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SURFACE ANALYSIS OF METAL MATERIALS AFTER WATER JET ABRASIVE MACHINING

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Abstract

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In this article, we deal with a progressive production technology using the water jet cutting technology with the addition of abrasives for material removal. This technology is widely used in cutting various shapes, but also for the technology of machining such as turning, milling, drilling and cutting of threads. The aim of this article was to analyse the surface of selected types of metallic materials after abrasive machining, i.e. by assessing the impact of selected machining parameters on the surface roughness of metallic materials.

Keywords: abrasive water jet, mechanical properties, metallic materials, machining parameter, workpiece shape, technology, roughness, cutting

INTRODUCTION

In engineering practice, it is necessary to deal with the machining technology and to solve material problems arising from conflicting demands on the final product properties. The necessity for this creative activity is understanding the physical basis of materials and methods of influencing these materials. Nowadays, it is necessary to find a compromise solution, to take into account various factors such as economic opportunities, the technology and ecology of production. It is important to examine the effect of machining on functional surfaces and mechanical properties of metallic materials (Wilkins and Graham, 1993; Hloch and Valíček, 2009; Fabianová, 2007; Hascalik *et al.*, 2007; Khan and Hague, 2007; Jegaraj and Babu, 2005; Wang and Wong, 1999; Palleda, 2007; Azmir and Ahsan, 2009).

The aim of the article was (1) to analyse the surface of selected metallic materials of steel and aluminium after abrasive water jet machining, (2) to explore the relationships when applying different parameters of cutting speeds, the amount of abrasive particles in different depths and thicknesses of materials, and (3) to monitor the impacts of different parameters on surface roughness of machined surface. In this article, we analyse the effect of individual parameters on machined surface roughness.

MATERIALS AND METHODS

Splitting Head FLOW PASER ECL Plus

The splitting head FLOW PASER ECL Plus shown in Fig. 1 ensures an optimum splitting power, the highest splitting rate at the lowest operating cost. The splitting head allows splitting all materials with pure water or water jet with an addition of abrasive while reaching the high quality of splitted areas.

With an active control of tolerance, components are produced at significantly higher speeds of splitting. This revolutionary method of splitting opens new possibilities in the manufacturing of tools, moulds and manufacturing of precision components.

1: *Splitting head FLOW PASER ELC Plus*
Source: own photo

Roughness Meter Surftest 301 Mitutoyo

The values of surface roughness of selected materials were measured with the roughness meter Surftest 301Mitutoyo shown in Fig. 2.

2: *Roughness meter Surftest 301 Mitutoyo*
Source: own photo

The roughness meter Surftest 301 Mitutoyo is a high-power roughness meter (Hloch and Valíček, 2009), it has an internal printer and a large LCD touch screen.

The measuring diamond centre with a sensor moves along the surface of the sample. Using an A/D converter, surface roughness or deviations of the centre are converted into a digital signal, which is processed in the evaluation device. Additional accessories include a cable for the RS232 interface, built-in battery pack, and the Elcometer 7060 software.

Samples

Two materials were chosen when assessing the quality of the surface after water jet cutting with the addition of abrasives. The first was the steel 11 373. It is an unalloyed structural steel of usual qualities suitable for simpler parts of machines of smaller thicknesses, loaded slightly statically and dynamically. The chemical composition of the steel 11373 is shown in Tab. I. It is used for water intake of water turbines, floodgates, less stressed welded pipes, flat, vaulted and lined high-pressure bottoms. The mechanical properties of this steel are given in Tab. II. Breaking strength is R_m = 340–470 MPa, and ductility is A = 25% (Dashöfer Holding, 2009).

The second material is aluminium 4413 or aluminium alloy AlMg3 used in the food and chemical industries, in engineering, for the construction of vehicles and ships, for load-bearing structures, heat exchangers, protecting covers and the elements of internal and external architecture. The chemical composition of aluminium alloy 4413 is described in Tab. III. It is a medium-hard material (R_m = 140–150 MPa), with very good resistance to corrosion, sea water and tropical conditions. It has very good chemical resistance, polishability and good weldability by

I: *Chemical composition of steel 11 373*

Steel 11 373	C	Mn	Si	P	S	N	Al
%	max. 0.170			max. 0.045	max. 0.045	max. 0.007	

II: *Mechanical properties of steel 11 373*

Mechanical properties	Format	
	Without heat treatment	Normalisation
Tensile strength R_m [MPa]	min. 370	min. 350
Yield point [MPa]	min. 250	min. 220
Ductility A_{10} [%]	min. 7	min. 20

III: *Chemical composition of aluminium alloy 4413 ($AlMg_3$)*

$AlMg_3$	Si	Fe	Cu	Mn	Mg	Zn	Ti	Fe + Si	Sb
%	0.50	0.40	0.10	0.05–0.40	2.60–4.00	0.20	0.20	0.60	0.25

IV: *Mechanical properties of aluminium alloy 4413 ($AlMg_3$)*

Tensile strength [MPa]	Yield point	Ductility [%]	Hardness [HBS]	Electrical conductivity [S]	Thermal conductivity [$W \cdot m^{-1} \cdot K^{-1}$]	Specific weight [$g \cdot cm^{-3}$]
190–240	---	min. 80	50	20–23	140–160	2.66

V: *Weight flow of abrasive in measured points*

	Weight flow of abrasive [g·min^{-1}]				
Area	A	B	C	D	E
Steel 11 373	495	410	325	240	155
Aluminium 4413 $AlMg_3$	495	410	325	240	155

all means. The mechanical properties are shown in Tab. IV. The machinability with cutting tools is unsatisfactory in a soft state but satisfactory in harder material. Ductility is A = 5%; the hardness is indicated by 50 HBS (Lexikón kovov, 2009).

Experiment

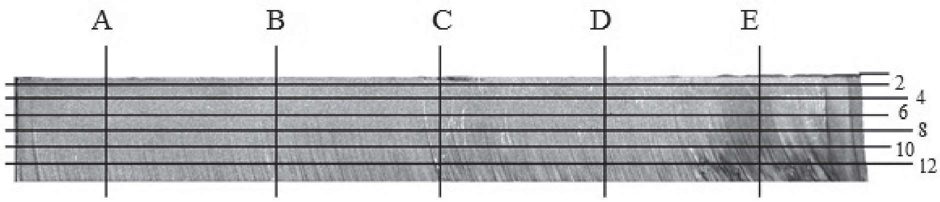
Dependence of Weight Flow of Abrasive for Constant Cutting Speed

The aim of measurement was to verify the dependence of profile roughness on the weight flow of abrasive for the constant feed speed of the cutting head (Fabianová, 2007; Hascalik *et al.*, 2007). Two different materials – steel 11 373 with a thickness of 15 mm and aluminium 4413 (AlMg3) with a thickness of 15 mm were cut using the water jet with abrasive. On both samples, five measurement points (A, B, C, D, E) were determined (as shown in Fig. 3). In these areas, the amount of added abrasive was changing during cutting (Tab. V).

In the samples cut this way, the roughness of the machined surface was measured using the measuring instrument Surftest 301 Mitutoyo (Fig. 2). Measurements were performed in the five areas, in the direction of cut through the material, in depths (2, 4, 6, 8, 10, 12) mm from the edge of the sample where the abrasive water jet was entering into the material. The measured roughness values are recorded in Tab. V and Tab. VI.

Chosen parameters of cut:

Pressure of cutting fluid	375 MPa,
Water amount	3.42 l·min^{-1},
Nozzle diameter	0.33 mm,
Weight flow of abrasive	155–495 g·min^{-1},
Diameter of abrasive nozzle	1.016 mm,
Distance from material	0.5588 mm,
Type of abrasive material	Indian garnet,
Grain size of abrasive	MESH 80,
Cutting speed	40 mm·min^{-1}.



3: *Indication of measuring area and depth of cut*

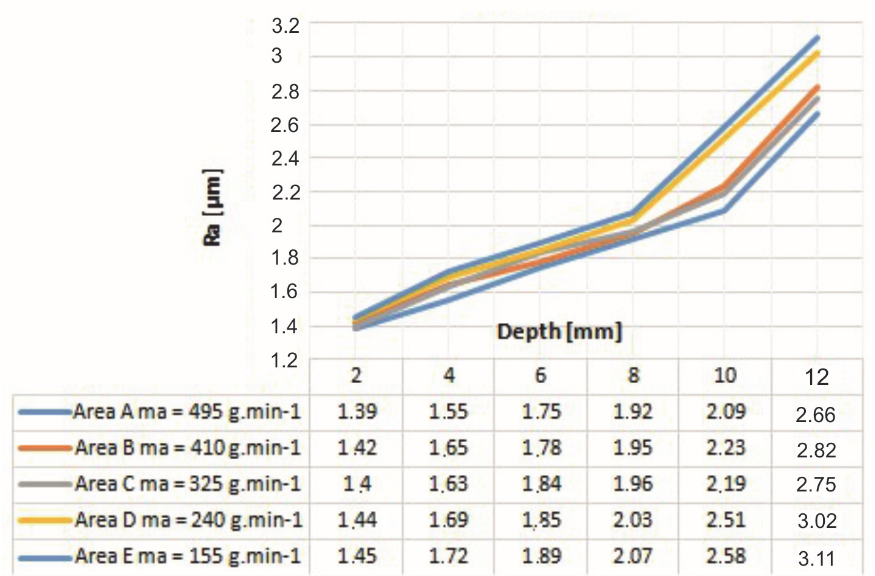
VI: *Measured values of roughness R_a of steel 11 373*

Steel 11 373	Ra [µm]				
Depth of cut [mm]	A	B	C	D	E
2	1.39	1.42	1.40	1.44	1.45
4	1.55	1.65	1.63	1.69	1.72
6	1.75	1.78	1.84	1.85	1.89
8	1.92	1.95	1.96	2.03	2.07
10	2.09	2.23	2.19	2.51	2.58
12	2.66	2.82	2.75	3.02	3.11

CONCLUSION

Figs. 4 and 5 show the effect of the weight flow of abrasive on the R_a value in different depths of cut. From the measured values that were plotted in graphical relationships it is evident that with a decreasing amount of added abrasive into the water jet the R_a value is growing. This is not true for the roughness of profile, which was measured in all the areas in the depth of 2 mm. The obtained roughness R_a values of the sample of aluminium 4413 were in the range of 0.19–0.24 µm, and for the sample of steel 11 373 in the range of 1.39–1.45 µm, independently of the amount of added abrasive, and that applies to both cut materials.

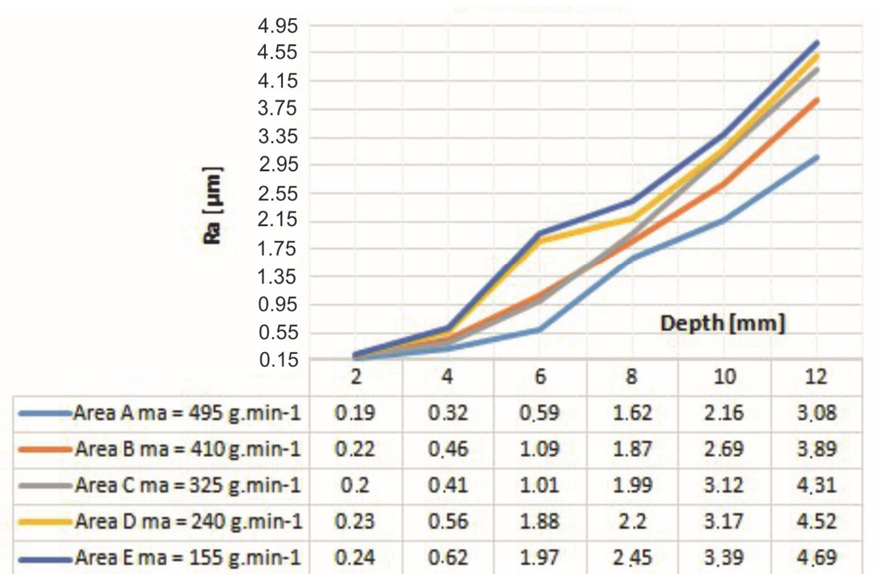
However, with increasing depth of measurement and decreasing amount of added abrasive such profile roughness is growing. Both graphs show that after using a larger amount of abrasive, higher roughness values are reached, which may be due to measurement inaccuracy, or by using a large



4: *Effect of the depth and weight flow of abrasive on roughness R_a for the steel 11 373*

VII: *Measured values of roughness R_a for aluminium 4413 ($AlMg_3$)*

$AlMg_3$			**Ra [μm]**		
Depth of cut [mm]	**A**	**B**	**C**	**D**	**E**
2	0.19	0.22	0.20	0.23	0.24
4	0.32	0.46	0.41	0.56	0.62
6	0.59	1.09	1.01	1.88	1.97
8	1.62	1.87	1.99	2.20	2.45
10	2.16	2.69	3.12	3.17	3.39
12	3.08	3.89	4.31	4.52	4.69



5: *Effect of depth and weight flow of abrasive on roughness R_a for aluminium 4413 ($AlMg_3$)*

(critical) amount of abrasive, where abrasive particles collide in the mixing nozzle itself, resulting in the reduction of cutting properties of abrasive water jet.

It follows from the experiment that roughness values vary with the depth of penetration of the abrasive water jet into the material, because the jet loses its kinetic energy, decelerates and deflects. The values of roughness in the top and bottom working zone are different, depending on the weight flow and depth of cut. The surface roughness of machined materials also depends on the angle of incidence or collision of particles (water jet). The structure of the material in the cutting zone is mainly influenced by the resistance of material determined by its mechanical properties such as hardness and feed speed of water jet.

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