ARCADA

Thesis

Investigation Of Multilayer Films For Packaging

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ABSTRACT	
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Abstract:

Three different methods were used in the investigation of multilayer films by using UV-Vis spectroscopy, artificial sunlight lamp and testometric tensile testing machine. Eleven kinds of multilayer films with different thicknesses and layers were tested by UV-Vis spectroscopy and radiation test was done by artificial sunlight lamp. Again the same samples were examined by UV-Vis spectroscopy. At last all the samples were tested by tensile test machine. After the experiment all the samples were found to be UV protected. Generally, the samples were divided into two parts i.e. transparent and opaque multilayer films. All the samples were observed unchanged visibly after radiation test but when the same samples were again tested by UV-Vis spectroscopy then all the transparent films were found affected in UV region (190-380) nm by the radiation of artificial sunlight lamp whereas opaque films (B, C and D) indicated insignificant changes. Likewise opaque and printed films (E and F) were also affected by radiation slightly. The reasons for these changes were not highlighted in this thesis because the composition of the samples was mysterious. Another work could continue to find out the details of these changes by the future researcher. Furthermore the tensile test results showed that the transparent films were more flexible and had less tensile strength in compared to opaque films. The possible sources of errors may involve in the method of sample preparation and the random errors during the repeatable procedure. Similarly it was a tough task to make a sample with specific length and width where fine and smooth edge was must. As there was not any particular tool to make the sample, scissor and scalpel was used. At last it was realized that the design of the testometric material testing machine was not suitable for this kind of experiment.

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Table of Contents

Abbreviations

1. LDPE: Low density polyethylene
2. LLDPE: Linear low density polyethylene
3. HDPE: High density polyethylene
4. PVC: Poly vinyl chloride
5. PET: Polyethylene terephthalate
6. EVOH: Ethylene vinyl alcohol
7. PS: Polystyrene
8. PP: Polypropylene
9. PA: Polyamide
10. PMMA: Poly methyl methacrylate
11. ABS: Acrylonitrile butadiene styrene
12. UV-Vis: Ultraviolet visible
13. WVTR: Water vapor transmission rate
14. RH: Relative humidity
15. HOMO: Highest occupied molecular orbital
16. LUMO: Lowest unoccupied molecular orbital

ACKNOWLEDGEMENTS

This thesis is the last part as completion of my Bachelor's Degree in Plastics Technology at Arcada UAS. The topic of this thesis is associated to the multilayer films and their analysis by different methods. The main reason for choosing this subject is to pursue higher degree of knowledge in the related field. I have been conducting this research from a very long time and I have experienced that period as very informative and motivating.

I would like to thank Rani Plast Company and especially to Eva Haggblom for providing samples for this project. A special thanks goes to my supervisor Mariann Holmberg. Her valuable insights and guidelines helped me to complete my thesis. I would also like to thank Mirja Andersson, Björn Wiberg, Stewart Makkonen-Craig, Valeria Poliakova, Erland Nyroth and to those who helped me directly and indirectly during my research.

Lastly, I would like to dedicate this thesis to my parents and to my beloved husband. I am always grateful for their support and inspiration.

Helsinki, April 2016

Reeta Karki

1. INTRODUCTION

Plastic films are used in a wide-ranging variety of applications. They are mostly used for food packaging, also to preserve fragrance and tastes. They are used in automotive industries and in agricultural field to protect plants. Furthermore, they are commonly used in shipping bags and they are widely used as trash bags. Consultants are skilled on polymer type and resulting film properties and grade selection for specific applications. Most of the plastics can be made into the film. Some of them are low-density polyethylene (LDPE), linear low-density polyethylene (LLDPE), high-density polyethylene (HDPE), poly vinyl chloride (PVC), polyethylene terephthalate (PET) and others. Each of them has a unique combination of properties that makes it deal for certain applications. [1]

Combining two or more polymer into a single film makes multilayer film. These kinds of films are mostly used in food packaging. When the required properties cannot be found in a particular polymer then multilayer films are produced for the needed properties. The combination of different polymers helps in reducing the process steps, cost and time. High strength product can be produced with good moisture and aroma barrier. Likewise, they are resistance to acid and alkalis. With these benefits of multilayer film, it has also a lot of challenges like to select and combine the materials and to get the preferred properties. [2]

The multilayer films that are used in this project for the practical work are offered by the Rani Plast Company that is one of the Nordic region's leading suppliers of plastic packaging films. The company was founded in 1995. They produced plastic films for agriculture, industry and processor that are prepared by the modern technology and advanced management system.

Aim

The main aim of the thesis is to make research and to produce overview properties of multilayer films where two or more different or similar kinds of the polymer are combined to make a single film i.e. multilayer film. It is mainly concern to make research on radiation and to find the mechanical properties of films that are tested by the tensile test as well as the impact analysis by UV-Vis. The function of plastic film is to wrap the products and to protect it from deteriorating and spoiling.

Research questions

- What are the impacts of artificial sunlight lamp in multilayer films?
- How do UV-Vis spectroscopy and tensile test method helps in determining the quality of multilayer films?

2. LITERATURE REVIEW

The plastic film can be manufactured by blown film extrusion method and co-extrusion method. These are the suitable procedure to produce multilayer films and co-injection stretch blow moulding process is used for multilayer bottle. Similarly, extrusion lamination is used to make a multilayer film in which the material itself is totally different not only its properties. The common methods for multilayer films manufacture are described below:

2.1 Co-extrusion method

Co-Extrusion is the process of pressing two or more materials through same die. The properties vary as the two plastics are combined. This method has opened new areas for material engineering and it has solved the previous problems that have arisen due to old process. It also reduces the cost of manufacture by using the recycled and reground scrap. This process can be seen in projects as varied as tubing and structural components or air blown food containers.

In this process the solid plastics pellets are gravity fed where the pellets are melt and feed the materials into a die. Co-extrusion involves multiple extruders forming layer. Even sometimes more than five materials are used in single cycle. It is different from ordinary plastic melting, where each plastic maintains its original properties, but is merged into compound material part. The end result is homogeneous product if mixed prior to extrusion.

Some polymers do not adhere to others and those polymers are not suitable for co-extrusion. But if the conductive middle layer is introduced this problem can be solved. Plastics with high difference in melting point are also unsuitable for co-extrusion. Also PVC and acetals should not be coextruded together because of high risk of violent reactions. A co-extrusion film application helps in oxygen permeability, strength, stiffness and wears resistance. The figure 1 below describes the co-extrusion process for multilayer films. Two hoppers are shown in the figure below for two different polymer resins. These two polymers are coextruded in a die and then it comes out as a film. The co-extrusion process offers strong adhesion between base and adhesive layers. After co-extrusion, it is cooled and winding. [2]

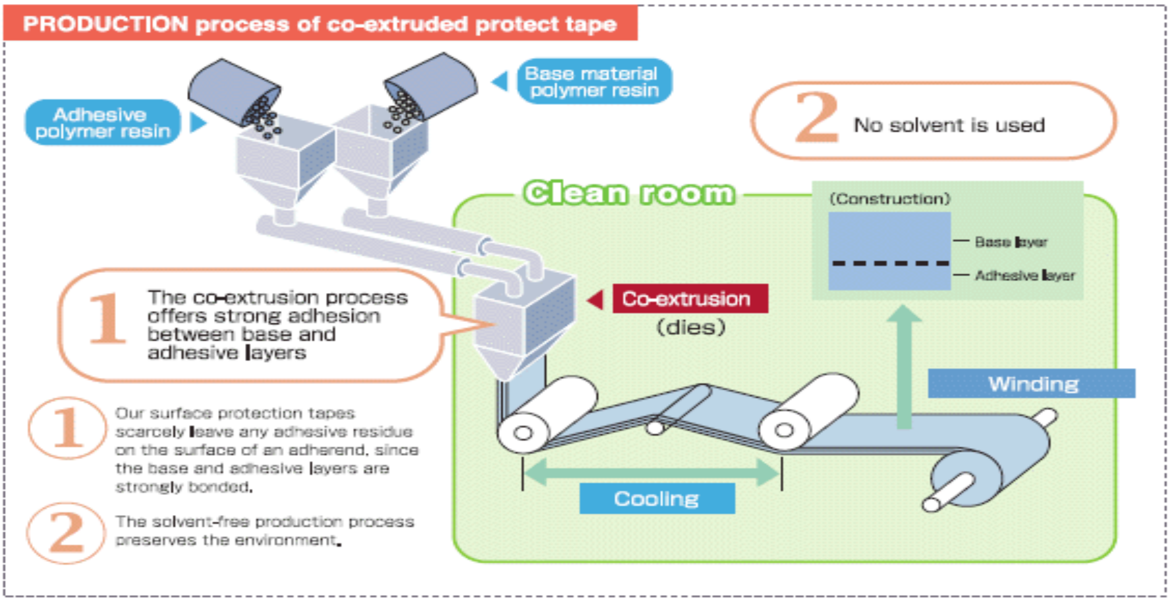


Figure 1: Co-extrusion process [3]

2.2 Blown film extrusion method

Blown film extrusion is one of the most common methods of film manufacture. This involves extrusion through a circular die. The main advantages of manufacturing film by blown film extrusion include ability to:

- Produce both flat and gusseted tubing in a solo operation.
- Controlling of the volume of air that is in the bubble, output of extruder and speed of the haul off to regulate width and thickness of film.
- It eliminates end effects.
- It allows the uniformity of mechanical properties.
- Used for the manufacture of co-extruder and multilayer films for food packaging.

In the process the plastic melt is extruded vertically for the formation of thin walled tube. From the center of the die hole the air is introduced to blow up the tube like balloon. On the top of the die, a high-speed air ring is mounted that blows onto the hot film to cool it. The tube of film is then move upwards cooling continuously and the tube is flattened to create ''lay-flat'' tube of film. The lay flat tube is again taken to extrusion tower through more rollers. After the process they are kept as such or they are slit off to produce two flat sheets. The expansion ratio between die and blown tube of film would be 1.5 to 4 times.

The material used in the process is mostly polyethylene like HDPE, LDPE, and LLDPE. Despite of that other blends and resins are also used. Applications of blown film extrusion are industry packaging, consumer packaging, laminating film and barrier film. Three layers of multilayers film can be formed from the following blown film extrusion shown in fig 2. In fig 2: A, B and C are assumed to be three hoppers where 3 different or similar kinds of polymer pellets can fed. The co-extruded blown film is blown keeping the molecular location in the direction of operating machine. Then the bubble of the film is cut at a specific angle by a spiral-cutting machine. Multilayers of the spiral films are laminated together with orientations at opposite angles. Then the molecules of the final products are isotropically positioned to improve the strength of the film. [4]

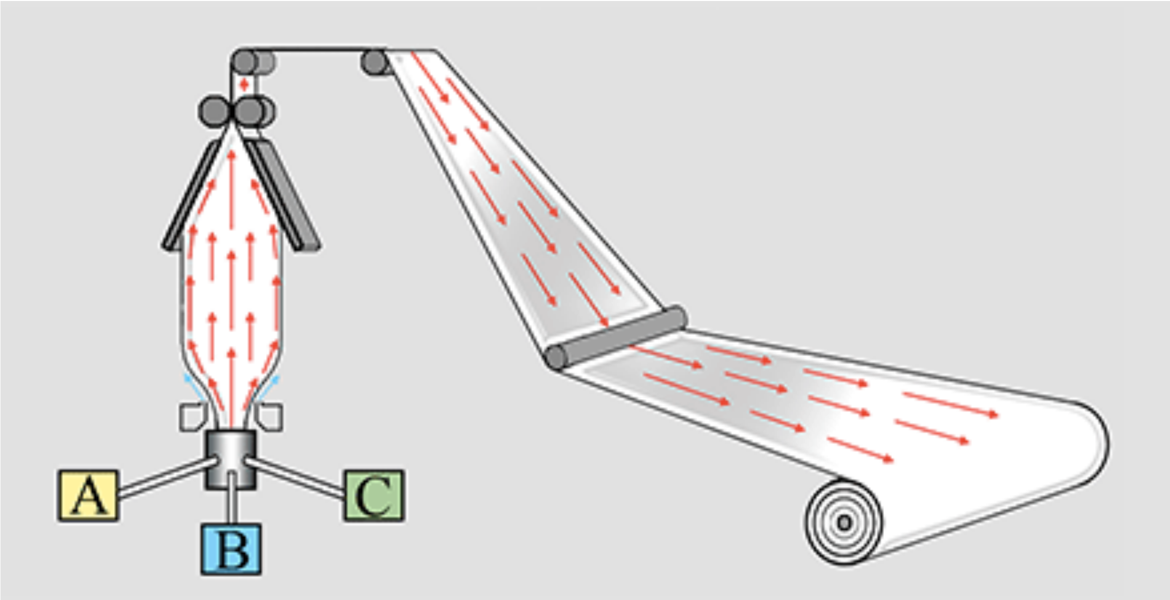


Figure 2: Blown film extrusion [4]

2.3 Spraying method

An open mould with hand lay up is used in the spraying method. This method is used to make films by composite materials. A gel coat is applied on the surface of the mould. The resin and the reinforcing material are sprayed together into the mould from a gun that chops the reinforcing fibers into short length and mixes them with the catalyzed resin. Then the mixture is rolled to make the surface smooth. Due to the robotically controlled guns and rollers, the production rate can be higher than that of hand lay-up. This method is especially used to make plastic shower stalls, bathtubs and others. When this method is used the factory must be dealt with the adverse effect of overspray on air quality. Two methods are shown in figure 3 i.e. hand lay up and spray lay up. There is only one difference between two of them. Brush is used in hand lay-up for coating whereas cutter and spray gun is used for coating in spray lay-up. Spray lay-up method is a better choice to produce many products in a short period. [3]

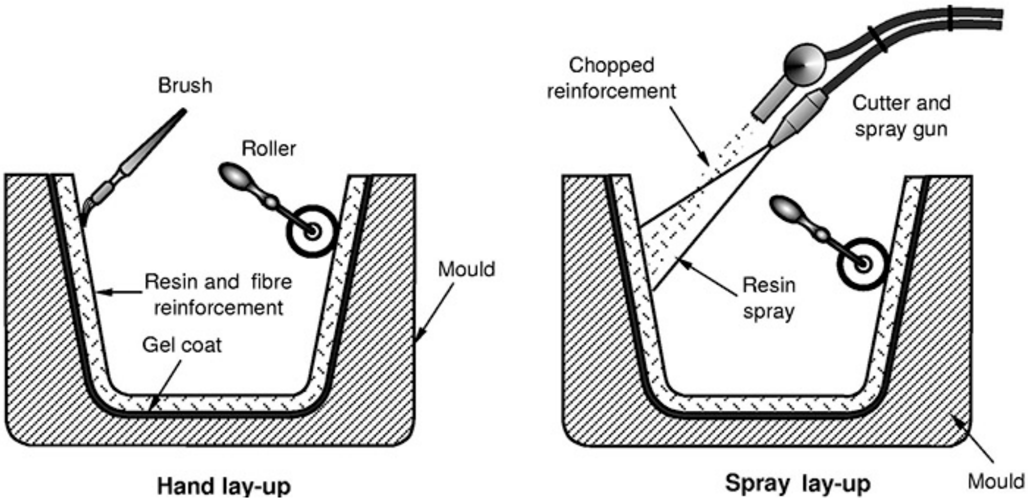


Figure 3: Spray-up moulding of a reinforced thermosetting plastic part [4]

3. PROPERTIES

Every polymer has very distinctive characteristics and the classification of the polymer is based upon the physical related to heating. The majority of the manufactured polymers are thermoplastic which soften on heating and become firm on cooling. Thermosets are softening on heating and can be moulded but hardened permanently. They decompose on reheating. For e.g. Bakelite, which is used in toasters and handle for pots and pans. The physical properties of the polymer like strength and flexibility depends on chain length, side group, branching and cross-linking.

When two or more properties cannot found in a single material then diverse material are used in design to make a complete final product. Things like paper, aluminum foil, metal, plastic and other materials can be combined to make a multilayer structure. It is not necessary to be the same kind of material but the factors like time, cost, production method and manpower plays a vital role. The main purpose of manufacturing a new product for the customer is to provide a new and unique design with low cost. It is the primary thing that every customer wants at first and the secondary thing includes its strength, lifetime and most of the time color of the product also matters depending on the kind of object inside it. On the other hand, the manufacturing process of multilayer structure can be fairly similar to most of the products but it is not exactly the same, it depends on the type of the design. For e.g. for meat packaging, films with good barrier properties of oxygen and water vapor are combined. The suitable combination for meat packaging is PA/PE. PA is comparatively oxygen proof but permeable to some extend to water vapour whereas PE has the opposite properties, i.e. water vapour proof but permeable to oxygen. This is the simplest structure of multilayer film. The table 1 shows the permeability of water vapour and oxygen in some main barrier plastics.

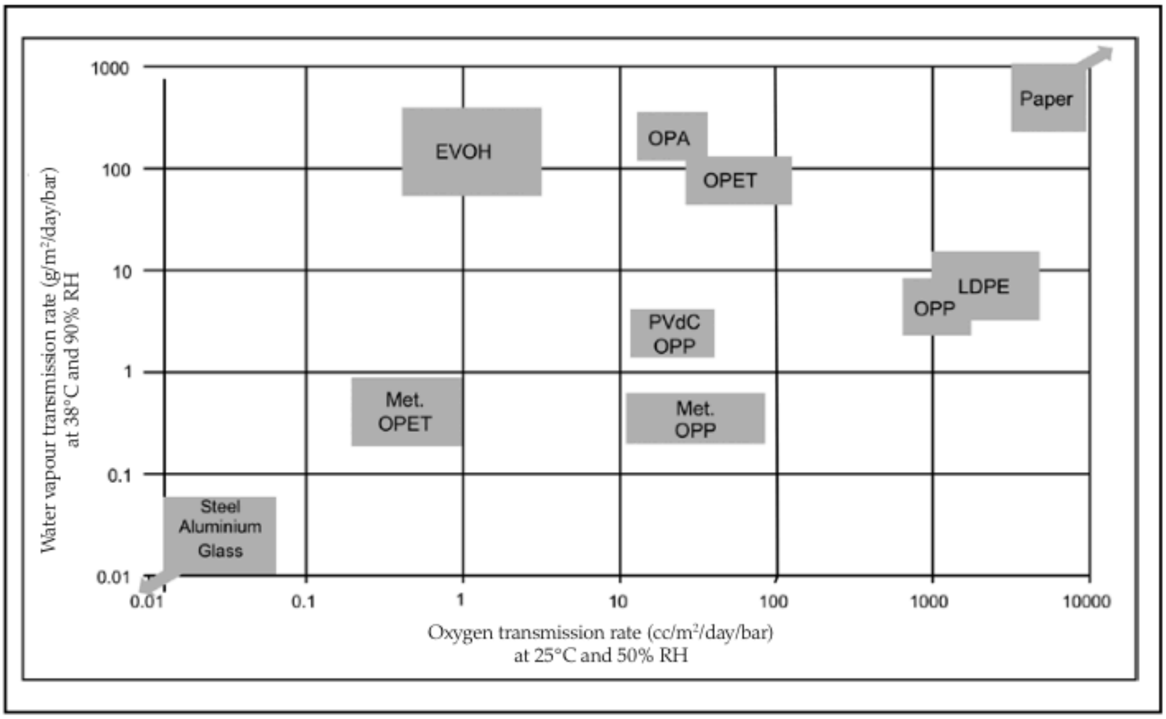
[5][6]

Table 1: Relative properties of the main barrier plastics [7]

Plastic Material	Water Vapour	Oxygen
High-Density Polyethylene (HDPE)	Very good	Poor
Ethylene-Vinyl Alcohol (EVOH)	Absorbs water	Excellent
Poly Vinyl chloride (PVC)	Excellent	Very good
Polystyrene (PS)	Poor	Poor
Polyethylene (LDPE)	Relatively impermeable	Relatively Permeable
Polypropylene (PP)	Relatively impermeable	Relatively Permeable
Polyester (PET)	Relatively impermeable	Average
Polyamide (PA)	Relatively Permeable	Relatively impermeable
Polyvinylidene Chloride (PVDC)	Excellent	Excellent

The above table shows that the PS is not good as barrier plastic because of the poor nature in permeability of water vapour and oxygen. The finest polymers that can be used as main barrier plastics are PVDC and PVC. EVOH absorbs water and it is outstanding in permeable of oxygen while HDPE is very good in permeability of water vapour but poor in oxygen permeable. Similarly, LDPE is relatively impermeable of water vapour and relatively permeable of oxygen.

The main function of the films is to keep dry products dry and moist products moist. Hence protective packaging is most important for the quality of goods. As mentioned above, a barrier to moisture and gases is needed for many packs. Therefore, the different barrier amounts of commonly used polymers that show the permeability’s to water vapour and oxygen are illustrated in figure 4 below:



Source: Typical values taken from industry data sheets

Figure 4. Permeabilities to water vapour and oxygen of some base material [7]

Note that log scales have been used. Water vapour transmission rate (WVTR) is a measure of the permeability of a material to moisture and in above figure the lower the figure, the better the barrier. WVTR is a standard measurement test to determine the lifespan of the product and it helps to decide the quality of food so as to improve the storage. Water vapour transmission rate (WVTR) values are given in tropical conditions of 38°C and 90% relative humidity (RH), an industry standard. In normal ambient conditions (23°C and 50% RH) the actual WVTR would be about 75% lower.

Note that the above values are only illustrative and the actual permeability will depend on the precise grade, thickness and the final structure in which the material is used. Material thicknesses used for the examples are shown in Table 2.

Table 2: Typical thickness of some commonly used base materials [7]

Abbreviation	Material	Thickness (microns)
Met. OPP	Metallised oriented polypropylene	20
Met. OPET	Metallised oriented polyethylene terephthalate (polyester)	12
LDPE	Low density polyethylene	25–100
OPP	Oriented polypropylene	15–50
OPA	Oriented polyamide	12–30
OPET	Oriented polyethylene terephthalate (polyester)	12–50
PVdC OPP	Polyvinylidene chloride-coated oriented Polypropylene	32
EVOH	Ethylene vinyl alcohol	2–10

The thickness of the film may vary from place to place. Table 2 shows that the thickness of low-density polyethylene (LDPE) is in the range of 25 - 100 microns i.e. 0.025 - 0.1mm. The samples of PE films (unknown whether they are LDPE or HDPE) that are provided by the company have the similar thickness as in table 2. The thicknesses of PE films are shown below in table 3.

Table 3: Thickness of commonly used LDPE and PE films used in this project

Samples	Layers	Thickness (mm)
B (PE)	3	0.065
C (PE)	3	0.471
F (PE)	3	0.123
G (PE)	1	0.026
H (PE)	3	0.05
I (PE)	3	0.065
J (PE)	3	0.024
K (PE)	3	0.029
Commonly used LDPE (theory)	Unknown	0.025 - 0.1

The samples that are listed in table 3 does not clearly classify whether they are HDPE or LDPE but by comparing their thicknesses with commonly used LDPE thickness it can be predict that they all might be LDPE. All the samples thicknesses lies in between the estimated value except sample F and J. Sample F is a polyethylene with 3 layers has 0.123 mm thickness and sample J is also a polyethylene with the same layers that has 0.124 mm thickness. There is not much huge difference between these two polymers and the assessed minimum thickness of LDPE.

Though polyethylene plays a dominant role in making films, there are also other polymers that are used in making multilayer films or single layer films. Most of the samples i.e. multilayer films that are provided by the Rani Plast Company are made from polyethylene (PE). There are also other few polymers that are used in making samples like PET and PP but the attractive part is they are again used with PE. The thicknesses of PET/PE, PP/PE and unknown samples are described in the experimental part 13.2 (Material).

4. APPLICATIONS OF MULTILAYER FILM

Most of the plastics can be made into film. Some of them are low-density polyethylene (LDPE), linear low-density polyethylene (LLDPE), high-density polyethylene (HDPE), poly vinyl chloride (PVC), polyethylene terephthalate (PET) and others. Each of them has unique combination of properties that makes it deal for certain applications. Plastic film can be colored by using additives if needed but most of the plastic film used for packaging is clear and transparent. Primarily, packaging purposes are divided into food packaging, non-food packaging and other packaging but it can vary by color, thickness and resin. Despite the fact that other polymers can also be used for packaging purposes, it has been seen that polyethylene plays a dominant role. The latest figures for packaging could not find so old statistics are written below.

a. Food packaging: It is a true fact that LDPE is used for food packaging. Food packaging film is used in stores for fruits and other groceries as well as candy and non-frozen baked goods. For food packaging film, LDPE accounts for 65.5% of the total with LLDPE making up 25.6% and HDPE making up 9.6% in 1995.
b. Non-food packaging: It includes agricultural field, medical field and industrial field. LDPE comprises 54.9%, LLDPE involves 35.5% and HDPE includes 9.6%. The given data is obtained before 21 years ago i.e. 1995.
c. Other packaging: In 1995, data compiled by modern plastics shows that LLDPE is most used in stretch wrap i.e. 74.7% whereas LDPE shrink comprises 17.9% and LDPE stretch comprises 7.4%. Also, it has been found that the data has been not available for HDPE. [1]

There are different plastic resins with which plastic film can be made. Following are the description of commonly used resins with their properties and applications in which they are mostly used.

1. Low Density Polyethylene (LDPE): It is popular for its high clarity, ease of processing and high gloss. Other properties of LDPE and LLDPE are similar to each other i.e. both have good clarity, are good moisture barriers and fair gas barriers, can be heat-sealed and are strong and highly flexible. The key applications of LDPE are

overwrap film for tissues; film for bakery goods, meat, frozen foods, non-food packaging and shrink-wrap. Its recycling number is 4. [1] [10]

2. Linear Low Density Polyethylene (LLDPE): The properties of LLDPE is quite similar to LDPE which was discussed above and the other specific reasons for choosing LLDPE are due to its tensile and impact strength as well as its heat sealability. They are used to make pouches, toys, covers, lids, pipes, buckets, containers, covering of cables and varieties of plastic bags. [1] [10]

3. Polypropylene (PP): PP is recognized for its tremendous moisture barrier characteristics, high gloss and good tensile strength. Due to its high melting point i.e. 130 °C it is chosen for those kinds of packages that requires sterilization at high temperature. PP alone cannot be used for meat packaging because it has poor gas barrier properties. PP are commonly is used to package such things as cigarettes, candy, snack foods, bakery products, cheese and sanitary goods. It also can be found in shrink-wrap, tape, tobacco wrap, diaper cover stock and the sterile wrap used in hospitals and other medical care facilities. Its recycling number is 5. [1] [10]

4. Poly Vinyl Chloride (PVC): PVC is very strong and rigid polymer and the special features includes, it is resistant to variety of acids and bases but it may be damaged by some solvents and chlorinated hydrocarbons. They are mostly used for water, gas and drainage systems but not working in hot water systems. They are found in some bags and liners, adhesive tape, labels, blood bags. Similarly, they are widely used for the packaging of fresh red meats due to its semipermeable nature that helps to keep the meat fresh and red by letting required amount of oxygen. Its recycling number is 3. [1] [11]

5. Polyethylene Terephthalate (PET): PET has a very good thermal and mechanical properties and it can be clear or pigmented that is why it has many applications such as x-ray film, camera film, audio recording film, video recording film, drafting film, solar control film, overheads ink jet film, labels, tobacco wrap, cigarette wrap and metallized bags. Its recycling number is 1. [1][10]

6. High Density Polyethylene (HDPE): HDPE belongs under PE group so it has many applications same as LDPE and LLDPE. The main property of HDPE involves its toughness and puncture resistance as well as it has a good moisture barrier. HDPE film is used in bakery bags, carton and box liners, cereal and cake, mix bags, shipping sacks, industrial liners, retail bags, grocery sacks, T-shirt bags, trash bags and liners, agricultural film, construction film and envelope material, as well as many other products and packages. Its recycling number is 2. [1][10]

7. Polyvinylidene Chloride (PVDC): Normally PVDC is used with other materials to make a multilayer film like PP due to its excellent moisture and gas barrier properties. Likewise it is resistant to grease and oil therefore it can be used for household wrap. Its trade name is Saran™. [1][12]

8. Ethylene Vinyl Alcohol (EVOH): EVOH has an excellent gas barrier properties but it looses its properties when it is exposed to moisture. This is reason why it is not used alone; it is commonly used with PE that has good moisture barrier properties. EVOH is typically used for making multilayer films. One example is packaging for fresh pastas, which require high nitrogen, high carbon dioxide atmosphere in order to stay fresh and extend their cooler life. EVOH may be selected for this package because it can keep the nitrogen and carbon dioxide inside the package and oxygen outside. (PVDC may be used in similar applications.) [1]

9. Polyamide (PA): Polyamide has relatively high melting point and it has good oxygen barrier properties. Its properties include toughness and durability. Therefore, polyamide can be used in microwave cooking applications and it acts as a perfect packaging material into cheese packaging because it does not allow oxygen into the package (which would spoil the cheese) but does allow carbon dioxide out (which, if trapped inside the package, would cause it to balloon). [1][13]

10. Ethylene Vinyl Acetate (EVA): It is also known as polyethylene vinyl acetate (PEVA). Normally, it is not used alone. It is used with some other polymer like PE to make a multilayer film. It has excellent adhesion, is inert and has good flex crack resistance and good heat-sealing properties. EVA is used to make boxed wine, juices and soft drink syrups. [1]

11. Polystyrene (PS): Polystyrene has a very broad range of properties including versatility, rigidity, clarity and brittleness. It has a poor barrier to oxygen and water vapour so it is less used for packaging, automobiles, toys, electronics and disposables. It is seldom recycled and its recycling number is 6. [13]

5. SPECTROSCOPIC ANALYSIS METHODS BY UV-VIS AND OPTICAL PROPERTIES

Spectroscopy is a technique that uses interaction of energy with a sample to perform an analysis. It is the wide area through which almost all of the analysis can be done. It is used in laboratories, industries, forensic lab, hospitals etc. It plays a great role in science and development. It is also used to measure the intensity of light or the wavelength of that the specimen absorbs. Hence, Spectroscopy is ever advancing in technology and their uses are countless. There are different kinds of spectroscopies as there are energy sources. Some of them are X-ray spectroscopy, Raman spectroscopy, IR spectroscopy, UV-VIS spectroscopy, Laser spectroscopy and many more. UV-Vis spectroscopic analysis method is described below.

UV-Vis spectroscopy: UV-visible spectroscopy is also known as electronic spectroscopy. Every time a molecule has a bond, the atoms in a bond have their atomic orbitals merged to form molecular orbitals, which can be occupied by electrons of different energy levels. Ground state molecular orbitals can be excited to anti-bonding molecular orbitals.

The electrons in a molecule can be of one of three types: namely σ (single bond), π (multiple-bond), or non-bonding (n- caused by lone pairs). These electrons when imparted with energy in the form of light radiation get excited from the highest occupied molecular orbital (HOMO) to the lowest unoccupied molecular orbital (LUMO) and the resulting species is known as the excited state or anti-bonding state.

1. σ-bond electrons have the lowest energy level and are the most stable bonds. These would require a lot of energy to be displaced to higher energy levels. As a result these electrons generally absorb light in the lower wavelengths of the ultraviolet light and these transitions are rare.
2. π-bond electrons have much higher energy levels for the ground state. These electrons are therefore relatively unstable and can be excited more easily and would require lesser energy for excitation. These electrons would therefore absorb energy in the ultraviolet and visible light radiations.
3. n-electrons or non-bonding electrons are generally electrons belonging to lone pairs of atoms. These are of higher energy levels than π-electrons and can be excited by ultraviolet and visible light as well.

Most of the absorption in the ultraviolet-visible spectroscopy occurs due to π-electron transitions or n-electron transitions. Each electronic state is well defined for a particular system i.e. a double bond in 2-butene would have a particular energy level for the π-electons which when absorbs a specific (or quantized) amount of energy would get excited to the π* energy level for the electrons. Absorption may be presented as transmittance ($T = I/I_0$) or absorbance ($A = \log I_0/I$), where I represent the intensity of light passing through the sample cell and I_0 is the intensity of light passing through the reference cell. [14]

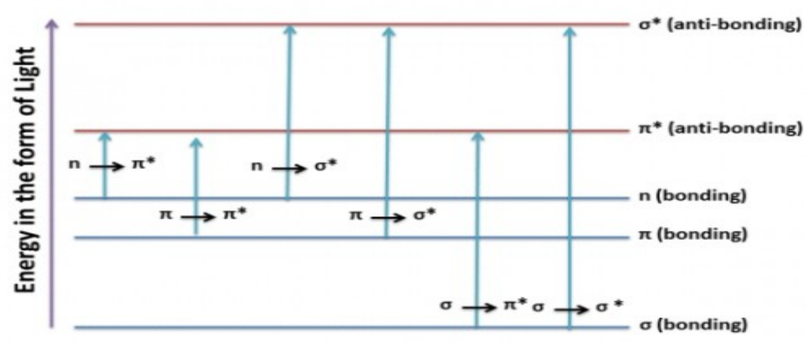


Figure 5: Different transitions between the bonding and anti-bonding electronic states when light energy is absorbed in UV- Visible Spectroscopy [14]

5.1 Types of bonds in the actual polymers

a)

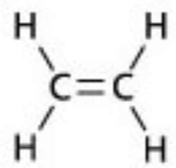


Figure 6: Ethylene (C_2H_4) [15]

It has two kinds of bonds. σ bond is formed in H-C whereas both σ and π bonds are formed in C=C.

b)

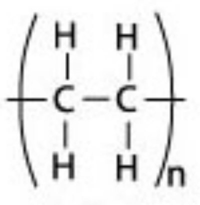


Figure 7: Polyethylene [15]

Polyethylene has σ bonds.

c)

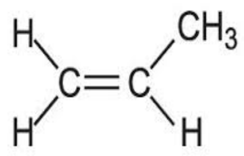


Figure 8: Propene (Propylene) [16]

Propene has both σ and π bonds in C=C and π bond in H-C.

d)

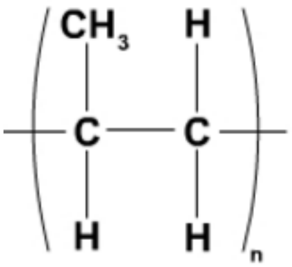


Figure 9: Polypropene (Polypropylene) [16]

Polypropene has σ bonds. The structure of the propene is asymmetrical so it forms the three different structures depending on the structure of methyl groups when polymerized. They are called isotatic, atactic and syndiotatic. The commonly used version is isotactic polypropene.

e)

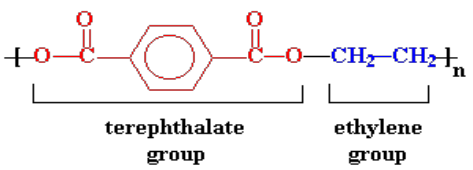


Figure 10: Polyethylene Terephthalate [17]

Polyethylene terephthalate has both σ and π bonds. Both σ and π bonds are found in C=O. Similarly, π bonds are found in H-C and C-O.

5.2 Optical properties and applications of multilayer films

Optical properties of polymers include color, clarity, general appearance and more directly measurable properties such as index of refraction. Polymers can be colored by using additives or pigments according to the need. Polymers like polystyrene (PS) and poly methyl methacrylate (PMMA) have the best optical property than that of some glasses. The ability of transmitting light into the material is measured as optical clarity. Polycarbonate (PC) is mostly transparent and it is used to make thin sheets whereas Acrylonitrile butadiene styrene (ABS) is an opaque thermoplastic that possesses a diverse combination of properties. Similarly, colored materials do not show optical clarity. However, for any dye to be effective it must be soluble into plastic and it is best incorporated in the plastic before moulding. The optical properties of polymers can be active and passive depending on their molecular structures. When the polymers used for transmission, reflection and so on, their optical properties does not change with any external force, they are acted as passive material. The polymers whose optical properties can be changed under external forces such as light or electricity are called active material. Insulating polymers are colorless because they do not contain delocalized π-electrons. Amorphous polymers such as polyethylene, polystyrene and poly (methyl methacrylate) are colorless and transparent in visible light because their refractive index are close to air and does not contain easily delocalized π-electrons. The refractive index of polymer depends on their chemical structure and conformation. The polymer containing aromatic ring has flatter structure than that of aliphatic polymer with ease of packaging conformation that can exhibit higher refractive index. [18][19]

Multilayer films do not improve the optical properties but they block the optical properties. If they are plastic thin sheets then they have many applications.
Optical application includes dimensional ability, scratch resistance, temperature limitation, weatherability and water absorption. [18]

6. INSTRUMENTATION AND WORKING OF UV-VIS SPECTROSCOPY

UV- Vis spectrometer operates on the double beam principle, with one beam passing through the sample and the other passing a reference cell. Both solid and liquid samples can be tested in UV-Vis spectroscopy. Sample holders are different for liquid sample and films. Liquid samples are normally placed in cells constructed with UV-Vis transparent materials like quartz, glass and plastic. Therefore three factors have to be consider while preparing the solid samples for UV-Vis spectroscopy i.e. type of cell, concentration of the solution and which solvent to use. Similarly, the solid samples like plastic films are placed directly into the sample holder compartment. Anyway the working principle is same for both kinds of samples. It has two lamps, one emitting in the UV range of 190 to 350 nm i.e. Deuterium lamp and other one is for visible part of the spectroscopic range 330 to 2700 nm i.e. Halogen lamp. The light from the source passes through the monochromator that consists of a prism or grafting for breaking down the beam into its component wavelengths and allowing one wavelength at a wave to pass through. The light emerging from the monochromator is then again divided into two beams with equal intensity; one beam passing through the sample and other one is passing through the reference cell. After passing through the cells, the light arrives at the detector, which gives the result and shows the graph of absorbance / T% versus wavelength. [20]

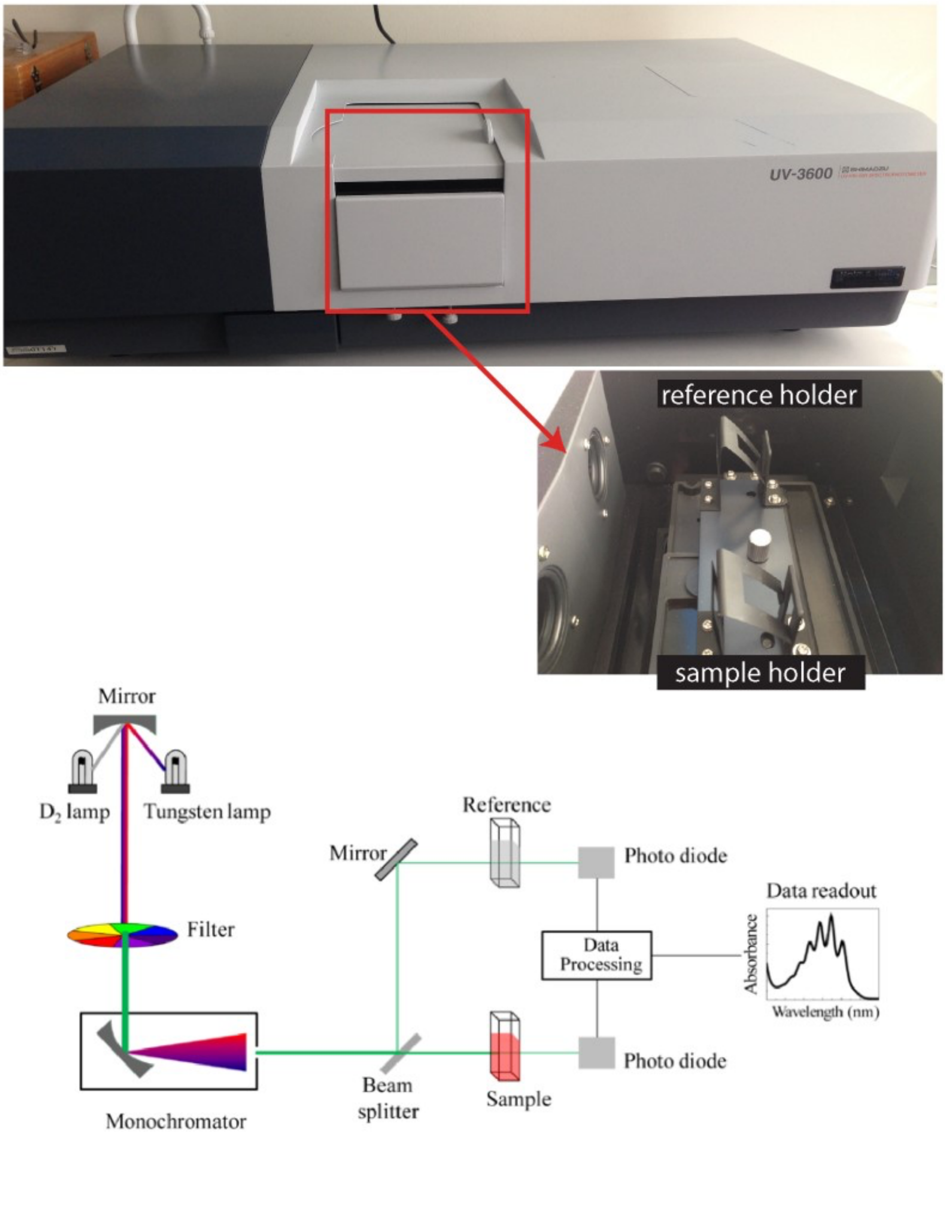


Figure 11: UV-Vis spectrometer is shown along with sample stage for films that comprise of a sample holder and a reference holder [21]

7. ARTIFICAL SUNLIGHT LAMP

The artificial sunlight lamp that is known as SolarConstant 1200 is a laboratory device to stimulate the so-called global radiation. The main purpose of designing this device is to help in the field of research and development. It has an exposed area of either 150 mm x 150 mm with a uniformity of ≤+/-3 % within exposed area or 300 mm x 200 mm with a uniformity of ≤+/-5 % within exposed area. The basic components of the Solar Test 1200 system are the radiation unit, the power supply and the control unit. The radiation source is installed in to the lamp house that includes the parabolic segment reflector system. The reflectors are made of anodised aluminium. The combination of lamp, reflector and filter offers a very special distribution that is very close to the natural sunlight. The EPS-Modul 1200 is an electronic supply that reduces the modulation of the radiation to less than 1% and control the intensity. The details of this instrument can be found in the appendices below. [22]

8. TESTOMETRIC MATERIAL TESTING MACHINE

Mechanical testing is defined as a test for determining the mechanical property of materials such as hardness, strength and impact toughness. In addition, materials can be subjected to various kinds of loads like tension and compression. During manufacture and assembly of products, there is a wide range of testing and inspection carried out to ensure the materials and items satisfy their specifications or are fit for the required purpose.
Tensile testing is a destructive test process that provides information about the tensile strength; yield strength and ductility of a material. The polymeric material behaves as linear elastic solid for low stresses and strains. The point where the behavior starts to be non-linear is called proportional limit. The maximum in the stress-strain curve is called the yield point and indicates the permanent deformation of the plastics. The most common testing machine used in tensile testing is called universal testing machine. There are four main parameters in machine i.e. force, speed, precision and accuracy. [23]

The testometric material-testing machine used to test the plastic films in this experiment is shown in figure 12.

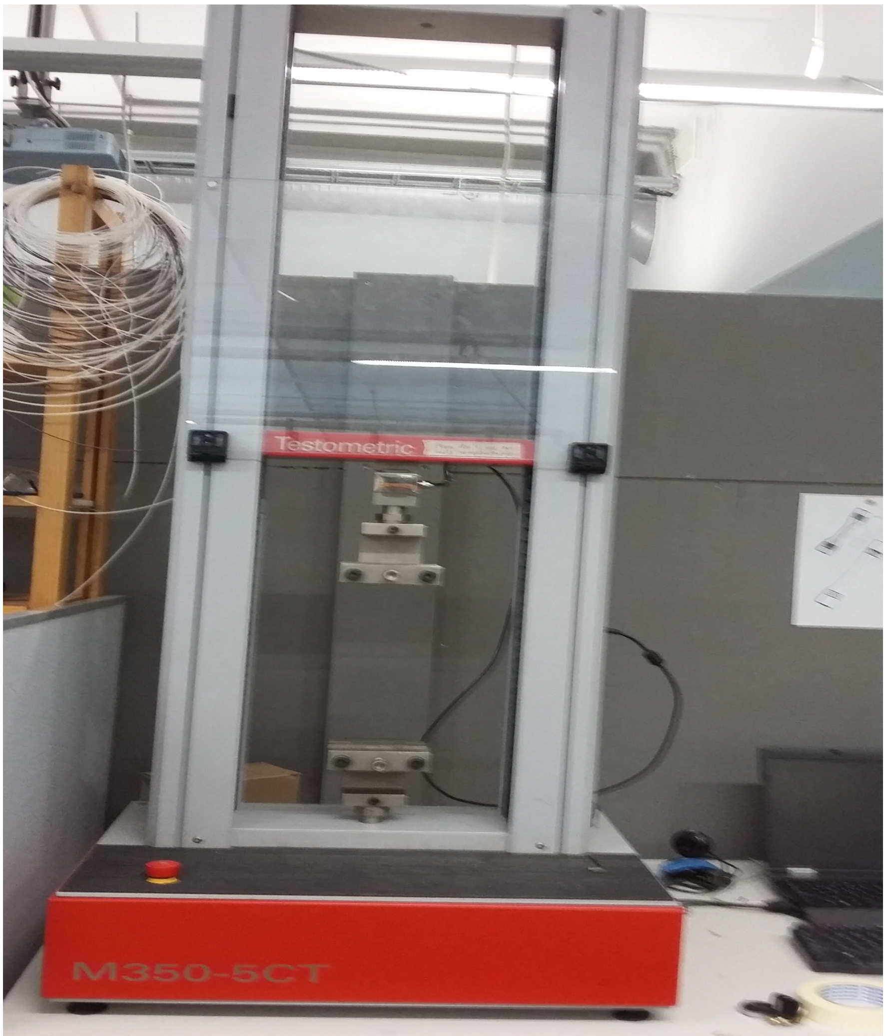
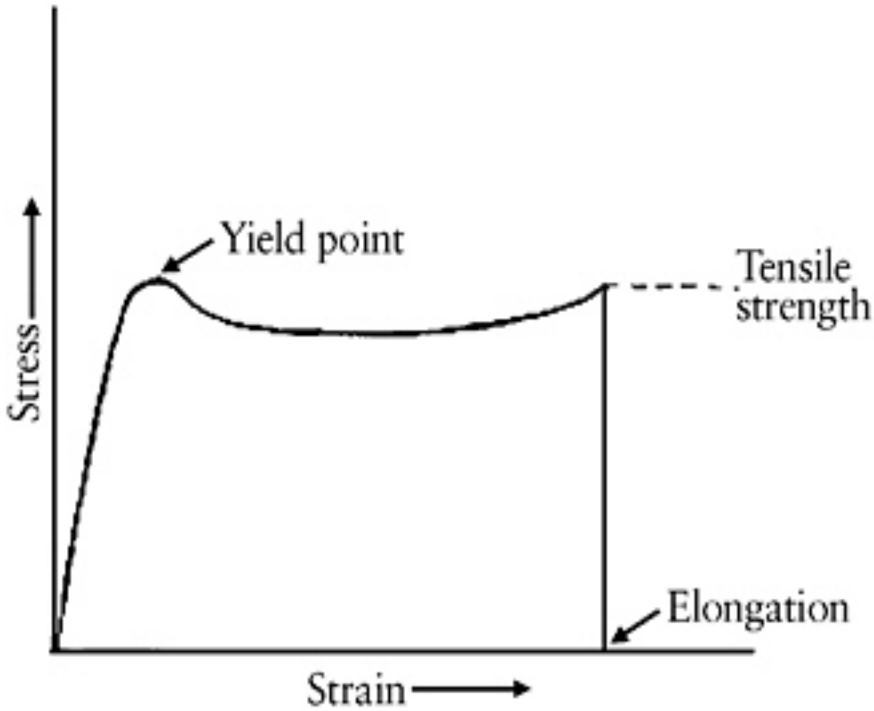


Figure 12: Testometric material testing machine [24]

The stress strain curve is shown in figure 13. The stress is measured in MPa and the strain is measured in percentage (%). The stress needed to break the sample is the tensile strength of the material and stress is a kind of deformation including elongation.

Mpa



%

Figure 13: Stress strain curve of polymers [23]

9. DEGRADATION OF POLYMERS BY RADIATION AND AGING

Polymer degradation is a change in properties like tensile strength, molecular weight, color, shape etc. under the influence of external factors such as heat, light, humidity, acids, alkalis and some salts. The undesirable changes that occur in polymer are often termed as aging. When they are aged they become more delicate and break. Polymer aging is useful for recycling/reusing the polymer waste to keep the environment stable. Polymer aging process can be further divided into physical aging, chemical aging and thermal aging. Physical aging is the process of deterioration in quality of polymers due to the factors like light, temperature and others. Thermal aging refers to both chemical and physical processes in polymers that occur at higher temperature. The effects of high UV radiation on plastics are loss of strength, impact resistance and mechanical integrity. Other physical change that occurs in polymers due to the high temperature is thermal expansion. Due to its reversible nature it does not show any significant affect on the life expectancy of polymers but it can have some affect on adhesive joints.

The physical change that occurs in polymers when the radiation is absorbed by the polymers is called weathering and more precisely known as photo oxidation of polymers. The most common plastics like polyethylene (PE) and polypropylene (PP) that is mostly used in agricultural mulch films, greenhouse films, plastic pipes etc. These kinds of polymers lose their extensibility and strength as well as their average molecular weight when they are exposed to high radiation. Thermo oxidative and photo oxidative degradation occurs rather than of direct photolysis.

PH → P° + H°

The amount of chemical reaction depends on the radiation exposure that is available in the quantity of UV light (<350nm) to which it is exposed. After the production of free radicals, it reacts with oxygen and produces hyper peroxides (POOH).

P° + O2 → POO°

POO° + PH → POOH + P°

After the formation of these free radicals it can continue to react via propagation reactions long until the initial UV exposure has ended. The formation and propagation of free radicals in itself does not seriously affect the mechanical properties of polymers because they cannot modify the long chain nature of polymer molecules. Degradation of mechanical properties happens due to the production of free radicals that are highly unstable and can easily undergoes chain reaction. The intensity of UV radiation decreases with increasing depth in the material so the reaction takes place to the near surface area. Since the oxygen is involved in the process there is an important balance between UV radiation, oxygen diffusion and temperature that will also determine kinetics of reaction and the transport of reactive species. Under the natural radiation exposure there is wetting, drying and dark periods that results recovery in the material due to the oxygen concentration. In dark periods, the concentration of the radicals reduces so that the oxygen can enter into the greater depth of the material. [25]

9.1 Additives to prevent aging of polymers

Additives are the substances that are added to plastics to improve the quality of the product or to prevent the products from aging. When the polymer reacts with oxygen then it causes oxidation. In some cases oxidation is good like in the formation of super durable anodized aluminum but when oxidation takes place in plastics it can cause loss of impact strength, elongation, surface cracks and discoloration. Light colored products are more affected than the black colored products. Likewise, when polymers are exposed to UV light or at high temperature it causes oxidation. Thus antioxidants are used prevent polymers from aging. [26][27]

10. EXPERIMENTAL (EQUIPMENTS, MATERIALS, CHEMICALS AND METHODS)

An experiment is carried out in Arcada UAS lab to investigate the multilayer films provided by the Rani Plast Oy by using three different equipments. The description of the equipments, materials, chemicals and methods are described below:

10.1 Equipments

- UV-Vis Spectrophotometer V-670
- Artificial Sunlight Lamp
- Testo 845- Infrared Thermometer
- Testometric Material Testing Machine

10.2 Materials

Additives used in the films are not known. Eleven kinds of multilayer films are used as sample and the thicknesses of the sample are measured by thickness measuring instrument in plastic lab of Arcada. They are as follows:

- Sample A = PP/PE (5 layers) = 0.043 mm
- Sample B = PE (3 layers) = 0.065 mm
- Sample C = PE (3 layers) = 0.471 mm
- Sample D = Unknown (7 layers) = 0.095 mm
- Sample E = PET/PE (1+ 3 layers) = 0.125 mm
- Sample F = PE (3 layers) = 0.123 mm
- Sample G = PE (1 layer) = 0.026 mm
- Sample H = PE (3 layers) = 0.05 mm
- Sample I = PE (3 layers) = 0.065 mm
- Sample J = PE (3 layers) = 0.024 mm
- Sample K = PE (3 layers) = 0.029 mm

10.3 Chemical

- Ethanol (C_2H_5OH) or (CH_3CH_2OH)

10.4 Methods [Experimental Part]

- UV- Vis Spectroscopy Test

First of all the samples were made by cutting it from the polymer films. All the samples were separated and kept in sample plastic bags. All of them were labeled. UV-Vis spectrophotometer was switched on and spectra manager software was opened. All the settings were checked and changed it if needed. When the machine was ready, baseline measurement was done to reduce the noises and unwanted peaks in graph. Each sample was cleaned by ethanol and the sample was tested accordingly and the results were shown. The selected wavelength of UV was 190 nm to 800 nm. All the samples were treated by light source. Two lamps were used as a light source. They are Deuterium lamp having wavelength 190 to 350 nm and Halogen lamp having wavelength 330 to 2700 nm. After radiation, again the same process was repeated for all the samples.

- Radiation Test By Artificial Sunlight Lamp

After spectroscopy test, again the samples were treated by artificial sunlight lamp. Cutting films into the small pieces made samples. Altogether 55 samples were made of almost equal size; 5 pieces from each film. Then all the samples were kept 100 cm far away from the light and pasted it on the wall that is shown the figure section below from 1 to 3. The maximum intensity of the lamp that was used was 99 and the minimum intensity used was 55 accordingly. All the samples were tested for 30 hours, 6 hours per day. All the details of the test can be found below in table 1. The temperature on the surface of the sample was measured by using the Testo 845- Infrared Thermometer during the test. The minimum temperature was 24°C whereas the maximum temperature was found to be 30°C.

- Tensile Test

The third method was the tensile test method to find out the mechanical properties of multilayer films. For this test, Testometric Material Testing Machine of standard ISO 527-1 was used. All the samples were cut into the small pieces with dimension 180*25 mm. 5 samples from each film were tested. All the settings were checked and updated but the thickness of the films were not set because they vary from each other. So, it changed after each film. The upper limit of the grip was 1000 mm whereas the lower limit was 270 mm. Then the specimen is gripped at both ends by an apparatus and tensile stresses are applied at a rate of 50 mm/min until it fractures.

11. RESULTS

Most of the samples that were tested in lab could be used for an outdoor application because they were UV protected. UV-Vis spectroscopy result showed that most of the films were UV resistance whereas the black colored plastic film did not show accurate results. Hence radiation test was performed after UV-Vis spectroscopy.

The radiation experiment was done for 30 hours, 6 hours a day by using artificial sunlight lamp. There were no visible changes in the films after the investigation. The details of the experiment are shown in table 4.

Again the same films were analyzed by UV-Vis spectroscopy test that indicated significant changes in graph of transparent films (A, G, H, I, J and K) while the opaque, colored and printed films (B, C and D) did not show any remarkable changes in the graph but the opaque, white and printed films (E and F) results in loss of transparency by around 50 %.

The results obtained from the tensile test method illustrate the strength of the plastic films. It showed the flexibility, elongation and tensile strength of the material. The samples (B, C, D, E and F) seem to have a very high strength because they did not break at all while performing the experiment whereas other non-colored clear samples (A, G, H, I, J and K) were broken at certain point. Most of the samples prolonged up to the maximum upper limit i.e. 1000 mm of the machine but some of them discontinued in the middle of the experiment due to the random errors during repeatable procedure. The graphs of the experimental results of tensile test method are found in the figures section below.

Table 4: Outcomes of radiation test

Samples	Total Hours	Changes Seen From Naked Eyes	Changes Seen After Radiation By UV-Vis Spectroscopy Test
B, C and D	30	No Changes [See Fig 1]	Insignificant Changes [See Fig 5]
A, G, H, I, J and K	30	No Changes [See Fig 1]	Significant Changes [See Fig 3]
E and F	30	No Changes [See Fig 1]	Notable Changes [See Fig 7]

From the above table it can be concluded that almost all the samples were degraded chemically by the radiation of artificial sunlight lamp to some extent.

12. DISCUSSION

All the multilayer films that were provided by the Raniplast Company were found to be UV protected. The common films when exposed to ultraviolet radiation may results in loss of transparency, yellowing and reduction in mechanical properties but certain kinds of multilayer films are UV protected as well as they are equally durable.

The amount of additives, plasticizers, chemicals and colors that are used in the samples were not known but it could be assumed that they played a vital role in the manufacturing process of multilayer films. From the above results, it was found that all the translucent films occurred changes especially in the UV region (190-380 nm) in the graphs of UV-Vis spectroscopy test after radiation. The results showed the increase in transparency percentage that means the transparent samples (A, G, H, I, J and K) were affected by the radiation of artificial sunlight lamp whereas the colored and opaque samples (B, C and D) have no tremendous changes. Nevertheless, there was a noticeable change found in the samples (E and F) during the test.

In this investigation the reasons for obtaining two different results in UV-Vis spectroscopy test before and after radiation were not included because the exact composition of the samples as well as the parameters of manufacturing process were unknown. The information provided was the total number of layers and the name of main polymers of the samples, which was not sufficient to find out the reasons for these changes. It would be interesting to use infra red (IR) spectroscopy to find out the functional groups of the polymers.

The applications of the tested multilayer films can be both indoors and outdoors but the mechanical strength of the films are found to be very strong for all the films although the structure, thickness, material, color and surface of the multilayer films were not same for all the films. Tensile properties of a multilayer film depend on different factors like specimen thickness, speed of testing, type of grips used and method of preparation. These aspects were wisely controlled during the experiment to obtain the precise results. However the design of the material-testing machine caused some errors in the results. At a certain point of the experiment the graphs were found irregular. The grip could not move smoothly upward due to the protective glass and screw of the machine. Similarly, the process of cutting the samples in a required length and width with smooth border by scissor and scalpel was found very demanding.

13. CONCLUSIONS

From the above analysis it proves that the properties of multilayer films are affected by the various factors though they have same layers and same polymer. The thickness, color, additives, amount of resins and chemical composition are responsible in making the good quality multilayer films. During the experiment, it was observed that clear and transparent samples (A, G, H, I, J and K) are highly affected by radiation. Those samples were found to be flexible and have lower tensile strength. The other white, opaque and printed films (E and F) whose tensile strength was found higher than the transparent films were appeared declined in quality after radiation. Likewise, other samples (B, C and D) stayed almost unchanged after radiation test and the samples were found to have high tensile strength.

The error may include in the method of preparation of sample for tensile test method because the exact equipment was not available to prepare the samples due to which the results might not be precise. It was a challenging task to cut the samples in a proper way by the help of scissor and scalpel.

Since the reasons for loss of transparency and chemically degradation material in the samples were unidentified in this research due to the lack of information about the chemical composition of the samples. It could be the topic of research to the students who is interested in this field to find out the reason for these changes.

When two or more properties cannot be found in a single material then separate material are used in design to make a complete final product. Similar or different kinds of polymers can be combined to make a particular multilayer film according to the requirements. The main purpose of manufacturing multilayer films is to provide a new and unique design with low cost including its strength, lifetime and most of the time color of the films depending on its purposes. It could be more attractive for the future researchers to find out the pros and cons about number of layers of films and the additives used in the manufacturing process.

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TABLES

Table 1: Description of radiation

Date	Day	Samples	Starting Time	Ending Time	Total Hours
24.09.2015	Thursday	B, C, D	13:15	18:15	6
28.09.2015	Monday	B, C, D	9:40	15:40	6
29.09.2015	Tuesday	B, C, D	14:20	20:20	6
01.10.2015	Thursday	A, B, C, D, E, F, G, H, I, J, K	11:20	17:20	6
06.10.2015	Tuesday	A, B, C, D, E, F, G, H, I, J, K	11:15	17:15	6
08.10.2015	Thursday	A, E, F, G, H, I, J, K	10:20	16:20	6
13.10.2015	Tuesday	A, E, F, G, H, I, J, K	9:13	15:13	6
15.10.2015	Thursday	A, E, F, G, H, I, J, K	9:30	15:30	6

FIGURES

1.

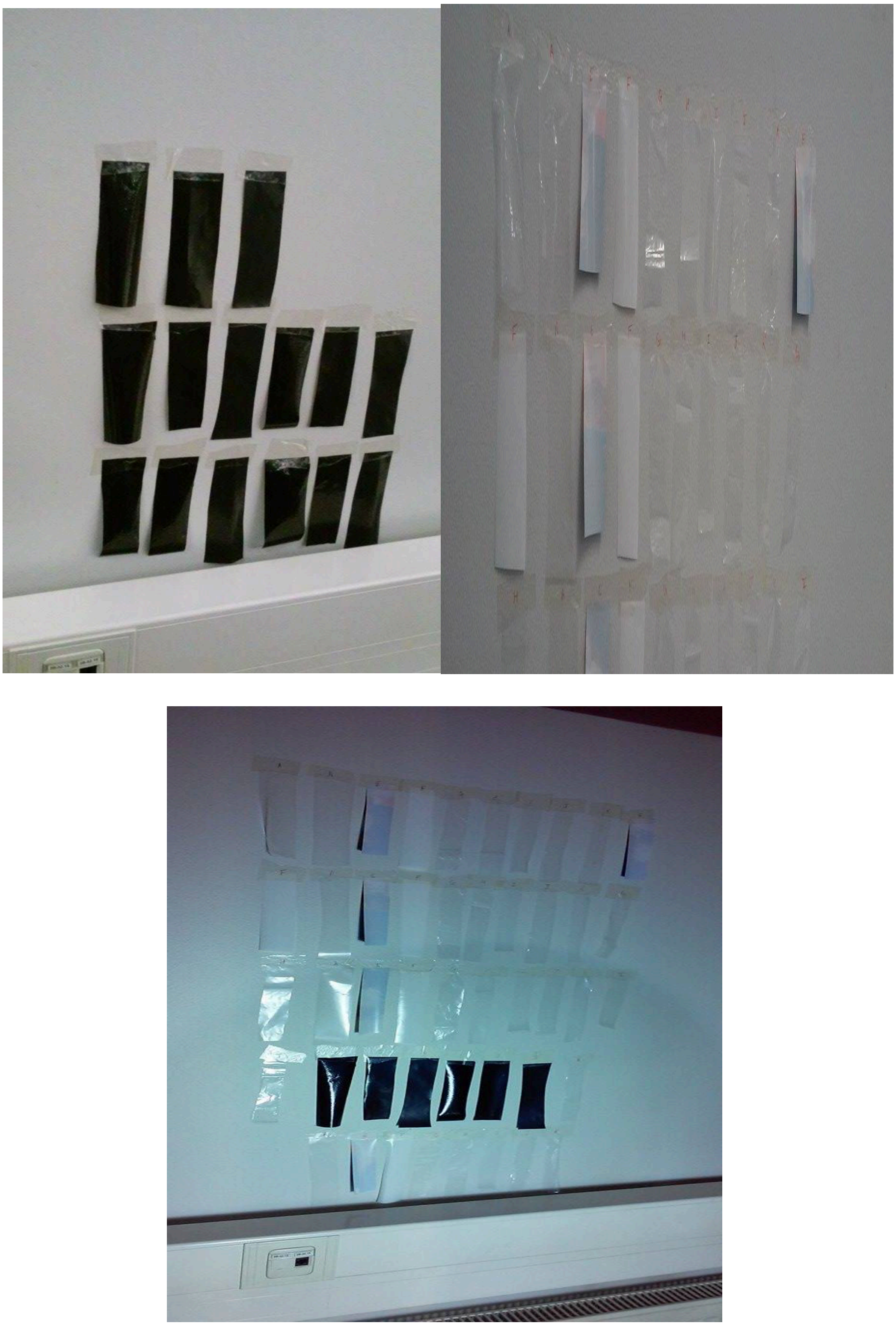


Figure 1: Samples tested in radiation

2.

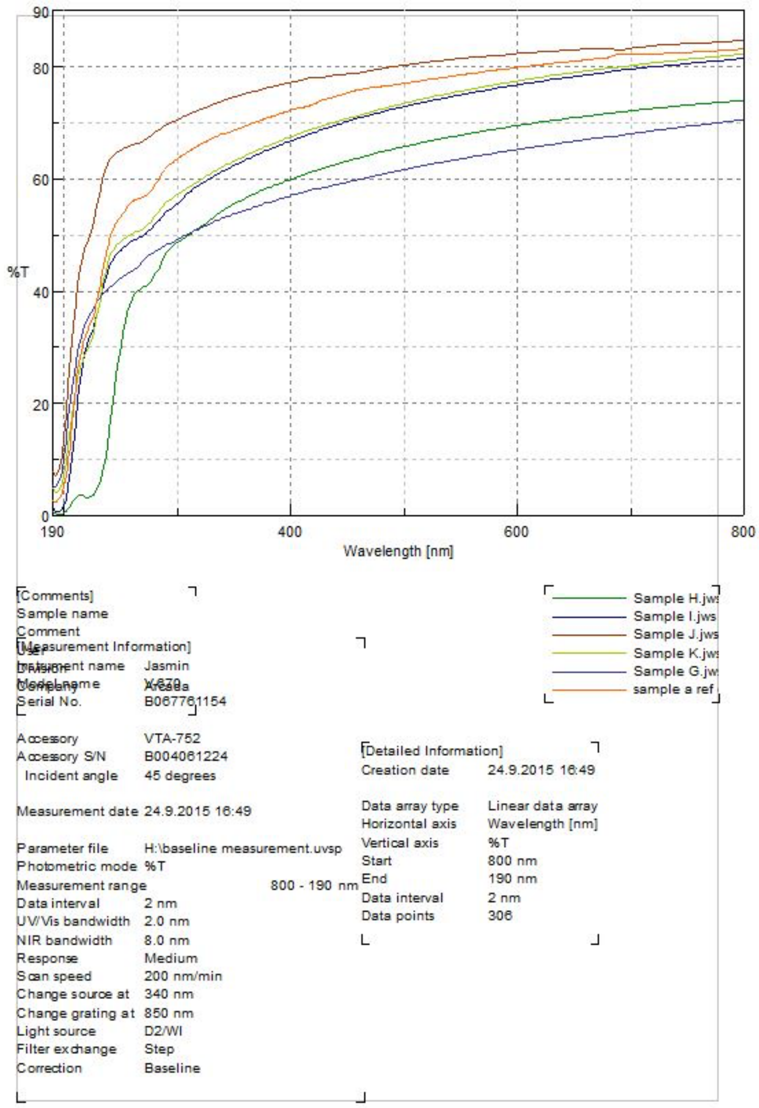


Figure 2: UV-Vis spectroscopy of sample A and G-K before radiation

3.

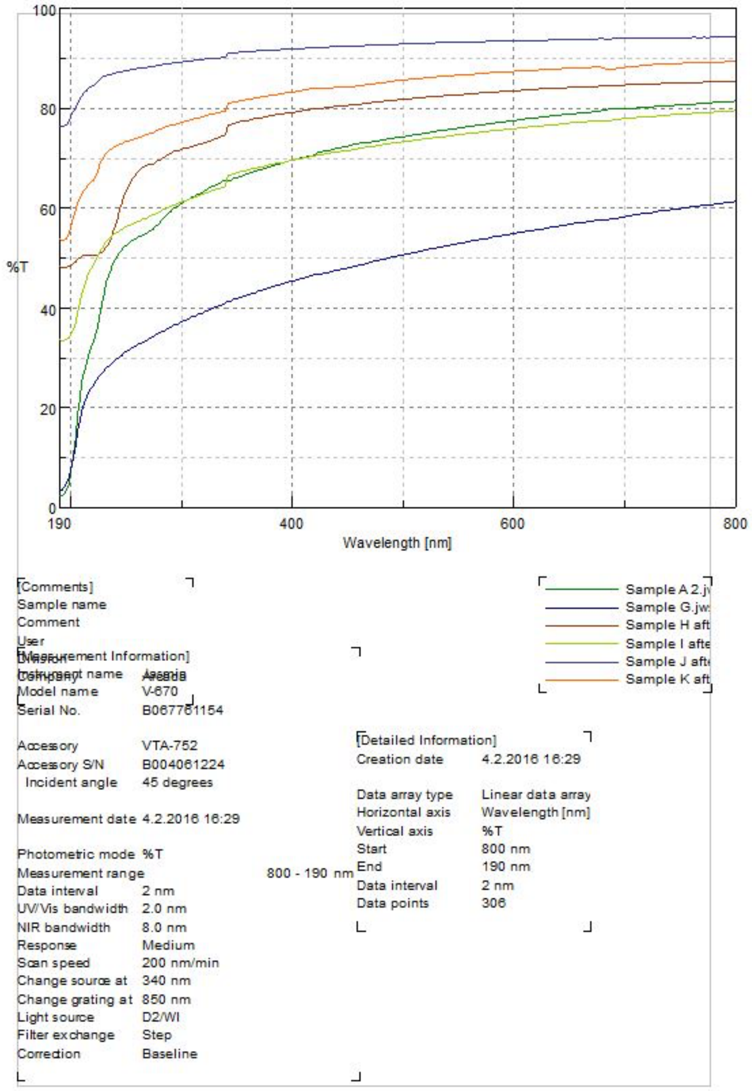


Figure 3: UV-Vis spectroscopy of sample A and G-K after radiation.

4.

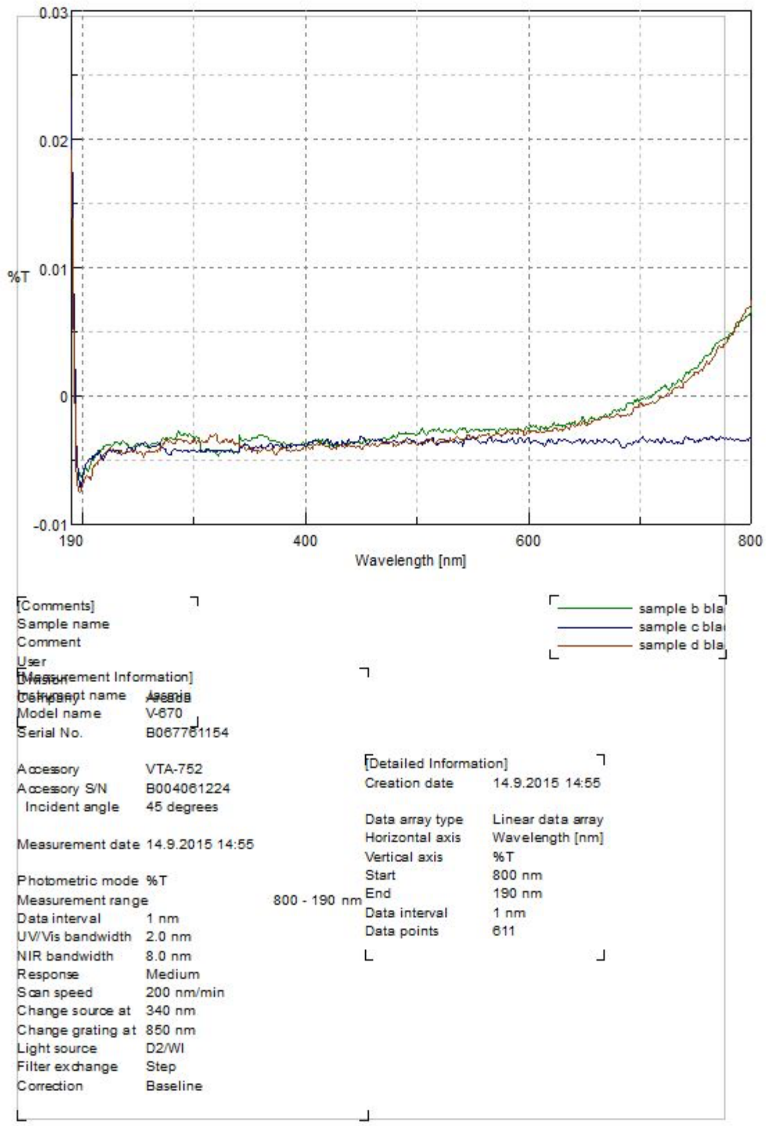


Figure 4: UV-Vis spectroscopy of sample B, C and D before radiation

5.

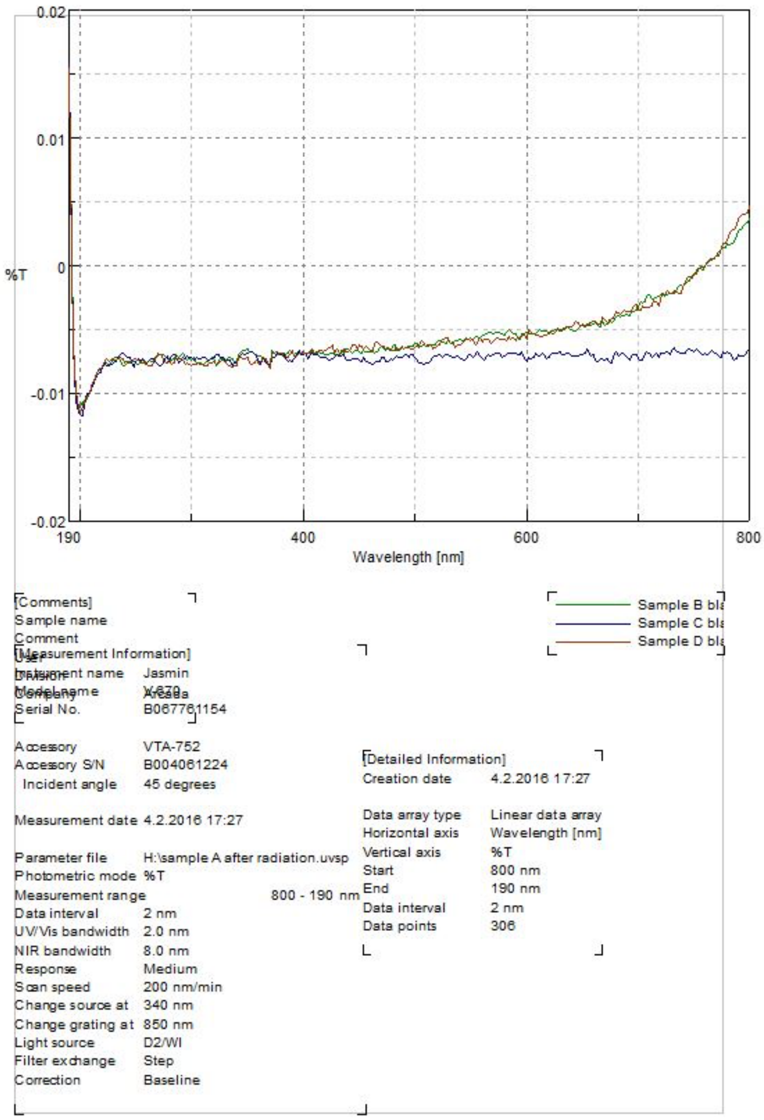


Figure 5: UV-Vis spectroscopy of sample B, C and D after radiation

6.

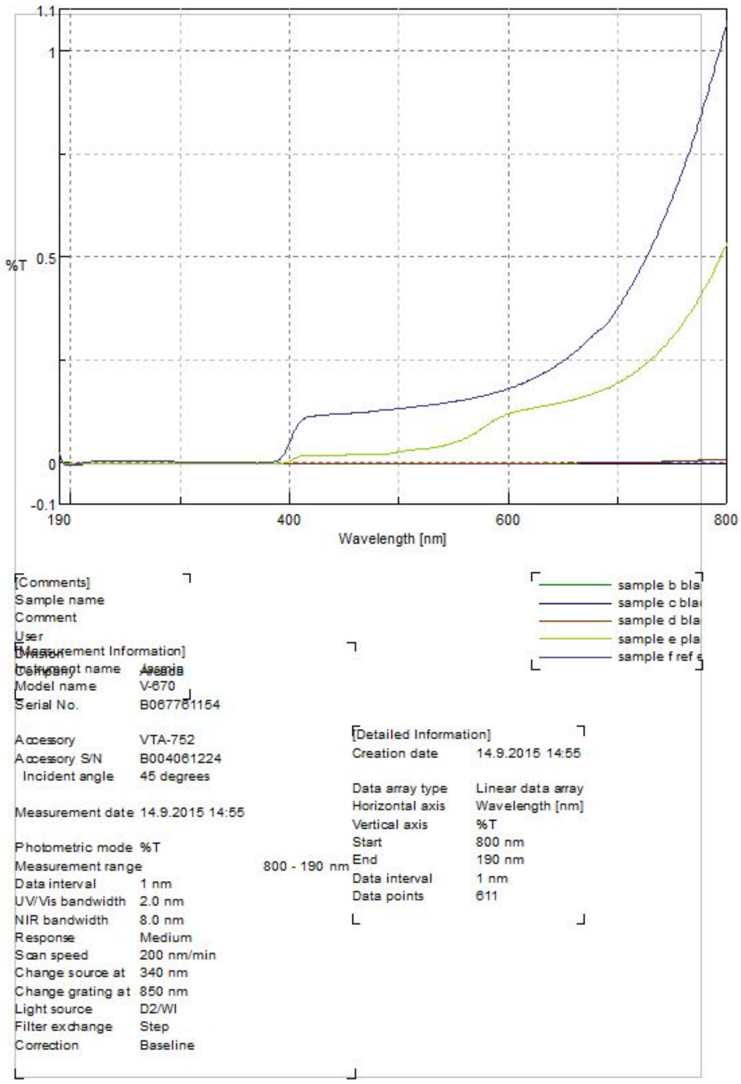


Figure 6: UV-Vis spectroscopy of sample E, F and (B-D) before radiation

7.

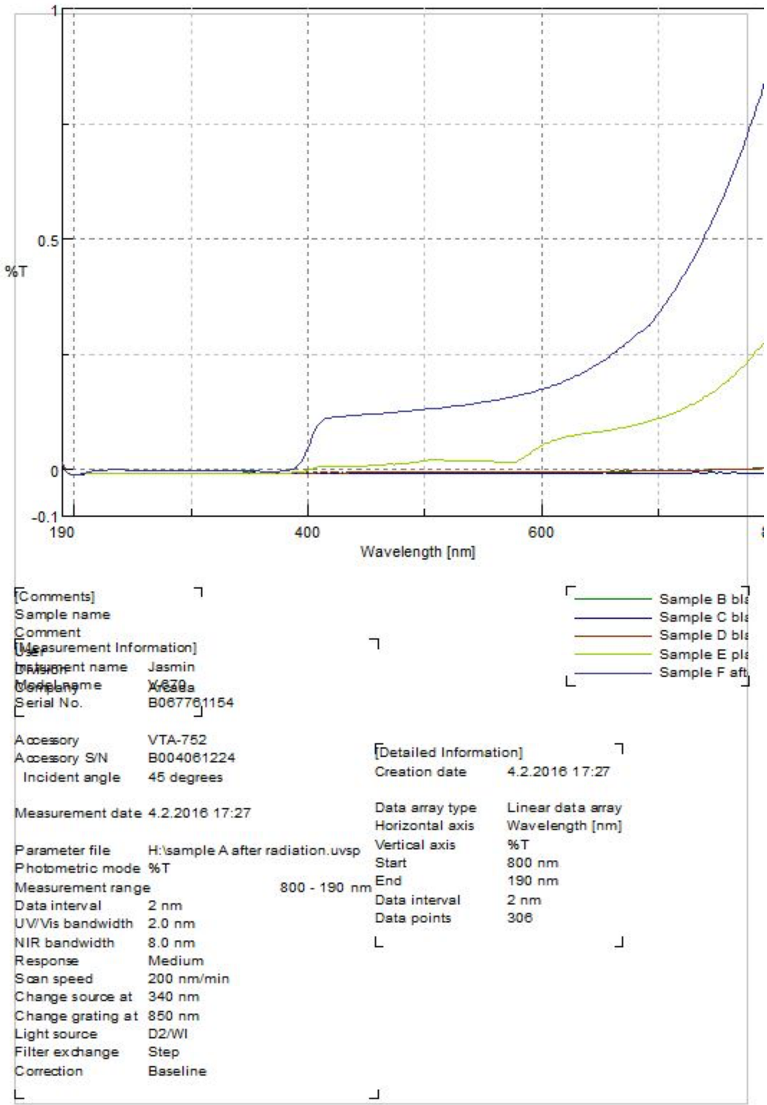


Figure 7: UV-Vis spectroscopy of sample E, F and (B-D) after radiation

8.

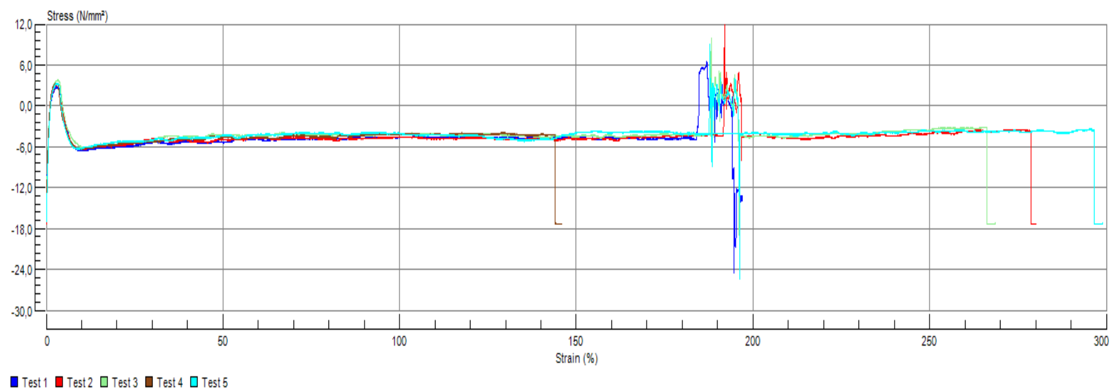
Testometric
materials testing machines

winTest™
Analysis

film structure : PP/PE 5 layers
thickness : 0,043

Test Name : Thesis_1.10.15_Reeta
Test Type : Tensile
Test Date : 24.3.2016 17:00
Test Speed : 50,000 mm/min
Pretension : Off
Width : 25,000 mm
Sample Length : 180,000 mm

Test No	Elong. @ Break (mm)	Elong. @ Yield (mm)	Force @ Break (N)	Force @ Yield (N)	Strain @ Peak (%)	Strain @ Yield (%)	Strain @ Break (%)	Stress @ Peak (N/mm²)	Stress @ Yield (N/mm²)	Stress @ Break (N/mm²)
1	354,762	4,880	-14,750	2,860	186,945	2,711	197,090	6,567	2,660	-13,721
2	504,142	5,659	-18,570	3,320	191,948	3,144	280,079	11,916	3,088	-17,274
3	483,341	6,016	-18,540	4,000	188,224	3,342	268,523	9,898	3,721	-17,247
4	262,762	5,132	-18,660	3,590	2,851	2,851	145,979	3,340	3,340	-17,358
5	538,242	5,853	-18,520	3,510	187,856	3,252	299,023	8,977	3,265	-17,228
Min	262,762	4,880	-18,660	2,860	2,851	2,711	145,979	3,340	2,660	-17,358
Mean	428,650	5,508	-17,808	3,456	151,565	3,060	238,139	8,140	3,215	-16,566
Max	538,242	6,016	-14,750	4,000	191,948	3,342	299,023	11,916	3,721	-13,721
S.D.	115,843	0,484	1,710	0,415	83,155	0,269	64,357	3,300	0,387	1,591
C. of V.	27,025	8,781	-9,604	12,022	54,865	8,781	27,025	40,546	12,022	-9,604
L.C.L.	284,813	4,907	-19,932	2,940	48,315	2,726	158,230	4,042	2,735	-18,541
U.C.L.	572,486	6,109	-15,684	3,972	254,814	3,394	318,048	12,237	3,695	-14,590



Page 1

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Figure 8: Data and graph of sample A (PP/PE, 5 layers) plotted at 50 mm/min in display monitor

9.

Testometric
materials testing machines

winTest™ Analysis

film structure : PE 3 layers
thickness : 0.065

Test Name : Thesis_1.10.15_Reeta
Test Type : Tensile
Test Date : 5.11.2015 12:30
Test Speed : 50,000 mm/min
Pretension : Off
Width : 25,000 mm
Sample Length : 180,000 mm

Test No	Elong. @ Break (mm)	Elong. @ Yield (mm)	Force @ Break (N)	Force @ Yield (N)	Strain @ Peak (%)	Strain @ Yield (%)	Strain @ Break (%)	Stress @ Peak (N/mm²)	Stress @ Yield (N/mm²)	Stress @ Break (N/mm²)
1	350,508	272,620	-8,230	4,550	189,315	151,456	194,727	13,563	2,800	-5,065
2	350,545	10,049	-11,860	5,200	189,332	5,583	194,747	15,052	3,200	-7,298
3	350,014	254,775	5,770	4,250	190,135	141,542	194,452	12,991	2,615	3,551
4	348,438	14,019	-12,240	4,520	188,144	7,788	193,577	13,612	2,782	-7,532
5	348,406	9,974	-11,390	4,500	188,167	5,541	193,559	13,809	2,769	-7,009
Min	348,406	9,974	-12,240	4,250	188,144	5,541	193,559	12,991	2,615	-7,532
Mean	349,582	112,287	-7,590	4,604	189,019	62,382	194,212	13,806	2,833	-4,671
Max	350,545	272,620	5,770	5,200	190,135	151,456	194,747	15,052	3,200	3,551
S.D.	1,080	138,371	7,635	0,354	0,855	76,873	0,600	0,761	0,218	4,699
C. of V.	0,309	123,230	-100,598	7,689	0,452	123,230	0,309	5,510	7,689	-100,598
L.C.L.	348,242	-59,521	-17,070	4,164	187,957	-33,067	193,468	12,861	2,563	-10,505
U.C.L.	350,923	284,095	1,890	5,044	190,080	157,831	194,957	14,750	3,104	1,163

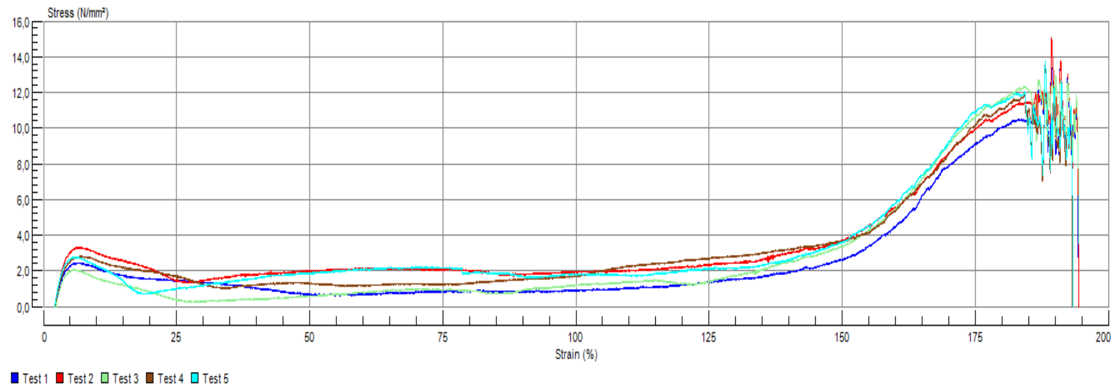

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Figure 9: Data and graph of sample B (PE, 3 layers) plotted at 50 mm/min in display monitor

10.

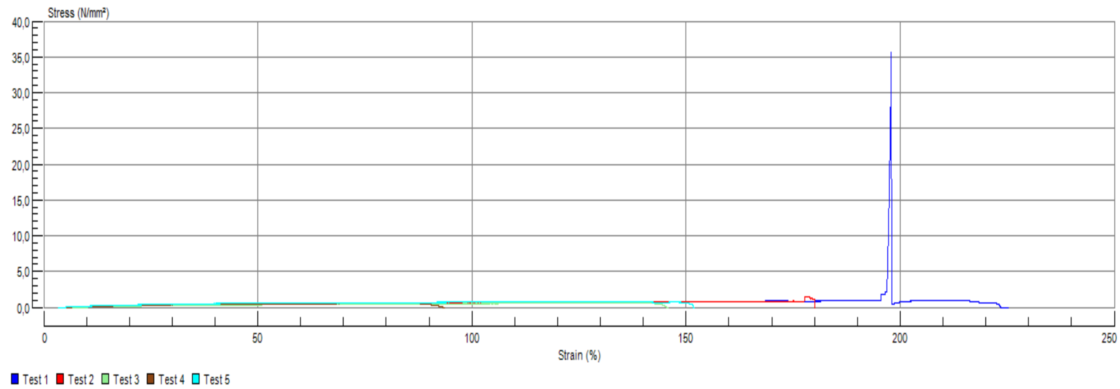
Testometric
materials testing machines

winTest™ Analysis

film structure : PE 3 layers
thickness : 0,471

Test Name : Thesis_1.10.15_Reeta
Test Type : Tensile
Test Date : 16.3.2016 16:01
Test Speed : 50,000 mm/min
Pretension : Off
Width : 25,000 mm
Sample Length : 180,000 mm

Test No	Elong. @ Break (mm)	Elong. @ Yield (mm)	Force @ Break (N)	Force @ Yield (N)	Strain @ Peak (%)	Strain @ Yield (%)	Strain @ Break (%)	Stress @ Peak (N/mm²)	Stress @ Yield (N/mm²)	Stress @ Break (N/mm²)
1	410,572	356,292	-19,090	419,480	197,940	197,940	228,096	35,625	35,625	-1,621
2	330,518	46,115	-19,060	4,080	177,786	25,619	183,621	1,508	0,346	-1,619
3	267,336	36,598	-18,980	1,790	138,644	20,332	148,520	0,613	0,152	-1,612
4	173,180	23,558	-18,950	1,570	86,020	13,088	96,211	0,551	0,133	-1,609
5	276,226	29,657	-18,900	3,070	125,364	16,476	153,459	0,798	0,261	-1,605
Min	173,180	23,558	-19,090	1,570	86,020	13,088	96,211	0,551	0,133	-1,621
Mean	291,566	98,444	-18,996	85,998	145,151	54,691	161,981	7,819	7,303	-1,613
Max	410,572	356,292	-18,900	419,480	197,940	197,940	228,096	35,625	35,625	-1,605
S.D.	87,346	144,385	0,078	186,425	44,108	80,214	48,526	15,548	15,832	0,007
C. of V.	29,958	146,667	-0,412	216,778	30,388	146,667	29,958	198,852	216,778	-0,412
L.C.L.	183,114	-80,831	-19,093	-145,475	90,384	-44,906	101,730	-11,486	-12,355	-1,622
U.C.L.	400,019	277,719	-18,899	317,471	199,917	154,288	222,233	27,125	26,961	-1,605



Page 1

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Figure 10: Data and graph of sample C (PE, 3 layers) plotted at 50 mm/min in display monitor

11.

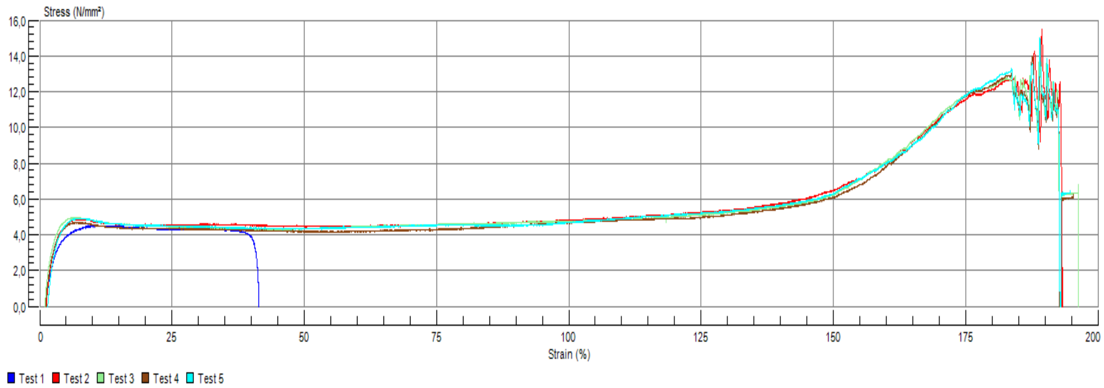
Testometric
materials testing machines

winTest™ Analysis

film structure : Unknown 7 layers
thickness : 0.095

Test Name : Thesis_1.10.15_Reeta
Test Type : Tensile
Test Date : 5.11.2015 14:40
Test Speed : 50,000 mm/min
Pretension : Off
Width : 25,000 mm
Sample Length : 180,000 mm

Test No	Elong. @ Break (mm)	Elong. @ Yield (mm)	Force @ Break (N)	Force @ Yield (N)	Strain @ Peak (%)	Strain @ Yield (%)	Strain @ Break (%)	Stress @ Peak (N/mm²)	Stress @ Yield (N/mm²)	Stress @ Break (N/mm²)
1	81,534	8,503	-16,770	9,050	9,224	4,724	45,297	4,522	3,811	-7,061
2	348,130	6,056	5,120	9,000	189,401	3,364	193,406	15,457	3,789	2,156
3	353,502	11,782	15,350	11,800	188,963	6,546	196,390	14,825	4,968	6,463
4	351,775	9,191	14,800	10,680	189,026	5,106	195,431	14,703	4,497	6,232
5	350,681	8,990	15,380	10,880	189,033	4,994	194,823	14,977	4,581	6,476
Min	81,534	6,056	-16,770	9,000	9,224	3,364	45,297	4,522	3,789	-7,061
Mean	297,124	8,904	6,776	10,282	153,129	4,947	165,069	12,897	4,329	2,853
Max	353,502	11,782	15,380	11,800	189,401	6,546	196,390	15,457	4,968	6,476
S.D.	120,534	2,040	13,866	1,223	80,446	1,133	66,964	4,690	0,515	5,838
C. of V.	40,567	22,909	204,637	11,893	52,535	22,909	40,567	36,368	11,893	204,637
L.C.L.	147,464	6,372	-10,441	8,764	53,244	3,540	81,924	7,073	3,690	-4,396
U.C.L.	446,785	11,437	23,993	11,800	253,014	6,354	248,214	18,721	4,969	10,102



Page 1

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Figure 11: Data and graph of sample D (Unknown, 7 layers) plotted at 50 mm/min in display monitor

12.

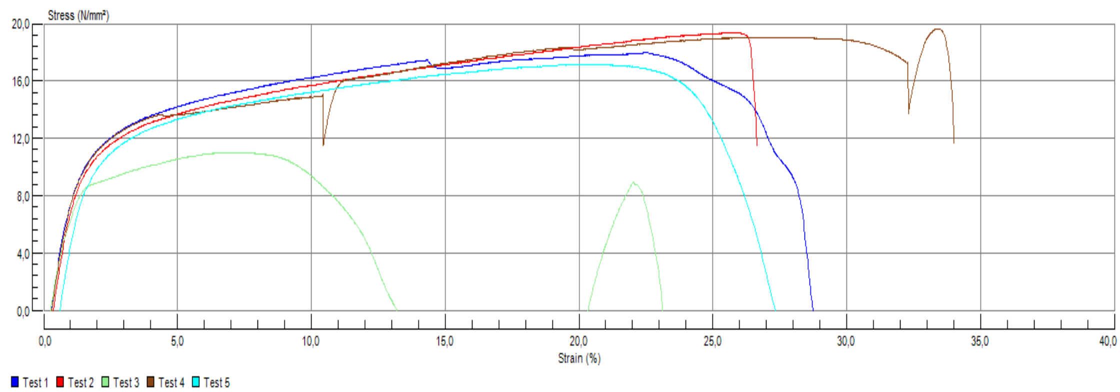
Testometric
materials testing machines

winTest™ Analysis

film structure : PET/PE 1+3 layers
thickness : 0.125

Test Name : Thesis_1.10.15_Reeta
Test Type : Tensile
Test Date : 5.11.2015 16:27
Test Speed : 50,000 mm/min
Pretension : Off
Width : 25,000 mm
Sample Length : 180,000 mm

Test No	Elong. @ Break (mm)	Elong. @ Yield (mm)	Force @ Break (N)	Force @ Yield (N)	Strain @ Peak (%)	Strain @ Yield (%)	Strain @ Break (%)	Stress @ Peak (N/mm²)	Stress @ Yield (N/mm²)	Stress @ Break (N/mm²)
1	62,968	11,027	-16,960	46,190	22,518	6,126	34,982	18,010	14,781	-5,427
2	47,952	16,859	36,040	48,450	25,854	9,366	26,640	19,354	15,504	11,533
3	44,753	9,377	-16,880	33,250	6,849	5,209	24,863	11,008	10,640	-5,402
4	61,236	8,009	36,500	42,590	33,415	4,449	34,020	19,651	13,629	11,680
5	64,862	17,855	-16,880	47,520	20,490	9,919	36,034	17,171	15,206	-5,402
Min	44,753	8,009	-16,960	33,250	6,849	4,449	24,863	11,008	10,640	-5,427
Mean	56,354	12,625	4,364	43,600	21,825	7,014	31,308	17,039	13,952	1,396
Max	64,862	17,855	36,500	48,450	33,415	9,919	36,034	19,651	15,504	11,680
S.D.	9,289	4,463	29,127	6,200	9,710	2,480	5,161	3,518	1,984	9,320
C. of V.	16,483	35,353	667,427	14,219	44,488	35,353	16,483	20,649	14,219	667,427
L.C.L.	44,821	7,083	-31,801	35,902	9,769	3,935	24,900	12,670	11,489	-10,176
U.C.L.	67,888	18,167	40,529	51,298	33,881	10,093	37,715	21,407	16,415	12,969



Page 1

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Figure 12: Data and graph of sample E (PET+PE, 1+3 layers) plotted at 50 mm/min in display monitor

13.

Testometric materials testing machines

winTest™ Analysis

film structure : PE 3 layers
thickness : 0.123

Test Name : Thesis_1.10.15_Reeta
Test Type : Tensile
Test Date : 5.11.2015 16:44
Test Speed : 50,000 mm/min
Pretension : Off
Width : 25,000 mm
Sample Length : 180,000 mm

Test No	Elong. @ Break (mm)	Elong. @ Yield (mm)	Force @ Break (N)	Force @ Yield (N)	Strain @ Peak (%)	Strain @ Yield (%)	Strain @ Break (%)	Stress @ Peak (N/mm²)	Stress @ Yield (N/mm²)	Stress @ Break (N/mm²)
1	352,457	10,166	17,760	15,430	189,955	5,648	195,809	11,366	5,018	5,776
2	340,867	7,986	25,340	16,030	187,423	4,437	189,371	12,400	5,213	8,241
3	325,432	12,979	27,950	17,270	176,403	7,211	180,796	13,928	5,616	9,089
4	167,797	10,425	-16,850	17,370	6,737	5,792	93,221	5,740	5,649	-5,480
5	280,048	10,028	-16,880	16,660	8,706	5,571	155,582	5,694	5,418	-5,489
Min	167,797	7,986	-16,880	15,430	6,737	4,437	93,221	5,694	5,018	-5,489
Mean	293,320	10,317	7,464	16,552	113,845	5,732	162,956	9,826	5,383	2,427
Max	352,457	12,979	27,950	17,370	189,955	7,211	195,809	13,928	5,649	9,089
S.D.	75,368	1,777	22,522	0,826	97,013	0,987	41,871	3,860	0,269	7,324
C. of V.	25,695	17,229	301,747	4,989	85,215	17,229	25,695	39,283	4,989	301,747
L.C.L.	199,740	8,110	-20,501	15,527	-6,611	4,505	110,967	5,033	5,049	-6,667
U.C.L.	386,900	12,524	35,429	17,577	234,301	6,958	214,945	14,618	5,716	11,522

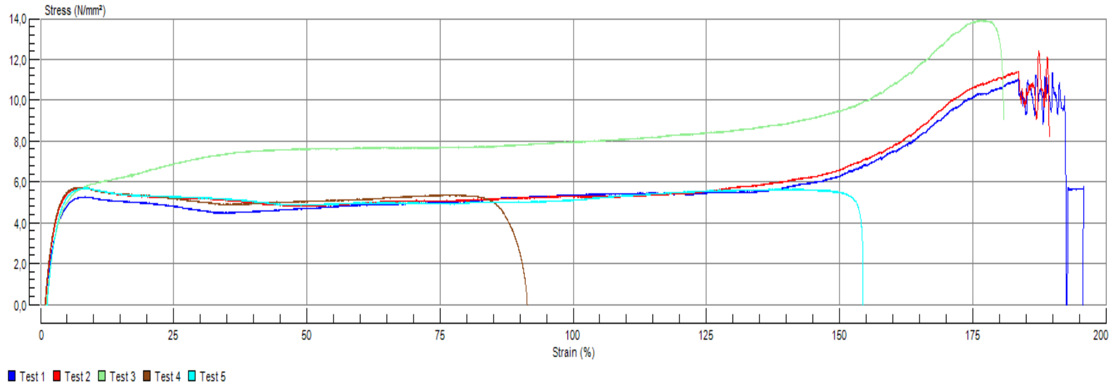

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Figure 13: Data and graph of sample F (PE, 3 layers) plotted at 50 mm/min in display monitor

14.

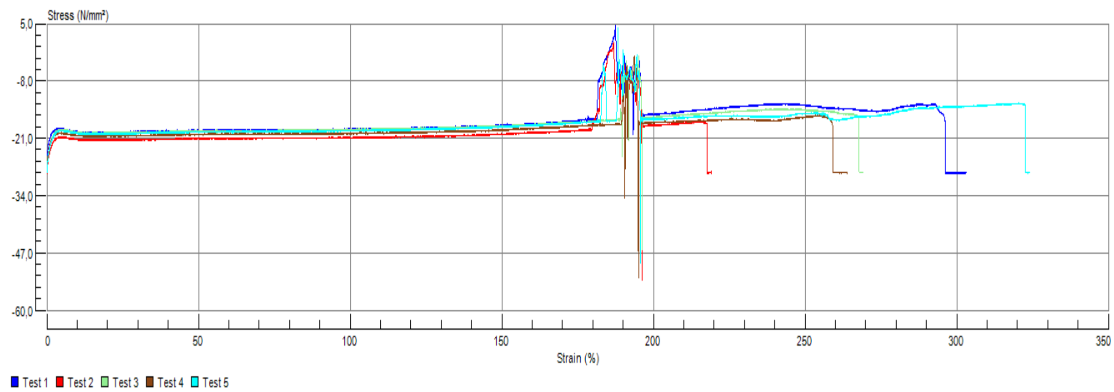
Testometric
materials testing machines

winTest™ Analysis

film structure : PE 1 layer
thickness : 0,026

Test Name : Thesis_1.10.15_Reeta
Test Type : Tensile
Test Date : 24.3.2016 15:56
Test Speed : 50,000 mm/min
Pretension : Off
Width : 25,000 mm
Sample Length : 180,000 mm

Test No	Elong. @ Break (mm)	Elong. @ Yield (mm)	Force @ Break (N)	Force @ Yield (N)	Strain @ Peak (%)	Strain @ Yield (%)	Strain @ Break (%)	Stress @ Peak (N/mm²)	Stress @ Yield (N/mm²)	Stress @ Break (N/mm²)
1	545,929	336,380	-18,680	1,220	187,467	186,878	303,294	4,569	1,877	-28,738
2	394,434	336,317	-18,570	0,500	186,843	186,843	219,130	0,769	0,769	-28,569
3	484,328	484,328	-18,630	-18,630	195,169	269,071	269,071	-2,369	-28,662	-28,662
4	475,170	475,170	-18,790	-18,790	193,721	263,983	263,983	-2,369	-28,908	-28,908
5	583,394	339,025	-18,630	2,530	188,347	188,347	324,108	3,892	3,892	-28,662
Min	394,434	336,317	-18,790	-18,790	186,843	186,843	219,130	-2,369	-28,908	-28,908
Mean	496,651	394,244	-18,660	-6,634	190,309	219,024	275,917	0,898	-10,206	-28,708
Max	583,394	484,328	-18,570	2,530	195,169	269,071	324,108	4,569	3,892	-28,569
S.D.	72,482	78,130	0,082	11,048	3,847	43,405	40,268	3,309	16,997	0,127
C. of V.	14,594	19,818	-0,442	-166,536	2,021	19,818	14,594	368,347	-166,536	-0,442
L.C.L.	406,655	297,235	-18,762	-20,352	185,533	165,130	225,919	-3,211	-31,310	-28,865
U.C.L.	586,647	491,253	-18,558	7,084	195,086	272,919	325,915	5,008	10,898	-28,550



Page 1

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Figure 14: Data and graph of sample G (PE, 1 layer) plotted at 50 mm/min in display monitor

15.

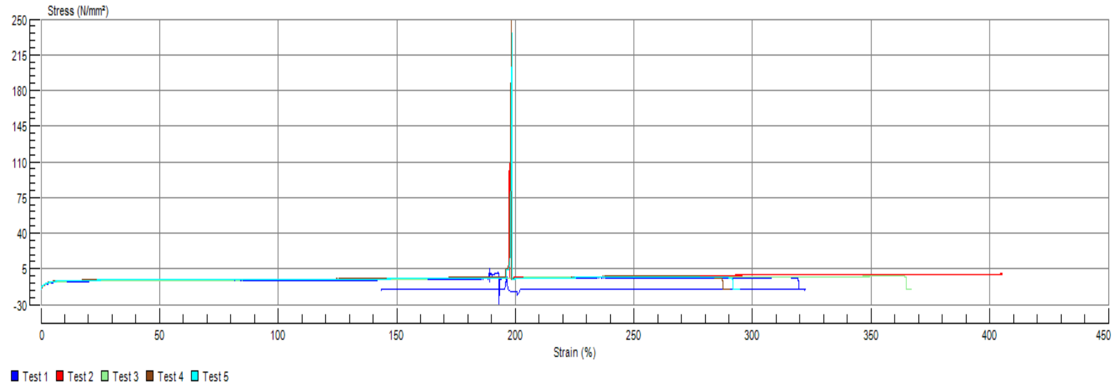
Testometric
materials testing machines

winTest™ Analysis

film structure : PE 3 layers
thickness : 0,05

Test Name : Thesis_1.10.15_Reeta
Test Type : Tensile
Test Date : 16.3.2016 18:11
Test Speed : 50,000 mm/min
Pretension : Off
Width : 25,000 mm
Sample Length : 180,000 mm

Test No	Elong. @ Break (mm)	Elong. @ Yield (mm)	Force @ Break (N)	Force @ Yield (N)	Strain @ Peak (%)	Strain @ Yield (%)	Strain @ Break (%)	Stress @ Peak (N/mm²)	Stress @ Yield (N/mm²)	Stress @ Break (N/mm²)
1	579,907	340,329	-18,840	6,870	189,072	189,072	322,171	5,496	5,496	-15,072
2	729,593	355,377	-0,100	134,700	197,432	197,432	405,329	107,760	107,760	-0,080
3	660,475	660,475	-18,840	-18,840	359,042	366,931	366,931	-2,104	-15,072	-15,072
4	522,665	356,911	-18,770	309,520	198,284	198,284	290,369	247,616	247,616	-15,016
5	530,337	357,422	-18,980	294,870	198,568	198,568	294,632	235,896	235,896	-15,184
Min	522,665	340,329	-18,980	-18,840	189,072	189,072	290,369	-2,104	-15,072	-15,184
Mean	604,595	414,103	-15,106	145,424	228,479	230,057	335,886	118,933	116,339	-12,085
Max	729,593	660,475	-0,100	309,520	359,042	366,931	405,329	247,616	247,616	-0,080
S.D.	88,859	137,908	8,389	154,561	73,092	76,615	49,366	120,294	123,649	6,711
C. of V.	14,697	33,303	-55,534	106,283	31,991	33,303	14,697	101,144	106,283	-55,534
L.C.L.	494,265	242,870	-25,522	-46,486	137,725	134,928	274,592	-30,429	-37,189	-20,418
U.C.L.	714,926	585,335	-4,690	337,334	319,234	325,186	397,181	268,295	269,867	-3,752



Page 1

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Figure 15: Data and graph of sample H (PE, 3 layers) plotted at 50 mm/min in display Monitor

16.

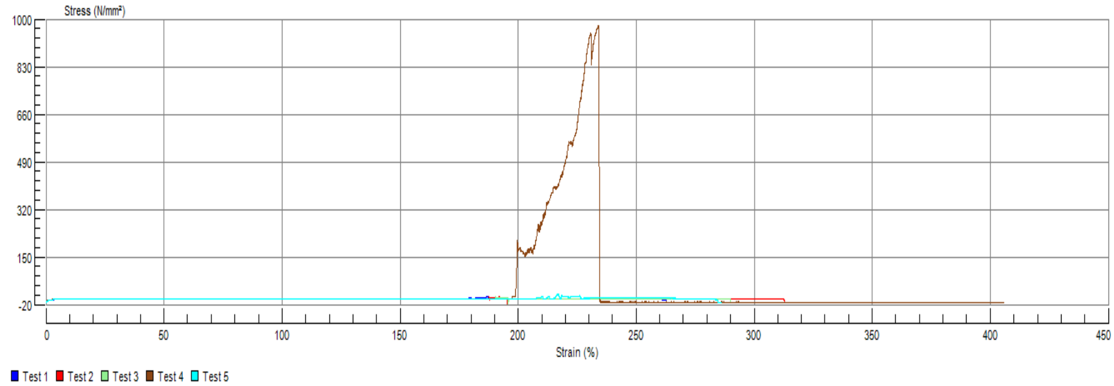
Testometric
materials testing machines

winTest™ Analysis

film structure : PE 3 layers
thickness : 0,065

Test Name : Thesis_1.10.15_Reeta
Test Type : Tensile
Test Date : 21.3.2016 18:36
Test Speed : 50,000 mm/min
Pretension : Off
Width : 25,000 mm
Sample Length : 180,000 mm

Test No	Elong. @ Break (mm)	Elong. @ Yield (mm)	Force @ Break (N)	Force @ Yield (N)	Strain @ Peak (%)	Strain @ Yield (%)	Strain @ Break (%)	Stress @ Peak (N/mm²)	Stress @ Yield (N/mm²)	Stress @ Break (N/mm²)
1	475,939	322,982	-18,840	7,270	186,955	179,434	264,411	8,572	4,474	-11,594
2	566,240	337,814	-18,950	15,080	187,674	187,674	314,578	9,280	9,280	-11,662
3	525,681	342,963	-18,840	12,870	190,535	190,535	292,045	7,920	7,920	-11,594
4	729,968	359,532	-18,380	337,300	234,086	199,740	405,538	975,200	207,569	-11,311
5	514,713	377,221	-18,350	9,180	216,674	209,567	285,952	15,477	5,649	-11,292
Min	475,939	322,982	-18,950	7,270	186,955	179,434	264,411	7,920	4,474	-11,662
Mean	562,508	348,102	-18,672	76,340	203,185	193,390	312,505	203,290	46,978	-11,490
Max	729,968	377,221	-18,350	337,300	234,086	209,567	405,538	975,200	207,569	-11,292
S.D.	98,984	20,868	0,284	145,913	21,218	11,593	54,991	431,521	89,793	0,175
C. of V.	17,597	5,995	-1,521	191,136	10,443	5,995	17,597	212,269	191,136	-1,521
L.C.L.	439,605	322,192	-19,025	-104,832	176,840	178,996	244,225	-332,506	-64,512	-11,707
U.C.L.	685,411	374,013	-18,319	257,512	229,530	207,785	380,784	739,086	158,469	-11,273



Page 1

Figure 16: Data and graph of sample I (PE, 3 layers) plotted at 50 mm/min in display monitor

17.

Testometric
materials testing machines

winTest™ Analysis

film structure : PE 3 layers
thickness : 0,024

Test Name : Thesis_1.10.15_Reeta
Test Type : Tensile
Test Date : 21.3.2016 15:34
Test Speed : 50,000 mm/min
Pretension : Off
Width : 25,000 mm
Sample Length : 180,000 mm

Test No	Elong. @ Break (mm)	Elong. @ Yield (mm)	Force @ Break (N)	Force @ Yield (N)	Strain @ Peak (%)	Strain @ Yield (%)	Strain @ Break (%)	Stress @ Peak (N/mm^2)	Stress @ Yield (N/mm^2)	Stress @ Break (N/mm^2)
1	729,672	336,744	-19,090	4,080	187,080	187,080	405,373	6,800	6,800	-31,817
2	526,189	358,434	-18,900	359,130	199,130	199,130	292,327	598,550	598,550	-31,500
3	486,575	358,984	-18,900	303,400	199,436	199,436	270,319	505,667	505,667	-31,500
4	580,648	337,285	-18,900	2,910	187,381	187,381	322,582	4,850	4,850	-31,500
5	109,567	109,567	-18,900	-18,900	4,223	60,871	60,871	-20,533	-31,500	-31,500
Min	109,567	109,567	-19,090	-18,900	4,223	60,871	60,871	-20,533	-31,500	-31,817
Mean	486,530	300,203	-18,938	130,124	155,450	166,779	270,295	219,067	216,873	-31,563
Max	729,672	358,984	-18,900	359,130	199,436	199,436	405,373	598,550	598,550	-31,500
S.D.	230,027	107,120	0,085	184,897	84,753	59,511	127,793	305,983	308,161	0,142
C. of V.	47,279	35,682	-0,449	142,093	54,521	35,682	47,279	139,676	142,093	-0,449
L.C.L.	200,918	167,198	-19,044	-99,452	50,217	92,888	111,621	-160,855	-165,753	-31,739
U.C.L.	772,142	433,207	-18,832	359,700	260,683	240,671	428,968	598,988	599,499	-31,387

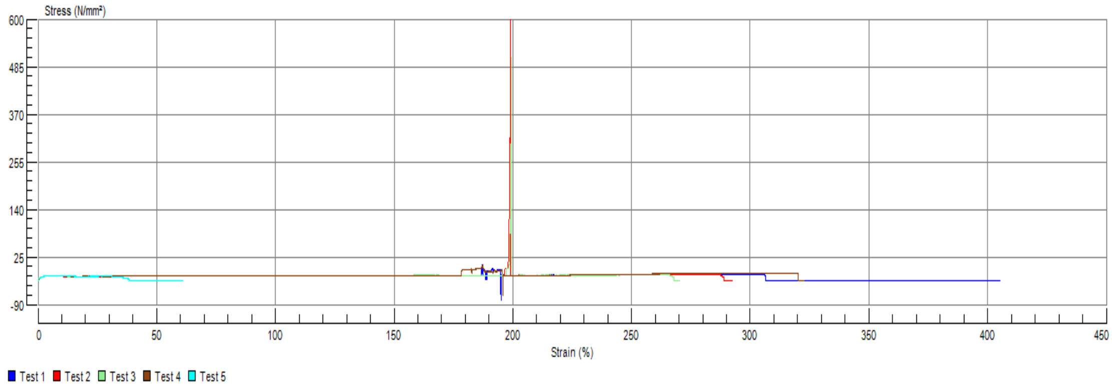


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Figure 17: Data and graph of sample J (PE, 3 layers) plotted at 50 mm/min in display monitor

18.

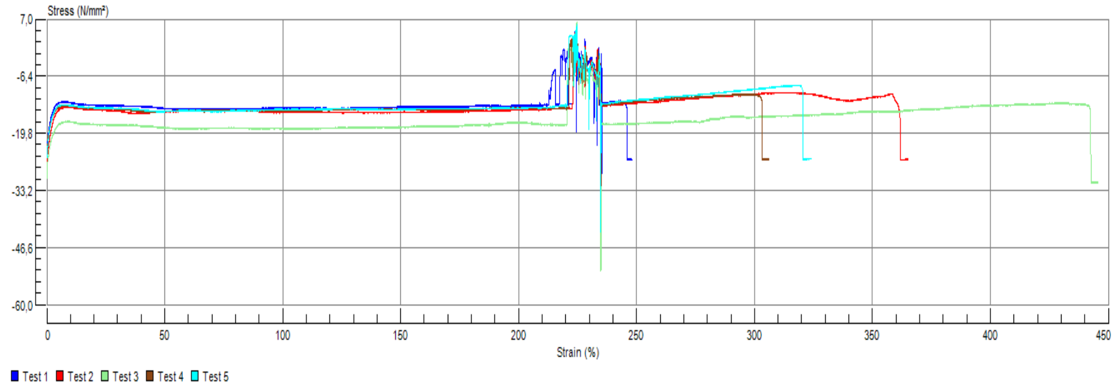
Testometric
materials testing machines

winTest™ Analysis

film structure : PE 3 layers
thickness : 0,029

Test Name : Thesis_1.10.15_Reeta
Test Type : Tensile
Test Date : 24.3.2016 14:36
Test Speed : 50,000 mm/min
Pretension : Off
Width : 25,000 mm
Sample Length : 150,000 mm

Test No	Elong. @ Break (mm)	Elong. @ Yield (mm)	Force @ Break (N)	Force @ Yield (N)	Strain @ Peak (%)	Strain @ Yield (%)	Strain @ Break (%)	Stress @ Peak (N/mm²)	Stress @ Yield (N/mm²)	Stress @ Break (N/mm²)
1	372,318	335,735	-18,810	2,940	223,823	223,823	248,212	4,055	4,055	-25,945
2	547,418	335,101	-18,740	1,500	223,969	223,401	364,945	4,345	2,069	-25,848
3	668,626	337,004	-18,740	3,840	224,669	224,669	445,751	6,400	6,400	-31,233
4	459,009	332,491	-18,770	0,890	224,747	221,661	306,006	4,814	1,228	-25,890
5	485,881	333,520	-18,630	2,280	224,815	222,347	323,921	5,779	3,145	-25,697
Min	372,318	332,491	-18,810	0,890	223,823	221,661	248,212	4,055	1,228	-31,233
Mean	506,650	334,770	-18,738	2,290	224,405	223,180	337,767	5,079	3,379	-26,923
Max	668,626	337,004	-18,630	3,840	224,815	224,669	445,751	6,400	6,400	-25,697
S.D.	110,277	1,788	0,067	1,163	0,470	1,192	73,518	0,987	1,999	2,412
C. of V.	21,766	0,534	-0,357	50,781	0,209	0,534	21,766	19,425	59,153	-8,957
L.C.L.	369,725	332,550	-18,821	0,846	223,821	221,700	246,483	3,854	0,897	-29,917
U.C.L.	643,576	336,990	-18,655	3,734	224,988	224,660	429,050	6,304	5,861	-23,928



Page 1

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Figure 18: Data and graph of sample K (PE, 3 layers) plotted at 50 mm/min in display monitor

APPENDIX/APPENDICES

ATLAS
MATERIAL TESTING SOLUTIONS

10. TECHNICAL DATA SHEET Osram

Technical Information
No. FO 4898

Edition: 11/00 - subject to change
Substitutes: 02/99
Status: valid

Mercury Safety Instructions for
Metal Halide Lamps

Product and operation description

OSRAM metal halide lamps are lamps of the families HMI®, HTI® and VIP® for DC and or AC operation in which the light arc burns in an atmosphere of rare earth elements, halogen and mercury vapour at high pressure. The lamps are available in wattages ranging from 35 W to 12000 W. The families named above includes HMP®, HSR®, HSD® and HMD® lamps.

In cold lamps of higher wattage (i.e. at room temperature) metallic droplets of mercury can be seen in the lamp bulb. During operation of the lamp the mercury vaporizes due to heating of the discharge tube (lamp body) and the gas between the electrodes approaches temperatures of up to 10.000 °C. The temperature of the discharge tube reaches approximately 800-900 °C. After the lamp is in thermal equilibrium (1 to 10 minutes after ignition), the vaporized mercury gives rise to a pressure up to 200 times the atmospheric pressure.

Mercury fillings of OSRAM HMI® and HTI® lamp families

Wattages	Mercury [mg]
≤ 250 W versions	max. 40
300 W to 700 W versions	max. 120
1200 W to 2500 W versions	max. 190
4000 W to 6000 W versions	max. 460
12 kW to 18 kW versions	max. 1120

Mercury fillings of OSRAM VIP® lamps

Wattages	Mercury [mg]
≤ 120 W versions	max. 10
170 W to 400 W versions	max. 25
≥ 1200 W versions	max. 180

Health hazards

Inhaling vapour or small particles of mercury or its compounds can be harmful to lung, kidney and nervous system. Injuries to one's health can also arise by penetration of the skin or resorption via the gastro-enteric tract.

Lamp breakage

In the rare case that metal halide lamps broke or burst and the mercury content is released, we recommend to consider the following security instructions:

- All persons should leave the surrounding area at once, in order that no mercury is inhaled.
- The area should be ventilated thoroughly (at least 20 to 30 minutes).
- After the lamp housing or luminary has cooled, any mercury residue should be picked up with a special adsorbent as for example *Mercurisorb* (source Karl Roth GmbH & Co. KG, Schömperlenstr. 3, D-76185 Karlsruhe, Phone: 0049 / (0)721 / 560 60; Germany).

Disposal of Metal halide lamps

Metal halide lamps contain specific quantities of potentially harmful substances (such as mercury; see table). Therefore they must be treated as special waste in accordance with the relevant national regulations.

OSRAM contact

If you need any further information please contact your local OSRAM representatives or the Photo Optics division, Marketing department at Berlin / Germany:

- Phone: 0049 30 / 3386 2174
  Telefax: 0049 30 / 3386 2359
  E-mail: entertainment-light@info.osram.com

ATLAS
MATERIAL TESTING SOLUTIONS

2.HAZARDS

The safety systems and safety notes described and contained in these Operating Instructions must be observed. Operation is from electrical operating panels (circuit cabinet, PC, fixed operator panels). Keep the area in and around the equipment and the operator workstations free of objects during operation to permit unimpeded access at all times.

*Note **pinch points** during work related to set-up, maintenance and repairs!*

*Note **electrical hazards** during work related to set-up, maintenance and repairs !*

*Heated components (hot surfaces) present a **burn hazard**. Wear proper personal protective equipment, e.g., protective gloves.*

*When entering the test chamber during solar simulation be aware of the **hazard** represented by **UV radiation** as well as **glare**. Always wear appropriate eye protection and personal protective equipment.*

STOP

Operational measures must be taken to ensure that no personnel is in the test chamber during tests with the lamps switched on.

- *Time spent in the test area should be kept to an absolute minimum while the equipment is operating.*
- *If the test area must be entered, a safety helmet an personal protective equipment must be worn and appropriate tools and aids must be employed to either completely avoid direct entry into the zone of most intense radiation or to strictly limit the*



amount of time spent there.

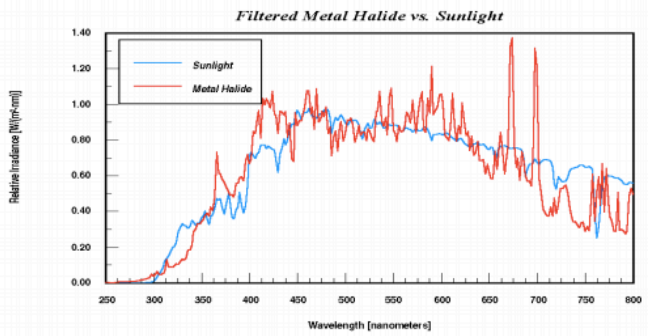
- *The personal protective equipment must protect the entire head and, in particular, the eyes. The faceplate must be heavily tinted or sunglasses must be worn in order to protect eyes against the high levels of light.*
  The faceplate or sunglasses must be able to filter out all UV radiation.

Caution when working on the equipment if bulbs have exploded. This may result in the release of ***mercury vapors****.*

Health hazards

Inhalation of mercury or mercury compounds in the form of vapor or dust will result in lung, kidney and nerve damage. Aside from inhalation, mercury can also enter the system through contact with the skin (penetration) or through the gastrointestinal tract (consumption, resorption) and result in health damage.
Always follow the instructions provided in the "Mercurisorb-Roth" booklet together with the material safety data sheets it contains as well as the safety information related to the operation of mercury halide lamps provided by "Osram".
These documents are included in the "Technical Documentation".

Metallhalid versus Sunlight



Swell spol. s r.o. Feb 2010 by Michal Kalik

ATLAS MATERIAL TESTING SOLUTIONS