THE EFFECTS OF RECYCLED POLYPROPYLENE MIXING RATIO ON THE TENSILE STRENGTH OF POLYPROPYLENE

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Thesis submitted in fulfilment of the requirements
for the award of the degree of
Bachelor of Manufacturing Engineering

Faculty of Manufacturing Engineering
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JUNE 13

Polypropylene blending has become an important field in polymer research and especially in the recycling area today. In this research the aim was to reduce the Polypropylene waste problem. Therefore, instead of throwing away wasted or unusable polypropylene to the environment where it may cause harm to the environment and the whole biodiversity, and thus flora and fauna and also the human kind, recycling of the Polypropylene material is done as a solution to this problem. Since polypropylene is a thermoplastic polymer, it is can be reheated and remoulded easily as it has linear molecular structures that become weak when elevated temperature is applied on it. In this research, specimens of dog bone shaped with standard size ASTM D638 are used specifically in order to carry out this research. Mechanical method of recycling this material was carried out where the specimens that are to be recycled are crushed into smaller pieces in the Crusher Machine in order to be melted easily in the injection moulding machine. Recycled polypropylene and virgin polypropylene were then mixed according to the desired mixing ratio and injection moulded into the shape of a standard size ASTM D638 in order to test its Ultimate Tensile Strength (UTS) of the mixed materials. The mixtures were injected with a range of temperature of 210 ^{o}C – 240 ^{o}C throughout the barrel. After the specimens were produced, they undergo Ultimate Tensile Strength (UTS) test in order to determine its tensile strength at maximum temperature according to its contents of mixing ratio or recycled polypropylene and virgin polypropylene. As a result, it is concluded that the specimen with higher percentage of recycled polypropylene that exceeds the percentage of virgin polypropylene obtains high tensile stress at maximum temperature. This is due to the higher amount of recycled Polypropylene that was mixed inside the mixture where it hardens and acts to wrap the mixture and enhancing its bonding forces within the molecular structures of the material. Thus, a higher tensile strength of material was achieved.

ABSTRAK

Percampuran “Polypropyelene” telah menjadi suatu bidang yang penting di dalam kajian polimer dan terutamanya di dalam konteks pengitaran semula hari ini. Berdasarkan kajian ini, tujuan utamanya adalah untuk mengurangkan kadar permasalahan pembuangan sisa-sisa bahan “Polypropyelene” yang semakin berleluasa kini. Dengan demikian, daripada membuang sisa-sisa bahan polimer seperti “Polypropylene” di persekitaran di mana ia boleh mendatangkan bahaya atau mencemarkan alam sekitar serta menjejaskan flora dan fauna dan juga spesis manusia, mengitar semula bahan “Polypropylene” merupakan suatu penyelesaian bagi menangani masalah ini. Oleh kerana “Polypropylene” merupakan salah satu polimer thermoplastik, ia boleh dipanaskan dan diubah bentuk kerana ia mempunyai struktur molekul yang “linear” yang menyebabkan ia mudah untuk merenggang apabila dipanaskan pada suhu yang tinggi. Di dalam kajian ini, spesimen berupa “dog bone” yang mempunyai saiz standard ASTM D638 digunakan semata-mata untuk kegunaan di dalam kajian ini sebagai spesimen ketika menjalankan ujian. Kaedah mekanikal digunakan bagi pengitaran semula bahan kajian dijalankan di mana bahan yang akan digunakan sebagai bahan kitar semula di hancurkan di dalam mesin penghancuran untuk mendapatkan saiz yang lebih kecil untuk memudahkan proses pengacuan suntikan dijalankan. “Polypropylene” yang telah dikitar dicampur dengan “Polypropylene” tulen dengan kadar nisbah yang tertentu dan di masukkan ke dalam mesin pengacuan suntikan untuk menjalankan proses pengacuan suntikan tersebut untuk mendapatkan bentuk “dog bone” tersebut bagi menjalankan ujian kekuatan tegangan dengan menggunakan mesin ujian universal. Campuran bahan tersebut disuntik ke dalam acuan dengan kadar suhu antara 210 ^{o}C hingga 240 ^{o}C. Setelah itu, spesimen tersebut diuji kekuatan tegangan untuk menentukan kekuatan tegangannya pada tahap apabila dikenakan daya paling maksimum mengikut nisbah yang ditentukan. Secara keseluruhan, didapati spesimen yang mengandungi peratus “Polypropylene” yang dikitar semula yang melebihi peratus “Polypropylene” tulen menunjukkan kekuatan tegangan yang tinggi berbanding yang mengandungi peratus “Polypropylene” yang dikitar semula yang rendah. Ini kerana, ditahap peratus yang tinggi “Polypropylene” yang dikitar semula akan mengeras dan membaluti campuran bahan tersebut dan menguatkan bon kekuatan antara struktur molekul. Justeru, meningkatkan kadar kekuatan tegangan sesuatu bahan.

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LIST OF SYMBOLS

σ	Standard Deviation
$\overline{X}$	Average or mean

LIST OF ABBREVIATIONS

ASTM	American Society for Testing and Materials
CAD	Computer-aided Design

CHAPTER 1

INTRODUCTION

1.0 BACKGROUND OF RESEARCH

Polypropylene plastics or also known as polypropene, are materials that are used worldwide since the 90's century. The main source of synthetic plastics is crude oil. Besides that, coal and natural gas are also used in producing this material. Unlike metals, they are light, easy to manufacture, resistance to water, low in cost production, resistance to corrosion and chemicals. Polypropylene plastics are widely used in our daily life as kitchen utensils, in toy productions, as insulators for electrical devices, as our daily attire and also in industrial sites as safety equipments. They play a huge role in reducing the world's economic growth where they are low in cost production and can be easily produced.

Since Polypropylene is widely used today in industries and also at home, the production of polypropylene has increase drastically over the years with increasing production of polypropylene made products. This increase in polypropylene productions also increases its waste productions, which then becomes a threat to the environment when the wastes are not decomposable. In addition to that, it was found that not many researchers have put their effort into solving this issue as a solution in solving the increasing of polypropylene wastes that is now acting as a threat to both human kind and the whole biodiversity.

As to this, this research was done to widely explore the effects of mixing recycled polypropylene with virgin polypropylene towards its mechanical property of Ultimate Tensile Strength (UTS).

1.1 PROBLEM STATEMENT

The usage of polypropylene in the production of plastic products today has spread throughout many industries in the world. Since polypropylene plastic presents more benefits to the users around, industries use more polypropylene materials for their production. Industries today tend to use polypropylene material up to more than the required amount. This causes the wastes of this material to be thrown without any proper usage of the heated waste materials. The wastes materials are stated as non-usable waste which useless to the industry. Throwing away the wastes may be harmful to the environment since polypropylene materials do not degrade in the near future. The non-degradable polypropylene wastes may also harm the human health as it is not kept in a proper storage but instead, thrown away in the sewers or brought to recycling centres to be recycled.

Therefore, polypropylene plastic products are the major contribution to the pollution in the world today. Its characteristic which cannot be able to degrade becomes harmful to the consumers as it cannot be eliminated in any way. Burning polypropylene in order to eliminate it may be more harmful to the consumer as the gas released by burned plastic is toxic to the human being, thus leading to a major crisis to the whole environment. As to this, the recycling of polypropylene plastic products is one of the factors in reducing the amount of wastes polypropylene materials that is produced every day. However, until today, the research on the mechanical properties of recycled polypropylene is not widely explored in open literature. Besides that, not much input of the properties of the recycled products either in mechanical or physical properties is comparable with the pure polypropylene materials. Thus, the study on the mechanical properties of the recycled polypropylene product is necessary.

1.2 PROJECT OBJECTIVE

The main objective of this project is:

a) To design and fabricate a mould of standard size ASTM D638 for the purpose as a specimen in this research by using Autodesk Inventor and AutoCAD software.

b) To study the effects of mixing percentage of recycled polypropylene with virgin polypropylene to the mechanical properties in terms of tensile strength by carrying out Ultimate Tensile Strength (UTS) test on specimen.

c) To determine the optimum range of mixing percentage of recycled polypropylene to virgin polypropylene in terms of the highest Ultimate Tensile Strength.

1.3 PROJECT SCOPE

This research is focused on carrying out tests and analysis in determining the percentage of recycled Polypropylene that is suitable to be mixed with virgin Polypropylene and analyzing mechanical property of Ultimalte Tensile Strength (UTS) or in other words, tensile strength. The tensile strength is tested by using Universal Testing Machine (UTM) with an American Society of Testing and Materials (ASTM) standard for a mixed recycled polypropylene and pure polypropylene of D638. The tests and experiments are carried out in the laboratory located in Faculty of Manufacturing Engineering, Universiti Malaysia Pahang.

CHAPTER 2

LITERATURE REVIEW

2.1 INTRODUCTION

The purpose of this chapter is to provide a review of the past research efforts related to the recycling of polypropylene; its mechanical method and procedure and the properties of recycled polypropylene mixed with virgin polypropylene. A review of other relevant research studies is also provided. The reviews are organized chronologically to offer an insight to how the past research efforts have laid out the initial groundwork for subsequent studies, including the present research effort. The review is detailed so that the present research effort can be properly tailored to add to the present body of literature as well as to justly the scope and direction of the present research effort.

2.2 POLYPROPYLENE

2.2.1 History of Polypropylene

For over thirty years after the discovery of stereoselective olefin polymerization in 1954, the world ‘polypropylene’ has meant, both scientifically and commercially, little else than the predominantly isotactic polymer achievable with the classical heterogeneous Ziegler –Natta catalysts. The picture, however, has changed dramatically in the last 15 years, due to the development of a variety of new transition metal catalysts with tunable structures and selectivities. Today, ‘polypropylene’ means a whole world of innovative polymers with novel and well-controlled microstructures, and –as a result- tailored properties and applications.

2.2.2 Molecular Structure of Polypropylene

Polypropylene is a thermoplastic polymer that is able to become pliable or mouldable above a specific temperature, and returns to a solid state upon cooling. Compared to thermosetting polymers, thermoplastics have high molecular weight, whose chains associate through intermolecular forces. Thus, this specific property of polypropylene enables it to be remoulded because the intermolecular interactions spontaneously reform upon cooling and enabling it to form reversible chemical bonds during curing process.

Polypropylene as a thermoplastic polymer has a linear molecular structure that enables it to soften when heated due to the weak molecular chains of the polymer. When heat is applied, the intermolecular joints break and molecules move in relation to one another and when cooled, these bonds or joints are restored. This allows polypropylenes to be recycled indefinitely until the polymers are broken down to the point that the material loses structural integrity.

From a microstructural point of view, as a polymer, polypropylenes are much more complex than metals and ceramics. On the contrary, they are cheap and easily processed. Polypropylenes have lower strengths and moduli and lower temperature-use limits than do metals or ceramics. Because of their predominantly covalent bonding, polypropylenes are generally poor conductors of heat and electricity. Polypropylenes are more resistant to chemicals than are metals, but prolonged exposure to ultraviolet light and some solvents can cause degradation of a polypropylene’s properties.

The molecules in polypropylenes are gigantic as they are often referred to as macromolecules. Within each molecule, the atoms bound together by covalent interatomic bonds. Polypropylene molecules are characterized by their very large size – a feature that distinguishes them from most other organic chemical components.

Polypropylene was born in Milan, Italy on March 11, 1954[1] . Polypropylene or also known as polypropene has a molecular formula C_3H_6 . Other than ethylene, it is the simplest alkene, but in the parlance of the polypropylene industry is more commonly called an olefin. Polypropylene may be polymerized through the action of catalysts. To obtain satisfactory quantities of strereoregular polypropylene, polymerization must be conducted under proper conditions using a transition metal catalyst and a metal alkyl cocatalyst. Other catalyst (free radical, cationic, etc.) typically produce low molecular weight amorphous polypropylene that is of limited commercial value.

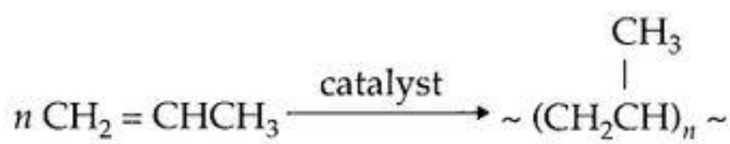

Figure 2.1: Action of catalyst [2]

Note that the basic repeating unit of polypropylene contains a primary (1^o), a secondary (2^o) and a tertiary (3^o) carbon atom. Note further that the tertiary carbon atom is a chiral. Several grade of polypropylene are used in food packaging, for example, blown film for candy and snack foods. In Europe, Canada, Japan, the USA, and other developed countries, the resin must satisfy governmental regulations for food contact. Catalyst residues are quite low in modern polypropylene and are considered to be part of the basic resin. In the USA, the resin must be compliant with FDA requirements for food contact, such as hexane extractables. The procedure for registration of polymers with governmental agencies can be complicated and protacted.

Polypropylene is available in dizzying array of compositions with different microstructures, various comonomers, a range of molecular weights, etc, predicated by selection of catalyst, polymerization conditions and other process options. Since 1951, when a small quantity of crystalline polymer was obtained unexpectedly from a laboratory experiment in Bartlesville Oklahoma, stereoregular polypropylene has grown enormously and is used today in megaton quantities in innumerable consumer applications. Though all forms of polyethylene (HDPE, LDPE, EVA, LLDPE,etc.) if taken together, remain the largest volume plastic, a recent analysis suggests that polypropylene is the single largest volume plastic produced globally, exceeding even that of HDPE which is the largest type of polyethylyene manufactured. Global polypropylene production in 2010 was estimated to be about 48 million metric tons[3].

2.2.3 Applications of Polypropylene

Famous with its trade names such as, Herculon, Meraklon, Moplen, Poly-pro, Pro-fax, Propak, Propathane, Polypropylene has properties that are resistant to heat distortion, perform excellently in electrical devices as insulators, has high fatigue strength, is chemically inert, is relatively inexpensive in the market and is also poor resisting UV light . This low in cost polymer acts as a good barrier, has good process-ability and good puncture resistance which enables it to be produced into flexible packaging such as food containers and confectioneries, while it's characteristic of high strength and good surface finish enables this material to be made into rigid packaging such as crates, bottles, caps and closures for beverages and cosmetic applications. Apart from that, Polypropylene is also commonly used in the production of sterilizable bottles, packaging film, television cabinets, and luggages. They are light weighted and rigid, has high tensile strength, acts as an excellent abrasion resistance, are easily machined and cut, acts as excellent thermal insulating materials and has long life span, which enables it to be suitable to be used as other household objects such as plastic cabinets, cups and plastic cutleries.

Polypropylene or also known as polypropene, is a polymer plastic that is a member of the 'polyolefin' (polymers produced from alkenes) family. It is a highly versatile material that has many beneficial physical properties, and most importantly it is also recyclable. In chemical terms, it is a linear hydrocarbon polymer, with little unsaturation. The addition of a methyl group on to the hydrocarbon chain can affect physical properties such as melting temperature. Polypropylene is an extremely versatile material and as such can be used for a wide range of applications. As mentioned previously, polypropylene is tough and yet flexible and classified as semi-rigid. It is extremely resistant to heat, chemicals and fatigue which is suitable in the production of plastic cutleries and food containers.

2.2.4 Mechanical Properties of Polypropylene

Polypropylene's key properties as an inexpensive, lightweight engineering plastic are its tensile strength and stiffness. Crucial to this is its ability to crystallize. This confers strength, permitting the resin to be useful in moulded forms. Crystalline polymers such as Polypropylene has high chemical resistance, high shrinkage, high warpage, high tensile strength and tensile modulus, low elongation, high creep resistance, high in flow of the polymer, is able to withstand a high maximum exposure temperature and has high density.

As mentioned previous, polypropylene is one the materials of thermoplastic polymer with linear molecular structures. As to this, when polypropylene is reheated, the molecular structure becomes weak thus allowing the material to reshape or reform. This characteristic of polypropylene enables it to be recycled into new products after reforming or reshaping process. Below are the estimated results of polypropylene under mechanical forces.

Table 2.1 is the list of mechanical properties of polypropylene and its value.

Table 2.1: The mechanical properties of polypropylene and its values [4].

Mechanical properties	Values
Elongation at break	200-500 %
Elongation at yield	6-200 %
Flexibility (Flexural modulus)	1-1.4 Gpa
Young Modulus	1-1.2 Gpa
Toughness (Notched Izod Impact at Room Temperature)	60-500 J/m

2.2.5 Reheating of Polypropylene

Polypropylene as described earlier has linear molecular structure that enables it to reconstruct its structure when heated. In this case, reheating of polypropylene would mean that it undergoes the heating process in the injection moulding machine before it is injected into the mould. This characteristic of polypropylene enables it be easily produced into new products as the reheating process itself

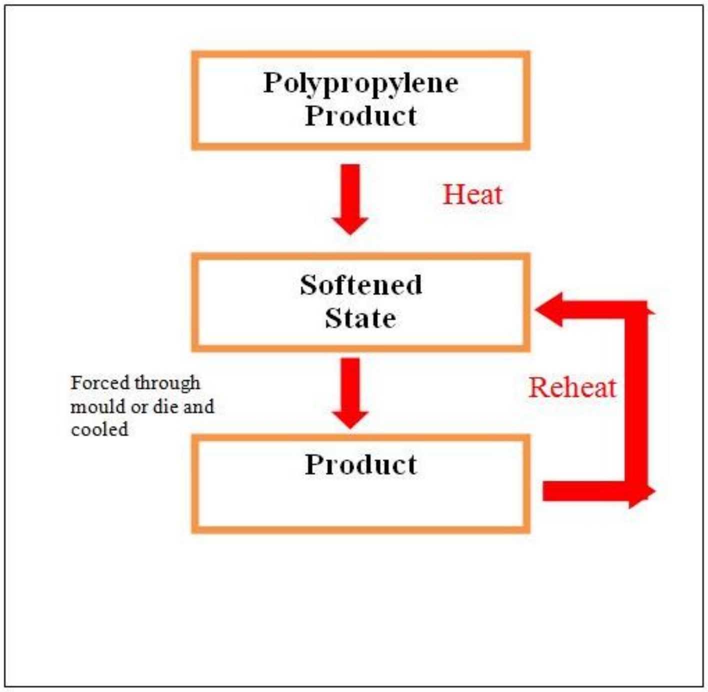

Figure 2.2: The process flow of reheating polypropylene.

2.3 CURRENT ISSUES ON RECYCLING POLYPROPYLENE

Polypropylene plastic products play a significant role in the environment, societal and economic dimensions of sustainable development. Our modern lifestyle would not be possible without plastics. Polypropylene plastics meet the needs of society by enabling the eco-sufficient manufacture of many valuable products. For example, protective packaging, light and safe materials in cars, mobile phones, insulation materials in buildings, medical devices, and important parts for applications as different as renewable energy production and protection in extreme condition. Nonetheless, the production of polypropylene plastics products today has exceed to an almost dangerous stage where the plastics are produce massively without the higher efforts on how to eliminate them as it causes landfills. In the 1970s and 1980s it was feared that the large volume of polypropylene plastic waste being generated would contribute to the filling of all available landfill capacity. Most waste streams, however, contain a mixture of polymers which are costly to segregrate. Two polymers, polypropylene (PP) and polystyrene (PS) are major sources of polymers in municipal solid wastes. In addition, a large variety of catalysts studied previously can be unrealistic from the point of view of practical use due to the cost of manufacturing and high sensitivity of the process to the cost of the catalyst.

Presently, 15% of all rigid plastics and films consumed in Brazil are recycled and return to the production chain as raw material. In this amount of recycled material, 60% is industrial residues and 40% is post-consumer plastic [5]. Recycling is a method to produce lower cost products, reduce the virgin raw-material consumed and reduce environmental impact. Nonetheless, compounding virgin with post –consumer or used polypropylene is not simple and several interactions of non-additive properties may occur. Besides, it is also necessary to add specific antioxidants prior to processing to minimize the degradation reactions.

Nowadays, there are four main approaches to polymer recycling [6]: primary recycling [7], secondary recycling [8], tertiary or chemical recycling [9], and quaternary recycling or energy recovery. A new method based on the dissolution of polymers is being developed. Solvent-based processes include cutting the waste into smaller pieces, treating it with an appropriate solvent such as tetrachloroethylene, filtrating the solution to remove any insoluble contaminants and additives, and finally, recovering the polymer by re-precipitation by methyl cellulose acting as non-solvent and drying. Separating and recycling polymers by this method appears to be technologically feasible and of considerable commercial interest for the following reasons:

- Polymeric waste is converted or reproduced into an acceptable form of manufactured goods.
- Insoluble contaminants and additives can be removed by passing the polymer solution through a far finer mesh screen, leaving pure polymeric material. Moreover, additives can be re-used.
- Solvent-based processes are able to separate plastics from other types of waste and can deal with mixtures of polymers of different chemical nature and polymer blends. This is due to the principle of "selective dissolution".

However, the dissolution process has some disadvantages such as the toxicity of solvents and the related environmental problems, and the energy consumption when the dissolution is carried out at elevated temperatures.

In terms of direct recovery (Primary Recycling), reprocessing in the melt phase remains the most popular recycling technique. It ensures simplicity and low cost, especially when done 'in-plant' and feeding with clean, uncontaminated, single-type plastic scrap of controlled history. However, this routine often leads to degraded products, as during processing use a plastic may undergo chemical reactions that may affect its physical properties. If in some way, these properties are affected to any marked extent the plastic may become unsuitable for its original use.

Apart from that, mechanical recycling is the processing of end-of-life polypropylene plastic products into a re-usable material through a physical rather than a chemical process. Physical processing essentially does not break down the original polymer chains and molecules within the original material. The materials are able to be re-formed into useful new products whilst leaving the material's original structure and properties intact. Mechanical recycling typically comprises the separation of pure fractions of specific polymers into commercially saleable, ready for processing, plastic pellets that the converting industry can use to make new products. The treatment process consists generally of shredding old products down to small pieces, separation units to extract specific sizes or materials from the main material flow (e.g. magnetic drums to separate ferrous metals and sophisticated sorting techniques, like infra-red scanning, to differentiate by colour); and mills and extruders to convert the separated plastics fractions into new machine-ready granules.

Therefore, landfills of these plastic wastes today can be controlled and hence, reduced by recycling the wastes products by using the current technologies used in the world today. This great technology may reduce the chances of petroleum depletion in the near future and thus reduce the landfills in the environment which lead to a safe, clean and healthy environment.

2.4 MECHANICAL TESTING OF POLYPROPYLENE

Recycling of plastic materials such as polypropylene is strategically very important for the environmental policy of industry. This is especially true for high consumption plastics as polypropylene (PP). The key factor to the success of polypropylene is its versatility, which is due to the fact that the structure and properties of polypropylene can be tailored to requirements or in other words, be reproduced.

Fracture toughness, or in other words the ability of the material to withstand failure at a specific period of time acts as a material parameter that implies stiffness, strength and strain to against failure, is of basic importance for application fields in which recycled plastics are subjected to impact and severe safety requirements need to be fulfilled by the designer.

Ultimate Tensile Strength (UTS) test or also known as tensile strength test is one of the most common mechanical tests performed on brittle or ductile materials in order to determine its ultimate tensile strength. For polypropylene, the specimen commonly undergoes tensile strength test on the Universal Testing Machine at room temperature following ASTM D-638. During the tensile strength test, different deformation and fracture miromechanisms develop at the skin and core region of the dog bone. Tensile tested of a polypropylene specimen showed a core region where stress-whitened was developed, whereas the skin layer remained transparent.

2.4.1 ULTIMATE TENSILE STRENGTH (UTS) TEST

Ultimate tensile strength (UTS), or shorter, tensile strength (TS) or ultimate strength is the maximum stress that a material can withstand while being stretched or pulled before failing or breaking. This Ultimate tensile strength (UTS) is commonly found by performing a tensile test and recording the stress versus strain value on the graph where the highest point of the stress-strain curve is the UTS. Since it is an intensive property, the values are not dependent on the size of the test specimen, but dependent on other factors such as the preparation of the specimen, the presence of surface defects, and the temperature of the test environment and material. Some materials will break instantly, without deforming, in what is called a brittle failure such as glass, ceramic and brittle polymers such as Acrylonitrile-butadiene-styrene (ABS) and Polycarbonate.

On the other hand, ductile materials including most metals and ductile polymers such as Polypropylene and Polyethylene will stretch and necking will occur at the point of maximum stress on the specimen as that area stretches out. Tensile strength is defined as a stress, which is measured as force per unit area. In the SI system, the tensile strength unit is pascal (Pa) or often in megapascals (MPa). In this research, the unit megapascal (MPa) was used to measure the tensile strength of the testing specimen under the certain load.

2.4.2 DUCTILITY OF POLYPROPYLENE

In materials science, ductility is a solid material's ability to deform under tensile stress; this is often characterized by the material's ability to be stretched into a wire. In this research, ductility takes place when the specimen is under a certain amount of stress as necking occurs on the specimen. Ductility is linear to elastic behaviour, defined by a linear