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The importance of PET filtration for the possibility of material recycling

G. Wróbel [a,*], R. Bagsik [b]
[a] Division of Metal and Polymer Materials Processing, Institute of Engineering Materials and Biomaterials, Silesian University of Technology, ul. Konarskiego 18a, 44-100 Gliwice, Poland
[b] Bagsik TPTS Ltd, Toruńska 8, 44-100 Gliwice, Poland
* Corresponding author: E-mail address: gabriel.wrobel@polsl.pl

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Materials

ABSTRACT

Purpose: With the development increasing of plastics production the problems associated with their disposal have appeared on. Because of the large volume of plastic wastes and their limited long-term resolution, there is a need for treatment and reuse. For this purpose, with tests of properties, studies on plastics recycling and reprocessing into new products (recyclate) are conducted. The basic technological problem connected with using of secondary material is to clean it. The basic utility problem is the impact of recycling operations on the properties of the secondary material. The work to this issue is mainly devoted.

Design/methodology/approach: One of the basic surgery to restore the plastics reusing ability is impurities removing. An available modern way is to use a specialized system of filtration sieves. Optimization problem is to select the proper filter in terms of mechanical properties of the resulting recyclate. In the work, the secondary material with using of grid filter of varying size has been tested. Prepared, with using of purified secondary plastic, three layer film to tensile test was subjected.

Findings: The result of the tests described in this work is the preliminary determination of the filtration effect on the mechanical characteristics of the selected secondary materials.

Research limitations/implications: The results confirm the impact of the quality of filtration of thermoplastics in the process of secondary processing on the base product properties. The accuracy of the pollution elimination process affects directly on the mechanical characteristics of secondary material. Used in the research procedure filtration system with automatic filter change operation helps to minimize the impact of filtering on the performance of the extrusion process.

Practical implications: Practical benefit of the study is the confirmation of the possibility and desirability of material recycling, particularly with using of modern filtration system.

Originality/value: The original value of the research are qualitative and quantitative assessment of the effects of filtration on the characteristics of the secondary material.

Keywords: Thermoplastics; Recycling; Filtration systems; Tensile; Extruding process

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1. Introduction

With the development increasing of plastics production the problems associated with their disposal have appeared on. Because of the large volume of plastic wastes and their limited long-term resolution, there is a need for treatment and reuse. For this purpose, with tests of properties, studies on plastics recycling and reprocessing into new products (recyclate) are conducted. But before the plastic is recycled, treated, must go through several processes of segregation and appropriate cleaning.

This work studies mechanical properties of the three-layer film, produced with the use of recycled material [4]. Recycled material in the molding process is subjected to a filtration process using the sets of filter sizes. The study aimed to determine the effect of precision of filtration process on the quality of layer film of polyethylene terephthalate PET.

Using prepared filters, extrusion process of layer foil, made of 80% recycled material and 20% of the materials of the original will be conducted. Secondary material will be subjected to filtration using seven different sets of filters, then there will be strength tests of the film, in terms of the impact of filtering on the test characteristics, conducted.

2. Polyethylene terephthalate (PET) as an example of plastic

PET is a high-molecular compound (polymer) obtained by polycondensation reaction of terephthalic acid and ethylene glycol. As a result of this reaction the thermoplastic material for many different applications is formed. It is known for several decades. In the beginning it was used for the production of films and fibers. As a construction material for the first time it has been used in the late sixties of last century and next, in late seventies, it was widely used in various types packaging production. PET has the following features [5]:

- excellent dielectric, mechanical and strength properties,
- high resistance to aging and light
- good resistance to low and high temperatures
- good resistance to oils and fats, dilute acids and alkalis, aliphatic and aromatic hydrocarbons
- low moisture absorption
- physiologically is indifferent and approved for contact with food (is sterilized with ethylene oxide or UV light irradiation) [5].

In the group of plastics, it is characterized by high density, so that it can easily be separated from a mixture of plastics, and high mechanical strength, chemical and thermal resistance. It also has special optical properties. Thanks to its characteristics, it was widely used as raw material for the manufacture of various types of packaging, both in the food industry (production of bottles, films) as well as in the textile and construction industry [6].

2.1. Raw materials used for production of PET

The traditional method of production of polyethylene terephthalate is a two stage process, which uses as raw materials terephthalic acid (TA) or its dimethyl ester (DMT) and ethylene glycol, which are illustrated in Figure 1 [3]:

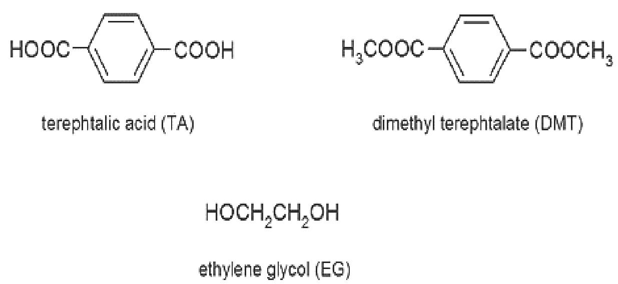


Fig. 1. The compounds included in the construction of plastic from PET [3]

Raw materials, from which PET is produced, must have a high purity (> 99.0%), and therefore the dominant raw material used several years ago was DMT, because he had great ease of purification. Today, available technologies allow to obtain TA with a purity of up to 99.9%. Currently, the largest amount of PET can be obtained by using terephthalic acid, which is the product of petrochemical origin. It is obtained by oxidation of xylene at 150 ° C. under a pressure of 1.5 MPa. This reaction proceeds in the liquid phase, in an environment of glacial acetic acid, using a homogeneous catalyst such as cobalt acetate (Fig. 2) [3]:

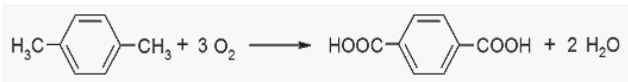


Fig. 2. Oxidation of xylene [3]

Terephthalic acid is an aromatic dicarboxylic acid. It is a colorless, crystalline substance which has the form of needles and sublimating at 300°C. Practically, it is not in water and many organic solvents soluble. In the world is produced almost 25 million tones of terephthalic acid per year and it is mainly for production of PET used.

Ethylene glycol is a sticky, sweetish and colorless liquid that has a boiling point equal to 197°C. It is a product of petrochemical origin, which may be obtained during the hydration of ethylene oxide (Fig. 3). This reaction is carried out in the liquid phase, using a large excess of water, without a catalyst, at a temperature of about 200 °C and a pressure of about 2 MPa.

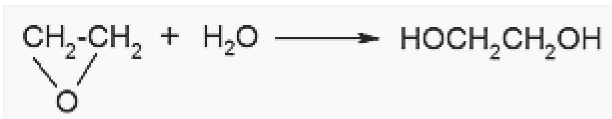


Fig. 3. Hydration of ethylene oxide reaction

The world produces more than 12mln tons per year of ethylene glycol, from which a very large portion to the production of plastics is dedicated.

2.2. Production of polyethylene terephthalate

The production process of polyethylene terephthalate is composed of two reactions - esterification and polycondensation (Fig. 4) [3]:

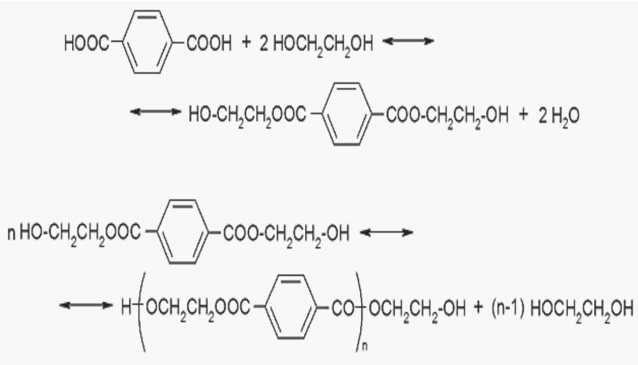


Fig. 4. Esterification and polycondensation reactions [3]

The first phase consists in the esterification of terephthalic acid by excess of ethylene glycol to yield the diglycolic ester of terephthalic acid, or terephthalate bis (2-hydroxyethyl). When formed in the first phase water and excess of glycol will be destilled, the polycondensation together with the separation of ethylene glycol, which is a byproduct, is carried out. Both of these reactions proceed at 250-280°C, are reversible reactions, and the resulting by-products (water and ethylene glycol) shift the equilibrium state toward the substrates side. Therefore, their rapid removal from the reaction medium is necessary, what is quite difficult in the case of ethylene glycol, because this compound has low volatility.

For the polycondensation reaction proceeded well, it is appropriate to reduce the pressure. PET is produced in anaerobic conditions (under nitrogen). Due to the high melt viscosity and difficulty in mixing, in the reaction of polycondensation is possible to obtain a product with a molecular weight of the order of 15,000. Polyester having such molecular weight and having a relatively low viscosity may be suitable for processing into fibers, but not applicable in the production of packaging, such as a bottle, for example. To obtain a product with twice the molecular weight (about 30,000) and a higher viscosity the additional polycondensation in the solid phase is carried out - polyester granules obtained in the first stage is maintained within a few hours at a temperature of 280°C in an inert atmosphere [3].

2.3. Polyethylene terephthalate processing and application

A slight majority of the world production of polyethylene terephthalate processed into fibers. They are polyester fibers, which are in the group of synthetic fibers. Polyester fibers have the largest share, approximately 55% in the group of all synthetic fibers (the other known synthetic fibers are polyamides - Nylon, Polyurethane - Lycra, polyacrylonitrile - Anil). World production of polyester fibers is close to 10 million tones and with each next year the production is increasing. They can be obtained by dry forming alloy (liquid fiber is cooled in a cold room). Thus, the polymer melted at a temperature of 275-285°C is extruded through the spinneret (with holes of small diameter) for air-cooled chamber, where the solidification of the fiber is followed.

Then, further processing is carried out (stretching, crimping, cutting and finishing), after which the fiber is ready for processing in the textile industry - is designed for both fashion and technology.

PET films are formed by extruding the molten polyester through a nozzle-shaped slot, and then stretching and heat treatment are performed. The main use of these films were in production of light-sensitive films (film and photographic film), film and packaging, and recording and video tapes. Less than 10 million tons of polyethylene terephthalate is used for packaging, 80% of which is the bottle. Polyethylene terephthalate was used as one of the main and most widely used plastics for wrapping in the food industry (the bottles for water, carbonated and non-carbonated drinks, for milk and various kinds of edible oils are made from it), and due to its high resistance to chemical agents - in the chemical industry (packaging for household products and cosmetics). The biggest advantages of PET is [8]:

- are light, safe and easier to transport than glass bottles,
- are very mechanically durable, it makes easier to their filling, transportation and storage, • are transparent and have a gloss,
- are resistant to chemicals (water, fats, organic solvents, acids),
- are a good barrier to gases (oxygen, carbon dioxide, nitrogen), so that the products retain their flavor and aroma [8].

The main methods of polyethylene terephthalate processing are related to the blow-molding, in which the material in a plastic state is blown inside the mold, using compressed air or steam. Products of the manufacturing by this method are: bottles, containers, etc. Another method of processing PET is tubular film extrusion, in which the material in a plastic state is forced into the mold in the shape of the tube, then it is blown in by air. Made in this way the foil sleeve is in the next step sealed or cut to desired size. In this way production of various types of bags and films is possible [6].

3. Material recycling on the example of polyethylene terephthalate

Due to the significant increase in the use of PET bottles the world's environmental problems arise. Pet quickly becomes a waste because of its short life. Packaging waste does not pose a high risk to the environment, however, pose segregation problems because of the volume occupies. A considerable amount of PET waste is landfilled, in Poland tens of thousands of tons per year.

For ecological and economic reasons activities that are aimed at recycling of waste from PET are conducted. For this purpose it is necessary to organize the collection and sorting of waste plastics, or separation of the various groups - are used for this purpose optical methods, electrostatic methods, hydraulic classification, selective dissolution (separation of PET from the polyolefin is not cumbersome, more difficult is to separate PET from PVC). It is noteworthy that PET can be quite easily processed with the use of virtually all methods of polymeric materials recycling [4].

We can distinguish five stages of the recycling of plastics, these are:

1. Collection by individual users
1. Collection organized by local authorities or companies that specialize in this direction
2. Sorting of waste plastics by type of material
3. Washing to remove labels, dirt and other residues.
4. Reprocessing into granules or fibers, and using them to new products [4].

Material recycling is called simple and efficient method of recycling of thermoplastics (which also includes PET), which consists of reprocessing material into new products. This process involves secretion, fragmenting and melting polyester waste leading to a refined alloy, which in the next phase is formed on a new product by injection or extrusion (or only the pellets are obtained, which can be further processed).

How recyclate will be used determines the quality and purity of the material. It can be used in the textile industry (technical fibers), for the manufacture of insulation materials, carpet yarn and in the construction industry, to strengthen the construction with help of various glass fibers, as well as for the production of films and containers [6].

Material recycling is an alternative for the raw materials recycling, also called the chemical recycling and energetic recycling.

4. Plastics filtration

4.1. Purpose of carrying out of filtration of plastics intended for the production of PET film

The purpose of the molten recycled plastic filtering is to eliminate all pollution. Melted plastic and their solutions contain impurities of various sizes. The main pollutants include: forms of catalysts, derived from the wear of mechanical parts, detached and burned remnants of the material located between the cylinder and screw, corrosion products and others. However, the most contaminants can be found in regranulates and plastics additives such as dyes, pigments and fibers. Also, as an impurity in the material should be called: no fully polymerized material, granules unmelted and easily deformable gels. The aim is to eliminate these impurities, or extract from the plastic because [11]:

- diminish the quality of the finished product,
- decrease the integrity and quality of the film,
- decrease the electric strength of the cable jackets,
- decrease the strength of fibers, films and other products,
- increase the surface roughness,
- accelerate the aging of the material,
- alter the optical properties (color)
- effect on parts wear (such as nozzles, material pumps and other) [11].

4.2. Filtration sieve

The concept of filtration in plastics processing means cleaning of plastic material or it’s solution from the mechanical and unwanted particles through the filter material. As a tools for filtering can serve fibers of various types, sand (quartz), woven metal mesh, sintered powders or membranes.

Taking into account the specific technical requirements such as temperature, corrosion resistance and mechanical strength, the special place occupy the filter nets made of stainless steel.. The metal woven meshes are the ideal filtering tools, due to their specific properties and parameters. Square mesh nets have a simply set the mesh size, with close tolerances and precisely defined openning areas, and equally porosity on the entire surface. In addition to the nets with a square or rectangular mesh also are used a filtering meshes with warp or thread wires located so close together that create so-called unmesh weave. Due to its special design of the grid have extremely narrow distribution of porosity under normal operating load. Through the combination of different specifications of the meshes, there is the possibility of combining networks of certain properties such as mesh filter packets. To the other advantages of meshes in comparison to other ways of filtration, we can include:

- chemical inertness
- high abrasion resistance
- good ductility
- no change of particle during the filtration process
- flat surface structure
- recyclability
- high reproductiveness, especially in the field of the structure and accuracy of filtration [11].

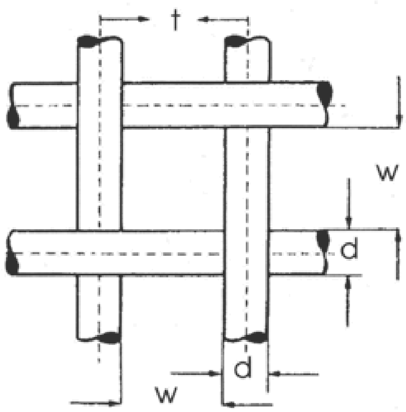


Fig. 5. Filtration grid scheme [11]

Selection of optimal parameters mesh (Table 1) has a great impact on the manufacturing process. For this reason, the result should be carefully defined, and the impact of a specific size determined. It is necessary to remember to specify:

- scope of using,
- filtration precision

- conditions of the production process (temperature, pressure, etc.),
- chemical and mechanical requirements,
- any further procedures [11].

Characteristic parameters of the grid shown in Figure 5, where [11]:
w - mesh size in mm
d - wire thickness in mm
t - pitch in mm, t=w+d
A_0 - open space: the percentage of open mesh area in the total mesh area
$A_0 = w^2/(w+d)^2$
Mesh = 25.4/w+d=25.4/t.

5. Preparation of regrind of plastic recycled

In Poland, more than 100 thousand tons of PET bottles per year are emptied. One ton of material is equal to 25 thousand bottles produced from this material. Still relatively few companies are involved in the processing of PET material used for secondary raw material but from year to year the number is growing. The problem is that the degradation of PET bottles in the environment may take up to 400 years. Acquisition of the secondary raw material allows the removal of environmental pollutants in the form of PET bottles as well as their processing and reuse [12].

The wastes are acquisited by separate collection and segregation carried out at the landfill. Can be found among them material in the form of plastic caps and household chemicals bottles. After the selection to stakeholders, dealing with the falsification and destruction these wastes, are delivered. PET bottles are shipped from the warehouse to the manufacturing floor in the form of compressed bales, and then are transported to a special screening drum, in which the mechanical impurities are separated. Next bottles are segregated by type of polymer, and it is on transmission tapes. Especially sorted PET bottles are crushed in a mill on the petals.

The next stage is using of a label separator, through which dirt and dust are separated from the mill. Grinding is in turn subjected to flotation separation of washing, which consists of removing the paper, PP and PE. In the final stage of preparation the milling is dried. After preparing the raw regranulation process begins. Extrusion

Table 1.
Parameters of square mesh nets [11]

Mesh size [mm]	Wire diameter ø [mm]	Open surface %	No. of mesh per cm^2	Mesh per inch	Weight (steel) kg/m^2
0.025	0.025	25	40.000	500	0.16
0.036	0.028	32	24. 430	400	0.16
0.040	0.035	28	17.777	325	0.21
0.050	0.040	31	12.343	280	0.23
0.063	0.040	37	9.428	250	0.20
0.075	0.050	30	6.400	200	0.25
0.090	0.050	41	5.102	180	0.23
0.100	0.063	38	3.758	150	0.31
0.125	0.080	37	2.381	120	0.40
0.140	0.110	31	1.600	100	0.61
0.160	0.100	38	1.482	100	0.40
0.200	0.125	38	949	80	0.61
0.250	0.160	37	595	60	0.79
0.280	0.220	31	400	50	1.23
0.315	0.160	44	445	50	0.69
0.400	0.230	40	252	40	1.04
0.500	0.320	37	149	32	1.59
0.550	0.300	42	139	30	1.55
0.630	0.250	51	130	28	0.91
0.630	0.400	37	94	25	1.97
0.800	0.500	38	59	20	2.44
0.870	0.400	47	62	20	1.55
1.000	0.500	44	45	18	2.12
1.000	0.630	38	37	16	3.10
1.250	0.800	37	24	12	3.96
1.600	0.500	58	23	12	1.51
1.600	1.000	38	14	10	4.90
2.000	1.000	44	14	8.5	4.23
3.000	1.250	50	14	6	4.67

through the extruder is carried out, and then slicing. Thanks to this a material - a polymer called R-PET - in the form of flakes or regrind of different colors is created.

The recipients of this type of material are large companies that produce films, preforms and bottles for beverages. In modern recycling line PET is washed using only the water circulating in closed circuit. By using ultra-filtration system it is possible to reuse the water in the lobes washing process. Devices that are part of the recycling line are characterized by low energy consumption. It is not required to heat the circulating water in their circulation [12].

Fig. 6. RSF Genius filter system [13]

For the individual system components for waste PET bottles recycling the initial segregation lines, flaking lines, cleaning, washing and granulating lines are numbered [11].

Granulating line, which consists of PET flakes dehumidification system, which has a temperature and the level of raw material indicators. Dried petals can reach a moisture content no higher than 0.1%. Received PET flakes should not have any dust, because in the next stage of the process, they are subjected to melting and extrusion. For extrusion process extruder screw with vacuum degassing and sight glasses is designed. Snail is made of special hardened and nitrided steel. In other parts of the granulating line includes a control panel controlling operation of the extruder, extrusion head of the polymer strands, water bath for cooling the polymer threads and the pelletizer for cutting polymer strands. Granulation of PET is performed on special knives, and the size of granules is dependent on cutting speed [12].

6. Filtering methods on the example of Gneuss Kunststofftechnik equipment

Gneuss Kunststofftechnik GmbH Company is a leader in the field of filtration of plastics. It specializes in developing, manufacturing and sales of melt plastics filtration systems, and instrumentation for measuring and evaluating the pressure and temperature in the melt viscosity. Currently, Rotary Filtering System meets the highest technological standards. Fully automated operation mode, a wide range of applications, even during the treatment of "difficult" materials such as PVC and strongly corrosive fluorine-containing polymers and filtering below the 1μm can improve the quality of the product [13].

6.1. RSF Genius filtration system

RSF Genius system (Fig. 6) is completely automated and with constant pressure filtration system that allows its use in the automation of the production process in order to achieve the highest quality final product. It is used mainly for filtration requiring exceptional purity in a need for precise temperature of the product output due to the melting point of the processed material [13].

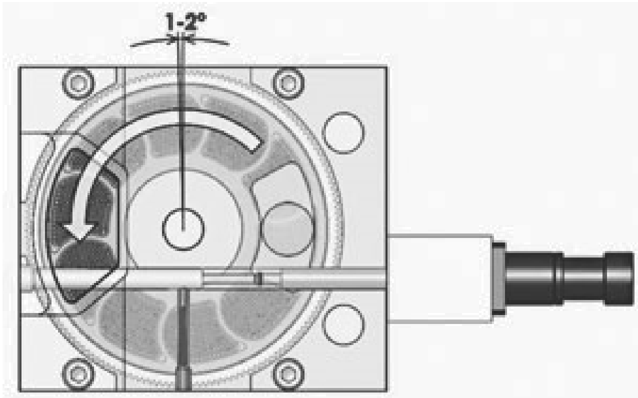


Fig. 7. Flter drive Genius RSF [13]

This system features characterized by the automatic mode of operation, particularly self-cleaning mode of operation. The operation of this filter system is fully automated and provides 100% use of line. Depending on the level of pollution the mesh (screen) is changed. Operation of mesh change takes about 20 to 30 minutes on average once every 1 - 5 months and has no effect on the production process and product quality Constant parameters of the active mash maintaining: pressure, temperature and viscosity is a guarantee of the highest product quality [13].

Figure 7 shows the disk filter used in filtration system RSFGenius. The openings on each sieve are arranged annularly and are enclosed by two blocks of the filter. Sieves can be inserted into the space by opening a small flap giving access to the chambers. The production process is not disturbed by the procedure of the sieve changing. With the modular design of the filtration system it is possible to replace with one block several parts occurring in traditional systems (such as the heater elements and sieve).

6.2. RSF Magnus filtration system

SFX Magnus filtration fystem (Fig. 8) works automatically, continuously providing a constant pressure process. It is suitable for use in any solution, and has a large active area of the screen, compact design and extreme simplicity. Procedures for changing the sieve do not affect the quality of the product. What's more, short flow through the channel - free of dead spots - provides up to a short residence time in the melt / flow system [13].

The benefits that entails the use of a SFX Magnus filtration system:

- high economic efficiency. Increased active area of the sieve in relation to the size of the sieve changer allows for exceptional economic performance.
- consistency of melting / flow parameters of pressure, temperature and viscosity in the process. By ensuring the proper transmission of the active surface of the screen, the parameters of the pressure may be maintained during the production process at a constant level (with a small transient deviations). Temperature and viscosity are also free to change at any time. Constant product quality is even during screen changes guaranteed..
- guaranteed the purity and quality of the process of melting / flow. Purity and quality of the melting / flow process in filtration system is constantly being achieved, and the optimal designed channel, preventing accumulations, is very important.
- short residence time in the filter. Rheologically optimally designed flow channel eventually guarantees the purity and quality of remelting after filtration. A short time melting, and the residence of the material in the filter system (<1minute) allows the use of "rapid materials" and color changes.
- simplicity activities during sieve changing. In due time, the operator is informed by the control system of the impending need to the sieve changing. Change operation is a simple and rapid procedure and has no impact on the process and its quality.
- small compact size and easy installation. Small and compact implementation of the SFX Magnus filtration system unit makes, that even the very limited space can be easily and effectively utilized [13].

Fig. 8. Magnuss RSF filtration system [13]

7. The issue of treatment and use of different filters in the filtration of plastics

The aim of the study was to examine the mechanical properties of a layered film made of polyethylene terephthalate (PET) and to determine whether applied in the production of film filters to purify the materials of pollutants from recycling have an impact on mechanical properties improving. Film, which was used for testing is composed of 80% recycled materials, which constitute the inner layer of film and 20% of the original material, known as the pure PET, which is the outer layers.

The outer layers reduce the inner layer made from recycled materials have better mechanical properties but they are much more expensive. Layered film is produced in order to reduce costs by using in its production of recycled materials and reduce the pollution that results from waste PET material, originating mainly from the used bottles.

They are suitable for processing in a simple way for a new product, in this case film, and retain good mechanical and functional properties, and have a high resistance to various chemicals (very good resistance to water, oils and most acids), which perfectly suitable for packaging food. To check whether this type of film meets the requirements of strength and if exist a possibility to improve by using different kinds of filters, endurance tests was needed to carry out .

To this end, for the production of a layered film seven different types of filters for filtration of recycled materials was used, starting with a set of filters with a higher mesh size equal to 0.125 [mm], through the filters of increasingly smaller mesh size 0.100 [mm], 0.075 [mm], 0.063 [mm], 0.040 [mm], 0.036 [mm] and ending on a set of filters with a mesh size equal to 0.025 [mm].

These studies were to show whether the use of filters with smaller mesh size will cause improvement in mechanical properties of films and to what extent they can get close to the foil material produced from the original (clean). The process of film production of R-PET (Fig 9,10), using seven sets of filter sizes and strength tests were held in a company Plastic Hanex GTX SP zoo in Dąbrowa Górnicza, specializing in packing plastics industry producing

In part for virgin material processing, which does not require such fine filtration as a secondary material, process started with the delivery of pre-dried material in the tray, from which it was supplied in sufficient quantities depending on the type of manufacturing process to the extruder. There took place pre-melting and degassing of the material, and then through the contained in the extruder screw the material was passed through fittings to the filter.

Temperatures that prevail in the extruder have values from 220 ° C at the beginning to 270°C at the output. It is possible to provide to the processed material a special dye in granular form, which has the task of adding the color to produced film. The melt is delivered to the filter was subjected to filtration through what all sorts of pollution have been eliminated from it.

In the next phase through the connector to the pump was delivered. The role of the pump is pumping the purified material to a common element called black box, which combines a set of components for industrial processing of primary materials with a set of devices for processing secondary materials. Special machines for secondary (recycled) plastic processing, was very similar to the set used for the processing of pure PET.

Fig. 9. The R-PET film production line

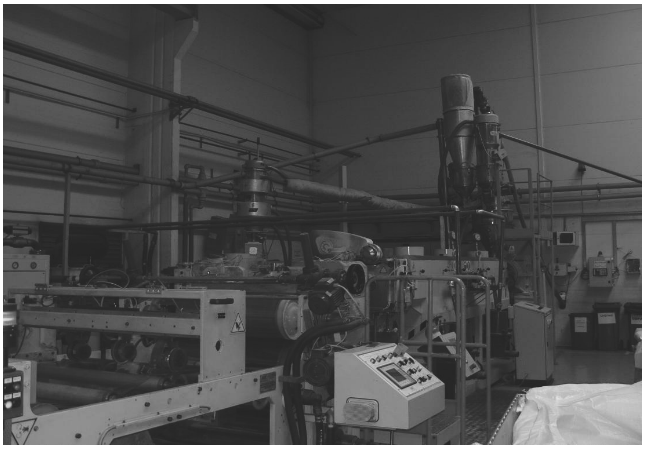


Fig. 10. The R-PET film production line

Also had a tray on a pre-dried material, the more powerful the extruder, but the temperature in it differed from those by which the original material was processed. At the beginning of the extruder there are temperatures of 320^{o}C, and at the end the temperature reached 270^{o}C. The device, which in the case of lines to process recycled plastics is significantly different from that of the lines from the original material was a filter. In this case, it was much more technologically advanced and designed for more demanding filtration.

The machine used to clean the filter material in the case of this line is a filter system brand GNEUSS RSF called Genius. It is thoroughly described in the previous chapter. Purified by means of the filter material was supplied through the connector at the pump, and then through another liaison, he was pumped to the black box where the film takes place in the layer stacking (Fig. 11).

The purified and processed recycled material was inner layer of film (80% of the film), and had slightly worse properties than the origin of the prepared material, which was laid in the two outer layers (20% film) restricting the secondary material. Temperatures that prevailed in the black box had a value of about 275^{o}C. So arranged in three layers of material in the black box was delivered to the head, which was tasked with finished film extrusion on special rollers (Figs. 3,7). Their task was to cool the produced film in such a way and to give it the appropriate tension so that on the surface of the formation are mechanical damage limited. Such prepared film was wound onto rolls.

8. Strength tests

8.1. Preparation of samples

From prepared during the production process seven kinds of films in the form of rolls, have been cuted pieces of film on a dedicated cutter. Then just cut out pieces of film were cut to equal size. Dimensions, which had cut the samples were 120 mm in length and 15 mm in widt - because of the need to leave the place in which the sample is mounted in the holders of the measuring machine. The distance between the handles is equal to 50 mm and is dependent on the standard (DIN EN ISO 527-1), under which the test was carried out.

However, the thickness obtained in the process of film production was 0.35 mm, while it fluctuated in the range from 0.348 mm to 0.358 mm depending on the filters have been applied. With each sheet previously produced films, subjected to filtration using 7 different sets of filter sizes, were excised 12 samples for later researches of them - for each type of mesh was performed 10 stretching tests.

8.2. Researches on the Zwick / Roell testing machine

The machine, which was used to carry out of endurance tests for the prepared samples of a film subjected to different types of filtration is a German machine Zwick / Roell with the serial number: 182632, made in 2008 by Zwick GmbH & Co. KG. Factory name of this machine is: BT1-FR2.5TN.D14. It is owned by the company GTX Hanex Plastik, in which the sampling and strength tests took place. It is a device for universal application, fully compatible with the requirements of international and national standards related to a wide range of research problems that describe industry standards or in-house.

Holder, that has been used during the test, is a screw holder with the scope for the maximum test force equal to 2.5 [kN]. This handle is a unilaterally closed handle for the tensile test (static, constant, threshold).

8.3. Plan and strength testing process

Testing process on the Zwick / Roell testing machine consisted in placing of pre-prepared samples in the testing machine mounting holders, respectively strong clamping fixture, so that the sample was firmly and evenly placed in the axis of research direction.

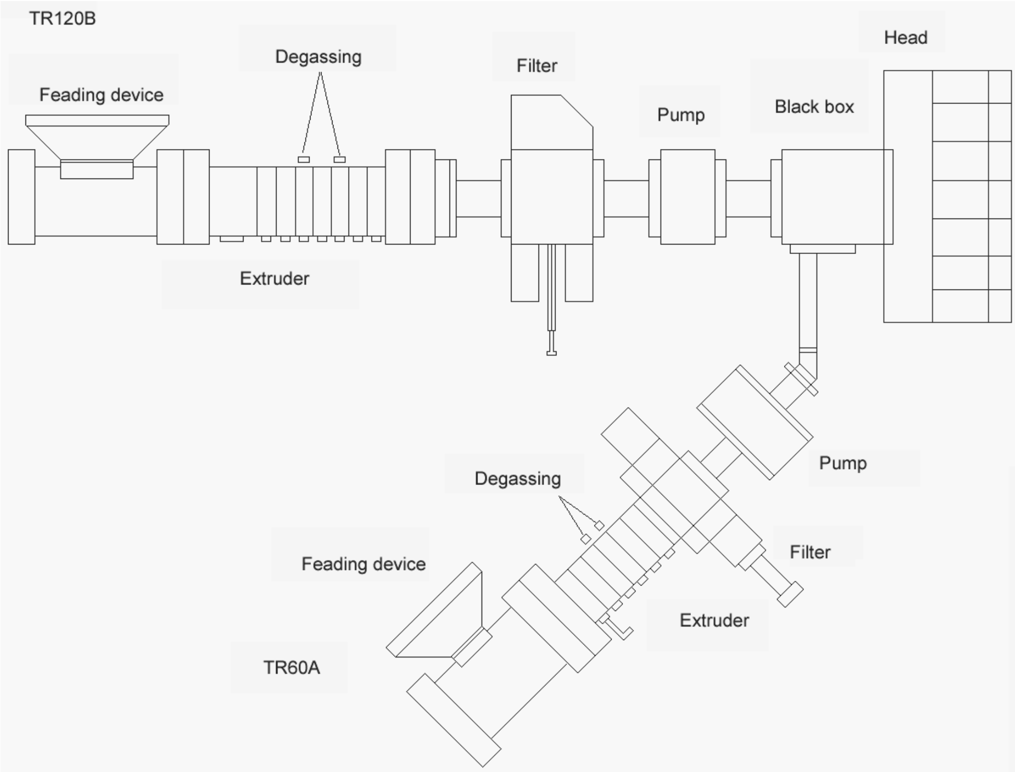


Fig. 11. Diagram of the UNION production line

It should not be fastened too tightly because it risked breaking the sample, but also too light fitting pose any adverse effects in the form of sliding out of the sample holder during the study, and thus the test results and graphs can be deformed. Each sample was mounted in a mounting holders at a distance between the upper and lower holder of 50 [mm].

After placing the sample in the grips start of the "testxpert II installed in a computer integrated with the testing machine, used to measure and draw diagrams with the stress that accompanied the endurance test. Initial strength tests, which accompany each sample was 0 [N], while the speed of the test each sample was constant and amounted to 100 mm / min.

After each test the purity and quality of the grips was checked. It is the condition of fully reflection of the film properties. The investigation plan included the verification of strength of film subjected to filtration using 7 types of filters. In each of the seven types of film a set of 10 samples was prepared. After examining the film samples of each series corresponding to each filter, the program "testxpert II" prepared a tensile strength chart for the entire series. From so obtained graphs for seven different sets of samples seven different types of charts with a series of values corresponding to the yield stress were obtained. From these plots have been reading the other the strength characteristic of the examined films. Strength properties are read from the graphs:

- tensile strength (Tables 2,3)
- stress at break
- elongation at maximum stress and at break
- elasticity module

Table 2.
The values of tensile strength for 10 samples

No.	σ_M [MPa]
1	55.0
2	54.9
3	54.3
4	54.1
5	54.1
6	54.0
7	53.8
8	53.7
9	53.4
10	52.0

Table 3.
The average value of tensile strength for 10 samples

n=10	σ_M [MPa]
x	53.9

Fig. 12. The Zwick / Roell testing machine

Table 4.
Parameters of filters

No.	Mesh size [mm]	Mesh per inch cal^{-1}	Number of meshes per cm^2
1	0.125	120	2.381
2	0.100	150	3.758
3	0.075	200	6.400
4	0.063	250	9.428
5	0.040	325	17.777
6	0.036	400	24.430
7	0.025	500	40.000

8.4. Description and test diagrams of samples used for research

As the first to endurance test were subjected samples obtained as an effect of film production process with filtration using filters with the following parameters:

- mesh size equal to 0.125 [mm]
- mesh per inch = 120,
- the number of meshes per cm^2 = 2.381.

The thickness of the samples ranged from 0.348-0.355 [mm].

Following this study, we have received plots of stress for 10 samples and the table of values at which the sample reached the yield strength and the average yield for a 10 film samples subjected to filtration using the same kind of filter - mesh sizes. Strength properties were read from plots and their increased fragments (Figs. 12 - 14).

Another samples subjected to strenght tests there are the film fragments obtained by filtration with using of filters with the parameters as in the Table 4.

From the resulting graph (Fig.15) we can see that the values of resistance change with a change of filter sizes. The value of the first type of film (PET R-120) is inflated against three next types of film because at the time of their production line worked near of full their capacity, but when changing the filter mesh nets with smaller mesh was modified line efficiency at around 50% of their capacity. We can see that the change in film production line efficiency affects the subsequent mechanical properties of the product.

However, considering the films made with a mesh filter sets with increasingly smaller mesh, we can see the increase in strength. For example, comparing the properties of films made by using nets with mesh size equal to 0.100 [mm] and the film made using nets with mesh size equal to 0.025 [mm] shows significant differences in strength. Film derived from the first filter has a much poorer tensile strength of 53.1 [MPa], than the film derived from the second filtration, the tensile strength of which is 55.4 [MPa].

Another strength property, which had to be read from the chart were the tensions that existed at break, ie the final value of stress, at which the sample was broken. Considering the obtained graphs can be seen that these values are significantly different from each other and not just depending on the deployed networks, but also for the set of sieves with the same mesh sizes. Values of stress at break can be found in Table 5.

Next results, that have been read from the chart concerned elongation and maximum stress at break. Also in this case it was difficult to determine accurate results for each sample, but it can be observed that for different sets of values are slightly different. In most specimens the maximum stress was achieved at the time they cross a yield, but it happened that the samples reached the maximum stress at the time of rupture. Therefore be considered separately extending the sample suffered when crossing yield, and separately at the moment of rupture of the sample (Fig. 16)

From the calculations conducted on the basis of charts obtained the approximate value of the elastic modulus for the film samples taken from seven sets of filter sizes at a stress of 50 (Figs. 17-19) [MPa].

Table 5.
Values of stress at deformation at break

No.	Average breaking stress [MPa]	Elongation %	Modulus E [MPa]
1	48.1	4.15	1.515
2	47.9	4.25	1.470
3	48.4	4.35	1.450
4	49.5	4.45	1.428
5	50.0	4.55	1.400
6	50.1	4.70	1.388
7	50.3	5.00	1.350

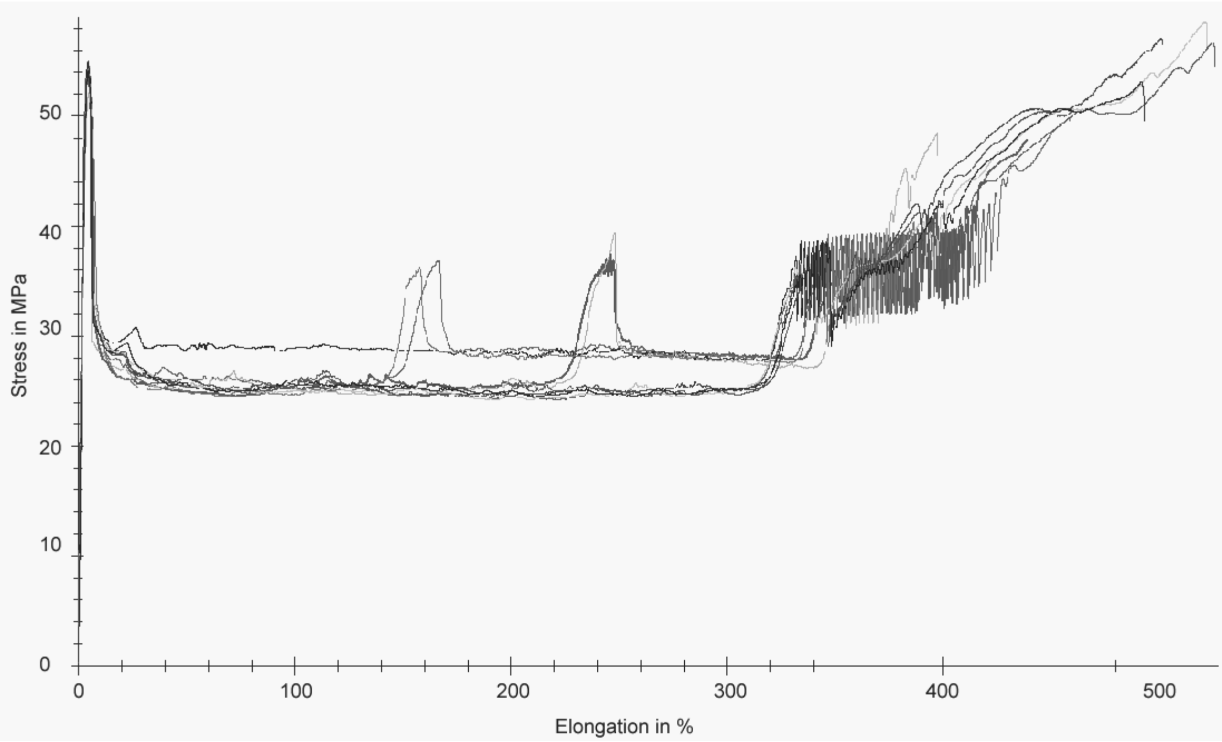


Fig. 13. Tensile testing graphs

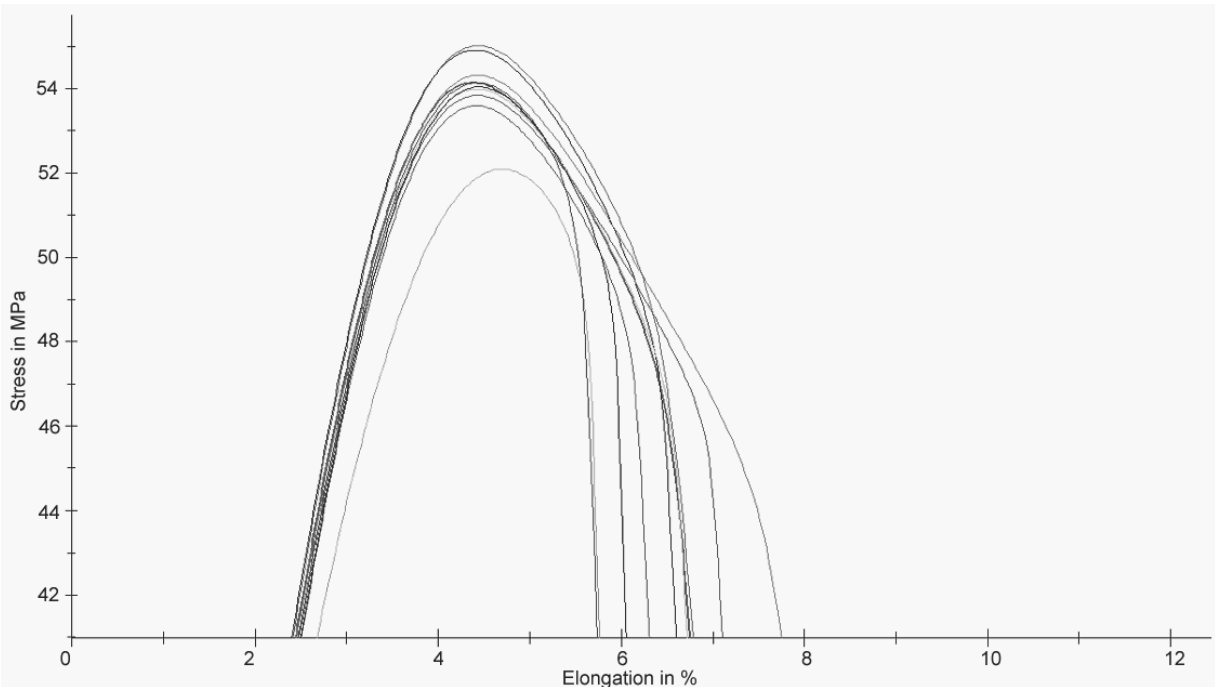


Fig. 14. The fragments of the graphs showing the tensile yield point

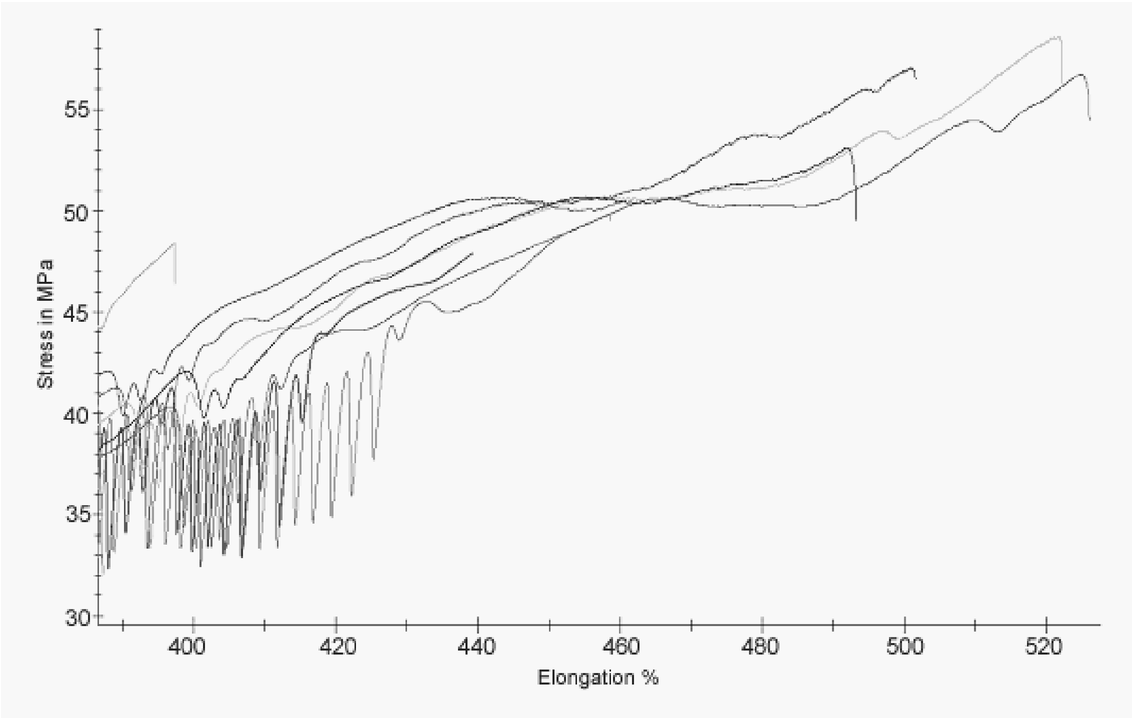
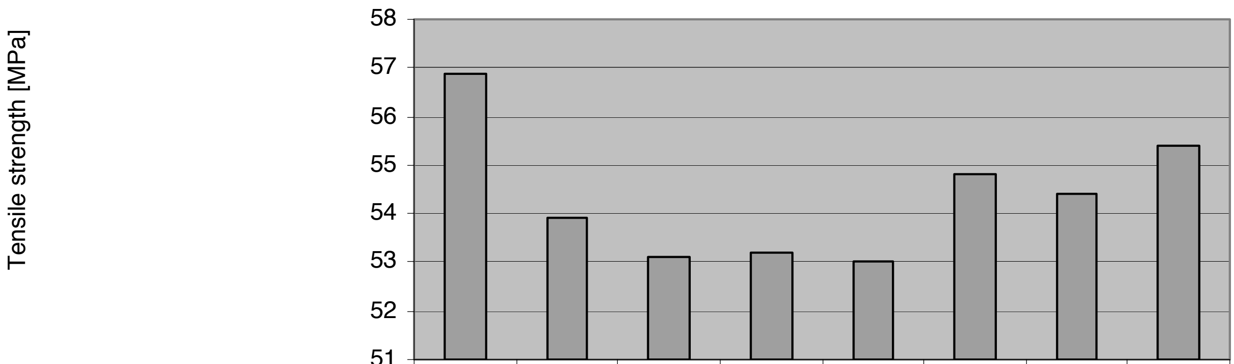


Fig. 15. The fragments of the graphs showing the rupture of samples zone

Comparison of the tensile strength for films made from virgin material (A-PET) and films made from recycled materials (R-PET) subjected to different types of filtration process



	A-PET	1. R-PET 120	2. R-PET 150	3. R-PET 200	4. R-PET 250	5. R-PET 325	6. R-PET 400	7. R-PET 500
Tensile strength for different types of films	56,9	53,9	53,1	53,2	53	54,8	54,4	55,4

Fig. 16. The graph showing the the differences between the tensile strength of film made from virgin material A-PET and films made from recycled materials R-PET

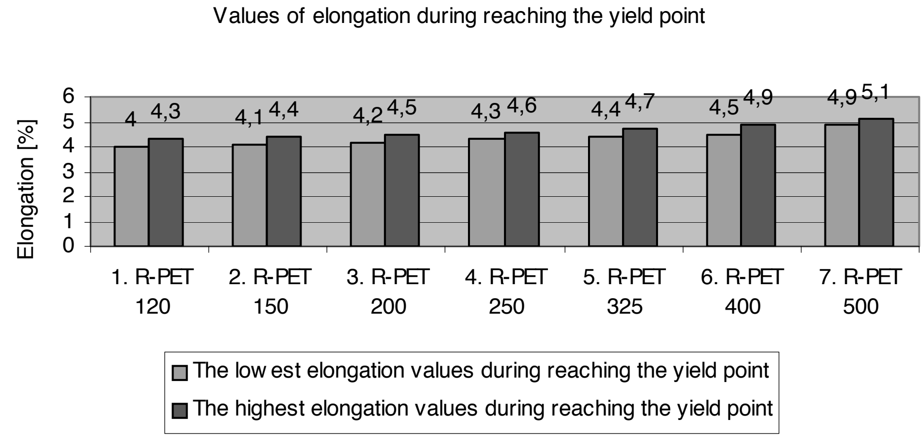


Fig. 17. Chart of elongation growth rate for the 7 sets of samples during the achievement of their yield point

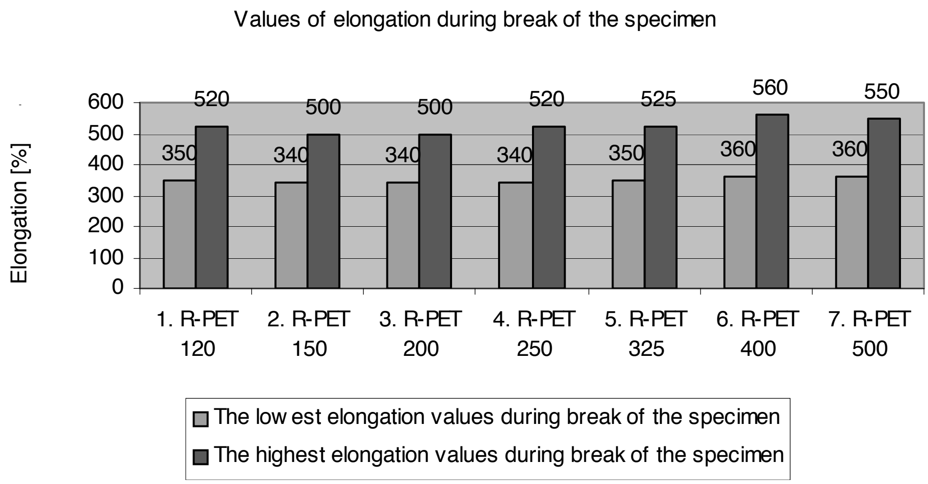
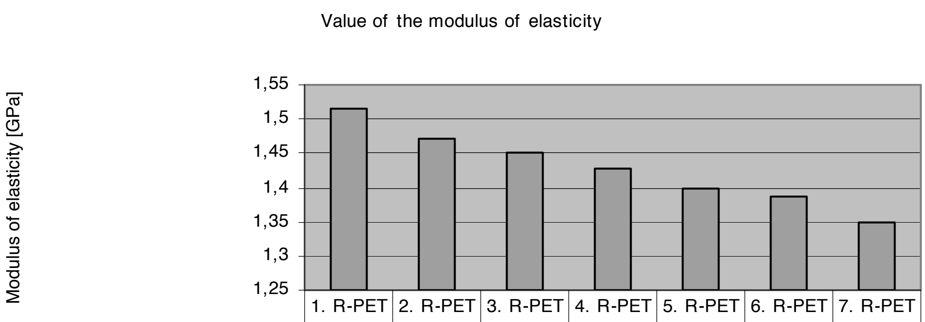


Fig. 18. Chart of elongation growth rate for the 7 sets of samples occurring in the breaking point of the sample



	1. R-PET	2. R-PET	3. R-PET	4. R-PET	5. R-PET	6. R-PET	7. R-PET
Value of the modulus of elasticity	1,515	1,47	1,45	1,428	1,4	1,388	1,35

Fig. 19. Chat of modulus E values for films subjected to filtration with using of 7 different sets of filters, at a stress equal to 50 [MPa]

9. Conclusions

On the basis of tests of film exposed to filtration using 7 different sets of filters, the following conclusions have been formulated:

1. The use of a set of filters smaller mesh size, leads to improved mechanical properties of the test film.
2. Improving of the mechanical properties is observed with a change in the set of filter sizes, hence can be determined that the higher the filtration accuracy of recycled materials, the better the quality obtained in the process of film production.
3. Comparing obtained from tests the mechanical characteristics of the R-PET film to the characteristics of which have A-PET film can be seen that with the improvement in the accuracy of filtration of materials used in the production of R-PET film quality of the film significantly closer to the quality of A- PET.
4. Impact on the improvement of quality may also have the capacity utilization degree of the production line.

References

[1] L.A. Dobrzański, Fundamentals of materials science and metallurgy. Engineering materials with the basics of designing a material, WNT, Warsaw, 2006.

[2] www.tworzywa.info.

[3] S. Penczek, Z. Floriańczyk, Polymer Chemistry, Volume II. Basic synthetic polymers and their applications, University of Technology Publishing House, Warsaw, 2002.

[4] K. Świda, Research on the influence of different filtration systems on the quality of the PET film layer. Master Thesis. Silesian University of Technology, Gliwice, 2010.

[5] D. Żuchowska, Construction Polymers, WNT, 2000.

[6] J. Pielichowski, A. Puszyński, Plastics Technology, WNT, 2003.

[7] W. Przygocki, A. Włochowicz, Arrangement of macromolecules in polymers and fibers, WNT, 2006.

[8] www.wiedza.info.

[9] H. Saechtling, Plastics. Guide, WNT, 2007.

[10] W. Kucharczyk, W. Żurowski, Processing of plastics for mechanics, Publisher University of Radom, 2005.

[11] www.bagsik.net.

[12] www.recykling.pl.

[13] www.gneuss.com.

[14] www.zwick.pl.

[15] www.segreguj.pl.