Influence of the process conditions on the roundness deviation of cylindrical holes produced by abrasive water jet cutting

Wpływ wybranych warunków procesu cięcia strugą wodno-ścierną na odchyłkę okrągłości otworów cylindrycznych wykonanych technologią AWJ

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This paper discusses experimental results concerning the geometric accuracy of cylindrical holes. The input variables were the cutting speed, the distance between the abrasive water jet nozzle and the workpiece, and the abrasive mass flow rate. The output variables were roundness deration, which were measured in three sections. The holes made in aluminum alloy by a high-pressure jet of water containing almandine garnet as an abrasive substance.

KEYWORDS: abrasive water-jet cutting, cutting parameters, roundness deviation

Striving for a better quality of cut surfaces when reducing the number of technological operations is a developmental factor for alternative materials shaping. One of the new machining technologies of the machine parts is the high-pressure abrasive water jet cutting (AWJ) [2]. This is a technology that uses a concentrated stream of water jet energy mixed with abrasive grains. The addition of abrasive grains is expected to intensify the machining process. Due to the absence of a heat-sensitive zone, the technology is referred to as "cold", whereby the AWJ cutting has recently become an effective and attractive method of cutting materials, mainly in the case of non-heating elements [7]. In high-pressure treatment, the water-abrasive blast erosion process takes place with a slight force on the workpiece.

Cutting with the use of water-abrasive jet has many advantages. It is a universal method - it can be used to shape most materials, both thin and thick, which gives it a wide range of machining applications. At the same time, it is difficult to overcome competition for commonly used materials cutting methods [4]. The AWJ technology works very well for complex shapes.

Parameters characterizing the cutting process

The parameters characterizing the cutting process of a high-pressure abrasive-water jet can be divided into [5]: hydraulic (jet pressure, jet diameter, jet power), abrasive properties (abrasive type, abrasive granulation, abrasive efficiency) Cutting distance, end of water-abrasive nozzle from cut material).

Surface structure after abrasive cutting is usually determined visually by means of quality class indicators.

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Understanding the influence of particular parameters of the processing on the quality of the obtained intersection area will allow to develop a model of the process of cutting the examined material [3]. This will allow for eliminating technological surpluses in the form of, for example, too low feedrate or a dispensed dose. Obtaining a good or very good quality after AWJ cutting involves relatively large and unnecessary cutting costs, which should be minimized.

Methodology of research

The purpose of the study was to determine the influence of selected conditions of the high-pressure abrasive-water jet cutting process, such as feed speed (*v*), the distance of the water-abrasive nozzle from the surface of the cut material (*s*), and the mass of the metered abrasive (m_a) AWJ on the roundness deviation value of cylindrical holes cut by means of AWJ method.

▪ **Subject of study**. The performance of the cutting process, in addition to the machining parameters, is also influenced by properties of the material to be machined, among which the thickness of the material to be cut and the erosion resistance are the most commonly mentioned.

The study used a 15 mm thick sheet made of aluminum alloy EN AW-2007. It is characterized by good strength properties and very good machinability. In addition, this material has high fatigue strength. Table I shows the normative chemical composition of the test material.

TABLE I. Chemical composition of aluminum alloy EN AW-2007 [6]

Chemical composition of aluminum EN AW-2007 %						
Cu	Pb	Mg	Mn	Fe	Si	Zn
3,3-4,6	0,8-1,5	0,4-1,8	0,5-1,0	max 0,8	max 0,8	max 0,8

▪ **Test conditions**. In the cutting process, a set of 0.30 mm diameter water nozzle and a 1.02 mm diameter and 75 mm long forming nozzle were used. The tests were carried out at a pressure of 280 MPa. The abrasive material used in the cutting process was garnet # 80 E.

Experimental studies were carried out in accordance with Box-Behnken's plan. This plan assumes a mutual investigation of the impact of three input factors with three levels of code values onto the baseline values. The range of input parameters in the experiment was determined on the basis of literature analysis and own research.

During the experiment, 30 mm diameter holes were cut in the aluminum alloy plate [1]. Measurements of hole diameter values were made using the Prismo Navigator coordinate measuring machine. During measurement, a contact ball with a diameter of 2 mm, traveling at 5 mm/s, was used.

Results and analysis

Table II lists values of input parameters and results of measurement of holes roundness deviation. Circular deviation measurements were carried out in three sections: P1 - measurement 2 mm below the jet inlet of the cut material, P2 - measurement in the center of the material to be cut, P3 - 2 mm measurement above the jet of the cut material.

TABLE II. Study plan and measurement results

No. of expo sure	Input parameters			Roundness deviation		
	v, mm/min	*s*, mm	m_a, g/min	*P1*, µm	*P2*, µm	*P3*, µm
1	20	2	340	35,1	35,6	39,6
2	100	2	340	69,8	80,3	115,2
3	20	6	340	38,1	40,0	51,0
4	100	6	340	86,4	86,0	131,8
5	20	4	230	41,2	42,6	46,1
6	100	4	230	76,5	103,1	175,8
7	20	4	450	34,9	37,8	40,2
8	100	4	450	49,8	54,3	80,4
9	60	2	230	38,2	47,0	78,3
10	60	6	230	45,3	58,5	89,1
11	60	2	450	36,0	41,0	61,4
12	60	6	450	42,8	52,4	80,2
13	60	4	340	41,3	42,7	66,8
14	60	4	340	42,1	44,0	69,9
15	60	4	340	42,5	44,2	69,3

Dependence of the output parameters as a function of the input parameters is presented in Table III in the form of partial correlation coefficients. The correlation for which condition k>|0.5| is fulfilled, is significant. In the case of negative correlation, the increase in the value of the input parameter decreases the value of the parameter.

The strongest linear correlation was obtained for parameter *v*, for section P3. The input parameters *s* and m_a have (negative correlation), due to determined value, are not significant correlations. The value of a square (nonlinear) effect in any case does not reach the assumed significance condition.

TABLE III. Coefficients of partial correlations determined for the examined sections

Input parameter	Correlation coefficient		
	P1	*P2*	*P3*
v(L)	0,78	0,79	0,83
v(Q)	-0,41	-0,33	-0,16
s(L)	0,20	0,16	0,15
s(Q)	-0,07	-0,06	-0,03
$m_a(L)$	-0,22	-0,31	-0,32
$m_a(Q)$	0,17	-0,03	-0,05

The figure shows the effect of roundness deviation values of cylindrical hole as a function of the parameters *v* and *s* (at a fixed value m_a = 340 g/mm) for section P3. The analysis of the graph indicates that with the increase of parameter *v* in the range of its variability, the value of its roundness deviation increases almost linearly. On the other hand, the change in parameter *s* has little effect on the test deviation.

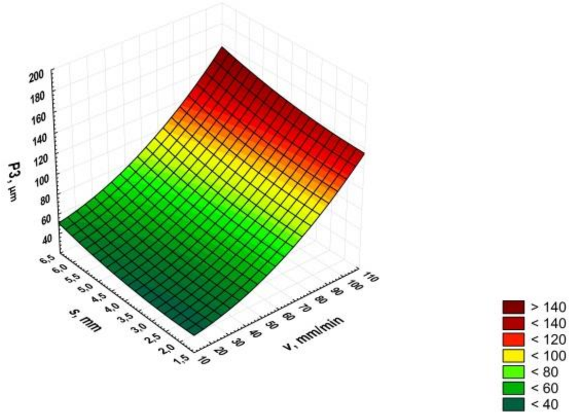

Fig. Surface roundness deviation curve plot for P3 cross-section with respect to *V* in mm/min and *s* in mm (for m_a = 340 g/min)

Conclusions

The obtained values of partial correlation coefficients for the linear effects confirm the significant influence of parameter *v* on the resulting value of the roundness deviation for the examined sections. This is a significant positive correlation, which for the P3 cross-section reaches value of 0.83.

Input parameters *s* and m_a in the test interval less affected the roundness of the cylindrical holes. There were no significant correlations in this case. As the parameter increases, the roundness deviation decreased.

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