INVESTIGATION OF SURFACE ROUGHNESS IN HYDROABRASIVE MACHINING DEPENDING ON CHANGES IN ABRASIVE GRAIN SIZE AND PRESSURE

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Abstract

The article investigates the surface roughness generated on HARDOX-500 chromium-nickel steel blanks in hydroabrasive machining as a function of changes in abrasive grain sizes. The study examines the intervals of roughness variation based on various technological, kinematic, structural, and processing environment factors, and identifies optimal roughness values. Experimental results indicate that as the granularity of abrasive grains increases, the surface roughness on the cut surface of the blanks also increases. However, as the pressure of the water-abrasive mixture and the consumption of abrasive grains rise, the height of the resulting surface roughness decreases.

Keywords: hydroabrasive machining, steel blanks, abrasive grains, surface roughness, regression coefficient, granularity, pressure.

I. Introduction

Chromium-nickel alloyed steels of the HARDOX-500 grade find extensive application in various fields of mechanical engineering, including the aerospace, shipbuilding, and other sectors. The alloying of steel with up to 1.5% chromium and nickel enhances its resistance to bending, wear, and friction, but also complicates its mechanical processing to some extent. Therefore, performing cutting operations on HARDOX-500 steel blanks using the hydroabrasive method can improve productivity and quality parameters in the production of machine parts. In this process, steel sheets and blanks are cut by a waterjet mixed with abrasive particles, applied to the surface of the processed blank at high pressure (3500 bar) on a specialized machine [1]. Depending on the thickness of the cut blank, the surface roughness and wave patterns produced in hydroabrasive cutting can vary across the height of the cut surface [11]. Studies have shown that the formation of geometric surface features is influenced by the physical and technological characteristics of the hydroabrasive cutting process, cutting parameters, as well as the physical-mechanical properties and composition of the material being processed. Thus, examining the roughness, waviness, and other geometric parameters of hydroabrasively cut surfaces in HARDOX-500 steel blanks is one of the relevant challenges in the mechanical engineering industry [2].

One of the primary objectives of studying surface roughness and waviness in the hydroabrasive cutting of chromium-nickel steel is to efficiently determine the sequence of preliminary mechanical processing technology for parts to be manufactured from these blanks. By analyzing the topography of roughness and form errors on the cut surface, we can evaluate the resulting geometric features and irregularities to ensure proper control over the chip formation process when directing abrasive particles onto the blank surface with a waterjet across the cut thickness in HARDOX-500 steel [3-5].

Theoretical research has indicated that explaining the formation of quality parameters in manufacturing machine parts from hard-to-process chromium-nickel materials using hydroabrasive cutting is theoretically complex. Therefore, experimentally studying the output parameters and synthesizing these findings with theoretical results is crucial for determining the optimal technological parameters for hydroabrasive cutting. Experimental studies examine quality parameters such as surface roughness (R_a), (R_z), dimensional accuracy (Δ), microhardness of the processed surface (H_μ), processing time (t), processing efficiency, and other factors [2, 6-9].

The symbols and units of measurement for the parameters given in the article are provided in the table 1.

Table 1: *Symbols and Units of Measurement for Parameters*

R_a [μm]	arithmetic average roughness
Rz [μm]	mean roughness depth
Z [μm]	abrasive particle size
P [Mpa]	pressure of the water-abrasive jet
Q [g/l]	abrasive consumption
S_{long} [mm/min)	feed rate
H_μ [μm]	microhardness of the processed surface
t [sec]	processing time
Δ [μm]	dimensional accuracy

Several articles dedicated to the study of the problem posed by us have been published in periodicals.

In abrasive waterjet processing, surface roughness depends on cutting parameters, including the pressure of the water-abrasive jet, the feed rate of the mixture in the cutting zone, the variation speed of the longitudinal feed movement of the nozzle or workpiece, the thickness of the workpiece, and other factors. Accordingly, experimental research has been conducted on surfaces processed with a FLOW-Gut model CNC-controlled abrasive waterjet machine in the "Metal-Cutting Machines" Department at Brandenburg University, Germany, using various devices based on a methodology developed for these experimental studies.

The research has shown that the surface roughness of a workpiece processed by abrasive waterjet cutting varies significantly depending on the thickness of the workpiece. Given the sharp variations in cross-sectional shape and dimensions as the thickness of the workpiece changes, examining the resulting surface roughness enables an exploration of the technological capabilities of this operation [9].

Purpose of the study. The study investigates the surface roughness obtained in the cross-section during the abrasive waterjet cutting of HARDOX-500 steel workpieces with thicknesses of 5, 10, and 15 mm, focusing on the effects of variations in abrasive particle size, granularity, abrasive consumption, and the pressure of the water-abrasive jet.

II. Methodology

The investigation involves studying the surface roughness obtained during the abrasive waterjet cutting of workpieces with thicknesses of 5 mm, 10 mm and 15 mm, using a feed rate of S_{long}=26,7 mm/min, an abrasive particle size of 80÷200 μm, and an abrasive consumption of

Q=125g/l, while varying the pressure of the water-abrasive jet from 200 Mpa to 350 MPa. This study encompasses the establishment of various curves, corresponding mathematical equations, and regression coefficients using experimental and theoretical values in an Excel program, as well as discussing the obtained results.

One of the output parameters from the conducted experiments is the roughness, which is determined with high accuracy using the "JENOPTIK" device, designed to measure the surface roughness based on the granularity of the abrasive and the longitudinal feed rate [3].

III. Discussion of the results

The surface roughness formed during the cutting of HARDOX-500 steel workpieces varies based on numerous technological, kinematic, structural, and processing environment factors. Consequently, one of the most important technological factors affecting the roughness formed on the surface during abrasive waterjet cutting is the pressure of the water-abrasive mixture applied to the cutting zone. An increase in the pressure of the water-abrasive mixture enhances the cutting capabilities of the water-abrasive, which plays the role of the cutting tool in the steel cutting process, thereby intensifying the cutting of the workpiece. Our research has determined that the study of the surface roughness dimensions in hydroabrasive machining varies widely depending on the processing conditions and regime parameters of the process. Therefore, examining the regularities of roughness changes during the machining of the selected material is one of the important tasks for identifying the advantages of the process. In this case, the roughness formed on the processed surface, depending on the optimal cutting process, has been determined through experimental research to remain within the required limits. In the experiments, a workpiece thickness of 15 mm was taken, with a longitudinal feed rate of S_{long}=26,7 mm/min, an abrasive particle size of 80 μm, and an abrasive consumption of Q=125g/l, while the surface roughness obtained during abrasive waterjet cutting [3] is shown in Figure 1, and the dependence of the obtained experimental and theoretical values on the influence of the water-abrasive jet is presented in Tables 2 and 3.

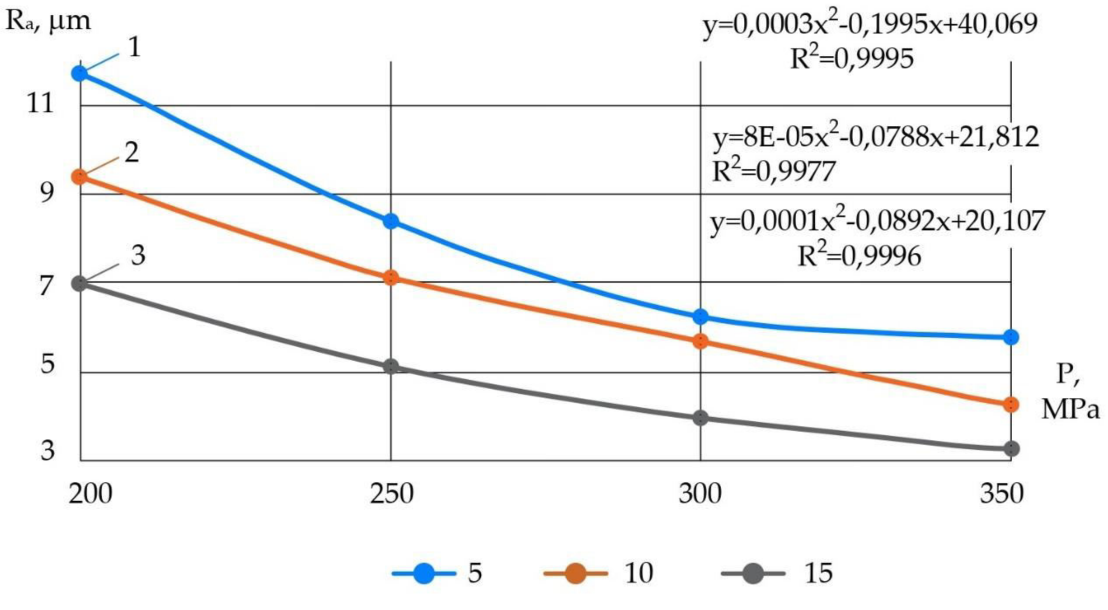

Figure 1: *Dependencies of surface roughness obtained on the cut surface during abrasive waterjet machining on the pressure of the water-abrasive jet*

Table 2: *Experimental values of surface roughness obtained on the cut surface during abrasive waterjet machining*

$00P$, [MPa]	200	250	300	350
R_{a1} ,[μm]	11,732	8,365	6,214	5,742
R_{a2} ,[μm]	9,375	7,115	5,675	4,234
R_{a3} ,[μm]	6,98	5,113	3,964	3,273

The theoretical values of surface roughness obtained on the cut surface during abrasive waterjet machining are presented in Table 3.

Table 3: *Theoretical values of surface roughness obtained on the cut surface during abrasive waterjet machining*

P_0, $[MPa]$	200	250	300	350
R_{a1} $[\mu k]$	12,169	8,944	7,219	6,994
$R_{a2}[\mu k]$	9,252	7,112	5,372	4,032
$R_{a3}[\mu k]$	6,267	4,057	2,347	1,137

The mathematical equations of the obtained graphical curves (Figure 1) are presented in equation (1).

$$\begin{gathered} R_{a1} = 40{,}069\text{-}0.1995P_0\text{+ } 0{,}0003\ P_o^2 \\ R_{a2} = 21{,}812\text{-}0{,}0788P_0\text{+ } 0{,}00008\ P_o^2 \\ R_{a3} = 20.107\text{-}0.0892P_0\text{+}0{,}0001P_o^2 \end{gathered} \tag{1}$$

Figure 1 shows that the first curve corresponds to a thickness of 5 mm, the second curve to a thickness of 10 mm, and the third curve to a thickness of 15 mm, representing the surface roughness of the cut materials as the pressure of the water-abrasive jet varies from 200 MPa to 350 MPa. As seen from the graphs, in all cutting cases, the surface roughness of the cut material decreases as the pressure of the water-abrasive jet increases from 200 MPa to 350 MPa.

Experiments reveal that as the pressure of the water-abrasive jet increases, the forces generated upon impact of the abrasive particles on the processed surface also increase, resulting in a higher number of broken particles. As the incidence of abrasive particle breakage rises, the number of sharp edges in the newly fractured abrasive particles increases, which in turn reduces the thickness of the resulting chips. Consequently, the average height of the generated surface roughness decreases.

Research has shown that as the thickness of the workpiece increases, the surface roughness in the cutting zone decreases. This can be explained by the fact that at smaller workpiece thicknesses, such as h=5mm (Curve 1), fewer abrasive particles concentrate in the cutting layer during hydroabrasive cutting, resulting in a lower number of abrasives per unit surface area. Consequently, the thickness of the chip layer removed from the surface increases, which leads to greater roughness. Additionally, with fewer abrasive particles directed at the cut, the total impact forces decrease, leading to less breakage of abrasive particles and thus a reduced likelihood of new cutting edges forming, which also contributes to increased roughness. As the thickness of the workpiece increases (e.g., to 10 mm, 15 mm), the water-abrasive jet supplied to the cutting zone does not escape beyond the contact area, resulting in an increased number of cutting particles

forming chips. Consequently, the volume of chips removed by each abrasive particle decreases, which reduces the height of the roughness. It has been observed that the trend of decreasing roughness with increasing workpiece thickness holds at all pressures of the water-abrasive jet.

One of the critical factors in the cutting of metals with free abrasive particles, i.e., in hydroabrasive cutting, is the geometric shape and size of the abrasive particles, with granularity defined according to existing standards [10, 12]. During the experiments, particles with sizes of 80 μm, 120 μm, 160 μm and 200 μm were used in the hydroabrasive process. The variation in roughness as a function of abrasive particle size is shown in Figure 2, and the experimental values for the effect of particle size on roughness are provided in Table 4. Particle size is denoted by Z, and its impact on roughness formation is studied as Z increases.

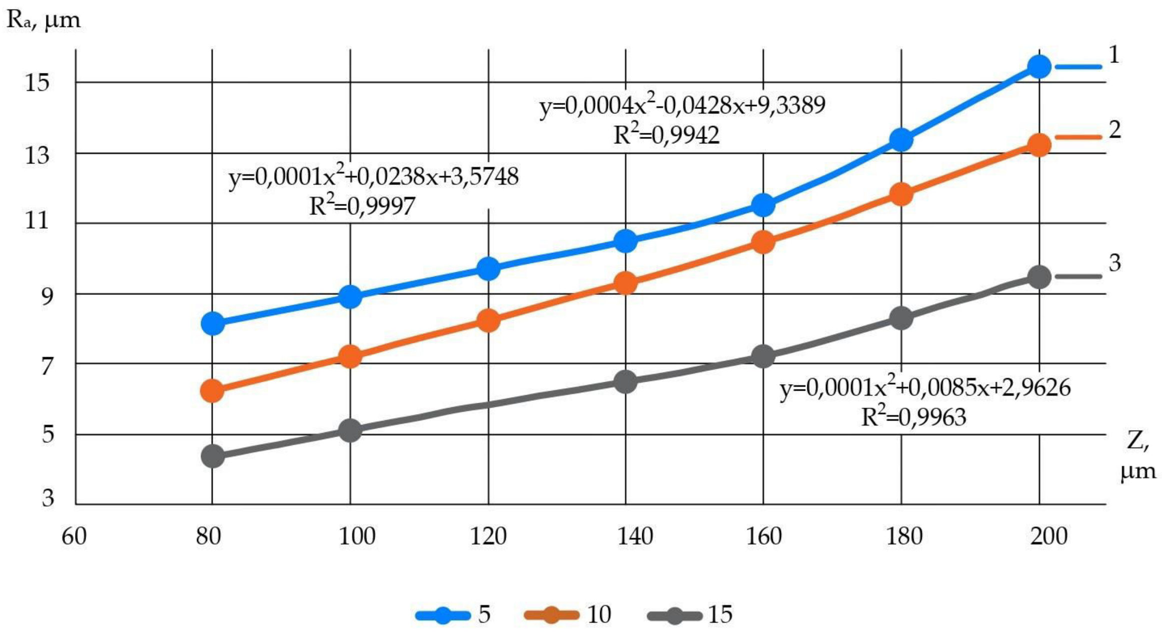

Figure 2: *Graph of the variation in roughness based on abrasive particle size and granularity*

Table 4: *Experimental values of the effect of abrasive particle size (Z μm) and granularity on roughness*

Z, [μm]	80	120	160	200
R_{a1}, [μm],h=5mm	8,16	9,743	11,564	15,485
R_{a2}, [μm],h=10mm	6,245	8,26	10,465	13,265
R_{a3}, [μm],h=15mm	4,354	5,852	7,216	9,475

The equations determined by solving the mathematical expressions of the curves based on the values in Table 4 are presented in (2).

Table 5 provides the theoretical values for the dependence of roughness on Z.

Table 5: *Theoretical values of the effect of abrasive grain size (Z) and granularity on roughness*

Z, [μm]	80	120	160	215
R_{a1}, [μm],h=5mm	8,4749	9,9629	12,7309	16,7789
R_{a2}, [μm],h=10mm	5,9149	4,2029	2,4909	0,7789
R_{a3}, [μm],h=15mm	4,2826	5,4226	6,8826	8,6626

Equations determined by solving the mathematical expressions of the curves derived from the values shown in Table 4.

$$R_{a1}\text{=}9{,}3389\text{-}0{,}0428Z\text{+}0{,}0004Z^2$$
$$R_{a2}\text{=}3{,}5748\text{+}0{,}0238Z\text{+}0{,}0001Z^2 \quad (2)$$
$$R_{a1}\text{=}2{,}9626\text{+}0{,}0085Z\text{+}0{,}0001Z^2$$

The graphs shown in the figure correspond to cutting samples with thicknesses of h=5 mm (Curve 1), h=10 mm (Curve 2), and h=15 mm (Curve 3). The dependency of the average surface roughness (R_a) on changes in abrasive particle changing from 80 μm to 200 μm has been analyzed. It has been found that, for all three thicknesses, the average roughness (R_a) increases as the abrasive grain size increases. This result is explained by the fact that as the grain size increases, the number of particles in a unit volume of the waterjet participating in the cutting process decreases sharply. As particle size increases, their geometrical dimensions increase, resulting in larger cutting edges forming the chip, which, in turn, increases the chip size in the cutting zone. Additionally, as abrasive particle size increases, their resistance to cutting forces also rises, reducing the number of particles subjected to breakage. Consequently, dulling of the abrasive particles due to edge wear becomes more prominent, making the chip formation process more challenging and leading to a higher average roughness.

Nevertheless, since the number of abrasive particles involved in cutting process decreases, the roughness height increases. Studies have shown that while the rate of increase in average roughness height is lower with smaller abrasive particles (eg., 80 μm), as particle size and workpiece thickness increase, the roughness range becomes significantly higher (see the values obtained with a particle size of 200 μm in Figures 1, 2, and 3).

Thus, for hydroabrasive cutting, it is essential to select abrasive particles of an optimal size that meets the required roughness limits. Considering that an average roughness height of 4,5 μm to 6,5 μm is typically required for machine parts made from chrome-nickel steel, it is recommended to use abrasives with particle which sizes between 80 μm and 120 μm for cutting HARDOX-500 steel parts with thicknesses of 15 mm to 20 mm. Cutting with these recommended abrasive sizes results in fine, thin chips, ensuring that the roughness of the processed surface meets the required conditions.

One of the factors influencing the formation of roughness on the cut surface in hydroabrasive processing is the mass of abrasive particles mixed with the waterjet. As the mass of abrasive particles mixed into the waterjet increases, the amount of abrasive involved in cutting also rises, thereby increasing the volume of chips removed from the contact zone per unit time in hydroabrasive processing. This is because, as the weight of the abrasive particles increases, the number of particles actively cutting at any given time also rises.

IV. Results

1. In hydroabrasive cutting, the change intervals of roughness are studied based on the size of the abrasive particles, their weight consumption, the feed rate of the cutting motion, the pressure of the water-abrasive mixture, and other factors, with optimal values determined.

2. Experimental studies have shown that as the pressure of the water-abrasive mixture and the consumption of abrasive particles increase, the height of roughness formed on the processed surface decreases.

3. Research indicates that as the granularity of the abrasive particles increases, the values of roughness formed on the cut surface of the workpiece in hydroabrasive cutting rise, which is why it is recommended to select abrasive particle which sizes between 80 μm and 125 μm for this process.

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