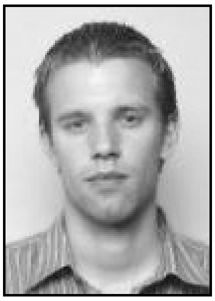
Michal ZELEŇÁK [1], **Jan VALÍČEK** [1], Marta HARNIČÁROVÁ [2], Sergej HLOCH [2], Petr HLAVÁČEK [1]
[1] INSTITUTE OF PHYSICS, FACULTY OF MINING AND GEOLOGY VŠB-TU OSTRAVA, Czech Republic
[2] FACULTY OF MANUFACTURING TECHNOLOGIES, TECHNICAL UNIVERSITY OF KOŠICE WITH A SEAT IN PREŠOV, Slovak Republic

The Measurement and Analysis of Titanium Surface Roughness, created by Abrasive Waterjet and CO_2 Laser Beam Cutting

Eng. Michal ZELEŇÁK

Graduated from the Department of Machining and Assembly, Faculty of Mechanical Engineering VSB-TU Ostrava in the year 2009. Currently he is an Ph.D. student at the Institute of Physics, Faculty of Mining and Geology VSB-TU Ostrava in the field Applied Physics. He currently works in the project RMTVC in Ostrava on the position of research assistant. His scientific and professional focus is to metrology quality surface materials generated by various technological processes especially technologies AWJ and LBC.

e-mail: michalzelenak@centrum.cz



Ph.D. eng. Sergej HLOCH

Graduated from the Department of Management and Environmental Sciences at Faculty of Manufacturing Technologies of Technical University in Kosice with a seat in Presov. He wrote over 250 publications. S. Hloch was awarded by the Werner von Siemens Excellence Award 2008. Holds honorary recognition „Scientist of 2008 "awarded by the Slovak Academy of Sciences and the Association of Slovak Science Societies and Clubs of Science Journalists Slovak Syndicate of Journalists in the category "young scientist".

Ph.D. eng. Ján VALÍČEK

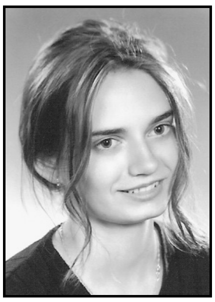
Graduated from the Faculty of Mining and Geology, Technical University of Ostrava in 2000. He received his Ph.D. degree in 2004 and position Assoc. Prof. in 2008. Currently he is working as an associate professor in Institute of Physics, Technical University of Ostrava. He is a specialist in measurements of surface quality of materials created by progressive technologies (e.g. laser and hydroabrasive cutting). He published over 130 scientific papers in various international and national journals, book chapters, and conference proceedings.

Eng. Petr HLAVÁČEK

Graduated from the Department of Machining and Assembly, Faculty of Mechanical Engineering VSB-TU Ostrava. In 2009 he started Ph.D. study at the Institute of Physics, Faculty of Mining and Geology VSB-TU Ostrava. He wrote more than 20 publications issued in 4 countries and one utility model. He was awarded by prices of Werner von Siemens Excellence Award for the best diploma thesis „Measurement of Surfaces Texture Created by Hydroabrasive Dividing of Fine Grain Materials" in 2009.

Eng. Marta HARNIČÁROVÁ

Graduated from the Technical University in Kosice, Faculty of Manufacturing Technologies in Prešov by taking a state examination in the study field of Manufacturing Engineering in 2008. Currently she continues doctoral studies in the branche of Mechanical Engineering and Materials at the Faculty of Manufacturing Technologies. Her current scientific focus within the doctoral thesis is Laser Cutting Technology. She is an author of several professional publications.



Abstract

This paper deals with an evaluation of the surface roughness quality of titanium samples created by abrasive waterjet cutting (AWJ) and by CO_2 laser, considering an impact of the selected traverse speeds on the final quality of machined surfaces. Experiments were carried out on titanium samples of ASTM B265-99. The machined surfaces were measured by a contact profilometer Surftest SJ 401. The obtained data were used to compare the surface roughness parameter R_a at the selected traverse speeds and to compare a material proportion within an initiation zone.

Keywords: surface roughness, titanium, abrasive waterjet cutting, CO_2 laser.

Pomiar i analiza chropowatości powierzchni tytanu po cięciu wysokociśnieniową strugą wodno-ścierną oraz po cięciu wiązką lasera CO_2

Streszczenie

Tytan i jego stopy są materiałami coraz częściej stosowanymi w różnych dziedzinach przemysłu lotniczego, maszynowego, chemicznego, petrochemicznego i elektronicznego. Obróbka tytanu i jego stopów przy pomocy konwencjonalnych technologii jest bardzo trudna. Tytan jest silnie reaktywny chemicznie w przypadku cięcia w temperaturze około 500 °C. Często jest to przyczyną mikro-spawania w miejscu cięcia. Jednym ze sposobów zwiększenia wydajności procesu cięcia jest implementacja technologii niekonwencjonalnych [1-2], takich jak metody hydrostrumieniowe lub metody laserowe. Są one coraz częściej wykorzystywane w przemyśle ze względu na ich przewagę nad innymi tradycyjnymi technologiami. Stosuje się je do różnych rodzajów obróbki materiałów, takich jak cięcie, wiercenie, wykrawanie oraz do modyfikacji powierzchni [3]. Są one stosowana w produkcji w połączeniu ze sterowaniem CNC. Umożliwiają również wycinanie skomplikowanych kształtów, które są bardzo trudne do uzyskania metodami tradycyjnymi. Cięcie tytanu i jego stopów laserem CO_2 jest stosunkowo nową technologią. Lasery CO_2 są powszechnie stosowane do cięcia takich materiałów jak stal nierdzewna, aluminium, miedź, tworzywa sztuczne, itp. Obecnie proces cięcia jest w pełni zautomatyzowany dzięki skomputeryzowanym systemom sterowania. W artykule przedstawiono wyniki pomiarów topografii powierzchni powstałych w wyniku przecinania arkuszy tytanu ASTM B265-99 o grubości 10 mm wysokociśnieniową strugą wodno-ścierną oraz laserem CO_2. Eksperymenty przeprowadzono celem porównania chropowatości powierzchni (*Ra*) ze względu na prędkości posuwu 350, 450 i 550 mm/min. Zauważono, że wzrost chropowatości powierzchni jest spowodowany zwiększaniem się prędkości posuwu. Przy wycinaniu elementów krzywoliniowych metodą hydrostrumieniową zmiana jakości powierzchni cięcia w zależności od szybkości posuwu jest nieznaczna. Natomiast przy cięciu podobnych elementów laserem CO_2 zauważa się znaczne zróżnicowanie stanu powierzchni cięcia, co może być spowodowane nadmiernym wytwarzaniem ciepła w strefie obróbki.

Słowa kluczowe: chropowatość powierzchni, tytan, wysokociśnieniowa struga wodno-ścierna, laser CO_2.

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 its exceptional corrosion resistance. It has become an attractive engineering material that is available in a wide range of wrought forms such as plate, sheet, billet, extrusions, etc. The major applications are in the aerospace, mechanical, chemical, petrochemical and electronics industry. The machinability of titanium and its alloys by conventional technologies is very poor. Titanium is strong chemical reactive at the cutting temperature of (500 °C) with almost all tool materials available. This is often a cause of micro - welding at the place of the cut. One of the ways to increase productivity of the cutting processes is an implementation of nonconventional technologies

[1-2]. The abrasive waterjet cutting and CO_2 laser beam cutting technology are one of the most recently developed non-traditional manufacturing technologies. They are increasingly used in the industry due to their various distinct advantages over the other conventional cutting technologies. They have been used for a wide range of materials processing applications such as cutting, drilling, turning and surface modification [3]. The AWJ cutting process represents a cold, precise cutting with no thermal strain. This technology meets the requirements for quality and manufacturing productivity and is applied under fully automated production workplaces with automatic CNC control. It is also suitable for cutting difficult shapes, which are not possible to cut by a saw. The mixture of water (water is used as an accelerating medium) and abrasive garnet, causes the cutting itself. A detail of the abrasive waterjet cutting head is illustrated in Fig. 1 [4].

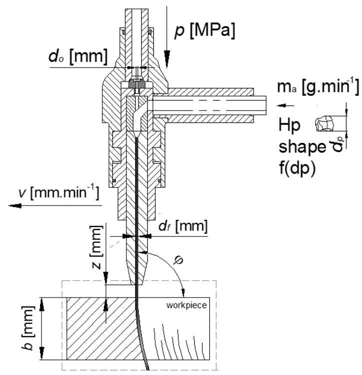


Fig. 1. Abrasive waterjet cutting - set up
Rys. 1. Schemat stanowiska do cięcia wysokociśnieniową strugą wodno-ścierną

CO_2 laser cutting is a relative new technology. The CO_2 laser is based on a gas mixture in which light is amplified by carbon dioxide (CO_2), helium (He_2) and nitrogen (N_2) molecules. The laser beam is focused onto the material surface. The focused laser beam heats the material surface and causes the formation of high melting capillary passing through a material. The power of laser or electromagnetic radiation is used to cut various thicknesses of materials. The CO_2 lasers are widely used to cut and for welding metals such as stainless steel, aluminium, copper, wood, plastic materials, die boards, etc. The cutting process is fully automated by a CNC control system. The Fig. 2 shows a detail of the cutting head in the cutting process.

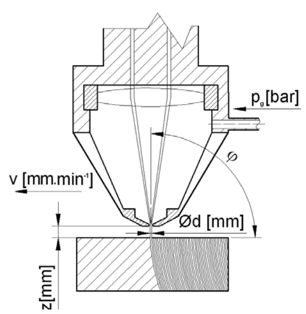


Fig. 2. CO_2 laser beam cutting set up
Rys. 2. Schemat prezentujący technologię cięcia laserem CO_2

2. Current state of the problem

The quality of the resulted cutting surfaces created by AWJ and CO_2 laser beam cutting process is affected by particular factors. Generally, all these factors can be divided into two groups, i.e. input factors and output parameters. The goal is to determine the final surface quality, which is a function both of geometric characteristics of used technologies and adjustable parameters. The surface roughness can be seen due to micro-geometrical surface irregularities. A result of these cutting processes depends on a large number of input process factors [4-5]. Fig. 3 shows the basic input factors and output parameters of AWJ and CO_2 laser cutting. These parameters that mostly affect the surface roughness are marked with a grey colour. The main objective of this paper is to compare both cuttings methods (AWJ and CO_2 laser beam cutting) in term of the surface quality evaluation for the selected traverse speeds.

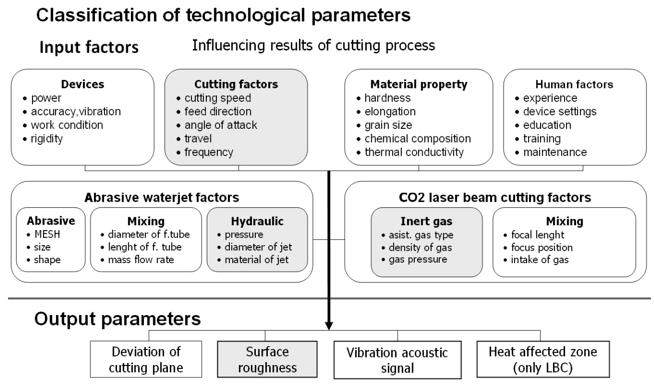


Fig. 3. Technological parameters in AWJ and CO_2 laser beam cutting process
Rys. 3. Parametry technologiczne dla cięcia wysokociśnieniową strugą wodno-ścierną i laserem CO_2

3. Material

The initial material for experimental purposes was unalloyed titanium with the specification ASTM B265-99, supplied in t annealed condition. The chemical and mechanical properties of the used titanium are given in Table 1.

Tab. 1. Chemical composition and -mechanical properties of ASTM B265-99
Tab. 1. Skład chemiczny i mechaniczne właściwości ASTM B265-99

Fe	C	O	H	N
0.2% max	0.08% max	0.18% max	0.015% max	0.03% max

Yield strength 0.2%	Yong's module	Elongation %
172 – 310 MPa	103 GPa	25 – 37

Titanium samples were cut out from rectangular plates with a cross-section of 70 mm×10 mm and a length of 100 mm to a cross section of 10 mm×10 mm and a length of 60 mm, using both technologies (see Fig. 5 and Fig. 6). The sample preparation is schematically shown in the Fig. 4.

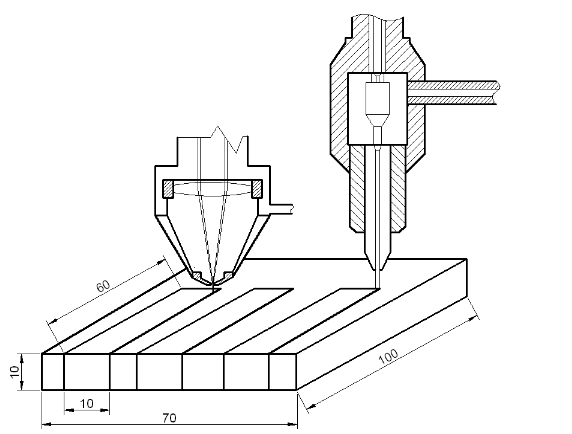


Fig. 4. Schematic plan of cutting the samples by AWJ and CO_2 laser beam technology
Rys. 4. Schematyczny plan cięcia wysokociśnieniową strugą wodno-ścierną i laserem CO_2

The experimental cutting conditions are given in Table 2.

Tab. 2. Experimental conditions of AWJ and CO_2 laser beam cutting
Tab. 2. Parametry obróbki wysokociśnieniową strugą wodno-ścierną i laserem CO_2

AWJ			
Technological parameter	Sign	Unit	Value
liquid pressure	P	MPa	370
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	250
standoff distance	Z	mm	4
traverse speed	V	mm/min	variable 350, 450, 550
abrasive size	-	mesh	80
abrasive material	-	-	Australian garnet GMA

CO_2 laser			
Technological parameter	Sign	Unit	Value
pressure of inert gas	p_g	bar	17
power	P	W	3500
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_p	mm/min	variable 800, 500, 500
type of inert gas	N_2	-	nitrogen
frequency	f	Hz	0

Fig. 5. CNC WJ2020B-1Z-D device from PTV company used for preparation of the samples by AWJ technology
Rys. 5. Urządzenie CNC WJ2020B-1Z-D firmy PTV zastosowane do cięcia próbek wysokociśnieniową strugą wodno-ścierną

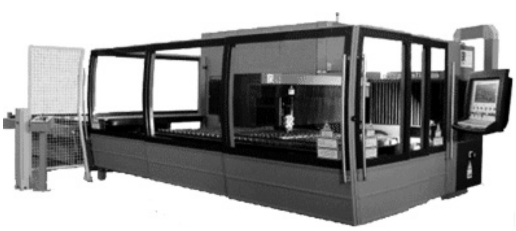


Fig. 6. 2D CNC PLATINO 2040 /3500 CP device used for preparation of the samples by CO_2 laser cutting technology [6]
Rys. 6. 2D CNC PLATINO 2040 /3500 CP – urządzenie do cięcia laserem CO_2 [6]

As mentioned before, the AWJ cutting technology process did not have any thermal effect on the material while in comparison with the CO_2 laser cutting technology, the material was always subjected to the thermal load. The size of heat affected zone in CO_2 laser cutting process depends on physical – mechanical properties of cut material, heat conductivity, final depth of cut and used power of laser. As can see in the Fig. 7 the samples created by CO_2 laser are more roughened and the roughness is increasing for higher traverse speeds in both cases (see Fig. 9). Periodical formation of waviness in CO_2 laser cutting process was not in this experiment observed.

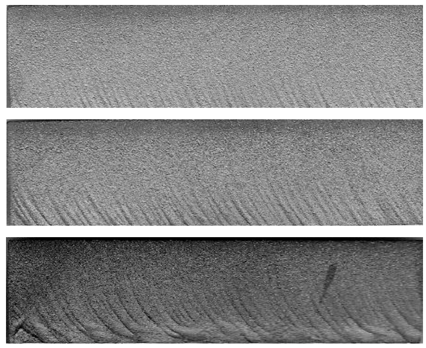
AWJ technology

Traverse speed | Photo

v = 350 mm/min

v = 450 mm/min

v = 550 mm/min



CO_2 laser technology

Traverse speed | Photo

v = 350 mm/min

v = 450 mm/min

v = 550 mm/min

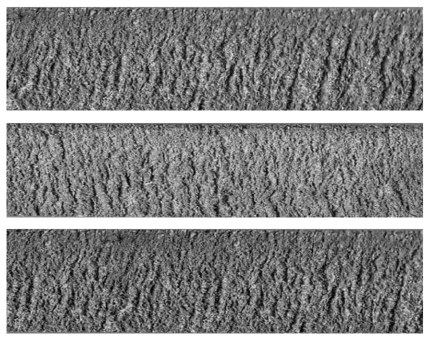


Fig. 7. Photographs of surfaces after cutting processes
Rys. 7. Fotografie powierzchni próbek po procesach cięcia

4. Results and discussion

The surfaces created by AWJ and CO_2 laser beam cutting technologies were measured by a contact profilometer Surftest SJ 401 (Fig. 8). Every sample was measured in 19 depth traces. The obtained signals have been analysed and also statistically processed. The surface quality and identification of irregularities have been evaluated according to the average value of the roughness profile *Ra*.

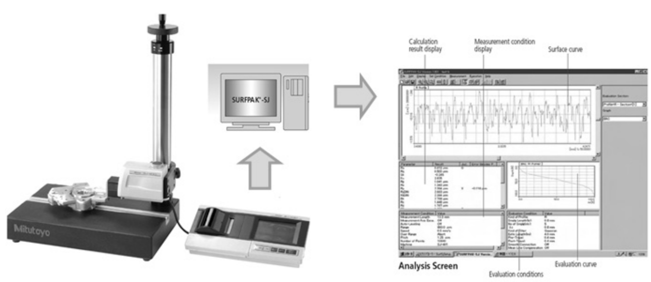


Fig. 8. Contact profile meter Surftest SJ 401
Rys. 8. Profilometr stykowy Surftest SJ 401

The Fig. 9 displayed below, illustrates the results of the evaluation of the impact of the average roughness *Ra* profile parameter on the depth of cut *h* in relation with the traverse speed. The graph shows that with a decreasing traverse speed decreases also the measured profile roughness - according to the theoretical assumptions. Only in the case of CO_2 laser cutting using a traverse speed of 350 mm/min (Fig. 9) has the surface roughness parameter within the initial zone a significantly higher value. It is caused by a higher output speed of an inert gas (800 m/min) that has a negative influence on the size of the heat-affected zone and surface roughness. The comparison of the roughness parameters between the AWJ and CO_2 laser cutting technologies (Fig. 9) shows that the AWJ technology exhibits a five times lower *Ra* values obtained by CO_2 laser cutting, therefore indicates that the AWJ technology shows a significantly higher quality of the machined surfaces. The CO_2 laser beam cutting technology exhibits the significant differences in curve behaviour compared to AWJ technology.

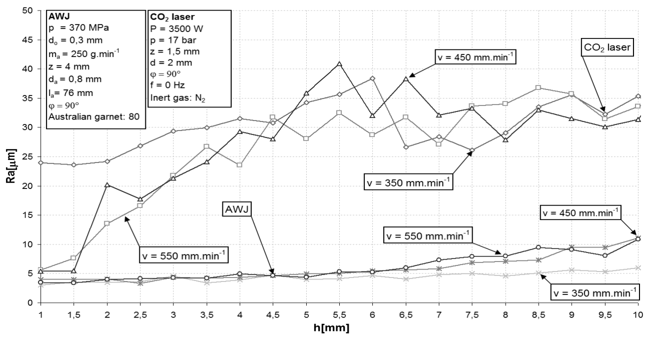


Fig. 9. Dependence of the surface roughness parameter *Ra* on the cut depth *h* for AWJ and CO_2 laser beam cutting

Rys. 9. Zależność parametru chropowatości powierzchni *Ra* od głębokości cięcia *h* przy metodach cięcia wysokociśnieniową strugą wodno-ścierną cieczy oraz laserem CO_2

The next objective of this experiment was to determine the influence of the material proportion in the initial regions of the waterjet and laser beam. The initial regions in particular samples interfere into a maximum depth of *l* = 1.5 mm. The behaviour of the curves of the proportion of material in Fig. 10 shows the relationships for the particular cutting speeds.

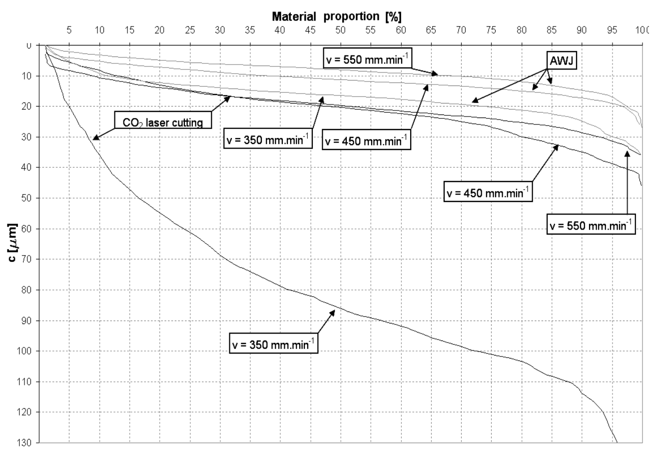


Fig. 10. Dependence of the material proportions on the depth of the highest lug *c* for AWJ and CO_2 laser beam cutting

Fig. 10. Zależność udziału materiałowego na głębokości najwyższego *c* przy metodach cięcia próbek wysokociśnieniową strugą wodno-ścierną oraz laserem CO_2

These curves show that with an increasing traverse speed, the highest length *c* (µm) of the intersecting element decreases. A significant deviation of the curve was reached at the speed of v = 350 mm min^{-1} due to the higher speed of the outgoing gas, as it was mentioned earlier. On the base of the elemental lengths at the selected levels of the material proportions, it is clear, that the lower values are achieved by AWJ technology. The created surfaces is possible to describe as wrinkled, containing the more extreme differences (valleys and peaks), in comparison to the surface created by CO_2 laser cutting where this trend moves toward a smoother behaviour of the surface [7-14].

5. Conclusions

The paper presents the results obtained from the surface topography that was created by AWJ and CO_2 laser beam cutting of titanium samples ASTM B265-99 with a thickness of 10 mm. The experiments were used to compare the surface roughness (*Ra*) parameters for the traverse speeds at 350, 450 and 550 mm/min. As it can be seen in Fig. 9, we can claim the following conclusions. The surface roughness increases with increasing traverse speed. The behaviour of the curve of AWJ technology shows the minimal differences and the smooth behaviour at the particular speeds, which indicates a good optimization of the cutting process and an appropriate setup of the input parameters. The curves when laser cutting clearly shows the significant variances of the values. These variances are caused by excessive heat generation in the heat-affected zone. The evident presence of nitride precipitates on the cutting walls of titanium shows the interaction of the overheated metal with gas (nitrogen), which blows the melt from the cutting gap when laser beam cutting (Fig. 7). A subsequent development of the wrinkled surface and its topography is strongly influenced by the output speed of inert gas (see Fig. 9 and Fig. 10 – variations of the curves for the traverse speed of v = 350 mm min^{-1}). Therefore many authors such as Almeina, Rossi, Berretta, Lima, Nogueira, Wetter and Vieira [15] have recommend argon as an assist gas for cutting of titanium with CO_2 laser. By comparing the proportion of material in the initials zones of samples have been demonstrated the similar removal characteristics of the material for both compared technologies. Searching and defining of the common relationships of the surface topography is important to understand the mechanism of removal and handling with optimization of the cutting process to an efficient and economic utilization of production facilities.

6. Nomenclature

p	liquid pressure [MPa]
b	thickness [mm]
c	length of the intersecting element [µm]
d	diameter of beam [mm]
d_f	focusing tube diameter [mm]
d_o	water orifice diameter [mm]
f	frequency [Hz]
l_a	focusing tube length [mm]
m_a	abrasive mass flow rate [g/min]
N_2	nitrogen
P	power [W]
p_g	pressure of inert gas [bar]
R_a	is the arithmetic average of the absolute values of the roughness profile ordinates [µm]
v	traverse speed [mm/min]
z	standoff distance [mm]

The work has been supported by projects SGS No. SP2011/78, GAČR No. 101/09/0650, MŠMT No. MSM6198910016, RMTVC No. CZ.1.05/2.1.00/01.0040 and MEB051021 – 8071/2010.

7. References

[1] Ezugwu O. E., Wang Z. M.: Titanium alloy and their machinability – a review. Journal of Materials Processing Technology, 68, Elsevier, 1997, pp. 267-274.
[2] Machado A. R., Wallbank J.: Machining of titanium and its alloy – review. Journal of Engineering Manufacture, Proc. Inst. Mech. Eng., 204, 1990, pp. 53-59.
[3] Manohar M.: CO2 laser beam cutting of steels: Material issues. Journal of Laser Applications, 18, 2006, pp. 101-111.
[4] Valíček J., Hloch S., Kozak D.: Study of Surface Topography Created by Abrasive Waterjet Cutting. Mechanical Engineering Faculty – Slavonski Brod, 2009, monograph.
[5] Hlaváček P. et al.: Measurement of Fine Grain Copper Surface Texture Created by Abrasive Water Jet Cutting. Strojarstvo, Vol. 51, No. 4, 2009, pp. 273-279.
[6] http://www.primaindustrie.com/pages/Platino_gb.jsp
[7] Radvanská A., Ergič T., Ivandič Ž., Hloch S., Valíček J., Mullerova J.: Technical Posibilities of Noise Reduction in Material Cutting by Abrasive Water-jet. Strojarstvo, Vol. 51, No. 4, 2009, pp. 347-354.
[8] Valíček J., Hloch S.: Optical measurement of surface and topographical parameters investigation created by Abrasive Waterjet. International Journal of Surface Science and Engineering, Vol. 3, No. 4, 2009, pp. 360 – 373.
[9] Valíček J., Hloch S.: Using the acoustic sound pressure level for quality prediction of surfaces created by abrasive waterjet. The International Journal of Advanced Manufacturing Technology, Vol. 48, No. 1 – 4, pp. 193-203.
[10] Valíček J. et al.: An Investigation of Surfaces Generated by Abrasive Waterjets Using Optical Detection. Strojniški vestnik: Journal of Mechanical Engineering, Vol. 53, No. 4, 2007, pp. 224 – 232.
[11] Valíček J. et al.: Experimental analysis of irregularities of metallic surfaces generated by abrasive waterjet. International Journal of Machine Tools and Manufacture, Vol. 47, No. 11, 2007, pp. 1786 – 1790.
[12] Radvanská A.: Abrasive waterjet cutting technology risk assessment by means of failure modes and effects analysis method. Tehnički vjesnik-Technical Gazette, Vol. 17, No. 1 2010, pp. 121-128.
[13] Hloch S., Valíček J., Simkulet V.: Estimation of the smooth zone maximal depth at surfaces created by Abrasive Waterjet. International Journal of Surface Science and Engineering, Vol. 3, No. 4, 2009, pp. 347-359.
[14] Hloch S. et al.: Experimental study of surface topography created by abrasive waterjet cutting. Strojarstvo, Vol. 49, No. 4, 2007, pp. 303-309.
[15] Almeida I. A., de Rossi W., Lima M. S. F., Berretta J. R., Nogueira G. E. C., Wetter N. U., Vieira N. D. Jr.: Optimization of titanium cutting by factorial analysis of the pulsed Nd:YAG laser parameters. Journal of Materials Processing Technology, Vol. 179, Issues 1-3, 2006, pp. 105-110.

otrzymano / received: 09.02.2011
przyjęto do druku / accepted: 04.05.2011 *artykuł recenzowany*

INFORMACJE

Informacje dla Autorów

Redakcja przyjmuje do publikacji tylko prace oryginalne, nie publikowane wcześniej w innych czasopismach. Redakcja nie zwraca materiałów nie zamówionych oraz zastrzega sobie prawo redagowania i skracania tekstów oraz streszczeń.

Artykuły naukowe publikowane w czasopiśmie PAK są formatowane jednolicie zgodnie z ustaloną formatką zamieszczoną na stronie redakcyjnej www.pak.info.pl. Dlatego artykuły przekazywane redakcji należy przygotowywać w edytorze Microsoft Word 2003 (w formacie DOC) z zachowaniem:
- wielkości czcionek,
- odstępów między wierszami tekstu,
- odstępów przed i po rysunkach, wzorach i tabelach,
- oznaczeń we wzorach, tabelach i na rysunkach zgodnych z oznaczeniami w tekście,
- układu poszczególnych elementów na stronie.

Osobno należy przygotować w pliku w formacie DOC notki biograficzne autorów o objętości nie przekraczającej 450 znaków, zawierające podstawowe dane charakteryzujące działalność naukową, tytuły naukowe i zawodowe, miejsce pracy i zajmowane stanowiska, informacje o uprawianej dziedzinie, adres e-mail oraz aktualne zdjęcie autora o rozmiarze 3,8 x 2,7 cm zapisane w skali odcieni szarości lub dołączone w osobnym pliku (w formacie TIF).

Wszystkie materiały:
- artykuł (w formacie DOC),
- notki biograficzne autorów (w formacie DOC),
- zdjęcia i rysunki (w formacie TIF lub CDR),

prosimy przesyłać w formie plików oraz dodatkowo jako wydruki na białym papierze (lub w formacie PDF) na adres e-mail: wydawnictwo@pak.info.pl lub pocztą zwykłą, na adres: Redakcja Czasopisma Pomiary Automatyka Kontrola, Asystent Redaktora Naczelnego mgr Agnieszka Skórkowska, ul. Akademicka 10, p.21A, 44-100 Gliwice.

Wszystkie artykuły naukowe są dopuszczane do publikacji w czasopiśmie PAK po otrzymaniu pozytywnej recenzji. Autorzy materiałów nadesłanych do publikacji są odpowiedzialni za przestrzeganie prawa autorskiego. Zarówno treść pracy, jak i wykorzystane w niej ilustracje oraz tabele powinny stanowić dorobek własny Autora lub muszą być opisane zgodnie z zasadami cytowania, z powołaniem się na źródło cytatu.

Przedrukowywanie materiałów lub ich fragmentów wymaga pisemnej zgody redakcji. Redakcja ma prawo do korzystania z utworu, rozporządzania nim i udostępniania dowolną techniką, w tym też elektroniczną oraz ma prawo do rozpowszechniania go dowolnymi kanałami dystrybucyjnymi.