Agnieszka Edyta CIENKA[1]
Barbara CIECIŃSKA[2]

OPTIMIZATION OF LASER CUTTING CONDITIONS OF POLYPROPYLENE AND POLYPROPYLENE WITH TALC

Laser cutting of materials requires the execution of processing tests and the selection of the most favourable variant from the point of view of the adopted criteria of process quality assessment. This paper presents the example of a preparatory process, which shows that cutting polypropylene and polypropylene with 5 mm thick talc is not an easy process of material handling. A CO_2 laser was used and by varying the utilized power from the laser and the beam speed relative to the material, cuts of varying quality were obtained. Criteria were also proposed for the selection of the best processing variant. It was concluded that the addition of talc to polypropylene can be a factor facilitating laser cutting of this material.

Keywords: laser, material cutting, plastics, polypropylene

1. INTRODUCTION

Plastics (polymers) are a group of ubiquitous construction materials and often used by manufacturers. Their widespread use is determined by their properties, in particular their low density (usually less than 2 g/cm^3), chemical resistance, flammability, moisture absorption, and lack of electrical conductivity. The properties of a given polymer depend on its structure, thus it is possible to find a plastic that is resistant to acids, for example, as well as the one that is not. Despite a number of advantages, plastics are characterized by low creep resistance, significant thermal expansion, and low resistance to UV radiation [5, 19].

Although the characteristics listed above with regard to disadvantages preclude the use of plastics in many situations, they find many areas where they can be applied successfully.

In order to allow the usage of polymeric plastics in various applications, a variety of additive ingredients are used, introduced intentionally altering the properties of the materials [4]. These ingredients can be divided into two groups: the first consists of fillers and reinforcing carriers, the second consists of auxiliary

[1] M. Eng. Agnieszka Edyta Cienka, FIBRAIN Sp. z o.o., Zaczernie, Polska
[2] PhD, Eng. Barbara Ciecińska, Rzeszów University of Technology, Rzeszów, Polska

agents, i.e. stabilisers, plasticisers, impact modifiers, colouring additives, flame retardants, anti-electrostatic agents, lubricants and others [17].

Fillers and reinforcing compounds are most often added to the polymer to reduce material cost, reduce shrinkage occurring in the injection molding process, modify hardness, impact strength, bending strength and compression strength [18]. The fillers can be natural (wood flour, flax fibre, cellulose fibres), inorganic (chalk, kaolin, quartz, talc, mica, silica), and synthetic (glass fibre, carbon fibres, graphite fibres, glass beads) [6, 18]. They occur in various forms: as powder fillers – spheres, flakes, short chopped fibres, and as fibrous fillers, in the form of long fibres, strands, and sheets (such fillers are used in the manufacture of laminates) [18].

Plastics are subject to varying degrees of degradation. It can occur due to factors such as radiation, living organisms, presence of metals, O_2, CO, NO_2, NH_3, SO_2, H_2O_2 molecules; stress, temperature, and water [14]. Various auxiliary additives are used to modify the properties of polymers. One method of improving the resistance to the aforementioned factors is to add stabilizers to the polymer. Due to the fact that stabilizers can affect the final properties of the polymer in different ways, and their mixtures are frequently used in synergy [8]. The stabilizers include UV absorbers, screening stabilizers (to reduce the permeability of radiation in a filter-like manner), free radical deactivators, antioxidants, thermal stabilizers (to prevent the release of, e.g. hydrogen chloride or bromine, which accelerate the degradation process).

Additional substances changing mechanical properties are also classified as auxiliary agents. These are, e.g. plasticizers, whose presence, e.g. influences the reduction of brittleness and glass transition temperature, hardness, tensile strength, and impact modifiers which increase the impact resistance of plastics [3, 16, 18]. The addition of other extra materials facilitates to obtain specific operating conditions of the plastic components:

- colorants and pigments provide the desired colour; colorants retain transparency of the polymer and are added in the amount of 2÷4 weight %, whereas pigments provide opaque colour and are added in the amount of 0.4÷1.2 weight % [4]. The added chemical compounds do not change electrical and mechanical properties of the polymer and they are UV resistant, nontoxic and water resistant, they do not change colour under the influence of temperature [18];
- flame retardants – due to the flammability of polymers, added to delay, prevent or reduce flammability, influencing the combustion process chemically and/or physically. [13];
- lubricants – added to improve the processing, to give gloss, smoothness, to reduce adhesion to mould walls, to reduce internal friction, to protect against overheating and thermal decomposition during extrusion or injection [4, 12, 18];

- anti-electrostatic agents – added to reduce, e.g. fire hazard, sedimentation of pollutants on the plastic surface, harmful effects on living organisms caused by static electricity [1, 20];
- fillers and reinforcing carriers – included in the composition of plastic due to the need to reduce manufacturing costs, shrinkage reduction during injection moulding, modification of hardness, impact strength, bending and compression strength, heat resistance, etc. [18].

2. LASER CUTTING OF PLASTICS

There are many ways of shaping plastic products in manufacturing processes. These may include pre-processing such as mixing, drying, grinding, forming of semifinished products, basic processing, called forming, and postprocessing [4, 19].

Secondary processing includes technological operations aimed at shaping a finished product from a previously prepared semi-finished product. There are joining techniques - welding, welding, gluing, machining techniques - turning, cutting, drilling, and others. For the processing of plastics, blasting techniques and laser treatment are also used [9, 11].

Laser is characterised by its unique properties. Laser devices generate electromagnetic radiation in the wavelength range from infrared, through visible light to ultraviolet, or even to X-rays.

The radiation beam is monochromatic, directed, temporally and spatially coherent and enables high power density [7, 10]. From a technological point of view, it is a non-wearing, non-contacting, easily controllable tool that can be automated and robotised. Due to the falling cost of purchase and their maintenance, lasers have become common in the manufacture of various products, including plastic products.

Laser cutting of plastics can be carried out by melting and blowing the liquid material, by evaporation (ablation) or by chemical degradation [15].

Melting and blowing cutting is common for thermoplastics. Molten plastic is blown away by a gas stream, which aims to prevent oxidation or combustion [9]. As a result of the beam's action, a crack of a certain width is formed, varying according to the type of the material and its thickness. During ablative cutting, the material changes from solid to gaseous state and it evaporates. During processing, gas is also used to remove vapours from the processing area and to stop the solidification and condensation of the material [9]. Chemical degradation cutting, on the other hand, is used in most cases to process thermoset plastics; material separation occurs as a result of plastic disintegration under the influence of radiation beam. The processing is accompanied by the formation of smoke and soot layer around the edges [15]. Different lasers are used to cut plastics: molecular laser CO_2, solid-state Nd:YAG, depending on the method.

From the point of view of processing effects, technical parameters are important - the width of input and output slots, parallelism of the cutting surface (expressed by the angle of the cutting surface in relation to the normal to the material plane), extent of the heat affected zone. With their help it is possible to assess the quality of laser cutting [15].

3. COMPARATIVE ANALYSIS OF THE EFFECTS OF LASER CUTTING ON SELECTED PLASTICS

Due to the variety of chemical substances added to plastics and their specific influence on properties, experimental studies have been carried out to determine their influence also on the laser cutting process. Polypropylene and polypropylene with 30% addition of talc were chosen for the tests.

In the cutting tests, a CO_2 laser with a power of 70W and a wavelength of 10.6 μm was used. The device has a focusing lens with 20 mm diameter and a focal length of 101.6 mm, and the laser beam is approximately 0.3 mm wide. The controlled parameters were the laser power and the speed of the beam movement in relation to the material surface. The position of the collimation focus was established inside the material and it was a constant value [2].

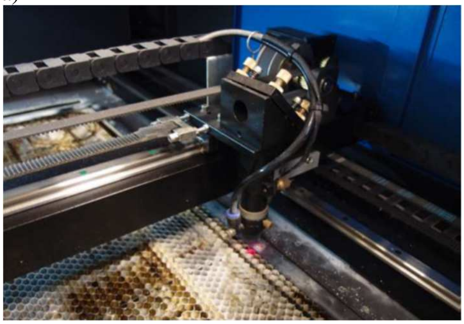
4. CHARACTERISTICS OF THE CHOSEN MATERIAL

Polypropylene is a thermoplastic transparent material with good impact strength, significant tensile strength, high hardness and rigidity. It is resistant to water, acids, alcohols, solvents and salt solutions. The addition of chemically neutral talc to a medium degree improves compressive strength, increases the modulus of elasticity, reduces thermal expansion, reduces processing shrinkage, increases thermal conductivity, increases electrical resistance, abrasion resistance and rigidity. It does not change the chemical resistance of the material, while it affects the reduction of product manufacture costs [18]. Plates of 5 mm thickness in both variants were used in the study.

5. EXPERIMENTAL STUDIES AND RESULTS

To determine the technological parameters of CO_2 laser cutting of polypropylene, pre-cuts were performed. They allowed to choose the range of beam speed in relation to the material and to determine the appropriate laser power, while the cut quality was the criterion for the selection of technological parameters. Laser plotter used in the experiment and the possibility to control it by defining lines and their respective laser operating parameters in the RDWorksV8 programme are shown in Fig. 1.

a)



b)

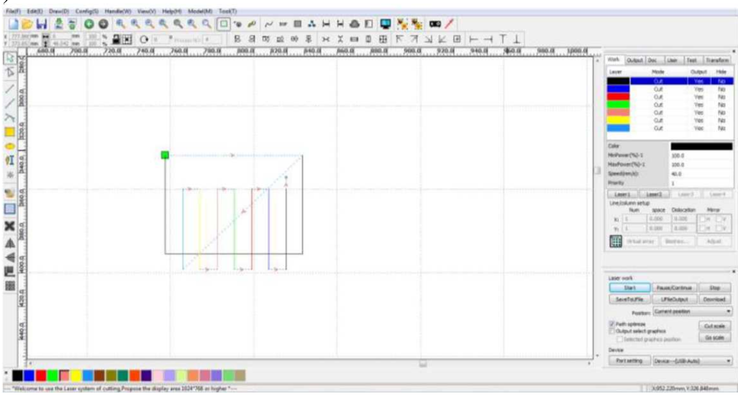


Fig. 1. CO_2 laser plotter (a) and cutting programming (b)

The following criteria were taken into account to assess the cutting area:

- separation of the material throughout the thickness (the achievement of the machining aim),
- obtaining of the narrowest gap, meaning minimal machining overheads and material saving,
- parallelism of the cut edges (maintaining accuracy and dimensional tolerances for both plate planes),
- lack of beading and scorching, classified as product defects (due to the necessity of additional processing and, in case of its absence, the impossibility of achieving accuracy and desired appearance; loss of aesthetic features).

The examples of cuts considered defective in the presented experiment are shown in Fig. 2.

To determine the best processing variant, the position of cutting was observed. Fig. 3÷5 shows the effects of cutting.

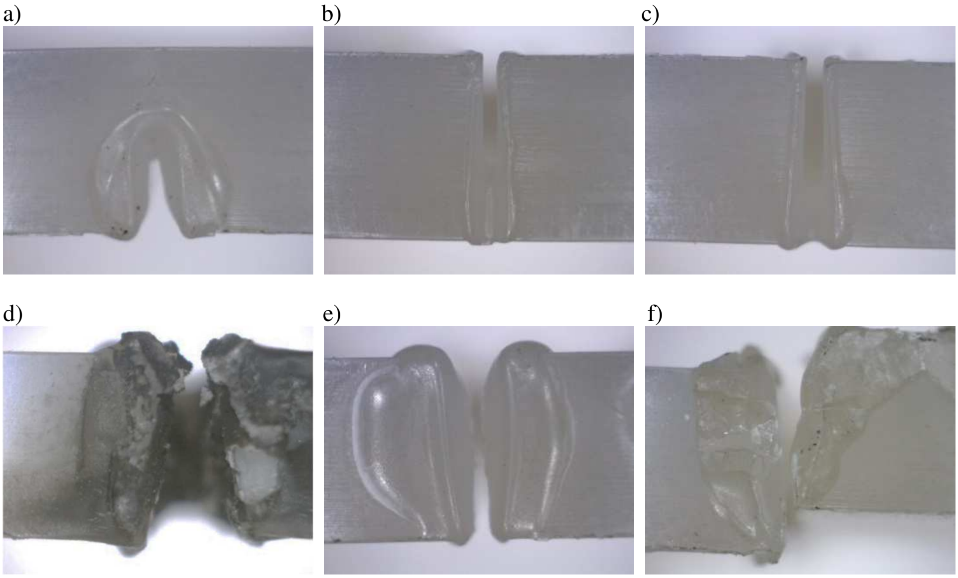


Fig. 2. Various cuts classified as defective: a) incomplete, b) resealed, c) with uneven edges, d) scorched, e) with excessive protrusion, f) distorted

Table 1. Processing options and joint widths (in *mm*)

Laser power, W	Speed, mm/s	20	25	30	35	40	45	50	55	60
35	PP	*	0,5	0,5	*	**0,45**	*	**0,45**	**0,45**	0,6
	PP+30% talc	0,4	*	*	**0,2**	0,25	*	0,5	0,5	0,45

Laser power, W	Speed, mm/s	1	2	3	4	6	8	10	15	20
ap-prox. 52	PP	*	*	0,5	0,5	**0,45**	*	*	*	*
	PP+30% talc	*	0,45	0,45	0,4	**0,3**	*	*	*	*
ap-prox. 70	PP	*	*	*	*	0,4	**0,35**	*	*	*
	PP+30% talc	*	0,45	0,45	0,4	**0,35**	*	*	*	*

* no intersection
Grey box - best option for aesthetic reasons
Values in bold - narrowest gap

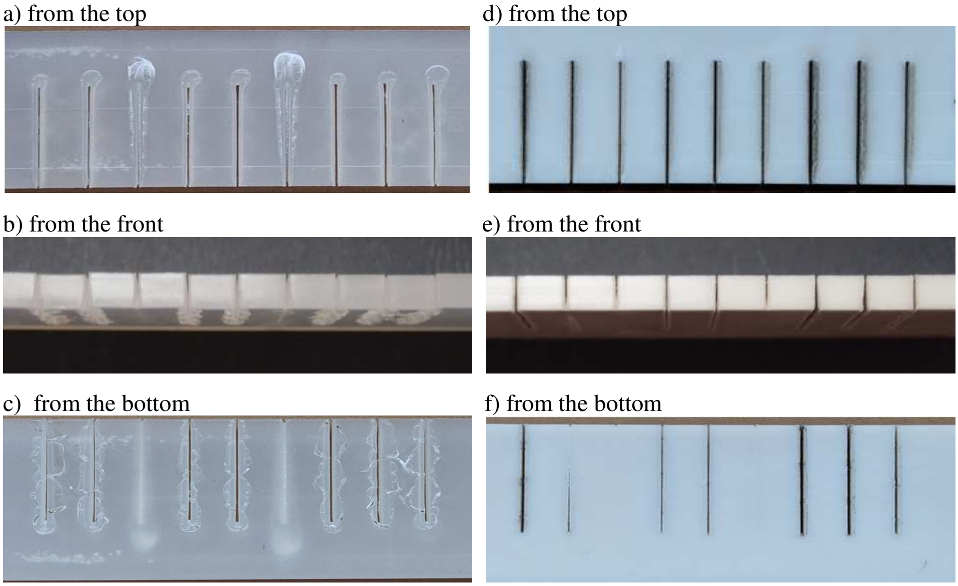


Fig. 3. Polypropylene (a-c) and polypropylene with talc (d-f) cut at speeds (from the left): 20, 25, 30, 35, 40, 45, 50, 55, 60 mm/s at laser power of 35W

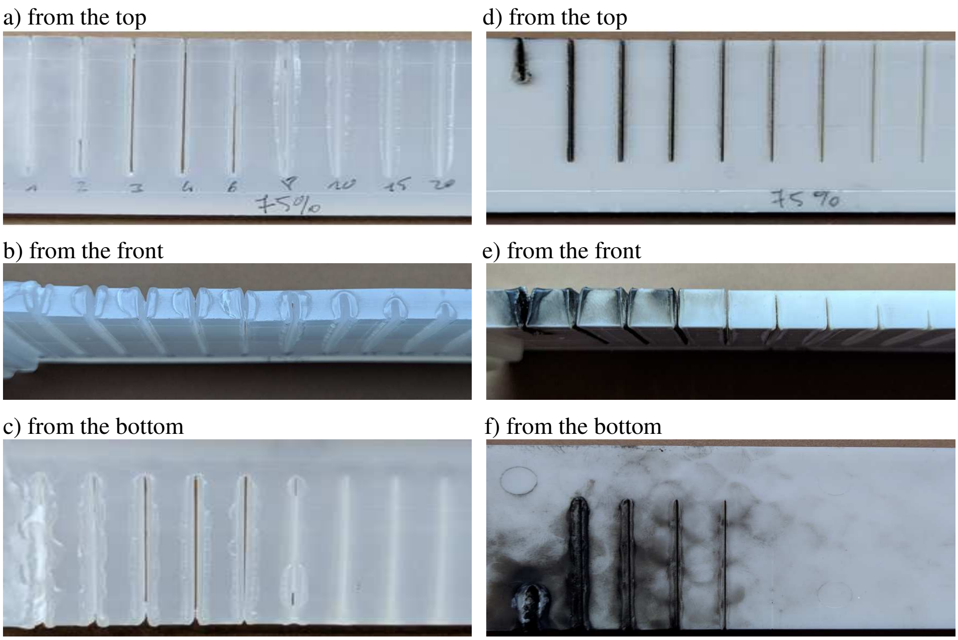


Fig. 4. Polypropylene (a-c) and polypropylene with talc (d-f) cut at speeds (from the left): 1, 2, 3, 4, 6, 8, 10, 15 and 20 mm/s at laser power of approx. 52W

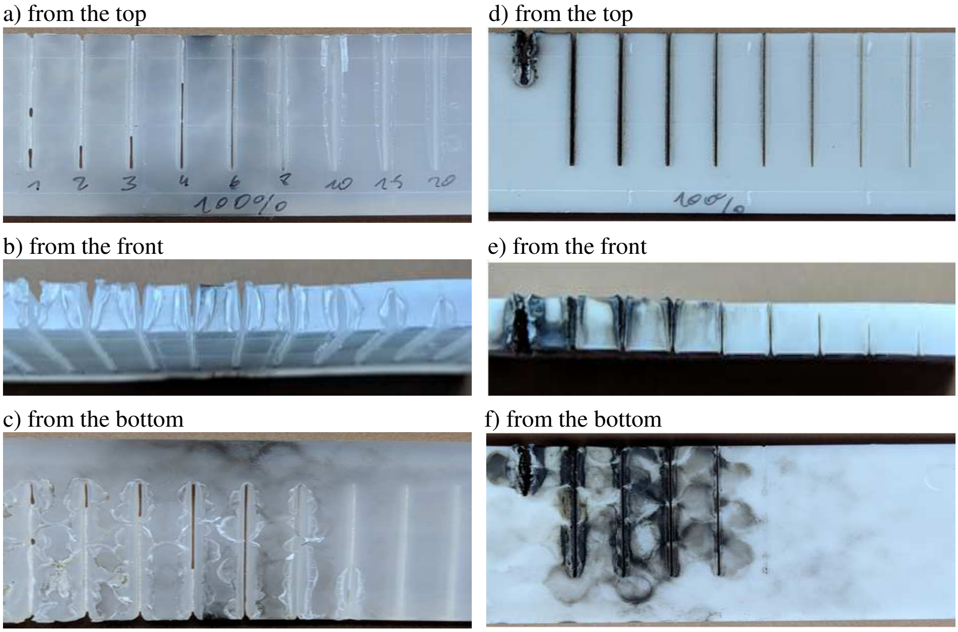


Fig. 5. Polypropylene (a-c) and polypropylene with talc (d-f) cut at speeds (from left): 1, 2, 3, 4, 6, 8, 10, 15 and 20 mm/s at laser power of approx. 70W

The cutting operation was carried out at three laser power values: 35W, approx. 52W and approx. 70W (which gives the laser power of 50%, 75% and 99%, respectively), successively cutting the material at different speeds. As a result of the different beam exposure conditions, the cutting gap either did not form or varied in width. The gap size in *mm* was determined by measuring it with a gap gauge. The treatment variants and the results obtained are shown in Table 1.

It was found that the narrowest gaps were obtained in the cases:

- for polypropylene: 35W power and speeds: 40, 50 and 55 mm/s, approx. 52W power and speeds of 6 mm/s, approx. 70W power and 8 mm/s;
- for polypropylene with talc: 35W power and speed of 35 mm/s, approx. 52W and approx. 70W power, speed of 6 mm/s in both cases.

The slits considered the narrowest in most cases were also the best for aesthetic reasons, except for laser treatment of polypropylene at approx. 52W power and approx. 70W power. Choosing the most aesthetic slit is associated with obtaining a slightly wider slit gap (by 0.05 mm in both cases).

Processing with other parameters also showed a deterioration in quality according to other criteria: in many cases the material was not separated, the edges of the cracks with larger widths were generally not parallel, and in the case of polypropylene with talc additive, surface carburisation could not be avoided, but this proved to be easily removed when processing with the optimal (preselected) parameters.

6. CONCLUSIONS

Based on the analysis of the results, it can be concluded that it may be justified to carry out preliminary tests of the planned machining process for laser processing of plastics. In the investigated cutting operation with the laser of the lowest power (35W - 50%), no unambiguous relation between the beam speed and the optimum gap width can be indicated. In addition, many of the assumed variants are inefficient (the material was not separated).

By increasing the power and at the same time reducing the beam travel speed relative to the material, and thus extending the time for the concentrated energy beam on the material, better results can be obtained. Both for the power of approx. 52W (75%) and approx. 70W (99%), a range of effective speeds can be indicated. It is therefore already possible to think of a CO_2 laser for cutting 5 mm thick plastic in production conditions.

A dilemma may arise during the selection of the best variant: whether to choose a variant giving the narrowest gap or the smoothest edge. A difference of 0.05 mm may be irrelevant to ensure economic accuracy (a familiar concept in machine technology). The manufacturer may decide to take a slightly larger allowance for chiselling, but will receive an aesthetically pleasing product that does not require finishing. This was the case when cutting polypropylene, when using a laser of approx. 52 W power and 4 mm/s (not 6 mm/s) and of approx. 70 W and 6 mm/s (not 8 mm/s), the aesthetically pleasing edges were obtained. The criterion of aesthetics was not the same as the criterion of saving the use of the material.

Another important finding of the result analysis is that talc is a beneficial additive to polypropylene also for laser processing. For this material variant, a wider range of effective cutting speeds was obtained, and a logical dependence of the slit width on this speed is also apparent – the lower the speed, the wider the slit. This may be influenced by the properties obtained after the addition of talc, which had the effect of reducing expansion and increasing thermal conductivity. Thus, changes in the form of the material during laser processing could be more predictable.

In conclusion, it can be said that the processing of the selected 5 mm thick material is not as easy as one might expect. It is justifiable to carry out preliminary tests on the material before starting the actual manufacture, to adapt the laser in possession, or to purchase a new one, taking into account the observations and after choosing the criteria that determine the processing parameters.

Acknowledgement: The authors would like to thank Dr Leszek Pyziak of the Department of Applied Optics, Faculty of Mathematics and Applied Physics, Rzeszów University of Technology, for technical assistance in sample preparation.

BIBLIOGRAPHY

[1] Bortel K., *Środki pomocnicze stosowane w przetwórstwie tworzyw polimerowych*. Cz.2. Przetwórstwo Tworzyw 6, 2008.

[2] Cienka A. E.: *Analiza porównawcza efektów cięcia laserowego tworzyw sztucznych z wybranymi dodatkami*. Praca inżynierska, ORPD, Politechnika Rzeszowska, Rzeszów 2020

[3] Gruin I., *Materiały polimerowe*. Wydawnictwo Naukowe PWN, Warszawa, 2003.

[4] Heneczkowski M., Oleksy M., *Technologia przetwórstwa tworzyw sztucznych*. Oficyna Wydawnicza Politechniki Rzeszowskiej, Rzeszów, 2014.

[5] Hyla I., *Tworzywa sztuczne: własności, przetwórstwo, zastosowanie*. Wydawnictwo Politechniki Śląskiej, Gliwice, 2000.

[6] Klepka T. (red.), *Nowoczesne materiały polimerowe i ich przetwórstwo. Część 1*. Wydawnictwo Politechniki Lubelskiej, Lublin, 2014

[7] Kujawski A., Szczepański P., *Lasery. Podstawy fizyczne*. Oficyna Wydawnicza Politechniki Warszawskiej, Warszawa, 1999.

[8] Latos M., Masek A., Zaborski M., *Fotodegradacja materiałów polimerowych*. Przetwórstwo Tworzyw 4, 2017.

[9] Oczoś K., *Kształtowanie materiałów skoncentrowanymi strumieniami energii*. Wydawnictwo Politechniki Rzeszowskiej, Rzeszów, 1988.

[10] Owczarek G., Wolska A., *Aspekty bezpieczeństwa przy obsłudze urządzeń laserowych*. Bezpieczeństwo Pracy, 11/2008, ss. 2-5

[11] Pająk E., *Obróbka ubytkowa. Technologia obróbki wiórowej, ściernej i erozyjnej oraz systemów mikroelektromechanicznych*. PWSZ w Koninie, Konin, 2016.

[12] Rabek J. F., *Współczesna wiedza o polimerach. T.2, Polimery naturalne i syntetyczne, otrzymywanie i zastosowanie*. Wydawnictwo Naukowe PWN, Warszawa, 2017.

[13] Riegert D., *Sposoby modyfikowania właściwości palnych tworzyw sztucznych*. BiTP Vol. 30 Issue 2, 2013.

[14] Rojek M., *Metodologia badań diagnostycznych warstwowych materiałów kompozytowych o osnowie polimerowej*. Open Access Library, Volume 2, 2011.

[15] Rytlewski P., *Studium laserowego i plazmowego modyfikowania warstwy wierzchniej materiałów polimerowych*. Wydawnictwo Uniwersytetu Kazimierza Wielkiego, Bydgoszcz, 2015.

[16] Saechtling H., *Tworzywa sztuczne: poradnik*. Wydawnictwo Naukowo-Techniczne, Warszawa, 2007.

[17] Sasimowski E. (red.), *Przetwórstwo tworzyw polimerowych: aspekty technologiczne i nowe trendy. Część 1*. Wydawnictwo Politechniki Lubelskiej, Lublin, 2015.

[18] Szlezyngier W., Brzozowski Z. K., *Tworzywa sztuczne: chemia, technologia wytwarzania właściwości, przetwórstwo, zastosowanie. T.3, Środki pomocnicze i specjalne zastosowanie polimerów*. Wydawnictwo Oświatowe FOSZE, Rzeszów, 2012.

[19] Wilczyński K. (red.), *Przetwórstwo tworzyw sztucznych*. Oficyna Wydawnicza Politechniki Warszawskiej, Warszawa, 2000.

[20] https://www.plastech.pl/wiadomosci/Srodki-antystatyczne-po-co-sa-dodawane-do-tworzyw-13246 (dostęp 24.11.2019)

DOI: 10.7862/rf.2021.pfe.1

Received: 18.03.2021
Accepted: 28.09.2021