The Theory of Drilling Industrial Plastics

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Abstract: *The cutting of industrial plastics has begun to develop a growing interest from companies processing cutting machines in various industries worldwide. The aircraft construction industry, machine manufacturing, civil and military defense have begun to develop the range of products they own and manufacture in their plants, the use of industrial plastics brings a number of significant benefits compared to their metallic materials or alloys. The properties of polymeric materials can be adapted to almost any functional need, so that the attention paid not only in the industrial environment is increasing. The complex parts of these types of materials also require complex processing operations to obtain the desired surface quality, the challenge that occurs in the case of these materials is their melting point, the temperature they reach during drilling.*

Keywords: *surface roughness; castamide; end milling; cutting edge.*

1 INTRODUCTION

Plastics usually mean *synthetic macromolecular* products, which can take the desired shape using the common property - plasticity. Regardless of the category in which they fall, plastics have some general characteristics presented below:

i. low specific weight, generally below 1.8 g/cm^3, due to the fact that the component elements (mainly H and C) have a low atomic mass;
ii. good resistance to bending, stretching and good compression;
iii. remarkable chemical stability compared to most aggressive middles;
iv. high specific expansion coefficient due to Van der Waals connections (weak connections) between chains and their conformation;
v. flammability (in most cases) and low thermal stability due to the fact that they are organic substances; for the same reason they can be degraded by microorganisms (biodegradability);
vi. adjustable porosity (structure with closed or open pores);
vii. relatively simple machinability;
viii. zero electrical conductivity and low thermal conductivity;
ix. their properties are affected by visible spectrum radiation, ultraviolet and ionizing radiation that can break the connections between chains and / or between monomers modifying the initial structure by reducing the degree of polymerization;
x. aesthetic aspect (mass colored products, translucent or transparent);
xi. low cost.

The plastic materials according to the heating can be classified as follows: (Mărașcu, K, V, 2010)

i. thermoplastic plastic materials - subjected to heating, can be processed by various processes. The products can be subjected to many melts or further softening, without undergoing chemical transformations;
ii. thermosetting plastics - they soften by heating, can be processed, and then harden irreversibly, because the molecules undergo chemical transformations.

Polymeric materials are part everywhere of our lives, especially among consumer goods, such as bottles, toys. Their use does not only refer to consumer goods, during their manufacturing process it is possible to adapt the properties according to functional requirements through the addition of additives / reinforcements such as fibers that influence the mechanical properties. A very important side of polymeric materials used in mechanical processing is the temperature range of the thermoplastic phase and the decomposition temperature between 100° C and 400° C, depending on the polymer. The thermoplastic temperature is critical for the machining process, because the material softens plastically and adheres to the cutting/drilling tool, or to the machined surface (Mărașcu, K, V, 2010). The drilling process of plastics is very often performed with the help of drill-type cutting tools, however anisotropy (the property of a substance to have various physical characteristics depending on the direction of measurement and observation) and lack of homogeneity of materials prevent effective drilling causing defects in holes such as: delamination; low dimensional accuracy; poor surface quality. Also the wear of the cutting tool is high. Thermoplastic plastic materials used mainly in industry and suitable for cutting operations: Polyethylene (PE); Polypropylene; Polyvinyl chloride (PVC); Polytetrafluoroethylene (PTFE); Polystyrene; Acrylic polymers; Polyamide (PA - nylon); Polyesters (unsaturated); Polycarbonates; Polyacetals; Elastomers (polyisoprene, acrylic, nitrile, silicone rubber, etc.). The thermosetting thermoplastic materials are the following: Phenolic polymers (phenoplasts); Polyamines (aminoplasts); Thermosetting polyesters (saturated); Epoxy polymers; Polyimide;

2 PLASTIC MATERIALS AND THEIR ROLE IN INDUSTRY

There is a growing interest in the use of composite plastics instead of conventional materials used so far in various fields and industrial applications, among the most important are aerospace structures, in the construction of aircraft, automobiles, shipbuilding, etc. Plastic composite materials, reinforced with carbon fiber, have superior properties to steel and titanium due to their hardness and rigidity, while maintaining their lighter weight. Carbon fibers are used especially in the aeronautical industry to reduce the weight of structures, so considerable improvements have been observed in terms of reducing fuel consumption, reducing pollutant emissions and increasing the aircraft's load capacity. For example, in the construction of the Boeing 787 aircraft, the construction company uses 50% composite materials. A problem identified in making these types of plastic parts is that assembly requires a large number of holes which results in problems in the drilling process which is often associated with delamination of the material, the appearance of geometric defects and thermal changes following the actual process of cutting. Plastic materials will represent the future of the construction industry in various fields, they will end up replacing in a high percentage steels and derived materials. (Cotetiu, R. et all 2008)

3 STUDIES REGARDING PLASTIC PROCESSING

The processing of industrial plastics is anovelty element and a challenge for the machining industry by cutting or assembling different components, the different properties related to metallic materials have increased the degree of interest and attention global market. The industry responds promptly to new materials, the desire to change and competitiveness has increased the degree of research on the possibilities of processing and use of plastics, but with the increase of this interest appeared also problems developed by the workability and quality of the resulting surfaces. In this monographic study I wish to analyze and highlight the positive and negative aspects of machining, especially drilling of industrial plastics.

3.1 The experiment of Şeref Aykut, on determining the precision of processing of castamide surfaces (PA6 G)

Castamide is a cast polyamide, widely used in industry due to the fact that it is light and has good corrosion resistance. It is used in the construction of gear components, where it has replaced a large part of the parts made of metal materials. Milling is one of the fundamental machining operations, very common, in this experiment surface finishing is a key factor in evaluating and determining the surface quality of a part.

3.1.1 The process of the experiment

In practice, a desired value of the surface roughness is determined by the correct choice of cutting parameters. In this study in practice, a desired value of the surface roughness is determined by the correct choice of cutting parameters (Şeref Aykut 2011). In this study the cutting parameters of the castamide type material are established on a vertical center with numerical control, the average surface roughness is observed experimentally the cutting parameters of the castamide type material are established on a vertical center with numerical control, the average surface roughness is observed experimentally. The detection of the average roughness value was performed by random experiments in which the cutting speed (V_c), feed rate (f) and cutting depth were modified. The processing was performed using high speed steel (HSS) and carbide (WC) milling cutters. The researcher used the following cutting parameters in order to determine the surface quality in relation to the cutting parameters. The chosen cutting parameters were: Cutting speed = 100, 120, 140 m / min; Feed rate = 75, 100, 125 mm / min; Cutting depth = 1, 1.5, 2 mm. These values were chosen according to the recommendations of the literature for the cutting of polyamides.

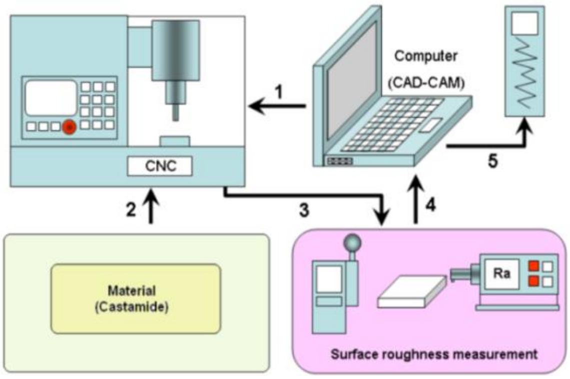

Fig 1. Schematic representation of the process
[Şeref Aykut 2011]

To measure roughness, the researcher used a portable MarSurf PS1 device. The measuring pin has a diameter of 2 µm and an average pressure force of 0.7 mN. The scan length of the measurements was adjusted to 5.6 mm. For each input model, the predicted value of the surface roughness was compared with the experimentally obtained value. It was found that the average surface roughness was close to the experimental values. The image below shows a graphic of the anticipated and experimental values of the surface roughness. The maximum error was 1.59 µm, and the minimum 0.015 µm (Şeref Aykut 2011). The absolute error was found to be less than 20% for most cases. In the image below we have graphically presented the values of roughness (Ra) resulting from the test and the value provided in the studies performed in the literature.

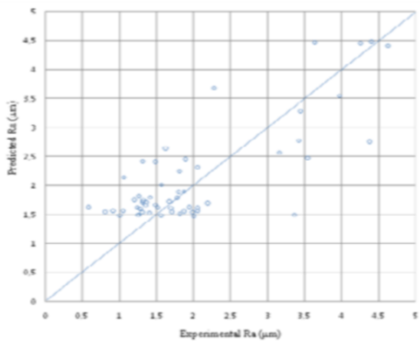

Fig 2. The experimental and predicted values of the roughness Ra [Şeref Aykut 2011]

3.1.2 Conclusions and results

Within this experiment the most important output parameter was the determination of the surface roughness (Ra), its determination represented the main objective of the work, the researcher compared the results obtained from the experiment with the values provided in the literature to specify that in case of processing of this material (Castamide, PA6 G) the resulting values were close to those provided, the material behaves well in machining, the most decisive element was the establishment of optimal values of cutting parameters, the surface roughness is directly influenced by the values of the parameters. To calculate the average of the resulting values, a mathematical algorithm was used where the input values were represented by the cutting parameters and the output values of the surface quality measured by means of the roughness Ra (Şeref Aykut 2011). The results of this aiming the determining the quality of surfaces.

3.2 The experiment of the researchers Miguel Álvarez-Alcón, Luis Norberto López de Lacalle and Francisco Fernández-Zacarías, regarding the monitoring of the drilling process, the definition of the drilling parameters, the surface roughness in the processing of plastics reinforced with carbon fiber.

The specimens used for testing in the experiment are parts found in the aeronautical industry and have the following dimensions: 210 x 210 x 4.5 mm. The material is composed of unidirectional layers of carbon fiber with intermediate mode. The matrix is impregnated with epoxy resin and has a volume of 34% before curing.

3.2.1. The execution of the experiment

Regarding the practical part of the test, two machine tools were used, namely: 5-axis machining center, Kondia Five 400, equipped with an iTNC530 control device; Kondia HS 1000 3 - axis high - speed machining center, equipped with an iTNC530 control device. The following devices were used to measure the data resulting from the experiment: The Mahr Perthometer PGK 120 roughness tester, equipped with MFW 250, for measuring the roughness (Ra); A digital micrometer with an accuracy of 0.001 mm was used to measure the diameters of the holes; The Mahr Formtester MMQ 44 was used to measure the cylindricality of the holes. The measured deviations can be within the following tolerances of 0.02 + 0.005. The equipment has 3 linear axes and an axis of rotation, responsible for the rotation of the shaft. A drill with a diameter of 7.92 mm and a top angle of 140° and 118° were used. In this experiment, 25 drilling cycles x 12 holes were performed, a total of 300 holes using the following cutting parameters (Miguel, A, A, et all. 2020): Cutting speed Vc [m / min] = 85, 105, 125, 145; Feed rate Vf [mm / min] = 250, 300, 400.

Parameters	Values
Drill bit diameter, φ, D (mm)	7.92
Cutting speed (m/min)	85, 105, 125, 145
Spindle speed (rpm)	3416, 4220, 5024, 5828
Feed rate (mm/min)	250, 300, 400
Feed rate (mm/rev)	0.04–0.12
Lubrication	Dry
CFRP material thickness (mm)	4.50

Fig 3 Cutting parameters [Miguel, A, A, et all. 2020]

3.2.2 Conclusions and results

Following the experiment, the following aspects were established: low values of feed rate increase the contact time between the cutting tool and the material of the part, this can cause internal damage and inherent temperature problems, a variable that is not at all favorable for industrial plastics due to molecular composition (Miguel, A, A, et all. 2020). Authors from the literature stated that there is a connection between the temperature of the processing procedure and the surface roughness at the same time as the delamination and the circularity of the holes.

On the other hand, it was stated that the orientation of the fibers of the material influences the process temperature, increases the cutting forces, increases tool wear, abrasion being the main factor with a direct effect on surface quality. Global researches suggest that in the drilling process in the cryogenic environment, better values of surface roughness were achieved, with smaller deviations of the cylindricality of the holes. Consequently, the main factor for determining the quality of the surfaces is the relations between the temperature during the cutting process and the values of the cutting parameters, especially of the feed rate. The lowest roughness values were obtained for the following experimental data: Vc = 105 m / min and Vf = 300 mm / min, however in the case of cylindricality the best results were recorded for Vc = 85 - 105 m / min and Vf = 300 mm / min, more precise where the highest values of the force-traction torque are given (Miguel, A, A, et all. 2020).

It was not possible to determine a significant empirical relation, with a coefficient of determination greater than 40% for roughness depending on the traction force and the resulting torque. Compared to the cutting parameters, it was possible to obtain a relationwith a coefficient of determination higher than 70%. The effects of cutting parameters on surface quality are shown graphically in the image below.

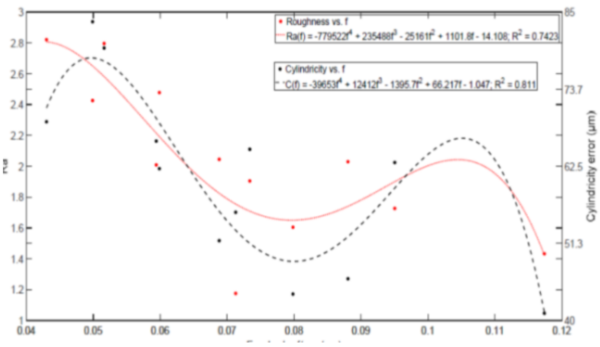

Fig 4. Effects of feed rate on surface quality
[Miguel, A, A, et all. 2020]

3.3 Experiment of researchers Richard Horvath and Agota Dregelyi-Kiss on the machinability of PA-6 polyamide

Due to the widespread use of industrial plastic materials, many researchers are investigating their workability. Such research is usually made with the help of experimental design, because a lot of information can be achieved from relatively few but experimentally well-chosen samples.

3.2.1. The execution of the experiment

The authors of the work also experimented also the machinability of aluminum alloys, building predictive models for surface roughness parameters (Ra and Rz). The purpose of the experiment was to be able to construct empirical models and with it the surface roughness parameters can be easily estimated from the cutting parameters (Richard, H., Agota, D. 2018). The average surface roughness parameter Ra and the high surface roughness parameter Rz were taken into account in order to perform the experimental research. Machining tests were performed using the response surface method (RSM).During machining, the three cutting parameters were tested, namely: cutting speed [m / min], feed rate [mm / min] and cutting depth [mm]. The values of the cutting parameters have been changed five times. The output parameters were measured with the dependent variables with the roughness parameters Ra and Rz. The graphs below show the surface roughness parameters as a function of the minimum value, the roughness values decrease as the cutting speed increases.

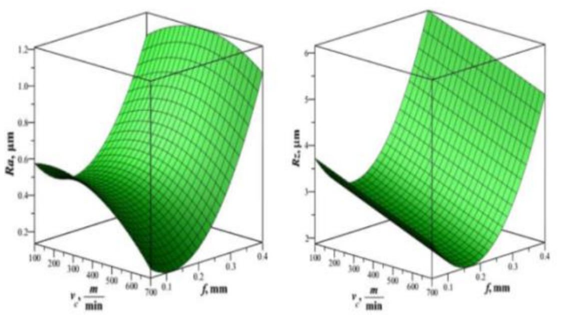

Fig 5. Roughness values [Richard, H., Agota, D. 2018]

3.3.2 Conclusions and results

Within the range of the examined cutting parameters, the minimum roughness Ra and the minimum Rz, have minimum values if for Ra results Vc = 300 m / min, Vf = 0.12 mm / min, and for Rz results Vc = 300 m / min, Vf = 0.16 mm / min, Ra = 0.15 µm and Rz = 1.8 µm. It can be stated that in order to minimize both parameters of the surface roughness, a cutting speed of 300 m / min and an feed rate between 0.12 - 0.16 mm / min is recommended. Experimental design is a suitable method for exploring research, as a lot of information can be obtained relatively easily (Richard, H., Agota, D. 2018).

3.4 The experiment of researchers B.P. Mishra, D. Mishra, P. Panda on drilling fiberglass-reinforced composites

Fiberglass-reinforced composites find high application in various engineering fields, are widely used in the automotive, naval, aeronautical industries, represent the technology of the future in the field of materials due to their superior properties and advantages.

3.4.1 Execution of the experiment

Research on the development of the field of drilling by composite materials focuses mainly on the mechanics of drilling, the geometry and material of the cutting tool, the delamination process, the cutting force, the wear of the tools. In drilling composite materials, the quality of the holes is the main priority, a quality that is determined by the best possible finish of the machined surface. In addition to surface roughness and circularity error, the delamination factor is also one of the quality measures. Delamination is a process of damage that occurs due to the anisotropy and fragility of the material. Delamination is found in the first phase at the entry of the cutting tool into the material and in the second phase at the exit of the material, hence a degradation of the surface quality of the material on both sides, the cutting parameters are factors that directly influence the quality of processed surfaces. The parameters used in drilling the composite materials in this experiment are presented below (Mishra, B, P, et all. 2018).

Table 1. Parameters of the cutting process
[Mishra, B, P, et all. 2018]

Workpiece Material	**Tool Material**	**Hole Diameter (mm)**	**Material Thickness (mm)**	**Cutting Speed (m/min)**	**Feed Rate (mm/rev)**
Graphite-epoxy	Carbide	4.85	6.35	60.9	0.0254
Glass-epoxy	HSS	--	12.5	15.0	0.028
Glass-epoxy	HSS	8	12	40.2	20-460 mm/min
Carbon-epoxy	Carbide	3	10	33	0.05

For high drilling performance it is necessary to choose the appropriate process parameters, this means high drilling quality, minimal damage and a good machined surface. The different geometries of the cutting tool such as: tip angle, diameter, etc., directly influence the traction force and torque. The angle at the top of the drill strongly affects the quality of the holes in the case of composite materials reinforced with fiberglass. The figure below shows the value of the delamination factor for different drill geometries.

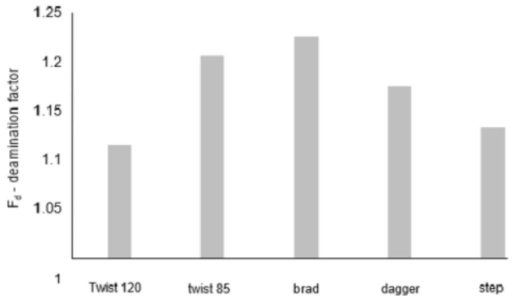

Fig 6. Drill geometry [Mishra, B, P, et all. 2018]

3.4.2 Conclusions and results

In addition to the values of the cutting parameters studied, the delamination factor and the surface quality also play an important role in the processing of composite materials. The factors mentioned together with the auxiliary aspects (lubricant, vibrations part - machine - cutting tool) greatly affect the quality of the holes and machined surfaces. If adequate processing conditions are adopted, the quality of the cutting process and implicitly of the processed surfaces can be considerably improved, establishing the optimal choice of tools, parameters, technology, an algorithm to compensate for research conducted so far in the literature (Mishra, B, P, et all. 2018). Predictability is a factor that is mainly used in experimental studies, the lack of a solid foundation will generate the need for more detailed and precise studies on this topic.

4 PERSONAL CONTRIBUTIONS

1. Research and analysis of specialized works in the field of plastics processing in order to establish experimental - empirical data and the realization of the monographic work;
2. Establishing the types of plastics used mainly in industry and constructive-functional analysis to determine the information needed for the study;
3. Systematization of information on the quality and roughness of processed surfaces for plastics selected in the study;
4. Determining the relation between the cutting parameters and the quality of the surface resulting from the processing;
5. Analyzing the results of the study and establishing future research directions in order to determine some information to answer the problems identified in previous studies.

5 CONCLUSIONS

1. The knowledge and information presented in the literature so far regarding the drilling of metallic materials cannot be transferred to the field of drilling of polymeric / plastic materials. From the research we found that for the processing by cutting plastics we need a different approach related to the parameters of the manufacturing process;
2. The chemical structure has a major role, the differences are given by the amount of crystal as the structure and orientation of the fiber. This influences the shape of the chip and the quality of the machined surface, especially the non-coaxiality of the holes;
3. During the drilling of the carbon fiber-reinforced polyamide the heat generated was transmitted to the drill on the surface of the polyamide, for this reason the resulting chips were less affected by the heat released by the process but the surface quality underwent changes;
4. Thermal damage can have negative and significant effects on the material and can compromise the success of drilling operations;
5. Further studies and intensive research are needed regarding the starting point of the cutting parameters in the stability of the cutting process of thermoplastic materials;
6. The geometry of the cutting tools directly influences the temperature of the cutting process, which is directly responsible for the quality of the processed surfaces;
7. The thermoplastic temperature is critical for the machining process, as the material softens plastically and adheres to the cutting / cutting tool, or to the machined surface, it is necessary to use a coolant or well-established cutting parameters that not to thermally influence the cutting process.

6 IDENTIFIED RESEARCH DIRECTIONS

1. Determining the research and application framework of the information from the literature known so far regarding the drilling of polymeric materials to achieve a processing interval that determines the optimal cutting parameters for drilling in favorable conditions of the studied materials;
2. Preparing a study on determining the optimal processing temperature of polymeric materials (plastics), taking into account the research in the literature and conducting research to establish favorable processing conditions (use of cryogenic agent, use of the method of lubrication in minimum quantity - MQL or dry environment processing);
3. Carrying out an in-depth study on the processing (drilling) and the optimal geometry of the cutting tool (tools provided with the possibility of being cooled from the inside or outside) for plastics with a high content of fiberglass and carbon;

4. Determining the optimal processing geometry of the cutting tools and their durability in the processing of industrial polymeric (plastic) materials in order to achieve a good control of the temperature resulting from the cutting process.

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