THE EFFECT OF THE RE-GRANULATE ADDITION ON THE TENSILE STRENGTH MODIFICATION OF THE SAMPLES TAKEN FROM THE INJECTION VOLUME

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DOI: 10.17973/MMSJ.2024_06_2024007

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Polymeric materials are increasingly used in the construction of machines and devices. As their use increases, so does the proportion of the waste produce in the industry. One of the ways to reduce the waste is the addition of recycled material into the re-production. Although the addition of the return material reduces the proportion of produced waste, it can lead to the modification of mechanical properties of the produced products. The subject of the present article is precisely investigating the mechanical properties modification of the final injection moulding during the plastic injection technology. The tensile strength Rm of the samples taken from the injection volume produced from the material composed of pure and return material in the ration 100/0, 30/70, 50/50, 70/30 and 0/100 is investigated. Considering the possibility of Rm modification in the injection volume, individual samples are taken from four zones depending on the position from the ingate. It is demonstrated that Rm decreases with the increasing ratio of the return material as well as with the increasing distance from the ingate.

KEYWORDS

thermoplastic, injection moulding, recycled material, tensile test, tensile properties

1 INTRODUCTION

Environmental awareness is becoming more and more important nowadays. The development of new, lightweight materials for the construction of machinery is essential to reduce the ecological footprint, especially in the automotive industry, where it is possible to significantly reduce carbo dioxide emissions by designing lighter cars [Volpe 2019, Varga 2021]. Due to their processing and useful properties, polymer materials are material in demand for ordinary and special use. They also largely replace the conventional materials, thanks to their low density and good impact properties [Majernik 2014].

As the popularity of polymer materials increases, so does the amount of their waste. In recent decades, the production of plastic waste has been constantly increasing all over the world due to the increasing use of this type of material for the industrial production of goods and for packaging. It is estimated that about 380 million tons of plastics are produced each year, and that more than 60 % of municipal solid waste is polyolefins, but less than 20 % of the plastics produced are currently recycled at the end of their lifespan [Badini 2023]. The disposal of plastic waste is now considered a key issue to be faced in order to prevent environmental contamination and climate change, as well as to protect human health from the effects of pollutants, global warming and soil/water contamination [Lee 2023]. The issue of removing or reusing waste materials has been a key topic in recent times. It is about the following: firstly, the possibility of removing or reducing the amount of waste, and secondly, the possibility of recovery, or material recycling in practice [Majernik 2017].

Plastic processing companies are constantly looking for ways to reuse them. The re-addition of waste materials into the production must be subjected to an examination of the properties of newly developed materials and testing whether the required properties are within the tolerance ranges for the selected product [Majernik 2017, Gaspar 2018, Anisimov 2019]. The recovery and recycling of plastics can be more or less difficult depending on the type of waste that needs to be processed, such as industrial residues, end-of-life components and municipal waste. The mechanical recycling of industrial waste, i.e., the reincorporation of single polymer residues into the production cycle of plastic pellets, is a well-evaluated and widely accepted practice. Pellets, flakes and powders can also be obtained by processing plastic components after their lifespan and then used for the production of new plastic goods [Wagner 2019, Murcinkova 2021].

Among the wide range of thermoplastic processing methods, injection moulding is one of the most widely used. Basically, plastic pellets are plasticized by a threaded rod in a tempered injection cylinder and then the melt is injected into the mold through cold or hot gating systems via ingate into the mold cavity. Since it is not always possible to use a hot runner system to minimize the waste, the molten plastic is fed into the mold cavity using the cold runners, often doubling the weight of the final product [Matykiewicz 2023]. From this plastic processing method, it is the inflow residue, formed by runners and cold ingates, that makes up the majority of the produced thermoplastic waste [Lee 2023]. A quick option for processing this type of waste is recycling it directly in the production company. A certain disadvantage of addition the return material into production is its degradation due to the heat, UV radiation, moisture and contact with other substances, which deteriorates the material properties of plastic. For these reasons, these regenerated plastics are generally used by mixing them with original materials [Wagner 2019]. It is clear that in short terms there may be no changes in the performance properties of the parts, but in long term, the presence of degraded recycled material will have adverse consequences on their service life [Behalek 2021, Husain 2021]. A static tensile test is often used to determine the mechanical properties of materials obtained by adding a certain proportion of recycled material [Do 2021]. Newly created materials are tested by using sprays of tensile test rods injected into special molds. Since many materials are statistically microstructurally inhomogeneous in cross-section, it is desirable to be able to consider the structural gradient [Rimar 2014]. The inhomogeneities are mainly caused by the initially solidified crust at the contact of the melt and the face of the mold, as well as different grain size gradients in the polycrystals caused by undirected solidification of the injection in the mold [Gulyaev 2022]. Thus, the tensile properties of specially made samples for tensile testing can significantly differ from the properties of the material in the injection volume, because the flakes lack crystal separation in one spatial axis [Gluge 2020]. In this direction, research was conducted with regard to the change in tensile properties taken from the volume of the injection.

This contribution deals with the determination of the strength characteristics of injection moulding with different proportions of recycled material added to the pure base material. The evaluated parameter is the tensile strength - Rm. Considering the fact that thermoplastic materials are microstructurally inhomogeneous, test samples are taken from four different zones of the injection volume. The examination of the tensile strength Rm depending on the change in the ratio of the return material to the base material is performed on the injection moulding of the go-kart chain cover, when 0 %, 30 %, 50 %, 70 % and 100 % of the return material is added to the pure material polypropylene FT-14: J1000. Two phenomena emerge from the results presented in the contribution, specifically:

1. As the distance from the ingate increases, the tensile strength Rm of the samples decreases.
2. The tensile strength Rm of the samples decreases with the addition of return material. A certain extreme occurs with samples made of 100 % return material. This extreme will be subjected for further investigation.

2 EXPERIMENTAL SECTION

The investigation of the effect of recycled material addition on the modification of tensile strength σm of the samples taken from injection volume was performed on a component serving as a go-kart chain cover. The dimensions of the molded part are given in Fig. 1.

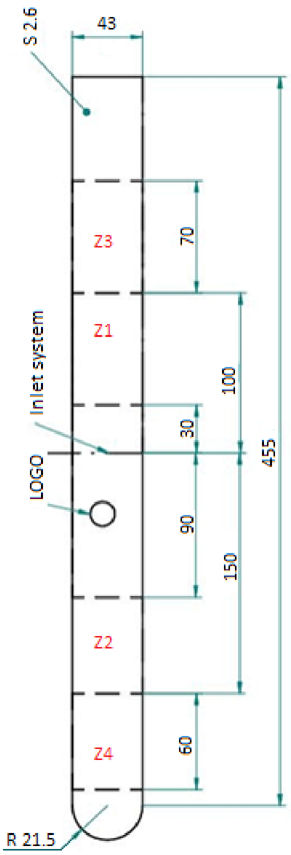

Figure 1. Sketch of examined molded part (dimensions in mm)

An arburg 270 S 250-150 injection molding machine was used to produce the injection molded part. The temperature of the injection unit was set to 210 °C. Before the start of the injection molding and during the individual injection cycles, the mold and injection mechanism were tempered to operating temperature for 30 minutes.

2.1 Material used

Polypropylene FT-14: J1000 was used for the production of individual molded parts. It is a polypropylene homopolymer with basic stabilization. The pure input material used is shown in Fig. 2.

Figure 2. Pure input material

Recycled return material was made from gating residue, such as gating systems, scraps, offcuts and rejects. Blade miller MNP-150 was used for regranulation of the return material. Fig. 3 shows the fraction of return material after recycling.

Figure 3. Fraction of return material

Before the actual injection, ratios of recycled and pure new material were prepared according to Tab. 1. A scale was used to accurately determine the ratio. Each batch was made from one kilogram of mixed material. The material was properly mixed before being poured into the machine.

Table 1. The composition of injected material

Sample	Share of primary material	Share of return material
100/0	100%	0%
70/30	70%	30%
50/50	50%	50%
30/70	30%	70%
0/100	0%	100%

2.2 *Test samples*

Since the samples were taken from the injection volume according to Fig. 1, it was not possible, even with regard to the zoning of the injection for the purpose of monitoring the modification of tensile strength Rm in its volume, to produce standardized samples. In accordance with the CSN EN ISO 20753 standard, reduced samples were taken from the injection volume according to Fig. 4, with a thickness identical to the thickness of the injection, that is S = 2.6 mm.

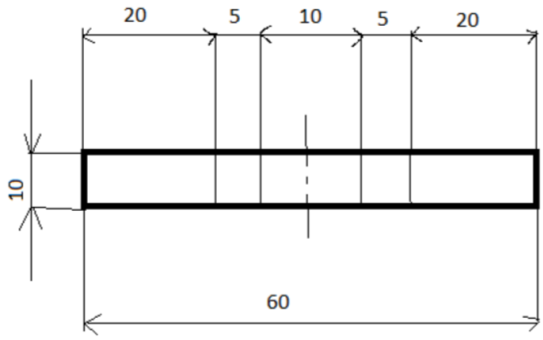

Figure 4. Dimension of test sample (dimensions in mm)

The following distances were then marked on the test samples. The first one is the middle with dashed line, then there is a zone marked 20 mm from the edge, which is used for clamping. From the central axis, 10 mm zone is marked on each side, where the measurement will take place.

From individual molded parts made from material with the composition according to Tab. 1, samples were taken from individual zones Z1 – Z4 (see Fig. 1) depending on the position within the molded part, or distance from the ingate.

2.3 *Tensile strength test*

The static tensile strength test to determine the Rm values of the test samples was performed in accordance with the CSN ISO 527-1 and CSN ISO 527-2 standards. The CSN ISO 527-1 standard establishes the basic tensile properties of plastics and plastic composites under defined conditions; the CSN ISO 527-2 standard proposes to define the tensile properties of pressed and shaped plastics for test conditions. The test process, the selected test equipment and the evaluation of the measured values complied with the draft regulations. The tensile testing machine WDW-50 was used as a testing device. The test was performed at an ambient temperature of 21 °C, a relative humidity of 42 % and an atmospheric pressure of 992 HPa.

Since the shape of the molded part did not allow proper sampling which were modified according to Fig. 4, individual dimensions were marked on the samples before the experimental test was performed. Thickness and width were measured with a digital calliper at three locations on each sample. Accurate calculation determined their average value and cross-sectional zone in sample A_0. Subsequently, the testing sample was clamped to the jaw of the ripper WDW-50 where it was tensile stressed until torn. A great emphasis was put on clamping the sample to the jaws, which enables for the testing unit to intersect the centre of the jaw clutch. At the same time, its direction should be coincident with the direction of tensile strength. During the testing process, neither sample attached to the jaws showed any yield. Simultaneously, the maximum force required to tear Fmax was subtracted from the test unit. The tensile strength Rm of the test samples was calculated from the measured maximum force Fmax.

The stress values are calculated from the initial cross-section of the test unit to:

$$Rm = \frac{F_{max}}{A_0} \quad (1)$$

3 RESULTS

The results of tensile strength test were compiled into tables. Tests were performed five times for each proportion of return material in the pure one. After their evaluation, the exact arithmetic averages of the results for individual proportional material representation were processed. In addition, based on the results, detailed diagrams of the dependence of parameters on the material composition were designed.

The average values of the tensile strength Rm, which were obtained from the tensile strength test on the samples made of materials with ratio of return material, are shown in Tab. 2.

Table 2. Average values of tensile strength Rm

	Zone			
	Z1	**Z2**	**Z3**	**Z4**
Sample	**Tensile strength Rm, MPa**			
100/0	45.88	44.39	43.80	42.00
70/30	38.53	38.29	38.27	37.71
50/50	38.28	38.27	38.19	37.24
30/70	38.22	38.13	38.04	36.34
0/100	44.76	43.99	40.02	39.43

From the measured values listed in Tab. 2, two phenomena result:

1. As the distance from the ingate increases, the tensile strength Rm of the samples decreases, for all variants of the ration of pure and return material. This phenomenon is shown in Fig. 5.

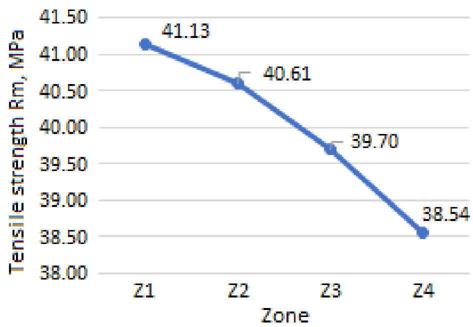

Figure 5. Average values of tensile strength Rm depending on the location of molded part

Fig. 5 is designed as an average of all the measured values of the tensile strength Rm of the samples taken from individual zones of molded part, regardless of the ratio of pure and return material.

2. With an increasing ration of return material, the tensile strength Rm decreases, regardless of the zone of the sample taken. A certain extreme occurs in samples made in the ration of pure/return material 0/100, when the tensile strength Rm of samples made from 100 % return material exceeds the values of Rm of samples made with the ration 70/30, 50/50 and 30/70. Visualisation of this phenomenon is shown in Fig. 6.

Fig. 6 is designed as the average of all measured values of tensile strength Rm of the samples depending on the material composition, regardless of the molded part zone from which they were taken.

Based on the above-mentioned measurement results, it is clear that the addition of the regranulated return material affects the tensile strength Rm values of the samples taken from the molded part.

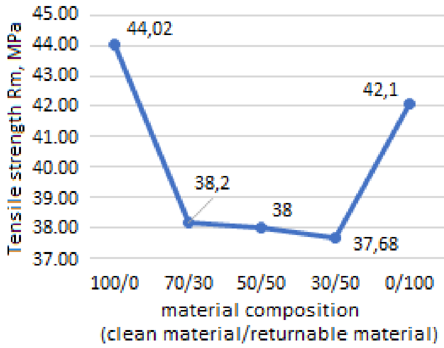

Figure 6. Average values of tensile strength Rm depending on the material composition

4 CONCLUSIONS

The contribution presents the results obtained during the investigation of the tensile properties verification, namely tensile strength Rm, of the samples taken from the molded part of the go-kart chain cover depending on the change of the sampling location with respect to the position of the molded part and simultaneously regarding to the modification of the composition of injected material in terms of the variable ratio of pure and return material.
The incorrect implementation of newly created materials in production entities according to the requirements for the quality of the final product brings a reduction in the qualitative properties of the final product and the limit tolerance of the strength properties acceptable for the material. Provided that the material complies with these conditions, it can be effectively used for economic purposes or for saving resources.
Based on the results of the tests, it was proven:

1. As the distance from the ingate increases, the tensile strength Rm of the samples decreases.
2. With an increasing ration of added return material, the tensile strength Rm decreases.

In the case of a modification in the tensile strength Rm values depending on the material composition, a certain extreme in the decreasing trend of the Rm value is noticeable. Although the Rm values in the case of the 0/100 material composition (pure/return material) show a lower Rm value compared to the 100/0 samples, they exceed the Rm values of the 70/30, 50/50 and 30/70 samples. This finding will be verified in further research at the microstructural level with regard to the interconnectedness of individual polymer chains, and simultaneously from the point of view of the rheological properties of the material with a variable ratio of added return material.
With the respect to the molded part function, the tensile strength Rm is not the only determining parameter. It should be remembered that the processing use of polymer materials and their implementation into production process is not only related to the values considered in the contribution. The properties of polymer affect the modulus of elasticity, elongation and other values that affect the resulting material property under the stress or its user properties. In connection with the function of the molded part, the surface hardness and abrasion resistance of the material, as well as its resistance to the degrading effects of an aggressive environment and UV radiation, depending on the ratio of pure and return material, will be verified in the following research activities.

ACKNOWLEDGMENTS

Article is the result of the Project implementation: Development of excellent research capacities in the field of additive technologies for the Industry of the 21st century, ITMS: 313011BWN5, supported by the Operational Program Integrated Infrastructure funded by the ERDF.

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