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CONTROL OF DEVIATIONS FROM CIRCULARITY WHEN DRILLING POLYMERIC MATERIALS

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ABSTRACT

Polymeric materials represent synthetic macromolecular products, from which objects of various shapes can be manufactured, through mechanical or thermal processing. These materials are used in various industries due to their versatility and ability to adapt to various applications. The paper presents an analysis of deviations from circularity in the drilling process of three types of polymeric materials: PA6 (polyamide), PEHD (high density polyethylene) and POMC (polyacetal). The main purpose of this analysis is to evaluate and measure the deviations from circularity in the drilled plates using specific drills on the EMCO MILL 55 CNC machine and the precise determination of these deviations is realized with the help of the Sinowon 3D measuring machine. In the context of the processing of polymeric materials, both technical performance criteria and their associated factors in drilling operations are examined. In the study, two types of helical drills were used, with two rectilinear cutting edges, having different diameters, Ø8 mm and Ø10 mm, made of high-speed steel.

KEYWORDS: polymeric materials, drilling, SINOWON 3D, circularity, deviations.

1. INTRODUCTION

Metal cutting is a complex process involving five essential elements, each with a distinct and crucial role in achieving the desired results in metal processing [1-5]:
- cutting tools: they are made of specific materials, having an adapted geometry to allow efficient and precise operation; the shape, material and sharpness of the tools influence the quality and efficiency of the cutting process.
- cutting regime: includes parameters such as the depth of cut (how much material is removed in one way), the feed (speed with which the cutting tool moves in relation to the material) and the cutting speed; these parameters are essential to obtain a suitable finish and to maintain the integrity of the tool and the processed material;
- the material to be processed: the properties of the material, such as hardness, ductility, thermal and electrical conductivity, directly influence the way in which the cutting process is realized; knowing these characteristics is essential to choose the right cutting tools and optimal cutting parameters;
- cutting conditions: the way the cutting process is realized can vary depending on factors such as the working environment (dry, wet), temperature (cold or hot) and other ambient conditions; these variables can influence the quality of the parts and the durability of the cutting tools;
- machine-tool: represents the equipment used to realize the cutting process; it must have a specific kinematics, adapted to ensure the stability, precision and control required during processing.

Each of these elements must be well understood and controlled in order to achieve an efficient cutting process and to ensure the quality and precision of the processed parts. Among them, the cutting tools represent an important element in the processing procedures. They constitute an essential part of the technological equipment, contributing significantly to the realization of the shape, dimensions and final quality of the processed surfaces, in accordance to the desired specifications.

Types of tools used for processing of the holes are diversified in construction and are adapted according to their specific purpose, Figure 1.

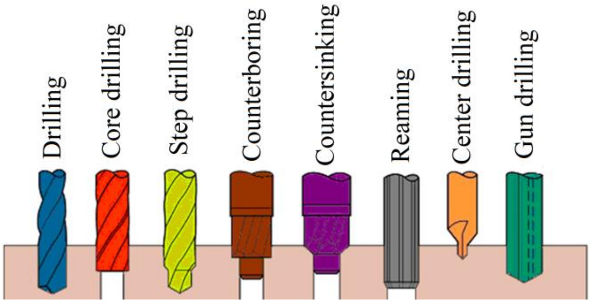


Fig. 1. *Types of tools used for processing of the holes [6]*

These tools are designed to perform precise drilling operations and the variability of their construction is determined by the specific needs of the machining process and the processed materials. The configuration, material and geometry of the tools directly influence the final result of the processing, contributing to the precision, quality and efficiency of the process [4,7].

Although metal cutting operations are widely used processes in various fields, considerable importance is given to polymeric materials, which represent a viable alternative to conventional metallic materials [8].

Polymeric materials have become increasingly used due to their distinct properties and adaptability to various applications. They offer a number of advantages such as reduced weight, corrosion resistance, thermal and electrical insulation, as well as versatility in processing [8,9].

The increased interest in polymeric materials has changed the landscape of materials processing. Polymeric materials, as alternatives to traditional metals, have gained popularity due to distinct characteristics such as ease of processing, corrosion resistance, thermal and electrical insulation and versatility in various applications.

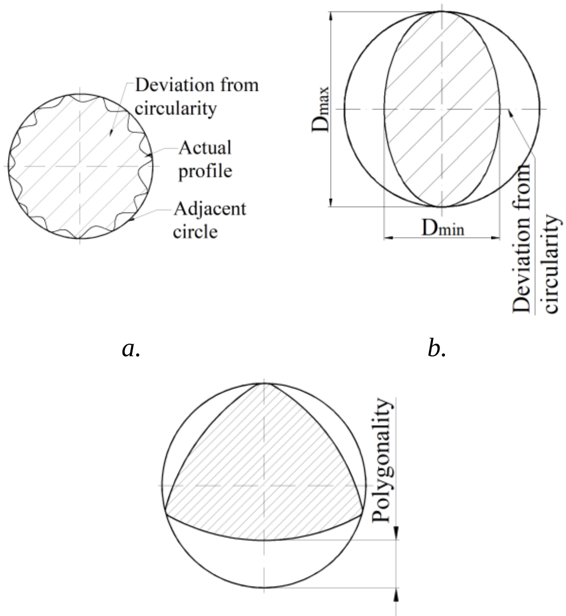
For example, drilling operations in polymeric materials require specific approaches and technological adaptations to ensure precision, quality and durability. This changing in the machining paradigm involves the search and implementation of efficient and accurate drilling methods that match the unique properties and characteristics of polymeric materials [9-11].

This often involves the adaptation of tools and processing parameters in order to match the specifics of polymer materials. Also, advances in processing technology have led to the development of specialized equipments and tools as well as process optimization in order to address the specific needs and requirements of polymeric materials in drilling operations [4,11].

This evolution in processing of the materials emphasizes the importance of technological understanding and adaptation to fully exploit the advantages and potential of polymeric materials in various industrial fields.

2. ASPECTS REGARDING THE DEVIATIONS FROM CIRCULARITY OF SURFACES PROCESSED BY DRILLING

The deviation from circularity or non-circularity is defined as the maximum distance between the real profile and the adjacent circle, Figure 2a.



a. *b.* *c.*

Fig. 2. *Deviation from circularity [12]*

Frequently encountered are the simple forms of deviations from circularity, namely: ovality and polygonality, Figure 2b and Figure 2c.

Ovality (O_v) occurs when the actual shape of the profile is approximately ellipsoidal. This represents the part's difference or deviation from an ideal circular shape and is calculated according to the relation [12]:

$$O_v = D_{max} - D_{min}, \qquad (1)$$

where D_{max} and D_{min} represent the maximum and minimum diameter of the ellipsoidal profile.

In the case of ovality, the cross-section of the part may not be perfectly circular, but more like an ellipse. This deviation from circularity can be observed by measuring the diameters in two perpendicular axes and comparing them.

Polygonality is when the actual profile is roughly polygonal in shape. In this situation, the contour or profile of the part is not perfectly circular, but more inclined to a polygon-like shape.

The circularity tolerance represents the maximum allowed value of the deviation from the ideal circular shape. This measure specifies how much the actual shape of the part may deviate from a perfect circle and is an indication of the level of precision accepted in production.

In other words, it represents an admissible limit of the variation of the actual shape from the ideal circular shape and is established in the technical specifications to ensure the proper quality and functionality of the processed parts.

Polygonality control and compliance with circularity tolerances are essential in ensuring precision and quality in production. These measures are implemented to ensure that manufactured parts meet the required standards and that their functionality is optimal in their final applications.

These deviations are important to identify and measure in production because they can affect the functionality and potential of interconnection or cause difficulties in the assembly or proper operation of parts. By recognizing and controlling these forms of deviations, compliance with specifications and final quality of finished products can be ensured.

When processing the revolution surfaces, the inaccuracy of the machine-tool determines the appearance of deviations from circularity and cylindricity.

Deviations from circularity in a section of a part are determined by measuring the diameters of the section in different directions. Classically, two-point measurement of the diameters of a cross-section is performed using a universal device (comparator) with a spherical or plane palpator, Figure 3a [12,13].

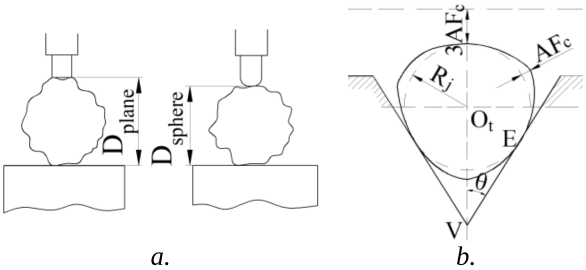


Fig. 3. *Definition of deviation from circularity [12]*

The two-point measurement of diameters is not sufficient to identify or detect deviations from circularity generated by curvilinear polygonal shapes of the same diameter.

These deviations from the circular shape, which may occur as a result of centerless rectification, can be detected and measured by using a specific ”*V*”-shaped support, Figure 3b.

The angle formed by this prism is determined by the number of polygon sides with the relation [12,13]:

$$2 \cdot \theta = 180^o - \frac{360^o}{n}, \qquad (2)$$

where:

- $2 \cdot \theta$ represents the angle of the ”*V*” shaped prism;
- n - the number of sides of the equidiameter curvilinear polygon.

Using a ”*V*”-shaped support, this method allows the detection of curvilinear polygonal shapes and the evaluation of deviations from circularity.

For a given polygon, the angle of the prism is adjusted to match the specific number of sides of that polygon.

This measurement process is useful for identifying and quantifying deviations from circularity generated by the polygon shapes, providing a more accurate assessment of the actual shape of the part and possible deviations from the ideal circular shape.

3. EXPERIMENTAL RESEARCH REGARDING THE CUTTING BEHAVIOR OF THE HELICAL DRILLS WITH TWO RECTILINEAR CUTTING EDGES

3.1. The premises of the experimental research

When processing the metals, due to their isotropic structure, it is necessary to analyze both the technical performance criteria and the factors associated with them in drill operations, systematically defined in Figure 4.

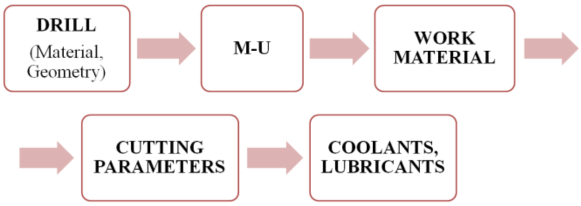


Fig. 4. *Factors associated with drilling operation*

In the paper, the experimental determinations are based on a comparative study of the cutting performance of drills with two rectilinear cutting edges: determining the deviations from the circularity of the surfaces of the holes processed by drills, experimentally, through comparative analysis, with the values obtained based on a simplified geometrical model.

Synthetically, the experimental research on the cutting behavior of helical drills with two rectilinear cutting edges can be represented according to Figure 5.

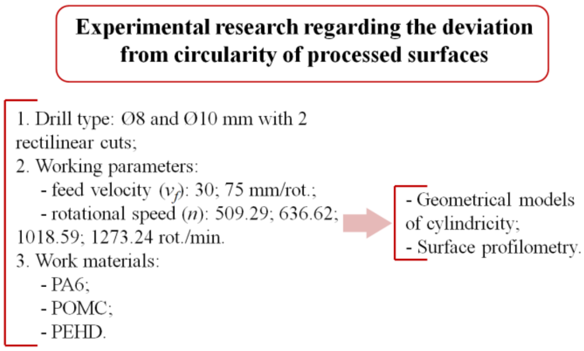


Fig. 5. *Schematic representation of experimental research*

3.2. Description of the equipment and the experimental research methodology

In the experimental research, a set of two high-speed steel helical drills, Rp3, with two rectilinear cutting edges, in the diameter range of Ø8 mm and Ø10 mm, was used, Figure 6.

Fig. 6. *Drills in the range of Ø8 and Ø10 mm diameters used in the processing of the plates*

In order to realize the tests, 18 plates with dimensions of 210x62x32 mm were used, 6 from PA6 (polyamide), 6 from POMC (polyacetal) and 6 from PEHD (high density polyethylene).

The experimental research was realized using a numerical control machine, EMCO MILL 55 CNC.

The tests were carried out under the same cutting conditions, without changing the linear crossing edge of the standard drills.

Thus, the 210x62x32 mm plate was fixed on the machine table by means of clamps, Figure 7.

Fig. 7. *The clamping system of the plate from EMCO MILL 55 CNC drilling machine*

In order to establish the accuracy of the movements on the *X* and *Y* axes of the CNC machining center, preliminary tests were carried out using drills with similar standard rectilinear edges.

It was agreed that for the plates processing with Ø8 mm and Ø10 mm drills, a working plan should be established, generically shown in Figure 8 [4].

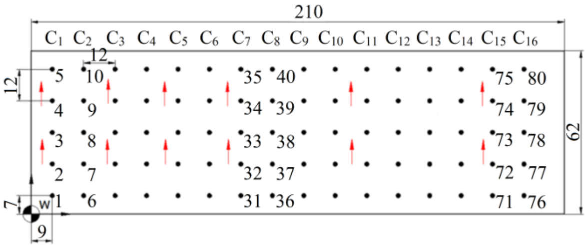


Fig. 8. *Choosing the origin of the CNC machine [4]*

In this context, it was considered that the origin of the first hole will be located at a distance of 9 mm from the corner of the plate, on the positive directions of the *X* and *Y* axes of the CNC machine. Before the actual machining, a Ø8 mm diameter drill was used to pre-drill the 80 holes. After the centering of these holes was completed, adjustments were made to the CNC code to move to a new machining step, from center drilling to drilling. After the drilling operation, a cleaning pass was performed on the 80 processed holes [4,11]. The drilling depth for both types of drills was 15 mm. This preliminary information, along with parameter specifications for the cutting regime, were integrated into the *G*-code, transmitted to the CNC machine. These stages and specifications had the role of ensuring the correct and precise execution of the machining, being essential for establishing how the CNC machine will execute the drilling operation according to the established requirements and tolerances [4,11].

The results obtained after the processing procedure of the holes of the plates are presented in Figure 9.

Fig. 9. *The results obtained from the processing of the plates holes*

The equipment used for video measurement of deviations from circularity is SINOWON 3D, Figure 10 [14]. This type of device can perform both plane and three-dimensional measurements, being used for precision industrial measurements such as: electronic components, precision calibers, small automotive components, parts made of lightweight materials etc.

Unlike other tools, such as profile projectors, the SINOWON 3D video measurement device requires a PC-type computer to display the image obtained by the digital video camera.

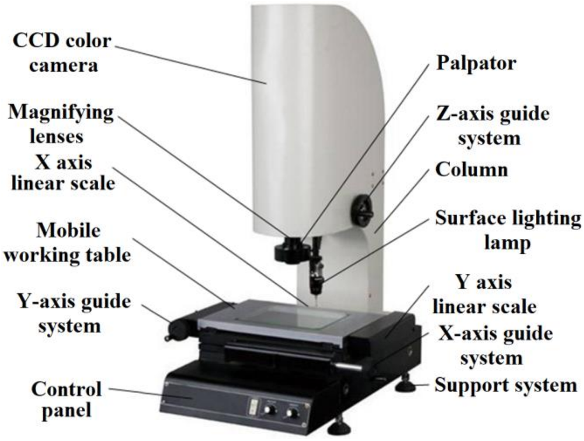


Fig. 10. *SINOWON 3D video measuring machine [9]*

The preparation of the measurement involves, in addition to the preparation of the machine itself, the launch of the measurement software.

The units of measurement in which the measurement will be made and the establishment of the display mode of the coordinates (Cartesian or polar coordinates) are established following the establishment of the reference system of the part.

After these steps, the image is focused by moving the digital camera vertically and determining the type and level of illumination. In modern versions of video measurement systems, the movement of the equipment table and the vertical movement of the camera can be done automatically, Figure 11.

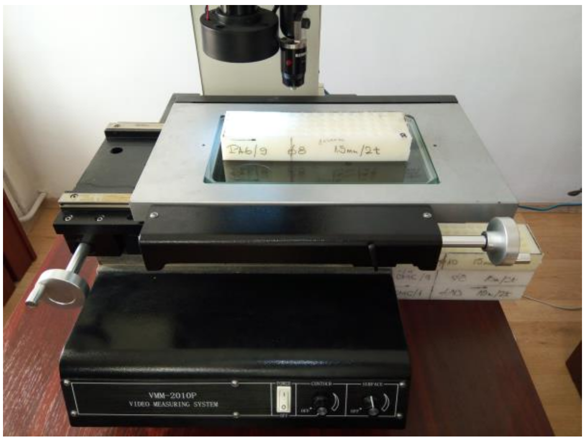
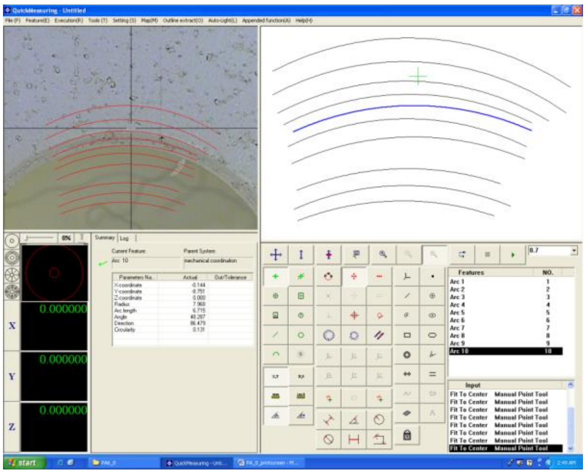


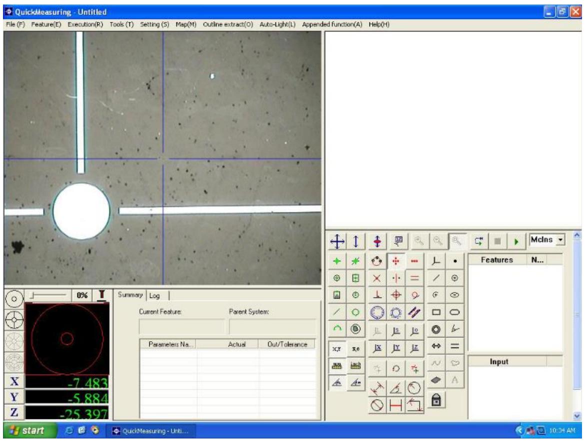
Fig. 11. *Preparation of the measurements*

The Sinowon 3D system has three measurement modes: on surface, on profile and on height.

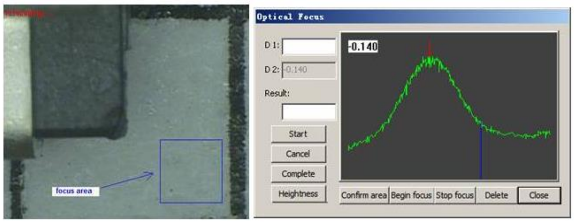
Contour lighting is used to measure the profile of the parts, which improves the quality of the obtained image. The disadvantage is that the surface of the parts cannot be seen, Figure 12a.



a.



b.



c.

Fig. 12. *Measurement of parts: a - on the profile; b - on the surface; c - on the height.*

The measurement of the surfaces is realized by illuminating the respective surfaces by means of the lamp, obtaining an enlarged image of the part, Figure 12b.

Height measurement is performed by adjusting the focus of the image on two plane surfaces of the part. The system allows precise height displacement measurement, the quota difference between the two camera positions representing the height difference between the considered surfaces, Figure 12c.

4. THE OBTAINED RESULTS AND INTERPRETATION OF THE MEASUREMENTS

The parameters of the working regime for the plates were established according to Table 1. Thus, after drilling the plates of three polymer materials - PA6, POMC and PEHD - using as processing tools two helical drills of diameters Ø8 and Ø10 mm and varying the cutting parameters, the measurements obtained with the help of *Quick Measuring* software and the device Sinowon 3D video measurement were summarized in a table and graphically presented, according to Table 1 and Figures 13÷18, for 6 of the 18 plates.

Table 2. *Values of the arithmetic average of the circular profile, d + δ [mm]*

Material	d [mm]	n [rot/min]	v_f [mm/rot]	d + δ [mm]
PA6	10	509.29	30	10.02
	10	509.29	75	10.01
	10	1018.62	75	9.99
	8	636.62	30	7.96
	8	1273.24	30	7.94
	8	636.62	75	7.95
PEHD	10	509.29	30	10.02
	10	509.29	75	10.01
	10	1018.62	30	9.99
	8	636.62	30	7.95
	8	1273.24	30	7.94
	8	636.62	75	7.95
POMC	10	1018.62	30	10.02
	10	509.29	75	10.01
	10	1018.62	75	9.99
	8	636.62	30	7.96
	8	1273.24	30	7.93
	8	636.62	75	7.98

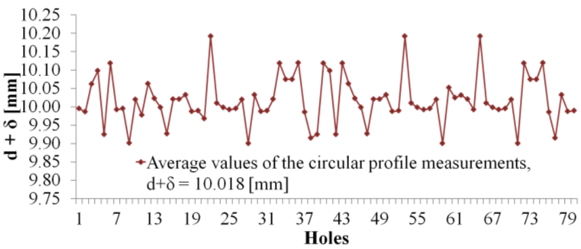


Fig. 13. *Variation of circular profile measurements - PA6, d=10 mm, v_f=30 mm/rot, n=509.29 rot/min*

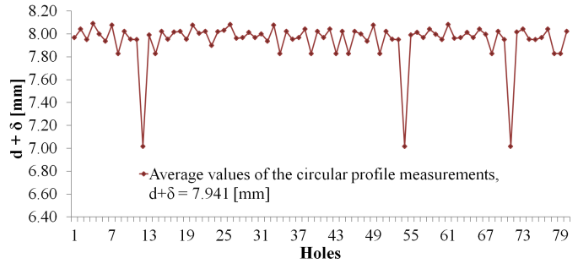


Fig. 14. *Variation of circular profile measurements - PA6, d=8 mm, v_f=30 mm/rot, n=1273.24 rot/min*

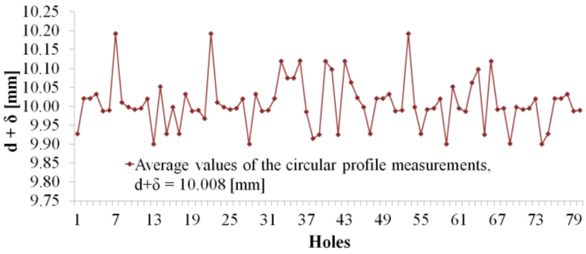


Fig. 15. *Variation of circular profile measurements - PEHD, d=10 mm, v_f=75 mm/rot, n=509.29 rot/min*

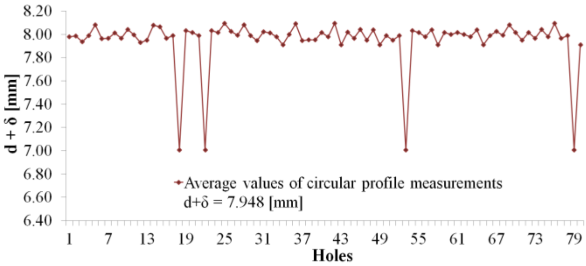


Fig. 16. *Variation of circular profile measurements - PEHD, d=8 mm, v_f=30 mm/rot, n=636.62 rot/min*

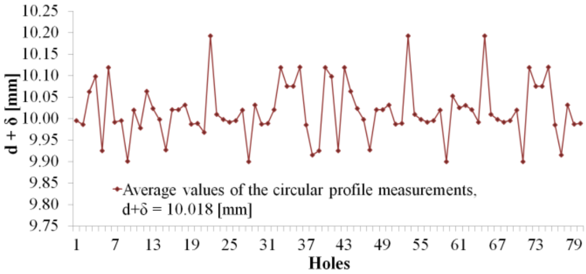


Fig. 17. *Variation of circular profile measurements - POMC, d=10 mm, v_f=30 mm/rot, n=1018.62 rot/min*

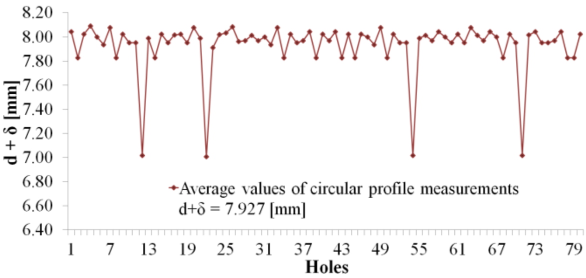


Fig. 18. *Variation of circular profile measurements - PEHD, d=8 mm, v_f=75 mm/rot, n=636.62 rot/min*

The measurements of the deviations were taken with the *Quick Measuring* software, which allowed the quantification of the results in tabular form.

The process capability analysis aims to determine the relationship between the product specifications and the results obtained from the process by which the product is made.

For a statistical calculation of the deviations resulting from the drilling processing, two people responsible for measuring the holes were chosen. Each of these people will measure the same holes, for the same plates and diameter.

The results were centralized in Tables 3÷5 and graphically represented in Figures 19÷24.

Table 3. *Measurement report no. 1 (PA6 Ø10 mm)*

Crt. no.	1	2	3	...	8	9	10	Average
Person A								
1	10.001	10.050	10.010	...	9.990	9.810	9.870	9.998
2	10.091	10.052	10.011	...	9.892	9.812	9.871	9.939
3	10.092	10.051	10.010	...	9.891	9.813	9.872	9.940
Average	10.061	10.051	10.010	...	9.924	9.812	9.871	9.959
Deviation	0.001	0.002	0.001	...	0.002	0.003	0.002	0.003
Person B								
1	10.120	10.040	10.010	...	9.910	10.080	10.010	9.993
2	10.121	10.040	10.013	...	9.911	10.082	10.010	9.994
3	10.122	10.041	10.012	...	9.910	10.081	10.012	9.994
Average	10.121	10.040	10.012	...	9.910	10.081	10.011	9.994
Deviation	0.002	0.001	0.003	...	0.001	0.002	0.002	0.002

Table 4. *Measurement report no. 2 (PEHD Ø10 mm)*

Crt. no.	1	2	3	...	8	9	10	Average
Person A								
1	10.181	10.071	10.091	...	10.09	10.011	10.062	10.070
2	10.180	10.070	10.090	...	10.09	10.010	10.06	10.069
3	10.182	10.027	10.089	...	9.989	10.002	10.062	10.058
Average	10.061	10.051	10.010	...	9.924	9.812	9.871	9.959
Deviation	0.001	0.002	0.001	...	0.099	0.003	0.002	0.003
Person B								
1	10.120	10.040	10.010	...	9.910	10.080	10.010	9.993
2	10.121	10.040	10.013	...	9.911	10.082	10.010	9.994
3	10.122	10.041	10.012	...	9.910	10.081	10.012	9.994
Average	10.121	10.040	10.012	...	9.910	10.081	10.011	9.994
Deviation	0.002	0.001	0.003	...	0.001	0.002	0.002	0.002

Table 5. *Measurement report no. 3 (POMC Ø10 mm)*

Crt. no.	1	2	3	...	8	9	10	Average
Person A								
1	9.951	10.090	9.870	...	10.090	10.011	10.062	10.008
2	9.950	10.090	9.872	...	10.090	9.870	9.870	9.974
3	9.989	9.989	10.012	...	9.989	9.872	9.872	9.995
Average	10.061	10.051	10.010	...	9.924	9.812	9.871	9.959
Deviation	0.001	0.002	0.001	...	0.003	0.003	0.002	0.002
Person B								
1	9.924	9.812	9.924	...	9.910	10.080	10.010	9.993
2	0.099	0.003	0.099	...	9.911	9.870	9.870	9.994
3	10.122	10.041	10.122	...	9.910	9.872	9.872	9.994
Average	10.121	10.040	10.121	...	9.910	10.081	10.011	9.994
Deviation	0.002	0.001	0.002	...	0.001	0.002	0.002	0.002

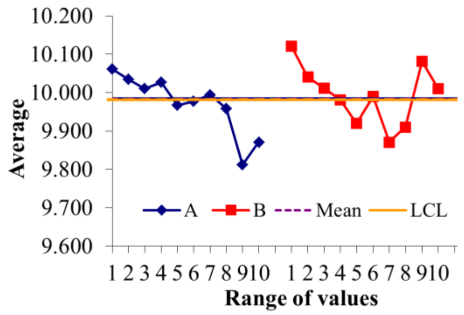


Fig. 19. *Average deviation values (PA6 Ø10 mm)*

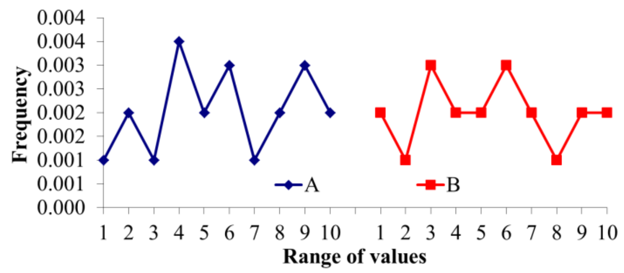


Fig. 20. *Frequency of deviations (PA6 Ø10 mm)*

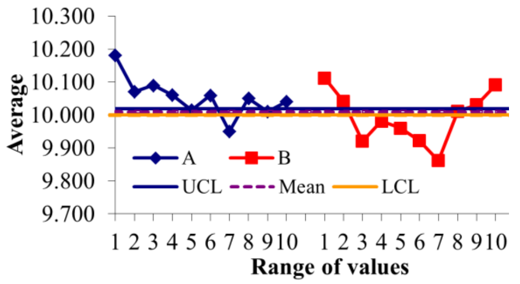


Fig. 21. *Average deviation values (PEHD Ø10 mm)*

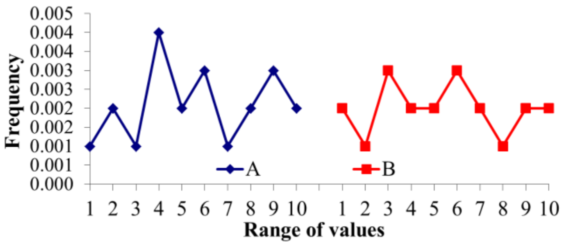


Fig. 22. *Frequency of deviations (PEHD Ø10 mm)*

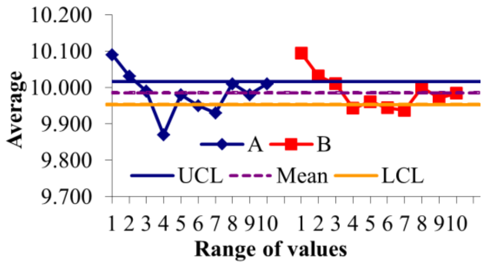


Fig. 23. *Average deviation values (POMC Ø10 mm)*

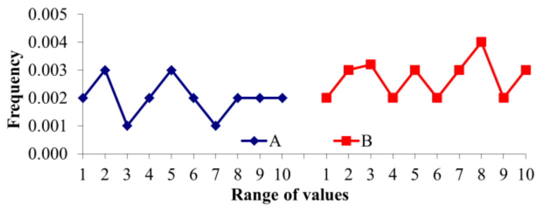


Fig. 24. *Frequency of deviations (POMC Ø10 mm)*

5. CONCLUSIONS

In the paper, an analysis was realized regarding the deviations from circularity during the processing by drilling of three distinct types of polymeric materials: PA6 (polyamide), PEHD (high density polyethylene) and POMC (polyacetal).

The main objective of this analysis was to evaluate and measure the deviations from circularity present in the drilled plates using two reactilinear cutting edges helical drills on the EMCO MILL 55 CNC drilling machine. To obtain accurate and detailed measurements of these deviations, the Sinowon 3D measuring machine was used. The main purpose of this approach was to evaluate the level of precision and uniformity of the shapes obtained from the drilling process, especially regarding the circular shape of the holes on the specified polymer materials.

The results of the measurements showed a direct correlation between the circularity of an inner cylindrical surface and the feed used in the machining process of that surface. It has been observed that the feed used, directly influences the accuracy of the circular shape of the processed surface.

Also, from the analysis of the results, it was found that the use of helical drills with two rectilinear cutting edges led to obtaining some surfaces with an improved circularity. The measurements made in laboratory have shown that these drills have contributed to more precise shapes and closer to ideal circularity compared to other types of cutting tools. This establishment emphasizes the importance of proper selection of cutting tools to achieve quality results and desired shapes.

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