

PERFORMANCES OF MULTI-FLUTE DRILLS COMPARED TO STANDARD DRILLS

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Abstract: *Multi-flute curved edge drills have constructions characterized by the geometry of the main edge having a variable clearance angle, decreasing from top to periphery. As a result, the performances of this construction are different from those of a standard drills as far as wear behaviour is concerned regarding axial force and the torque of cutting generated in the process, as a result of increasing the active length of the main edge of the drill.*

The paper presents experimental research of curved edge drills, performed comparatively with standard drills, as far as wear size over time is concerned and research regarding geometric roughness of generated surface, in an identical work environment, when processing A570 type steel.

The experimental research of the size of axial force and of torque, generated in the process of drilling, allowed us to determine the constants and the exponents in the relationships of axial force calculations and torque for cutting when processing alloys, with straight edge drills, as well as curved edge drills.

Keywords: *helical drill, curved edge, wear, roughness, axial fore, torque*

1. Introduction

With the purpose of achieving optimal performances in drilling, several constructive solutions were developed supported by experimental tests, with the purpose of constantly improving the characteristics of drills.

Special drill geometries were created [1], [2], [3], which lead at an essential decrease in axial force or torque, as well as comparative studies for different geometries of helical drills with the purpose of highlighting their influence in resistance [4], [5], [6].

Developing predictive models of roughness, with the scope of estimating some parameter values for roughness of machined holes [7], [8], [9], was doubled by studying the effects of parameters of the cutting state on roughness of machined surfaces for different materials [10], [11].

At the same time, it was considered the development of the drilling process in the circumstance of minimum force of cutting, correlated with a high resistance of helical drills. Thus, a variety of predictive models were proposed – analytic, numeric or experimental, for

determining the components of cutting force and torque [12], [13], [14], [15].

In this paper, we present a special constructive form of helical drill with three curved edges which is characterized by the fact that the energetic load, that goes on the length of the edge, is relatively uniform in all the points on the edge, as opposed to what is known about straight edge drills with constant clearance angle. We present an analytical model of a sharpening method for curved edge – hyperboloidal sharpening and the associated device. For this model, it is specific the fact that the main back surface has a helical shape, with a variable clearance angle, decreasing along the cutting edge.

We present the results of tests on the new drills, compared with standard drills, as far as behaviour to wear, roughness of generated surface and experimental determination of axial force and torque are concerned, proving the superiority of the new construction in comparison with the two edge standard drill.

2. Hyperboloidal sharpening process

Modifying the geometry of the drill - the edge shape in particular – curved edge – lead to a spatial

edge model that requires new sharpening methods of the main clearance surface. It is required as sharpening surface a hyperboloidal revolution surface, the drill placement depending on this.

The main kinematics of the cutting process is comprised by three movement, fig. 1:

A is the cutting movement – rotation of the grinding wheel, around its own axis;

B – oscillation movement of the sharpened drill in relation to the straight line generatrix of the grinding wheel;

C – feed motion of the sharpened drill along its own axis.

The active generatrix of the grinding wheel is rectilinear and belongs to an exterior surface of revolution. The generatrix is disjunct from the axis of the sharpened drill and it is at the distance of R_0 from the axis of the generated hyperboloid.

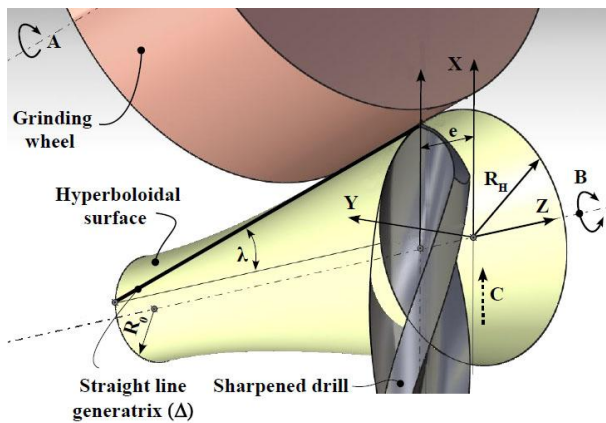


Figure 1: The kinematics of the hyperboloidal sharpening process

The analytical process of generating back surfaces of three curved edge helical drills is defined by starting from the fact that the clearance surface of the main curved edge belongs to a hyperboloidal surface of rotation - figure 1, generated, in the oscillation movement of the drill, in relation to the generatrix of the grinding wheel.

The analytical model of the clearance surface for the main edge of a drill with curved edges is at follows:

$$\begin{aligned} X &= u \cdot \sin \lambda \cdot \cos \varphi - R_0 \cdot \sin \varphi; \\ Y &= u \cdot \sin \lambda \cdot \sin \varphi + R_0 \cdot \cos \varphi; \\ Z &= u \cdot \cos \lambda. \end{aligned} \quad (1)$$

The following are defined:

- R_0 is the radius size of the minimum transversal section of the integral hyperboloid of the clearance surface;

- λ – gradient of the straight line generatrix of the hyperboloidal surface in relation to the hyperboloid's axis;

- u and φ – variable parameters.

The parameters that determine the circular shape of the cutting edge is at follows:

$$e = \frac{\sqrt{D^2/4 - d_0^2/4}}{\cos \kappa_p - \cos \kappa_t} \cdot \kappa_t; \quad (2)$$

$$R_H = \frac{\sqrt{D^2/4 - d_0^2/4}}{\cos \kappa_p - \cos \kappa_t}. \quad (3)$$

In equations (2) and (3) there were defined:

- e is the offset size of the origin circle to which the cutting edge belongs, in relation to the drill's axis;

- R_H – the radius that represents the crossing section of the hyperboloid. In this way, the cutting edge is an arc belonging to the R_H circle of radius;

- κ_t – the size of the clearance angle, to the top;

- κ_p – the minimum clearance angle, minimum, at the periphery;

- D – drill diameter;

- d_0 – drill core diameter.

The device associated with the hyperboloidal sharpening method for multi-flute helical drills, with circular arc cutting edge (fig. 2 and 3) is made from an grinding wheel (1) with an exterior cylindrical active surface and with the generatrix of this exterior cylindrical surface, disjunct and inclined from the oscillation axis of the drill (2), towards which the drill, mounted on the prism of a ruler (3), is engaged in an oscillation movement around the axis of a bearing.

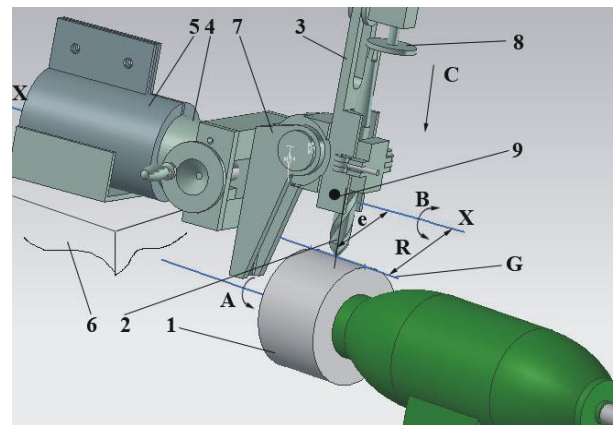


Figure 2: Hyperboloidal sharpening device - 3D view

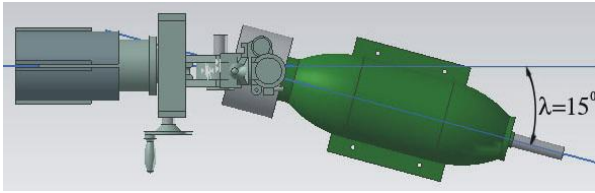


Figure 3: Hyperboloidal sharpening device – top view

This has the axis disjunct and at a distance given by the exterior straight line generatrix of an grinding wheel and a slide that allows offsetting of the drill axis from the oscillation axis of the bearing.

The hyperboloidal back surface of revolution is generated by the swing movement of the ruler (3), in relation to the XX axis, which is disjunct with the straight line generatrix of the grinding wheel, through a bearing, (4), mounted in a clasp (5), fixed on a framing (6), ensuring the positioning at a preset R distance of the XX oscillation axis from the straight line generatrix of the grinding wheel [16].

A slide (7) allows the offsetting of the ruler (3) and implicitly of the sharpened drill axis (2) in relation to the XX oscillation axis, with a preset size e , depending on the diameter size of the sharpened drill. The intermittent axial advance of the drill is performed through the screw mechanism, (8), fixed on the ruler (3), and the angular positioning at sharpening, towards the drill's own axis is ensured by index system (9). The system of axis advance and of sharpened edge separation places the axis of the drill to be sharpened perpendicular and eccentric to the axis around which the oscillation movement takes place, of limited angle, with the purpose of creating the back surface of hyperboloidal shape.

The advantages derived from using such a device for hyperboloidal sharpening are:

- ensuring a circular shape of the cutting edge, which leads to a longer edge and, as a result, a lower energy load per unit for it;
- simple kinematics, by using a cylindrical grinding wheel, whose shape is easily generated;
- ensuring a proper roughness of the sharpened back surface and an increase in helical drill resistance.

3. Comparative experimental research: three-curved edge drills vs. standard drills

Some comparative tests are presented, regarding two-edge standard drills, drills made in the same conditions at the Rîșnov Tool Factory,

România, from high-speed steel, HS 18-0-1. Tests were performed concerning drill wear, tests concerning machined surfaces roughness and also tests concerning axial force and torque when drilling.

3.1. Experimental aspects regarding drill wear

The tests were performed using the vertical machining center, CNC, HAAS-VM3, with an installed power of 22,4 kW and maximum rotation of 12.000 rot/min. In order to do the tests, A570 general use, carbon steel plates of 350x350x50 mm were machined. The wear criterion V_B was employed. In order to record the wear, it was used a Olympus stereomicroscope, model SZX 10, with multiple objectives and a maximum optical zoom of 126x, having attached an Olympus E330 Digital SLR camera and its respective AnalySIS FIVE software. The actual measurement of the wear was performed with the help of the Digimizer software product, the 4.1 version – fig. 4.

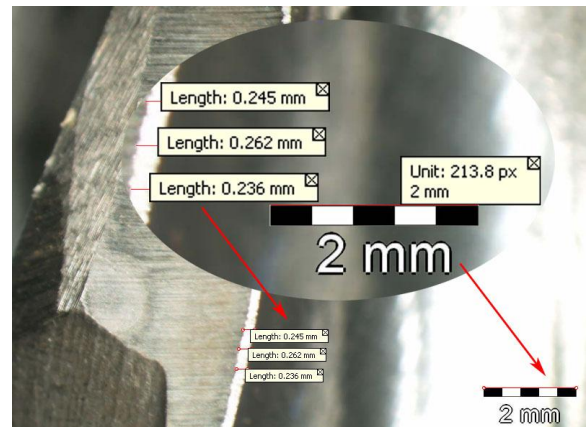


Figure 4: Wear measurement, V_B criterion, with Digimizer

The measurements were made for each set 28 holes with a diameter of $\text{Ø}20\text{mm}$ and 32 holes for those with a diameter of $\text{Ø}16\text{mm}$ – according to a work cycle controlled through the CNC program of the vertical machining center. There were considered as main factors of evaluation, the cutting speed and the drill's geometry – table 1.

Table 1: Work parameters

Drills	s [mm/rot]	v [m/min]	n [rot/min]
$\text{Ø}20\text{mm}$	0,16	28,26	450
$\text{Ø}20\text{mm}$	0,16	32	510
$\text{Ø}16\text{mm}$	0,10	25,12	500
$\text{Ø}16\text{mm}$	0,10	40	796

In figures 5÷12, the wear-time dependencies - when cutting with two-edge drills (standard) and with three curved edges of the A570 steel - and the wear of the drills are presented. The notations are: BTR – straight edge drill; BTC – curved edge drills.

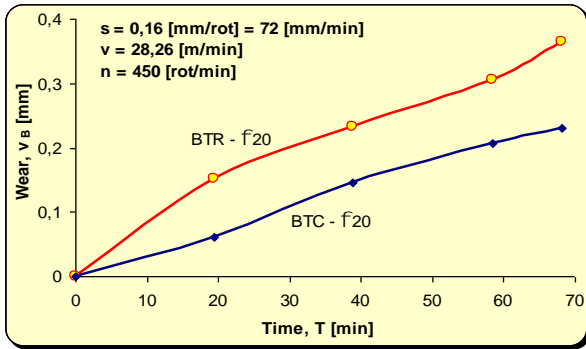


Figure 5: Wear evolution in relation to time; drills diameter Ø20 mm

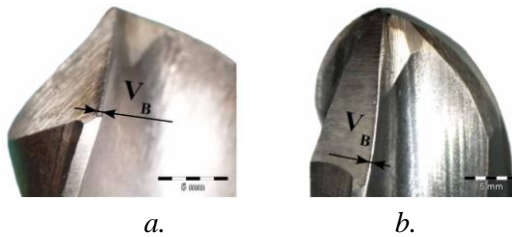


Figure 6: BTR1_Ø20; optical zoom: 8x (a); BTC1_Ø20; optical zoom: 6,3x (b)

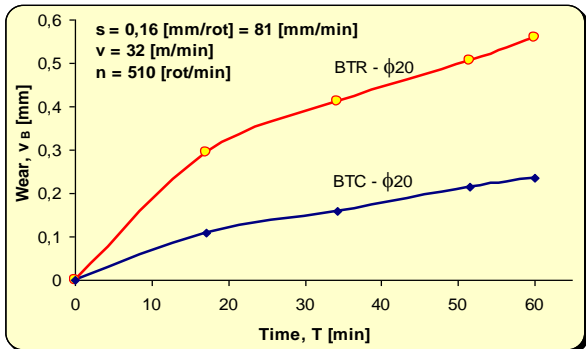


Figure 7: Wear evolution in relation to time; drills diameter Ø20 mm

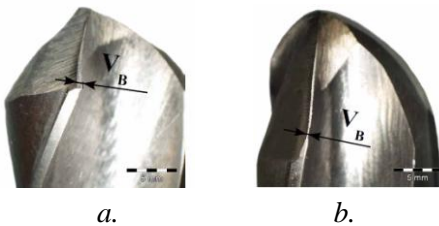


Figure 8: BTR2_Ø20; optical zoom: 6,3x (a); BTC2_Ø20; optical zoom: 6,3x (b)

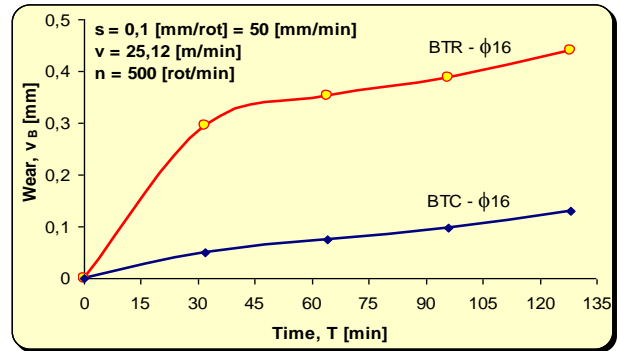


Figure 9: Wear evolution in relation to time; drills diameter Ø16 mm

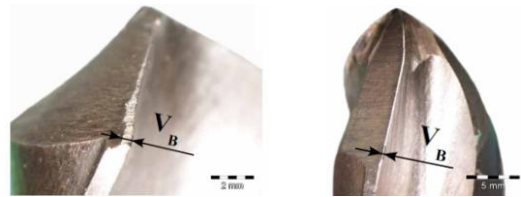


Figure 10: BTR1_Ø16; zoom optic: 12,5x (a); BTC1_Ø16; optical zoom: 6,3x (b)

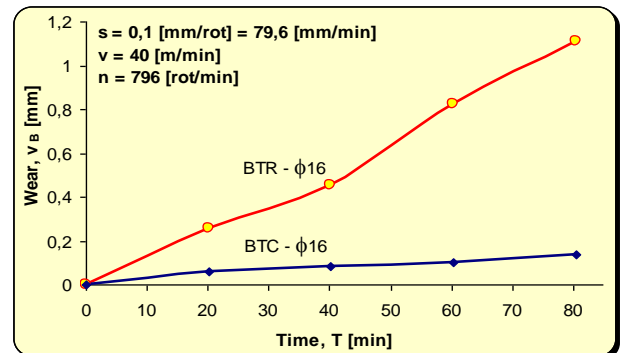


Figure 11: Wear evolution in relation to time; drills diameter Ø16 mm

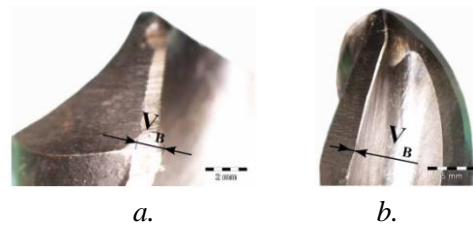


Figure 12: BTR2_Ø16; optical zoom: 12,5x (a); BTC2_Ø16; optical zoom: 6,3x (b)

The wear test performed were meant to highlight the particular wear of the main edge for drills with sharpened curved edges after the hyperboloidal method.

It is obvious that drills with curved edges have, in the same work conditions, a lower wear (criterion V_B) compared to standard drills.

3.2. Experimental aspects regarding machined surfaces roughness

In order to establish the role of the new proposed shape of the main edge geometry in the drill processing, comparative trials of roughness were performed, when working with standard straight edge drills and with three curved edges drills.

In the experimental try out, there were used a set of four helical drills made of HS 18-0-1 high-speed steel, two of them being standard, HSS, with two straight edges (BTR), and the other two being three curved edges drills (BTC), with diameters of Ø20 mm and Ø18 mm. To done the tests, A570, general use carbon steel plates of 350x350x50 mm were used.

The experimental research was done using the drilling machine G16, roughness meter Taylor Hobson Surtronic 3+. The working conditions parameters, for the tested plates, were establish according to table 2.

Table 2: Working parameters

Drills	s [mm/rot]	v [m/min]	n [rot/min]
BTR- Ø 18	0,1;	10,17; 25,43	180; 450
BTR- Ø 20		11,3; 28,26	180; 450
BTC- Ø 18	0,16;	10,17; 25,43	180; 450
BTC- Ø 20	0,25	11,3; 28,26	180; 450

The depth of holes, when drilling steel with Ø18 and Ø20 mm diameter drills, was limited at the value of 25÷30 mm (1,5D), in order to avoid the risk of chips settling in the drill's flutes.

For each machined bore, profile measurements were taken in four areas, on a inspection length of 4 mm, on the same generatrix, from the bottom of the bore towards the area of entry of the drill.

The profiles that included the bottom and the edge of the hole were excluded from data analysis. For each profile there were recorded 8000 of values, 2 values for each micron covered. In figure 13, it is presented an example of a profile for a drill processing and the values of the measured parameters [EN ISO 4287-1997].

After the parameters that characterize the micro-geometry of the surface according to direction of measurement, we take into account only the height parameters R_a and R_q [EN ISO 4287-1997].

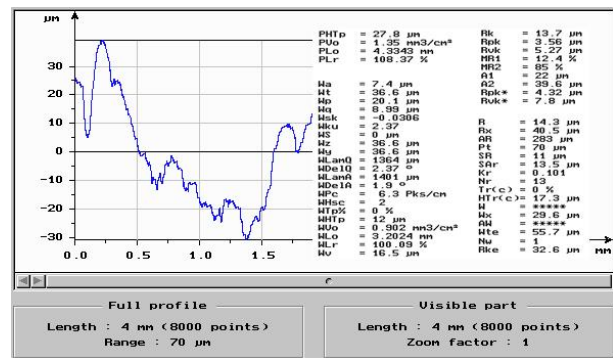


Figure 13: Profiles and parameters of the measured surface

The values of parameters R_a și R_q were defined for unfiltered profiles.

In figures 14÷17, a few parameter profiles of roughness are comparatively presented (R_a).

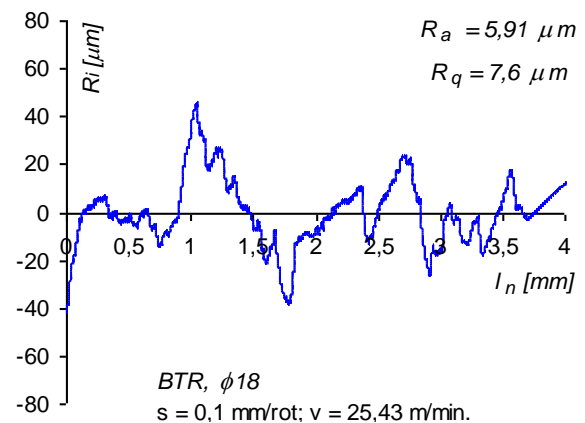


Figure 14: BTR Ø18; s = 0,1 mm/rot; v = 25,43 m/min

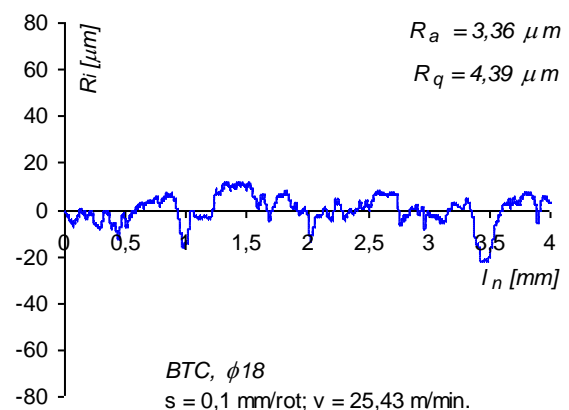


Figure 15: BTC Ø18; s = 0,1 mm/rot; v = 25,43 m/min.

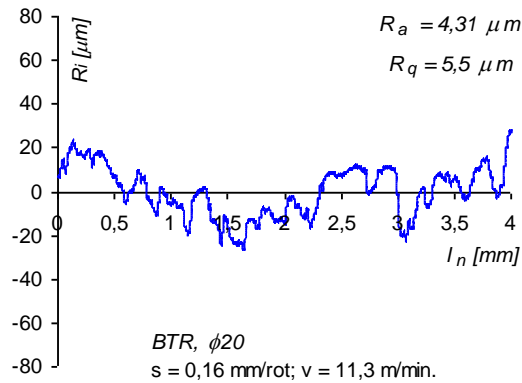


Figure 16: BTR Ø20; $s = 0,16$ mm/rot; $v = 11,3$ m/min

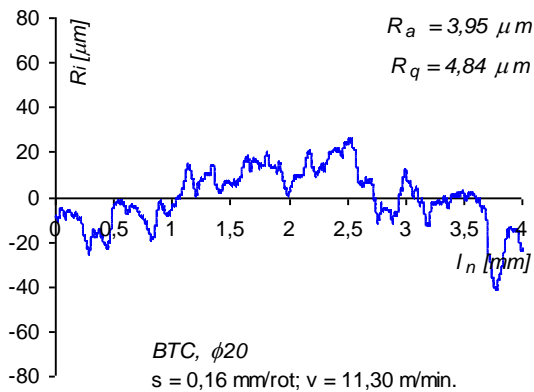


Figure 17: BTC Ø20; $s = 0,16$ mm/rot; $v = 11,3$ m/min

The measurements show that, when working with curved edge drills, roughness of the generated surface (criterion R_a) is lower, in the same working conditions, that when working with standard drills.

3.3. Experimental aspects on determining axial force and torque when drilling

In order to establish the dependency between axial force and drill diameter, as well the dependency between cutting torque and drill diameter, we used 3 helical drills HSS with straight edges (with diameters of Ø20mm, Ø18mm and Ø16mm) and 3 HSS drill with curved edges, in the range of diameters.

The machined samples were made from 16MnCr5, of Ø50x70 mm, and A570, of 90x50x50 mm.

The equipment use in the experimental research of axial force and of torque moment when drilling were the drilling machine 6GM-A1 and the part of data acquisition made from the strain gauge mass Kistler 9272 – fig. 18, an electronic amplifier Kistler 5070Ax01xx, connection cables (Kistler 1677A5 și 1678A5) and the computer with the acquisition data board.



Figure 18: Sample reinforcing – adapter piece – dynamometer

The tests were made in dry cutting conditions, the values of depth for the holes (at the most $1,5D$, in which D – drill diameter) being correlated during acquisition (chosen of 10 and 7 seconds).

The working parameters, for tested samples, were established according to table 3.

Table 3: Working parameters

Drills	V_c [m/min]	V_f [mm/min]	s [mm/rot]
BTR-BTC/20	17,6	44,8	0,16
BTR-BTC/18	15,8	70	0,25
BTR-BTC/16	14,1	115	0,4

The work rotation used was of 280 rot/min. According to the dynamometer reference system there were measured the cutting force F_z , on the direction of axis Z and torque M_z , around the axis Z – see figure 19.



Figure 19: Kistler 9272 dynamometer reference system

In tables 4-7, medium values of axial force and torque are presented, the interval of selection for the calculation is considered to be the area where the helical drills have their work load.

Table 4: Axial force values F_z [N] when processing A570 material

A570	$D_{\text{drill}} = \text{Ø}20 \text{ mm}$ s [mm/rot]			$D_{\text{drill}} = \text{Ø}18 \text{ mm}$ s [mm/rot]			$D_{\text{drill}} = \text{Ø}16 \text{ mm}$ s [mm/rot]		
	0,16	0,25	0,4	0,16	0,25	0,4	0,16	0,25	0,4
BTR	922,63	1108,16	1468,44	844,73	915,54	1303,43	747,13	874,41	1198,01
BTC	724,9	920,72	1228,46	635,76	807,42	1027,11	590,96	720,04	969,95

Table 5: Torque values M_z [N·m] when processing A570 material

A570	$D_{\text{drill}} = \text{Ø}20 \text{ mm}$ s [mm/rot]			$D_{\text{drill}} = \text{Ø}18 \text{ mm}$ s [mm/rot]			$D_{\text{drill}} = \text{Ø}16 \text{ mm}$ s [mm/rot]		
	0,16	0,25	0,4	0,16	0,25	0,4	0,16	0,25	0,4
BTR	26,27	36,22	53,55	24,06	30,87	46,57	17,53	24,15	34,95
BTC	41,81	56,31	70,31	36,69	40,79	55,87	25,84	34,17	41,35

Table 6: Axial force values F_z [N] when processing 16MnCr5 material

16MnCr5	$D_{\text{drill}} = \text{Ø}20 \text{ mm}$ s [mm/rot]			$D_{\text{drill}} = \text{Ø}18 \text{ mm}$ s [mm/rot]			$D_{\text{drill}} = \text{Ø}16 \text{ mm}$ s [mm/rot]		
	0,16	0,25	0,4	0,16	0,25	0,4	0,16	0,25	0,4
BTR	679,07	925,25	1244,4	653,04	882,62	1107,37	567,7	729,85	998,02
BTC	654,68	805,16	1108,24	597,52	776,11	1013,8	531,54	644,69	877,69

Table 7: Torque values M_z [N·m] when processing 16MnCr5 material

16MnCr5	$D_{\text{drill}} = \text{Ø}20 \text{ mm}$ s [mm/rot]			$D_{\text{drill}} = \text{Ø}18 \text{ mm}$ s [mm/rot]			$D_{\text{drill}} = \text{Ø}16 \text{ mm}$ s [mm/rot]		
	0,16	0,25	0,4	0,16	0,25	0,4	0,16	0,25	0,4
BTR	22,02	27,27	52,48	17,68	25,37	40,62	14,81	18,58	34,91
BTC	26,17	61,91	65,24	22,77	47,51	59,42	16,21	37,09	41,46

In figures 20÷23, profiles for the axial force and for the torque in time are presented, as an example.

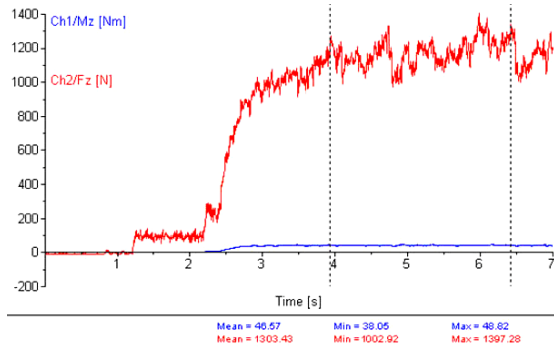


Figure 20: A570, BTR Ø18, s=0,4 mm/rot

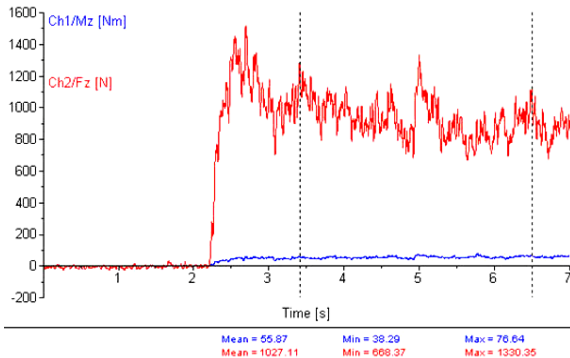


Figure 21: A570, BTC Ø18, s=0,4 mm/rot

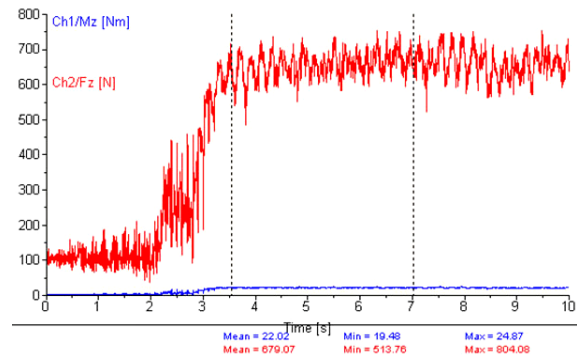


Figure 22: 16MnCr5, BTR Ø20, s=0,16 mm/rot

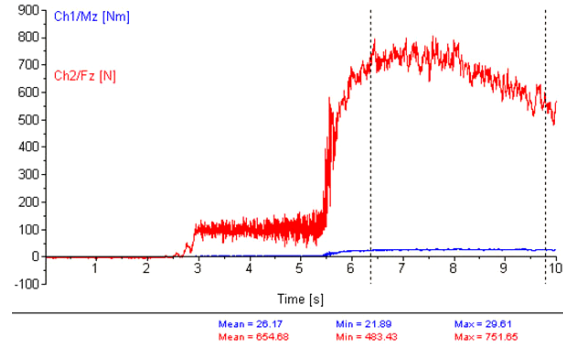


Figure 23: 16MnCr5, BTC Ø20, s=0,16 mm/rot

4. Conclusions

Verifying the quality in cutting for multi-flute drills with hyperboloidal sharpening surface (in relation to straight cutting edge drills) targeted:

- drill wear;
- quality of the cutting surface;
- determination of forces and cutting moment sizes.

Experimental data prove that: curved edge drills ensure a higher resistance, criterion V_B , in relation to straight edge drills, as a result of energy load per unit, equal along the edge; roughness of generated surfaces when processing with curved edge drills, criterion R_a , is lower than when working with standard drills in the same conditions, cutting speed and feed. At the same time, three curved edge drills need a driving moment bigger than the one needed for straight edge drills, in a similar work environment, axial forces being lower as compared to standard drills.

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