

Changes in mechanical properties of recycled polypropylene

Dan Weckström

EXAMENSARBETE	
Arcada-Nylands svenska yrkeshögskola	
Utbildningsprogram:	Plastteknik
Identifikationsnummer:	9109
Författare:	Dan Weckström
Arbetets namn:	Förändring av mekaniska egenskaper hos återvunnet polypropen.
Handledare (Arcada):	Mariann Holmberg
Uppdragsgivare:	
<p>Sammandrag:</p> <p>Syftet med detta slutarbete var att undersöka hur återvinning påverkar de mekaniska egenskaperna av polypropen. De mekaniska egenskaperna som undersöktes var draghållfasthet, Youngs modul och smält index. De mekaniska egenskaperna hos råmaterialet polypropen var jämförda med det återvunna materialets egenskaper. Samma material återvanns 14 gånger för att få en bild av att hur återvinningen påverkar de mekaniska egenskaperna av polypropen. Jämförelsen av de mekaniska egenskaperna gjordes mellan råmaterialet polypropen och samma material i återvunnen form med en testometrisk dragprovsmaskin och smält index maskin. Test bitarna, som användes för dragprovsmaskinen, hade formen av ett hundben. Draghållfastheten och Youngs modul testades med hjälp av dragprovsmaskinen. Materialet som användes för smältindex maskinen hade formen av plastgranulat. Smält index maskinen testade smält indexet för plastgranulatet. Materialet återvanns genom användningen av en maskin som bryter ner plastmaterial till fint granulat, som sedan gick att återanvända. Hundbenen tillverkades med hjälp av en formsprutningsmaskin. Slutarbetet gjordes av personligt syfte och intresse. Återvinningsprocessen och testningen gjordes i plast laboratoriet belägen i Arcada - Nylands svenska yrkeshögskola. Arcada stod för materialet och maskinerna som användes för att utföra testerna.</p>	
Nyckelord:	Polypropen, återvinning, mekaniska egenskaper
Sidantal:	64
Språk:	Engelska
Datum för godkännande:	

DEGREE THESIS	
Arcada-University of Applied Sciences	
Degree Programme:	Plastic Technology
Identification number:	9109
Author:	Dan Weckström
Title:	Changes in mechanical properties of recycled polypropylene.
Supervisor (Arcada):	Mariann Holmberg
Commissioned by:	
<p>Abstract:</p> <p>The objective of the thesis was to find out how recycling affects the mechanical properties of polypropylene. The mechanical properties were tensile strength, Young`s modulus and melt flow index. The mechanical properties for the raw material of polypropylene were compared with the recycled ones. The same material was recycled 14th times in order to get a view of how the recycling affects the mechanical properties of polypropylene. The mechanical properties were tested with a testometric tensile testing machine and a melt flow index machine. The test specimen was a dog bone, for the testometric machine in order to find out the tensile strength and young`s modulus, and recycled granulates, for the melt flow index machine in order to find out the melt flow index. The material was recycled by using a plastic shredding machine and the dog bones were created with an injection molding machine. The thesis was done for personal use and interest. The recycling and testing part was done in the plastic laboratory located in Arcada - University of Applied Sciences. The school, Arcada in this case, provided the material used and the machines to perform the tests with.</p>	
Keywords:	Recycling, polypropylene, mechanical properties
Number of pages:	64
Language:	English
Date of acceptance:	

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1 VOCABULARY

C

Clamping force: The amount in kilo newton`s that keeps the female and male molds together.

Composite: Combination of two or multiple materials.

Cooling time: The time required to cool down the injection molded part.

Crystallinity: The degree of structural order in a solid.

D

Density: The mass density or density of a material is defined as its mass per unit volume.

Dog bone: Injection molded part used for testing mechanical strength of polymeric and composite materials.

E

Elastomer: Plastic materials which stretch when a force is applied to the material and recover to their original state when the force is removed.

Extrusion and injection molding: Shaping process used for plastic materials out of plastic melt.

G

Glass transition temperature: The temperature at which a substance shifts from hard and brittle state into molten or rubber like state.

Granulates: Shape of plastic raw material

H

Homopolymer: The plastic material is formed from a single monomer via polymerization.

I

Injection molding cycle: The time it takes for a certain part to be produced with an injection molding machine.

Intermolecular bonds: Bonds located between the molecules within the atoms of a polymer.

Isotactic, atactic, syndiotactic: Defines how the CH₃ is arranged in polypropylene.

M

Melt flow value (melt flow index): Measurement of the ease of flow of the melt of a thermoplastic polymer.

Melting point (Melting temperature): Temperature when a substance changes from solid to liquid.

Mold: Consists of a male and female mold and contains the shape of the plastic part produced.

Molecular weight: The mass of one molecule of a specific substance.

N

Necking: In engineering when fairly large amount of strain localize disproportionately in a small region of the material.

O

Opacity: The degree to which light is not allowed to travel through.

P

Plastic recycling: Process of recovering plastic waste and reprocessing this material into useful products, sometimes in completely different form from their original state.

Plastic shredder: Machine used for shredding material.

Polarity: A concept in chemistry which describes how equally bonding electrons are shared between atoms.

Polymerization: A chemical process where monomers are combined with each other in order to form long molecular chains called polymers.

Polymers: Consists of thousands of smaller units known as monomers.

Polypropylene: Combining many monomers called propylene with the help of polymerization process into Polypropylene.

Pre drying: Technique used to remove extra moisture from plastic material before usage.

R

Reciprocating screw: Screw type used for the injection molding and extrusion machines. Its purpose is to transport the plastic forward inside the machine.

Resin identification codes: Identification system for recyclable plastics.

Shot size: The shot size is the amount of plastic material needed to fill the whole mold.

S

Strain: A deformation in the product produced by stress.

Stress: The average amount of force exerted per unit area.

T

Tensile strength: The ultimate stress that material can withstand while being pulled before starting to significantly contract, necking.

Testometric tensile testing machine: Machine used for testing mechanical strength.

Thermoplastics: Plastic materials which can be solidified by cooling and melted over again by using heat.

Thermosets: Plastic materials which retain their shape during cooling and heating cycles.

Y

Young`s modulus: A measurement of the stiffness of an elastic material.

2 INTRODUCTION

The recycling business in today's world invest on quantity over quality. Were the products are recycled many times over and over again and rather small mechanical properties are needed. But how do the mechanical properties actually change when products made out of polypropylene are being recycled. Is recycled propylene something that could be used in products that need high mechanical strength or is it a hopeless case.

The thing to see is that how the mechanical strength changes when polypropylene is being recycled. How are the mechanical properties, of the recycled material, comparable with the original mechanical properties. Is the graph a linear curve were the strength decreases linearly by each recycling run or is the drop in strength smaller than this. Polypropylene is and good choice as a testing material due to its similarity in mechanical properties to many other thermoplastic materials on the market these days.

The main task in this thesis is to compare the original mechanical properties of polypropylene with the recycled properties of polypropylene. The same material is recycled fourteen times in order to get a view of how the recycled material compares to the original starting material. This type of testing can then be applied to other materials, when information about mechanical properties of recycled material is needed. The steps of recycling polypropylene are gone through, so that comparable testing can be done in the future for other types of plastic materials.

2.1 Aims and Objectives

The object with this research is to see how recycling affects the mechanical properties of polypropylene. The starting of raw material will be polypropylene in form of granulates. This material will then be tested and its mechanical properties will be obtained in form data output from machines created to test material properties. The starting of material will then be recycled and values from each recycling run will be collected. The target is then to investigate how the mechanical properties change from when using a fresh and never recycled material to a material which has been recycled a number of times.

The two methods to be used, in testing mechanical properties, are machines used for testing tensile strength and melt flow index. The raw material will be prepared with injection molding and recycled back to raw material with a shredder. The testing piece, used for the testometric tensile testing machine, will have a shape of a dog bone; the dog bone shape makes it easy to test the strength of the material. The material for the melt flow index test will be compared in the same way as for the tensile testing. Never recycled granulates will first be tested on the machine to get some start of values. The recycled material will then be tested in order to see how the properties change with each recycling run of the material. The total amount of test runs with the melt flow index machine will be fifteen.

Another task is to show how plastic material, in this case, is recycled and tested. This data is then something which can be applied to other materials which are in need of being tested and investigated. The goal is to receive data from the tests which can be evaluated and compared with existing values.

2.2 Background and theory

The literature will be about the different machines used for the testing and how they are used. Material choice will also be represented and the reason why. Basic information about recycling and benefits of recycling will be gone through. The data received from the test will be explained and crucial values showing the mechanical strength will be clarified.

2.3 Methods

Half of the work will be done in the plastic lab located in the Arcada - University of Applied Sciences and the other half will be done in form of research and literature reading. The testing of polypropylene will be done first due to the time factor. The literature research and actual writing will be done then when the testing of polypropylene is finished.

2.4 Restrictions

The restriction can be divided into three different things; material, testing parameters and machines used.

2.4.1 Material

The material used has the trade name of polypropylene 505P and is produced by SABIC (Saudi Basic Industries Corporation) (Arcada Plastic Laboratory, 2012). This material was chosen due to two factors. The first reason was the materials fairly good mechanical properties and possibility to processes the material with an injection molding machine. The second reason was the materials availability in the plastic laboratory of Arcada. The material was kept as pure as possible and not modified in any way. The material was also not affected by the nature or surrounding in form of e.g. heat, pollution or natural sunlight. The surrounding has a rather big influence on plastic products which are recycled in the industry. This was not the case when recycling the polypropylene 505P and was considered as a restriction when the material was recycled. The material which will be gone through is the polypropylene homopolymer, due to the fact that the tested material is of that kind.

2.4.2 Testing parameters

The testing parameters will be scaled down to three different values, these are tensile strength, young`s modulus and melt flow index. These values will be explained under the sections of theoretical background.

2.4.3 Machines used

The third and final restriction is the machines used for the tests. The machines used are injection molding machine, testometric tensile testing machine, melt flow index ma-

chine and plastic shredder. The injection molding and plastic shredder are used for processing the material. The function of the testometric tensile testing machine and melt flow index machine are to test the properties of the material.

3 THEORETICAL BACKGROUND

The goal with this section is to explain all the machines and values which will be used when testing the recycled polypropylene 505P. The sections will be divided into three different ones.

The first will explain about the recycling of plastics in general and how it is done in the industry. The benefits behind recycling plastics will also be gone through.

The second one will describe the different machines used and how they are used within the plastic industry for different applications.

The third part will contain explanation and formulas for the values showing mechanical strength for the recycled material.

3.1 Plastics

The term plastics contain a large variety of resins or polymers with different characteristics and uses. Plastics are produced by converting basic hydrocarbon building blocks such as methane and ethane into long chains with repeating molecules called polymers. (Masters, Ela page.628, 2008). Polymers or plastics are made out of combining thousands of smaller units known as monomers together. This combining process is done by using a process called polymerization. Polymerization is a chemical process where monomers are combined with each other in order to form long molecular chains called polymers. Polypropylene is made by combining many monomers called propylene with the help of polymerization process into Polypropylene. (Crawford, Page. 2, 1998)

Plastics can be divided into three different categories: thermoplastics, thermosets and elastomers. This classification is related to the thermal performance and mechanical properties. All of these materials can be used as solids. However, thermoplastics can be solidified by cooling and melted over again by using heat. Thermoplastic is the plastic

type that is used for recycling, due to the fact that the material can be melted over and over again. The material is recyclable due to its weak bond between the molecules within the polymer itself. Example of thermoplastics is polyethylene and polypropylene. (Grulke, Page. 4,1994)

Thermosets retain their shape during cooling and heating cycles. They are cross-linked between the molecular structures within the polymer. This makes it impossible to recycle the plastic again like thermoplastics. Thermosets are used for plastic parts that demand higher mechanical strength, but don't need to be recycled over and over again. Examples of thermosets are cross-linked polyester and polyurethanes. (Grulke, Page. 4, 1994)

The third and final group is elastomers. Elastomer stretch when a force is applied to the material and recover to their original state when the force is removed. The term rubber may be used for elastomers that are from natural sources. The typical advantages and disadvantages of plastics can be found in Table 1 below. (Grulke, Page. 4, 1994)

Table 1 Typical characteristic of plastics (Terselius, Page. 126, 1998)

Advantages	Disadvantages
+ Low density	– High heat expansion
+ Corrosion resistance	– Bad thermal/UV/Chemical resistance
+ Good sound/shock absorber	– Statical charge

3.2 Recycling of plastics

Plastic recycling is the process of recovering plastic waste and reprocessing this material into useful products, sometimes in completely different form from their original state. One example is when soft drink bottles made out of PET, or polyethylene terephthalate, are recycled into products like plastic chairs and tables. (Wikipedia, 2012)

The Plastic Bottle Institute of the Society of the Plastic Industry has developed a voluntary coding system for plastic bottles and other rigid products made out of recyclable plastics. The system uses the three arrow triangle with a numerical designation that indicates the type of resin/polymer used in the plastic. Figure 1 below shows the labeling system and Table 2 shows the usages of these labeled plastics.

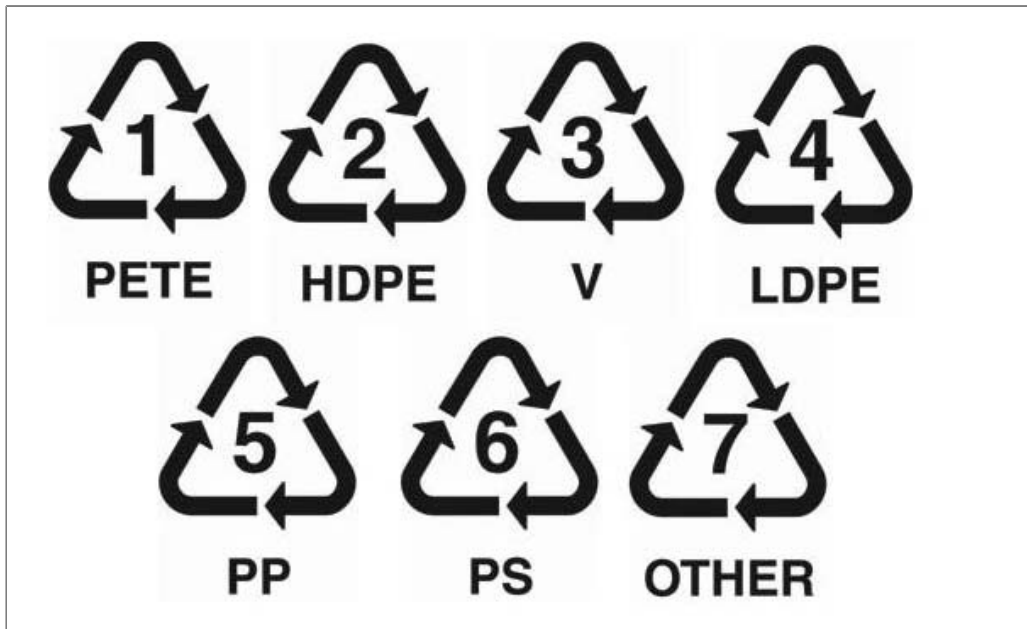


Figure 1 Resin identification codes (Wilkinson, 2011)

Table 2 Applications for recyclable resins (Masters and Ela, Page. 629, 2007)

Designation	Polymer/Resin	Applications
PETE	Polyethylene terephthalate	Soft drink bottles, Peanut bottle jars
HDPE	High-density polyethylene	Milk, water, juice, detergent, motor oil bottles
V	Vinyl/polyvinyl chloride	Cooking oil bottles, credit cards, household food wraps
LDPE	Low density polyethylene	Shrink wrap, garbage and shopping bags
PP	Polypropylene	Snack food wraps, straws
PS	Polystyrene	Pharmaceutical bottles, styrofoam cups,
Other resins		Mixed material containers

When plastics are recycled, it is often important to carefully separate them by resin type and color. Different resins have different melting points, so if a batch of mixed plastics are being heated and transformed into new products, some resins may not melt at all, and some may end up burning. As an example can be mentioned that a single PVC bottle in a batch of 20,000 PET bottles will ruin the whole batch and potentially destroy the manufacturing equipment, which in this case could be an injection molding machine or an extrusion machine. Another example is if polypropylene, which is rather difficult with the naked eye to distinguish from polyethylene, contaminates a batch of recycled polyethylene, the resulting blend would be useless. While it is usually important to separate recovered plastics carefully, some applications are emerging that can use mixed

types of plastic resin. Mixtures can be shredded, melted and extruded into useful forms. Plastic lumber can be used for different outdoor furniture and lumber material is formed in this kind of way. Plastic lumber is more expensive than lumber made out of wood, but plastic lumber is resistant to insect and weather damage which wood lumber is not. Plastic lumber can be categorized as a composite, where many different materials are combined together into one product. (Masters and Ela, Page. 628-630, 2007)



Figure 2 Plastic lumber (Wikipedia, 2012)

3.3 Polypropylene Homopolymer

Polypropylene belongs to thermoplastic group of plastics. The word homopolymer means that the material, which in this case is polypropylene (PP), is formed from a single monomer via polymerization. Polypropylene belongs to the crystalline group and this crystallinity can be noticed in the transparent color in products made out of polypropylene. Polypropylene has many modified versions of which SABIC® PP 505P is of most interest, because it will be used as the testing material in how mechanical strength is affected by recycling cycles. (Crawford, Page. 3-5, 1998)

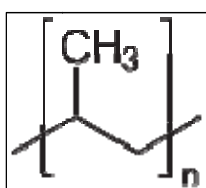


Figure 3 Picture of polypropylene (Wikipedia, 2012)

3.3.1 Chemical Constitution; Polymerization

During polymerization, the CH₃ groups of PP can be sterically arranged in different configurations and in that way create different properties, properties like crystallinity, density and melt flow index value. These configurations can be divided into isotactic, syndiotactic and atactic. The names come from how the CH₃ is organized within the polymer. If the CH₃ group is on the same side then the material is isotactic. If the group jumps up and down in continues arrangement, then it is syndiotactic. If there is no order at all, then it is atactic. The majority of polypropylene materials that contain is of isotactic structure, and that is the reason why polypropylene is considered to be isotactic. The configurations can be seen below in Figure 4. Table 4 below shows a comparison be-

tween different PP grades. A couple of terms are in place to explain. The explanations are listed in Table 3 below. (Osswald, Baur, Page. 535-536, 2006)

Table 3 Property explanation (Wikipedia, 2012)

<u>Property</u>	<u>Explanation</u>
Density	The mass density or density of a material is defined as its mass per unit volume.
Stress	The average amount of force exerted per unit area.
Strain	A deformation in the product produced by stress.
Melt flow value	Measurement of the ease of flow of the melt of a thermoplastic polymer.
Opacity	The degree to which light is not allowed to travel through.
Crystallinity	The degree of structural order in a solid.
Melting temperature	The temperature at which a substance changes from solid to liquid state

Table 4 Comparison of properties between different Polypropylene configurations (Osswald, Baur, Page. 538, 2006)

<u>Configuration</u>	<u>PP-Isotactic</u>	<u>PP-Syndiotactic</u>	<u>PP-Atactic</u>
Density (g/cm ³)	0,903	0,9	0,855
Stress (MPa)	20-35	2,4	2
Strain (%)	100-300		2000
Melt flow value (g/10min)	1,8	3	0,1
Opacity (%)	85	1,7	18
Crystallinity(%)	40-66	30-40	Amorphous
Melting temperature	163	168	

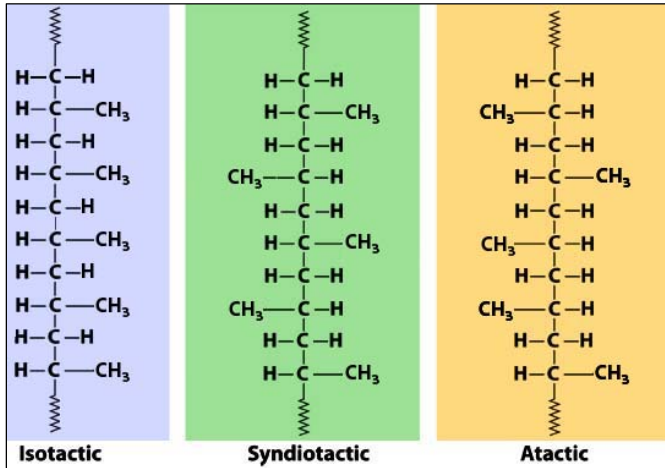


Figure 4 Three different configurations of polypropylene (Steinwall Inc., 2008)

3.3.2 Properties

The variety of available PP grades is wider than that of most other plastic materials. Molecular structure, average molecular weight varies between 200,000-600,000 g/mol. Molecular weight is the mass of one molecule of a specific substance. The molecular weight varies due to the fact that there are many types of polypropylene materials. Stiffness and hardness range between those of polyethylene (PE) and engineering plastics, such as acrylonitrile butadiene styrene (ABS), polyamide (PA) and others. The dynamic load capacity is relatively high. Polypropylene has a glass transition temperature of 0°C, all polypropylene homopolymer grades becomes brittle at low temperatures. The crystalline melting point ranges from 160-165°C, higher than that of PE. Therefore, maximum service temperatures are also higher: short term 140°C, long-term 100°C. The electrical properties compare to those of PE and are not affected by exposure of water. (Osswald, Baur, Page. 537, 2006)

PP exhibits only minimal water absorption and permeability. Due to its non-polar structure, PP is highly chemically resistant up to 120°C. Polarity is a concept in chemistry

which describes how equally bonding electrons are shared between atoms. PP is also highly chemically resistant, up to 120°C, to aqueous solutions of salts, strong acids and alkalis, as well as brines. Brine is solutions of salt. High crystalline grades provide particularly good resistance to polar organic solvents, alcohols, esters, ketones, fats and oils. (Osswald, Baur, Page. 537, 2006)

3.3.3 Processing

PP grades for injection molding cover a wide range of different requirements ranging from high-temperature resistant, rigid to elastic, to low-temperature impact resistant grades. The melt temperature ranges from 250-270°C, the mold temperature from 40-100°C. Moisture can condensate on the surface of the pellets in humid climates and should be removed by drying or with help of vented extruders before processing. Blown films, flat films, sheet, pipe, blow molded parts, and monofilaments made out of PP are extruded at melt temperatures from 220-270°C. Because of the high cooling demands during film production, chill-roll flat sheet die processes are preferred or tubular film blowing, which requires intensive water cooling of the film tube. (Osswald, Baur, Page. 536, 2006)

The most typical manufacturing processes for polypropylene are extrusion and injection molding. Common extrusion methods include production of melt-blown and spun-bond fibers. These methods produce products like face masks, filters, nappies and wipes. The most typical shaping technique for polypropylene is injection molding, which is used for parts like cups, caps, housewares and automotive parts such as batteries. The two methods related to injection molding and extrusions are blow molding and injection-stretch blow moldings are also used to produce parts out of polypropylene

3.3.4 Market of polypropylene

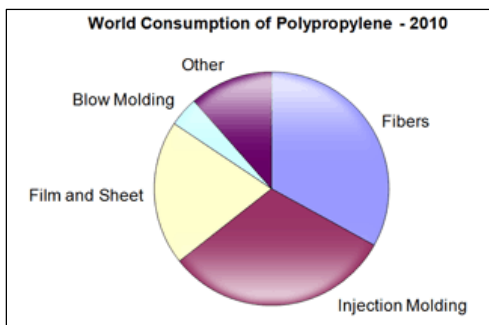


Figure 5 Consumption of polypropylene in the world in year 2010 (HIS Inc., 2012)

Global consumption of polypropylene in the year of 2010 was approximately 48,4 million metric tons. Polypropylene consumption is estimated to have an increase with 5,4% per year from 2012 to 2015 and slowing down to 4,5% per year from 2015 to 2020. The primary markets for polypropylene are in fibers and injection molding, these account together for about 60,7% of the total global consumption of polypropylene. Other applications include film and sheet production of blow molding. (HIS Inc., 2012)

3.3.5 SABIC PP 505P – description and general information

The material used for the testing was SABIC® PP 505P and is produced by SABIC which is shortened from Saudi Basic Industries Corporation.

SABIC® PP 505P		IDES Prospector	
Polypropylene Homopolymer Saudi Basic Industries Corporation (SABIC)			
Product Description			
SABIC® PP 505P is a multi purpose grade for extrusion and injection moulding applications. SABIC® PP 505P provides an excellent stretchability and is therefore particularly suitable for extrusion of tapes, strapping, high tenacity yarns and for thermoformed articles. For injection moulded parts SABIC® PP 505P shows a moderate stiffness, good impact resistance and very good surface hardness and is therefore applied for caps and closures and houseware articles.			
General			
Material Status	• Commercial: Active		
Availability	• Europe		
Features	• Good Impact Resistance • Good Stiffness	• Homopolymer • Med.-Wide Molecular Weight Distrib.	
Uses	• BCF Yarn • Caps	• Closures • Household Goods	• Strapping • Tape
Forms	• Pellets		
Processing Method	• Extrusion	• Injection Molding	• Thermoforming
Physical		Nominal Value Unit	Test Method
Density		0.905 g/cm ³	ISO 1183
Melt Mass-Flow Rate (MFR) (230°C/2.16 kg)		2.0 g/10 min	ISO 1133
Mechanical		Nominal Value Unit	Test Method
Tensile Stress			ISO 527-2
Yield		41.0 MPa	
Break		36.0 MPa	
Tensile Strain (Break)		600 %	ISO 527-2
Flexural Modulus		1450 MPa	ASTM D790
Thermal		Nominal Value Unit	Test Method
Vicat Softening Temperature			
--		152 °C	ISO 306/A50
--		87.0 °C	ISO 306/B50
Notes			
1 Typical properties: these are not to be construed as specifications.			

Figure 6 Datasheet of SABIC® PP 505P (Arcada Plastic Laboratory, 2012)

The material datasheet provides some information about the material processing properties and methods. The datasheet informs the user if the material should be dried or not before processing it in order to remove moisture from the material. The moisture removal is usually done with a specific dryer created for this task. No moisture had to be removed from this material.

The datasheet also informs the user about important physical, mechanical and thermal properties values which are according to the manufacturer the correct ones when a certain test method is used. The test method is usually an ISO standard of some certain type. ISO testing methods are of different types and used for different things. The standard defines the testing conditions that should be when testing a certain thing. The ISO standard makes it possible to compare values received from similar tests.

PP 505 is a multipurpose material used for extrusion and injection molding parts. PP 505P provides excellent stretch ability and is due to this particularly suitable for extrusion tapes, strapping, high tenacity yarns and thermoformed articles. For injection

molded parts PP 505P shows good impact resistance, moderate stiffness and good surface hardness. The material is used for caps and housewares articles due to its suitable properties. (Arcada Plastic Laboratory, 2012)



Figure 7 SABIC PP 505P granulates (Arcada plastic laboratory, 2012)

PP 505P is commercially available in Europe for anybody to buy. The material features good impact strength, good stiffness, and medium-wide molecular weight distribution. PP 505P is a homopolymer and has an isotactic structure. The material is used to produce yarns, closures, strappings, caps and household goods. (Arcada Plastic Laboratory, 2012)

The material was actually chosen due to its good mechanical properties and similarity to other materials on the market these days.

3.4 Injection molding

Injection molding is one of the most common shaping methods used to manufacture plastic parts in today plastic industry. Parts varying from small office widgets to bigger parts intended for cars are produced by usage of this type of plastic machine. This section will go through the basic principles behind injection molding, covering the ma-

chine, production steps of a plastic part and the usage of the injection molding machine for the testing of SABIC® PP 505P material. (R.J.Crawford, Page. 278, 1998)

3.4.1 The machine

The injection molding machine consists of a series of different parts. The basic things like screw, barrel, heating system and clamping system basically work the same in all machines related with injection molding. The mold and the cooling system is something which varies depending on the product made. The different parts and functions of an injection molding machine will be gone through in the text below.

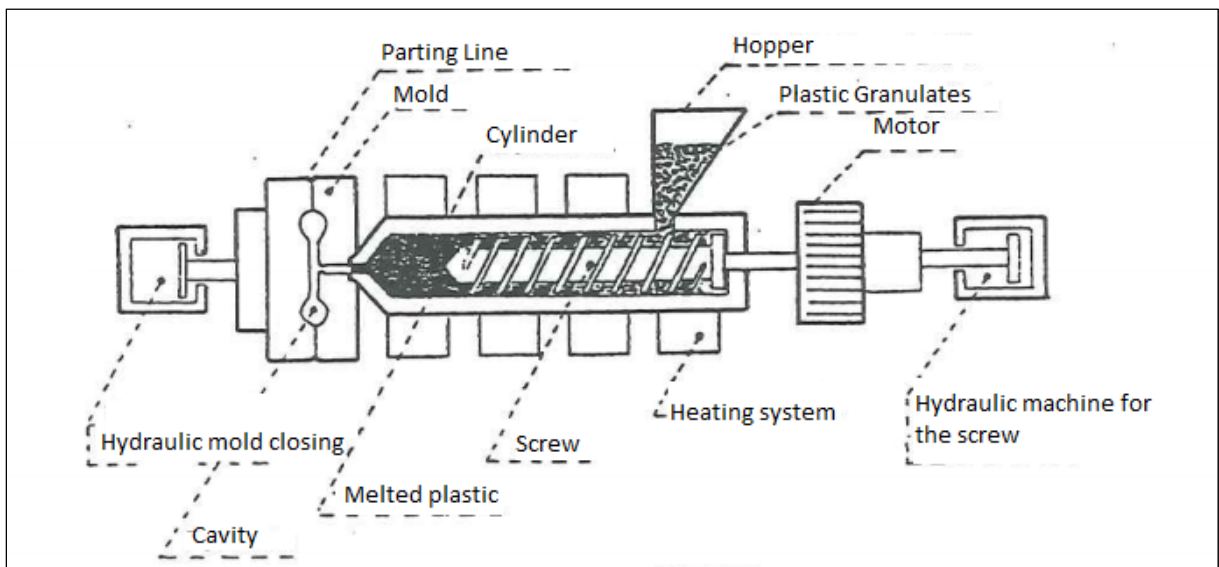


Figure 8 Part list for an injection molding machine (B. Terselius, Page. 155, 1998)

The list of the different explanations can be found in Table 5 below. An important part which isn't shown in the Figure 8 is the cooling system of an injection molding machine. The cooling system is used for controlling the temperature of the mold and for the rest of the injection molding machine. Each plastic material has a certain cooling temperature. The cooling system for the mold is usually located both in the core and

cavity side and can be seen as hose going in at a certain point of the mold parts. The removal line for the cooling water is also located on the mold parts.

Table 5 Parts of an injection molding machine (Dan Weckström, 2012)

<u>Part</u>	<u>Description</u>
Cavity	Produces and contains the shape of the injection molded part.
Cylinder	The screw moves inside the cylinder. The heating system heats up the cylinder and the cylinder heats up the plastic material. The friction created between the cylinder and the screw also affects the melting of the plastic material.
Heating System	The heating system is located at different points on the cylinder, in order to accomplish a unified heating of the cylinder. One heater is also located in the hopper. All plastic material has specified heating temperatures. The temperature is usually lower in the beginning of the cylinder. The temperature then slightly increases when the plastic moves towards the nozzle.
Hopper	Transportation devices for granulates to move from storage device(bag, barrel etc.) to cylinder
Hydraulic mold closing	The machine that closes the moving part of the mold with the stationary part of the mold at injection stage.
Mold	Contains the shape of the part produce. Also contains runners and gates that transport the material from the nozzle to the cavity. A mold consists of a core (male mold) and a cavity (female mold).
Motor	The power input from the motor makes the screw circulate within the cylinder
Parting Line	Surface that separates the cavity side from the core side of the mold
Screw	Transportation device for the plastic material within the cylinder
Hydraulic machine for the screw	Pushes the cylinder forward at the injection stage of the plastic material.

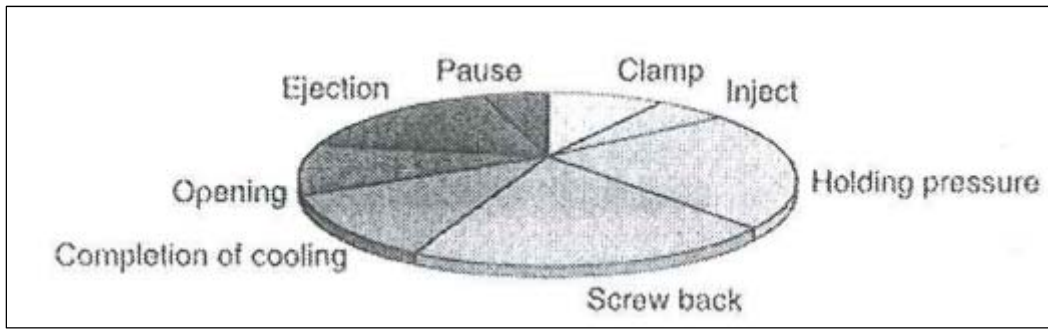


Figure 9 Stages during injection molding cycle (R.J.Crawford, Page 281, 1998)

The Figure 9 above shows the cycle time for a part produced with an injection molding machine. The different steps can be seen in the picture above. Figure 10 below shows an injection molding cycle and the different steps included.

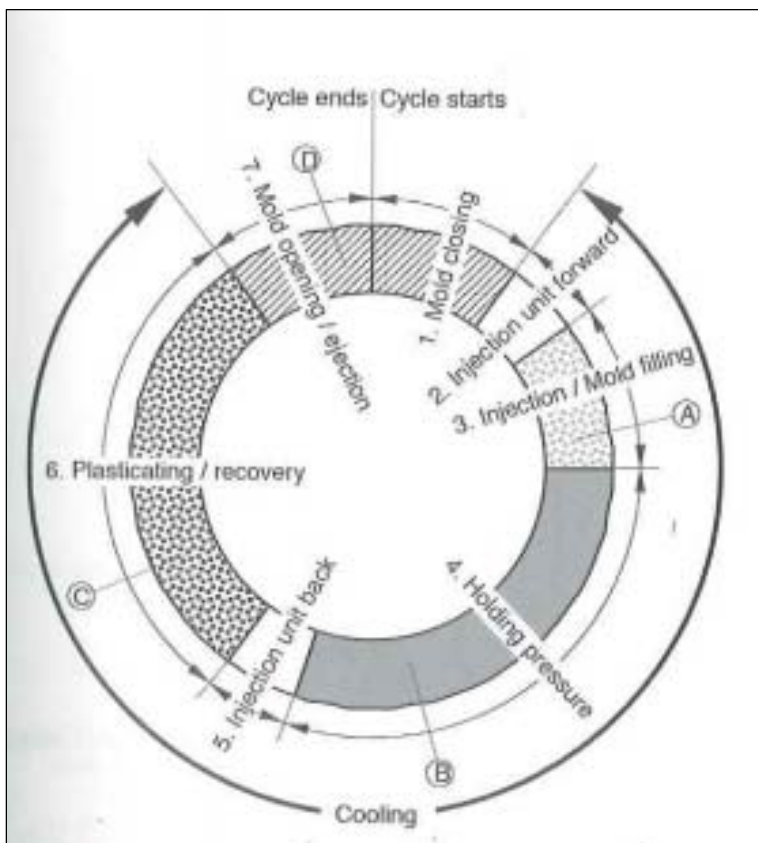


Figure 10 Injection molding cycle (Osswald, Baur, Page 317, 2006)

3.4.2 The process

The process behind injection molding is fairly simple. A thermoplastic material, which is in form of, granulates or powder, passes from a hopper into a barrel where the material is heated and becomes soft and turns into a plastic melt. The screw inside the barrel then pushes the melt forward and forces it to go through a nozzle into a relatively cold mold which is clamped together with a certain amount of force. When the part has solidified enough the mold opens, the part produced is ejected from the mold and the process is repeated over again. (R.J.Crawford, Page. 279, 1998)

The machine used for the tests and the most typical kind of machines in today's industry are fitted with a reciprocating screw. The screw functions as following. On the one hand it rotates like a normal screw to push forward the plastic material within the barrel inside the machine. On the other hand it works like a plunger and only pushes forward the material when it is not rotating. The pushing forward motion happens when the screw is injecting the plastic melt into the mold. The rotational movement is done before the pushing movement in order to create a shot size in front of the screw. The shot size is the amount of material needed to fill the mold when it is closed. The steps when the melt is injected into the mold are explained and demonstrated below:

1. When the mold has closed. The screw (not rotating) pushes forward the plastic melt into the cold mold. The air within the mold will be pushed out through small vents and holes (R.J.Crawford, Page 282, 1998)

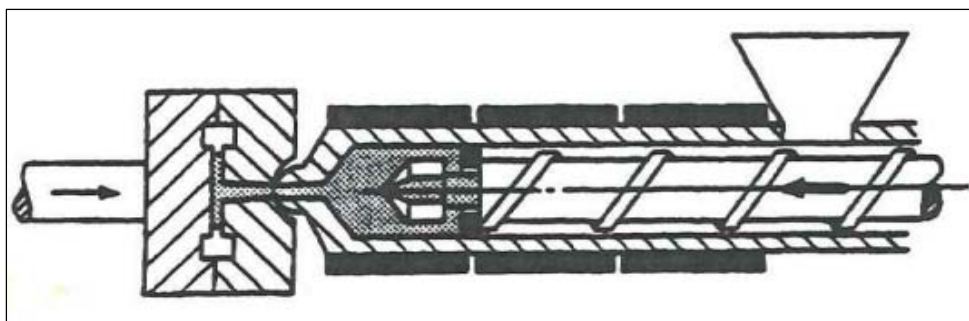


Figure 11 Injecting plastic into the mold (R.J.Crawford, Page 281, 1998)

2. When the cavity inside the mold has been filled up completely, the screw keeps on pushing forward in order to apply a holding pressure. This motion creates the effect of squeezing extra melt into the cavity to compensate for the shrinkage of the part when it cools down. This holding pressure is only effective as long as the gates within the mold are kept open. Gate is the place where the plastic melt enters the cavity of the part produced. (R.J.Crawford, Page 282, 1998)

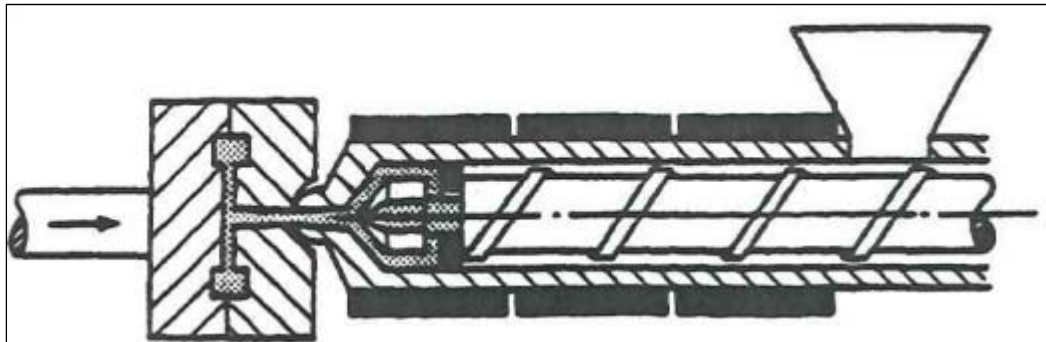


Figure 12 Applying the holding pressure (R.J.Crawford, Page 281, 1998)

3. Once the gates freeze (solidifies) no more plastic can enter the mold and so the screw starts to move backwards. The screw starts to rotate and draw new granulates from the hopper into the barrel. This plastic melt is transported to the front of the screw, but as the mold already is filled up with plastic, the effect is to push the screw backwards. This operation prepares the next shot by applying the desirable amount of plastic in front of the screw. When the pre-set amount of the shot size is reached, the screw stops rotating and the machine sits and waits for the next injection to start. (R.J.Crawford, Page 282, 1998)

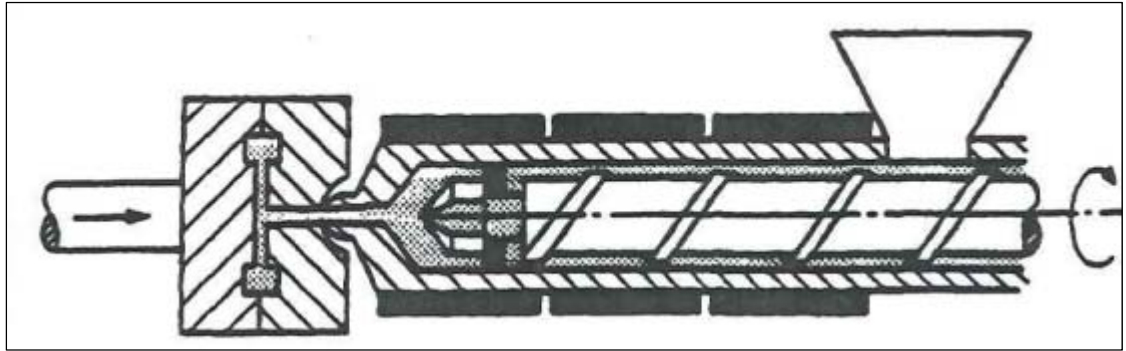


Figure 13 Applying shot size in front of the screw (R.J.Crawford, Page 281, 1998)

4. When the molded part has cooled down sufficiently enough so that the part keeps its shape, the mold opens and the molded part is ejected and a new cycle is started over again. (R.J.Crawford, Page 282, 1998)

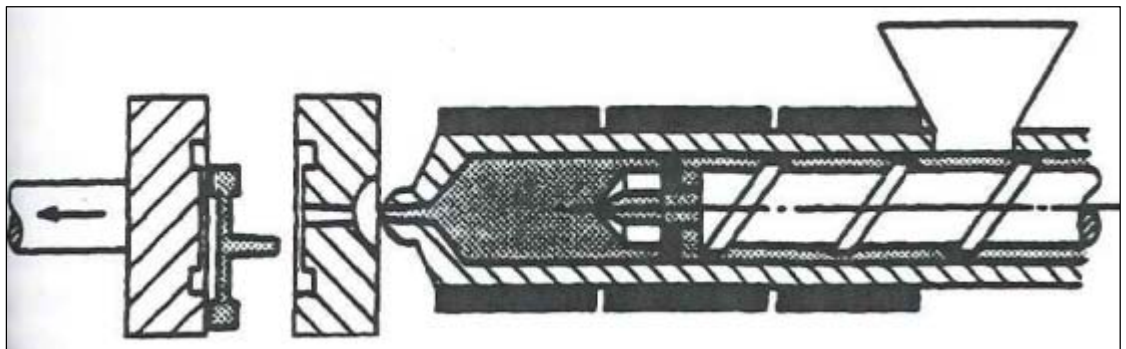


Figure 14 The part is ejected and the machine is ready for a new cycle (R.J.Crawford, Page 281, 1998)

3.4.3 Dog bones made out of SABIC® PP 505P

The machine used for the test was an ENGEL ES 200/50HL CC90 Injection molding machine. The machine was located in the plastic lab of Arcada-University of Applied Science, where all the other tests also were done. The test piece done was produced

with the injection molding machine and had the shape of a dog bone. Some of the input values for the injection molding machine were received from the datasheet that SABIC® provides with granulates that they produce. The other values like clamping force, injection time, cooling time etc. were calculated due to the fact that these are related to the mold construction and part shape, whereas melting temperature is only related to the material itself.

3.4.4 ENGEL ES 200/50HL CC90

The injection molding machine, used for the recycling tests, was produced by Engel. The machine is similar to those used in the injection molding industry these days. The machine also worked similar to the process explained above about the injection process of plastic into a mold. The machine part list was also similar to that one showed in Table 5. The Table 6 shows the technical data of the injection molding machine. The table shows the maximum values that the machine is capable to be used with. But also some basic information like weight of the machine and values about the hydraulic unit is shown.



Figure 15 ENGEL ES 200/50HL CC90 injection molding machine (Arcada plastic laboratory, 2012)

Table 6 ENGEL ES 200/50HL CC90 technical data (V. Poliakova and C. Stohr, 2012)

Injection Unit		
Screw diameter	mm	30
Metering stroke	mm	140
Screw speed	rpm	20-480
Flow rate ²	g/sec	20
Injection rate ²	g/sec	82
Maximum shot volume	cm ³	98
Maximum shot weight ²	g	88
Specific injection pressure	bar	2200
Nozzle stroke	mm	200
Nozzle contact force	kN	28
Heating capacity	kW	4.4
N of heating zones	n	3+ optional nozzle heating
Clamping unit		
Clamping force	kN	500
Opening stroke	mm	330
Ejection force	kN	25.4
Ejection distance	mm	100
Max tool height	mm	-
Min tool height	mm	110
Stationary platen		
- Total dimensions	mm	460*310
- Between horizontal beams	mm	-
Beam diameter	mm	-
Dry run	sec	1.5
Hydraulic unit		
Pump capacity	kW	15
Oil capacity	l	130
Weight		
Netto	kg	2700

3.4.5 Input values

The input values are depending on the material used and piece produced. The producer, SABIC in this case, provided the datasheet for the material used. The datasheet contained vital information about pre drying and temperatures while processing the material.

The material did not need any pre drying due to the fact that this had already been done before it was purchased. Pre drying is done in order to avoid moisture within and on the surface of the raw material. Moisture within the material will make it really runny and cause lots of impurities within the material in form of air bubbles.

The temperatures, used for the injection molding machine, were given by SABIC. The temperatures were not any specific ones for each and every heating region on the injection molding machine. This was due to the fact that there are many different types of

polypropylene produced by SABIC and all the polypropylenes differ a bit from each other.

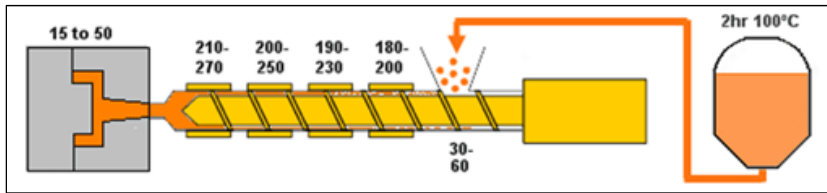


Figure 16 Temperature values for SABIC polypropylene (SABIC, 2008)

To improve the transportation of granulates; the temperature of the cooled zone (the hopper) should be kept between temperatures of 30-60°C. The other temperatures were tested and modified during the actual making of the dog bone in order to receive good processing temperatures. (SABIC, 2008)

3.4.6 Calculated values

The calculated values for the injection molding machine were the following:

Clamping force:

$$F = P * A \quad \text{Formula 1 (V.Poliakova, 2012)}$$

F = Clamping force (N), p =mean affective pressure (bar), A = total projected area (mm²)

The clamping force was calculated to be 300 kN (kilo newton`s)

The clamping force is the amount in kilo newton`s that keeps the female and male molds together

Cooling time:

$$t = c * s^2 \quad \text{Formula 2 (V.Poliakova, 2012)}$$

T = cooling time (s), c = 2 to 3 (s/mm²), s = wall thickness (mm)

The cooling time was calculated to be 25 s

The cooling time starts when the mold has been completely filled with plastic melt and ends when the mold is opened again.

Shot size (required to determine the plasticizing stroke)

$$V = \pi r^2 * d \quad \text{Formula 3 (V.Poliakova, 2012)}$$

V=Volume of the material plasticized (mm³) = Volume of the part, r = screw diameter (mm), $\pi = 3,14$

The shot size was calculated to be 43 mm³. The shot size is the amount of plastic material needed to fill the whole mold.

The shot size should not be greater than 2/3 of the maximum shot size for the machine, which is 88g for the ENGEL ES 200/50HL CC90 used for the producing the dog bone.

Some other values were also inserted into the machine in order to produce a dog bone piece. These can be seen in the Table 7 below. The parameters are temperature, mold fastening (mold closing), mold opening, injection, holding pressure and dosage.

Table 7 Injection molding parameters from SABIC PP 505P (Arcada plastic laboratory, 2012)

Parameters	Unit	Value
<u>Temperature</u>		
Nozzle	C°	210
Cylinder 2	C°	200
Cylinder 3	C°	190
Cylinder 4	C°	180
Hopper	C°	50
<u>Mold fastening</u>		
Clamping force	<u>kN</u>	300
<u>Mold opening</u>		
Cooling time	s	25
<u>Injection</u>		
Injection speed	m/s	50
Limitation of injection pressure	bar	70
Injection time	s	3
<u>Holding pressure</u>		
Holding pressure	bar	50
Holding time	s	5
Cushion	mm	2
Plasticizing stroke	mm	43
<u>Dosage</u>		
Back pressure	bar	4

All of these inserted values are important in order to produce a good piece. The temperatures can slightly vary and it does not really matter if they are not the exact ones. This is the case with all the other values also. But the values should be as close to these as possible. If the variation is big enough then faults with the finished piece can be noticed when it is ejected out of the cavity.

3.5 Dog Bone

The dog bone, which will be used for the recycling tests of this thesis, has the shape of a dog bone. This shape is used in order to test the mechanical strength of polymeric materials. The shape makes it possible to attach the upper and lower part of the bone into a testing device and to test the strength of the mid-section.



Figure 17 Shape of a dog bone made out of SABIC PP 505P (Arcada plastic laboratory, 2012)

The dog bone piece is not straight in the middle, which can be seen in Figure 16. Instead it has a curving form, in order to avoid large stresses to be created when testing the piece.

The dog bone in Figure 17 was made with the Engel injection molding machine when using the right parameters explained in the text above. The right parameters can be seen in that the plastic melt has filled up the whole piece.

3.6 Testometric tensile testing machine

Testometric tensile testing machine is used for testing the mechanical properties of a polymeric material. The machine is connected to win-test analysis software that brings the testing data to life in form of numbers and charts. This machine was used for testing the SABIC PP 505P mechanical properties before recycling and during the recycling stages in form of a dog bone.

The software itself is fairly easy and the steps that have to be done before using the machine can be listed as following:

1. Insert the desired testing way and values that the software will calculate when the tensile test starts. For the testing of SABIC PP 505P it was tensile test, and the values were tensile strength and young`s modulus.
2. Insert the right dimension of the part being tested. The dimensions are length, thickness and width. The length is distance between the two clampers in the machine that hold the piece in place. The thickness and width are measured at the middle of the piece. The dimensions in the case of the dog bone were the following, length: 100mm, width: 12,8mm and thickness: 3,3mm.
3. Start the test and do as many tests that are needed. The machine is using an force 5 kilo newton`s that the machine is pulling up with. The upper part of the clamber, which can be seen in Figure 18, pulls upwards and the lower one stays stationary. 5 kilo newton`s is usually enough when testing materials made out of plastic.
4. When all the tests have been done, then a result sheet can either be saved as a PDF file or printed out the old fashioned way. The datasheet contains the desired value/values that the user was searching for in the beginning.



Figure 18 A dog bone being tested with the testometric tensile testing machine (Arcada plastic laboratory, 2012)

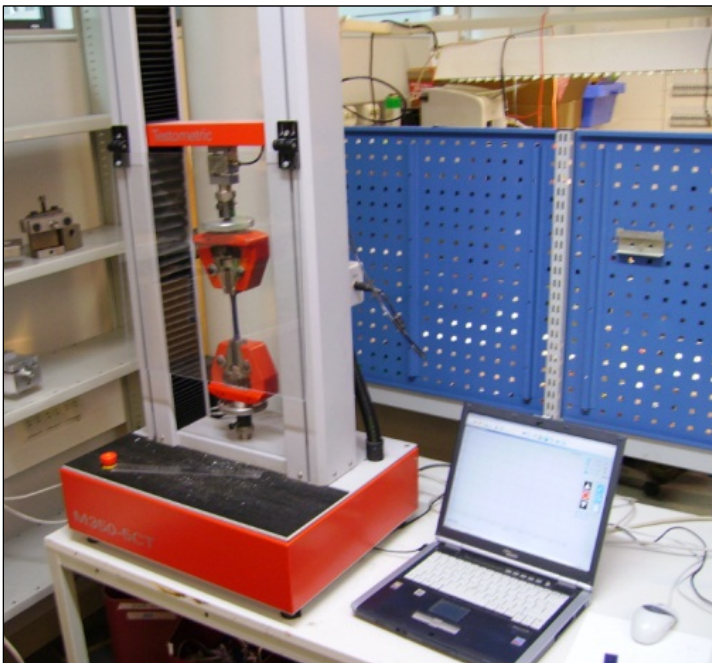


Figure 19 Testometric tensile testing machine connected to a computer using the win test software (Arcada plastic laboratory, 2012)

The same steps, as were explained above, were used when testing the tensile strength and young's modulus of polypropylene in the recycling tests. The dimensions of the tested dog bone were the same and the pulling force of the machine was the same. The testing of the dog bone was done according to the ISO 527-2 with which the machine pulls upwards with a speed of 50 mm/min.

3.7 Melt flow index machine

The melt flow index test (MFI) is a measurement of how well or poorly a thermo-plastic polymer is able to flow. The definition is mass of polymer, in grams, during a period of 10 minutes through a capillary with a specific diameter and length. The melt is pressed down with a specific weight in order to make it flow through the capillary. (Wikipedia, 2012)

Melt flow rate is an indirect measurement of the molecular weight of a plastic. High melt flow rate corresponds in low molecular weight and vice versa. The melt flow rate is also a measurement of how well the melt flows under pressure. The test also shows the material viscosity, how well the material flows. But the flow of the material is also depending on the weight, with which the material is pressed down with. There is a standard for this and the standard for polypropylene is ISO 1133. (Wikipedia, 2012)

The test, according to ISO 1133, is done by applying a load of 2,16kg onto a piston which then pushes down the plastic melt through a die with a diameter of 2mm. The material is preheated at 230°C for 6 min at first before starting the melt flow index test. The temperature, weight size and testing time are to most vital ones when doing a melt flow index test according to the ISO 1133 standard. (Wikipedia, 2012)

The tests for the dog bones were done with the ISO 1133 standard. The material was heated at 230°C for 6 min; 2,16kg was applied on to of a piston in order to push down the material. Material was recovered for 10min in order to get the melt flow index value. (Wikipedia, 2012)



Figure 20 Melt flow index machine (Arcada plastic laboratory, 2012)

3.8 Plastic shredder

The plastic shredder was used for shredding the material into recyclable material. The material was then used for the injection molding machine to produce dog bones out of recycled SABIC PP 505P.

The shredder works as following. Material which is desired to be recycled is thrown through a hopper into a shredder which cuts the material into recyclable material. The recycled material is then collected into a collector. A filter is placed before the collector which task is to collect pieces that are too big in size. The size of the recycled material has to be uniform; otherwise it may get stuck up when applying it into the hopper of the injection molding machine. The big size is not either good for the screw within the cyl-

inder of the injection molding machine. There is a big chance that these big plastic pieces damage the screw and that is not desirable.

The material was recycled two times with the shredder in order to ensure a good size of the recycled material.

The problem with recycled plastic material is the shape of it compared with fresh and never recycled plastic granulates. Plastic granulates are uniform in shape and are very suitable to be processed with an injection molding machine. The recycled plastic material is in other hand not uniform in shape and this makes it much trickier to recycle. Not impossible, but a bit harder.



Figure 21 Plastic shredder (Arcada plastic laboratory, 2012)

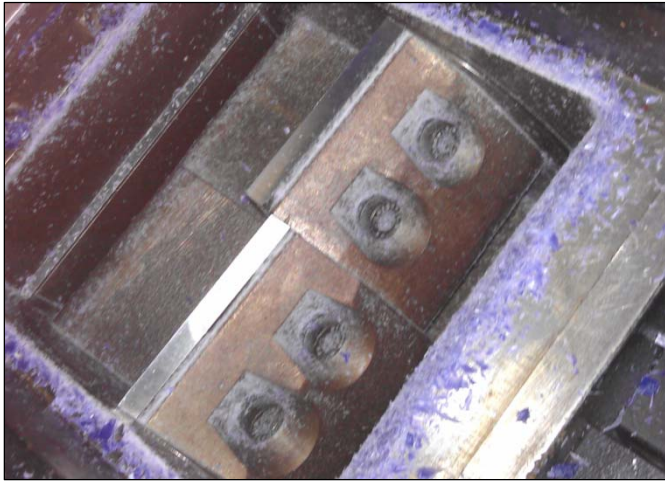


Figure 22 Metal blades that cut the plastic material inside the shredder (Arcada plastic laboratory, 2012)

3.9 Mechanical strength values

The mechanical values to be received from the tests are tensile strength, young's modulus and melt flow index. These are values which are easily comparable with other materials, but are also an easy and effective way to see how the mechanical strength changes when polypropylene is being recycled. The following will go through the values and how they are calculated

3.9.1 Tensile strength

Tensile strength (TS) often referred as ultimate tensile strength (UTS) is the ultimate stress that material can withstand while being pulled before starting to significantly contract, necking. Necking is in engineering when fairly large amount of strain localize disproportionately in a small region of the material. This phenomena result in advanced decrease in local cross-sectional area. The cross-sectional area for the dog bone is the thickness 3,3 mm and 12,8 mm at the middle of the bone. Tensile strength is the complete opposite to compression. Compression is when a piece is pressed together.

The easiest way to find the tensile strength is to perform a tensile test, where stress is put versus strain. The highest point of this stress versus strain curve is the tensile strength of the material being tested. Tensile strength is defined as stress which is defined as force, in newton, per area, in millimeters. The unit for tensile strength when dividing force (N) with area (mm^2) is Mega Pascal (MPa). (Wikipedia, 2012)

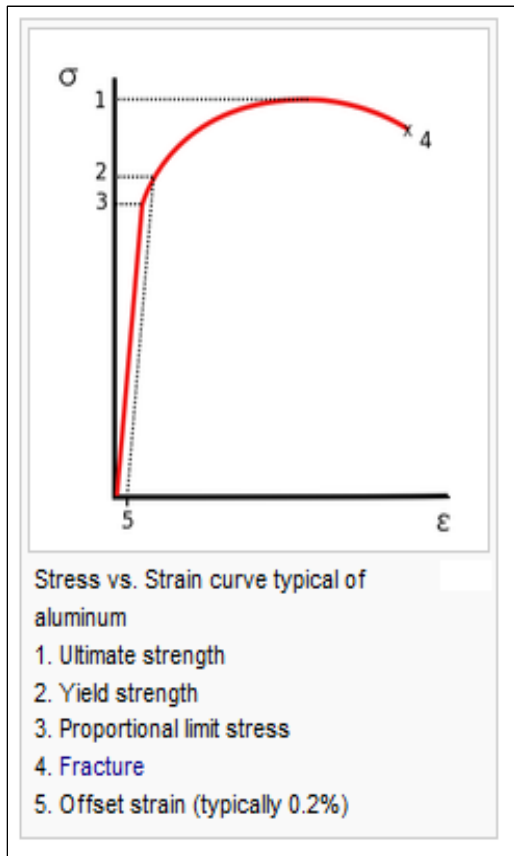


Figure 23 Stress vs. Strain curve (Wikipedia, 2012)

3.9.1.1 Calculation of tensile strength

Tensile strength is calculated by dividing the force with the cross sectional area of the specimen. The force is the maximum amount that the material can withstand when being pulled with a testometric tensile testing machine. The cross sectional area is measured at the middle of the testing piece. For the dog bone it was measured by multiplying the thickness of 3,3 mm with width of 13,8 mm. The formula for calculating tensile strength can be seen below. (Wikipedia, 2012)

$$\sigma = \frac{F}{A} \quad \text{Formula 4: Tensile strength (Wikipedia, 2012)}$$

$\sigma = \textit{tensile strength}$ (Tensile strength is calculated in N/mm² (MPa))

F = Force (Force is calculated in Newton (N))

A = Area (The cross sectional area of the piece (mm²))

3.9.2 The Young`s modulus

Young`s modulus, which is also known as the tensile modulus, is a measurement of the stiffness of an elastic material: Young`s modulus is also used as a value to characterize materials. It is defined as the ratio of uniaxial stress over uniaxial strain. The stress being measured in force and strain being measured in how much the material deforms when being stretched. (Wikipedia, 2012)

Young`s modulus is used for calculating the change in dimension of a bar made out of isotropic elastic material under either tensile or compressive load. The value predicts how much a material sample will extend under tensile load or shorten under compressive load. (Wikipedia, 2012)

3.9.2.1 Calculation of young`s modulus

Young`s modulus is calculated by dividing the tensile stress with the tensile strain in the elastic portion of the stress-strain curve. The calculation of young`s modulus can be seen in the following text below.

$$E = \frac{\textit{tensile stress}}{\textit{tensile strain}} = \frac{\sigma}{\epsilon} = \frac{F/A}{\Delta L/L} \quad \text{Formula 5: Young`s modulus (Wikipedia 2012)}$$

E = Young`s modulus or modulus of elasticity (MPa)

F = Force exerted on an object under tension (N)

A =Original cross sectional area of the piece tested (mm²)

ΔL = Amount that the sample changes in length when being pulled (mm)

L = Original length of the piece being tested (mm)

3.9.3 Melt flow index

Melt flow index is measurement measuring the ease of a thermoplastic material to flow. The melt flow index is an indirect measurement of the plastics molecular weight. (Rich Geoffroy, 2004)

One of the key properties of polymers is the molecular weight. It is the very long molecules which give the polymers its e.g. high elongation, toughness, impact strength. In crystalline polymers, these long-chain molecules get caught up in one or more adjacent crystalline sections and act like links (they tie molecules together) between crystallites. Crystallites are small, microscopic crystals. (Rich Geoffroy, 2004)

When there is a failure in the material, one often wants to determine if the molecular weight of the material is the same as it was specified to be, or has it been altered during processing or use. Small reductions in average molecular weight can be responsible for significant reduction in tie-molecule density; this affects e.g. the performance of the material. (Rich Geoffroy, 2004)

The strength of the material is located in the bonds holding molecules together in atoms within the polymeric material. The length of the bonds are also important when determine the strength of a polymeric material. Long chains give better strength than shorter chains. (Rich Geoffroy, 2004)

In a melt flow index measurement one can see how well or poorly the material flows when a certain temperature, to heat up the material, is used and a specific weight is applied in order to push the material down through the die. Low melt flow rate results in higher mechanical strength and higher melt flow rate results in lower mechanical strength. The strong bonds within the material make the plastic melt much harder to flow. When a material e.g. is recycled then these bonds are cut up into smaller bonds and this ends up in a higher melt flow rate. This is due to the matter that the resistance of the plastic melt is lower, due to the intermolecular bonds within the molecules inside

the atoms. The lower resistance makes the melt flow rate higher and thus. The conclusion, according to literature is that low melt flow rate results in high molecular weight and high melt flow rate results in low molecular weight. The experiments are then to determine if this fact is correct or not. (Rich Geoffroy, 2004)

3.9.3.1 Melt flow index calculations

Melt flow index is calculated in a bit different way than the tensile strength and young`s modulus. Young`s modulus and tensile strength calculations demand mathematical formulas in order to be determined. This is not the case for melt flow rate however. Melt flow index is determined by using a melt flow index machine. The input values for the machine depend on the polymeric material used. The values varying are melting temperature of the material, melt flow time and the weight used to push down the plastic melt through the die. The values are usually ISO standards and vary a bit from one material to another. The value received from the machine is the amount of material, in grams, that has flown through the die in 10 minutes.

4 RESEARCH METHODS

The testing methods for completing the recycling tests of SABIC® PP 505P are explained in this chapter. The methods can be divided into two different one: processing the material and testing the material. The processing step was done by using the injection molding machine and the plastic shredder. The testing part was carried through by using the testometric tensile testing machine and melt flow index machine. The processing step prepared the material for being tested and the testing part then tested the processed material.

4.1 Executing the experiment

The objective with the experiment was to compare the original mechanical strength of SABIC® PP 505P with recycled material of the same kind. The same material,

SABIC® PP 505P, was recycled 14 times in order to see how the mechanical properties change due to recycling. Original mechanical properties, of the material, were firstly collected in order to get some mechanical values in form of tensile strength and young`s modulus. These mechanical values were then collected from each recycling cycle in order to see how the mechanical properties change when recycling SABIC® PP 505P.

The following goes through one cycle of processing and testing the material. Each and every cycle after this was then done in the same fashion. The melt flow index part was chosen to be done at last. This was done, due to the fact that it was most suitable in that way. All of the material was used in order to produce dog bones during each recycling run. The number of dog bones used for testing the mechanical strength with the testometric tensile testing machine was set to be three. A small amount of material was put to side after each recycling run in order to test the melt flow index.

4.1.1 Preparing the material

Normally one may have to pre dry the plastic material before processing it in e.g. an extruder or injection molding machine. This is done in order to remove extra moisture from within and from the surface of the plastic granulates. Extra moisture may destroy the material when being processed. The extra moisture can be noticed in runny plastic melt and air bubbles within the plastic melt. This was not however the case when using SABIC® PP 505P, because it had already been performed by the granulate producer, SABIC in this case. The need to pre dry plastic granulates is usually mentioned in the datasheet that the producer provides with the material. The pre drying step in a recycling experiment like this is only done in the beginning when preparing the material for the test. The material preparation is not done after each recycling stage, only before the experiment.

A certain amount of material was then chosen, enough to be sure that the material would last for 14 recycling runs.

4.1.2 Injection molding the dog bones

The dog bones, to be tested with the tensile testing machine, were produced by using an injection molding machine. The process behind injection molding is explained in chapter 3.4.2. This kind of process was also used when producing the dog bone pieces for this experiment. The input values, for the injection molding machine, can be seen in chapter 3.4.5 and 3.4.6. These values were calculated for this specific dog bone using SABIC® PP 505P. Material selection, product design and input values into the machine go hand in hand and are always calculated before making any product. Correct input values ensure that the product will be good.

The same input values were used for each and every recycling run. This was done in order for the values to be comparable with each other. The values could not have been compared with each other otherwise.

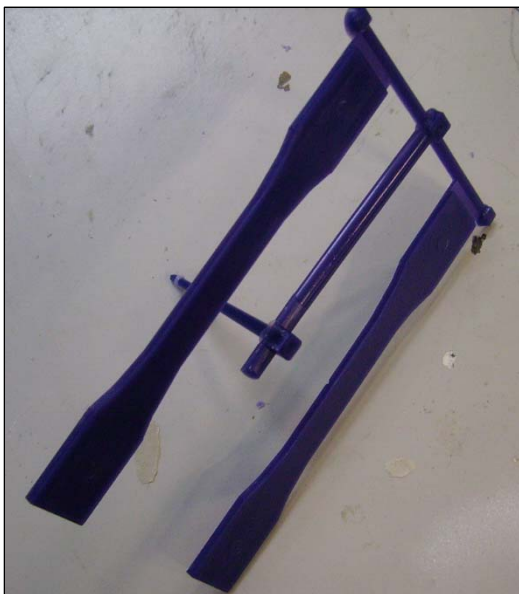


Figure 24 Injection molded dog bone piece (Arcada plastic laboratory, 2012)

4.1.3 Tensile testing the dog bones

The injection molded dog bones were then tested with a testometric tensile testing machine. The procedure behind the testing steps is listed in chapter 3.6. The testometric

tensile testing machine was used in order to get the tensile strength and young`s modulus of the dog bones made out of SABIC® PP 505P. The amount of dog bones tested per each recycling run was set to be 3 in order for the testing result to be as accurate as possible. The dog bones were also let to cool down for 24h after being produced by the injection molding machine. This was done in order to ensure that all the 3 pieces had the same condition parameters before performing the test. If the pieces would have been tested, when coming straight out of the injection molding machine, then the results wouldn`t have been accurate. Then the temperature stored within the dog bones, received from the injection molding process, would have played a rather big impact on the mechanical properties. The temperature would have caused the molecules to stay in movement within the plastic. The movement would have been noticed in a decrease in mechanical strength.

The data received from the test were saved as PDF files for later investigation and conclusion.

4.1.4 Recycling the material with the plastic shredder

The injection molded and tested material was recycled using a plastic shredder. The shredder contains powerful metallic blades that convert the plastic material into recycled material. The external difference of this material, compared with fresh and never recycled raw material, is the shape. Plastic material recycled with the shredder has the shape of chips instead of pellets. All of the material, produced with the injection molding machine and tested with the testometric tensile testing machine, was recycled by using the plastic shredder. A small amount of the recycled material was collected into a plastic bag for the melt flow index test.

Each and every recycling run was done in the same fashion as listed above. The same processing and testing machinery was used in order to get as comparable values as possible.

4.1.5 Melt flow index

The melt flow index was done at last, when all the other testing and recycling was done. This was done, as already earlier said, due to suitability to be done last. The melt flow index process is explained in chapter 3.7. The test was done in similar fashion to the other tests. Original values for the raw material were tested first and then the recycled material was tested thereafter.

4.2 Recycling guide of plastic material

The following chapter contains information about the different steps when recycling a certain plastic material. Different guidelines for each step are gone through and some ideas to keep in mind when doing the experiment.

4.2.1 Pre drying stage

Always dry the material before use if so is mentioned by the material producer or provider. Never do it during the recycling runs, it is not necessary and it may change the properties of the material which is not good if one wants to keep the testing boundaries the same during the whole recycling experiment.

4.2.2 Injection molding stage

Find out the right parameters before starting the experiment. This is rather necessary in order to use the machinery properly and not break it in the worst scenario. Never insert granulates into a cold injection molding unit, it may cause the plastic to get stuck inside the cylinder and entangle itself onto the screw. Always let the machine heat up to the right material processing temperatures before usage. Also remember to empty the machinery after use; it is easier for the next user of the injection molding machine in that.

The ventilation is also good to put on, in case the plastic material starts to fume when being processed.

4.2.3 Testometric tensile testing stage

The correct input values are also good to know before using this machinery. Each material has certain ISO-standard values that differ from one material to the other. ISO-standard values are created in order for other people to recreate already done experiments. Standards also exist so that comparable test can be done with other plastic materials. The main standards for tensile testing are testing speed and the dimension of the testing piece.

4.2.4 Plastic shredder stage

Plastic shredder is the most dangerous machine when executing the experiment. It is good to keep goggles on when recycling the plastic so that eventual eye injuries can be prevented. Hands are also good to keep out of the machine, always turn of the machine if something gets stuck within the machine while shredding plastic material.

The plastic material is also good to recycle two times in order to prevent large chunks of recycled plastic. These large pieces of plastic may get stuck in the hopper part of the injection molding machine and prevent other material from entering the barrel inside the cylinder. Large pieces may also in the worst case damage the screw inside the barrel.

4.2.5 Melt flow index stage

The standards are again the most important ones to keep in mind when performing this test. Right standards and input values mean that the test will be executed correctly and similar tests can be performed in the future. These tests can then be compared with existing ones.

5 RESULTS

The result data was collected from the testometric tensile testing machine and melt flow index. The tested data were tensile strength, young`s modulus and melt flow index. The following chapter will go through the original testing values for SABIC® PP 505P and recycling values for the same material. These will then be compared with each other.

5.1 Initial mechanical strength of SABIC® PP 505P

The first step is to show the initial mechanical strength for the material tested. The values are tensile strength, young`s modulus and melt flow index and are listed in Table 8.

Table 8 Initial mechanical strength (Dan Weckström, 2012)

Tensile strength (MPa)	Young`s modulus (MPa)	Melt flow index (g/10min)
29,0	806,3	5

5.2 Recycled mechanical strength of SABIC® PP 505P

The material was recycled 14 times using the same processing steps and input values. The mechanical strength values are listed in tables and charts below.

5.2.1 Tensile strength

Table 9 Tensile strength of recycled material (Dan Weckström, 2012)

Recycling runs	Tensile strength
1	27,9
2	30,5
3	27,7
4	28,6
5	28,2
6	28,4
7	29,3
8	28,8
9	29,9
10	28,4
11	28,0
12	27,5
13	27,3
14	26,3

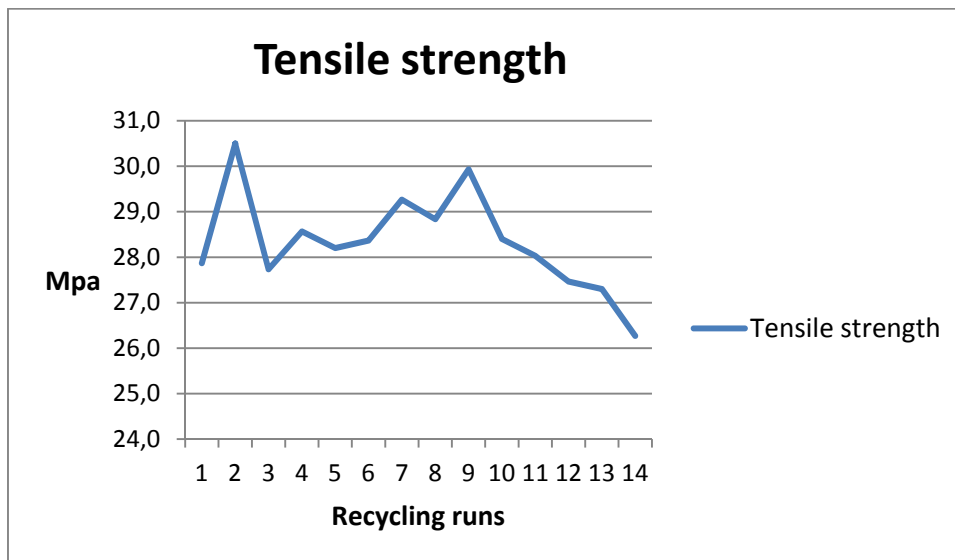


Chart 1 Tensile strength chart of recycled material (Dan Weckström, 2012)

5.2.2 Young`s modulus

Table 10 Young`s modulus of recycled material (Dan Weckström, 2012)

Recycling runs	Young`s modulus
1	748,0
2	751,8
3	609,7
4	645,4
5	668,3
6	651,0
7	729,4
8	706,4
9	740,1
10	681,1
11	672,4
12	659,3
13	656,5
14	695,7

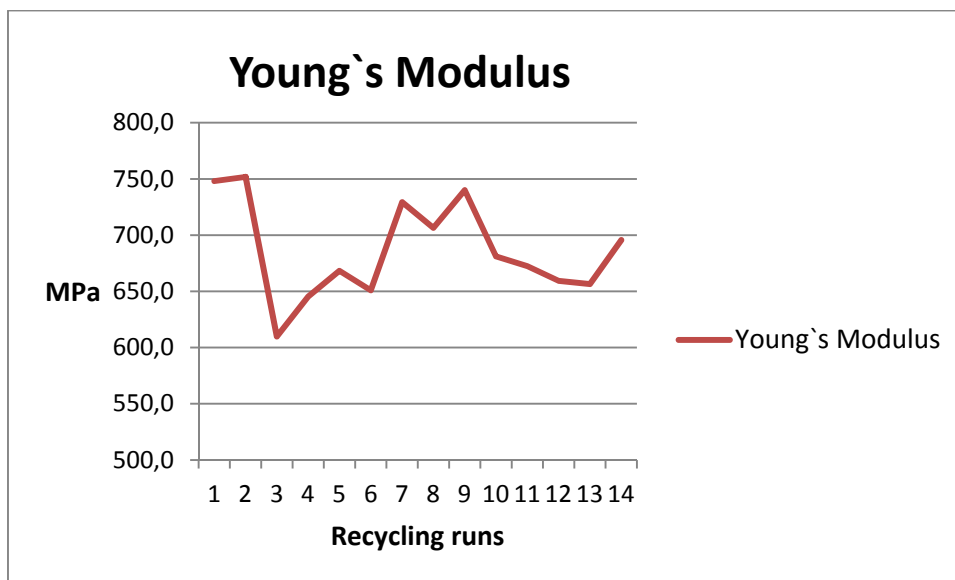


Chart 2 Young`s modulus chart of recycled material (Dan Weckström, 2012)

5.2.3 Melt flow index

Table 11 Melt flow index of recycled material (Dan Weckström, 2012)

Recycling runs	Value (g/10 min)
1	11
2	10
3	7
4	6
5	6
6	6
7	7
8	8
9	8
10	8
11	10
12	10
13	12
14	11

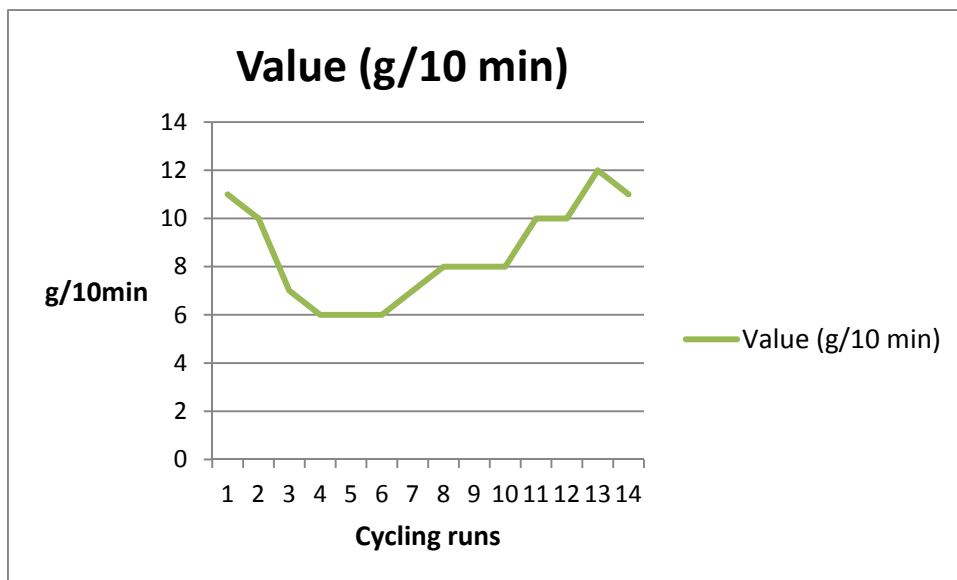


Chart 3 Melt flow index chart of recycled material (Dan Weckström, 2012)

5.3 Evaluating the recycling values results

Comparisons between starting of values and recycling values will be gone through in this section.

5.3.1 Tensile strength

The starting of tensile strength value for the raw material was tested to be 29 MPa. The value received from the last recycling cycle, 14th, was 26,3 MPa. The decrease was 2,7 MPa, which is 9,3%, from the original value of the raw material.

5.3.2 Young`s modulus

The starting of Young`s modulus value for the raw material was tested to be 806,3 MPa. The value received from the last recycling cycle, 14th, was 695,7 MPa. The decrease was 110,6 MPa, which is 13,7%, from the original value of the raw material.

5.3.3 Melt flow index

The starting of melt flow index value for the raw material was tested to be 5g/10min. The value received from the last recycling cycle, 14th, was 11g/10min. The increase was 6g/10min, which is 120%, from the original value of the raw material.

6 CONCLUSION

An overview of the recycling results will be gone through during this section. Also why the results turned up as they did will be explained.

6.1 Results

The results could be divided into two separate sections, the once testing strength, tensile strength and young's modulus, and the results showing melt flow index.

All of these three values are dependent of each other in a way, because a decrease in melt flow index, explained in chapter 3.9.3, is noticeable in when testing the tensile strength and young's modulus. The values should go in a fashion like this, when the melt flow index increases, then the tensile strength and young's modulus decreases.

6.1.1 Effect of results

The testing results were rather surprising and unexpected. The melt flow index, used as an indirect measurement to test the molecular weight property, showed an increase when the material was recycled many times. This was not comparable with the tensile strength value. The tensile strength was rather close to the original tensile strength throughout the testing cycle. Only a decrease of 9,3%, from the original material to the 14 recycling run, was lost in tensile strength when testing the material made out of SABIC® PP 505P. This decrease, when defining the indirect molecular weight through the use of melt flow index, was calculated to be 120%. If these would be comparable to each other, then the tensile strength should be much lower than it was tested to be. Now the difference is much higher, which shows that the material can withstand the recycling effects really well.

The young's modulus value was rather inconsistent throughout the recycling process. This phenomenon was due to the fact that the material elongated irregularly and showed no pattern of increase or decrease on this aspect. The one noticeable thing however was

that the strength, in form of young's modulus, was rather consistent and no huge drop or increase in strength occurred throughout the 14th recycling runs. This phenomenon was similar with the tensile strength.

6.1.2 Evaluating the results

The own thoughts of the testing results are the following. The big drop in material strength did not occur throughout the recycling runs, because the bonds within the material got more and more entangled when the material was recycled over and over again. This entanglement replaced the original strength that the material got from the intermolecular forces within the atoms of the polymeric material. The decrease in forces between the chains could be seen in the increase of melt flow index. The material was able to flow better and that is the reason why the melt flow index value increased from the original value.

The conclusion is that thermoplastic material of this sort is really good to recycle due to small losses in material strength when being recycled. An optimum solution is to blend recycled plastic material with fresh plastic raw material of the same sort as the recycled material is. This is something that many companies within the plastic industry perform, in order to save material, money and the environment.

7 DISCUSSION

The discussion part is intended for the writers own thoughts concerning the writing and testing done in the thesis.

7.1 Own thoughts

Personally I think that it was interesting and eye opening at the same time when performing the recycling tests and writing the thesis. The tests showed unexpected values which I did not expect before performing the tests. The unexpected values made it even more interesting to write the thesis and figure out the reason behind the testing results.

The choice of doing the testing part before the literature part was in my mind a good solution. This made it possible to get some thoughts and personal ideas for the literature part. Also some aspects of using the testing equipment could have been unnoticed if the literature part would have been done firstly and not secondly.

7.2 Improving the test

The tests could have been improved in a couple of ways.

Some other similar plastic materials could be compared with the one used for the tests. This would widen the knowledge about how similar plastic materials behave when being recycled. One example is to recycle isotactic, atactic and syndiotactic plastic materials and compare the test results with each other.

The testing material could also be affected by humidity, heat and other elements that affect plastic products used in everyday life. This would make the testing circumstances much more realistic and could also have a big influence on the properties of the plastic material.

A third improvement could be to add never recycled plastic raw material to the recycled material and see how the properties change due to this. Are the properties equally good, when comparing to the never recycled plastic raw material, or do they slightly differ.

The fourth and final improvement could be to see if drying the material after each recycling run would change the strength of the material in a positive or negative way.

7.3 The end

Thank you for reading this thesis, I hope that it has been useful and eye opening in some kind of way.

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