University of Salford

BEng(Hons) Mechanical Engineering

Material Science Lab Report

Mechanical Properties of Polypropylene

Author: Joshua Jones
Tutor: Dr.W S Jouri
Group: Mech2
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Summary

The following Laboratory report is aimed at outlining the theory, method and procedure of obtaining mechanical properties of Polypropylene through the means of tensile testing The results of an experimental procedure are displayed and the necessary calculations are performed on the data to determine the value of:

- True Fracture Stress
- Tensile Ductility
- Nominal Yield
- Youngs Modulus of Elasticity

All equipment used will be detailed as will the theory and method of measurement used, including a brief section on the chemistry of Polypropylene, and a discussion of the results.

1 Introduction

1.1 History

Propylene was first polymerized to a crystalline isotactic polymer by Giulio Natta as well as by the German chemist Karl Rehn in March 1954. This pioneering discovery led to large-scale commercial production of isotactic polypropylene by the Italian firm Montecatini from 1957 onwards. Syndiotactic polypropylene was also first synthesized by Natta and his coworkers.

Polypropylene is the second most important plastic with revenues expected to exceed US$145 billion by 2019. The demand for this material was growing at a rate of 4.4% per year between 2004 and 2012.[1]

1.2 Laboratory introduction

This laboratory report was written to record the procedure of obtaining the mechanical properties of polypropylene by means of tensile testing, the dimensions of the specimen were measured, and the specimen was subjected to destructive testing at a variety of speeds in order to determine if the speed at which tensile load is applied effects the material properties.
Polypropylene (PP) is a linear hydrocarbon polymer, polypropylene is one of those most versatile polymers available with applications, both as a plastic and as a fibre, in virtually all of the plastics end-use markets.[2]
Given the widespread applications of polypropylene it is important to understand the material properties in order to design safe, functional products.

2 Laboratory Procedure

2.1 Definitions and equations of mechanical properties

The mechanical properties to be determined :

- True Fracture Stress
- Tensile Ductility
- Nominal Yield
- Youngs Modulus of Elasticity

2.1.1 True Facture Stress:

The equation used in this laboratory for true fracture stress:

$$\text{True Fracture Stress} = \frac{\text{Fracture Load}}{\text{Cross Sectional Area@Fracture}}$$

With units of $\frac{N}{mm^2}$

True Fracture Stress is the term used to describe the stress the specimen can withstand before breaking, and at the value of stress the material will fail. This stress can be used to specify the critical load of the specimen for example and as such under normal circumstances the specimen should never be subjected to anything near this load.

2.1.2 Tensile Ductility

The equation used in this laboratory for Tensile Ductility:

$$\text{Tensile Ductility} = \frac{\text{Extension@Break}}{\text{Original Gauge Length}}$$

Tensile Ductility is a measure of how much deformation or strain a material can withstand before breaking, in the case of polypropylene this ductility is dependant on the rate of load because the slower the load is applied the more time the long chain polymers have in order to untangle and straighten in the direction of the load, which increases the ductility of the material this leads to the trend of a fast deformation provides poor ductility and a slow deformation allows for the polypropylene to become more ductile.

2.1.3 Nominal Yield

The equation used in this laboratory for the Nominal Yield:

$$\text{Nominal Yield} = \frac{\text{Load @High Yield}}{\text{Cross Sectional Area}}$$

With units of $\frac{N}{mm^2}$

The Nominal Yield Stress of a material is the material is defined in engineering and materials science as the stress at which a material be- gins to deform plastically. Prior to the yield point the material will deform elastically and will return to its original shape when the applied stress is removed. Once the yield point is passed, some fraction of the deformation will be permanent and non-reversible.

2.1.4 Youngs Modulus of Elasticity

The equation used in this laboratory for the Nominal Yield:

$$\text{Youngs Modulus (E)} = \frac{\frac{\text{Load @ High Yield}}{\text{Cross Sectional Area}}}{\frac{\text{Extension at High Yield}}{\text{Gauge Length}}}$$

With units of $\frac{N}{mm^2}$

Young's modulus, also known as the tensile modulus or elastic modulus, is a measure of the stiffness of an elastic material and is a quantity used to characterize materials. It is defined as the ratio of the uniaxial stress over the uniaxial strain in the range of stress in which Hooke's law holds.[3]

2.2 Descriptions of apparatus and equipment

The machine used for the tensile testing of polypropylene specimens was a J.J Tensometer rated at 5kN

The tensometer has a variety of sensors and abilities in order to measure the load and extension of a specimen inserted into it's jaws and is capable of producing graphs. One feature that was used was the ability to vary the rate of application of load in order to control the speed of deformation.

A point-tipped micrometer was used to measure the Width and Thickness of the specimen to determine the area. The micrometer is acurate to 100^{th} of a millimeter.

A Standard Engineers rule was used to measure the Gauge Length of the specimen accurate to the nearest half-millimeter.

2.3 Measured Data and Test Results

2.3.1 Method of obtaining measured data

3 Specimens were used in order to increase the accuracy of our results and also to make comparisons to loading at different rates.

In order to determine the cross sectional area and Gauge Length of the specimens 3 parameters had to be measured:

- Thickness
- Width
- Gauge Length

All Specimens were measured to have guage length of 33mm, due to manufacturing inconsistencies the width and thickness had some variation.

2.3.2 Table of Measured Results

Specimen 1					
Thickness	2.15mm	2.16mm	2.14mm	Avg= 2.15mm	
Width	4.71mm	4.67mm	4.69mm	Avg=4.69m	CSA=10.0835mm^2
Specimen 2					
Thickness	2.31mm	2.29mm	2.27mm	Avg= 2.29mm	
Width	4.95mm	4.89mm	4.89mm	Avg=4.91mm	CSA= 11.244mm^2
Specimen 3					
Thickness	2.22	2.15	2.21	Avg= 2.19	
Width	4.70	4.77	4.74	Avg=4.736	CSA=10.386mm^2

2.3.3 Post-test measurements

The three specimens were tested to destruction by the Tensometer in order to determine the failure load.
Specimen 1 was tested at 100mm/min.
Specimen 2 was tested at 50mm/min.
Specimen 3 was tested at 25mm/min.
After Fracture the specimens were measured at the necking point to determine the new cross sectional area, the results of post-test measurements and data taken from the tensometer sensors is as follows:

Table 1: Post-Test Data:

Specimen 1 (100mm/min)	
Gauge Length	=33mm
CSA	$=10.0835mm^2$
CSA @ Fracture	$=2.697mm^2$
Fracture Load	$=224.61MPa$
Maximum Load	=300.3N
Extension @ max load	=3.418mm
Extension @ Break	=69.95mm
Load @ High Yield	=300.3N
Extension @ High Yield	=3.418mm
Specimen 2 (50mm/min)	
Gauge Length	=33mm
CSA	$=11.244mm^2$
CSA @ Fracture	$=2.652mm^2$
Fracture Load	$=239.26MPa$
Maximum Load	=307.6N
Extension @ max load	=6.335mm
Extension @ Break	=150.9mm
Load @ High Yield	=307.6N
Extension @ High Yield	=6.335mm
Specimen 3 (25mm/min)	
Gauge Length	=33mm
CSA	$=10.386mm^2$
CSA @ Fracture	$=1.972mm^2$
Fracture Load	$=344.24MPa$
Maximum Load	=344.2N
Extension @ max load	=243.7mm
Extension @ Break	=251.5mm
Load @ High Yield	=290.5N
Extension @ High Yield	=4.395mm

3 Calculation of results

Full Calculations for all 3 specimens:

3.0.4 Specimen 1 Calculations

$$\text{Fracture Stress} = \frac{F}{A}$$

$$\therefore$$

$$\text{Fracture Stress} = \frac{224.61}{2.697} = 83.3 \frac{N}{mm^2}$$

$$\text{Tensile Ductility} = \frac{\text{Extension at break}}{\text{Gauge Length}}$$

$$\therefore$$

$$\text{Tensile Ductility} = \frac{69.95}{33} = 2.12$$

$$\text{Nominal Yield} = \frac{\text{Load @High Yield}}{\text{Cross Sectional Area}}$$

$$\therefore$$

$$\text{Nominal Yield} = \frac{300.3}{10.0835} = 29.781 \frac{N}{mm^2}$$

$$\text{Youngs Modulus} = \frac{\text{Nominal Yield}}{\frac{\text{Extension @ High Yield}}{\text{Gauge Length}}}$$

$$\therefore$$

$$\text{Youngs Modulus} = \frac{29.781}{\frac{3.418}{33}} = 287.53 \frac{N}{mm^2}$$

3.0.5 Specimen 2 Calculations

$$\text{Fracture Stress} = \frac{F}{A}$$

$$\therefore$$

$$\text{Fracture Stress} = \frac{239.26}{2.652} = 90.22 \frac{N}{mm^2}$$

$$\text{Tensile Ductility} = \frac{\text{Extension at break}}{\text{Gauge Length}}$$

$$\therefore$$

$$\text{Tensile Ductility} = \frac{150.95}{33} = 4.57$$

$$\text{Nominal Yield} = \frac{\text{Load @High Yield}}{\text{Cross Sectional Area}}$$

$$\therefore$$

$$\text{Nominal Yield} = \frac{307.6}{11.244} = 27.357 \frac{N}{mm^2}$$

$$\text{Youngs Modulus} = \frac{\text{Nominal Yield}}{\frac{\text{Extension @ High Yield}}{\text{Gauge Length}}}$$

$$\therefore$$

$$\text{Youngs Modulus} = \frac{27.357}{\frac{6.335}{33}} = 142.5 \frac{N}{mm^2}$$

3.0.6 Specimen 3 Calculations

$$\text{Fracture Stress} = \frac{F}{A}$$

$$\therefore$$

$$\text{Fracture Stress} = \frac{344.24}{1.972} = 174.56 \frac{N}{mm^2}$$

$$\text{Tensile Ductility} = \frac{\text{Extension at break}}{\text{Gauge Length}}$$

$$\therefore$$

$$\text{Tensile Ductility} = \frac{251.5}{33} = 7.62$$

$$\text{Nominal Yield} = \frac{\text{Load @High Yield}}{\text{Cross Sectional Area}}$$

$$\therefore$$

$$\text{Nominal Yield} = \frac{290.5}{10.386} = 27.97 \frac{N}{mm^2}$$

$$\text{Youngs Modulus} = \frac{\text{Nominal Yield}}{\frac{\text{Extension @ High Yield}}{\text{Gauge Length}}}$$

$$\therefore$$

$$\text{Youngs Modulus} = \frac{27.97}{\frac{4.395}{33}} = 210.01 \frac{N}{mm^2}$$

4 Discussion of Results

The key changing factor of the three specimens was the strain rate, or speed at which the force was applied, by varying the strain rate we can determine the effect, if any strain rate has on the mechanical properties of Polypropylene and to some extent other thermoplastics.

The measured and Calculated results indicate that varying the rate of extension produces widely different results, this is due to the mechanical behaviour of the polypropylene, polypropylene is a thermoplastic Polymer made up of long chain molecules, these long chain molecules are intertwined and if stressed quickly the molecules have no time to realign in the direction of stress, in this fast stress situation the polymer exhibits a amphorous arrangement, the polymers are entangled and the overall length of the polymers is reduced, this makes the material more brittle and the specimen undergoes less extension before fracture.

Conversely when the specimen is subject to a low rate of tension the polymers have enough time to arrange parallel to the force and exhibit a semicrystiliine organisation which is allowed to stretch and giving the material a higher ductility and therefore a longer extension before breaking.

Some peculiarities exist in the results for example the Youngs Modulus from official sources show the modulus to be between 1.5 and 2 GPa ($10^9 N/m^2$) [4]
While the results taken from this test indicate a much lower modulus of 210 Mpa at 25mm/min and 287.53MPa at 100mm/min.

These could be due to error in measuring the Cross sectional area however being a factor of 10 out could indicate that there is an error in the calculations, most probably a unit conversion, however after numerous repetitions of calculation no error can be found in the units or the values, therefore it can only be assumed the measurements were innacurate and the method of experiment should be revised.

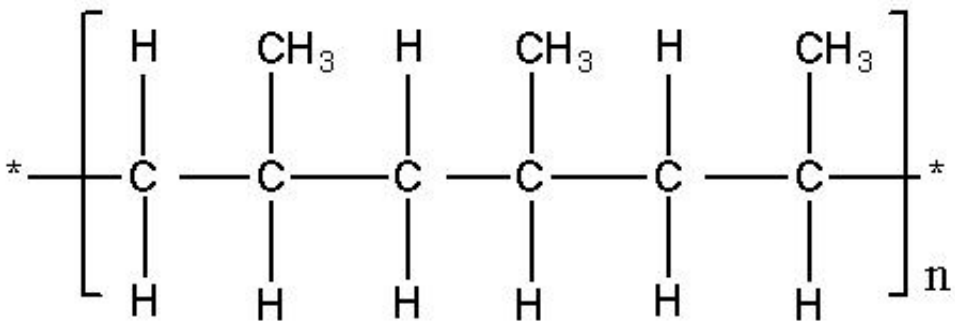
The expected results and the calculated results differ quite substantially, this could indicate a number of things, namely poor method and measurements, another possibility is that the sample was defective and the value used for the standard results is most likely extrapolated from thousands of specimens and averaged.

Avoidable errors include a more precise and careful measurement of the Cross sectional area, using more than 3 measurement points would increase the accuracy of the values.

4.1 Mechanical Testing

Note this text is from the handout given in the lab session
As Moulded the polymer usually long chain molecules, at low strains typically less than 10% the material obeys hookes law and is linear elastic, at about 10% strain the polymer begins to yield and draws yield propagates from a point of weakness or stress concentration at this point the area decreases as the molecules align parallel to the strain, the strained section is stronger than the unstrained section as the molecules have aligned in the same direction allowing a more even distribution of stress this is the effect known as strain hardening.

4.2 General Thermoplastic chemistry



Polymers exhibit two types of morphology in the solid state: amorphous and semicrystalline. In an amorphous polymer the molecules are oriented randomly and are intertwined, much like cooked spaghetti, and the polymer has a glasslike, transparent appearance. In semicrystalline polymers, the molecules pack together in ordered regions called crystallites.[5]

A thermoplastic polymer is a long, repeating chain of atoms, formed through the linkage of many molecules called monomers. The monomers can be identical, or they can have one or more substituted chemical groups. These differences between monomers can affect properties such as solubility, flexibility, or strength.

The attractive forces between polymer chains play a large part in determining a polymer's properties. Because polymer chains are so long, these interchain forces are amplified far beyond the attractions between conventional molecules. Also, longer chains are more amorphous (randomly oriented).

Polymers can be visualised as tangled spaghetti chains - pulling any one spaghetti strand out is a lot harder the more tangled the chains are. These stronger forces typically result in high tensile strength and melting points.

A thermoplastic is a plastic that softens when heated and hardens again when cooled. Thermoplastics can generally go through many melt/freeze cycles with no appreciable chemical change, making them suitable for recycling. These characteristics also lend thermoplastics to various manufacturing techniques; injection molding, thermoforming and welding.
Many thermoplastic materials are addition polymers (chain growth polymers), such as polythene and polypropylene. Thermoplastic Polymers are contrasted with thermosetting polymers, which cannot go through melt/freeze cycles.[6]

4.2.1 Glass Transition temperature

A simplistic view of a material's glass transition temperature (Tg) is the temperature below which molecules have very little mobility. On a larger scale, polymers are rigid and brittle below their glass transition temperature and can undergo plastic deformation above it. Tg is usually applicable to amorphous phases and is commonly applicable to glasses and plastics.[6] Polypropylene (isotactic) has a Glass Transition temperature of 100C.

4.3 Polypropylene Unique behaviour

Polypropylene, a synthetic resin built up by the polymerization of propylene. One of the important family of polyolefin resins, polypropylene is molded or extruded into many plastic products in which toughness, flexibility, light weight, and heat resistance are required. It is also spun into fibres for employment in industrial and household textiles. Propylene can also be polymerized with ethylene to produce an elastic ethylene-propylene copolymer.[7]

Propylene is a gaseous compound obtained by the thermal cracking of ethane, propane, butane, and the naphtha fraction of petroleum. Like ethylene, it belongs to the "lower olefins," a class of hydrocarbons

Polypropylene is a thermoplastic polymer, used in a wide variety of applications it is unusually resistant to many chemical solvents, bases and acids. Polypropylene can be manufactured to a high degree of purity, making it useful for the semiconductor industry. It is also resistant to bacterial growth, making it suitable for disposable syringes and other medical equipment.

It can be injection molded or fabricated (machined and welded). Other applications are piping, filter material and plastic products that require a higher quality than polyethylene.[6]

4.3.1 Bonding

Polypropylene lacks strong primary bonds of general molecules and instead the attractive force comes mainly from Van der Walls forces and Hydrogen bonds.

Van der Walls Forces: The attractive or repulsive forces between molecular entities (or between groups within the same molecular entity) other than those due to bond formation or to the electrostatic interaction of ions or of ionic groups with one another or with neutral molecules. The term includes: dipole–dipole, dipole-induced dipole and London (instantaneous induced dipole-induced dipole) forces. The term is sometimes used loosely for the totality of nonspecific attractive or repulsive intermolecular forces.[8]

Hydrogen Bonding: A form of association between an electronegative atom and a hydrogen atom attached to a second, relatively electronegative atom. It is best considered as an electrostatic interaction, heightened by the small size of hydrogen, which permits proximity of the interacting dipoles or charges.[9]

5 Conclusion

In Conclusion the Laboratory session was a success in that the objective of exploring the mechanical properties of polypropylene and by extension, thermoplastic polymers was met and the properties determined. Some unforseen issue has arisen in the fact the youngs modulus calculated does not match the youngs modulus value from official sources and this issue has not been rectified. The initial objectives have been met in that the **four properties** to be determined have been found using experimental methods. The outcome of the test has been that students have explored the nature of deformation of polypropylene and been exposed to the chemistry and mechanical properties of polymers.

6 References

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