Mechanical Properties Study of Recycled Machinable Wax

By:

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Dissertation submitted in partial fulfilment of
the requirements for the
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(Mechanical Engineering)

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CERTIFICATION OF APPROVAL

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Mechanical Engineering Programme
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(MECHANICAL ENGINEERING)

Approved by,

____
(Assoc Prof Dr Mokhtar Awang)

UNIVERSITI TEKNOLOGI PETRONAS

TRONOH, PERAK

May 2013

CERTIFICATION OF ORIGINALITY

This certify that I am responsible for the work submitted in this project, that the original work is my own except as specified in the references and acknowledgements, and that the original work contained herein have not been undertaken or done by unspecified sources or persons.

____

MOHAMMAD YUSOF BIN ZALEY

ABSTRACT

Machinable wax has been widely used nowadays. It is formulated to absorb no moisture, provides an accurate and dimensionally stable tool for master pattern machining. Machinable wax is important when doing project which requires producing prototype. This wax could be used in order to minimize the cost due to losses of unreliable production processes. Machinable wax is a very hard wax that is reusable and would not gum up the cutting surfaces of the equipment or cutting tool but yet it is soft enough to machine quickly. However, even though machinable wax is reusable, the mechanical properties of the wax before and after recycled must be taken into consideration since it might be some changes. These changes can affect the integrity of the prototype. Therefore, the objective of this is to study the mechanical properties of recycled machinable wax. Tensile test is done on machinable wax using dog bone shaped as recommended by ASTM D 638. At first, machinable wax is cut into smaller block before it can be recycled. After the wax is recycled, again specimen is shaped and this may continue until wax is recycled for third times. Next, laboratory testing is done by using the specimen and the mechanical properties are recorded. Stress strain curve is drawn based on tensile test result (force against elongation). Then, mechanical properties are calculated using the stress strain curve.

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Table of Contents

CERTIFICATION OF APPROVAL ….………………………………………..i

CERTIFICATION OF ORIGINALITY………………………………………...ii

ABSTRACT...……….……………………………………………………………iii

ACKNOWLEDGMEN ……………………………………………………….iv

LIST OF FIGURES ………………………………....………………………vii

LIST OF TABLES..………………………………………………………….viii

LIST OF EQUATIONS ……………………………………………………….ix

CHAPTER 1 INTRODUCTION

1.1 Project Background ………………………………………..1

1.2 Problem Statement …..……………………………………2

1.3 Objectives …...……………………………………………2

1.4 Scope of Study...………………………………………......3

CHAPTER 2 LITERATURE REVIEW

2.1 Jewelry Industry ……………………………………….…4

2.2 Application of machinable wax ………………………….4

2.3 Mechanical Testing on Wax ……………………………...4

2.4 Standard used for testing ……………………………….…6

CHAPTER 3 METHODOLOGY

3.1 Project Flow Chart ………………………………………...7

3.2 Project Activity ……………………………………….....8

3.3 Key Milestone ……………………………………...16

3.4 Gantt Chart/ Study Plan …………………………………17

Chapter 4 RESULTS

4.1 New Machinable Wax …………………………………...18

4.2 1st time recycled ……………………………………….....21

4.3 2nd time recycled ………………..…………………….....24

4.4 3rd time recycle ……………………………………….…...27

4.5 Comparison of Mechanical Properties ……………………30

4.6 Discussion ………………………………………………..32

Chapter 5 Conclusion

5.1 Recommendation …………………………………………37

Bibliography………………………………………………………………40

List of figures

Figure 1: Machinable wax

Figure 2: Dog Bone Specimen

Figure 3: Project flow chart

Figure 4: Dog-bone dimension

Figure 5: Procedure for a new wax

Figure 6: Procedure for recycled wax

Figure 7: Stress-strain curve

Figure 8: Various regions and points on the stress-strain curve.

Figure 9: Key milestone

Figure 10: Gantt chart

Figure 11: Stress strain curve 1(new wax)

Figure 12: Stress strain curve 2(new wax)

Figure 13: Stress strain curve 3(new wax)

Figure 14: Stress strain curve 4(new wax)

Figure 15: Stress strain curve 5(new wax)

Figure 16: Stress strain curve 1(1st time recycled

Figure 17: Stress strain curve 2(1st time recycled)

Figure 18: Stress strain curve 3(1st time recycled)

Figure 19: Stress strain curve 4(1st time recycled)

Figure 20: Stress strain curve 5(1st time recycled)

Figure 21: Stress strain curve 1(2nd time recycled)

Figure 22: Stress strain curve 2(2nd time recycled)

Figure 23: Stress strain curve 3(2nd time recycled)

Figure 24: Stress strain curve 4(2nd time recycled)

Figure 25: Stress strain curve 5(2nd time recycled)

Figure 26: Stress strain curve 1(3rd time recycled)

Figure 27: Stress strain curve 2(3rd time recycled)

Figure 28: Stress strain curve 3(3rd time recycled)

Figure 29: Stress strain curve 4(3rd time recycled)

Figure 30: Stress strain curve 5(3rd time recycled)

Figure 31: Comparison of Young's modulus

Figure 32: Comparison of Tensile strength

Figure 33: Internal view of melting tank

Figure 34: Impurities

Figure 35: Air bubbles

Figure 36: Extensometer

Figure 37: Bending test

List of tables

Table 1: Specimen dimension

Table 2: Young's modulus and Tensile strength (new wax)

Table 3: Young's modulus and Tensile strength (1st time recycled)

Table 4: Young's modulus and Tensile strength (2nd time recycled)

Table 5: Young's modulus and Tensile strength (3rd time recycled)

Table 6: Average of Young’s modulus

Table 7: Average of Tensile strength

List of Equations

Equation 1: Stress

Equation 2: Strain

Equation 3: Elastic Modulus

Equation 4: Percentage of reduction for 1st time recycled (Young’s modulus)

Equation 5: Percentage of reduction for 2nd time recycled (Young’s modulus)

Equation 6: Percentage of reduction for 3rd time recycled (Young’s modulus)

Equation 7: Percentage of reduction for 1st time recycled (Tensile strength)

Equation 8: Percentage of reduction for 2nd time recycled (Tensile strength)

Equation 9: Percentage of reduction for 3rd time recycled (Tensile strength)

CHAPTER 1

INTRODUCTION

1.1 PROJECT BACKGROUND

Machinable wax is a type of material used for the purpose of training and making prototype which normally is ferrous and non-ferrous materials and theirs alloys. Generally, prototypes are made of mild steel and aluminium but there are other materials used as well such as alloy steel, cast iron, copper alloys, phosphor bronze, magnesium alloy, plastic and other composite materials. Besides, computer controlled machining and designing methods have revolutionized manufacturing worldwide. With these advancements has raised a growing need to evaluate data "up front" more economically and safety, in less time and with accurate results. Due to these concerns, the materials used in the "prove-out" phase have become a major factor. Unlike metal, plastic and wood, wax is very machinable, dimensionally stable, safe to work with and very economical because it is reclaimable and remachinable. Addition, it is not only realized significant time savings in the prove-out project, but able to produce a low-cost prototype that could be assembled to check dimensions and verify the CAD/CAM program for production.

Machinable wax as shown in figure 1 is a type of material used for model making and prototyping, since it is very easy to machine and can be formulated so that it can take fine detail. This wax is a smart choice in selecting material to work with when a fine prototype parts is needed before risking time and materials on a new design. For many years, machinable wax has been the standard material used for proofing Computer Numerical Control (CNC) programming because it machines easier than urethane tooling boards or metals without sacrificing quality of finish, surface detail, or accuracy of dimension. Additionally, the properties of machinable wax such as non-abrasive and self-lubricating give it a huge advantages where it can be machined quickly with minimize or zero tool wear and also requires no messy coolant and lubricant.

When comes to environmental concern, machinable wax is much safer because unlike when machining plastic tooling boards, the cutting of machinable wax does not create excessive dust, hot chips and a strong odor. On top of that, the soft curls that are produced from machining operations may be melted and reclaimed to be used again. Thus, machinable wax can be classified as economical material and the ideal choice for many tooling applications.

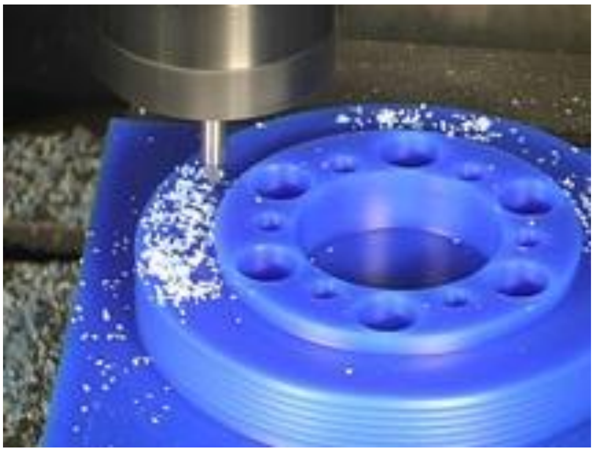


Figure 1: Machinable wax

1.2 PROBLEM STATEMENT

Machinable wax have been used widely in real life such as training aid material for education purposes, CNC systems set-up and demonstration, proofing CNC machining programs and producing accurate molds and prototypes. This wax has been used mainly due to the properties which is non-abrasive, user friendly, etc. Yet, it is very expensive material to lose in a burn out furnace. Due to this, the machinable wax is designed to be reused. However, there is doubt when it is being recycled whether its mechanical properties remain the same as before it is recycled.

1.3 OBJECTIVES

The main purpose is to find out the mechanical properties of machinable wax after it has been recycled. The mechanical properties of recycled machinable wax will be compared with the mechanical properties of machinable wax before it is recycled. The data analyzing shall be conducted after all specimens have been undergone the tensile test.

1.4 SCOPE OF STUDY

This project uses machinable wax which available in Universiti Teknologi PETRONAS (UTP) laboratory. Series of experiments are conducted by using dog bone shape specimens as shown in figure 2. This shape of specimen is recommended by ASTM D 638 and it is a standardized sample cross-section where it has two shoulders and a gauge (section) in between. The shoulders are designed large so they can be readily gripped, whereas that gauge section has smaller cross-section to allow deformation and failure occur in this area. These specimens will undergo tensile test, also known as tension testing in which the specimens are subjected to a controlled tension until failure. The properties that would directly be measured via a tensile test are ultimate tensile strength, maximum elongation and reduction in area, etc. From these measurements, other properties can also be determined which is Young’s modulus, tensile strength, Poisson’s ratio, yield strength and strain-hardening characteristic. The specimens also may undergo hardness test and other testing if needed.

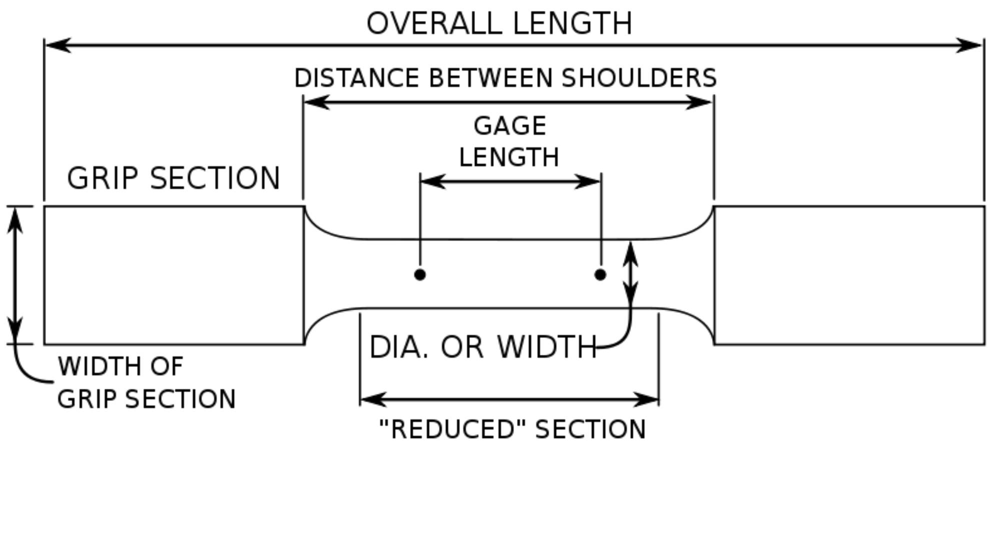


Figure 2: Dog Bone Specimen

Chapter 2

Literature Review

2.1 Jewelry Industry

Material known as wax is widely used in jewelry industry. The first known use of wax for modelling was the sculpting of bronze and jewellery with the lost-wax casting process also called by its French name, circe perdue. The process is illustrated in the scenes on the ‘Berlin Foundry Cup’, an early 5th century BC Greek cup [1]. This showed that wax contribute a lot to the jewelry industry.

2.2 Application of machinable wax

Wax generally used for making prototype, model and some used for molding. For instance, machinable wax was used to form two mold halves in. This is because this wax can give a desirable surface finish and easy to create [2]. Next, Kroo et al used machinable wax in their project where they need to create a prototype [3]. Therefore, they decided to use machinable wax since it causes little tool wear and smallest cutters can be used efficiently. When it comes to modeling, machinable wax is the most suitable material to be used. Research project by Ujjwal Singh, the pattern presented to the subject consisted of blocks, each of which had a ridge or was smooth [4]. The blocks were made with machinable wax blocks with a ridge milled onto its surface. The surface of the wax blocks were first smoothed down. Then a ridge, whose height varied from block to block, was milled onto the surface using small end mill cutters.

2.3 Mechanical Testing on Wax

Machinable wax also can be categorized as polymer since it fulfills some characteristics of polymer. Therefore, review about testing on polymers has been done. Craig et al. showed how important the strength properties of waxes in which used to compound dental and commercial casting waxes [5]. This is due to these waxes are subjected to forces developed during the setting of investments and also to temperature changes developed during the setting reactions. The modulus of elasticity, proportional limit, and compressive have been studied and measured on three principal natural waxes which is carnauba, paraffin and beeswax used for compound casting waxes and on several commercial dental casting waxes. The specimens have been tested at desired temperature in order to study the strength properties of the waxes. Morgan et al. also studied the mechanical properties of waxes and they measured these properties as a function of temperature [6]. Similarly, they used a variety of methods and techniques to identify the properties. In their study, the coefficient of friction of waxes was measured and compared with other samples.

Meanwhile, Fielder used a three-point bending test for measuring the mechanical properties of wax such as modulus of elasticity, strain at break point, load at break point and maximum load [7]. Enamul et al. studied the physical and mechanical properties of natural and synthetic waxes where it shows the microstructural weakening begins when a load whether compressive or tensile is applied to any material [8]. This study explores the potential of diameter stress-strain behavior of natural beeswax and synthetic paraffin wax samples by providing the uniaxial compressive test to measure their strength. The stress-strain curves have been constructed to show the difference of mechanical properties between beeswax and paraffin wax samples.

Kotsiomiti and McCabe did a research which to measure mechanical properties for 26 blends of paraffin wax, beeswax and inorganic filler for dental applications [9]. For this research, they measured the dental waxes properties such as plastic-flow stress, linear thermal expansion, elastic modulus and flexural strength. They used several methods to measure these properties. For plastic-flow tests, it was conducted in accordance with the corresponding ISO specification [10]. Based on normal procedure, the flow test measurements were conducted by calculating the percent height decrease of cylindrical specimens of 10 mm diameter and 6 mm height. These specimens then were kept at the testing temperature for 10 min under a load of 2 kg.

2.4 Standard used for testing

According to ASTM International [11], ASTM D638 is one the most common used for plastic strength specifications. It is also covers the tensile properties of unreinforced and reinforced plastics. ASTM's plastics standards are instrumental in specifying, testing and assessing the physical, mechanical and chemical properties of a wide variety materials and products that are made of plastic and its polymeric derivatives. During processing, these synthetic or semi synthetic organic solids have a very malleable characteristic that allows them to be molded into an assortment of shapes, making them very suitable for the manufacture of various industrial products. The ASTM allows plastics manufacturers and end-users to examine and evaluate their material or product of concern to ensure quality and acceptability towards safe utilization.

Meanwhile, Tabi on the analysis of processing and usage of injection molded biodegradable polymers made of starch and poly (lactic acid), a tensile test have been performed by right of MSZ EN ISO 527-1:1999 standard and Zwick Z020 universal tensile testing machine was used quipped with a type Zwick BZ 020/TN2S force measuring cell where the measuring error of the cell is 30 N below 4kN load [12]. The dumbbell shaped specimen was used as accordance ISO 3176A standard. The similar testing also been done by Keresztes et al [22]. They measured the tensile properties of the polymers according to MSZ EN ISO 527 standard with a type of INSTRON 5581 tensile machine.

Chapter 3

Methodology

3.1 Project Flow Chart

The process flow of this project is based on the figure 3.

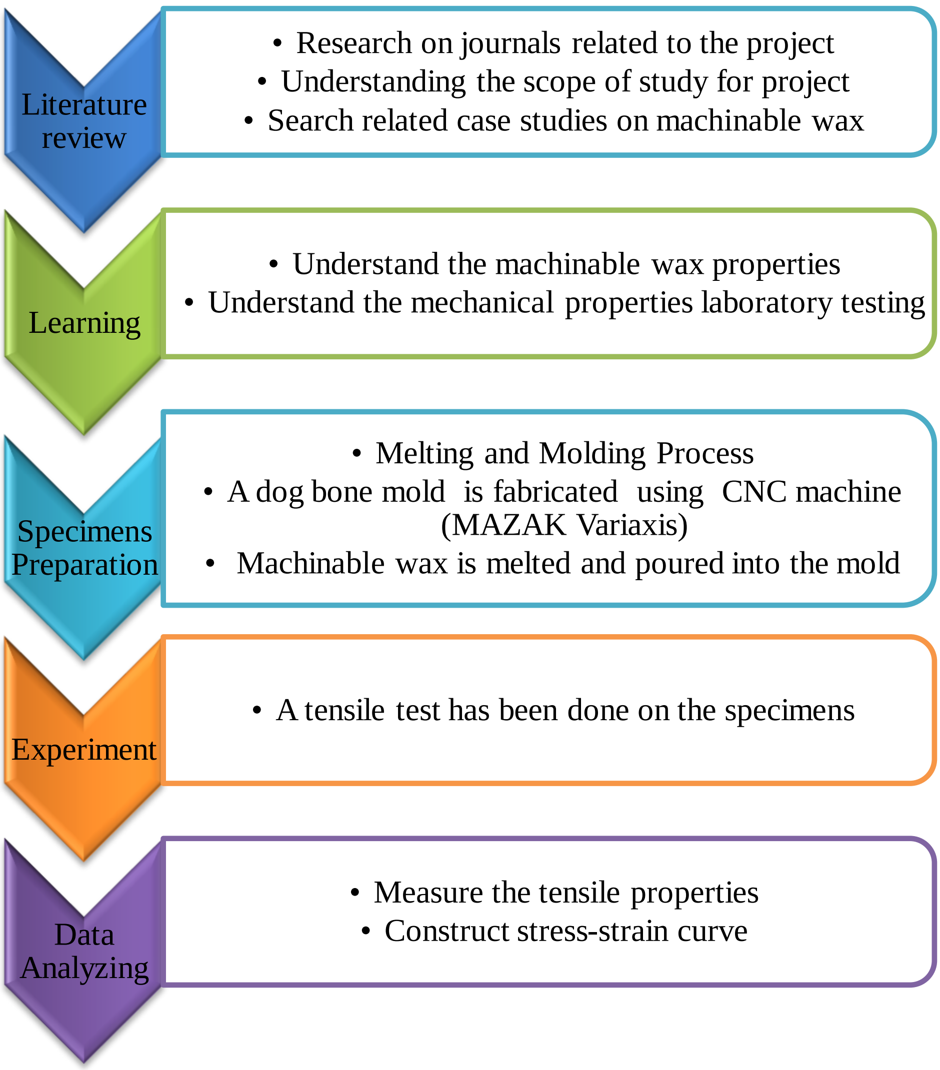


Figure 3: Project flow chart

The methodology used in conducting this research project is based on the discovery and experiment. First step in the methodology is gather all the related information about machinable wax from the journals and engineering books and compiled them.

By doing this, the important information may be known such as are there any experiment have been done before and the usage scale in jewelry industry. The research continues with determining the parameters as referred to American Society for Testing and Material. For this experiment, the ASTM D638 is most likely being referred because it provides the recommended standard test method for tensile properties of plastics. The parameters are selected as recommended by ASTM D638. Tensile properties may vary with specimen preparation and with speed and environment of testing. Consequently, where precise comparative results are desired, these factors must be carefully controlled. [13] Additionally, method of preparation of the material also shall be taken care especially when comparative tests of materials per se are desired. The samples must be prepared in exactly the same way, unless the test is to include the effects of sample preparation.

3.2 Project Activity

3.2.1 Specimens Preparation For New Machinable Wax

For the first specimen (original wax), the machinable wax is cut from large block into smaller block so that it can be machined into dog-bone shape as shown in figure 4 by using Computer Numerical Control (CNC) machining. The dimensions of the specimen are per recommended by ASTM D638. These dimensions as shown in refer table 1 should be approximately the same for each sample. Also, the sample must free from any defects such as impurities, crack or air bubble because the flaws or defects may affect the result. For this project, dog-bone shape type 1 will be used where recommended the thickness, T is 7mm and under.

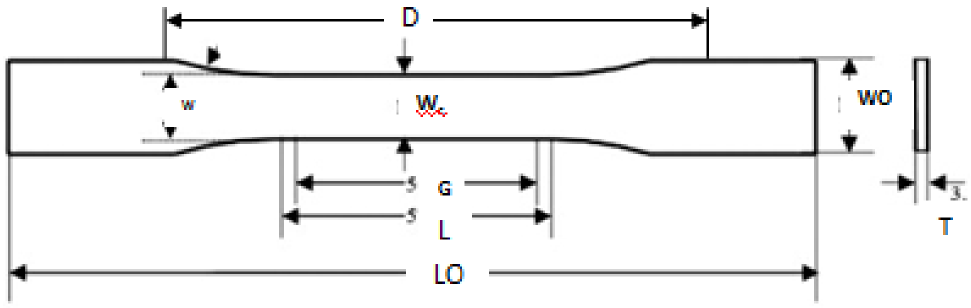


Figure 4: Dog-bone dimension

Table 1: Specimen dimension

Dimensions	Value (mm)
W-width of narrow section	13
L-length of narrow section	57
WO-width overall	19
LO-length overall	165
G-gage length	50
D-distance between grips	115
R-radius of fillet	76
T-Thickness	5.5

As referred to table 1, the dog bone shaped has overall length (LO) of 165mm, width overall (WO) is 19mm and the thickness (T) is 5.5mm. The gage length (G) of the specimen is 50mm, width of narrow section (W) is 13mm and length of narrow section (L) is 57mm.

- Create dog bone shaped using CNC machine (MAZAK Variaxis)

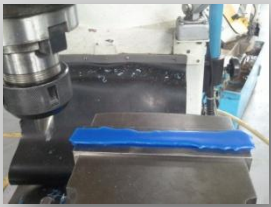
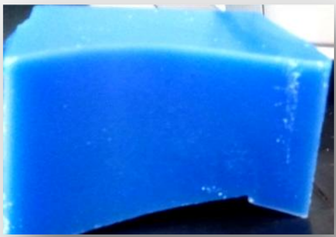
 	• Manual cutting using saw
 	• Specimen undergo milling process for surface finish and thickness
	• Measure the specimen dimension to ensure the dimensions is approximately to the designed dimensions • Check for any flaws on the specimen
	• Tensile Test

Figure 5: Procedure for a new wax

For procedure for new machinable wax is shown in figure 5. The first step is cut the large block into smaller block. Then, the dog bone shaped is produced by using Computer Numerical Control (CNC) named as MAZAK Variaxis. After it is done, the dog bone shaped is removed from the block by using small saw. Next, the specimens undergo milling process for surface finish and also for require the design thickness. The tensile test is done after the specimens meet the required dimensions.

3.2.2 Specimens Preparation For Recycled Machinable Wax

Meanwhile, a slightly different procedure shall be followed for recycled wax as shown in figure 6. After machinable wax has been cut into smaller block, it will be put into furnace or cookware and be heated between 150^{o} C and 160^{o} C. The temperature of this melting process must be controlled to avoid overheat temperature because too high temperature may affect the properties of machinable wax. Next, when the wax is completely melt, the wax is pour into the dog bone shaped mold and let it cooled at room temperature. Once specimens have completely cooled down, it will undergo milling process to get a good surface finish. After that, the specimens will be measured to ensure the dimensions are approximately to the designed parameters and also checked for any flaws. Finally, tensile shall be done as recommended by the ASTM D638 standard.

	• Cut a large block of machinablewax into smaller block
 	• Put the machinable wax into the furnace/cookware • Melt the machinable wax at between 150^{o}C and 160^{o} C
 	• Pour the wax into the container or mold • Let it to cool slowly for at room temperature

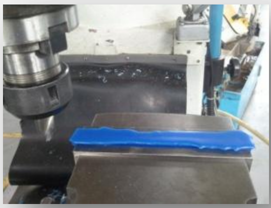
 	• Specimen undergo milling process for surface finish and thickness
	• Measure the specimen dimension to ensure the dimensions is approximately to the designed dimensions • Check for any flaws on the specimen
	• Tensile Test

Figure 6: Procedure for recycled wax

3.2.3 Instrument Setup

Make sure the proper 10kN load cell is installed. To switch load cells, make sure the machine is off. Then, unscrew the bolts and remove using the handle. Make sure to plug the new load cell into the port behind the machine. Next, calibrate the load cell by clicking on the button in the upper right hand corner. Make sure all loads are removed from the load cell and click calibrate. After that, install the correct type of clamps for the testing. Install the clamps using the pins. Also install height brackets if needed. Zero the load once the clamps are installed. Press the up and down arrows on the controller until the clamps are just touching. Press the reset gauge length button at the top of the screen to zero the position of the clamps. Use the up and down arrows until the clamps are about 100 mm apart. This is a typical gauge length for the dog bone samples. Then, place the polymer sample between the grips of both the tensile test machine. While holding the sample vertically with one hand, use another hand to turn the handle of the top grip in the closing direction as tightly as possible. (The specimen should be gripped such that the two ends of the specimen are covered by the grip, approximately 3 mm away from its gage-length. It is important that the specimens are tightly gripped onto the specimen grips to prevent slipping, which will otherwise result in experimental errors). Make sure that the specimen is vertically aligned, if not a torsional force, rather than axial force, will result. Next, turn the bottom handle in the "close" direction as tightly as possible. Visually verify that the sample is gripped symmetrically at its two ends. Zero the extension by pushing zero extension buttons at the top of the screen. Also zero the load if needed. Wait for a few seconds to let the computer return its value to zero.

3.2.4 Tensile Test

The tensile test is start by entering the geometry of the sample before starting. Click on the Start button. Both the upper and bottom grips will start moving in opposite directions according to the specified pulling rate. Observe the experiment at a safe distance (about 1.5 meters away) at an angle and take note of the failure mode when the specimen fails. (NOTE: Be sure to wear safety glasses. Do not come close to equipment when the tensile test is running). Finally, a plot of tensile stress (MPa) versus tensile strain (mm/mm) will be generated in real-time during the experiment.

3.2.5 Result and Analysis

For analytical purposes, a plot of stress (σ) versus strain (ε) is constructed during a tensile test experiment, which can be done automatically on the software provided by the instrument manufacturer. Stress, in the metric system, is measured in N/m^2 or Pa. From the experiment, the value of stress is calculated by dividing the amount of force (F) applied by the machine in the axial direction by its cross-sectional area (A), which is measured prior to running the experiment. Mathematically, it is expressed in Equation 1. The strain values, which have no units, can be calculated using Equation 2, where L is the instantaneous length of the specimen and L_0 is the initial length.

$$\sigma = \frac{F}{A} \qquad \text{(Equation 1)}$$

$$\varepsilon = \frac{L - L_0}{L_0} \qquad \text{(Equation 2)}$$

A typical stress-strain curve would looks like in figure 7 [14]. In reality, not all stress-strain curves perfectly resemble the one shown in figure 8. When a material reaches its ultimate stress strength of the stress-strain curve, its cross-sectional area reduces dramatically, a term known as necking. When the computer software plots the stress-strain curve, it assumes that the cross sectional area stays constant throughout the experiment, even during necking, therefore causing the curve to slope down. The "true" stress-strain curve could be constructed directly by installing a "gauge," which measures the change in the cross sectional area of the specimen throughout the experiment.

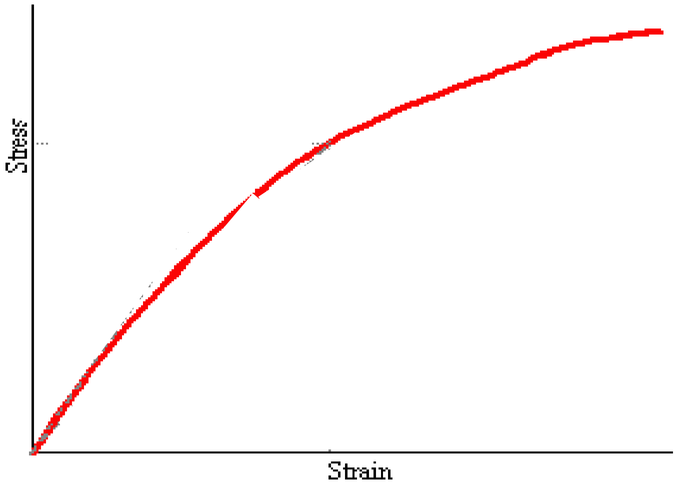


Figure 7: Stress-strain curve

Figure 8 also shows that a stress-strain curve for ductile material which divided into four regions: elastic, yielding, strain hardening (commonly occurs in metallic materials), and necking. The area under the curve represents the amount of energy needed to accomplish each of these "events." The total area under the curve (up to the point of fracture) is also known as the modulus of toughness. This represents the amount of energy needed to break the sample, which could be compared to the impact energy of the sample, determined from impact tests. The area under the linear region of the curve is known as the modulus of resilience. This represents the minimum amount of energy needed to deform the sample.

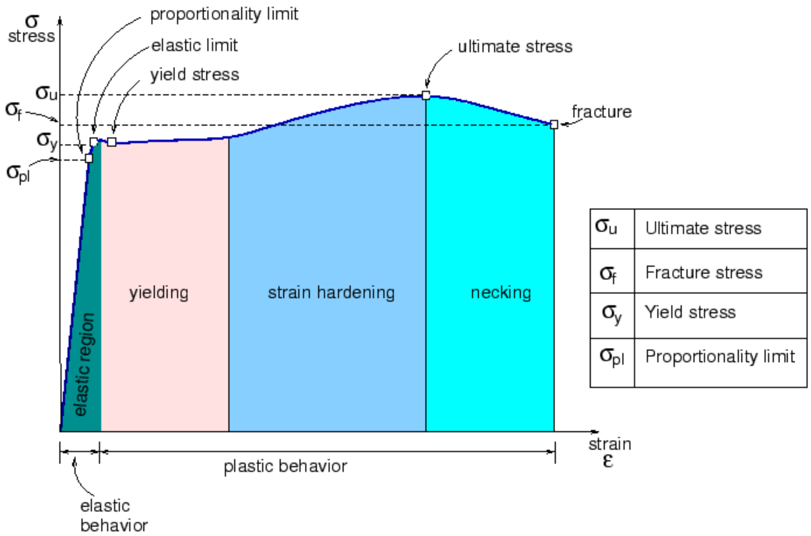


Figure 8: Various regions and points on the stress-strain curve.

The linear region of the curve of figure 8, which is called the elastic region (past this region, is called the plastic region), is the region where a material behaves elastically. The material will return to its original shape when a force is released while the material is in its elastic region. The slope of the curve, which can be calculated using Equation 3, is a constant and is an intrinsic property of a material known as the elastic modulus, *E*. In metric units, it is usually expressed in Pascals (Pa).

$$E = \frac{\sigma}{\varepsilon} \qquad \text{(Equation 3)}$$

3.3 Key Milestones

Several key milestones for this research project have been achieved in order to meet all the objectives of this project:

Figure 9: Key milestone

The key milestones for this project as shown in figure 9 are started with review of literature which is completed on 24th February 2013 followed by specimen fabrication, recycled wax and tensile test are completed on 26th July 2013. After that, result analysis has been completed on 12th August 2013 and finally thesis write up is completed on 16th August 2013.

3.3 Gantt Chart/ Study Plan

Description	Week No																													
	FYP 1															FYP 2														
	1	2	3	4	5	6	7	8	9	10	11	12	13	14		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15
Selection of Project Topic	27/1														SEMESTER BREAK															
Preliminary Research Work																														
1. Literature review				24/2																										
2. Data gathering																														
Submission of Extended Proposal						24/2																								
Proposal Defence								20/3																						
Outlined details experiment																														
Submission of Interim Report													22/4																	
Project Work																														
Sample Preparation																														
1. Mold fabrication																														
2. Recycling machinable wax																									26/7					
Testing/ Experiment Process																														
Submission of Progress Report																														
Result Analysis																										12/8				
Submission of Draft Report																														
Submission of Dissertation (soft bound)																														
Submission of Technical Paper																														
Oral Presentation																														
Submission of Project Dissertation (hard Bound)																														16/8

Figure 10: Gantt chart

Chapter 4

Results

4.1 New Machinable Wax (5 specimens)

Figure 11 shows the stress strain curve for 1st specimen of new machinable wax. The highest value of stress is about 7.4 MPa at a strain of 0.02.

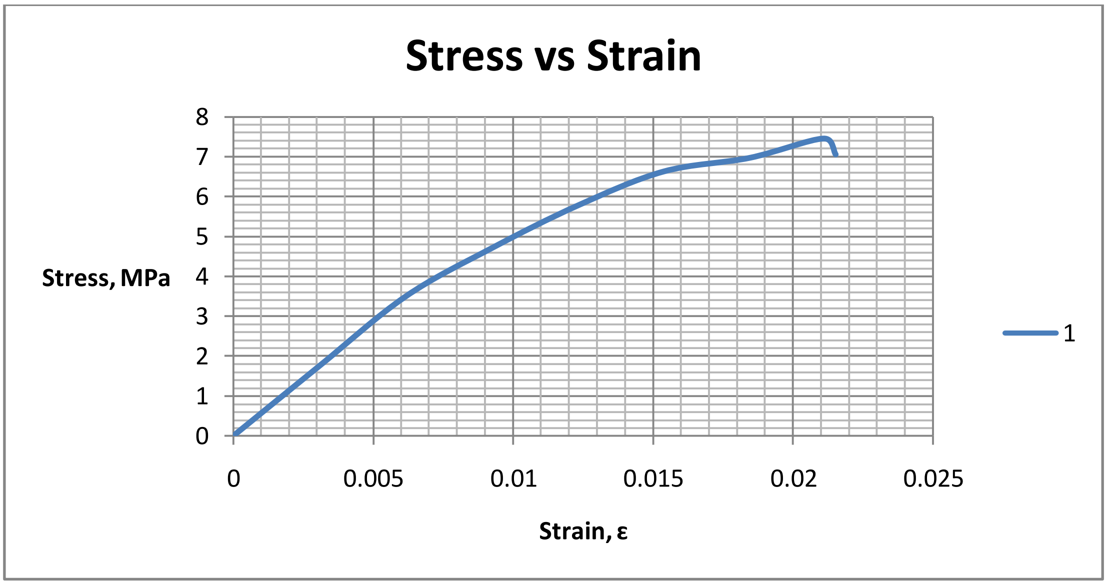


Figure 11: Stress strain curve 1

Figure 12 shows the stress strain curve for 2nd specimen with the highest value of stress about 7.5 MPa at a strain of 0.02.

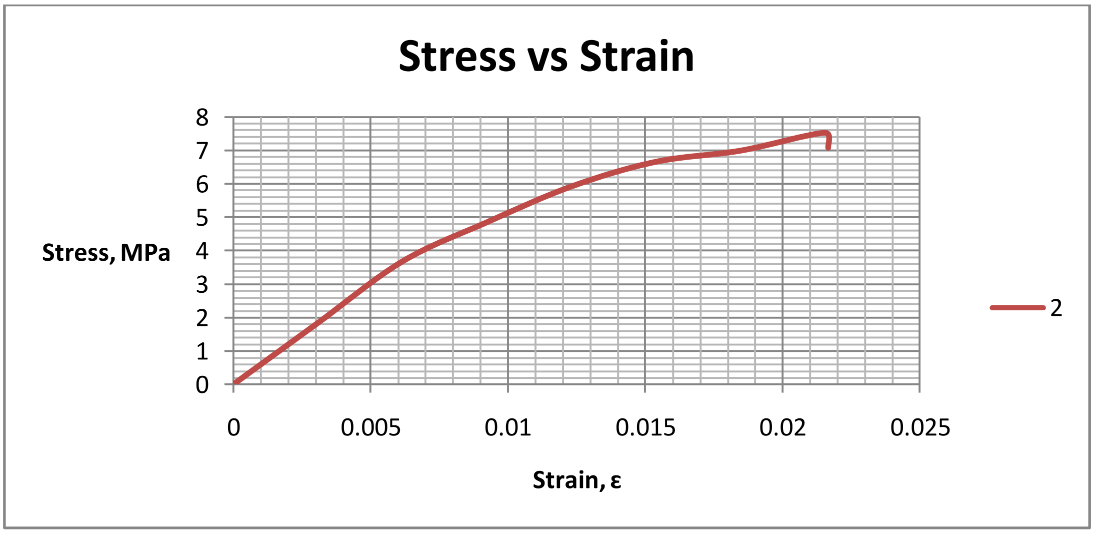


Figure 12: Stress strain curve 2

Figure 13 shows the stress strain curve for 3rd specimen with the highest value of stress about 7.5 MPa at a strain of 0.02.

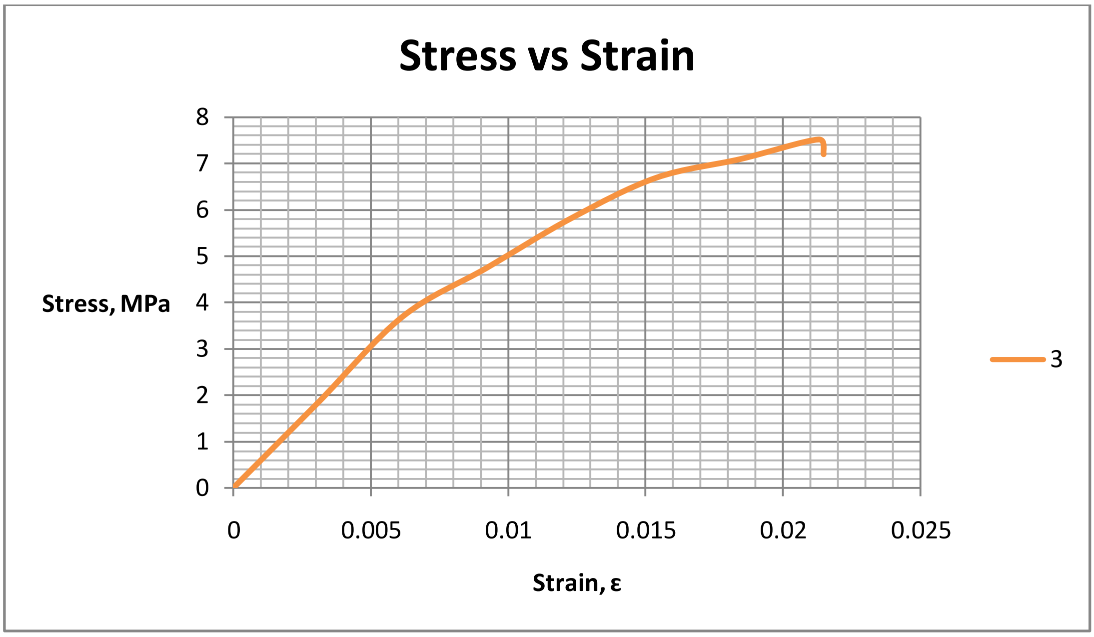


Figure 13: Stress strain curve 3

Figure 14 shows the stress strain curve for 4th specimen with the highest value of stress about 7.6 MPa at a strain of 0.02.

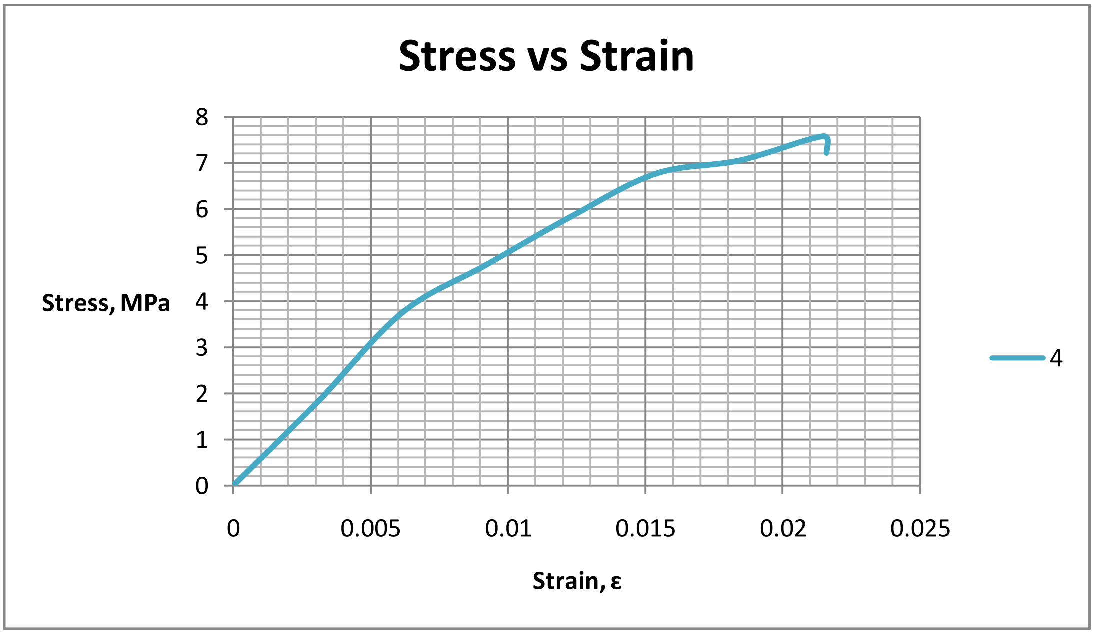


Figure 14: Stress strain curve 4

Figure 15 shows the stress strain curve for 5th specimen with the highest value of stress about 7.5 MPa at a strain of 0.02.

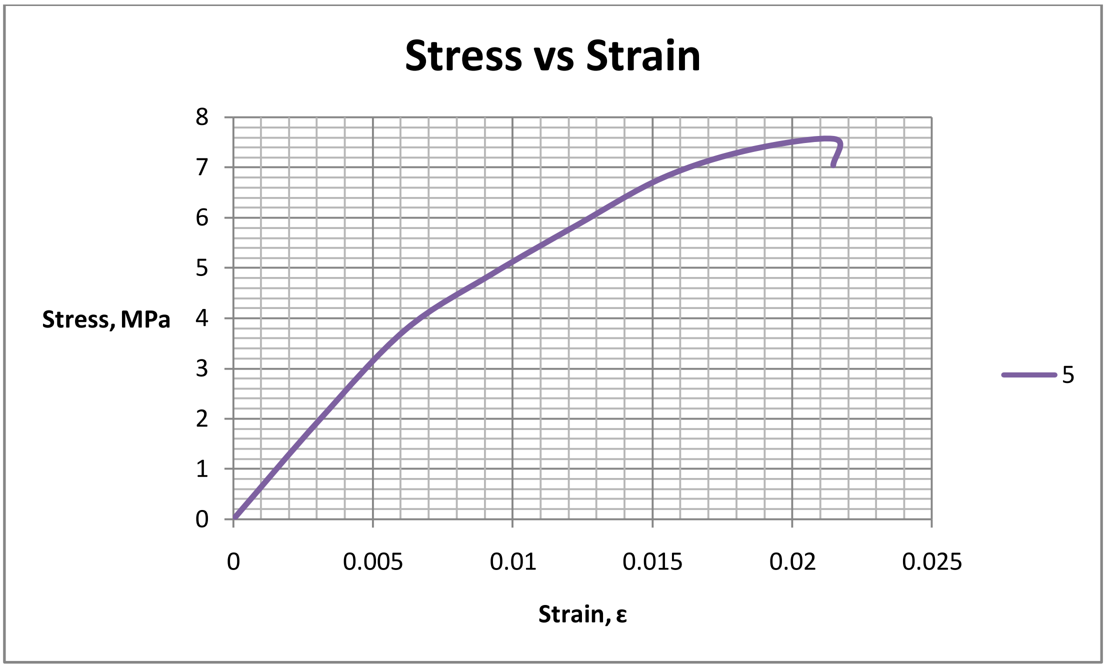


Figure 15: Stress strain curve 5

Table 2: Young's Modulus and Tensile strength

No. of specimen	Young's Modulus, MPa	Tensile strength, MPa
1	500	7.4
2	526	7.5
3	526	7.5
4	526	7.6
5	500	7.5
Average	**516**	**7.5**

Table 2 shows the value of Young's modulus and tensile strength for new machinable wax which has been calculated based on the stress strain curve.

4.2 1st time recycled (5 specimens)

Figure 16 shows stress strain curve for 1st specimen with the highest value of stress about 6.9 MPa at a strain of 0.028.

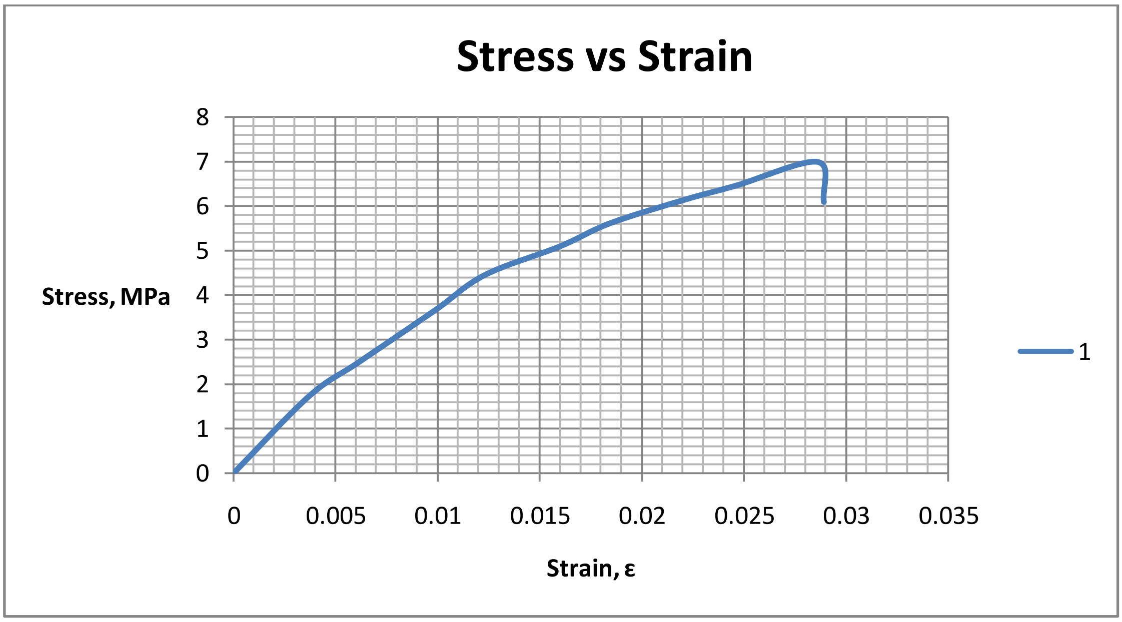


Figure 16: Stress strain curve 1

Figure 17 shows the stress strain curve for 2nd specimen with the highest value of stress about 6.9 MPa at a strain of 0.028.

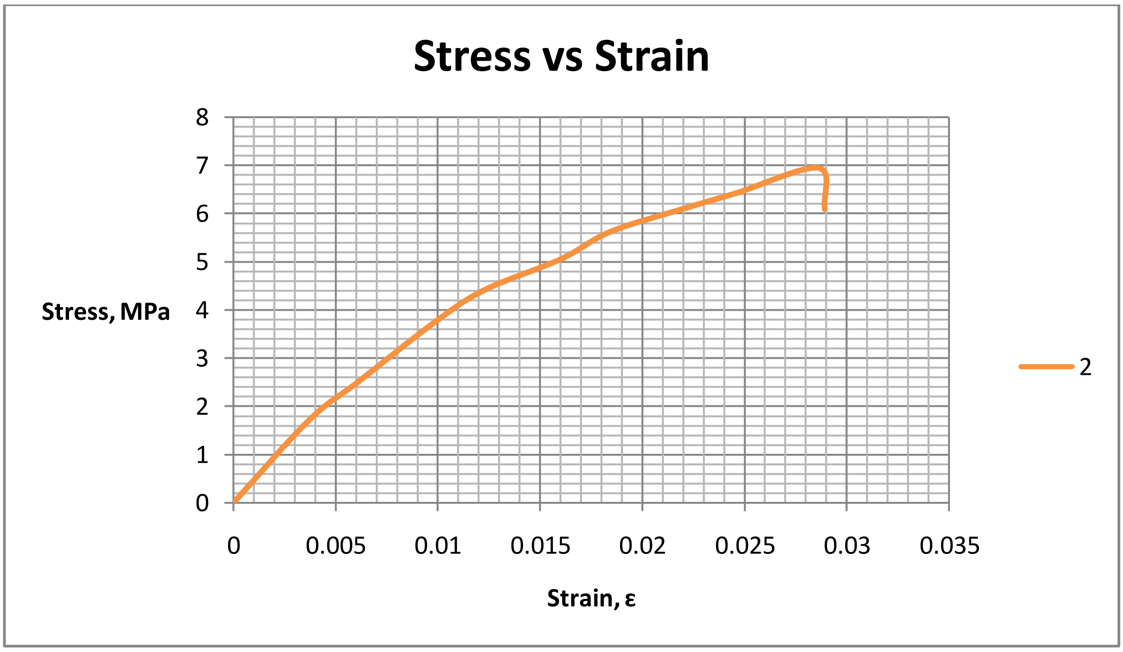


Figure 17: Stress strain curve 2

Figure 18 shows the stress strain curve for 3rd specimen with the highest value of stress about 6.9 MPa at a strain of 0.028.

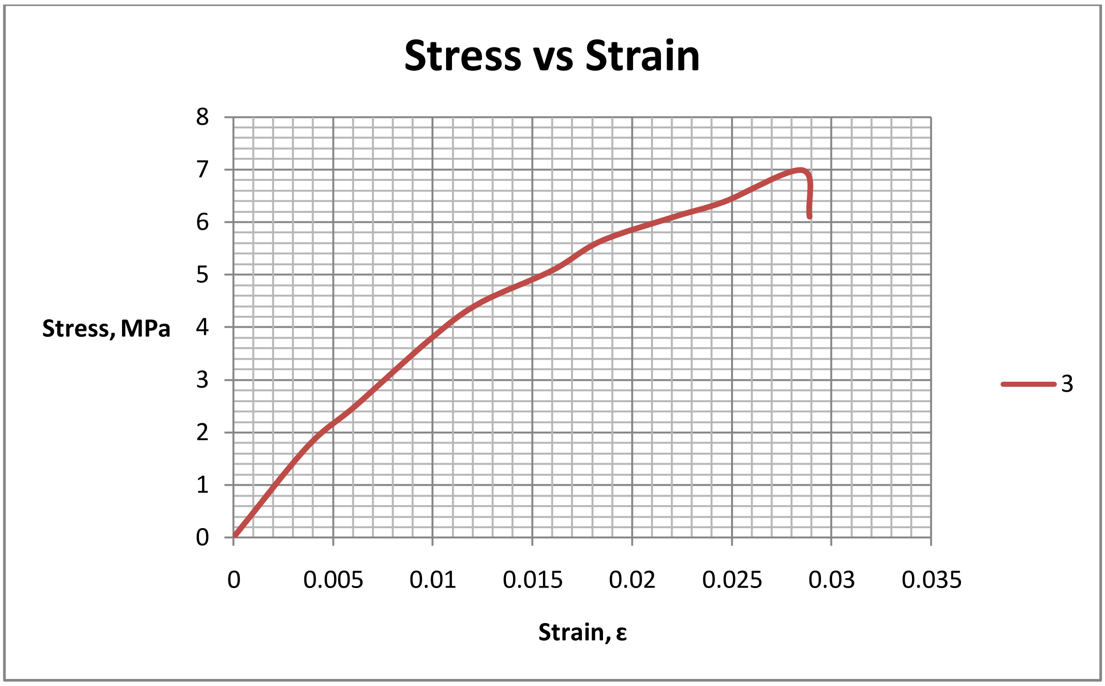


Figure 18: Stress strain curve 3

Figure 19 shows the stress strain curve for 4th specimen with the highest value of stress about 7 MPa at a strain of 0.028.

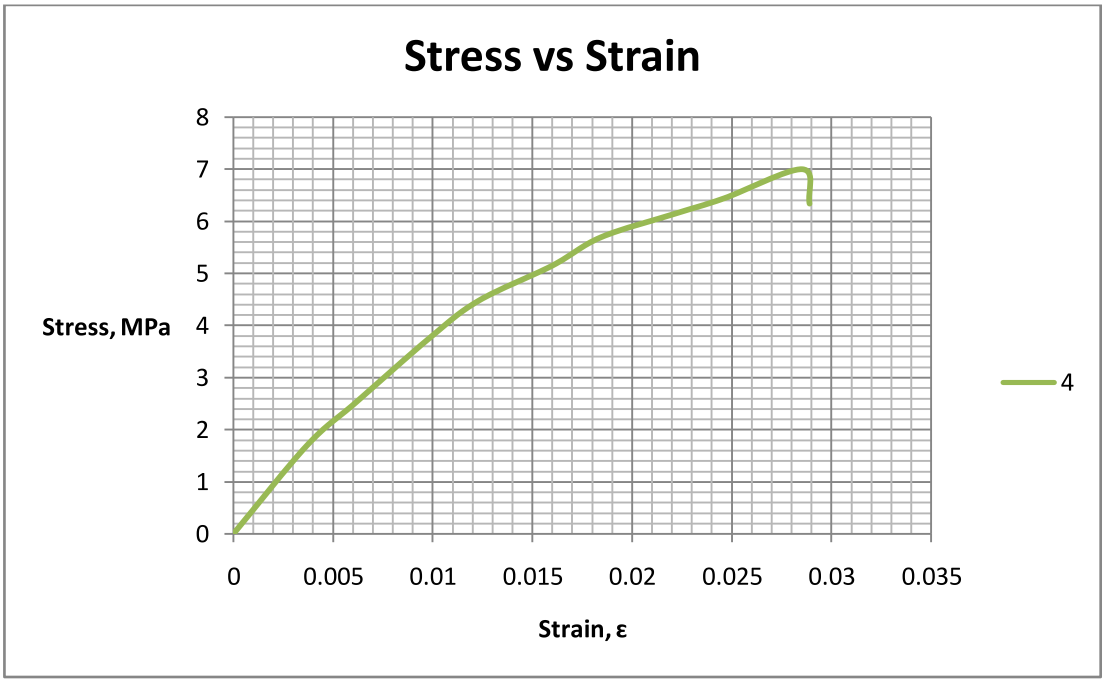


Figure 19: Stress strain curve 4

Figure 20 shows the stress strain curve for 5^{th} specimen with the highest value of stress about 6.9 MPa at a strain of 0.028.

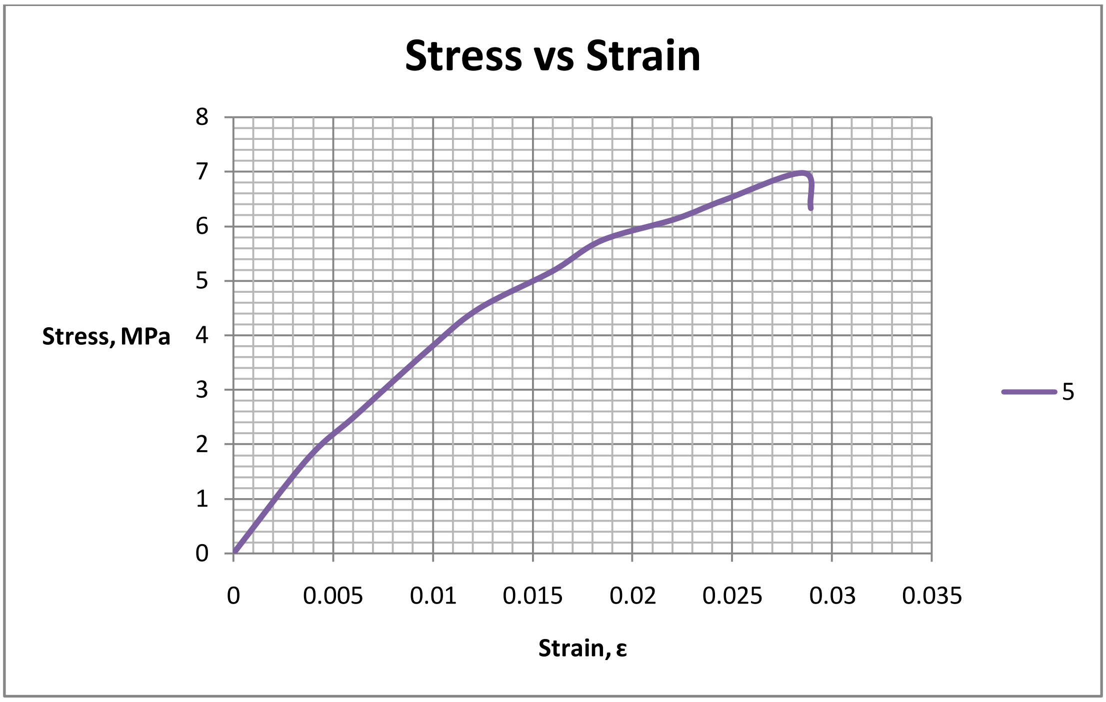


Figure 20: Stress strain curve 5

Table 3: Young's Modulus and Tensile strength

No. of specimen	Young's Modulus, MPa	Tensile strength, MPa
1	454	6.9
2	476	6.9
3	454	6.9
4	434	7.0
5	454	6.9
Average	455	6.9

Table 3 shows the value of Young's modulus and tensile strength for 1^{st} time recycled machinable wax which has been calculated based on the stress strain curve.

4.3 2nd time recycled (5 specimens)

Figure 21 shows the stress strain curve for 1st specimen with the highest value of stress about 6.7 MPa at a strain of 0.028.

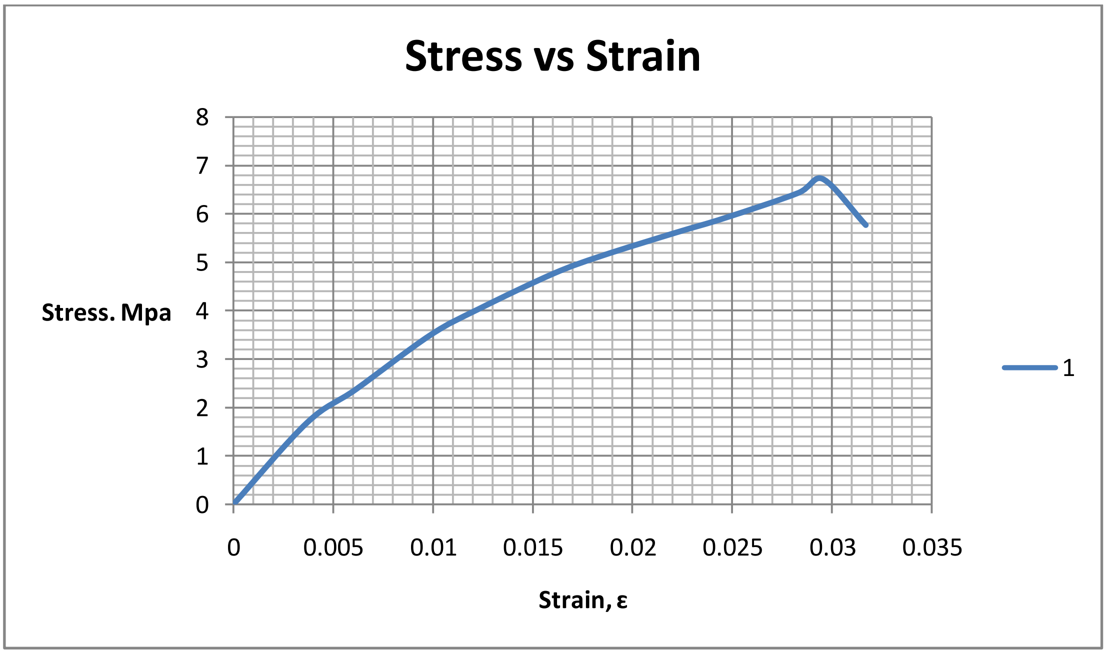


Figure 21: Stress strain curve 1

Figure 22 shows the stress strain curve for 2nd specimen with the highest value of stress about 6.8 MPa at a strain of 0.023.

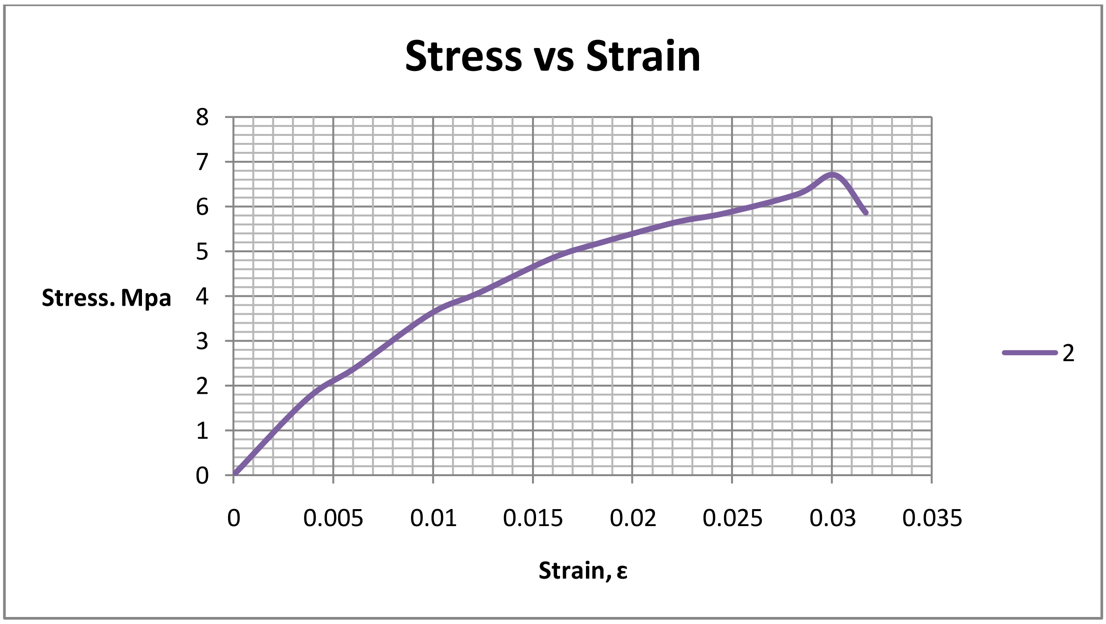


Figure 22: Stress strain curve 2

Figure 23 shows the stress strain curve for 3rd specimen with the highest value of stress about 6.7 MPa at a strain of 0.03.

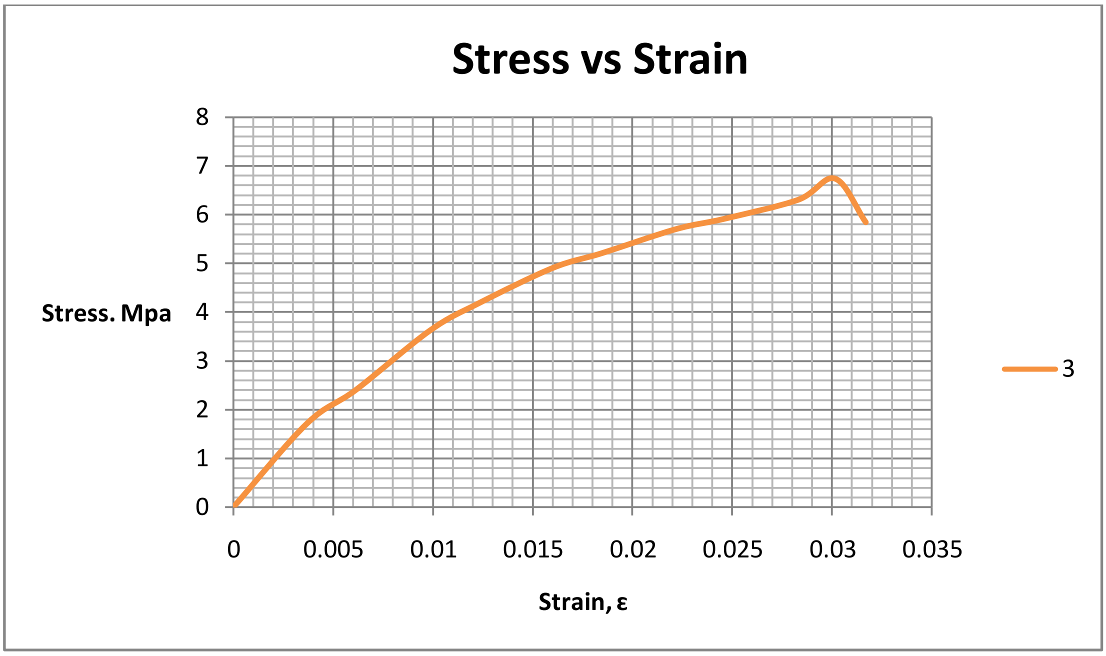


Figure 23: Stress strain curve 3

Figure 24 shows the stress strain curve for 4th specimen with the highest value of stress about 6.8 MPa at a strain of 0.03.

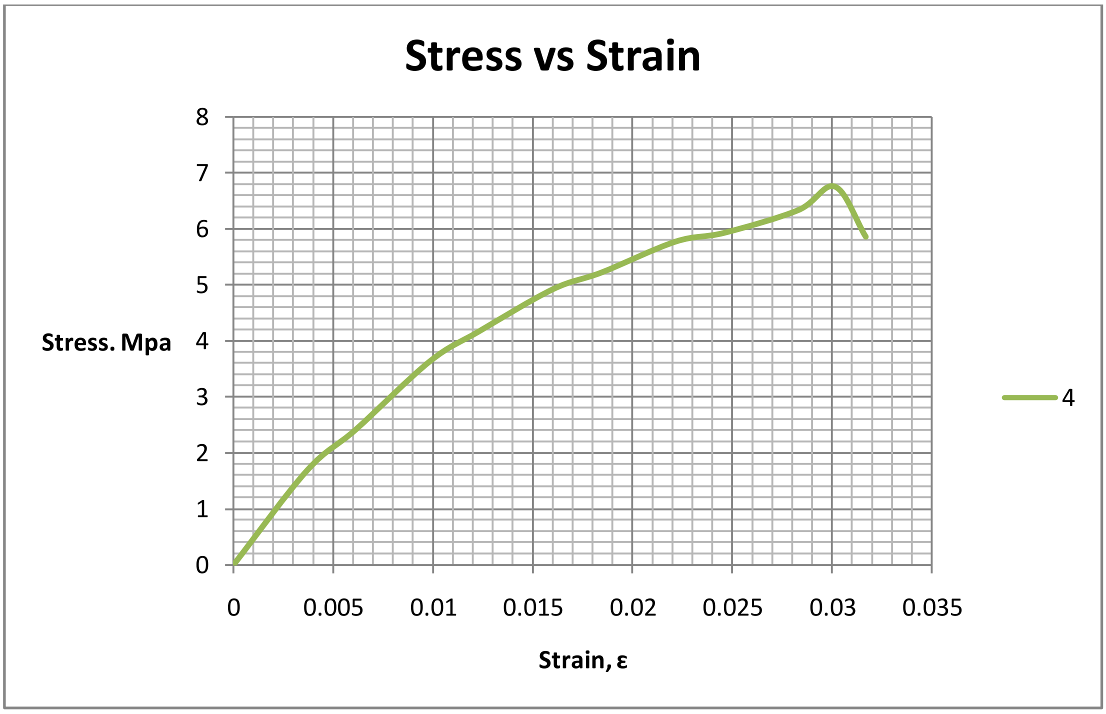


Figure 24: Stress strain curve 4

Figure 25 shows the stress strain curve for 5th specimen with the highest value of stress about 6.8 MPa at a strain of 0.03.

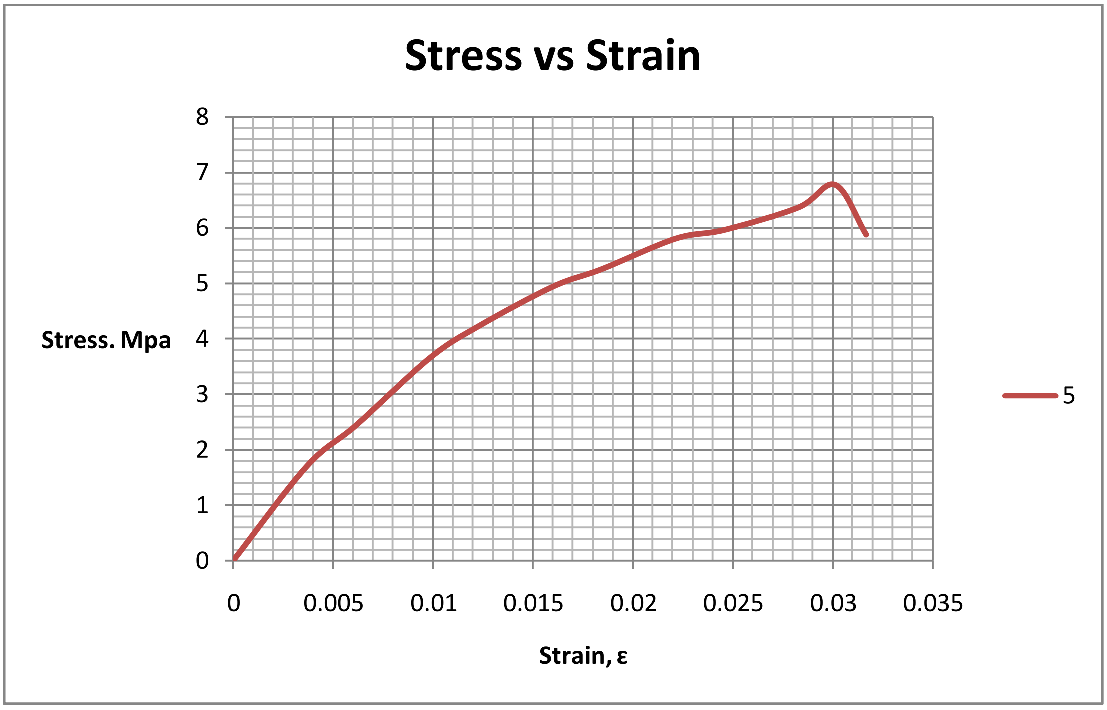


Figure 25: Stress strain curve 5

Table 4: Young's Modulus and Tensile strength

No. of specimen	Young's Modulus, MPa	Tensile strength, MPa
1	444	6.7
2	444	6.8
3	432	6.7
4	421	6.8
5	444	6.8
Average	437	6.8

Table 4 shows the value of Young's modulus and tensile strength for 2nd time recycled machinable wax which has been calculated based on the stress strain curve.

4.4 3rd time recycled (5 specimens)

Figure 26 shows the stress strain curve for 1st specimen with the highest value of stress about 6.8 MPa at a strain of 0.03.

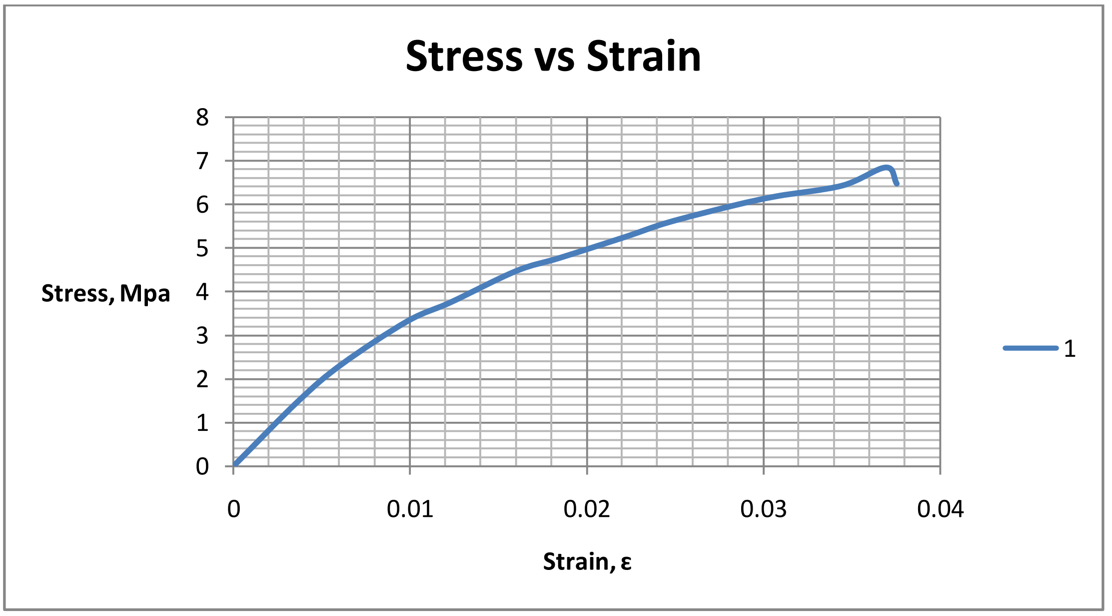


Figure 26: Stress strain curve 1

Figure 27 shows the stress strain curve for 2nd specimen with the highest value of stress about 6.7 MPa at a strain of 0.03.

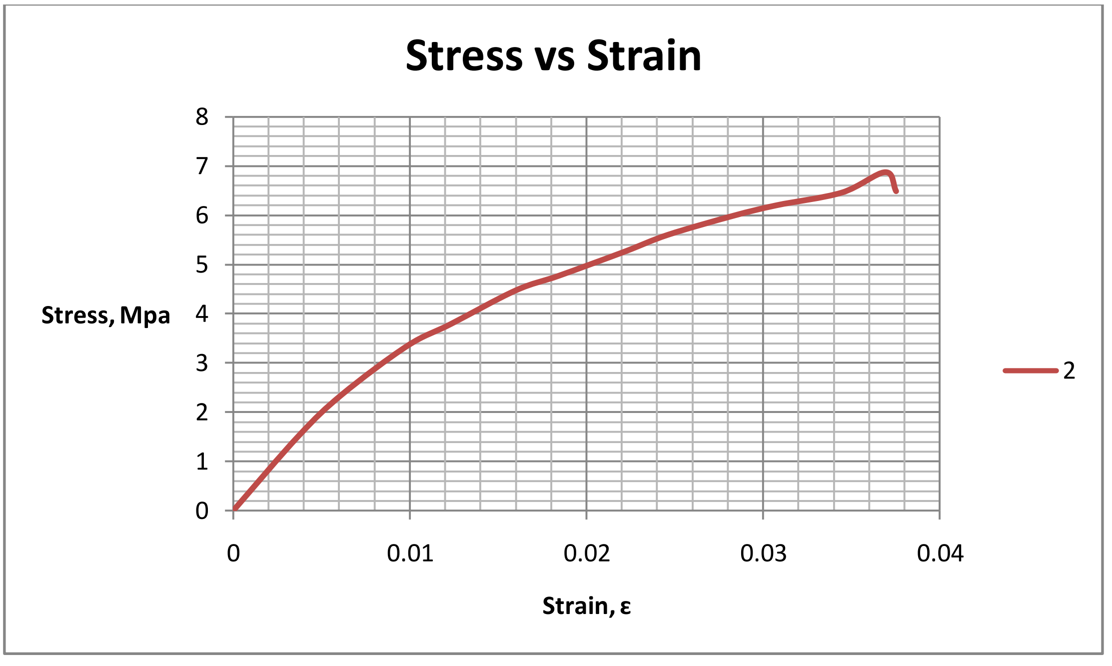


Figure 27: Stress strain curve 2

Figure 28 shows the stress strain curve for 3rd specimen with the highest value of stress about 6.7 MPa at a strain of 0.03.

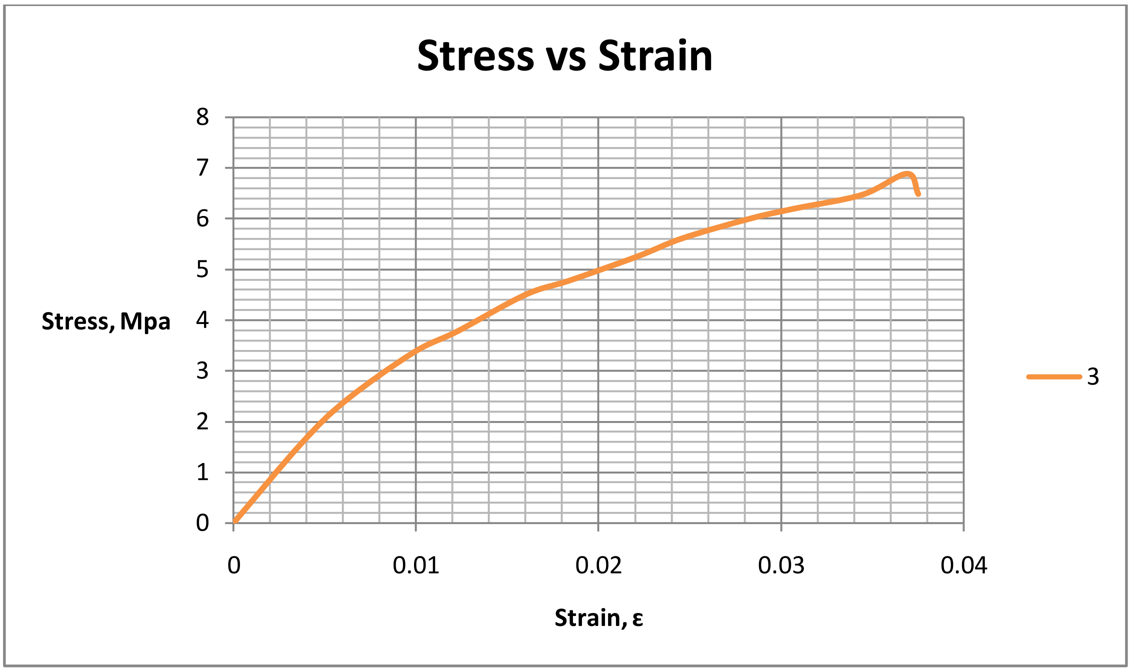


Figure 28: Stress strain curve 3

Figure 29 shows the stress strain curve for 4th specimen with the highest value of stress about 6.8 MPa at a strain of 0.03.

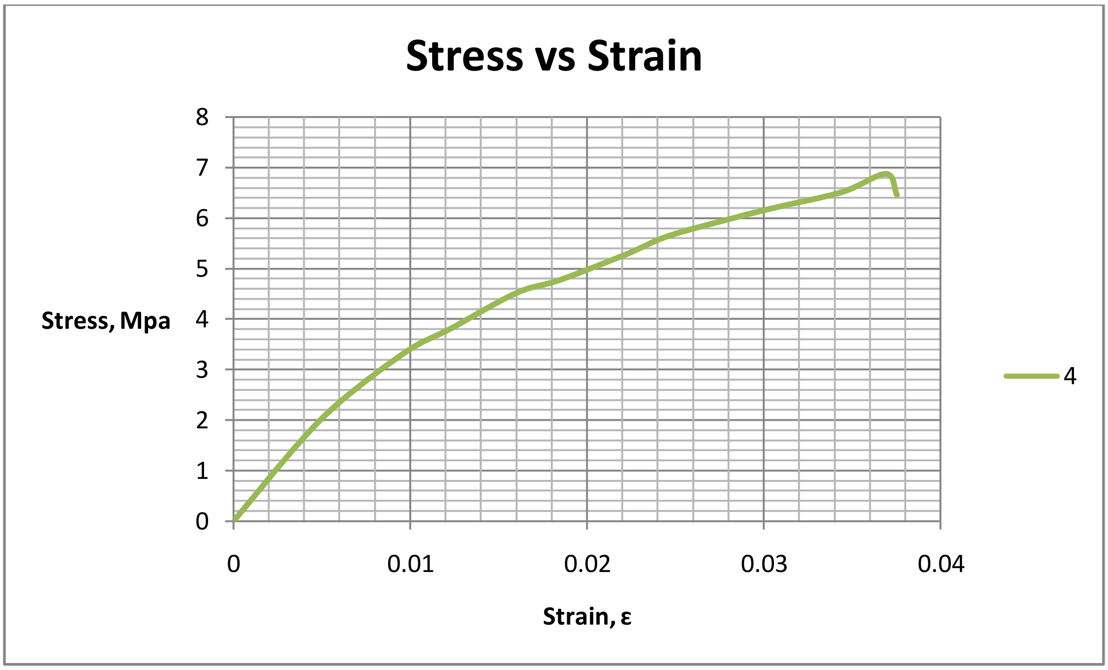


Figure 29: Stress strain curve 4

Figure 30 shows the stress strain curve for 5th specimen with the highest value of stress about 6.7 MPa at a strain of 0.03.

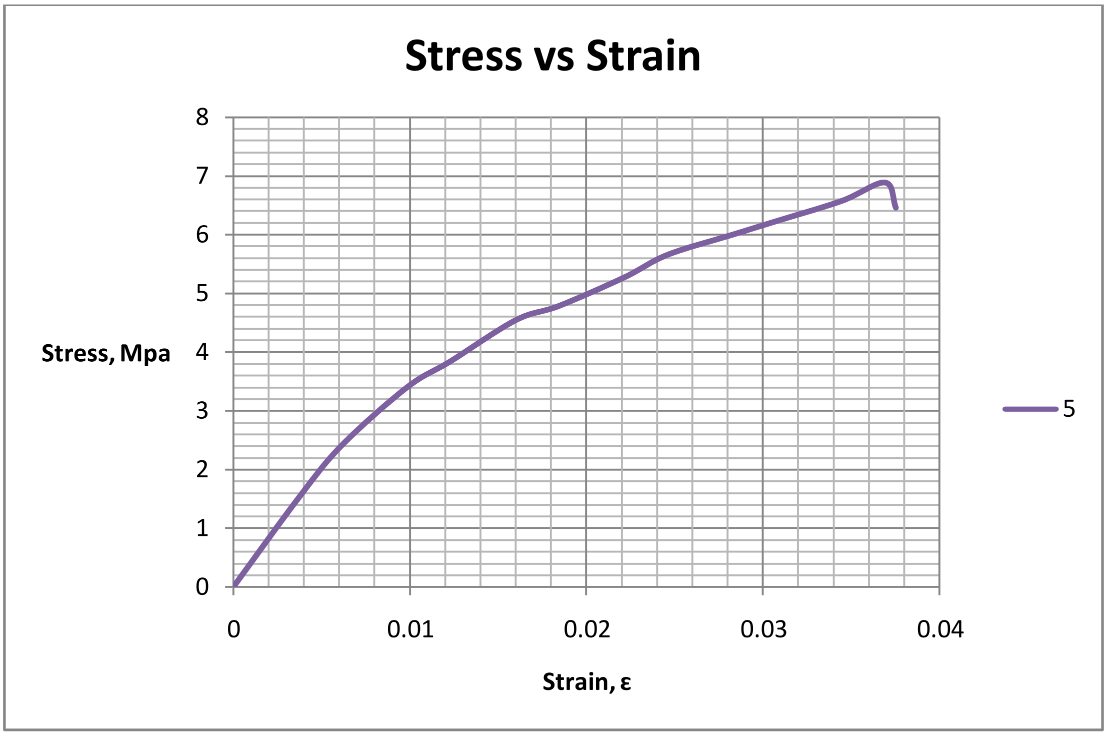


Figure 30: Stress strain curve 5

Table 5: Young's Modulus and Tensile strength

No. of specimen	Young's Modulus, MPa	Tensile strength, MPa
1	400	6.8
2	393	6.7
3	416	6.7
4	400	6.8
5	403	6.7
Average	403	6.7

Table 4 shows the value of Young's modulus and tensile strength for 3rd time recycled machinable wax which has been calculated based on the stress strain curve.

4.5 Comparison of Mechanical Properties

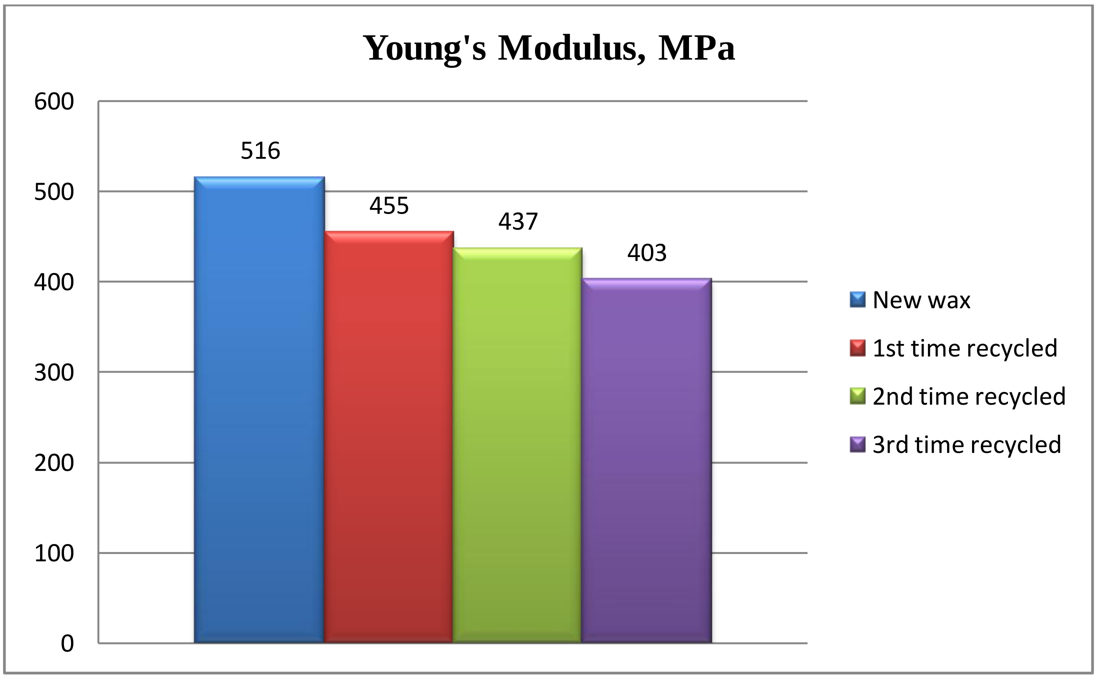


Figure 31: Comparison of Young's modulus

The graph in figure 31 shows the comparison of Young's Modulus for new machinable wax, 1st time recycled machinable wax, 2nd time recycled machinable wax and 3rd time recycled machinable wax. The value of the Young's modulus keeps on decreasing after it has been recycled.

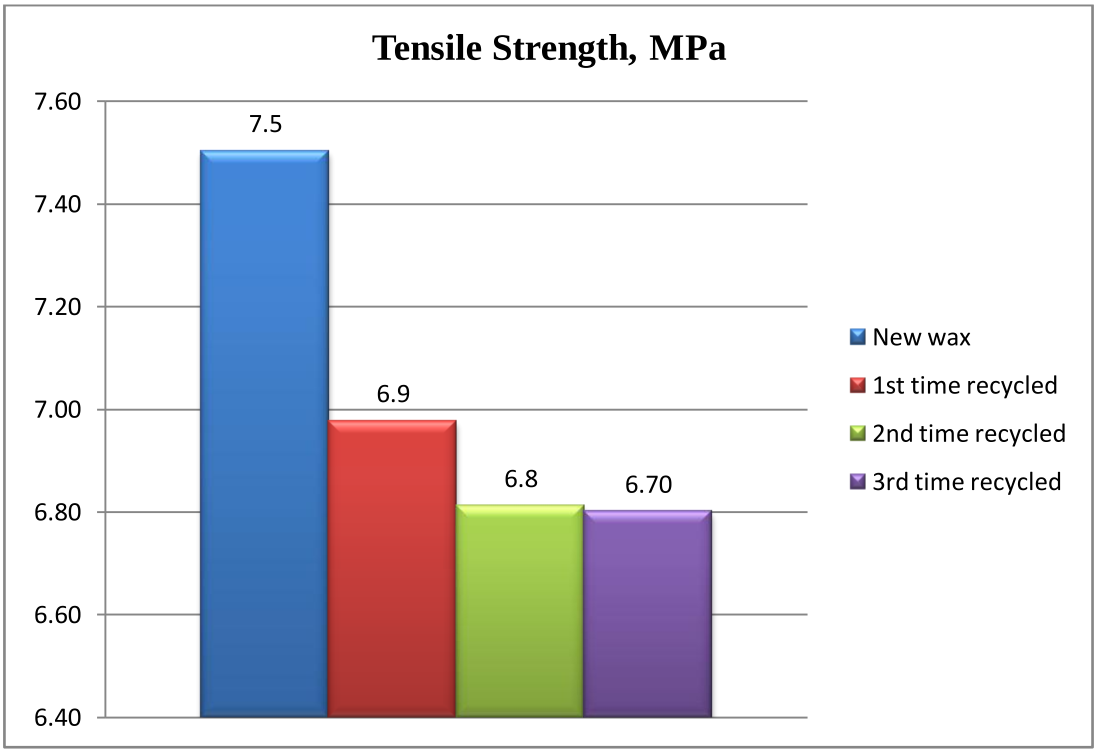


Figure 32: Comparison of Tensile strength

The graph in figure 32 shows the comparison value of tensile strength between a new machinable wax, 1st time recycled machinable wax, 2nd time recycled machinable and 3rd time recycled machinable wax. As referred to the graph, the tensile strength of machinable wax also decreasing after it has been recycled.

4.6 Discussion

4.6.1 Young's Modulus

Basically, Young's modulus is defined as the ratio of the stress along an axis over the strain along that axis in the range of stress in which Hooke's law holds [17]. As recommended by the standard ASTM D 638, five specimens have been tested for every experiment. Based on the stress strain curve for a new machinable wax, the highest value of Young's modulus which has been recorded is 526 MPa while the lowest reading is 500 MPa. Therefore, the average of the Young's modulus for a new wax is 516 MPa. Next, for 1st time recycled machinable wax, the graph shows that the highest reading is 476 MPa and the lowest reading is about 434 MPa. The calculated average for Young's modulus will be about 455 MPa. After that, as referred to stress strain curve for 2nd time recycled machinable wax, the highest value has been recorded is 444 MPa. Meanwhile, the lowest value of Young's modulus for this 2nd time recycled experiment is 421 MPa and the average reading is about 437 MPa. Lastly, for 3rd time recycled of machinable wax, the highest reading is 416 MPa and for lowest reading is about 393 MPa. With those readings, the average for Young's modulus is 403 MPa. As expected, the Young's modulus for machinable wax is reducing after a number of recycled.

Table 6: Average of Young's modulus

Experiment	Average of Young's Modulus, MPa
New machinable wax	516
1st time recycled	455
2nd time recycled	437
3rd time recycled	403

Percentage of Reduction for 1^{st} time recycled

((516-455)/516) x100 = *11.8%* (Equation 4)

Percentage of Reduction for 2^{nd} time recycled

((455-437)/455) x100 = *4.0%* (Equation 5)

Percentage of Reduction for 3^{rd} time recycled

((437-403)/437) x 100 = *7.8%* (Equation 6)

4.6.2 Tensile Strength

The tensile strength of a material quantifies how much stress the material will endure before suffering permanent deformation [16]. The tensile strength also can be calculated using stress strain curve. Based on the graph for a new machinable wax, highest tensile strength that has been recorded is 7.5 MPa whereas the lowest reading is about 7.4 MPa. The average reading for tensile strength is 7.5 MPa. After that, for 1^{st} time recycled machinable wax, the highest reading is 7.0 MPa and the lowest reading is about 6.9 MPa. The average of tensile strength is 6.9 MPa. Next, as referred to stress strain curve for 2^{nd} time recycled machinable wax, the highest value has been recorded is 6.8 MPa. Meanwhile, the lowest value of Young's modulus for this 2^{nd} time recycled experiment is 6.7 MPa and the average reading is about 6.8 MPa. Lastly, for 3^{rd} time recycled of machinable wax, the highest reading is 6.8 MPa and for lowest reading is about 6.7 MPa. With those readings, the average for Young's modulus is 6.7 MPa. Similarly, the value of tensile strength also reducing after recycled.

Experiment	Average of Tensile strength, MPa
New machinable wax	7.5
1st time recycled	6.9
2nd time recycled	6.8
3rd time recycled	6.7

Table 7: Average of Tensile strength

Percentage of Reduction for 1st time recycled

((7.5-6.9)/7.5) x 100 = *8%* (Equation 7)

Percentage of Reduction for 2nd time recycled

((6.9-6.8)/6.9) x 100 = *1.4%* (Equation 8)

Percentage of Reduction for 3rd time recycled

((6.8-6.7)/6.8) x 100 = *1.4%* (Equation 9)

4.6.3 Factors of Reduction

After a series of experiments, the data have been analyzed and it is found that the value of both, Young's modulus and tensile strength reduced with respect to number recycle. This may be due to melting process in which the heat or temperature during melting process effect the microstructure of machinable wax. The material that work with temperature will be affected not only affects its mechanical behavior as an additional load, but also modifying all material properties [18].

Another factor that affects the reduction is the experimental method. The melting process of the machinable wax for this project has been done using portable stove and nonstick carbon cookware. Therefore, the temperature of melting process cannot be controlled effectively because portable stove do not have that kind of function. Furthermore, there are impurities existed in the specimens of recycles machinable wax. These impurities as shown in figure 33 may a result of degradation of material of nonstick carbon cookware during melting process.

Figure 33: Impurities

Next, the other factor that may affect the machinable wax properties is air bubbles trapped in the specimens that shown in the figure 34. During melting process, the air bubbles are trapped in the specimens that only visible when machinable is in liquid form. Once the wax cooled, it is difficult to detect or see the bubbles. Besides, there are possibilities for the specimens to have flaws or crack before undergo tensile test. On top of that, all of these factors are only possibilities that may effects the percentage of reduction and also mechanical properties of machinable wax when it is recycled.

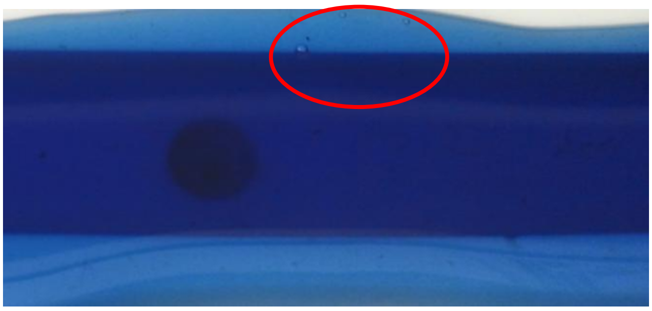


Figure 34: Air bubbles

Chapter 5

Conclusion

As conclusion, the data gathering for study of mechanical properties of machinable wax may have some errors due to several factors. However, the data still reliable since this project has been done according to the ASTM D638. As referred to the data and calculations in discussion part, the Young's modulus and tensile strength of machinable wax reduced after recycled. The highest percentage of reduction of Young's modulus is when new machinable wax has been recycled for first time. After that, the reduction of Young's modulus of 1st time recycled to 2nd time recycled is quite small. Similarly with tensile strength, the highest percentage of reduction is between new wax and 1st time recycled and then the percentage of reduction become smaller for 2nd time recycled and 3rd time recycled. By analyzing this data, it can be brought to a close that the mechanical properties of machinable wax are affected when recycled.

This data can be beneficial for jewelry industry since the wax is one of the materials that vastly used in making the jewelry. Referring to the handbook on investment casting written by Valerio Faccenda, the type of wax for investment casting is chosen according to the physical characteristics such as hardness, density, viscosity and also volume thermal expansion [20]. This is because every characteristic can be used to evaluate different things. For example, thermal expansion can be used for evaluating the cooling shrinkage of the wax patterns and calculating the real dimensions of the cast pieces. Even though the mechanical properties of wax may not play important role in jewelry industry, it is still can be factors of choosing the wax for making jewelries.

5.1 Recommendations

There are some recommendations could be done in order to increase the quality of this research in the future. All of these recommendations mainly inspired through observations on the project.

5.1.1 Molding Dimensions

After a few testing on created the dog bone shaped specimens using melting process, machinable wax shrink when it is cooled. The rate of shrinkage is about 1.5% after it is cooled. Therefore, the dimensions of the mold should be design slightly different which is higher from the desired dimensions of the dog bone shaped.

5.1.2 Machinable Wax Melting Tank

Machinable wax should be melted in the machinable wax melting tank as shown in figure 35. However, due to unexpected circumstances, the machine is malfunction. Thus, another method must be used in order to melt the machinable wax which is by using conventional method. The machinable wax will be melted using nonstick carbon steel cookware and portable gas stove. Therefore, for future research, a proper melting process by using melting tank should be done since it plays an important factor in this project.

Figure 35: Internal view of melting tank

5.1.3 Dog Bone Shaped Specimen

In this project, a good quality of dog bone shaped plays a crucial role because a good result can only be obtained from a good quality of specimen. A good quality of specimen shall be free from air bubble, flaws or crack and impurities which can affect the strength of dog bone specimen. For instance, if the specimen has some crack on its surface, it can be its weak point and that area is suspected to fail when undergo tensile test or tension test. The same thing happen when the dog bone has air bubble trapped and some impurities.

5.1.4 Tensile Test

An extensometer as shown in figure 36 is highly recommended to use in the future research. Commonly, an extensometer is a device that is used to measure changes in the length of an object and it is very common to use in tensile test [15]. However, for this project, the extensometer was not used since there was a problem regarding the tensile machine. Therefore, additional efforts required which is manual calculation such as Young's modulus, strain and stress. This may affect some values for mechanical properties.

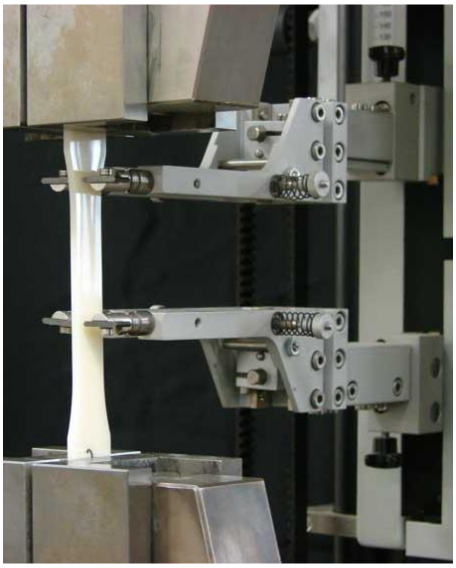


Figure 36: Extensometer

5.1.5 Undergo Other Type of Mechanical Testing

To create a more reliable and accurate value of mechanical properties, other type of experiment shall be done using this machinable wax. For example, flexural test as shown in figure 37 can be used to study the mechanical properties of machinable wax. Fundamentally, any structure under load can be used to determine properties provided the stress can be calculated and the strain can be measured at the same location [19].

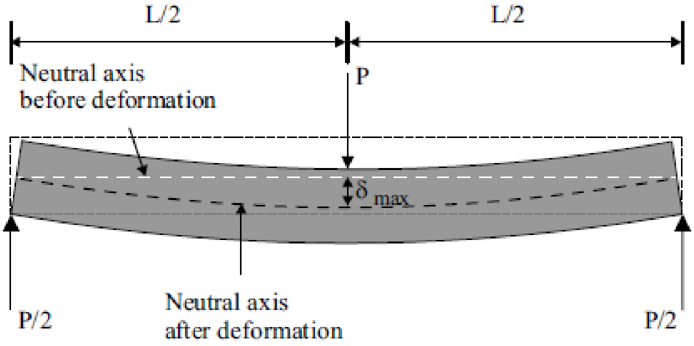


Figure 37: Bending test

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