



Investigation of the effect UV Radiation has on Polypropylene Polymers

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Abstract

Polymer Plastics are an ever growing popular material, used in various industries from building and construction to house appliances. However, these materials do not come without their downside, degrading due to ultra violet rays. The purpose of this report is to investigate and understand the reason behind UV degrading, how it is being countered and if a concept can be concluded to help tackle this issue. The investigation finds that the most likely and popular Polymer affected is Polypropylene plastic. It also notes that the type of UV that does this damage is known as type B UV. Many research papers state that micro cracking occurs deep in the bonding structure which weakens the material. Therefore, the experiment was to expose samples to UV-B rays and use tensile testing methods to investigate the effect of UVB on ultimate tensile strength. The outcome found that ultra violet does in fact have a large impact of Polypropylene Polymer Plastics and degrades the material more and more over time. The findings show that after just 7 days of concentrated UV-B exposure, the sample material had lost its elastic ability by almost a third (31%), fracture strength reduced by 8.7%, its tensile strength by 5.1% and finally, 4% of its yield strength. Further study directed at plastic UV degrading should look into applying an epoxy coat over the material to see how it slows down the degrading process.

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Chapter 1

Introduction

1.1 Background of the problem

The following report seeks to study and investigate the occurrence of ultra violet Polymer Plastics degradation. Polymer Plastics used outdoors such as garden appliances are known to degrade and discolour over time. The reason for this is the exposure to Ultraviolet Light (UV), which we know reduces the materials properties over time and discolour the surface **(Deanin et al, 1970)**. This issue is costly to manufacturers who use Polymer Plastics where UV light is present and must continuously replace them, such as building and construction, or home appliances. Therefore, coming up with a solution to counter this problem makes this project viable. By doing so manufacturers can be helped economically and environmentally, by removing the need to continuous replace the object, or even enhance the usefulness of Polymer Plastics for uses such as in space (International Space Station) **(Azwa et al, 2013)**.

This UV ray exposure degrades the material such that micro-cracks begin to appear in the bonding structure of the Polymer Plastics which can prove alarming. How and why is this alarming? Plastic Polymers are used in a variety of applications, one of them being space systems as mentioned previously **(Willis, 1999)**. The international space station consists of plastic polymer materials like thermal control coatings or tape and is in an environment where UV light exposure is known to be extremely high, due to the lack of atmosphere which absorbs UV type B and type C rays **(Krishnamurthy, 1995)**. Therefore, in such an environment, micro-cracks which can significantly reduce the mechanical properties of the Polymer can be fatal. So the importance and viability of this project is to improve the life span of Polymer Plastics in terms of UV light degradation which reduces cost and increases efficiency.

However, the problem does not only lie with space uses of Polymer Plastics, we are aware that the Ozone Layer is rapidly becoming depleted because of human factors that affect it. This layer protects us from many harmful UV rays and its depletion means more of these rays manage to pass the atmosphere and penetrate both humans and objects **(Fernandes et al., 2015)**. This issue means that we then need to improve Polymer protection against UV exposure as it is a problem that is increasing as well as on going.

Due to the dependency on polymer plastics, thanks to their light weight and strong characteristics, they are ideal candidates for multiple applications. As such, the improvement of anti UV degradation is highly in demand for the above examples. However, it is noted that work on UV light resistant plastics is not a new topic but one that has been studied. UV plastic stabilization has been a topic of study before. Such methods of UV degradation delay include in the introduction of epoxy coating which is designed to take the damage before it reaches the bonding structure of the material. Nonetheless we will analyse the literature review to find a gap in the knowledge so that the topic can still be explored for further analysis.

1.2 Aims and objectives of the project

To summarise the introduction, the overall aim of this project is to simply study and investigate the occurrence of Polymer Plastics mechanical degradation due to Ultraviolet light exposure. Focus will be put on the reason behind it, how much it actually affects the mechanical properties and to conclude an outcome for further study. So that this aim can be achieved we must set out a number of objectives first, the objectives are as follows:

1. Conduct thorough literature review/survey to research and understand the process and reasoning behind UV degradation.
2. Through research, select a type of Polymer Plastic that is going to be used for examination and UV exposure.
3. Find a gap in the research that could improve UV degradation prevention of this Polymer Plastic.
4. Obtain samples of the chosen Polymer type for experimental procedure.
5. Subject the samples to UV exposure for the selected amount of time.
6. Conduct lab tests of before and after UV exposure.
7. Use a type of destructive and/or non-destructive testing method to quantify findings.
8. Further investigate and amend where possible.

9. Summarise a method by which the Polymer Plastic can better deal with UV light exposure.

Note, the timing plan presented in the following section does not show the same aims and objectives, it displays the overall projects tasks which are different.

1.3 Timing plan (Gantt Chart)

Week No. from 26/09/2016 to 05/05/2017

Activity	w 1	w 2	w 3	w 4	w 5	w 6	w 7	w 8	w 9	w 10	w 11	w 12	w 13	w 14	w 15	w 16	w 17	w 18	w 19	w 20	w 21	w 22	w 23	w 24	w 25	w 26	w 27	w 28	w 29	w 30	w 31	w 32
Re-search/Literature Survey																																
Prepare a project proposal																																
Highlight an issue with UV and Polymers																																
Preparation for the project poster																																
Outline the experimental methods																																
Preparation of interim viva																																
Initial model testing																																
Further adjustments and recommendations																																
Preparation for second poster																																
Final model testing																																
Obtain results and further improve																																
Dissertation writing																																
Project presentation																																

1.4 Structure

Section 2 (timing plan) displays a Gantt chart of the overall project taken. Showing the tasks needed to complete this project and the time scale in which each one was completed.

Chapter 4 begins with the literature review/survey of the investigation. The point of this section is to fully understand the investigation in terms of historical, present and future work. Any scientific study must begin with a thorough literature review to have the background knowledge of what is being studied.

Chapter 5 explains the work carried out of which we will gain results from the investigation. Informing the reader of how we expect to lay out the data, present them to the reader and why. The method of any investigation must be outlined being carrying out the experiment itself. This gives us a direction so that we do not make mistakes or become confused.

The results will be presented in chapter 6 along with an analysis for what we see. Each outcome will be discussed and compared to the other results. Tables and graphs will show us the data in a presentable way so that we can easily compare and see the difference between the results. From this section we should have a clear understanding of what each parameter has contributed and what it means for the study. Finally, a clear outcome with what is the best solution for the problem found from the literature review.

As with all investigations and experiments, the person or persons doing the study may find out that things could have been done better throughout the work. Therefore, a section explaining the recommendations and limitations of the report will be detailed. This will inform the reader of why any mistakes occurred if any, or if the results could have been improved however the facility was not available to do so. Any future recommendations will help lead a future study and reduce the errors made in this study.

The report will close with a conclusion, outlying whether or not this study had succeeded in its aims and objectives, what the findings are of the whole study, what the main points to take from it is and finally, if it has opened up any new questions that require its own investigation.

Chapter 2

Literature review

1.1 Introduction

This section of the report researches, analyses and discusses the various work surrounding ultra violet light radiation and their effects on Polymers. Its purpose is to provide us with a better understanding of the problem, as well as what studies have been or are being conducted to counter this problem. We will explore various scientific reports in detail, which will be the backbone of our own investigation. It will enable us to justify our conclusions, decisions and minimize the scope of the work. The literature review will explore various aspects of UV radiation and materials; once identified a trade-off will help lead the direction of the study. It is essential these steps are followed as a project without a literature review is considered void by reason of ineffective research and no known (or at least evident) gaps of knowledge. Ultimately, we want to identify a gap in the research or at least one that can be explored further.

2.2 Plastics: Material Selection and its Disadvantages

Without argument, plastics are today one of the most popular and used materials. This is thanks to their many abilities including the capacity to be moulded and light in weight (**Freinkel, 2011**). We know this not only from production quantity, but also the amount of plastic being discarded throughout time. In fact, research shows that approximately 15 metric tonnes of plastic were disposed of in 1964 compared to an estimated 311 metric tonnes in 2014 (**Cheun, 2006**). This increase of roughly 95% in half a century shows the scale and growth of plastic use.

Despite this popular usage, plastics do not come without their cons as they are susceptible to ultra violet light radiation. Their atomic structure is prone to deterioration from radiation affects and tend to “break-up” (**Deanin et al, 1970**). “Break-up” referring to the molecular structure of the material (**Hawkins, 1984**). As a result, plastics become seriously weakened after prolonged UV light exposure and can visually be seen from discolouration (**Deanin et al, 1970**). One researcher states: “It is known that urethane type plastics, for example, have basic skeletons which tend to form conjugated double bond, and so they are apt to discolour by UV light” (**Miyamoto, 2016**). Meaning that a particular type of plastics tends to discolour due to their double bond structures, something not all plastics have. As one researcher mentions, a combination of water and UV exposure can lead to the fading of material colour and accelerated corrosion, this is also known as ‘chalking’ (**Wood, 2014**). This plastic behaviour

when exposed to UV light has attracted attention from the building and construction industry that heavily rely on materials such as Polymers(Arora et al, 2014).

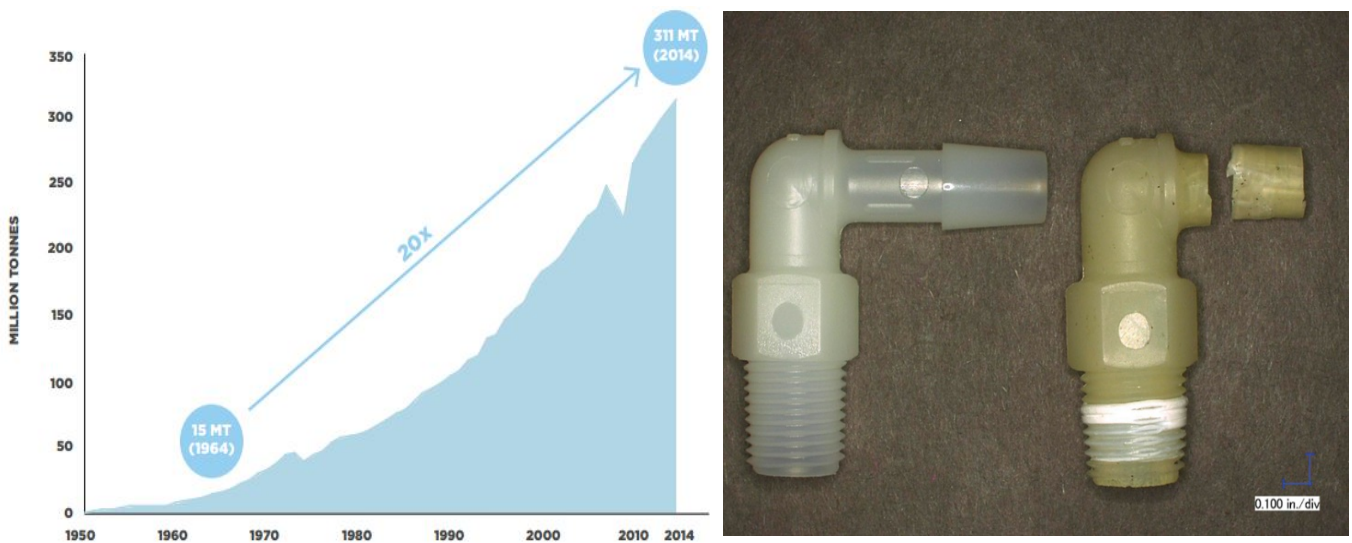


Figure 1 - Plastic waste over time (Cheun, 2006) [left] and Plastic discolouration and weakening example. Connector can be seen to have severe discolouration and broken due to weakness (Janson, 2015). [right].

2.3 Ultra Violet Light

In simple terms, UV light could be defined as being an electromagnetic radiation field with a wavelength range of approximately 100nm to 400nm (Andrady et al, 2016). About 5% of the total sunlight incidence that manages to reach the earth is said to be ultra violet rays (Chaundhary et al, 2014). The energy carried by these rays is much higher than that of the bonding strength of many materials and therefore can easily cause raptures of their molecular chains. Its strength is not only a problem for organic materials and polymers but is also known to potentially cause skin cancer (Loosemore et al, 2015).

It is confirmed that ultra violet light affects polymers such as Polypropylene amongst others, however one scientific paper notes that this degradation occurs within a specific region of UV wave length: “Most Polymers are sensitive to UV radiation in the wave length region between 300 and 360 nm.” (Hawkins, 1984). Generally, Ultraviolet falls within the region 10 nm – 400 nm just under the visible wavelength, however atmospheric absorption leaves just the higher wavelengths whilst the shorter ones are eliminated. The rest is then absorbed strongly by solid materials such as this case, Polymer Plastics (Nave, 2017). We further break down the remaining UV radiation wave length into three subcategories; ‘UVC’ (100-280 nm), ‘UVB’ (280-315 nm) and ‘UVA’ (315-400 nm) (Lucas, 2015). Each type describes the wavelength of the UV radiation which in return translates into the ‘strength’ (or the energy). UVC (which is ‘Type C’ UV radiation) is the shortest wavelength of UV light and hence is

likely absorbed mostly by the atmosphere (**Zhang et al, 2013**). As mentioned by Hawkins' research paper, Polymers are most sensitive within the range of 300 nm to 360 nm and we can then say the subcategory UVB (Type B) is the type of UV radiation that is responsible for Polypropylene degradation (**Hawkins, 1984**).

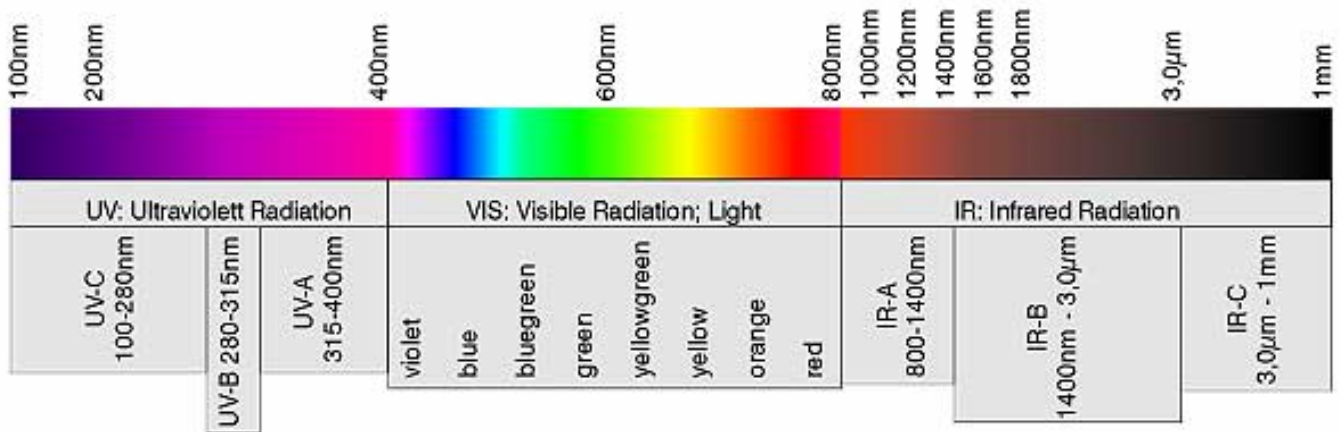


Figure 2 - The wavelength ranges of optical radiation ([Light-measurement.com](http://light-measurement.com))

As previously mentioned, not all ultra violet rays manage to enter the earth atmosphere with some being absorbed such as UV-C. This group, the shortest of the wavelengths, has the potential to cause large scale damage to both humans and natural substances because of their high strength. Thankfully however, this group of rays is mainly absorbed by the Ozone layer, leaving us with the other two sub groups of UV of which we will focus on UV-B(Lindgren et al, 2016).

Despite this, we know that the Ozone Layer is currently disappearing and at a rapid rate. This is because of the impact of human factors such as greenhouse gases and the continuous use burning of fuel, the release of carbon dioxide and so on (Krishnamurthy, 1995). As a result, we may see that Ultraviolet light becoming more of an issue to Polymer Plastics (and other things such as humans) then it currently poses. Therefore, we could expect this range of UV wavelength to change and should adapt to it accordingly.

2.4 Affected Plastics and Polymer Selection

Plastics come in many forms and types, it is important to look into the different types to understand if there is a difference in UV radiation affects and if so, why it may be the case. We note that “urethane type plastics” are mentioned in the previous paragraph when discussing discolouration according to Miyamoto. This indicates to us that a particular kind of plastic that tends to be affected; this can either be an indication that it is affect more so or that other types are not affected at all. Previous study indicates that plastics most vulnerable to UV light exposures are Polypropylene and Polyester due to their bonding structure, with both plastics losing a lot of strength when exposed for long periods of time (**Savage, 2015**).

Our scope is then focussed down to two main polymers affected by UV radiation, for the sake of brevity we must select one for investigation and analysis. Polypropylene is known as a simple chain polymer and due to this simple structure it has a tendency to degrade at a much higher rate than other plastics; rendering this type of plastic unsuitable for applications requiring long-term UV light exposure (**Savage, 2015**). Polyesters too suffer from UV radiation degradation with studies focussing on the stiffness and strength change after exposure (**Moezzi et al, 2013**). Historically, Izod impact tests were favoured to determine this (**Karian, 2003**). However, Polyester consists of a bonding structure not shared with Polypropylene. Two binding “R-groups” means the characteristic of Polyester is different to Polypropylene and as a result can withstand UV radiation much better than Polypropylene

the breakdown	POLYPROPYLENE	POLYESTER	NYLON
	Does not absorb water	Absorbs some water	Absorbs the most water
	Dries faster	Dries slower	Dries quickly
	266°F / 130°C*	Variable but likely around 500°F / 260°C*	490°F / 254°C*
	Less UV resistant	More UV resistant	Somewhat UV resistant
	Moderately resistant to stretching and shrinking	Resistant to stretching and shrinking, resists pilling	Greater stretchability, shrink resistant
	Mildew resistant	Mildew resistant	Mildew resistant
	Floats	Does not float	Does not float

Figure 3 - Polypropylene Vs Polyester Vs Nylon (**Quinn, 2017**)

plastics (**Savage, 2015**).

“Polypropylene is a popular commercial polymer thanks to its mechanical properties, efficient heat resistance, low cost, ease of processing and full recyclability” (**Chien-Lin, 2015**). Hence, the focus will be upon Polypropylene plastics and the effects UV light exposure has on these polymers.

In order to conduct a thorough investigation of UV light effects on Polypropylene plastics, we must begin by understanding the material we are dealing with. Polypropylene (also known as Polypropene) has outstanding properties that make it suitable for many applications, replacing glass, metals, cartons and other polymers for different applications (**Clements et al, 2013**). It is one of the most multipurpose polymers available today and mixtures consisting of Propene compounds include fillers, elastomers and more (**Clements et al, 2013**).

Properties of Polypropylene Plastics

• Low density	• Good impact/rigidity balance
• High stiffness	• Stretchability (film and fibre applications)
• Heat resistance	• High gloss (appearance)
• Chemical inertness	• Easy to weld (design)
• Steam barrier properties (food protection)	• Recyclability
• Good transparency	

*Table 1 - Polypropylene Characteristics Properties of Polypropylene Plastics (**Clements et al, 2013**)*

From Table 1 we can see that its properties make it a useful and popular material to use. Polypropylene is likely to be selected based upon these properties and hence we need to see whether they are maintained after UV exposure. Historical testing focused on impact testing after UV radiation exposure on Polypropylene (**Karian, 2003**). Therefore, as a reasonable examination, we can test the material for changes in stiffness, heat resistance and impact. Other tests that will confirm exposure can be discolouration (visual) and weight difference.

2.5 Material properties testing

Essentially, the investigation is about how ultra violet exposure affects the material properties of Polymer plastics and therefore we need testing methods to find this out. We have understood which plastic is likely affected, why and how, but how are we to quantify this?

Moezzi states in the previous section that stiffness and strength are the main material properties affected once UV exposure occurs **(Moezzi et al, 2013)**.

One of the reasons we see weakness in Polymer plastics after a time of UV exposure is due to the micro-cracking that occurs in the bonding structure of the material **(Azwa et al, 2013)**. These micro cracks can then lead to larger cracks and is the reason for weakness in strength and stiffness **(de Espinosa et al, 2015)**. As strength is one of the most important factor for building materials, we must find out what change UV has on it. The ideal method of testing a materials strength is using the popular tensile strength technique.

A tensile test consists of two mechanical arms which either side of the testing material is attached to. The function of these mechanical arms is to pull the material apart in either direction until it fails under the opposing forces. This will inform us of the materials tensile strength, whether it is brittle, ductile or a mixture of the two properties **(Gharagozlou, 2017)**.



Figure 4 - Tensile testing apparatus

2.6 Theory behind Tensile Testing

The tensile test informs us of the elastic capabilities of a material. It provides us with information such as ultimate tensile strength, Yield strength, fracture strength and Young's Modulus (otherwise known as the Modulus of Elasticity). All parameters can be read simply from the graph but the Young's Modulus needs to be calculated as it is the gradient of the slope. In mathematical form, the formula for Young's Modulus is simply:

$$E = \frac{\sigma}{\varepsilon}$$

Equation 1 - Young's Modulus

Where:

- $E = \text{Young's Modulus} \left(\frac{N}{m^2} \right)$
- $\sigma = \text{Stress} \left(\frac{N}{m^2} \right)$
- $\varepsilon = \text{Strain (Unitless)}$

Stress is defined as force per unit area of a material and therefore the equation becomes:

$$\sigma = \frac{F}{A}$$

Equation 2 - Formula for Stress

Where:

- $F = \text{Force (N)}$
- $A = \text{Area (m}^2\text{)}$

Strain is defined as the deformation of a solid due to stress, the change in length of that material by its original length:

$$\varepsilon = \frac{dl}{l}$$

Equation 3 - Formula for Strain

Where:

- $dl = \text{Change in length (m)}$
- $l = \text{initial length (m)}$

We can then present the Young's Modulus in the form:

$$E = \frac{\frac{F}{A}}{\frac{dl}{l}} = \frac{\sigma}{\varepsilon}$$

Therefore, after unit cancelling the equation for the Modulus of Elasticity is N/m²(Pascal), force per unit area. So this value allows us to evaluate how much force we can apply to a material before failure (per unit area). The following graph shows the tensile testing repre-

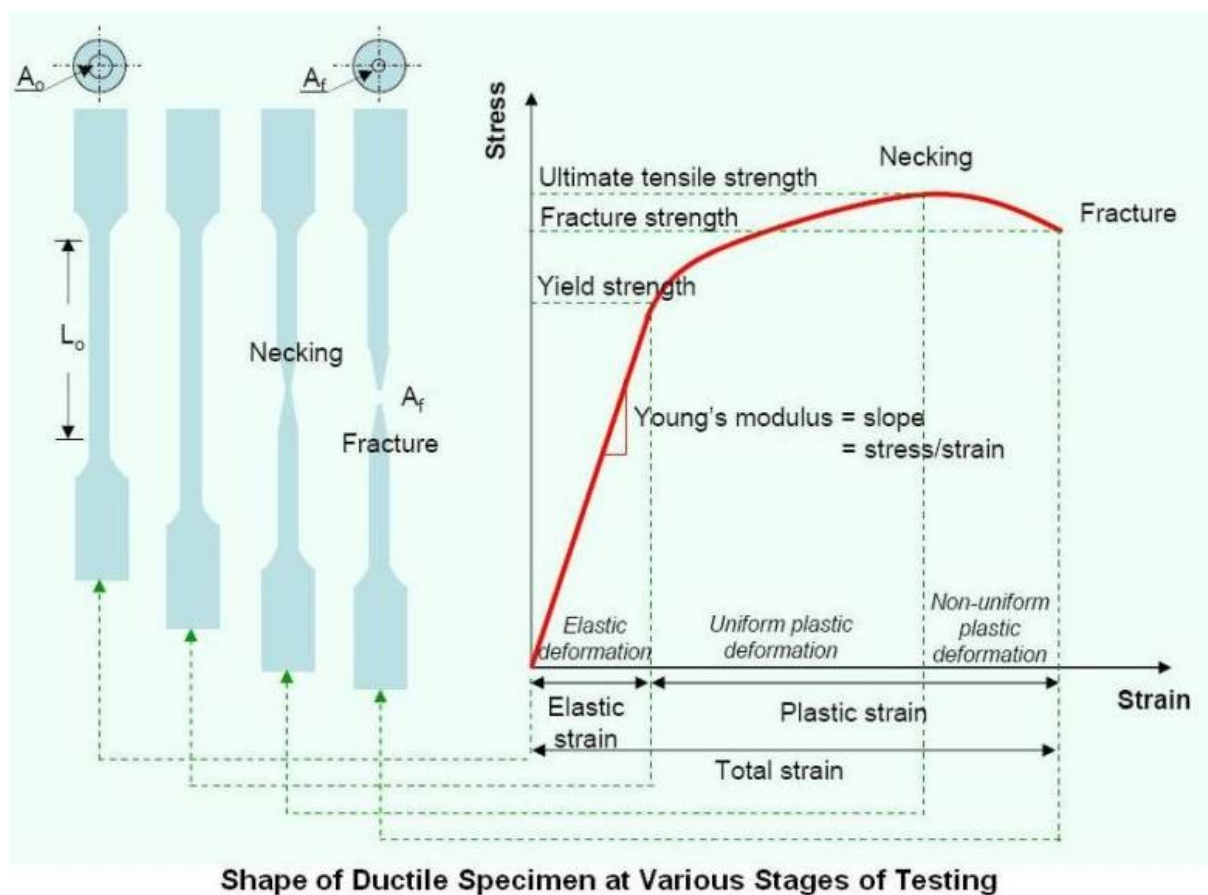


Figure 5 - Example graph of Tensile testing (Shah, 2012).

sensation of a material:

The figure illustrates the behaviour of a ductile material; we know this as the necking section is present for a period before fracture. Brittle materials tend to fracture upon initial necking. The graphs representing the results will be the same and should give us an understand of the UTS (Ultimate tensile strength), yield strength and fracture strength.

2.7 Studies Regarding Polymer Degradation

One scientific publication states: “Radiation-induced degradation is a general phenomenon, responsible for failure of polymers in many applications. Absorption of ultraviolet (UV) radiation during outdoor exposure rapidly degrades most polymers, unless they are properly stabilized. However, there are exceptions, e.g. poly(methyl methacrylate) and polytetrafluoroethylene, that resist this type of degradation by virtue of their molecular structure.” (**Hawkins, 1984**). From the text we are most interested in the mention of stabilization, which suggests there is a method of degradation prevention and that there are exceptions due to molecular structure. We must then focus most on polymer plastics that are affected due to a lack of molecular structure that cannot withstand UV exposure. We know the reason is down to the “molecular structure” which dictates how a material reacts to UV exposure. Finally, we can investigate the many methods used to stabilize plastics currently used.

Work on Polypropylene UV degradation resistance is not new and has been looked at before. In order to come up with a reasonable method of degradation prevention we need to understand what is degrading exactly and why. It is agreed amongst scientists that Polypropylene degrades from sunlight, which exposes the material to heat and ultra violet (in this case we are focussing on UV) (**Cacciari et al, 2003**). Oxidisation occurs within what is known as the “Tertiary Carbon” which reacts with a free radical and then amplifies the oxidisation process (**Cacciari et al, 2003**). Eventually these break up the carbon bonds which are visually seen as fine cracks that increase and become more serious over time, leading to the material “break-up” (**Moeller, 2007**).

One such UV-absorbing additive is known as “Nanoparticle Carbon black proxy coats” which delays UV degradation as much as possible by absorbing what it can before the UV influences the Tertiary Carbon (**Cacciari et al, 2003**). So how does an epoxy coating such as Carbon Black Nanoparticles improve material degradation (or delay it)? One research paper states that “epoxy resins, due to the presence of aromatic moiety (signifying part of a molecule) can absorb UV irradiations and degrade in the presence of UV” (**Ghasemi-Kahrizsangi et al, 2015**). From this we can say that the purpose of this epoxy coating is to absorb the UV radiation that would otherwise affect the molecular structure directly. However, this is not a permanent solution and even the epoxy coatings themselves eventually degrade due to UV, heat and chemical changes (**Ghasemi-Kahrizsangi et al, 2015**); hence this method is a degradation delay and not a permanent prevention. This technique proves that adding a Carbon Black (CB) nanoparticle coat improved degradation resistance as no visible cracks were observed (**Chien-Lin et al, 2015**). However, other researches would argue that cracks will be visible even with an epoxy coat for a given amount of UV radiation

(Ghasemi-Kahrizsangi et al, 2015). The work of Ghasemi-Kahrizsangi tests the method with focus of time of exposure. Carbon Black Nanoparticle coats have also seen to improve the tensile strength of Polymers as well as prevent degradation (Chien-Lin, 2015).

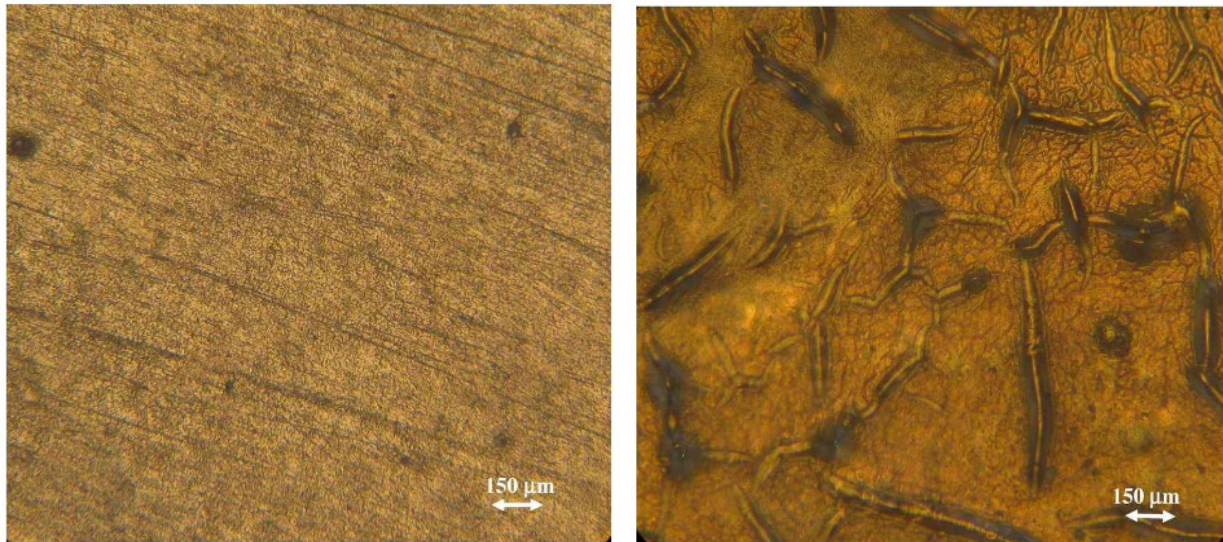


Figure 6 - Epoxy coating after 1000 h UV exposure (left) and Epoxy coating after 1000 h UV exposure (right) (Ghasemi-Kahrizsangi et al, 2015)

Figure 6 shows how the epoxy coating is affected by UV light after 1000 hours of exposure. From the image on the right we see visible cracks on the surface at 150 micrometers which indicates oxidation existence, whereas the left image displays the epoxy coating before exposure. This proves that even the coating itself becomes degraded by ultra violet radiation and is not a permanent fix. Therefore, although epoxy coatings can delay Polypropylene Polymer degradation, it is important to note that different types of coatings may behave differently. The type of coating used for the above figure is known as epoxy Epon Shell 1001 resin, hardened to the material using Polyamide (Ghasemi-Kahrizsangi et al, 2015).

2.8 Summary

The literature review draws up the problem that we have: plastics are becoming more and more popular over time yet have a con that limits their usability and capability; this negative (UV degradation) influences many plastics but namely Polypropylene Polymers in particular; the problem involves the molecular structure of the material which is broken down due to UV exposure; a solution to the existing issue has been introduced yet evidence shows it is not a permanent fix but a 'degradation delay' solution; UV light comes in a range of waves in which Type B is known to be the culprit of the problem ("UV Resistance - Layfield", 2017). Based on these points, the research can now look into other methods of UV degradation

prevention or improvement of existing methods. A solution other than the use of epoxy coating may be implemented or to further delay degradation by method of epoxy coating.

Before an alternative method of UV degradation methods can be investigated, we must begin by applying the literature review into a physical experiment to ensure its reliability and accuracy. This is to be done with the use of a tensile test which will present us with graphical information on its strength properties before and after UV exposure. We can then conclude from this the impact of UV, and further look into applying an epoxy coat for further testing to see if an improvement has been made. For the sake of time, we will expose 2 sets of Polypropylene samples to UV light at different durations. One will be exposed for 3 days whilst the other for 7. Three sets of samples are to be purchased (5 specimens per group) for tensile testing. This is so that we can take the graphs and values to provide an average for reliability and accuracy.

Chapter 3

Work Carried out

3.1 Introduction

This section will outline the methods of carrying out the experiment, the use of any machinery to do so and obtaining the results. We must take into account the uses of any external machinery that is used to obtain data for analysis purposes. It is important this section is included for the sake of understanding and error reduction. It will reduce any mistakes made or any confusion, it also informs the reader of exactly what was done to obtain the results and if the method is reasonable.

3.2 Work procedure

The work carried out for attaining tensile test data and other data is:

1. Purchase 15 pieces (3 sets of 5) of Polypropylene materials for testing.
2. Subject 5 piece directly for tensile testing, loading the samples 1 after the other onto the arms of the tensile testing machine.
3. Once completed, the samples must be removed and the tensile testing machine recalibrated for the next test.
4. Subject 5 piece for UV exposure of 3 days before tensile testing, following steps 2 and 3.
5. Subject 5 piece for UV exposure of 7 days before tensile testing, followed by conducted steps 2 and 3.
6. Obtain data and graphical representations for comparison and conclusion.

In order to expose the materials to UV, a machine to do so was necessary to quicken the process and therefore the use of an Accelerated Weathering Tester was needed. The process of UV exposure was done using this tester, the irradiation of the flat panel was achieved using a bank of 668 W coast wave backlight UV. The wave length of the UV-B lamps had a radiation of 355 to 365 nm in range and a length of 30 cm. Finally, the system had a flat polished aluminium reflector for maximum exposure. This was kept constant for all the materials and only the amount of time exposed was the changing factor.

The tensile test machine is connected to a computer which provides us with the analysis data and presents all the information in tables and graphs. On the graphs we can identify the important parameters such as the Yield Strength, Ultimate Tensile Strength and Fracture Strength. This allows us to easily compare the findings and gives us a visual representation of the findings which is easy to understand.

Chapter 4

Results and analysis

2.2 Introduction

This section will present the graphical data representations of the results found from tensile testing. Analysis as well as a comparison between this data will help us determine what affect UV has had on Polypropylene in terms of tensile strength based on time of exposure. The order of which the results are to be presented should be consistent and therefore will be as follows: graph from Polypropylene without UV exposure, graph from material after 3 days of exposure and finally the graph of the material exposed for 7 days. This should enable us to see a trend in the results as we compare. The graphs and tables are represented into test numbers, where test 1, 2 and 3 are the results of the no UV exposure, 72 hour UV exposure (3 day) and 7 day UV exposure respectively. These graphs and data were collected from the Tensile test machine available in the lab. For all experiments, from figure 7 to 19, the tensile test graphs are presented for each sample one after the other. From them we can see the UTS, fracture strength, yield strength and the elongation on the x-axis. This will help us visually see the behaviour of each sample subjected to tensile forces.

2.3 Tensile test 1 results – No UV exposure

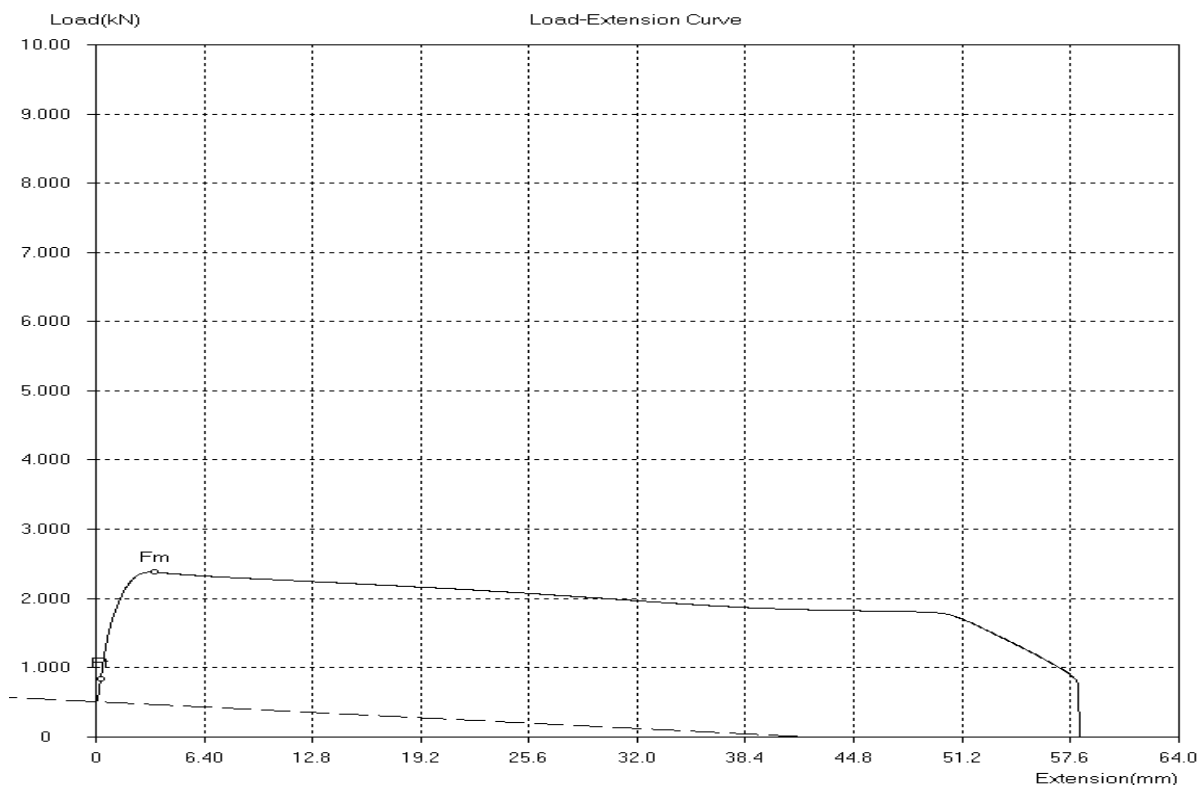


Figure 7 – Tensile test 1.1

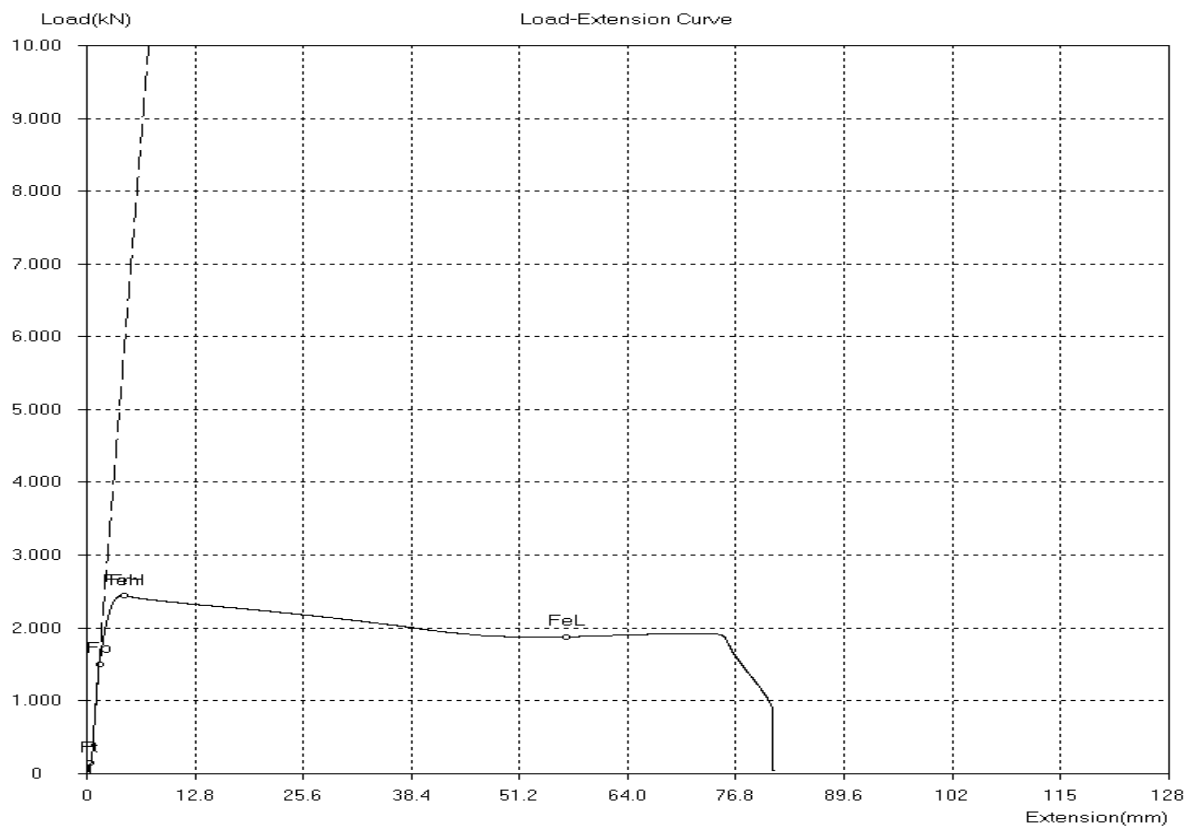


Figure 8 – Tensile test 1.2

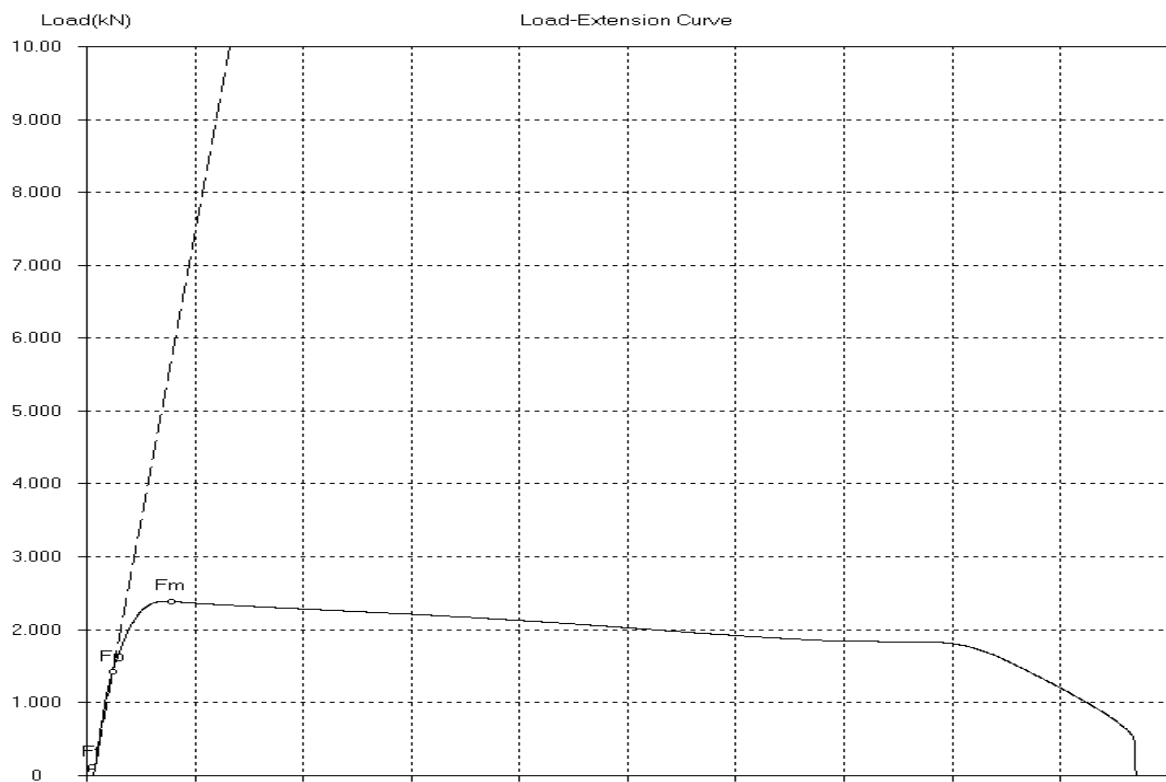


Figure 9 – Tensile test 1.3

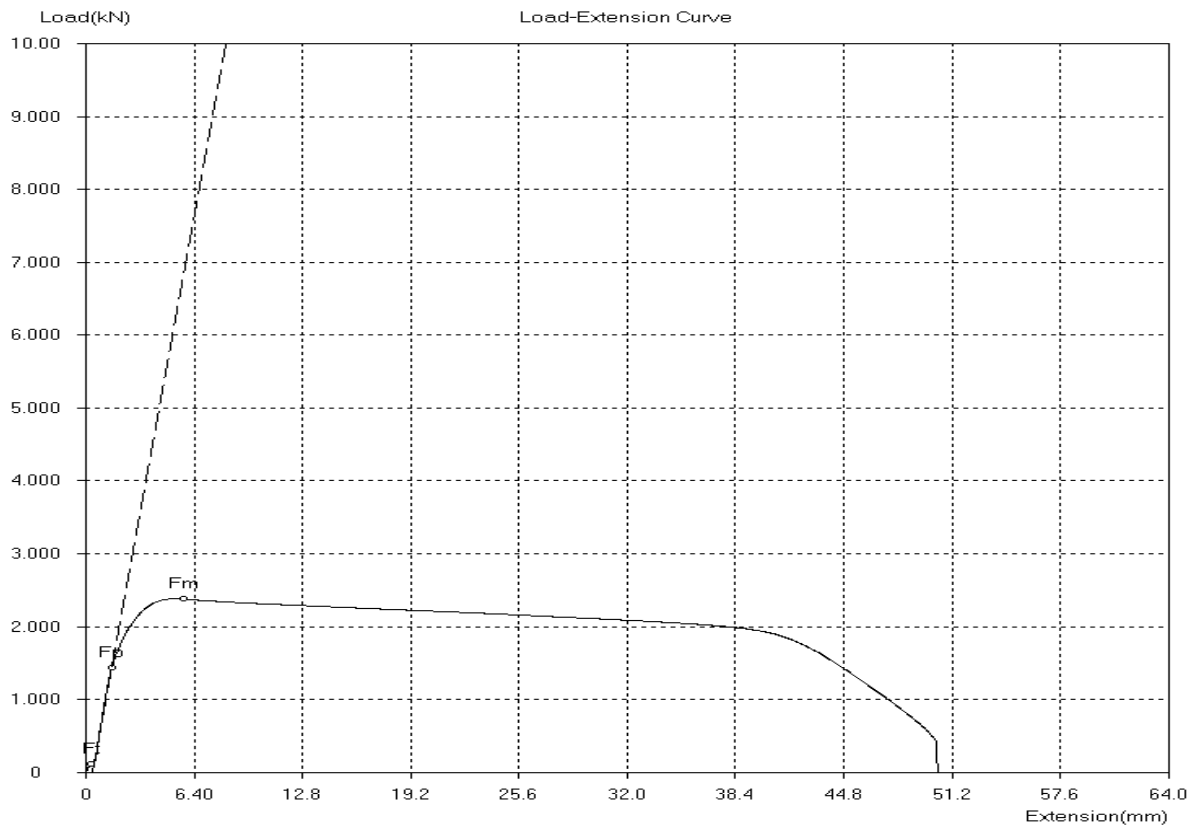


Figure 10 – Tensile test 1.4

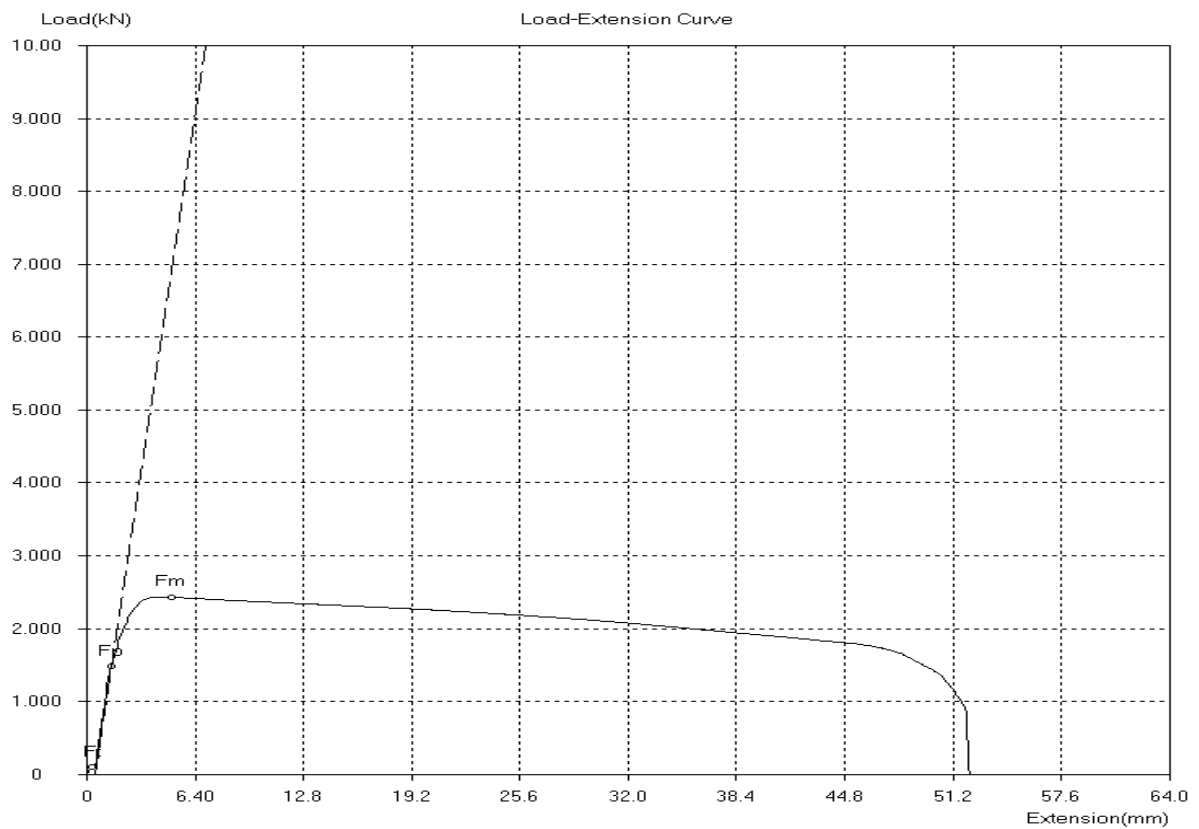


Figure 11 – Tensile test 1.5

	Test 1.1	Test 1.2	Test 1.3	Test 1.4	Test 1.5	Average
Yield Strength (MPa)	376	370	375	380	373	375
Ultimate Tensile Strength (MPa)	480	490	488	487	487	486
Fracture Strength (MPa)	302	290	299	304	295	298
Modulus of Elasticity	12	13	14	13	15	13

Table 2 - Tensile test 1 results

The most interesting outcome from test 1 is the values in comparison to the other two tests. Test 2 shows us a decrease in all parameters when compared to test 1. This trend does continue with test 3 and further decreases from test 2, which is predicted as that test had specimens subjected to UV-B rays for longer. However, the modulus of elasticity on average happens to be unchanged from test 1 (no UV exposure) which is not to be the same as test 2 (72 hour UV exposure). This can be down to the anomalies in the Young's modulus values found in test 1 which are high, giving us a larger average due to this difference.

We also see a difference between the results in elongation value. Although it might initially seem that the elongation values differ greatly, it is the scale on the x-axis of the graph that have changed. However, this change in scale means that the elongation values are not within the same range which should not be the case. For example, Test 1.2 displaying an elongation value of approximately 81 mm whilst test 1.4 shows us an elongation of roughly 50 mm. That is a difference in elongation of 31 mm which is very significant, a 38% difference in result. The reason for this could be a defect in one of the samples used or the way in which it was applied to the tensile testing machine.

Tensile test 2 results – 3 day UV exposure

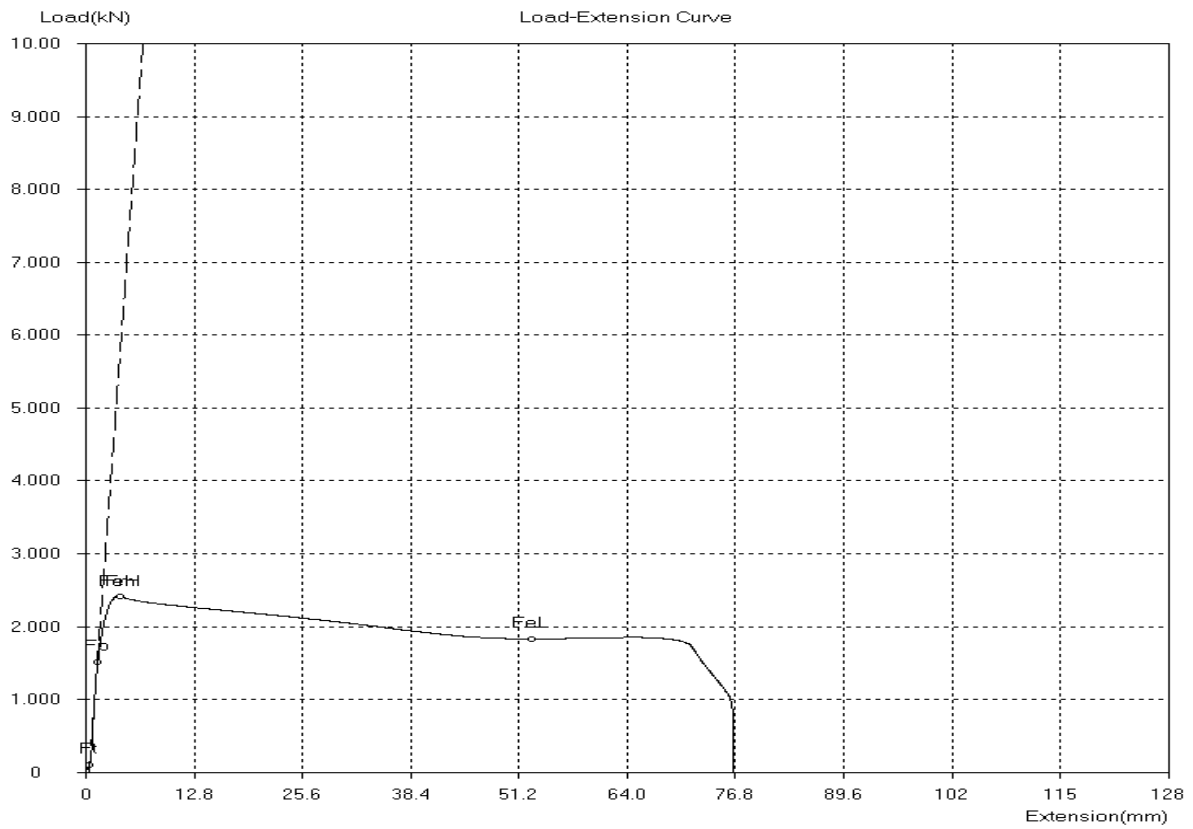


Figure 12 – Tensile test 2.1

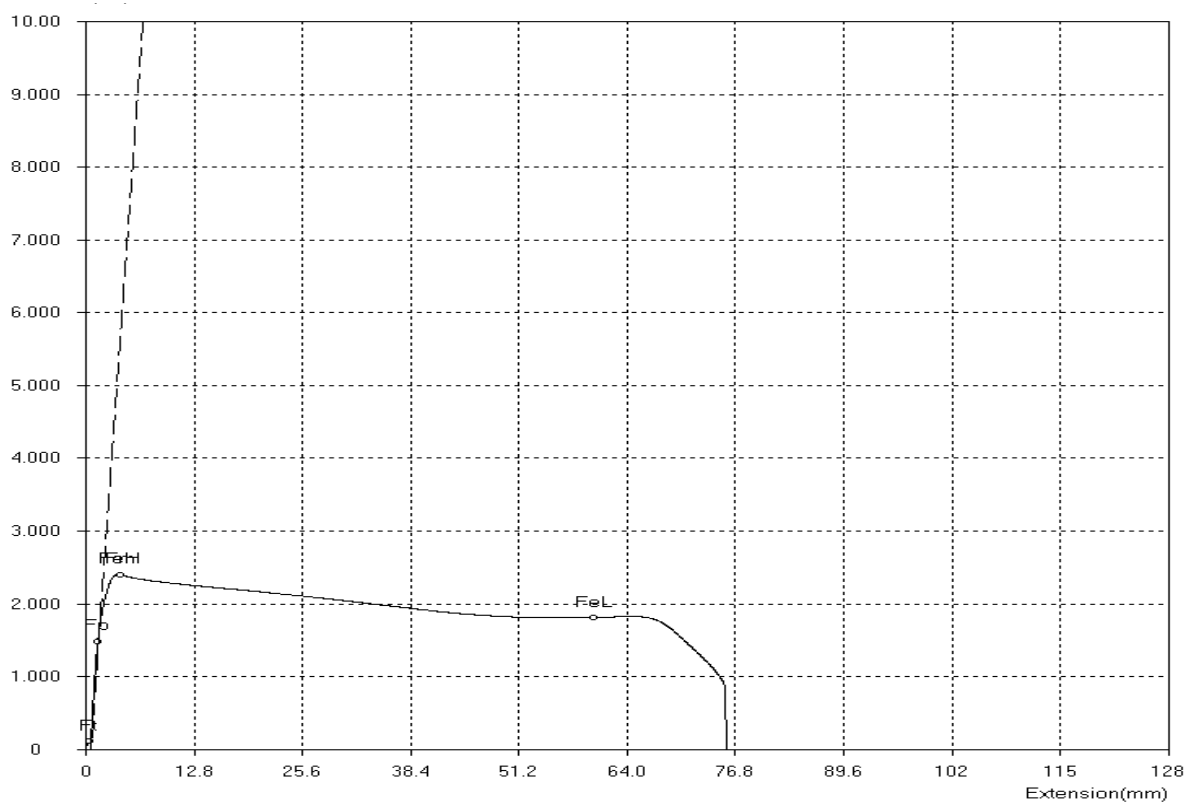


Figure 13 – Tensile test 2.2

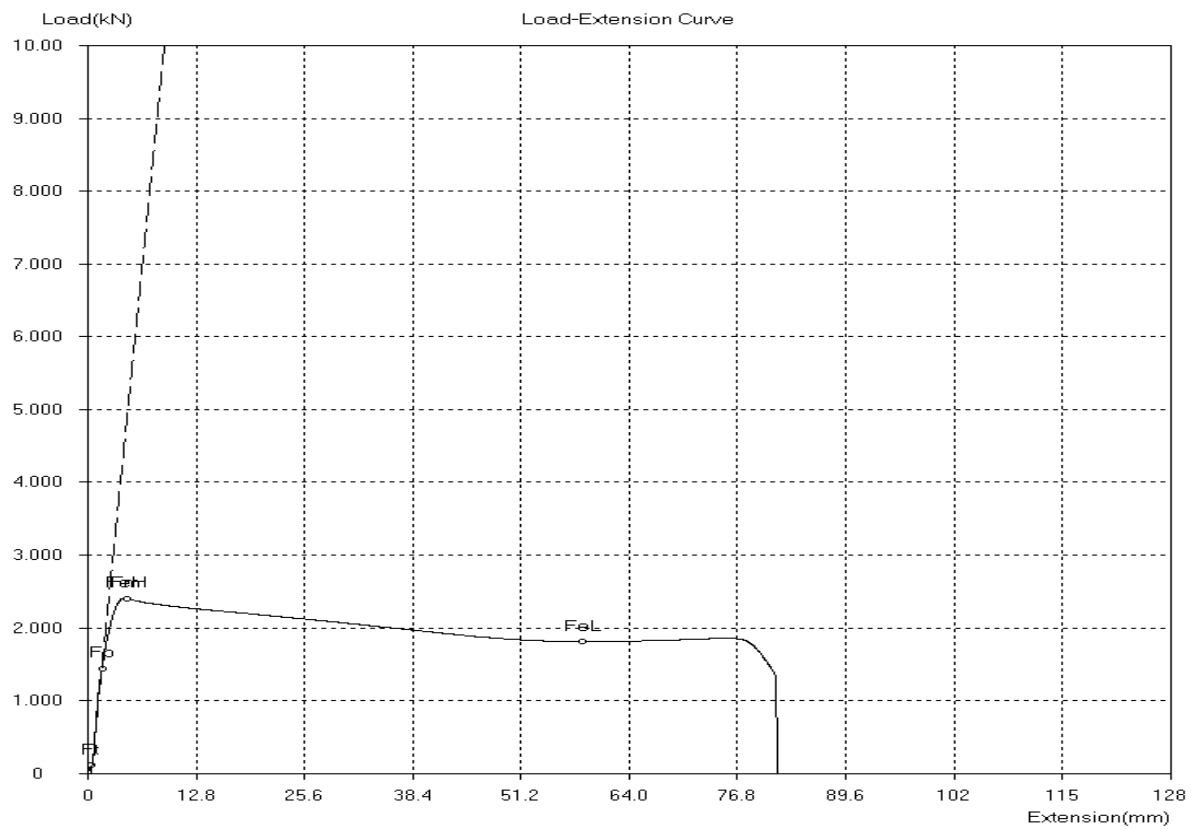


Figure 14 – Tensile test 2.3

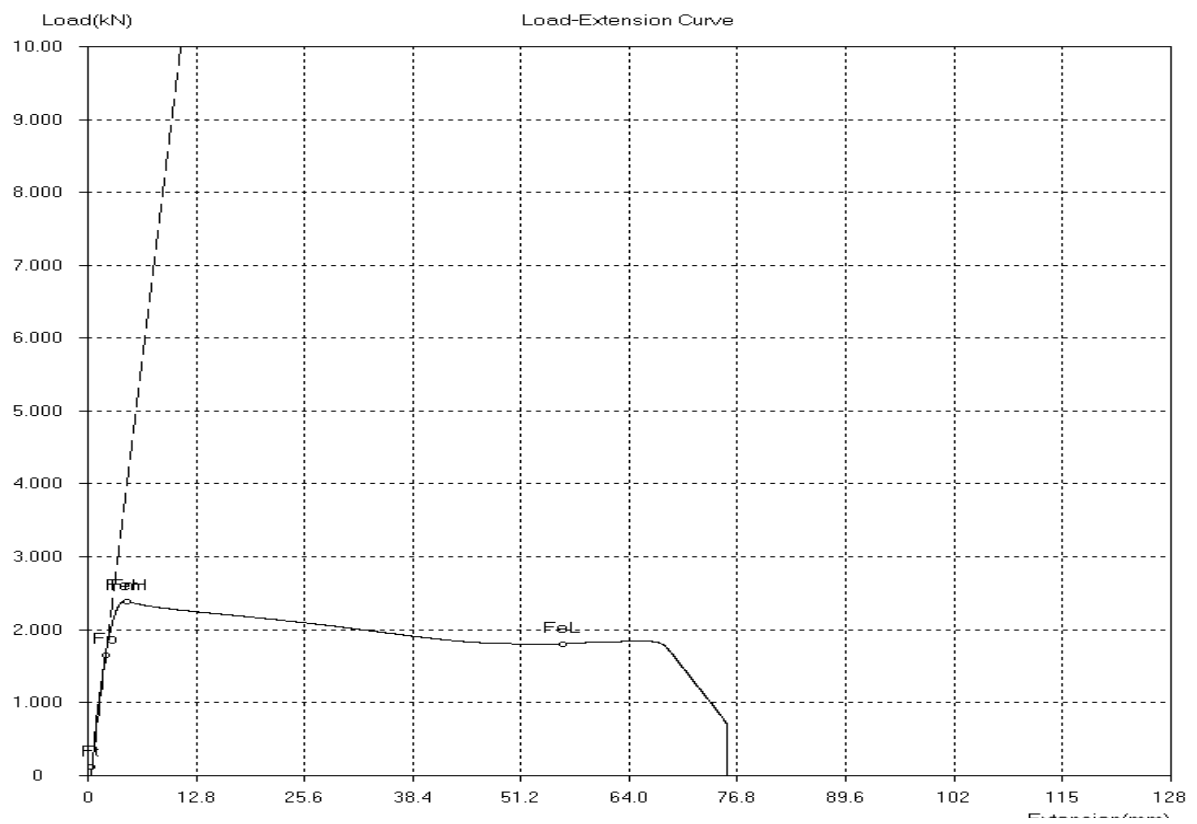


Figure 15 – Tensile test 2.4

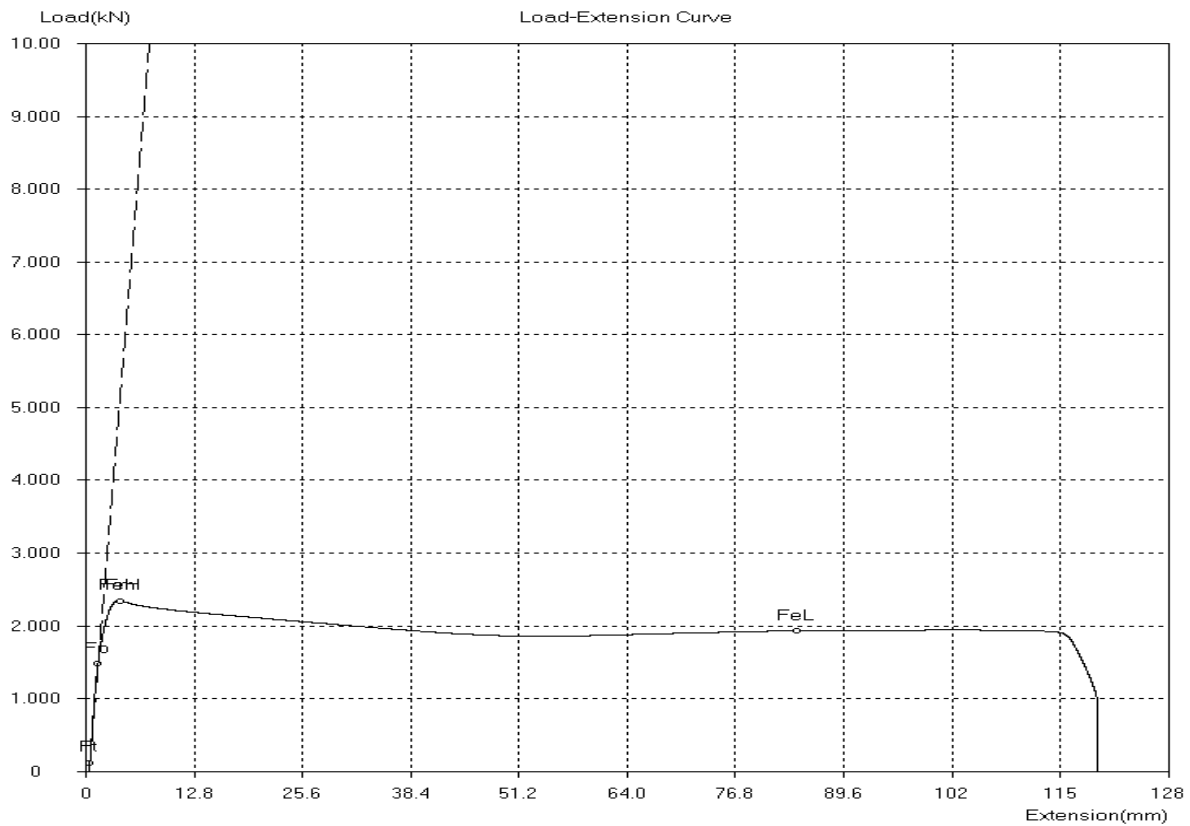


Figure 16 – Tensile test 2.5

	Test 2.1	Test 2.2	Test 2.3	Test 2.4	Test 2.5	Average
Yield Strength (MPa)	366	362	386	361	362	367
Ultimate Tensile Strength (MPa)	482	481	469	478	480	478
Fracture Strength (MPa)	303	288	295	330	296	302
Modulus of Elasticity	16	12	14	9	16	13

Table 3 – Tensile test 2 results

Instantly we can see that there are anomalies in test 2.4, with the stress applied at fracture and the Modulus of Elasticity very different to the rest of the tests. This is one reason why taking multiple tests was necessary. We will not ignore this value and take it as an average with the other results. From looking at the graph of test 2.4, we also notice the extension (or total strain) in comparison to the other tests is prolonged. Another anomaly is found in test 2.3, the stress at yield does not follow the same pattern as the other tests. Other than these two differences, the rest of the stresses are similar and reasonable. Lower values than test 1 is predicted from literature review as the Polypropylene material should lose out on strength as UV exposure causes degrading. However, we note that the average fracture strength is slightly larger than test one because of the mentioned anomaly in the results.

2.4 Tensile test 3 results – 7 day UV exposure

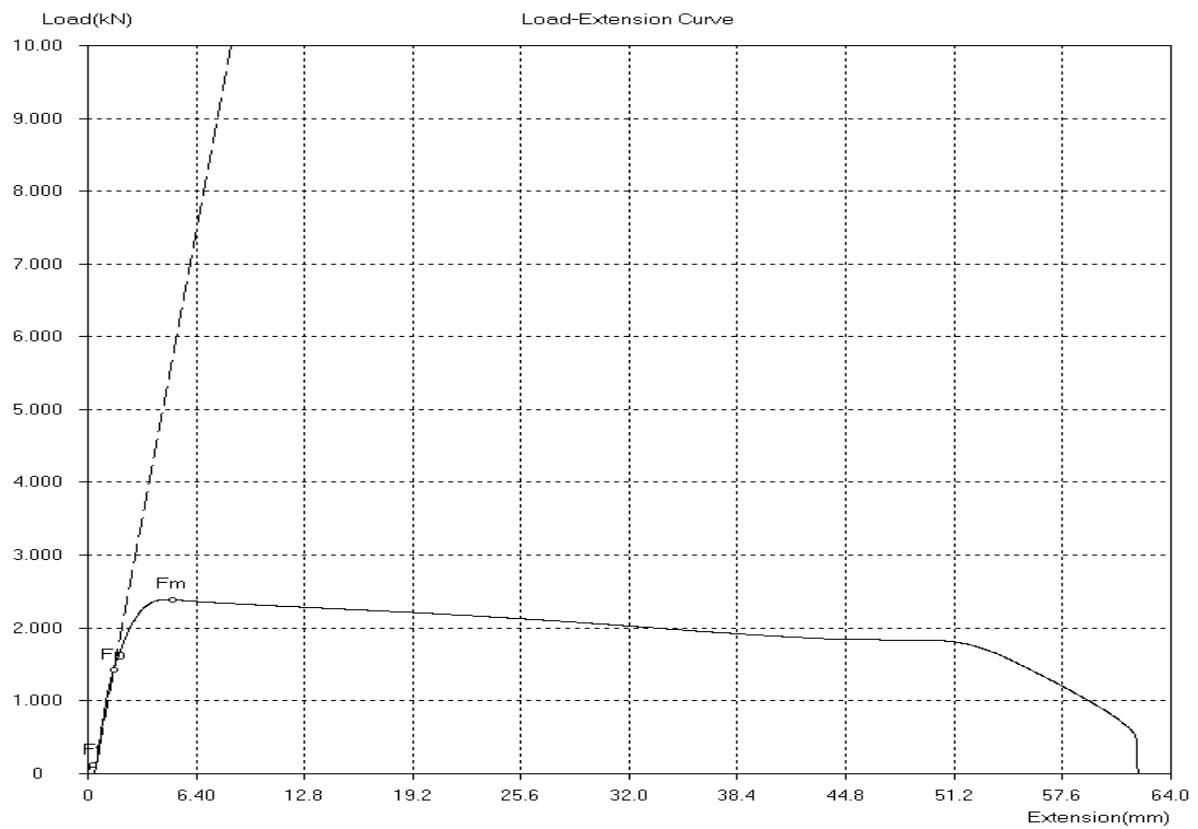


Figure 17 – Tensile test 3.1

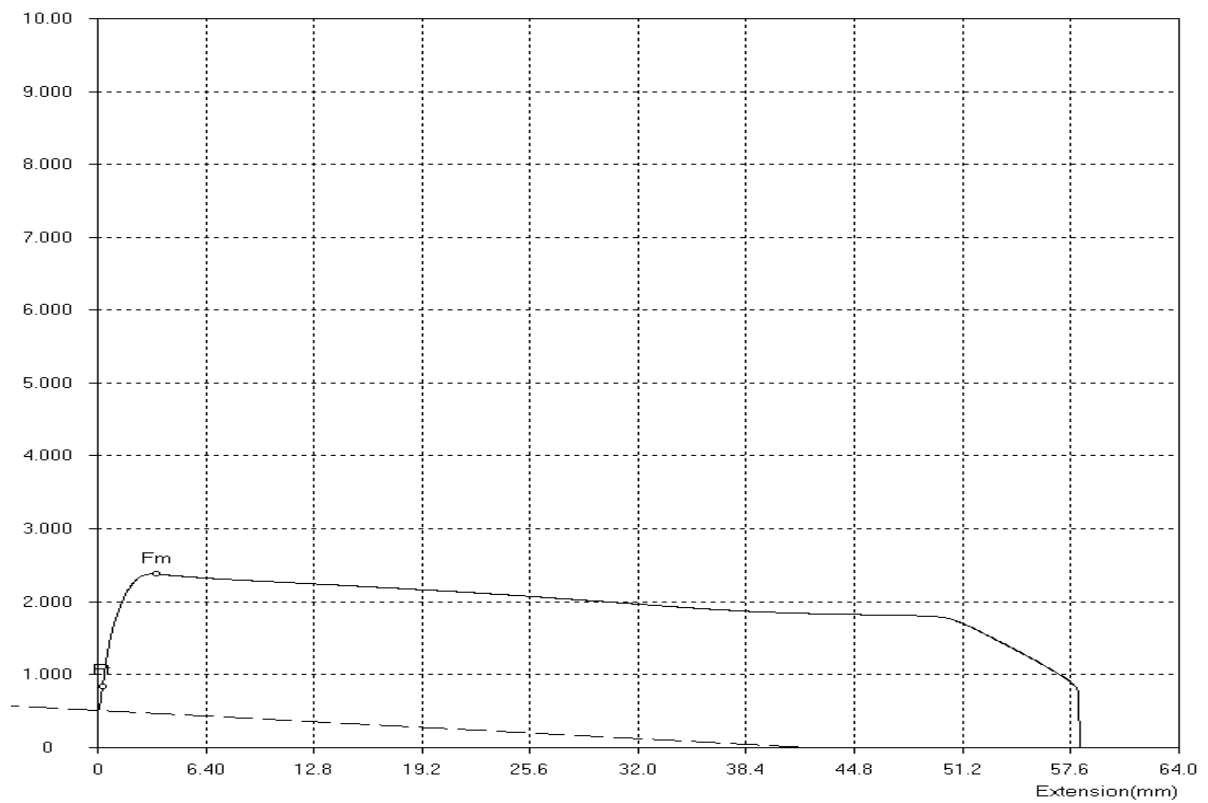


Figure 18 – Tensile test 3.2

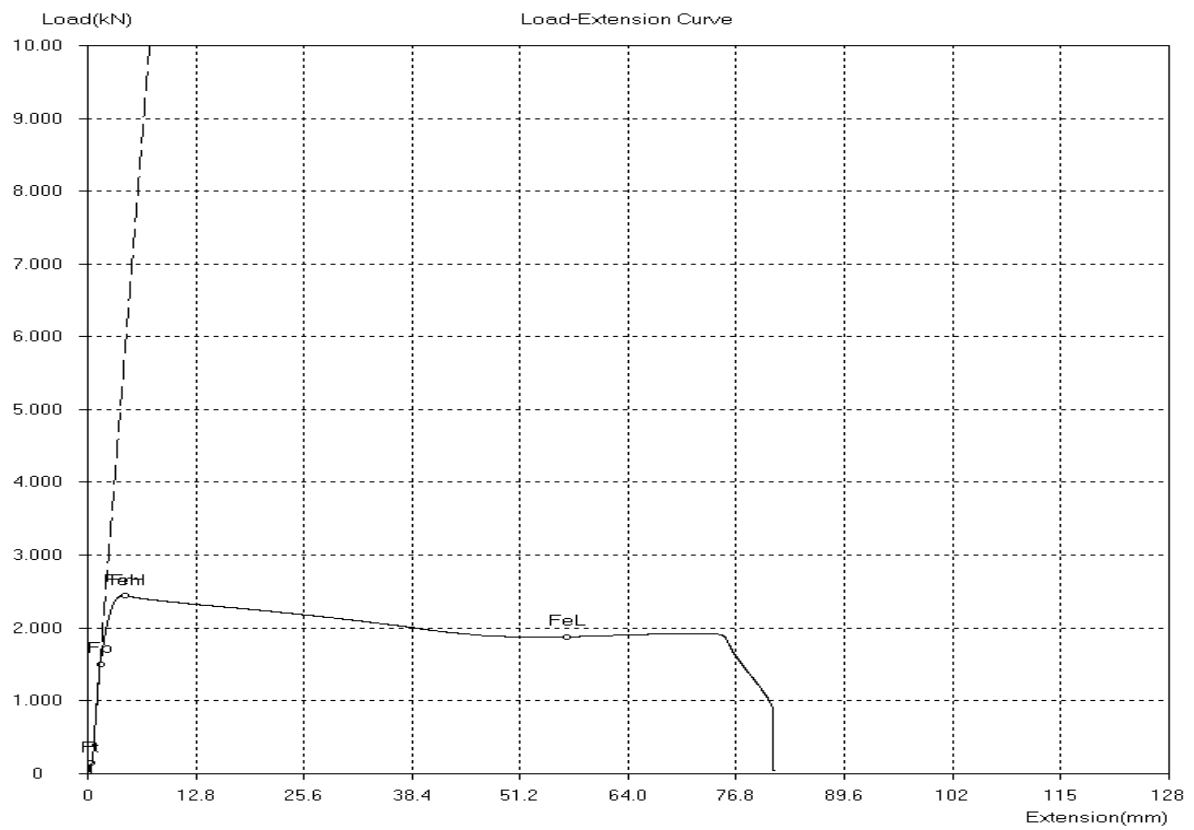


Figure 19 – Tensile test 3.3

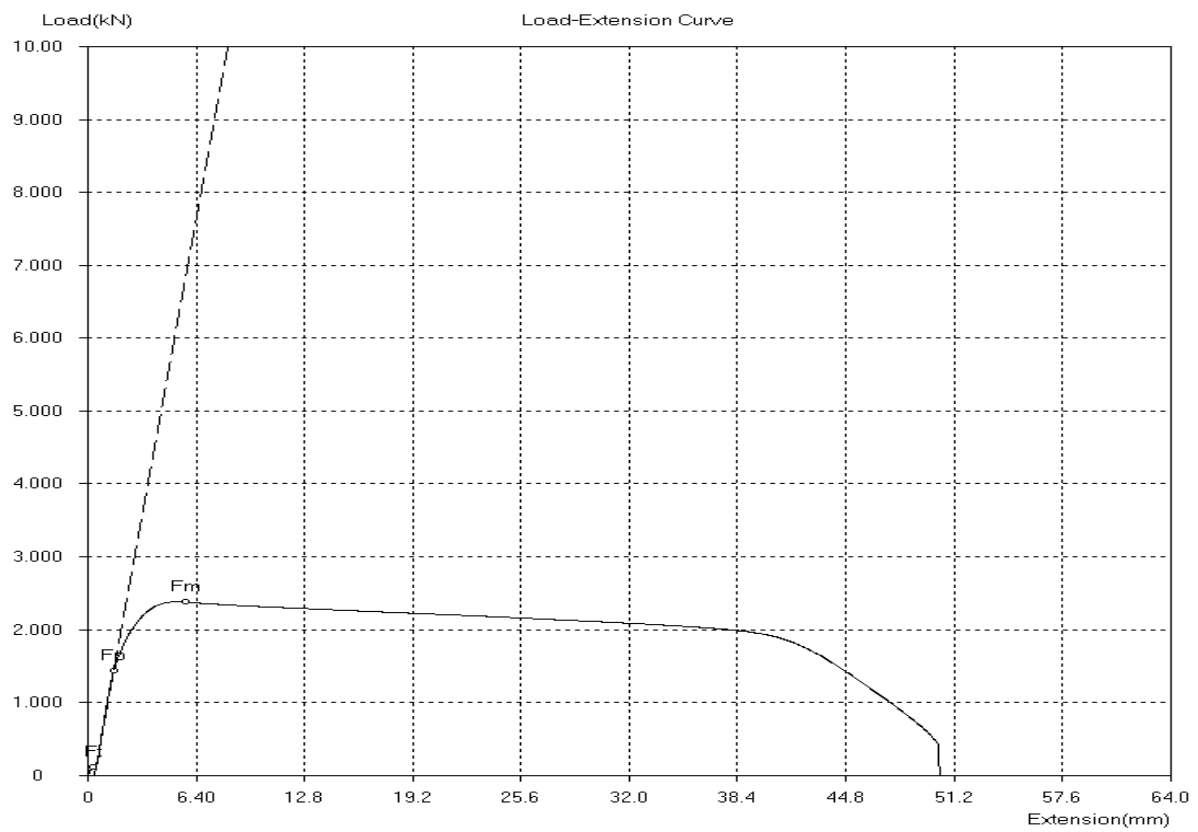


Figure 20 – Tensile test 3.4

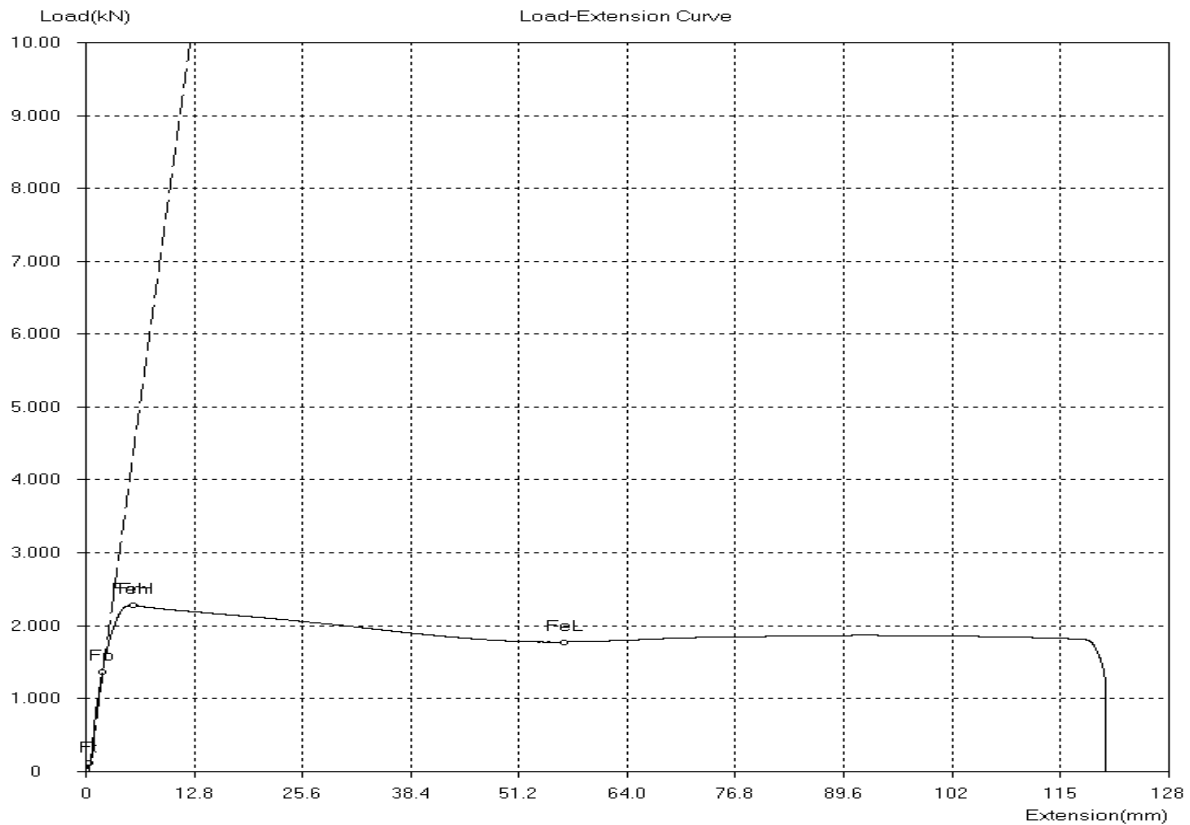


Figure 21 - Tensile test 3.5

	Test 3.1	Test 3.2	Test 3.3	Test 3.4	Test 3.5	Average
Yield Strength (MPa)	368	357	355	358	355	360
Ultimate Tensile Strength (MPa)	451	460	461	463	456	461
Fracture Strength (MPa)	269	274	274	273	272	272
Modulus of Elasticity	11	9	10	8	8	9

Table 4 - Tensile test 3 results

There are no anomalies too obvious in the tests conducted for the 7 day UV exposure types. The results are fairly consistent other than the initial test (3.1). Although the stresses are different it is not to the point where the average results are heavily affected. The average values for all the parameters are lower than the averages for the 3 day UV exposure experiment as expected. This already indicates a difference between the 3 day UV exposure and 7 day UV exposure results and tells us that a further 4 days of concentrated UV-B ray exposure makes a large difference.

Comparing the results

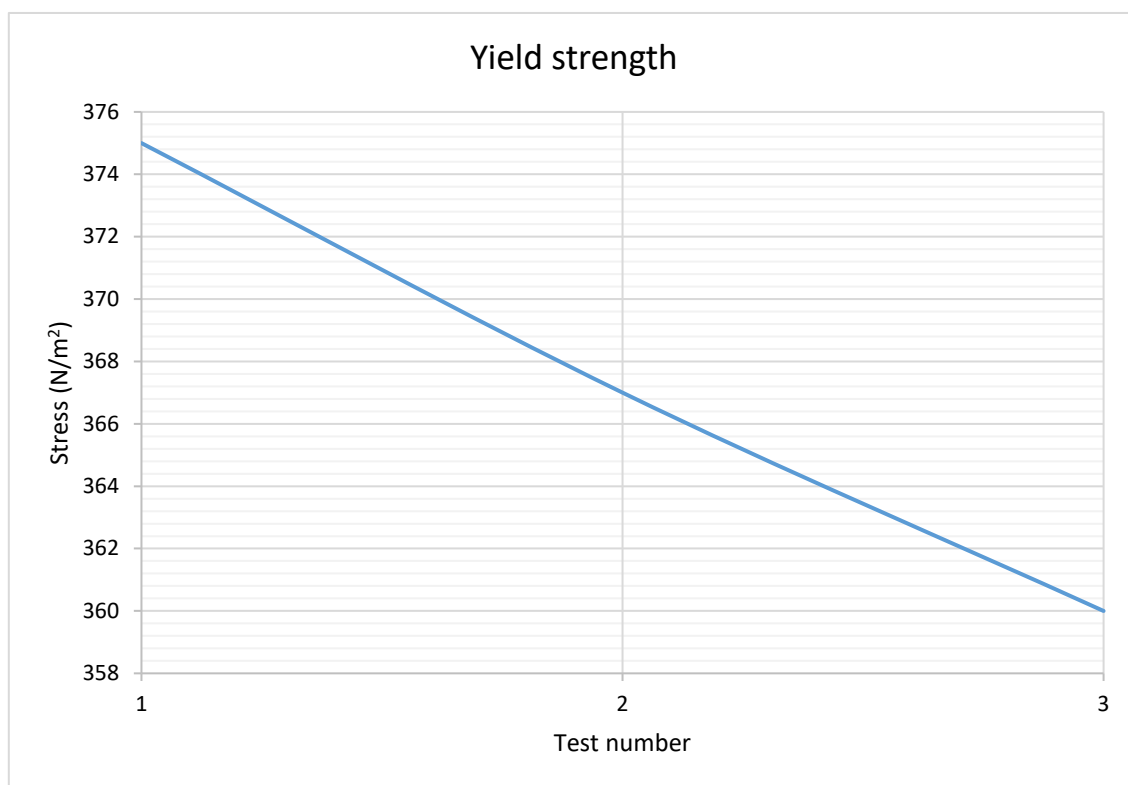


Figure 22 - Yield strength (Stress vs test No.)

The Yield strength is the point at which the material being tested begins to yield. Beyond this point it no longer returns to its original shape and starts to deform. This tells us how much stress a material can handle and still maintain its shape. We notice that after 3 days of UV exposure, the stress at yield is significantly lower, with test 1 and test 2 being 375 MPa and 367 MPa respectively. That is approximately a 2.1% decrease and 8 MPa lower after exposing Polypropylene to ultra violet days for a period of 72 hours. This result means that the material did in fact lose its elastic capabilities after UV exposure, over time it seems that the material can no longer keep its shape when the same stress is applied.

Unsurprisingly, test three does follow the same trend that we expect from the previous result. In fact, test 1 shows us a stress at yield of 375 MPa which is significantly higher than both tests 2 and 3. Test three is a decrease of 4% from the non-exposed which is 15 MPa. It also further decreased its stress from test 2 by 7 MPa to 360 MPa which is 1.9%. This is just under half of the total 7-day exposure. Therefore, we can say that if a further 4 days (which is more than half of 7 days) did not reduce the stress by more than a half (>2%) then the degrading process may be slowing down. This trend will be compared to the other parameters for validity.

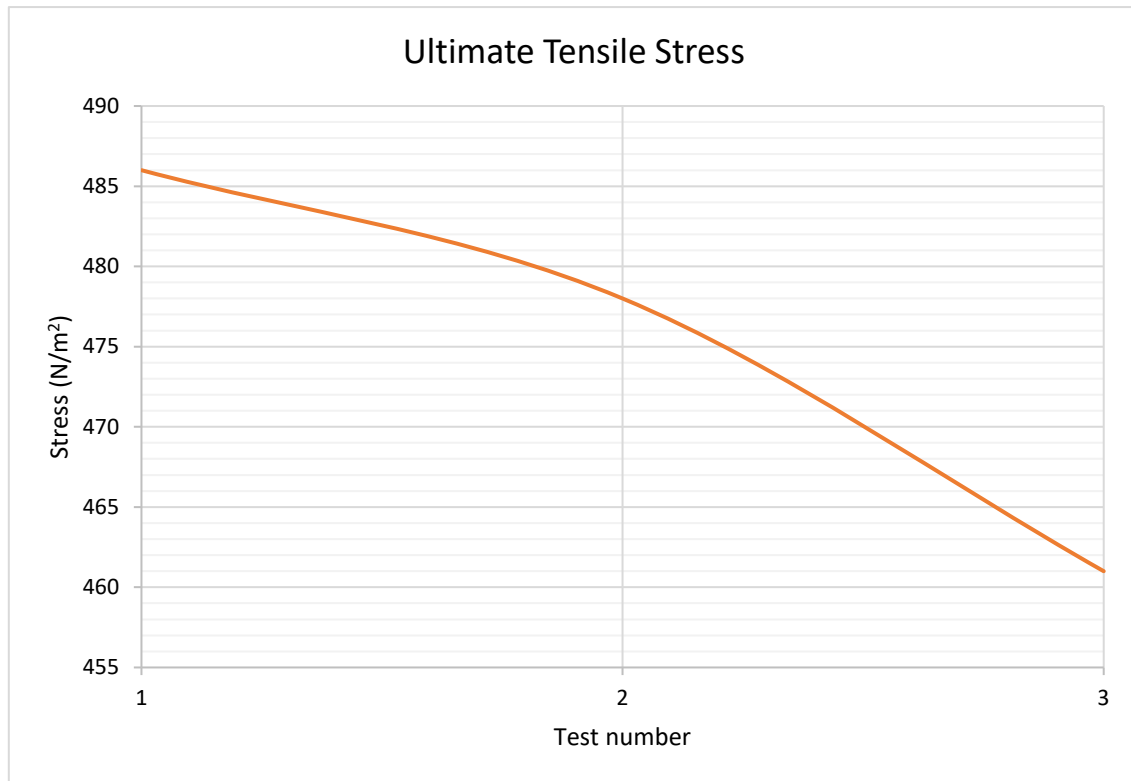


Figure 23 - Ultimate tensile strength (Stress vs test No.)

The ultimate tensile strength informs us of the materials capability of handling stress towards elongation. The maximum possible stress it can handle even beyond yield, before the material breaks. Therefore, it can elongate and have necking present but still withstand stress. Here we see a similar trend line as expected, although not the same gradient. We note that the sample that was not exposed to UV was able to handle more stress than the other two tests but significantly for test 3. This can indicate degradation in material strength after UV as micro cracking can cause the strength of a material to decrease.

In this case we see the UTS of Polypropylene decrease by 8 MPa from test 1 to 2. This tells us that it only took 3 days of concentrated UV-B exposure to reduce its strength by roughly 1.6%. Therefore, theoretically we can assume that we lose approximately 0.5% on UTS daily. Despite this test 3 tells us otherwise. A further 4 day of UV exposure would then mean 2% reduction in UTS (or 10.5 MPa), adding up to 3.6% theoretically, if this theory was correct. But the Polypropylene sample that was subjected to UV for 7 days decreases in strength faster than the 3-day exposure samples had. We know this as the reduction in Ultimate tensile strength is 5.1% in comparison to the initial sample test. This tells us that the rate at which the material degrades by UV is not consistent and may differ from time to time. In its early stages the material loses its strength slowly and seems to rapidly decrease as time goes on. At least this can be said for the ultimate tensile stress of the material and not the yield stress.

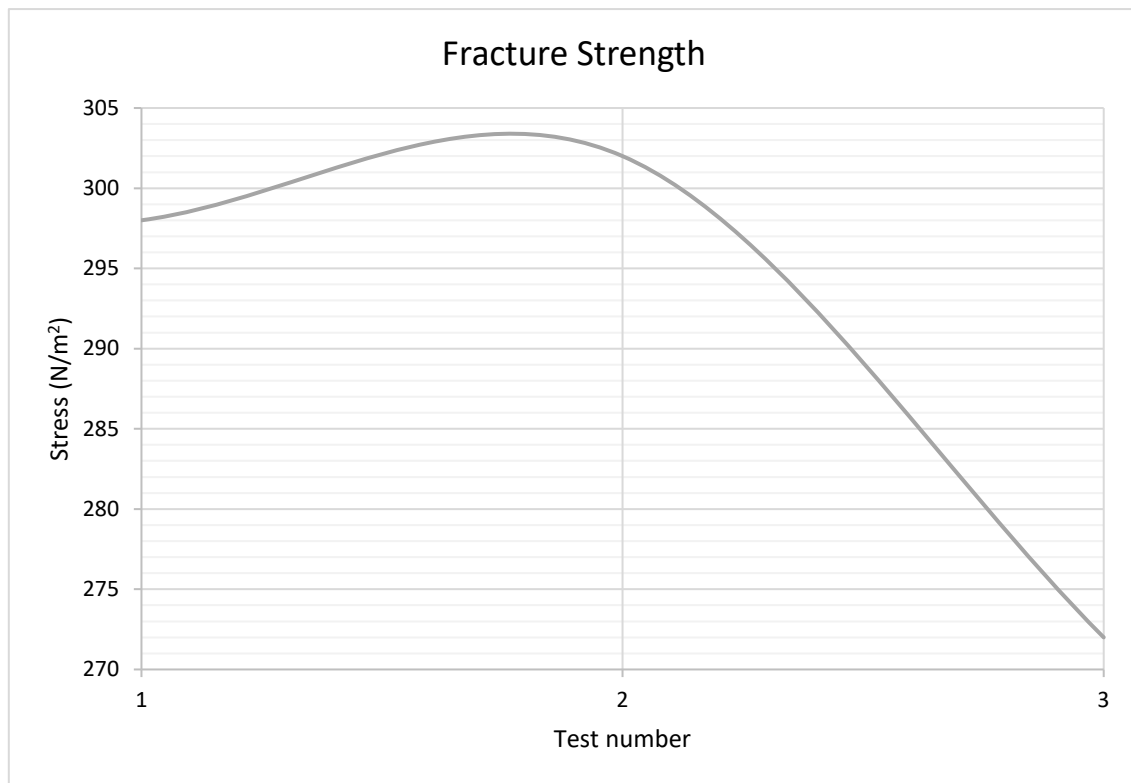


Figure 24 - Fracture strength (stress vs test No.)

Possibly the most important parameter of them all, the fracture strength tells us how much stress the material can take before being destroyed or fractured. That is after the elasticity stage if necking does occur, otherwise a brittle material will fracture instantly without necking. As the literature review informs us, micro cracking occurs deep within the materials surface when UV rays have an effect on Polypropylene. This makes them most likely to become brittle and fracture upon stresses. Overall the graph representing the experiment does show this, however we see an interesting increase in fracture stress capability as we move from test 1 to 2. That is after a UV exposure of 3 days, the material was able to withstand more stress than the material with no UV exposure before fracturing. We know this goes against theory and should not be the case so we can consider this issue to be the cause of an anomaly in the results as previously mentioned. This has affected the average result overall and has provided us with a fracture strength larger than test 1.

The cause for the anomaly (or any anomaly in fact) could be down to either that particular sample material itself being a defect, or even the way in which it was setup on the tensile testing machine. For instance, if the material was inserted into the arms differently than the others, extra area grip could increase stress needed to fracture the material. We can therefore ignore this anomaly as test 3 proves the theory to be correct as we expected. The frac-

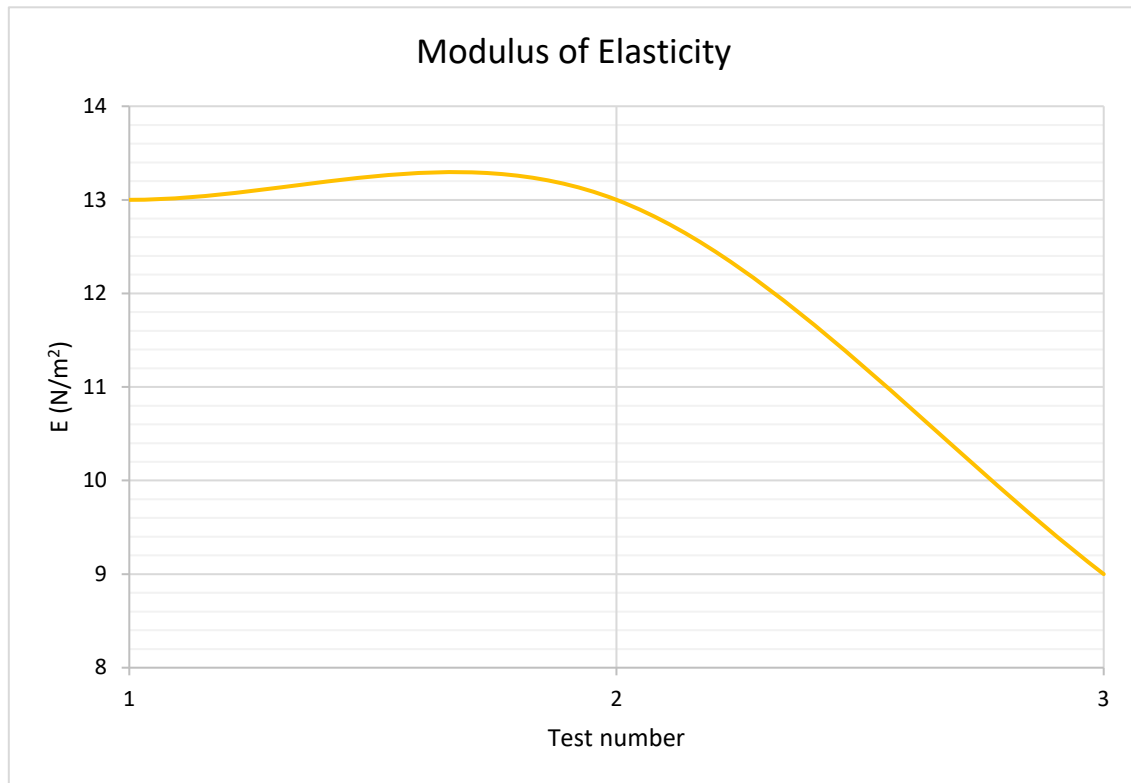


Figure 25 - Modulus of Elasticity (Young's Modulus vs test No.)

ture strength for the same with 7 days UV exposure is 272 MPa, whereas the initial material that was not subjected to UV managed to withstand up to 298 MPa. This difference is large in terms of stress (26 MPa) and is 8.7% less than it was before exposure. This is a significant drop in material strength capability.

The Modulus of Elasticity (or Young's Modulus) is the gradient of the tensile test in the elastic deformation stage, as shown in the theory section it is the stress applied divided by the strain. That tells us how much elongation has occurred to the material for the amount of stress applied, whilst being able to return to its original geometry. It is the rate at which the object elongates with stress. It is particularly useful to know if the material being tested must maintain its original shape while experiencing stress. This is the case with Polypropylene as we use it in applications such as garden chairs; where we apply a force by sitting on it and expect the object to not change shape after use.

As the graph implies, this Young's Modulus of Polypropylene decreases over time with exposure to UV-B rays. The graph shows us a trend similar to the fracture strength where test 2 happens to increase slightly in comparison to test 1 before a very large decrease in test 3. This anomaly initially found from the same sample has carried itself onto the Young's Modulus parameter and hence we see it affecting the results here. So we can ignore this anomaly and assume theory to be correct with this bad value than does not give us a viable outcome.

Test 3 confirms what we expected with a sudden large loss in the materials capability of managed stress per strain. A larger value indicates that the gradient is steep and therefore not a lot of strain occurs with stress, however a smaller value tells us that the gradient is not very steep indicating strain increase rapidly with stress. We have gone from 13 N/m² to 9 N/m² from test 1 and test 3 respectively. The Polypropylene has lost its ability to withstand 4 N/m² and elongate the same strain as it had without UV exposure. This is a 31% reduction in its ability to maintain its elasticity which is a huge drop in scientific terms. It shows that the more UV exposure occurs the more brittle the material will be, evidence of micro cracking within the surface of the material.

A factor that could have also affected the outcome and differences between the samples in the same group (especially group 2 and 3) is the amount of UV each sample absorbed in the accelerated weathering machine. Had the orientation of one sample been different to the others and placed in a location where UV might be more affective, i.e. away from the lid to avoid UV escaping, this would make a large difference although no obvious with the naked eye. However, all efforts were taken to ensure each sample had the same amount of UV exposure in the weathering machine regardless of location and orientation.

Chapter 5

Conclusion and Recommendation

5.1 Conclusion

The project set out the aim of researching and understanding the reason behind Polymer Plastic material degradation due to ultra violet rays. The objectives were to experiment this using Polypropylene plastic as it was highly popular and likely to be affected the most by UV degrading. Upon reading the theory and solutions, we were able to test this for ourselves and can confirm in fact that UV degrading is a major issue when dealing with Polymer Plastics; namely Polypropylene plastics. The results have proven that just a week of concentrated UV-B exposure can reduce a material ability to remain elastic by almost a third (31%), fracture toughness by 8.7%, Ultimate tensile strength by 5.1% and finally the Yield strength by 4%. All important parameters regarding a materials strength we found to be reduced as a result of degrading by means of UV rays. Most worryingly of all, the ability to maintain its shape (Young's Modulus) is most affected and decreases the most. Therefore, we expect that the most obvious sign of UV degrading will be the loss of material ductility and more brittle.

Based on these findings we can confirm the theory to be valid and the investigation to be successful in finding out the cause and reason behind Polypropylene plastic degrading. The bonding structure is largely affected by the sun's rays and must be maintained for an overall strong material. Epoxy coating is a very useful alternative to provide the material with better UV resistance. Other methods of UV protection should be sought for. This layer will act like a shield and become damaged before the rays manage to reach the bonding structure of the material. Effectively delaying the process of degrading depending on the epoxy thickness. This should be the focus of the next study and how much epoxy coating is needed to make a significant difference to the degrading process. Looking into various other methods also and how the epoxy coating may also pose a negative effect on the polymer plastics.

One of the main issues found in this investigation is the anomalies present in the results from tensile testing. These anomalies had made a large difference to the average result and should not be considered. It is best left out and considered as spurious data. However, they were inserted for the sake of research and to be mentioned. Even though, more care should be taken when doing the physical tensile testing to avoid any anomalies that could make the results seem opposite to theory. 5 samples for each group of study was used to avoid this but was not enough as it only took 1 sample in each group to make such a difference in the average. Further research should consider ignoring these anomalies to avoid confusion or

use more samples to get a better average overall. Also, focus on why the anomalies may have occurred can be focused on, such as the way in which the sample material was loaded onto the tensile test arms.

Another issue that would have limited the validity and conclusion of these report was the fact that only physical tensile testing was used as a method of investigation. This was due to time constraints and therefore could not continue to attempt trying other destructive or even non-destructive testing. The most testing methods used the more accurate and valid the findings would be. Computational methods would have also made a positive contribution to the investigation. This made the study limited to just one method and should the investigation be taken further or repeated, it is strongly advised to use more testing methods and other means to improve findings and validity.

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Appendices

Appendices A

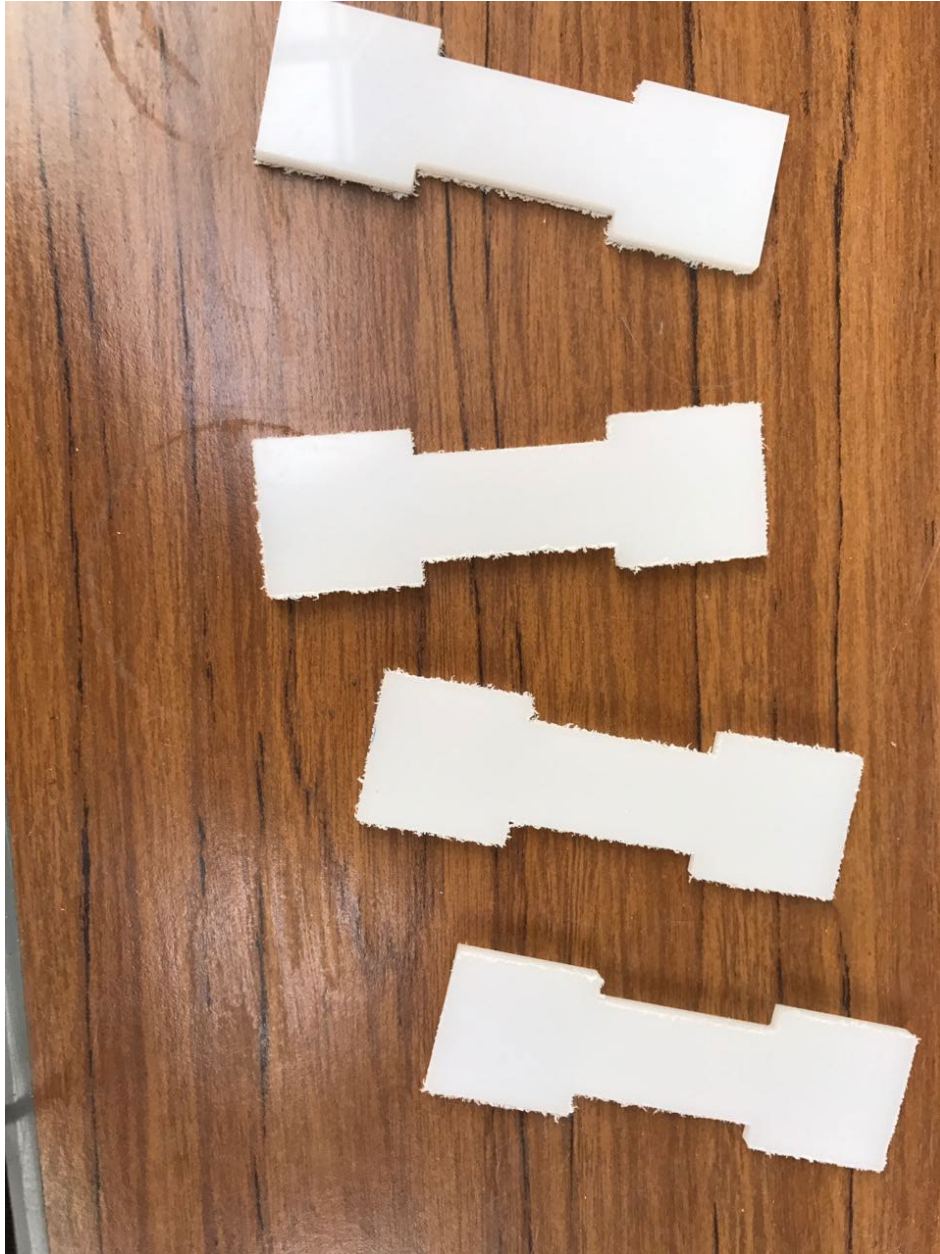


Figure 26 - No UV exposure specimens

Appendices B

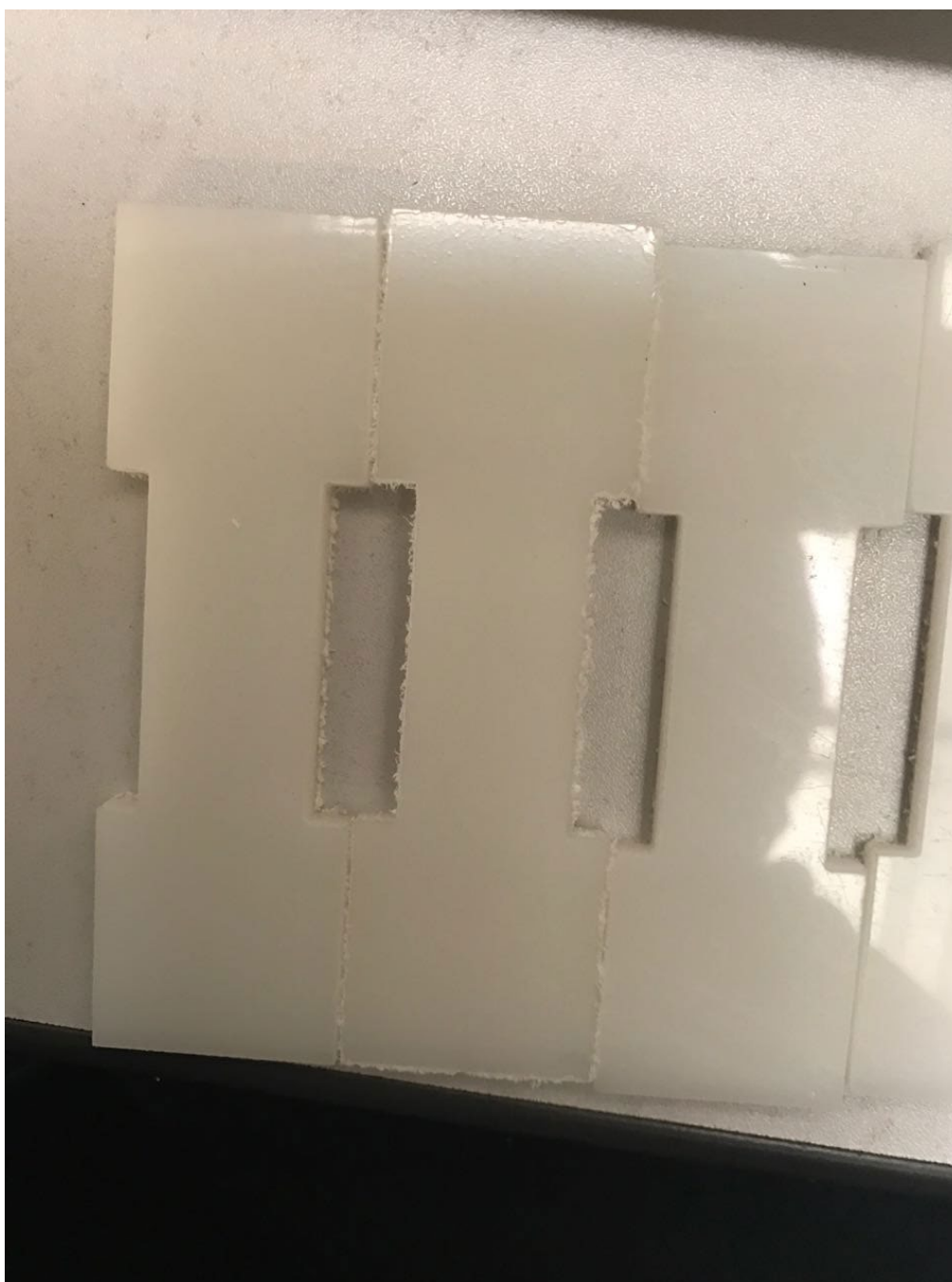


Figure 27 – 3 day UV exposure specimens

Appendices C

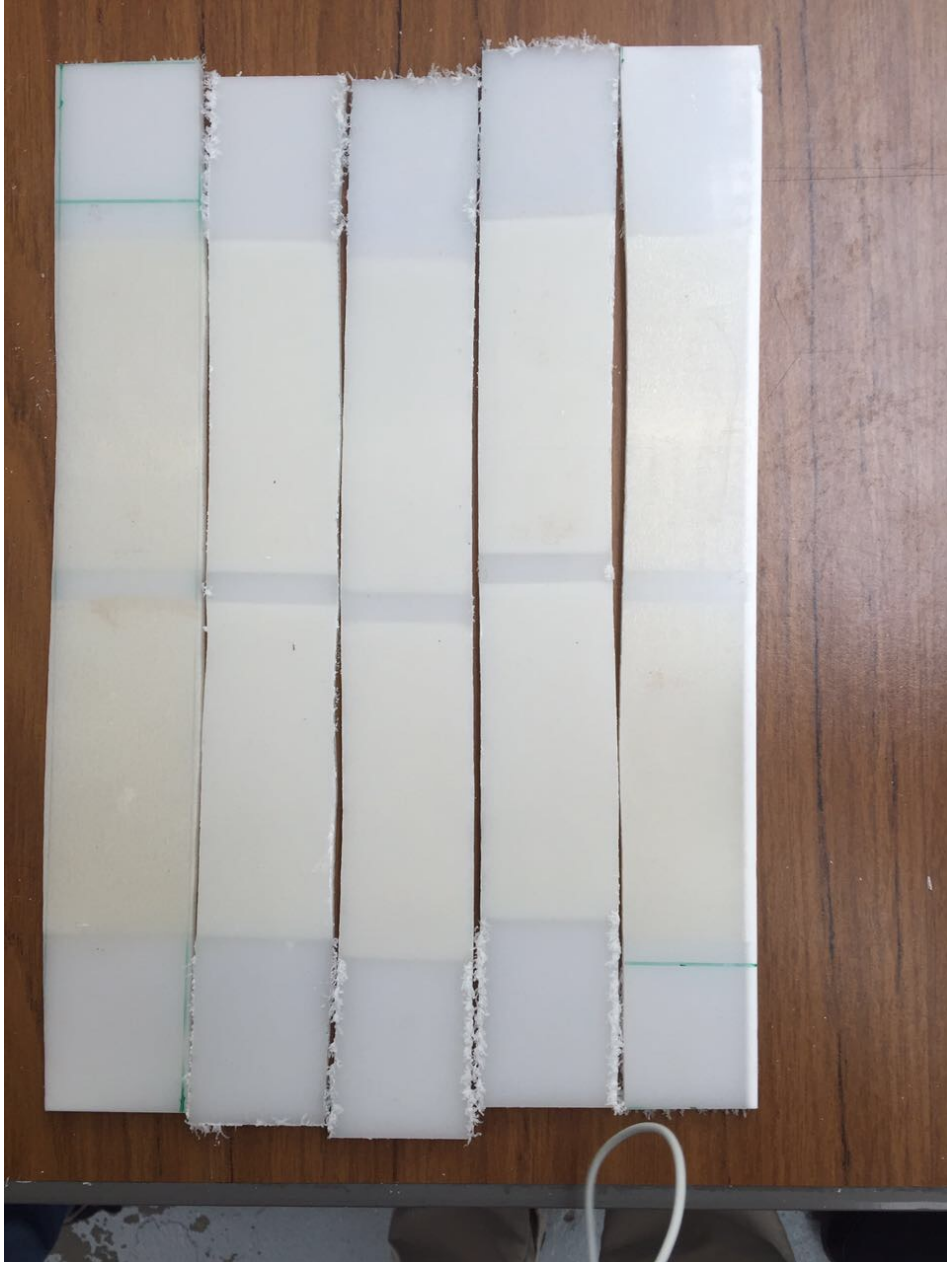


Figure 28 – 7 Day UV exposure specimens