

COMPARISON OF SURFACE ROUGHNESS QUALITY CREATED BY ABRASIVE WATER JET AND CO₂ LASER BEAM CUTTING

Michal Zeleňák, Jan Valíček, Jiří Klich, Petra Židková

Original scientific paper

This paper deals with an evaluation of the surface roughness quality created by abrasive water jet and by CO₂ laser, in terms of influence of the selected technological parameters on the final quality of machined surfaces. The main objective of these experimental studies was to consider the use of both technologies for cutting of difficult to cut materials. Experiments presented in the paper were carried out on titanium ASTM B265-99 samples. The machined surfaces of samples were measured by an optical profilometer. Subsequently, selected topographical characteristics were studied. The obtained data were used for comparison of surface roughness parameters R_a in different depths. Based on achieved results the comparison of both technologies was made.

Keywords: abrasive waterjet cutting, CO₂ laser beam cutting, optical profilometry, titanium sample

Usporedba kvalitete hrapavosti površine ostvarene rezanjem abrazivnim vodenim mlazom i CO₂ laserskim zrakama

Izvorni znanstveni članak

Ovaj se rad bavi procjenom kvalitete površinske hrapavosti ostvarene abrazivnim vodenim mlazom i CO₂ laserom, s obzirom na utjecaj odabranih tehnoloških parametara na završnu kvalitetu obrađenih površina. Glavni cilj ovih eksperimentalnih istraživanja bio je razmotriti uporabu obje tehnologije za rezanje materijala koji se teško režu. Eksperimenti prezentirani u radu provedeni su na uzorcima titana ASTM B265-99. Obradene površine uzoraka mjerene su optičkim profilometrom. Nakon toga, proučene su odabrane topografske značajke. Dobiveni podaci su korišteni za usporedbu hrapavosti površina parametara R_a u različitim dubinama. Napravljena je usporedba obje tehnologije na temelju postignutih rezultata.

Ključne riječi: rezanje abrazivnim vodenim mlazom, rezanje CO₂ laserskim zrakama, optička profilometrija, titanski uzorak

1

Introduction

Titanium and its alloys are favourable materials due to their excellent combination of high strength - weight ratio which is maintained at elevated temperature and their exceptional corrosion resistance. They have become attractive engineering materials for a wide range of applications. The major applications are in the aerospace, mechanical, chemical, petrochemical and electronic industry. The machinability of titanium and its alloys by conventional technologies is very poor. Titanium is strongly chemically reactive at the cutting temperature of 500 °C with almost all tool materials available. Micro - welding at the place of the cut is often caused by this undesirable property of titanium. One of the ways how to increase productivity of the cutting processes is an implementation of progressive technologies [1, 2].

Abrasive water jet (AWJ) and CO₂ laser beam are one of the most recently developed progressive manufacturing technologies. They are increasingly used in the industry due to their various distinct advantages over other conventional cutting techniques. They have been used for a wide range of material processing applications such as 2D cutting, drilling, turning and surface modification (roughening, engraving etc.) [3, 4].

AWJ cutting process represents cold, precise cutting with minimal thermal load. This technology covers requirements for quality and manufacturing productivity and can be applied under fully automated production workplaces with automatic CNC control. It is also suitable for cutting of difficult shapes, which are not possible to be cut by a saw. The mixture of water (water is used as an accelerating medium) and abrasive particles causes the cutting itself. A detail of the abrasive water jet

cutting head with important technological parameters is illustrated in Fig. 1.

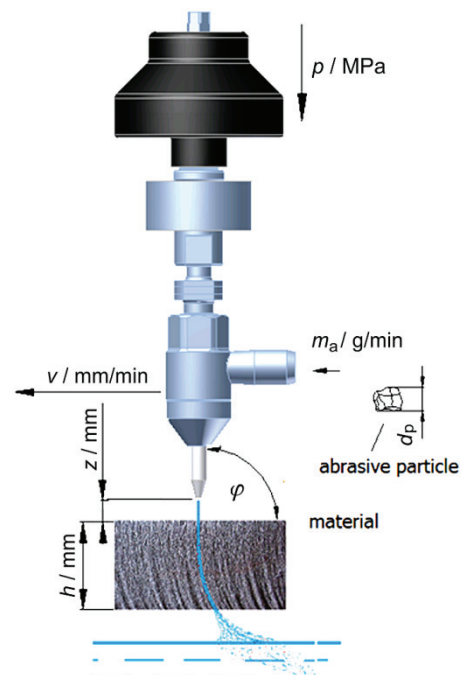


Figure 1 Abrasive water jet – detail of the cutting head

CO₂ laser cutting is a relatively new technology. The CO₂ laser is based on a gas mixture in which light is amplified by carbon dioxide (CO₂), helium (H₂) and nitrogen (N₂) molecules. The laser beam is focused onto the material surface. The focused beam heats the material surface and causes the formation of high melting capillary passing through a material. The power of laser is used to cut various thicknesses of materials. The CO₂ lasers are widely used to cut and weld metals such as stainless steel,

aluminium, copper etc. The cutting process is fully automated by a CNC control system. Fig. 2 shows a detail of the cutting head with factors important for cutting [6].

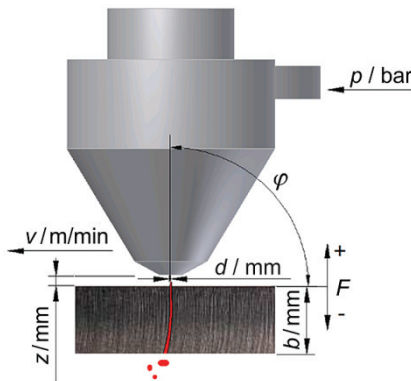


Figure 2 CO₂ laser beam cutting – detail of the cutting head

2 Current state of the art

The quality of surfaces created by AWJ and CO₂ laser is affected by several factors. Generally, all these factors can be divided into two groups, i.e. input factors and output parameters. The input factors are given by operational properties of the used device and set up of technological parameters. Output parameters are the result of cutting process. The goal is to determine the best result of final surface quality, which depends mainly on the adjustable parameters of both used technologies. Fig. 3 shows the basic input factors and output parameters of AWJ and CO₂ laser cutting. Parameters that mostly affect the surface roughness are marked with a dark colour. The main objective of this paper is to compare both cutting techniques (AWJ and CO₂ laser beam cutting) in terms of evaluation of the surface quality for the selected traverse speeds and other technological parameters.

Fig 4. shows comparison of traverse speeds for AWJ technology versus CO₂ laser technology for different alloys commonly used in mechanical industry (thickness 10 to 20 mm). The ranges of speeds for titanium alloys are similar for both technologies (see Fig. 4), but the question is which technique produces better quality of cut wall [7].

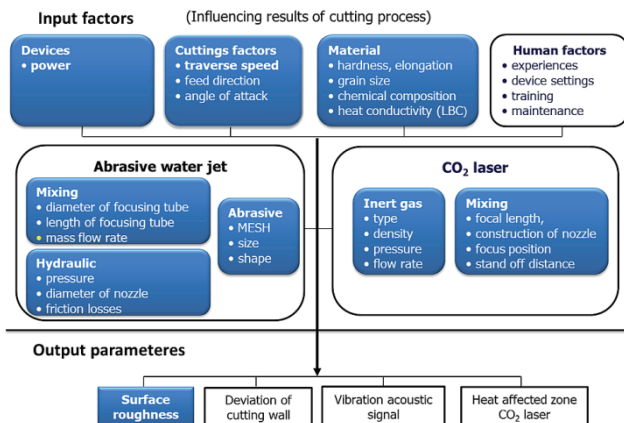


Figure 3 Classification of technological parameters

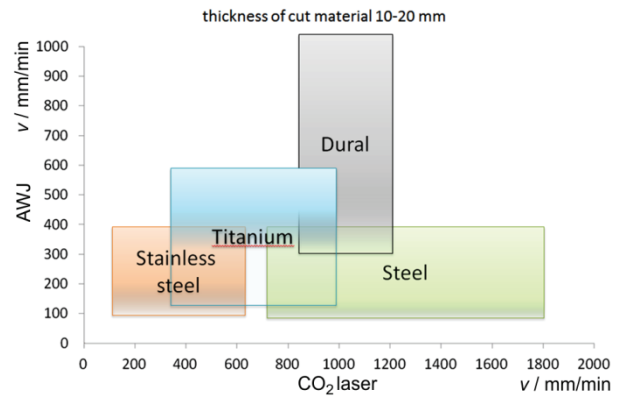


Figure 4 Comparison of traverse speeds AWJ versus CO₂ laser cutting

3 Experimental conditions and results

Unalloyed titanium with the specification ASTM B265-99, supplied in annealed condition was selected as an experimental material. Chemical and mechanical properties of the used titanium alloy are given in Tab. 1.

Table 1 Chemical and mechanical properties of ASTM B265-99

Fe	C	O	H	N
0,2 %	0,08 %	0,18 %	0,015 %	0,03 %
max	max	max	max	max
Yield strength 0,2 %		Young's module		Elongation / %
172 ÷ 310 MPa		103 GPa		25 ÷ 37

Titanium samples 60 mm long and 10 mm wide were cut from 10 mm thick rectangular plates with dimensions 70 × 100 mm using both technologies. The sample preparation is schematically shown in Fig. 5. Experimental cutting conditions are summarized in Tab. 2.

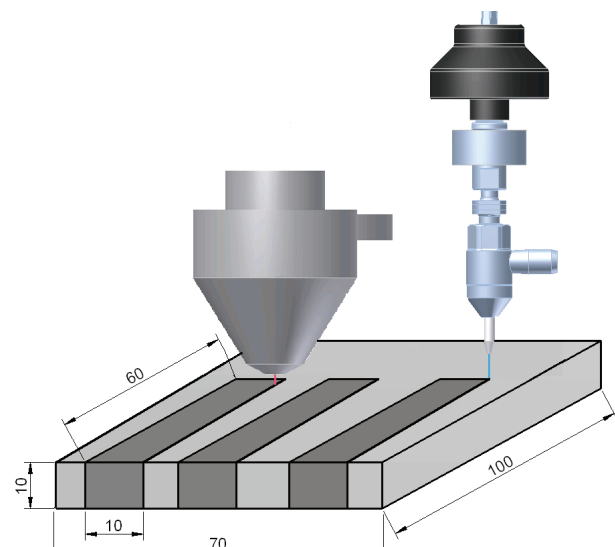


Figure 5 Schematic plan of cutting samples by AWJ and CO₂ laser beam (in mm)

As mentioned above, the AWJ cutting technology has no thermal effect on the material. During CO₂ laser cutting the material was always exposed to the thermal load. The size of heat affected zone depends on physical-mechanical properties of the cut material, heat conductivity, final depth of the material and the used

power of laser. Figs. 6 and 7 illustrate the surface quality of samples created by AWJ (without thermal load) and CO₂ laser beam (with thermal load) for different traverse speeds and other selected technological parameters. Walls created by CO₂ laser (Fig. 7) are more roughened and their roughness increases for higher traverse speeds. The similar effect can be seen on samples prepared by AWJ cutting technology. Periodical formation of waviness using both technologies was demonstrated by autocorrelation function for every sample during surface analysis (examples are given in Fig. 10).

Table 2 Experimental conditions of AWJ and CO₂ laser beam cutting

AWJ device for cutting by PTV: CNC WJ2020B-1Z-D			
Parameters	Sign	Unit	Value
water pressure	p	MPa	400
water orifice diameter	d_o	mm	0,3
focusing tube diameter	d_f	mm	0,8
focusing tube length	l_a	mm	76
abrasive mass flow rate	m_a	g/min	variable 250, 400
standoff distance	z	mm	4
traverse speed	v	mm/min	variable 350,450,550
abrasive particle	-	MESH	80
abrasive material	-	-	Australian garnet GMA
CO ₂ laser device for cutting by Prima industry: Zaphiro 2D CNC			
Parameters	Sign	Unit	Value
pressure of inert gas N ₂	p_g	bar	17
power of laser	P	W	variable 3500, 5000
traverse speed	v	mm/min	variable 350,450,550
standoff distance	z	mm	1,5
diameter of beam	d	mm	2
output speed of gas	v_g	mm/min	variable 800,500,500
type of inert gas	N ₂	-	nitrogen
Frequency	f	Hz	0
delay gas	D_g	ms	1000

AWJ technology	
Technological parameters	Photo
$v = 350$ mm/min $m_a = 250$ g/min	
$v = 450$ mm/min $m_a = 250$ g/min	
$v = 550$ mm/min $m_a = 250$ g/min	
$v = 350$ mm/min $m_a = 400$ g/min	
$v = 450$ mm/min $m_a = 400$ g/min	
$v = 550$ mm/min $m_a = 400$ g/min	

Figure 6 Photographs of surfaces after AWJ cutting

CO ₂ laser technology	
Technological parameters	Photo
$v = 350$ mm/min $P = 3500$ W	
$v = 450$ mm/min $P = 3500$ W	
$v = 550$ mm/min $P = 3500$ W	
$v = 350$ mm/min $P = 5000$ W	
$v = 450$ mm/min $P = 5000$ W	
$v = 550$ mm/min $P = 5000$ W	

Figure 7 Photographs of surfaces after CO₂ laser cutting

The topography of new surfaces created by AWJ and CO₂ laser beam cutting technologies was measured by an optical profilometer MicroProf FRT (Fig. 8) at the Institute of Geonics AS CR, v.v.i. 3D plot of surface topography was compiled from lines for every sample (the distance between lines was 0,1 mm). Subsequently, every surface was analysed in 20 spaced by 0,5 mm, starting 0,5 mm below top surface of the sample. Limit wavelength of filter cut off λ_c was set up according to EN ISO 4287 in range (0,8 ÷ 8 mm). All results were analysed in SPIP software. Fig. 9 shows examples of 3D visualization of measured surfaces in terms of comparison of the surface quality [5].

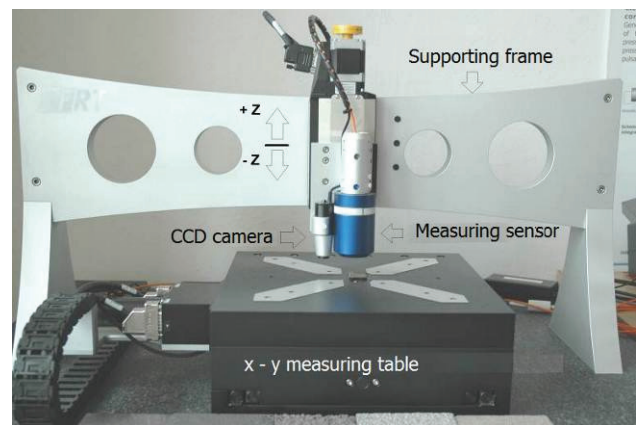


Figure 8 Optical profilometre MicroProf FRT with description of basics parts

The surface quality and identification of irregularities have been evaluated according to the average value of the roughness profile parameter R_a . This arithmetic value depends on the surface roughness:

$$Ra = \frac{1}{l_p} \int_0^{l_p} |y(x)| dx \quad \text{or} \quad Ra \approx \frac{1}{n} \sum_{i=1}^n |y(x_i)|, \quad (1)$$

where:

- l_p – measured length (m),
- $y(x)$ – profile description [1],
- $y(x_i)$ – coordinates of n points [1].

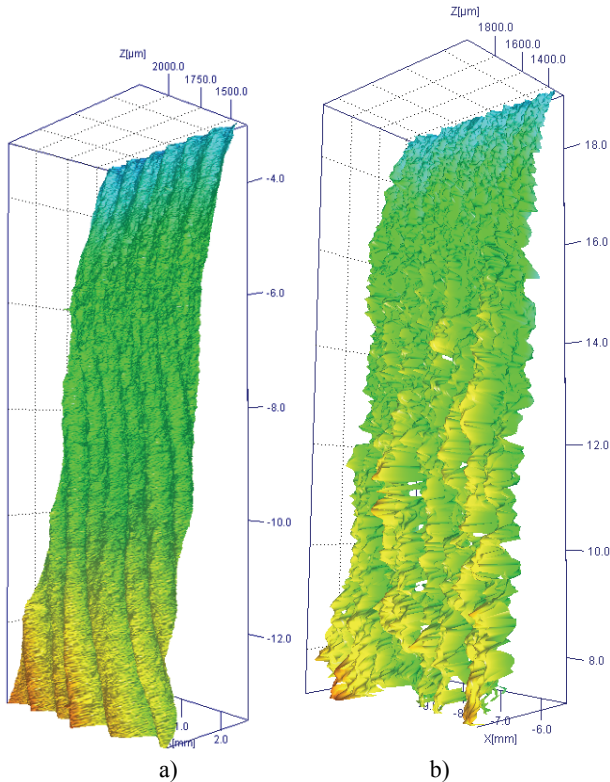


Figure 9 Examples of 3D visualizations of cut walls a) AWJ b) CO₂ laser

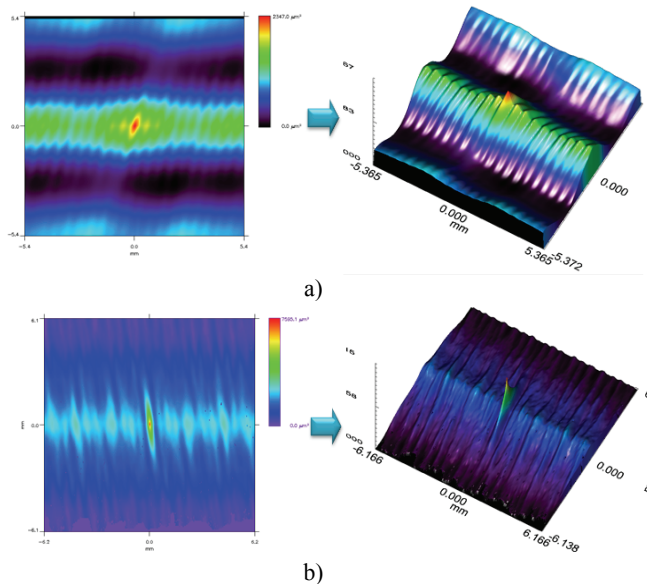


Figure 10 Examples of the use autocorrelation function for demonstration of periodical processes of cutting a) AWJ b) CO₂ laser

Fig. 11 illustrates results of influence of the depth of cut h on profile roughness Ra with respect to technological parameters (traverse speed, abrasive mass flow rate in waterjet process and power of laser). The graphs show that the measured profile roughness decreases with a decreasing traverse speed, but these changes are not that significant for both technologies.

Substantial differences of parameters Ra on the cutting wall created by AWJ can be observed with the change of abrasive mass flow rate from 250 to 400 g/min (Fig. 11 a). Similar effects can be perceived in case of CO₂ laser beam cutting at different powers of 3500 W and 5000 W. CO₂ laser beam power of 5000 W produces significantly higher profile roughness Ra , as can be seen in Fig. 11 b.

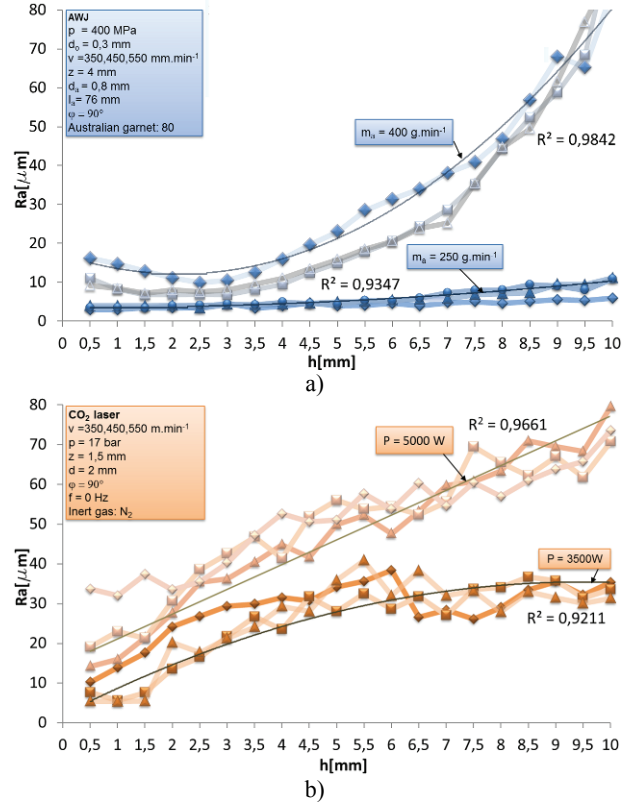


Figure 11 Dependence of the surface roughness parameter Ra on the depth of cut h for a) AWJ b) CO₂ laser beam

Fig. 12 shows comparison of the lowest values of parameter Ra obtained by AWJ and CO₂ laser. Generally, AWJ cutting produces lower values of parameter Ra compared to CO₂ laser beam cutting under given testing conditions. The lowest values of parameter Ra (within the range up to 12 μm) were obtained using AWJ cutting at traverse speed of 350 mm/min and abrasive mass flow rate of 250 mm/min. In CO₂ laser beam cutting, the lowest values of parameter Ra (within the range 5 ÷ 40 μm) were achieved using power of 3500 W and traverse speed of 450 mm/min.

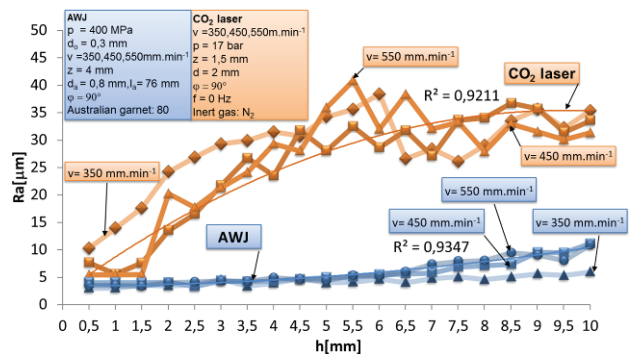


Figure 12 Comparison of the surface roughness between AWJ and CO₂ laser beam

The dependence of curves in AWJ technology shows the minimal differences and the smooth behaviour at particular speeds, which indicates a good optimization of the cutting process and an appropriate setup of the input parameters. The dependence of curves in case of laser cutting clearly shows the significant variances of the values. These variances are caused by excessive heat generation in the heat-affected zone. Subsequent development of the wrinkled surface and its topography is strongly influenced by the output speed of inert gas.

4

Conclusion and remarks

The paper presents results obtained from the analysis of surface topography that was created by AWJ and CO₂ laser beam cutting of titanium ASTM B265-99 samples. The experiments were carried out to compare the surface roughness (*Ra*) for selected technological parameters (traverse speeds, powers of laser device and abrasive mass flow rates in AWJ cutting process). Experimental results show that better quality of final cutting wall was achieved by the use of AWJ technology for comparable working conditions.

Searching for new possibilities how to increase efficiency of cutting of difficult to cut materials is an essential task of the future research. Although nowadays the progressive technologies AWJ and CO₂ laser cutting are very well known, only few works have been devoted to the issue of mutual comparison of these techniques from the point of view of final quality, accuracy of cutting and economic efficiency of the cutting process. Study of these interrelations will represent next step of our research.

Acknowledgement

The article has been written in connection with the project of the Institute of clean technologies for mining and utilization of raw materials for energy use, reg. no. CZ.1.05/2.1.00/03.0082 supported by Research and Development for Innovations Operational Programme financed by Structural Funds of the European Union and from the means of the state budget of the Czech Republic.

5

References

- [1] Ezugwu, O. E.; Wang, Z. M. Titanium alloys and their machinability. // *Journal of Materials Processing Technology*, 68, (1997), pp. 267-274.
- [2] Machado, A. R.; Wallbang, J. Machining of titanium and its alloy – review. // *Journal of Engineering Manufacture*, 20, 1990, pp. 53-59. ISSN: 09544054
- [3] Manohar, R. M. CO₂ lasers cutting of steels: Material issues // *Journal of lasers applications* 18, 2006, pp. 101-111. ISSN: 1042 -346X
- [4] Foldyna, J.; Sitek, L.; Švehla, B.; Švehla, Š. Utilization of ultrasound to enhance high-speed water jet effects. // *Ultrasonics Sonochemistry*, 11 (2004), Elsevier B.V., pp. 131-137.
- [5] Hlaváček, P. et al. Measurement of fine grains copper surface texture created by abrasive waterjet cutting. // *Strojárstvo*, 51, 4(2009), pp. 273-380.

- [6] Peržel, V. et al. Comparative analysis of abrasive waterjet (AWJ) technology with selected unconventional manufacturing processes. // *International Journal of Physical Sciences*, 6, 24(2011), pp. 5587-5593.
- [7] Sharma, V.; Chattopadhyaya, S.; Hloch, S. Multi response optimization of process parameters based on Taguchi-Fuzzy model for coal cutting by water jet technology. // *International Journal of Advanced Manufacturing Technology*, 56, 9-12(2011), pp. 1019-1025.

Authors' addresses

Michal Zelenák

Institute of Geonics of the ASCR
Institute of Clean Technologies for Mining and Utilization of Raw Materials for Energy Use
Studentská 1768/9
708 00 Ostrava-Poruba, Czech Republic
michal.zelenak@vsb.cz

Jan Valček

Institute of Geonics of the ASCR
Institute of Clean Technologies for Mining and Utilization of Raw Materials for Energy Use
Studentská 1768/9
708 00 Ostrava-Poruba, Czech Republic

Jiří Klich

Institute of Geonics of the ASCR
Institute of Clean Technologies for Mining and Utilization of Raw Materials for Energy Use
Studentská 1768/9
708 00 Ostrava-Poruba, Czech Republic

Petra Židková

Department of Production Machines and Design
VŠB – Technical university of Ostrava
17. Listopadu 15
708 33 Ostrava-Poruba, Czech Republic