BUDAPEST UNIVERSITY OF TECHNOLOGY AND ECONOMICS
FACULTY OF MECHANICAL ENGINEERING
DEPARTMENT OF POLYMER ENGINEERING

THE EFFECTS OF INJECTION MOLDING SCREW TIPS ON COLOR HOMOGENEITY AND PROCESS PARAMETERS

THESIS BOOK OF PHD DISSERTATION

MADE BY:
DÁNIEL TÖRÖK
MSC.

SUPERVISOR:
DR. JÓZSEF GÁBOR KOVÁCS

2019

The review and the defense report of the doctoral dissertation can be viewed at the Dean's Office of the Faculty of Mechanical Engineering of the Budapest University of Technology and Economics

1. Introduction

More and more plastics are used worldwide each year. This tendency is especially prominent in the case of commodity plastics but high-performance engineering plastics are also replacing metals and ceramics in more and more areas of application. The reason for the increasing popularity of plastics is their low manufacturing costs, low density compared to that of metals, and their very good damping and insulating properties. Also, their processing is far more energy and cost-effective than that of metals, and the manufacturing process is also very productive.

Plastics used in industry can be classified into two groups: Linear and cross-linked polymers. Within linear polymers, there are semicrystalline and amorphous polymers, most of which are thermoplastic. In most cases, they are processed by extrusion or injection molding. Injection molding is one of the most productive polymer processing technologies. With injection molding, products of complex geometry can be produced at high pressure and temperature in a closed mold. As opposed to extrusion, injection molding is a cyclic technology, but due to the high flow speeds, its productivity is comparable to that of extrusion. In Hungary, one-third of plastic products are manufactured by injection molding.

In the case of injection molding, almost always some additive is added to the polymer. The additive improves the processability, mechanical properties, or appearance of the polymer. The most widely used additives are colorants, but fillers, reinforcement, softeners, flame retardants and agents reducing degradation are also often used. The quality of the dispersion (it should be as homogeneous as possible) of additives is an essential factor, since their imperfect dispersion can lead to injection molding defects. These defects do not just impair visual appearance (uneven color, spots etc.), but can also influence the mechanical or thermal properties of the product.

There are several methods to improve homogeneity. The simplest and most cost-effective is the proper selection of the injection molding machine and the polymer, and using optimal technological settings. If these are not enough, special equipment improving mixing can be used. Such are mixers in the injection molding machine. They can be classified into two groups based on whether they move during mixing or not. Static mixers can be inserted in the injection unit, in front of the screw, and do not move while they mix the polymer melt. These mixers have complicated geometry and mix the melt during injection. On the other hand, dynamic mixers are built in as part of the screw, move with the screw and mix the melt during plastication.

Plastication is a crucial step in the injection cycle. In this phase, the melt is prepared to be injected in the cavity in the next step. The homogeneity of the melt is an important factor determining the quality of the product; this applies to the homogeneous dispersion of the fillers, and also homogeneity of temperature and pressure. The homogeneity of the melt can be greatly influenced by a non-return screw tip as well. Currently used screw tips usually have a check ring, but these are generally designed empirically. Their effect on the injection molding cycle and the quality of injection-molded products is little researched and therefore little known. Non-return screw tips can have a special design and serve as mixers as well, in addition to performing their basic function. The advantage of mixing elements integrated into a specially designed screw tip compared to static mixers is that they do not cause an extra pressure drop during injection. They do not shorten the useful length of the screw, as dynamic mixers do, therefore they do not considerably reduce plastication performance.

The main goal of my dissertation was to develop screw tips. First, I examine the effect of changing geometrical parameters of simple screw tips on the injection molding cycle and the color homogeneity of the products. I also plan to develop an algorithm to measure color homogeneity, which is based on digital image processing and can show the effect of screw tips. Then, based on the measurement results and experiences, I will define the design principles that need to be taken into account in designing screw tips, design screw tips with a complex mixing function, and examine their effect.

2. Literature review and critical analysis

In the first part of the literature review, I will review publications on injection molding, and mixing processes and machine elements related to injection molding. Due to the high productivity of injection molding, even a slight improvement of the technology can result in considerable extra profit, as the quality of the injection-molding machine has a decisive influence on the quality of the product. Therefore, I decided to focus on developing the injection-molding machine in my dissertation. An important step of the injection molding process is plastication, during which the polymer in the form of solid pellets is prepared for injection. In this process, the screw has an essential role, as the geometry of the screw will determine the quality of the polymer prepared for injection. In integral part of the screw is the non-return screw tip, which also takes part in plastication and affects its outcome.

Injection molding screw tips is a little researched area of injection molding. There are numerous patents of screw tips of different operating principles and layouts, but there are not many publications on screw tips. I only found a few publications that can be used well for the development of screw tips. Most of these are based on simulations and provide little information about the effect screw tips may have on the quality of the injection molding product or the manufacturing technology. I have not found any publications or other sources on the effect of screw tips on injection molding parameters. Also, there is no information in the literature specifically on the design of non-return screw tips. Based on this, I set as a goal the detailed investigation of the effect of screw tips on the injection molding cycle and the quality of the injection molded part.

The quality parameters of injection molded products can be very different. These parameters, whether they are mechanical, thermal or esthetic properties, can be greatly influenced by the dispersion of additives. The literature review revealed that one of the most common type of additives used in injection molded products is colorants. In industry, the dispersion of colorants in polymers is often a problem, and if not solved, it can impair the quality of products. Colorants and their use is an extensively researched area, which also explains why these additives need to be investigated. Numerous research projects have been conducted and books have been written on this topic. Colorants are usually dispersed in injection-molded products with static mixers, which mix by separating layers of melt, rearranging them and then recombining them. Static mixers are efficient but their disadvantage is that they work in the injection phase, and so they can affect technological parameters to some non-negligible degree. The most important technological parameter is injection pressure, which static mixers can reduce by up to several hundred bars and in extreme cases, this can lead to the production of incomplete products. The problem can be solved with mixing systems that do not work in the injection phase, but already during the dosing of the melt. Such mixing systems can be formed in the screw, or even in the non-return screw tips. The advantage of mixing elements in the screw tip is that they do not reduce the useful length of the screw and thus affect plastication less.

One of the basic aspects of judging the quality of mixing is the homogeneity of the mixture. Determining this, however, not an easy task. The first challenge is sampling, and within this the proper selection of the method of sampling and determining the size of the sample. The other difficulty is choosing the testing system and quantifying inhomogeneity. Literature sources indicate that in the testing of inhomogeneity, the role of digital image processing is becoming more and more prominent, thanks to advances in IT. Its advantage is that the test can be automated well and can be easily integrated into existing manufacturing systems, and the subjectivity of human evaluation can be eliminated. Digital image processing is well-known and widely used; there are many procedures for the modification or evaluation of digital images. There are numerous literature sources for the testing of mixing by digital image processing; most of these are used to determine the dispersion of powder mixtures.

However, I did not find many examples for the quantification of inhomogeneities in the color of injection molded products. Therefore, I consider it important to develop a system based on digital image processing, which can measure the inhomogeneity of the color of the surface of injection molded products, and can test the mixing capability of screw tips as well.

Based on the literature review, I set the following goals:

- detailed examination of screw tips and determining their effect on the technology and the color homogeneity of injection molded products,
- designing screw tips of simple geometry, which makes the investigation of individual geometrical parameters possible,
- developing a system for the analysis of color homogeneity, which can also examine the effect of screw tips on product quality,
- laying down guidelines for the design of screw tips, based on the measurement results,
- Investigating and evaluating screw tips of complex geometry, and comparing them to simple geometry screw tips.

3. Materials, equipment and methods used

This chapter includes the manufacturing and measuring equipment used.

3.1. Injection molding machine and mold

I used an ***Arburg Allrounder Advance 270S 400-170*** injection molding machine. Its injection unit has a universal, single-thread, three-zone nitrided screw of 30 mm diameter and an L/D ratio of 20. It has a maximum axial displacement of 120 mm, therefore the maximum shot volume is 85 cm^3. The maximum injection and holding pressure is 2000 bar. The screw is position regulated, therefore it is easier to keep shot weight and switchover volume during manufacturing.

The mold I used produced 80 mm x 80 mm x 1.2 mm flat specimens. The mold has two cavities, and the stationary and moving side has a replaceable insert. The cavity is in the moving side mold half (see Fig. 1), in the replaceable insert. The mold has a film gate. The surface of the stationary mold half is polished, which facilitates the better detection of inhomogeneities in the color of the product.

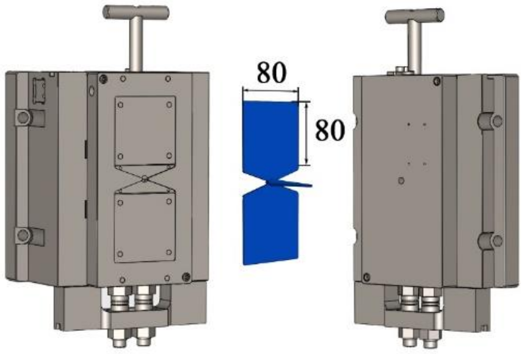

Fig. 1 Mold producing flat specimens, and the 3D model of the injection molded product

3.2. Dynamic mixers and screw tips

3.2.1. Commercially available screw tips and dynamic mixers

In the experiments, I analyze the effect of non-return valve screw tips of different geometries on the injection molding cycle and the color homogeneity of the products.

The ***Arburg CAA30B Free Flow*** screw tip (Fig. 2/1) is a non-return valve of traditional design; it does not contain mixing elements. The screw tip of check ring layout is connected to the 30 mm diameter screw with a thread.

The ***BASF Plasma Mixing-Ring System*** dynamic mixer screw tip (Fig. 2/2) can be used instead of a traditional non-return screw tip. The mixing elements are on the check ring and mainly facilitate distributive mixing. The screw tips can be used in the coloring of commodity plastics and also shear-sensitive and transparent plastics.

The ***Cavity Transfer Mixer type*** dynamic mixer (Fig. 2/3) is manufactured based on the patent of the mixer of Rapra Technology Limited, which is used for extruders. The dynamic mixer, similarly to the BASF screw tip, is built into the place of the non-return screw tip. In the rotating part of the screw tip (body) and on the check ring, there are hemispherical cavities, which the polymer melt flows through. Thanks to the narrow fitting between the ring and the rotor, the melt can only flow in the direction of the cavities, which exert great shear on the material as a result of their moving in relation to each other. The CTM mixer provides a high degree of dispersive and distributive mixing.

Fig. 2 Commercially available screw tips and dynamic mixers
(1) Arburg CAA30B Free Flow, (2) BASF Plasma Mixing-Ring System, (3) Cavity Transfer Mixer

3.2.2. Screw tips that I designed

In my experiments, I analyze the effect of non-return screw tips of different geometries on the injection molding cycle and the homogeneity of the products. For this, I designed screw tips that facilitate the investigation of the effect of gap size (v), flow length (L), the gap between the back ring and the cylinder (v_{ent}). I will present the screw tips I designed in detail when I write about the tests.

3.3. Polymers and masterbatches

I used unfilled acrylonitrile butadiene styrene (ABS, Terluran GP 35, Styrolution Group GmbH), which is a general-purpose, injection moldable amorphous polymer. It was available as pellets in packages of 600 kg; it should not be stored outside and in humid places due to its absorption of moisture. Before processing, the polymer must be dried for at 80 °C for 4 hours. The recommended melt temperature is 220 °C–260 °C, while recommended mod temperature is 30 °C–80 °C. I colored ABS with the pink masterbatch of Clariant (Renol-pink ABS143479Q, Clariant), which has a carrier of ABS. I assessed the different purging compounds using a blue masterbatch of custom-made recipe. According to the manufacturer's recommendation, I added the masterbatch to the polymer in 4 m%.

3.4. Measurement methods

3.4.1. Plastication performance

I measured ***plastication performance*** on the Arburg Allrounder Advance 270S 400-170 injection molding machine at three screw speeds (10 m/min, 25 m/min and 50 m/min) and at three nozzle temperatures (200 °C, 225 °C and 250 °C). During the test, the injection unit is in its back position, while the screw is in its front position. Back pressure is 300 bar, which prevents the axial movement of the screw during the measurement of plastication performance. I collected the polymer melt flowing through the nozzle during continuous plastication for 1 minute, then measured its mass. Form the plastication time and the mass of the polymer melt, plastication rate can be calculated (Eq. 14). I also determined plastication performance during the continuous manufacturing of specimens as well. In this case, plastication performance can be calculated from dosing time and shot volume, with the help of the specific volume of the polymer melt. Since the specific volume of the polymer melt, and therefore its density, greatly depends on temperature and pressure, the calculated plastication performance is only an approximation.

3.4.2. Measuring color homogeneity

As a first step of evaluation by gradients, I converted the scanned RGB images into the grayscale color space based on Eq. 1. The function maps the elements of the nxmx3 dimension real space describing the color image to the elements of the nxm dimension real space, therefore homogeneity can be examined more easily in the grayscale color space based on the combined information content of the three color channels (evaluation works in the case of any of the color channels). The matrix describing the image in the grayscale color space is:

$$I_{grey} = 0{,}3\mathrm{R} + 0{,}59\mathrm{G} + 0{,}11\mathrm{B}, \tag{1}$$

where I_{grey} is the matrix of the degree of gray, R, G and B are the intensity matrix of the red, green and blue color channels, respectively. There are many other ways to convert the images to the grayscale color space, but this is the most widely used method in digital image processing.

The next step of evaluation is determining the gradient matrix from the intensity values of the matrix describing the grayscale image. Similarly, to the previous conversion, there are several methods available to determine the gradient of the discreet functions. I determined the gradient of intensity using Eq. 2, with the central method (i=1…n; j=1…m, where n and m are the size of the image). The central method means that the gradient is determined based on the intensity values of pixels surrounding the given pixel.

$$I_{grad}(\mathrm{i},\mathrm{j}) = \sqrt{\left[\frac{\left(I_{grey}(i-1,j)-I_{grey}(i+1,j)\right)}{2}\right]^2 + \left[\frac{\left(I_{grey}(i,j-1)-I_{grey}(i,j+1)\right)}{2}\right]^2}, \tag{2}$$

where I_{grad} is the gradient matrix calculated from the grayscale matrix of the image, and I_{grey} is the grayscale matrix of the image. The gradient matrix therefore contains the magnitude of the gradient of the grayscale matrix.

The value of the homogeneity of the images is calculated by summarizing the elements of the gradient matrix. In order to make images of different sizes comparable, I divided the sum of the gradient matrix by the image size (Eq. 3).

$$IH_{grad} = \frac{\sum_{i=1}^{n}\sum_{j=1}^{m} I_{grad}(i,j)}{n \cdot m}, \tag{3}$$

where IH_{grad} is the inhomogeneity of the image, I_{grad} is the gradient matrix calculated from the grayscale matrix of the image, while n an m are the size of the image in pixels.

During evaluation, I blurred the images with different Gaussian filters, and determined the error for each filter, therefore the intensity difference and extent of the errors were also considered during evaluation.

3.4.3. The measurement of the purging characteristic of screw tips

For the experiments, I used ABS type Terluran GP-35, which I dried at 80 °C for 4 hours before the tests. I colored the polymer with a dark blue masterbatch, and injection molded 80 mm x 80 mm x 2 mm flat specimens from it. The mass of the products was 32.5 g together with the runner system. The injection unit contained neither static nor dynamic mixers. As a first step, I injection molded specimens from ABS colored with the blue masterbatch, until a steady state condition was reached. Following this, I continued manufacturing specimens using uncolored ABS, and examined the color change of the specimens from cycle to cycle. I digitized the samples with an Epson Perfection V600 Photo flatbed scanner. The digitized images had a resolution of 200 dpi and a size of 600 x 600 pixels. Fig. 3 shows the grayscale histograms of the injection molded specimens. As the blue color was disappearing from the color, the histograms shifted to a higher greyscale range. At the beginning, the residual colorant slowly cleaned out of the cylinder, and the specimens have a deep blue color. After a few cycles, fast cleaning can be observed, and the color of the specimens is shifted towards white; most of the masterbatch is quickly purged from the cylinder. Then the process slows down again. In purging the cylinder, this third phase is critical, when there is only little colorant in the specimens but contamination is still visible on the surface. This third phase is usually a very slow cleaning process; some products also display darker stripes. These can come from the parts of the injection unit where the material can struck and can cause problems in even later cycles.

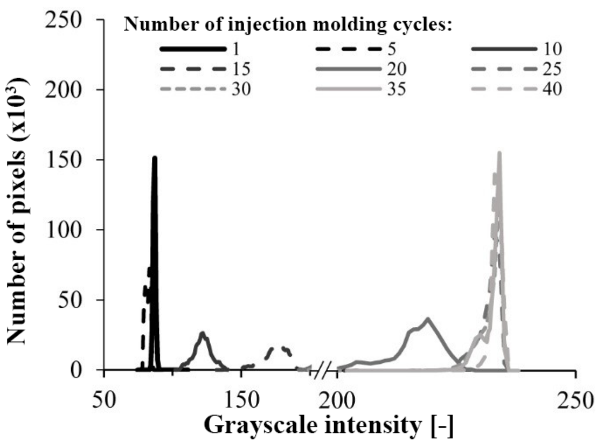

Fig. 3 The grayscale values of the color of the products (without the use of a purging compound)

I displayed the shift in the peaks of the histograms as a function of the amount of material passed through (number of cycles).

4. Summary

I started my dissertation with the literature review and presented in detail non-return systems that can be used in injection molding. Nowadays the most commonly used types are non-return valves with rings. In the literature review, I showed that there are many patents on non-return valves but on the other hand, it is a little researched area. In the literature review, I also detailed mixing mechanisms, the different colorants, and the different ways of assessing mixtures, with special attention on digital image processing. Based on the literature, I set the following goals for my dissertation: analysis and development of injection molding screw tips, and working out a measurement method which can determine and quantify the surface quality of injection molded products.

In the rest of the dissertation, I focused on the investigation of non-return screw tips. First, I designed simple geometry screw tips; on these, the effect of the characteristics of screw tips can be studied. I performed measurements on these screw tips and determined the effect of the different screw tips on plastication performance, melt temperature, injection pressure, dosing time, and the color homogeneity of the specimens.

I showed that plastication performance is greatly affected by the smallest flow cross-section of the screw tip. I described the relationship between the narrowest gap and plastication performance with a generalized saturation function, in which the fitting parameters are machine-dependent constants. With my formula, plastication performance can be determined for a given injection molding machine and polymer, with the use of the narrowest gap size and the peripheral speed of the screw. The formula makes the selection of the flow cross-section of screw tips a great deal easier, because with the plastication performance, the dosing time during the cycle can be estimated with great accuracy.

As a next step, I examined the color homogeneity of the surface of specimens injection molded with the use of the different screw tips. For this, I developed an image analysis algorithm based on a special use of Gaussian filters. Its principle is that large, intensive defects on the surface remain visible even after the blurring, filtering of the image. The more visible a defect is, the greater the standard deviation the filter has to have to make the defect disappear from the image. For the calculation of the error of color homogeneity, I used images blurred with filters of different standard deviation, and calculated the gradient of the intensity function of the grayscale value. The more color change the image has, the more inhomogeneous the image is the homogeneity curve characteristic of the image is can be obtained if the error values of images blurred with filters of different standard deviation are plotted as a function of the standard deviation of the filter. As a result of blurring, noise resulting from measurement can be eliminated. Large, visible defects do not disappear even after considerable blurring, therefore their effect appears in the homogeneity curve. Based on the measurements, I found that gap size and the diameter of the back ring have the greatest effect on color homogeneity.

I also examined the relationship between the color homogeneity of the products and the flow conditions in the screw tip. For this, I used the shear rate near the wall generated in the screw tip, which can be determined based on the flow properties of the polymer and the geometry of the screw tip. I showed that in simple geometry screw tips, shear rate near the wall and the color homogeneity of the product have a linear relationship. In the case of screw tips of complex geometry, I found that gap size can be neglected; the decisive factor in color homogeneity is the geometry of the screw tip. I also found that the mixing efficiency of the geometry can be determined if the results are compared to the measurement results of simple geometry screw tips. In the case of a given mixing geometry, the contribution of the geometry and the gap size to the efficiency of mixing can be separated.

In the last part of the dissertation, I focused on the purgability of the cylinder, and the effect of screw tips on the efficiency of purging. I worked out a measurement method to analyze the cleaning process. The method, similarly to the measurement of color homogeneity, is based on digital image processing. I found that the time and intensity of cleaning depends on the design of the cylinder and the screw tip. Purging can be sped up with additives (purging compounds). In the case of simple geometry screw tips, I showed that the purging process does not depend on the geometrical parameters (gap size, flow length stb.) significantly. I also showed that screw tips of a complex geometry are more difficult to clean than simple geometry screw tips, and my method can also quantify the difference.

My results can provide great help for the systematic design of screw tips and the testing of existing screw tips. Measurement methods can be further developed and fine-tuned, or can be used for the analysis of other problems with little modification.

5. Theses

Thesis I

I proved that the plastication performance of injection molding machines can be described as a function of the smallest gap size of the screw tip and screw speed:

$$P_r(v_k, A_{min}) = c_1 \cdot v_k \cdot \sqrt{1 - e^{-\sqrt{\frac{A_{min}}{c_2 \cdot v_k}}}},$$

where P_r is plastication performance [kg/h], v_k is the peripheral speed of the screw [m/min], A_{min} is the smallest flow cross-section of the screw tip [mm^2], and c_1 and c_2 are fitting constants. The $c_1 \cdot v_k$ product is the output of the plastication unit of the injection molding machine without the screw tip.

I proved my claim by measuring the plastication performance of an Arburg Allrounder Advance 270S 400-170 injection molding machine, equipped with screw tips of different flow cross-sections. I used ABS Terluran GP-35 as the polymer, and three different screw peripheral speeds [1].

Thesis II

I developed a method based on digital image processing, which can be used to quantify the homogenization ability of screw tips. The basis of measurement is that after the digitization of the samples, it determines a homogeneity parameter from the average gradient of the color functions describing the image. In the method, the standard deviation of Gaussian filters are varied and used on the original image. This gives a homogeneity function determined from images of different blurring. When this function is integrated, it gives a number characteristic to homogeneity, which takes into account both the size and intensity of defects [2-6].

I proved the applicability of the method using 21 different screw tips, and an Arburg Allrounder Advance 270S 400-170 injection molding machine. I used ABS Terluran GP-35 as the polymer and injection molded 80 mm x 80 mm x 1.2 mm flat specimens from it for the experiments.

Thesis III

I proved that the number characterizing the color homogeneity of the product has a linear relationship to the shear rate near the wall in simple geometry screw tips. I proved my claim with the use of several screw tips of constant gap size. The lower limit of the range of validity of the formula is a minimal shear rate above which plastication is possible, while the upper limit is determined by the sensitivity of the material to degradation. I proved my claim with specimens manufactured from GP-35 Terluran type ABS, using RenolPink masterbatch [1, 2, 4].

Thesis IV

I proved that the effect of complex screw tips on mixing is also considerably influenced by their complex flow pattern; mixing is not only the result of the shear of the melt. With these special geometry screw tips, great mixing efficiency can be achieved even at low shear rates; this way the heating of the polymer is avoided and output is not limited either.

I proved my claim using GP-35 Terluran ABS polymer and RenolPink masterbatch, on specimens injection molded with general injection molding settings [1, 2].

Thesis V

I worked out a new measurement method to analyze color change and purging. The method is based on the digitization of specimens manufactured continuously and digital image processing. I showed that with the intensity functions describing the images, the color change during color change and purging can be traced. I proved that the method is capable of determining the character and so the length of the cleaning process.

I also showed that the cleaning process can be modeled with the series connection of a first-order proportional and a delay block. If the excitation of system is taken into account, the time parameters belonging to the different screw tips can be determined with the use of the gain factor and the delay time. The response function characteristic to the system is then:

$$Y(t)=\begin{cases} K\ ; & 0 \le t \le Th \\ K+X(t)-X(t)e^{-\frac{t}{Tp}}\ ; & t \ge Th \end{cases}$$

where K is the average grayscale value of the polymer to be purged, Th is delay time, X(t) is excitation, which is the step change excitation corresponding to the grayscale value of the new polymer to be used, and Tp is the time constant of the examined system [7].

6. Publications

[1] Török D., Kovács J. G.: Effects of injection molding screw tips on polymer mixing. Periodica Polytechnica, 62, 241-246 (2018).

[2] Török D., Kovács J. G.: Effects of Dynamic Mixers on the Color Homogeneity and the Process in Injection Molding. Polymer Engineering & Science, 59, 189-195 (2019).

[3] Zsiros L., Torok D., Kovacs J. G.: The Effect of Masterbatch Recipes on the Homogenization Properties of Injection Molded Parts. International Journal of Polymer Science, (2017).

[4] Zsíros L., Török D., Kovács J. G.: Evaluation of the homogenization properties of masterbatches. Coloration Technology, 133, 431-438 (2017).

[5] Zsíros L., Török D., Kovács G. J.: Színegyenetlenség mérésére alkalmas mérőrendszer fejlesztése és alkalmazása statikus keverők minősítésére. 'OGÉT 2015 Csíksomlyó, Románia. 2015.04.23-2015.04.26., 415-418 (2015).

[6] Török D., Zsíros L., Kovács G. J.: Különböző kialakítású géttípusok és a szerszám felületérdességének hatása a fröccsöntött termékek színhomogenitására. 'OGÉT 2016 Déva, Románia. 2016.04.21-2016.04.24., 455-459 (2016).

[7] Török D., Suplicz A., Kovács J. G.: Csigatisztítók hatékonyságának minősítése. Polimerek, 2, 104-108 (2016).

[8] Zsíros L., Kovács J. G.: Surface Homogeneity of Injection Molded Parts. Periodica Polytechnica Mechanical Engineering, 62, 284-291 (2018).

[9] Török D., Zsíros L., Kovács J. G.: Különböző elemszámú és átmérőjű StaMixCo statikus keverők vizsgálata. Műanyag és Gumi, 51, 346-351 (2014)

[10] Török D., Suplicz A., Kovács J. G.: Mérési módszer fejlesztése a fröccsöntött, kompozit termékekben létrejövő szegregáció mérésére. in 'XXVI. Nemzetközi Gépészeti Konferencia: 26th International Conference on Mechanical Engineering Marosvásárhely, Románia. 2018.04.26-2018.04.29., (2018)