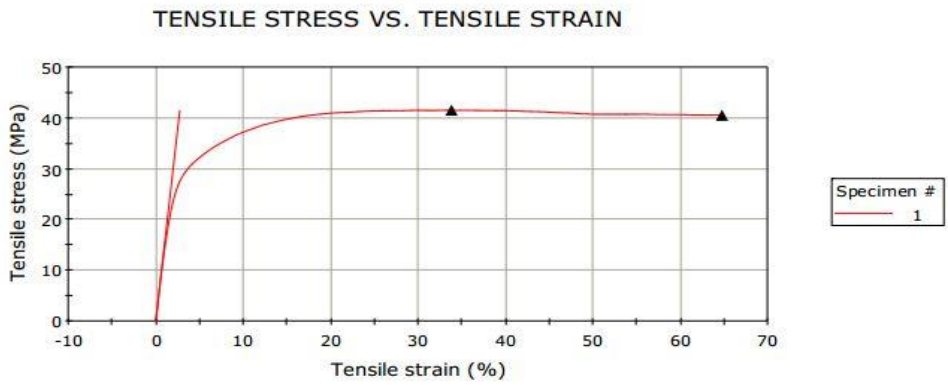
	Modulus (E-modulus) (GPa)	Load at Yield (Offset 0.2 %) (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Tensile stress at Maximum Load (MPa)	Tensile strain at Maximum Load (%)	Tensile stress at Break (Standard) (MPa)
1	3.8425	1.3678	35.9001	74.6766	6.8642	72.3036

	Tensile strain at Break (Standard) (%)	Strain 1 at Break (Standard) (mm/mm)
1	7.1941	0.0719

APPENDIX E2

TENSILE TEST RESULT – 5mm/min

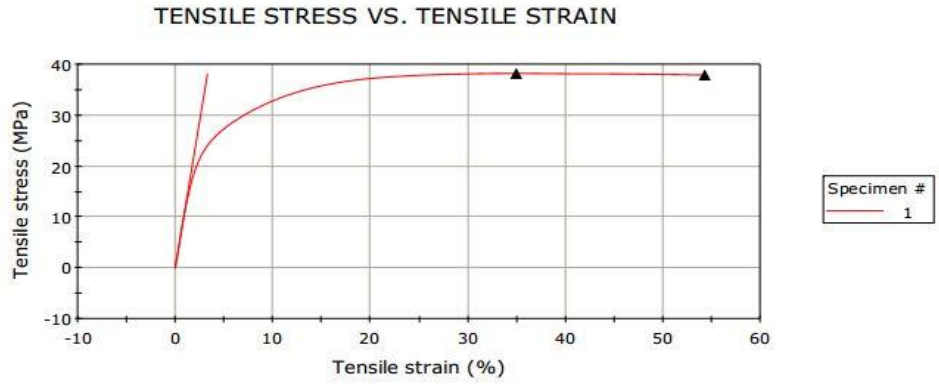
1. Pure Nylon, PA6 (Sample 1)



	Modulus (E-modulus) (GPa)	Load at Yield (Offset 0.2 %) (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Tensile stress at Maximum Load (MPa)	Tensile strain at Maximum Load (%)	Tensile stress at Break (Standard) (MPa)
1	1.5160	0.7454	19.5639	41.5628	33.7607	40.5550

	Tensile strain at Break (Standard) (%)	Strain 1 at Break (Standard) (mm/mm)
1	64.6837	0.6468

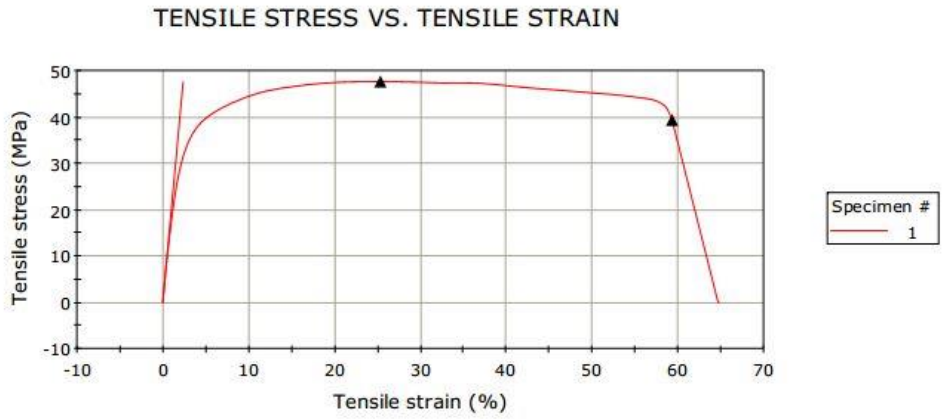
2. Pure Nylon, PA6 (Sample 2)



	Modulus (E-modulus) (GPa)	Load at Yield (Offset 0.2 %) (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Tensile stress at Maximum Load (MPa)	Tensile strain at Maximum Load (%)	Tensile stress at Break (Standard) (MPa)
1	1.1464	0.6465	16.9695	38.1947	34.9309	37.8785

	Tensile strain at Break (Standard) (%)	Strain 1 at Break (Standard) (mm/mm)
1	54.2215	0.5422

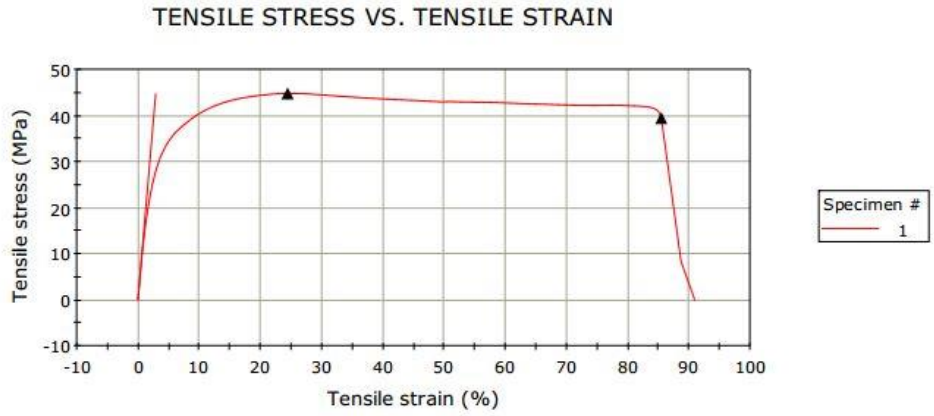
3. 95%PA6 + 5%GF (Sample 1)



	Modulus (E-modulus) (GPa)	Load at Yield (Offset 0.2 %) (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Tensile stress at Maximum Load (MPa)	Tensile strain at Maximum Load (%)	Tensile stress at Break (Standard) (MPa)
1	2.0109	0.7980	20.9450	47.6133	25.3035	39.3562

	Tensile strain at Break (Standard) (%)	Strain 1 at Break (Standard) (mm/mm)
1	59.2211	0.5922

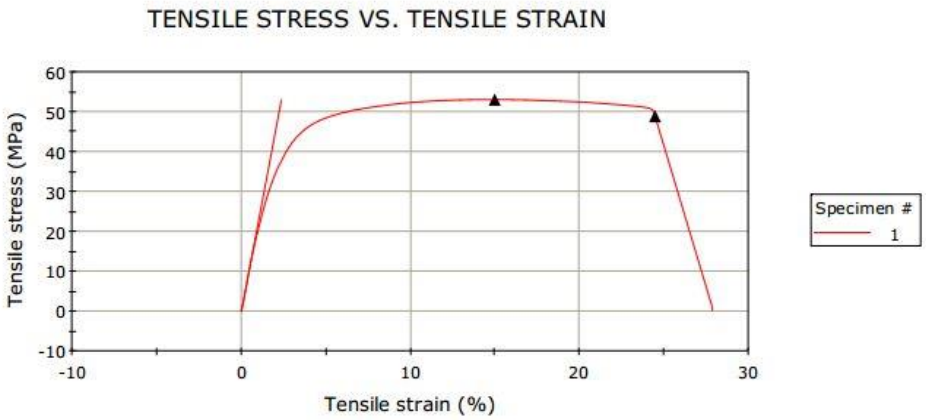
4. 95%PA6 + 5%GF (Sample 2)



	Modulus (E-modulus) (GPa)	Load at Yield (Offset 0.2 %) (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Tensile stress at Maximum Load (MPa)	Tensile strain at Maximum Load (%)	Tensile stress at Break (Standard) (MPa)
1	1.5334	0.6530	17.1395	44.7781	24.3840	39.4827

	Tensile strain at Break (Standard) (%)	Strain 1 at Break (Standard) (mm/mm)
1	85.3742	0.8537

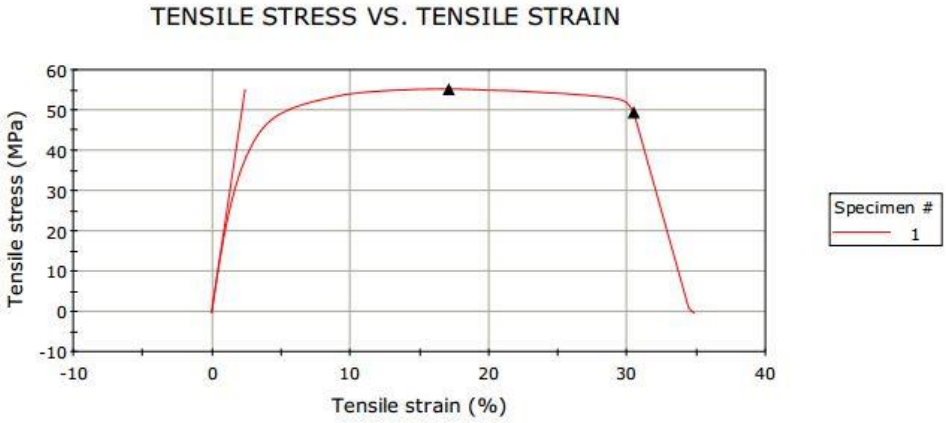
5. 90%PA6 + 10%GF (Sample 1)



	Modulus (E-modulus) (GPa)	Load at Yield (Offset 0.2 %) (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Tensile stress at Maximum Load (MPa)	Tensile strain at Maximum Load (%)	Tensile stress at Break (Standard) (MPa)
1	2.2521	1.0322	27.0915	53.0602	14.9668	48.8797

	Tensile strain at Break (Standard) (%)	Strain 1 at Break (Standard) (mm/mm)
1	24.4321	0.2443

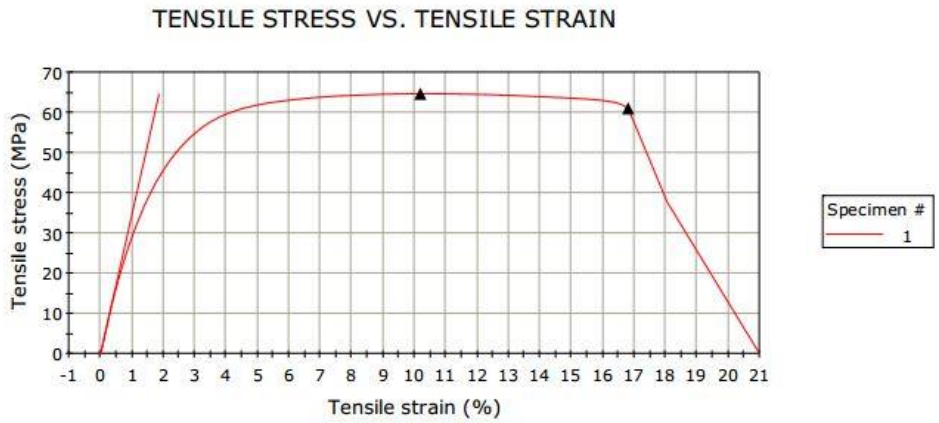
6. 90%PA6 + 10%GF (Sample 2)



	Modulus (E-modulus) (GPa)	Load at Yield (Offset 0.2 %) (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Tensile stress at Maximum Load (MPa)	Tensile strain at Maximum Load (%)	Tensile stress at Break (Standard) (MPa)
1	2.2841	0.9895	25.9714	55.2321	17.0851	49.4734

	Tensile strain at Break (Standard) (%)	Strain 1 at Break (Standard) (mm/mm)
1	30.4266	0.3043

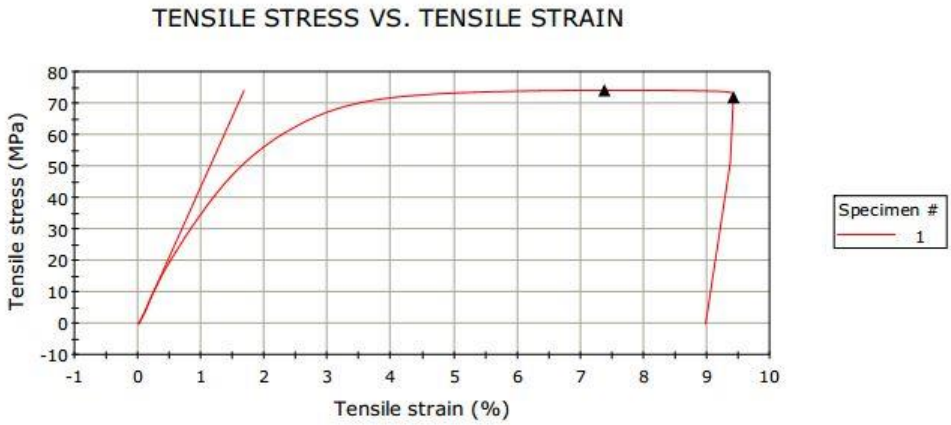
7. 85%PA6 + 15%GF (Sample 1)



	Modulus (E-modulus) (GPa)	Load at Yield (Offset 0.2 %) (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Tensile stress at Maximum Load (MPa)	Tensile strain at Maximum Load (%)	Tensile stress at Break (Standard) (MPa)
1	3.4585	1.1901	31.2367	64.6392	10.1803	61.0433

	Tensile strain at Break (Standard) (%)	Strain 1 at Break (Standard) (mm/mm)
1	16.7942	0.1679

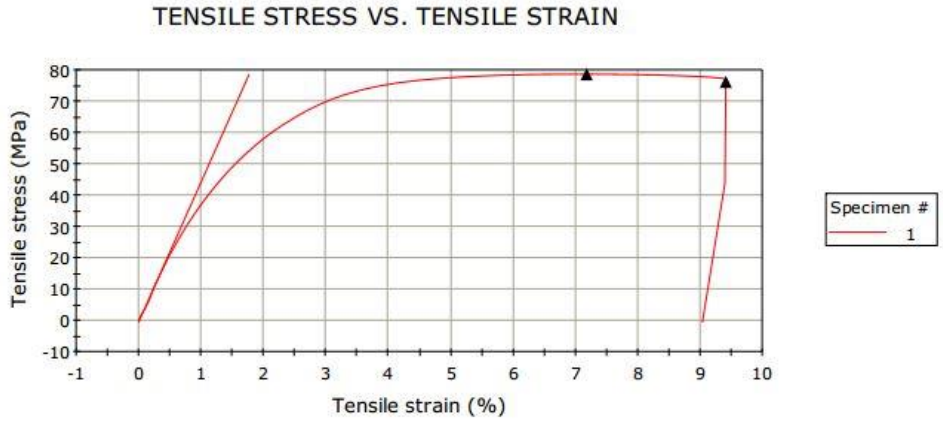
8. 80%PA6 + 20%GF (Sample 1)



	Modulus (E-modulus) (GPa)	Load at Yield (Offset 0.2 %) (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Tensile stress at Maximum Load (MPa)	Tensile strain at Maximum Load (%)	Tensile stress at Break (Standard) (MPa)
1	4.4598	1.3410	35.1968	74.0499	7.3714	71.8660

	Tensile strain at Break (Standard) (%)	Strain 1 at Break (Standard) (mm/mm)
1	9.4118	0.0941

9. 80%PA6 + 20%GF (Sample 2)



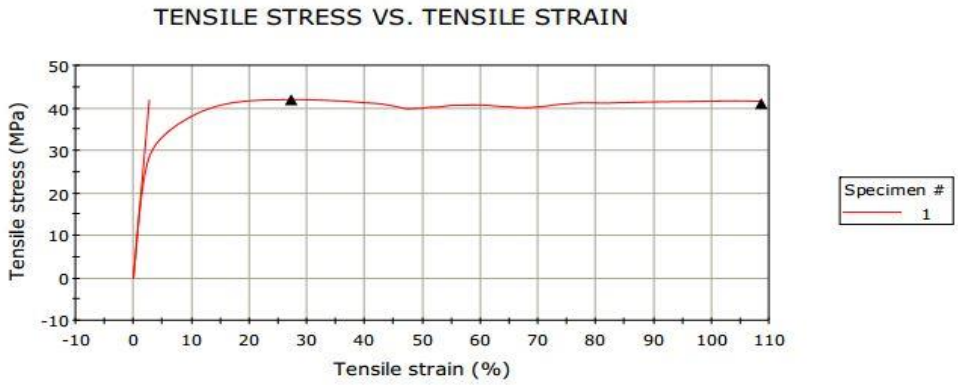
	Modulus (E-modulus) (GPa)	Load at Yield (Offset 0.2 %) (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Tensile stress at Maximum Load (MPa)	Tensile strain at Maximum Load (%)	Tensile stress at Break (Standard) (MPa)
1	4.4649	1.5113	39.6654	78.5932	7.1706	76.1270

	Tensile strain at Break (Standard) (%)	Strain 1 at Break (Standard) (mm/mm)
1	9.4005	0.0940

APPENDIX E3

TENSILE TEST – 10mm/min

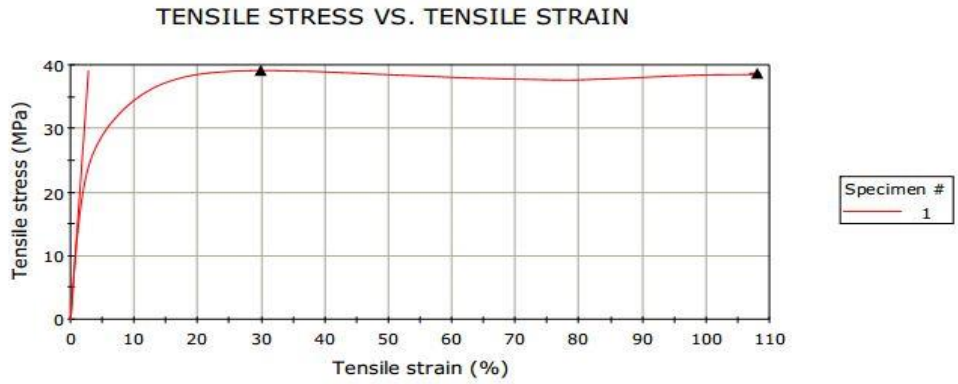
1. Pure Nylon, PA6 (Sample 1)



	Modulus (E-modulus) (GPa)	Load at Yield (Offset 0.2 %) (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Tensile stress at Maximum Load (MPa)	Tensile strain at Maximum Load (%)	Tensile stress at Break (Standard) (MPa)
1	1.5039	0.8196	21.5109	41.9764	27.2696	41.0444

	Tensile strain at Break (Standard) (%)	Strain 1 at Break (Standard) (mm/mm)
1	108.5045	1.0850

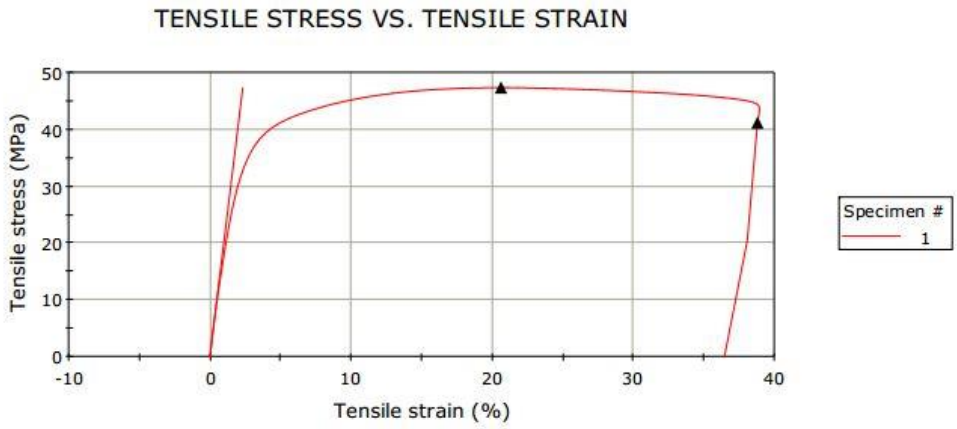
2. Pure Nylon, PA6 (Sample 2)



	Modulus (E-modulus) (GPa)	Load at Yield (Offset 0.2 %) (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Tensile stress at Maximum Load (MPa)	Tensile strain at Maximum Load (%)	Tensile stress at Break (Standard) (MPa)
1	1.3888	0.5950	15.6158	39.1093	29.8977	38.6809

	Tensile strain at Break (Standard) (%)	Strain 1 at Break (Standard) (mm/mm)
1	107.9294	1.0793

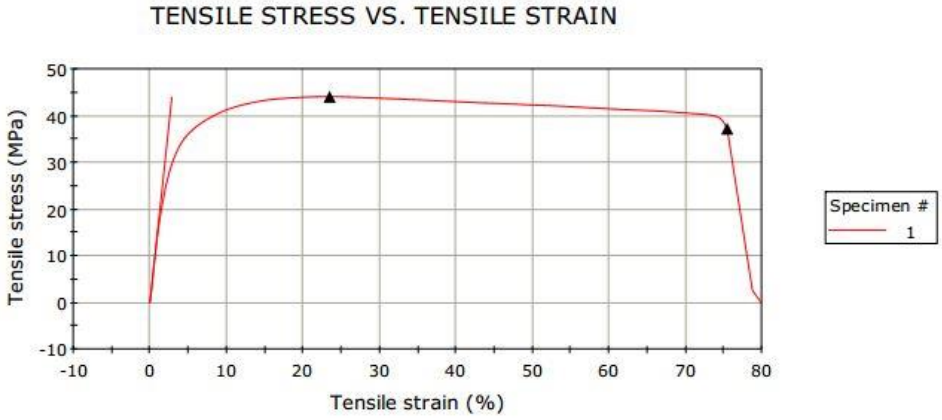
3. 95%PA6 + 5%GF (Sample 1)



	Modulus (E-modulus) (GPa)	Load at Yield (Offset 0.2 %) (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Tensile stress at Maximum Load (MPa)	Tensile strain at Maximum Load (%)	Tensile stress at Break (Standard) (MPa)
1	2.0220	0.8651	22.7052	47.3320	20.5839	41.1730

	Tensile strain at Break (Standard) (%)	Strain 1 at Break (Standard) (mm/mm)
1	38.7293	0.3873

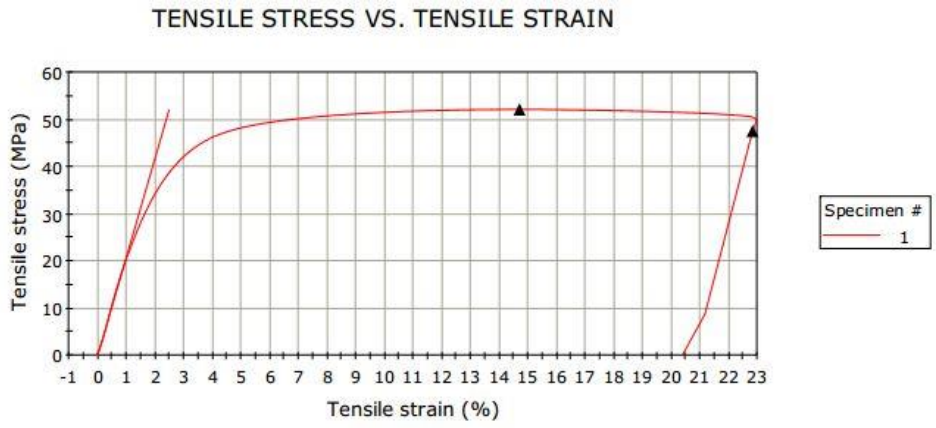
4. 95%PA6 + 5%GF (Sample 2)



	Modulus (E-modulus) (GPa)	Load at Yield (Offset 0.2 %) (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Tensile stress at Maximum Load (MPa)	Tensile strain at Maximum Load (%)	Tensile stress at Break (Standard) (MPa)
1	1.5467	0.7657	20.0981	44.0512	23.4517	37.2215

	Tensile strain at Break (Standard) (%)	Strain 1 at Break (Standard) (mm/mm)
1	75.3732	0.7537

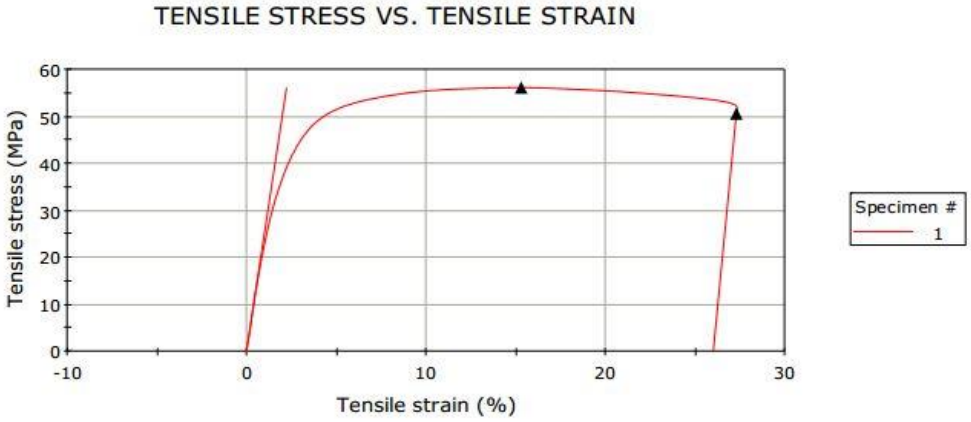
5. 90%PA6 + 10%GF (Sample 1)



	Modulus (E-modulus) (GPa)	Load at Yield (Offset 0.2 %) (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Tensile stress at Maximum Load (MPa)	Tensile strain at Maximum Load (%)	Tensile stress at Break (Standard) (MPa)
1	2.0903	1.1426	29.9894	52.1135	14.6970	47.5273

	Tensile strain at Break (Standard) (%)	Strain 1 at Break (Standard) (mm/mm)
1	22.8094	0.2281

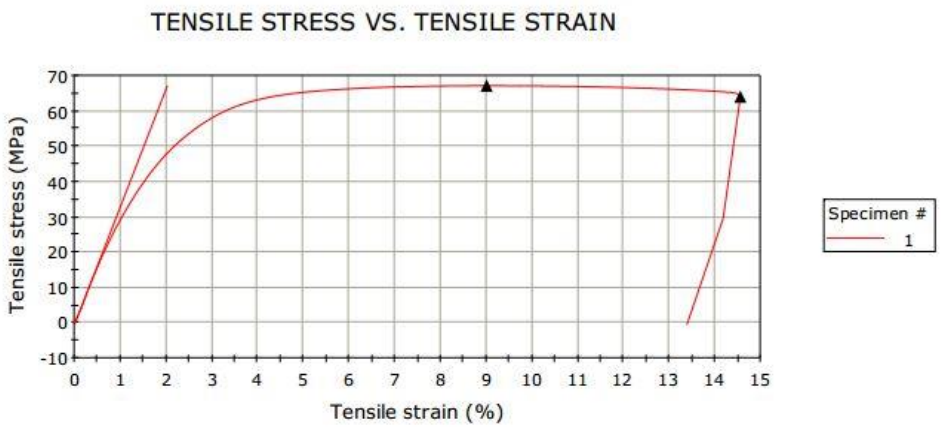
6. 90%PA6 + 10%GF (Sample 2)



	Modulus (E-modulus) (GPa)	Load at Yield (Offset 0.2 %) (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Tensile stress at Maximum Load (MPa)	Tensile strain at Maximum Load (%)	Tensile stress at Break (Standard) (MPa)
1	2.5116	1.0900	28.6083	56.1127	15.2779	50.5835

	Tensile strain at Break (Standard) (%)	Strain 1 at Break (Standard) (mm/mm)
1	27.2554	0.2726

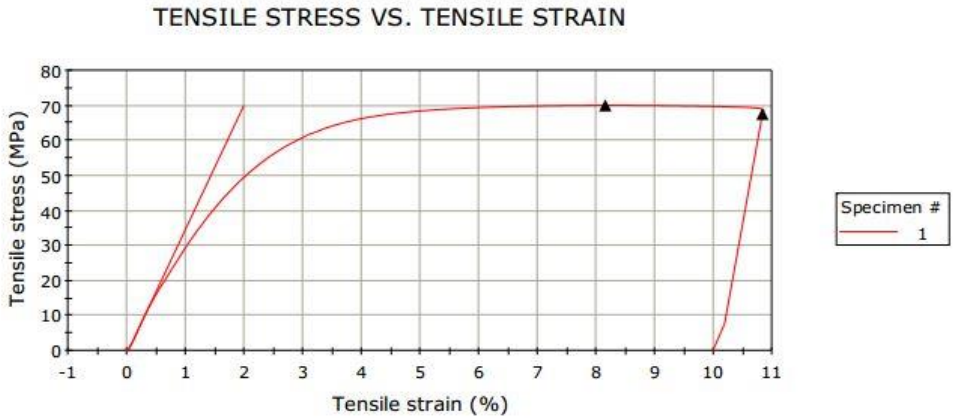
7. 85%PA6 + 15%GF (Sample 1)



	Modulus (E-modulus) (GPa)	Load at Yield (Offset 0.2 %) (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Tensile stress at Maximum Load (MPa)	Tensile strain at Maximum Load (%)	Tensile stress at Break (Standard) (MPa)
1	3.3244	1.3335	34.9991	67.0917	9.0067	64.0298

	Tensile strain at Break (Standard) (%)	Strain 1 at Break (Standard) (mm/mm)
1	14.5450	0.1455

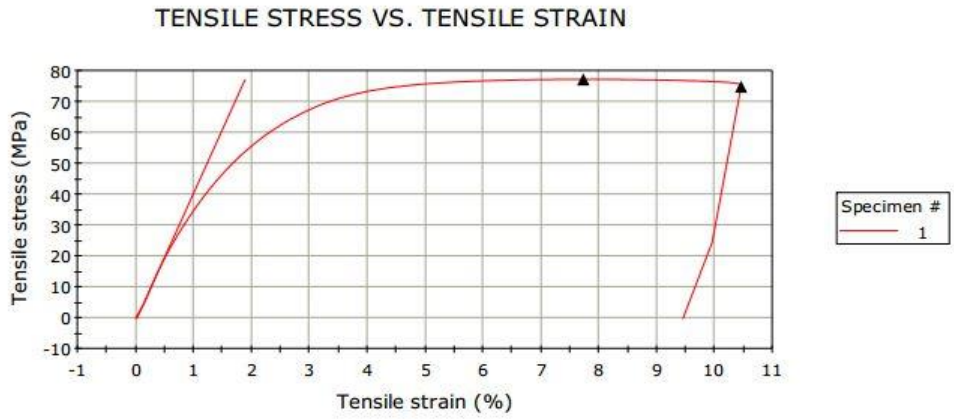
8. 85%PA6 + 15%GF (Sample 2)



	Modulus (E-modulus) (GPa)	Load at Yield (Offset 0.2 %) (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Tensile stress at Maximum Load (MPa)	Tensile strain at Maximum Load (%)	Tensile stress at Break (Standard) (MPa)
1	3.5438	1.2799	33.5922	70.0149	8.1488	67.5854

	Tensile strain at Break (Standard) (%)	Strain 1 at Break (Standard) (mm/mm)
1	10.8246	0.1082

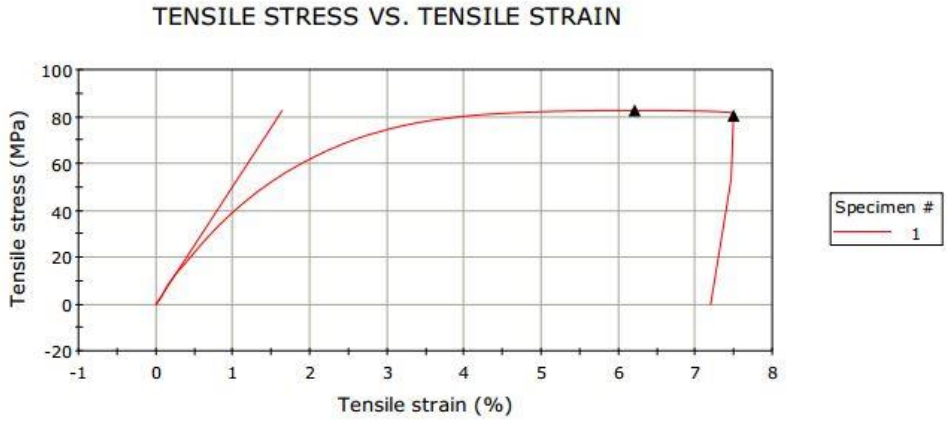
9. 80%PA6 + 20%GF (Sample 1)



	Modulus (E-modulus) (GPa)	Load at Yield (Offset 0.2 %) (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Tensile stress at Maximum Load (MPa)	Tensile strain at Maximum Load (%)	Tensile stress at Break (Standard) (MPa)
1	4.1328	1.4913	39.1422	77.1318	7.7217	74.7529

	Tensile strain at Break (Standard) (%)	Strain 1 at Break (Standard) (mm/mm)
1	10.4467	0.1045

10. 80%PA6 + 20%GF (Sample 2)



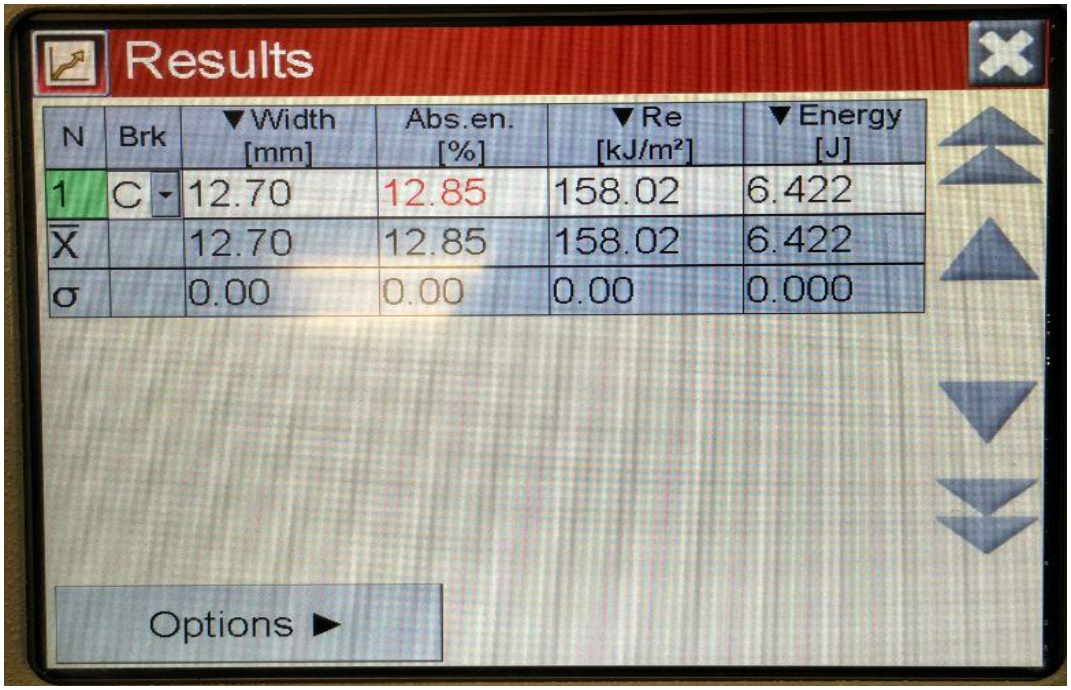
	Modulus (E-modulus) (GPa)	Load at Yield (Offset 0.2 %) (kN)	Tensile stress at Yield (Offset 0.2 %) (MPa)	Tensile stress at Maximum Load (MPa)	Tensile strain at Maximum Load (%)	Tensile stress at Break (Standard) (MPa)
1	5.0388	1.4447	37.9197	82.6548	6.2010	80.4761

	Tensile strain at Break (Standard) (%)	Strain 1 at Break (Standard) (mm/mm)
1	7.4837	0.0748

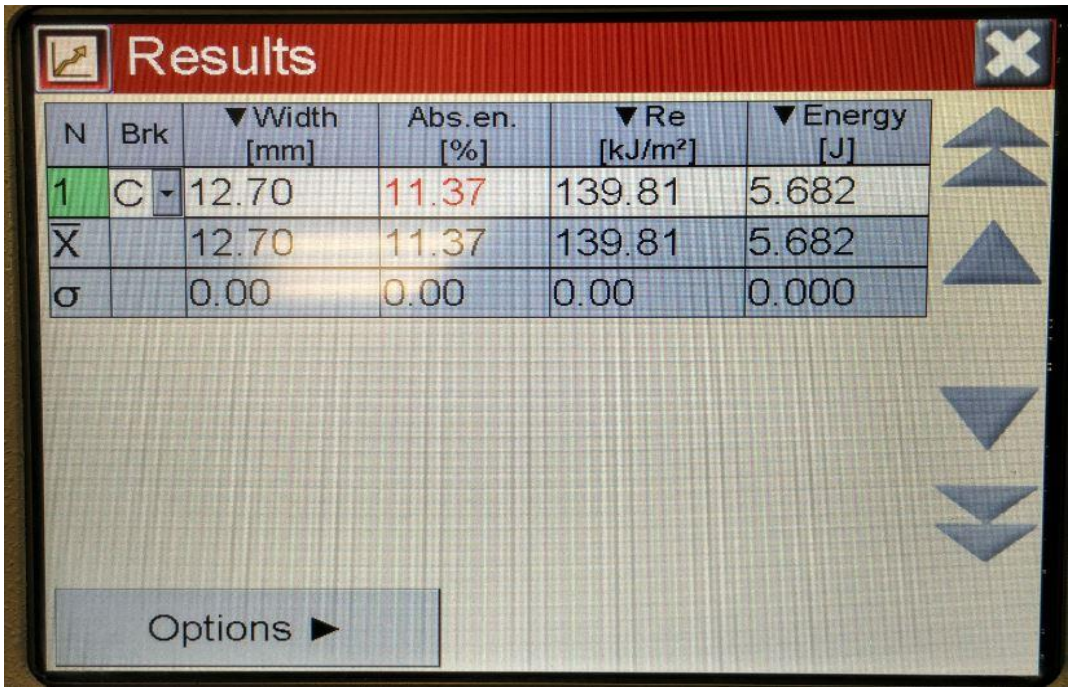
APPENDIX F

IMPACT TEST RESULT – 50 J

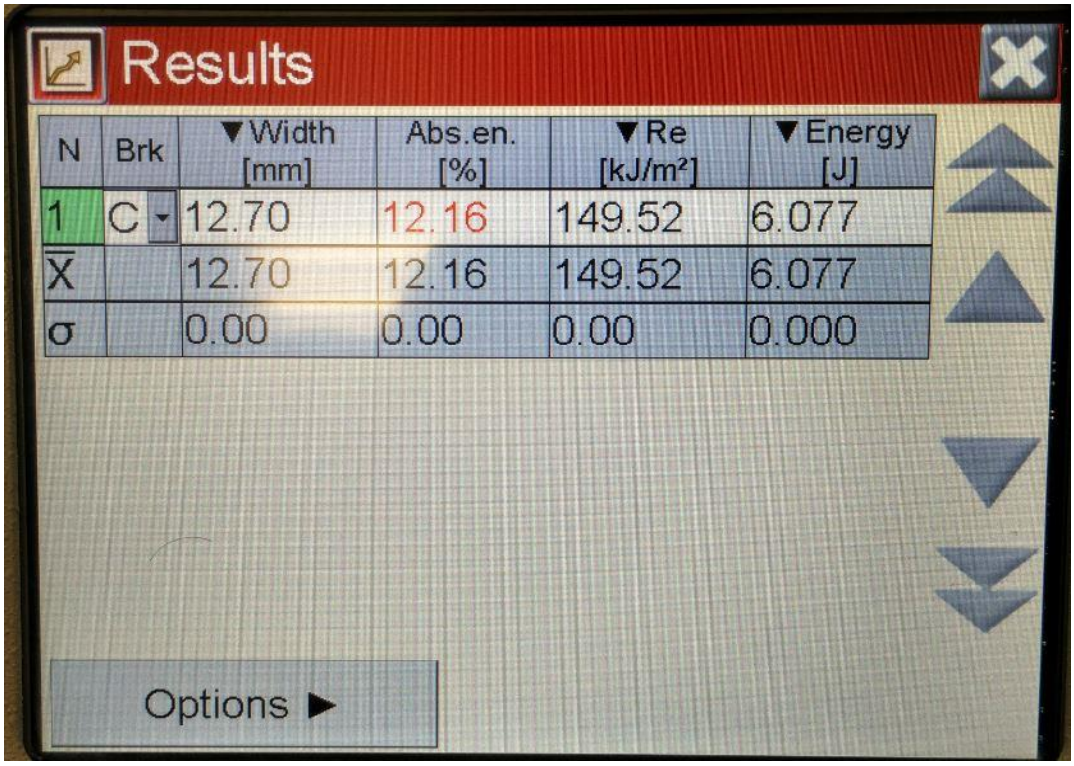
1. Pure Nylon, PA6 (Sample 1)



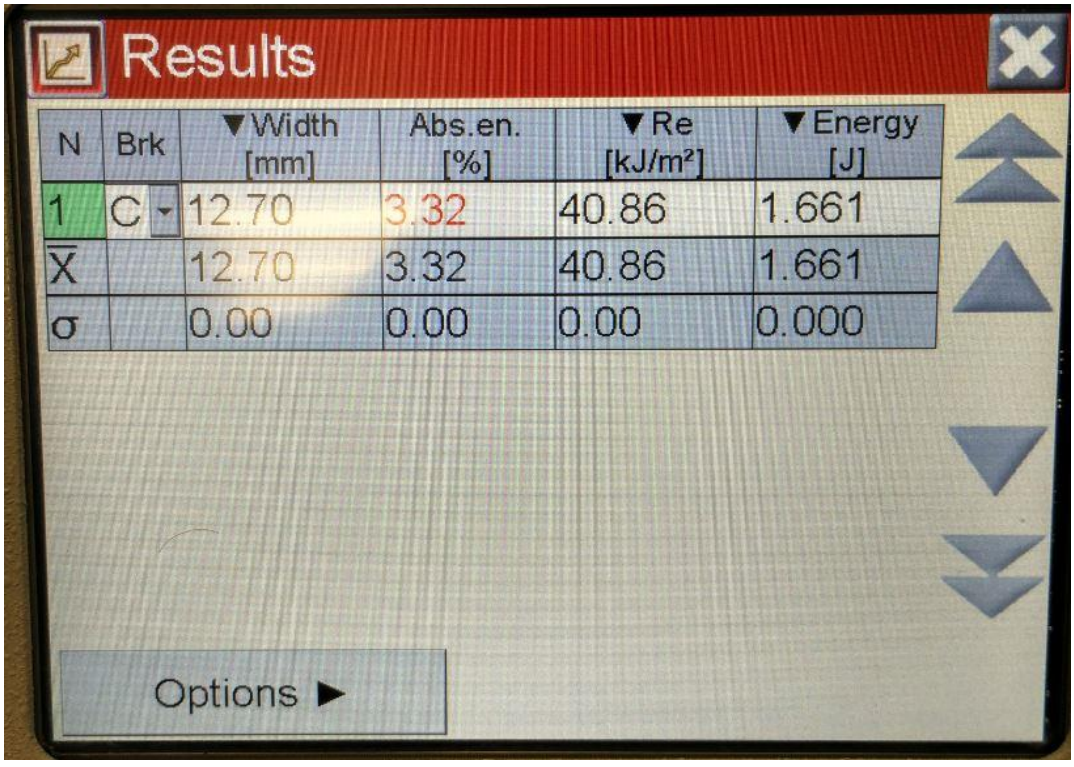
2. Pure Nylon, PA6 (Sample 2)



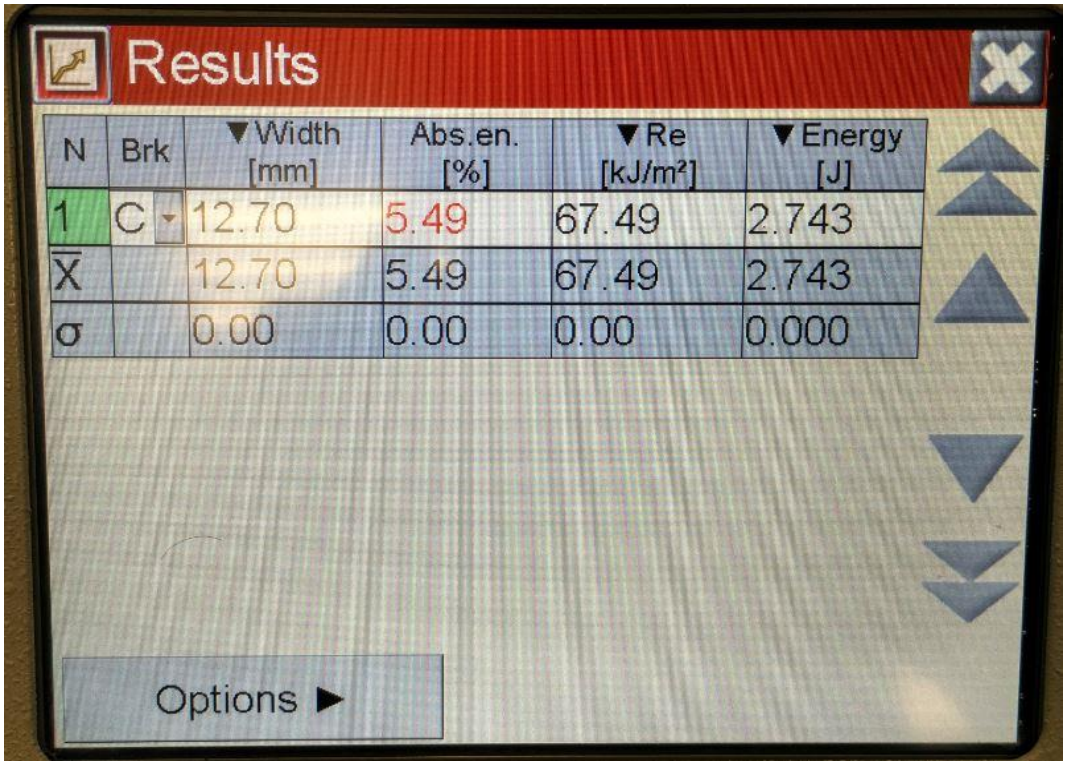
3. 95%PA6 + 5%GF (Sample 1)



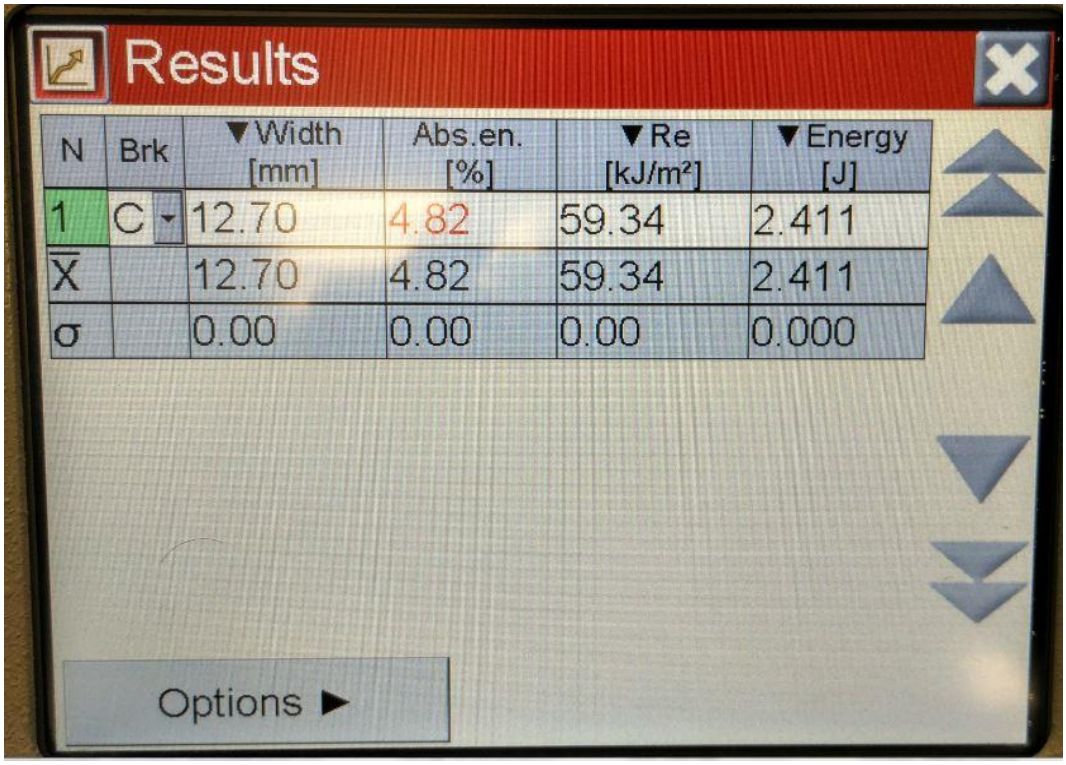
4. 95%PA6 + 5%GF (Sample 2)



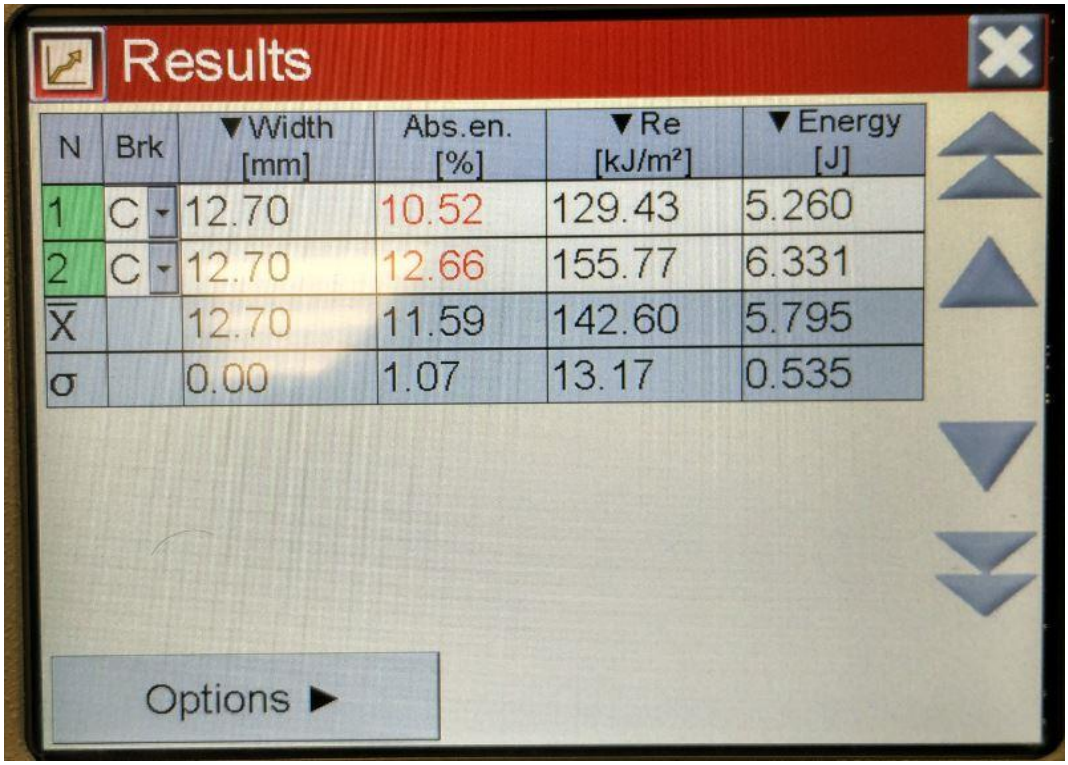
5. 90%PA6 + 10%GF (Sample 1)



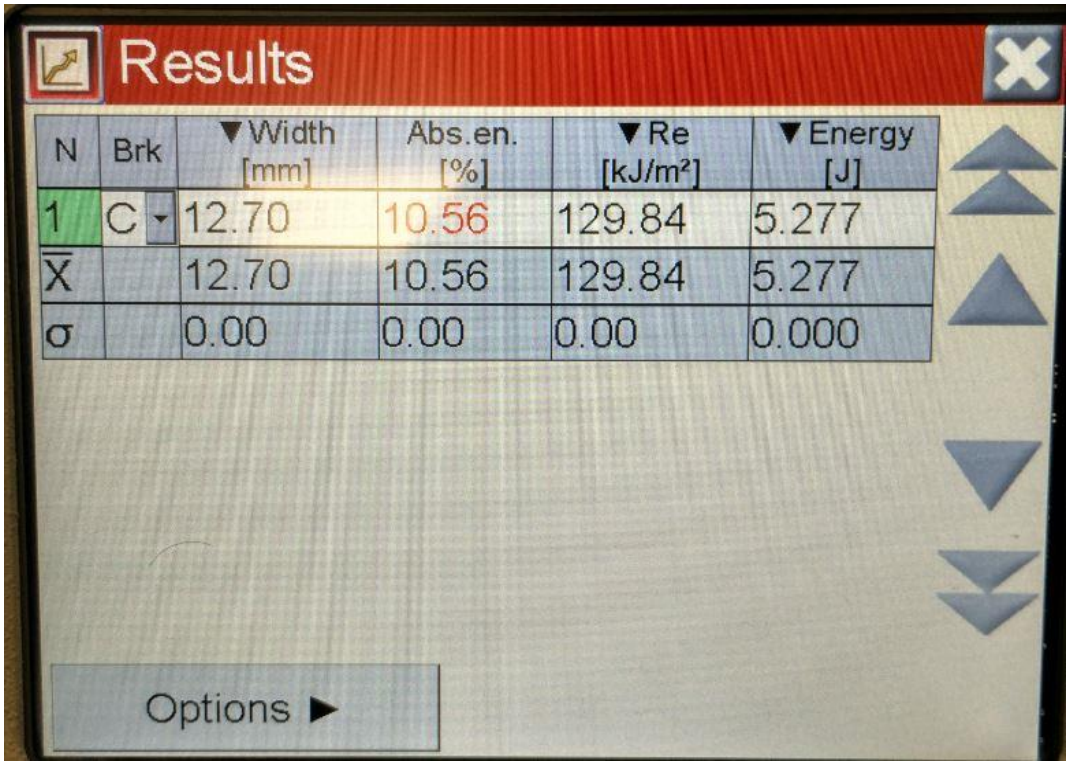
6. 90%PA6 + 10%GF (Sample 2)



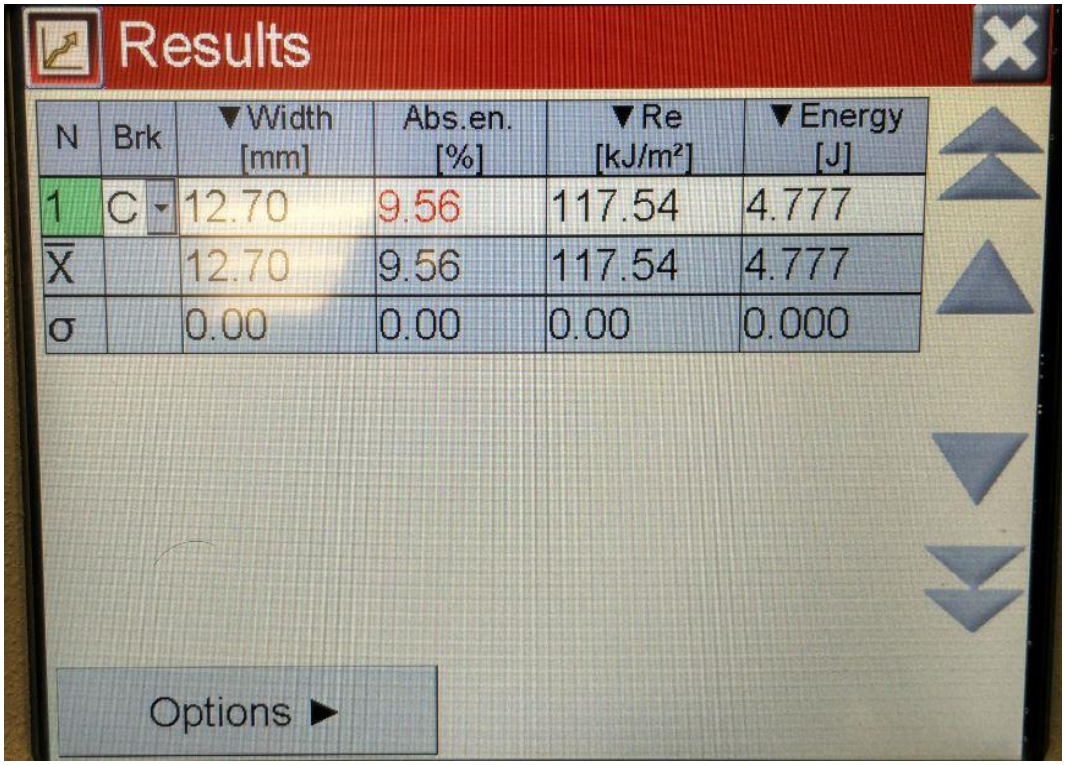
7. 85%PA6 + 15%GF (Sample 1 & 2)



8. 85%PA6 + 15%GF (Sample 3)



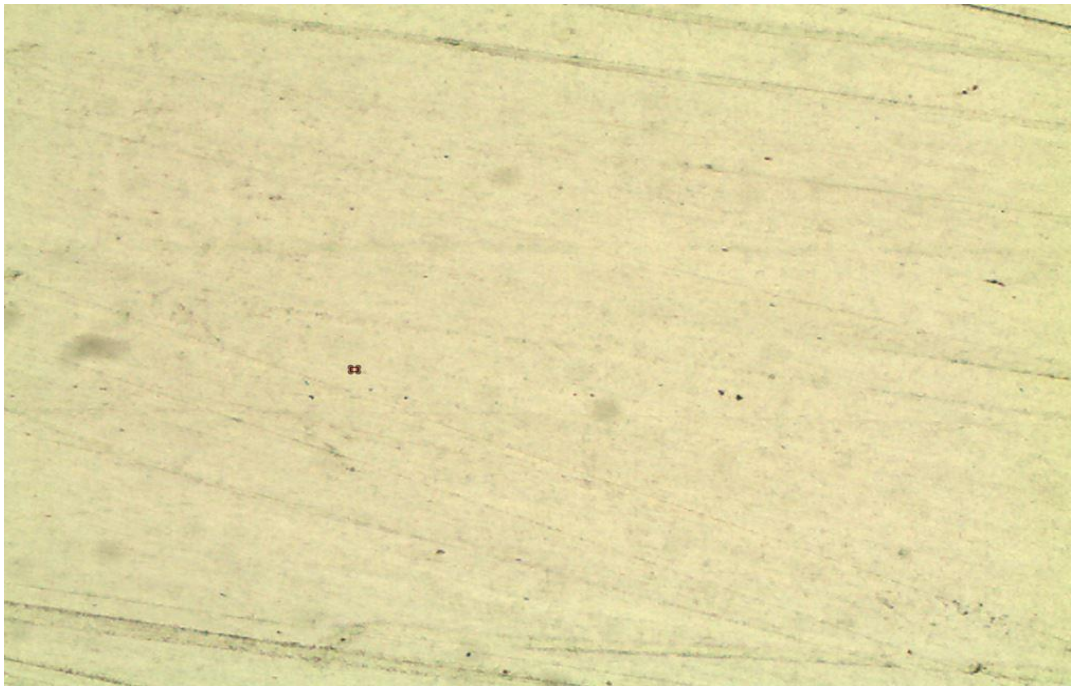
9. 80%PA6 + 20%GF (Sample 1)



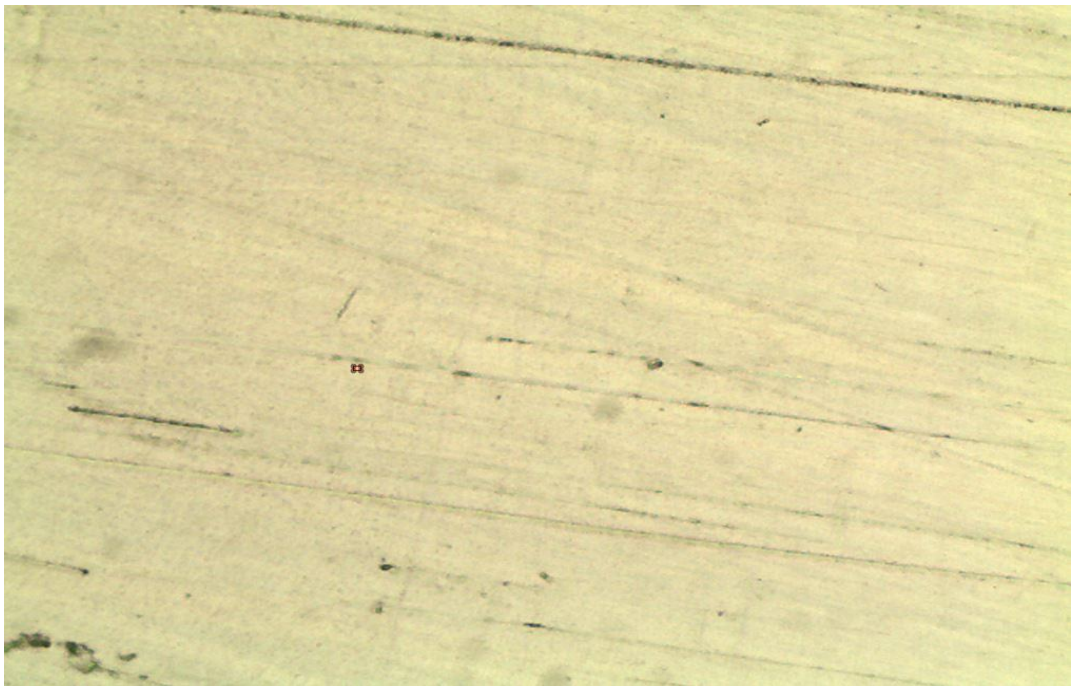
APPENDIX G

MICROSTRUCTURE ANALYSIS

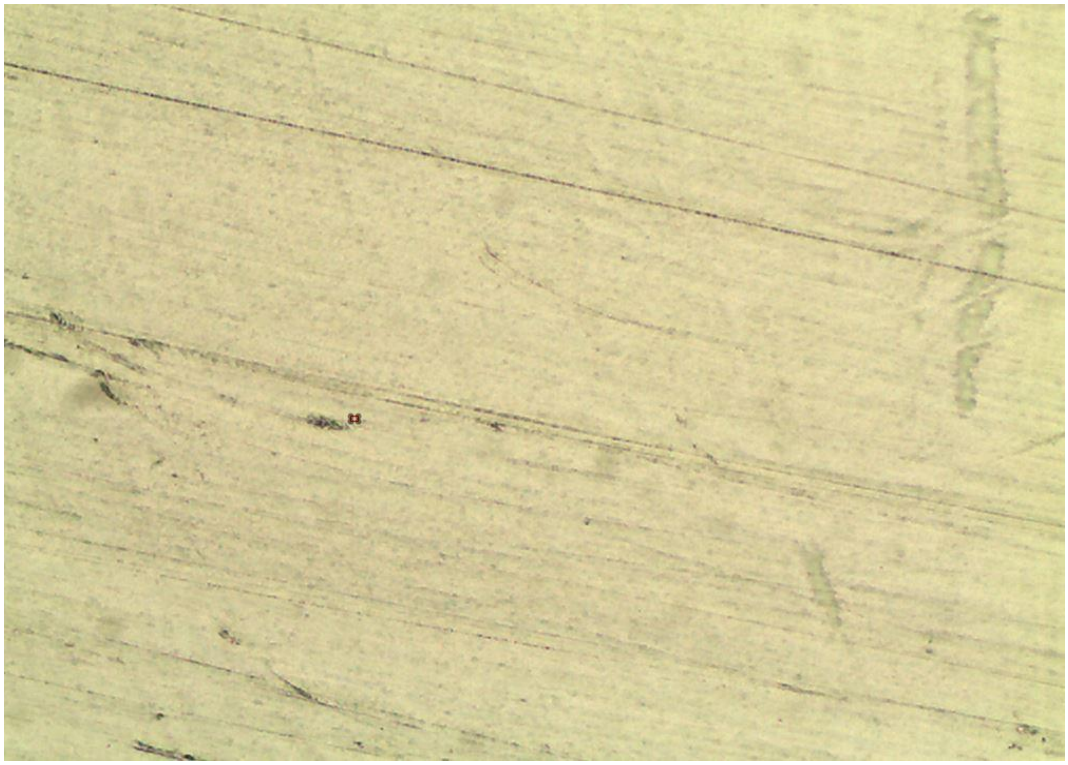
1. Pure Nylon, PA6 (Sample 1)



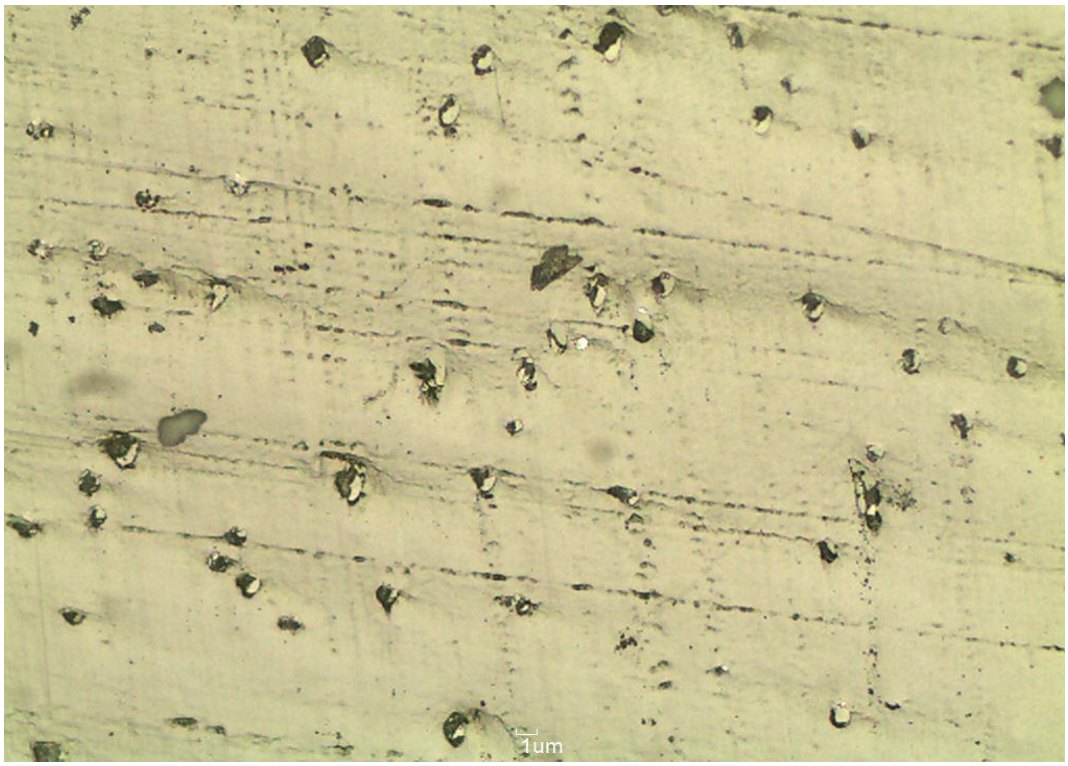
2. Pure Nylon, PA6 (Sample 2)



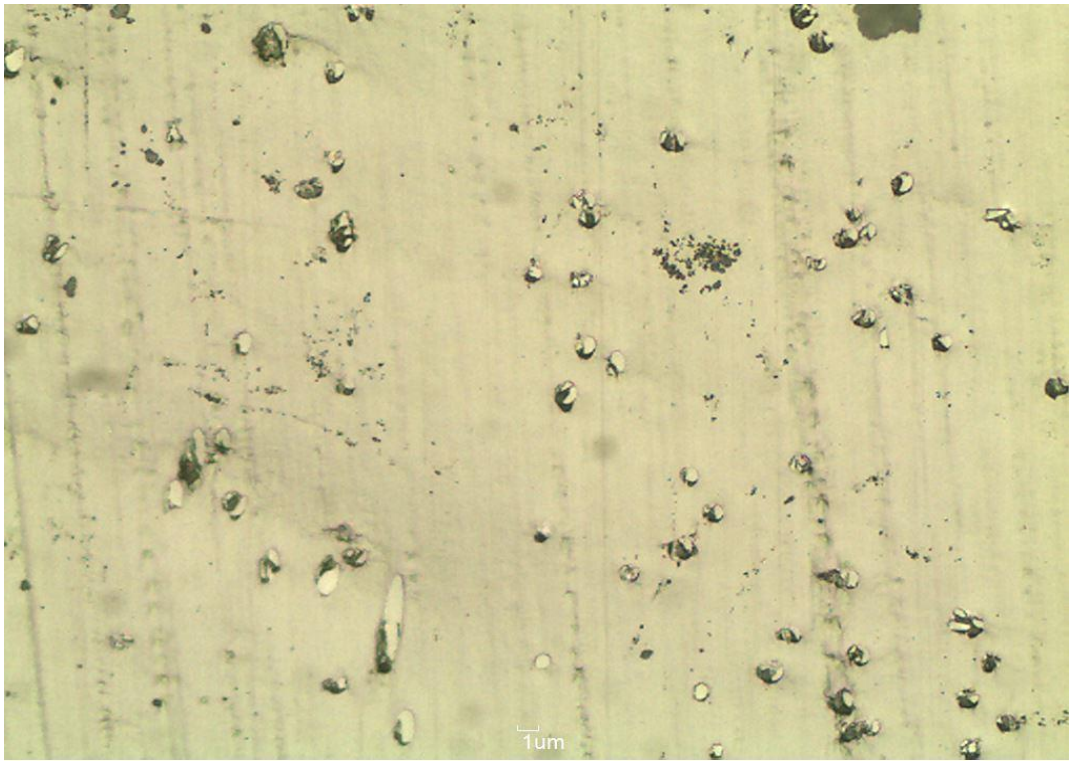
3. Pure Nylon, PA6 (Sample 3)



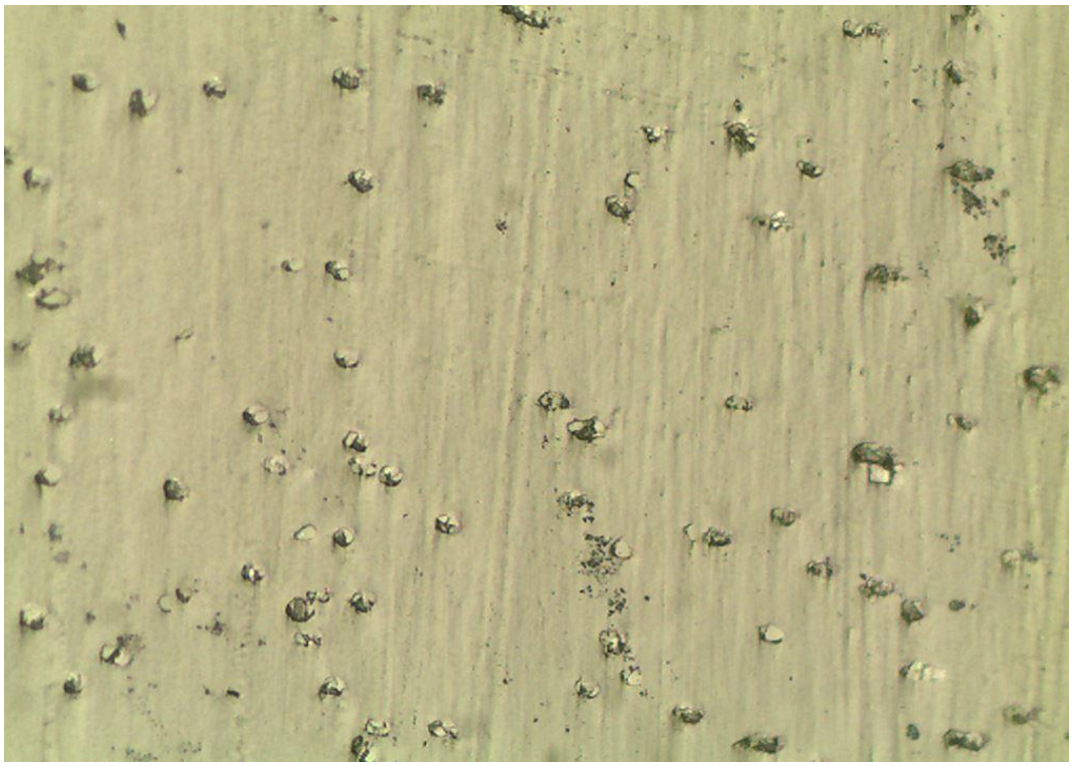
4. 95%PA6 + 5%GF (Sample 1)



5. 95%PA6 + 5%GF (Sample 2)

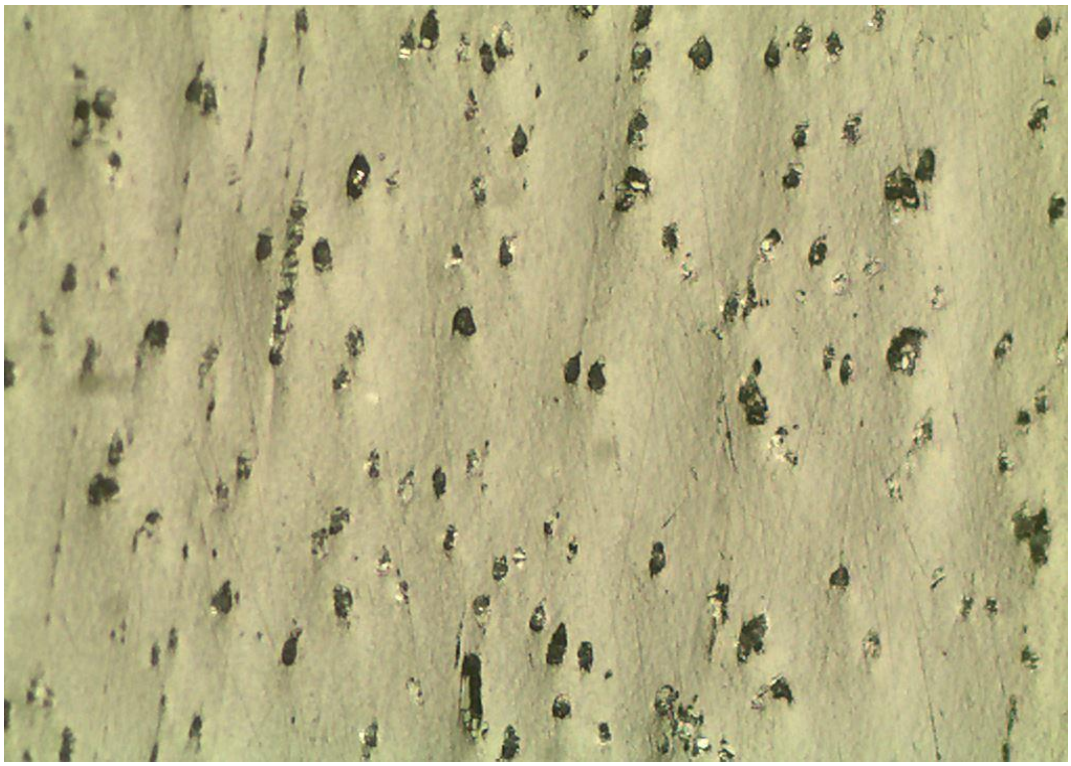


6. 95%PA6 + 5%GF (Sample 3)

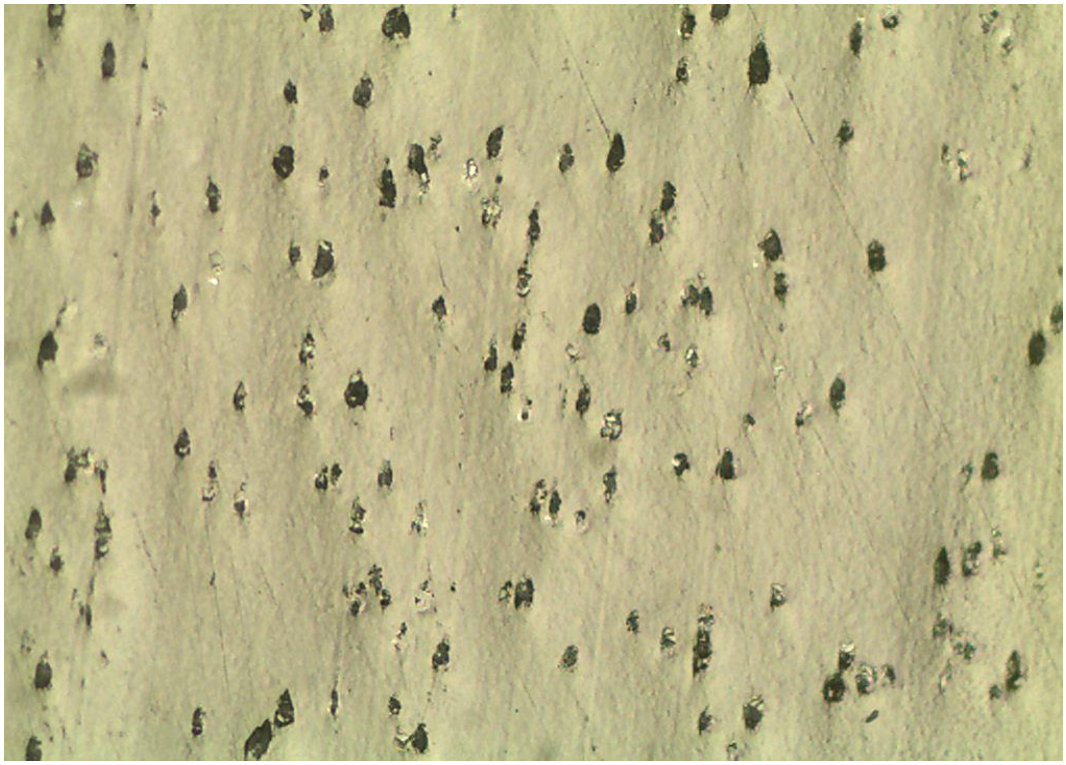


7. 90%PA6 + 10%GF (Sample 1)

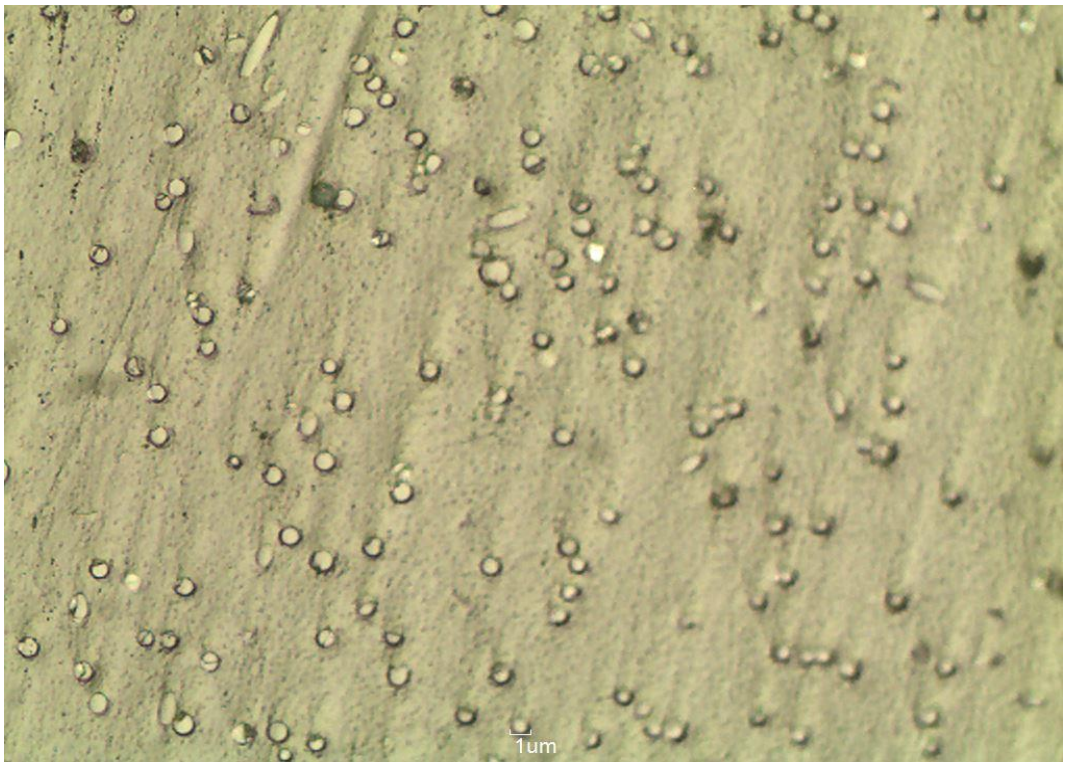
8. 90%PA6 + 10%GF (Sample 2)



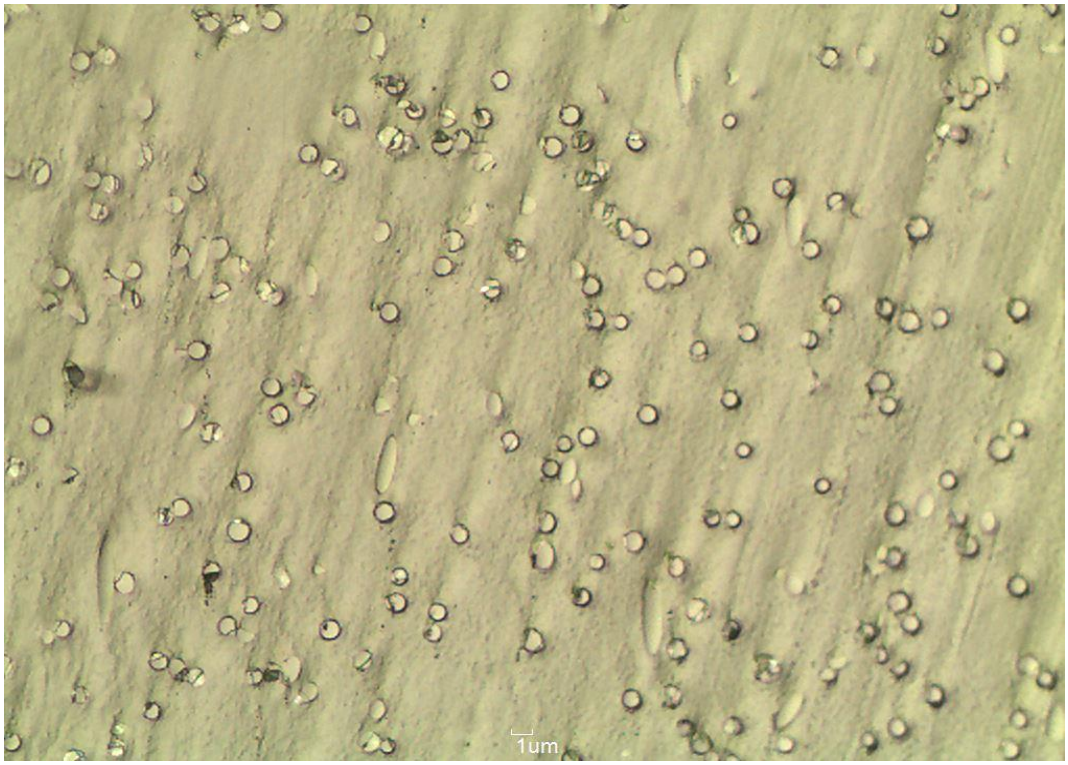
9. 90%PA6 + 10%GF (Sample 3)



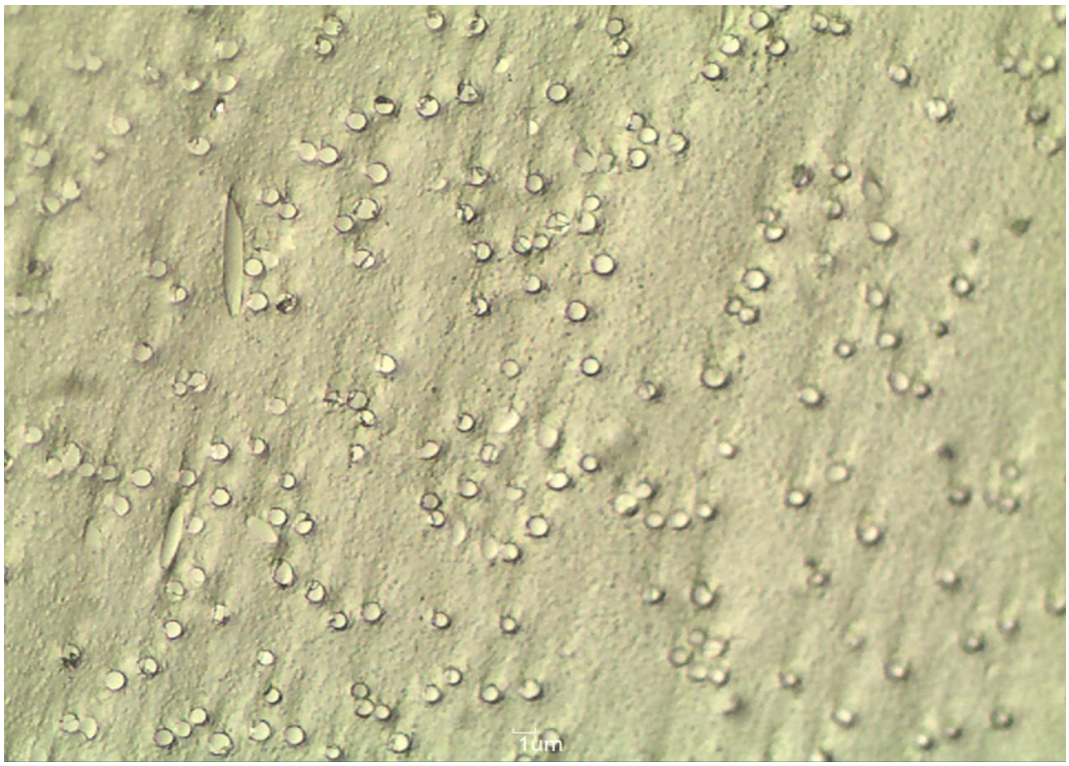
10. 85%PA6 + 15%GF (Sample 1)



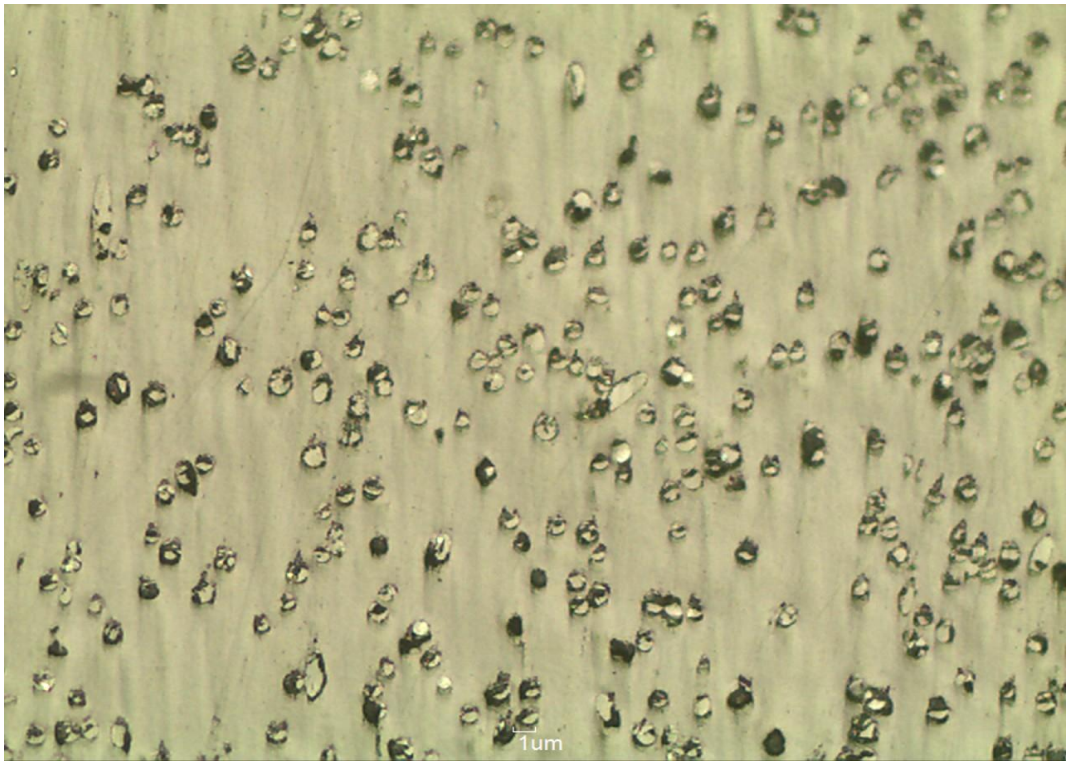
11. 85%PA6 + 15%GF (Sample 2)



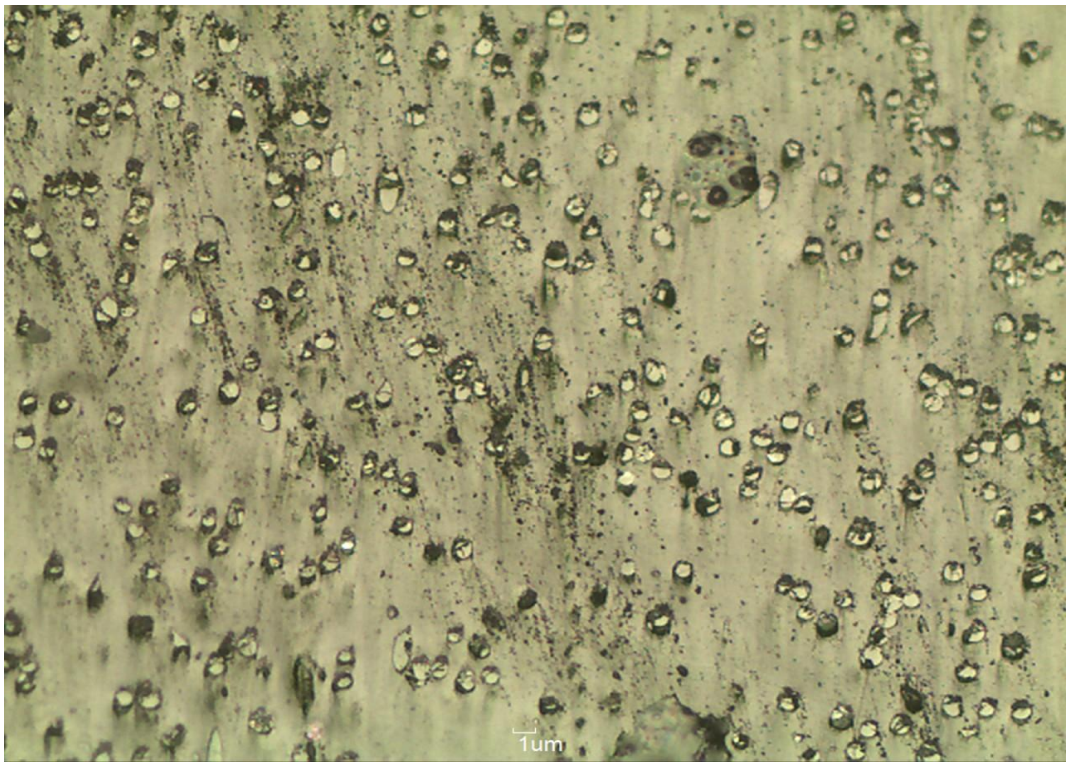
12. 85%PA6 + 15%GF (Sample 3)



13. 80%PA6 + 20%GF (Sample 1)



14. 80%PA6 + 20%GF (Sample 2)



15. 80%PA6 + 20%GF (Sample 3)