STATISTICAL PREDICTION OF THE SMOOTH ZONE MAXIMAL DEPTH AT ABRASIVE WATERJET CUTTING OF STAINLESS STEEL

СТАТИСТИЧЕСКОГО ПРОГНОЗИРОВАНИЯ ГЛАДКОЙ ЗОНЕ МАКСИМАЛЬНОЙ ГЛУБИНЕ В ГИДРОАБРАЗИВНОЙ РЕЗКИ ИЗ НЕРЖАВЕЮЩЕЙ СТАЛИ

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Abstract: *The study deals with proposal of the possibility of the statistical prediction smooth zone maximal depth of stainless steel surfaces created by abrasive waterjet. The proposal is based on experimental analysis of AISI surface irregularities created by abrasive waterjet by means of 3D optical measurement. The surface irregularities have been evaluated by static quality characteristics the arithmetic average height Ra, that has been obtained from 24 measurement traces. The surface irregularities have been measured by means of non-contact optical method, namely by using an optical commercial profilometer MicroProf (FRT). The main emphasis is put on the analysis of results for defining the process of creation of a new surface generated by the stream of abrasive waterjet.*

***KEYWORDS**: SMOTH ZONE, ABRASIVE WATERJET CUTTING*

1. Introduction

The ongoing problem associated with AWJ is a surface unevenness in the form of grooves and abrasiveness resulted from material cutting by the above mentioned technology. Causes of these surface defects limit wider use of the technology of high speed abrasive water jet in the industry. Taking into account this fact, it is surprising that nowadays there is no a study offering a complex evaluation of the surface topography. The technology of high speed abrasive water jet presents indeed a subject of numerous investigations, but their contribution is only partial. They target the evaluation of the certain ambiguous defined depth lines. Their approach is from an experimental point of view aimed at only one factor, to which the authors impute the significance [14], [15], [17]. However, on the present these works do not comply with particular practise requirements. The target of the presented study is an effort to get deeper into a problem of analysis and identification of the factors, in relation to the topography of surfaces, as well as targeting the solution of the above mentioned insufficiencies, with the aim of providing a new way of classification of smooth zone for surfaces created by AWJ. From the practical point of view, it is then necessary to talk on impacts on the quality of output control of products machined. In our opinion, in the mechanism of origin of newly generated surface topography because surface irregularities in the form of striations and roughness have been ongoing problems associated with abrasive waterjet (AWJ) cutting of engineering materials. The causes of these surface defects that put multifaceted limitations on the wider use of the AWJ technology in industry have been the subject of a large number of investigations [1], [2], [3]. A number of mechanisms that are thought to cause these observed striations and roughness on the cut-wall surfaces have been proposed by various authors who conducted studies in this area [4], [5]. In AWJ machining, the workpiece material is removed by the action of high-speed water mixed with abrasive particles. A high-speed waterjet transfers kinetic energy to the abrasive particles and the mixture impinges on to the workpiece [6], [7], [10], [11]. The material removal rate is dependent on the abrasive attack and mechanical properties of target metal [18], [19].

2. Related and previous works

A surface produced by the AWJ technology is characterised by duality. The upper part of the cut is rather smooth (according to [2] the cutting zone hc) and from a certain depth, the striated zone (deformation hd) occurs. This is caused by the fact that the jet loses its kinetic energy, which leads to a change in the mechanism of material removal, namely from the prevailing cutting mechanism of removal to the deformation one. According to this author, the depth of deformation mechanism of material removal h_d [2] can be calculated in a similar way. The above-mentioned relations are very complicated, because the process of AWJ cutting is affected by many parameters and factors. This calculation cannot include all factors influencing cutting, and that is why the calculated value may differ from the real value by even more than 50% [3]. The AWJ machining process is defined by a number of factors, which in turn govern the material removal rate and the development of the characteristics of the surface. A considerable effort was made in understanding the influence of the system operational process parameters such as waterjet pressure, abrasive flow rate, standoff distance, number of passes on depth of cut, angle of cutting, and traverse speed [5], [11], [13]. The results of the studies showed that the AWJ machining is significantly affected by the variation of process parameters. However, the degree of influence of parameters depends on the magnitude of parametric variation and machine ability of the material. Traverse speed of the jet has a strong influence on the surface finish of the workpiece and material removal rate [15], [16]. According to Ojmertz [15] has shown that low traverse speeds result in an irregular surface morphology and significantly increased material removal rates but despite this, lower surface roughness values are observed. Fowler et al. [15] have shown that low jet traverse speed not only results in high material removal rates, but also in high surface waviness. But according to published research papers, there is necessary to take into account more factors together or hydro-mechanical cutting process depends on a large number of process factors such as water pressure, orifice diameter, standoff distance, abrasive and material feed rate etc [16], [21], [23].

3. Experimental set up

In order to study of the AISI 304 surface irregularities a two dimensional abrasive waterjet machine Wating, was used in this work with following specification: work table x-axis 2000 mm, y-axis 3000 mm. The high-pressure intensifier pump was used the Ingersoll-Rand Streamline model with maximum pressure 380 MPa. As a cutting an Autoline cutting head from Ingersoll-Rand head has been used. Standoff distance z = 3 mm. Variable factors have been pressure p = 200 - 350 MPa, orifice diameter do = 0.25 mm, abrasive mass flow rate ma = 300 - 500 $g.min^{-1}$, focusing tube diameter d_f = 1 – 1,2 mm, and traverse speed v = 70 – 120 $mm.min^{-1}$. Specimens have been made from AISI 304. Cut surfaces of the square samples were prepared according to design of experiments. The properties of each sample are: the length of 35 mm, the width of 0,8 mm, and the height of 10 mm. The Barton Garnet was used as abrasive materials with MESH 80. From each abrasive material 10 samples were cut to be analysed. The surface quality of each side of the samples was measured by an optical method using an optical commercial profilometer MicroProf (FRT). From 24 depth traces have been obtained the surface profile parameters Ra and Rz.

4. Results and discussion

On the contrary, results obtained by an optical profilometer MicroProf (FRT) (fig. 1) show that more detailed information on the initial zone can be provided. From the mechanical point of view, this entry region is of importance to the subsequent clarification of a mechanism of material removal and the explanation of AWJ-material interaction in morphological different zones with different surface quality that can be expressed by plots of the surface profile parameters Ra, Rq and Rz experimentally obtained by means optical measurement of the samples surfaces (Fig. 2).

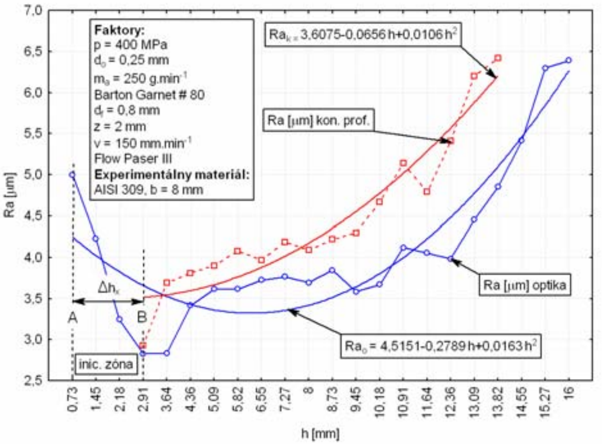

Fig. 1 Dependence of surface profile parameter Ra on depth of surface measured by means of contact and optical profilometer

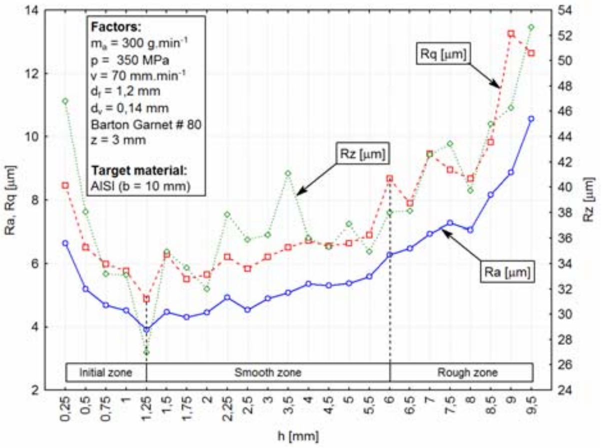

Fig. 2 Development of surface of profile parameters Ra, Rq and Rz, related to depth

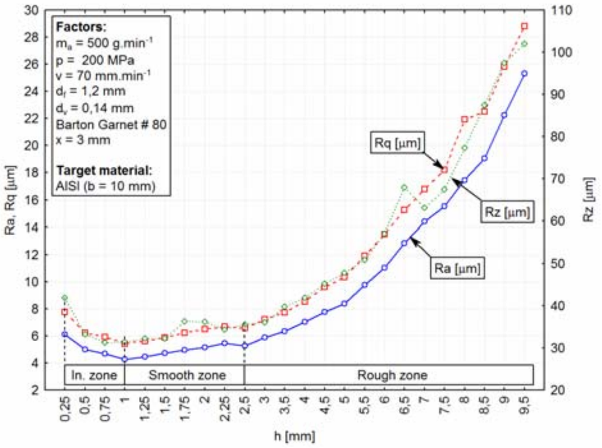

Fig. 3 Development of surface of profile parameters Ra, Rq and Rz, related to depth

Fig. 3 shows plots of the surface profile parameters measured in depth trace lines. Parametrical evaluation of the cutting surfaces of samples revealed three distinct zones which were identified as: a initial zone, which is cutting zone at shallow angles of attack; a smooth cutting region, which is cutting zone at large angles of attack and a rough (Ra < 10 µm) cutting zone, which is the jet upward deflection zone (Ra > 10 µm). The surface morphology in different regions of cutting surface is generated from the instantaneous penetration of abrasive waterjet. It is expected that these regions would change with an increasing interaction of the jet with the material, i.e., increased overlap at any region of cut. As can be seen from the figures, as the factors combination e.g. if traverse speed increases, the number of particles impinging on a given exposed target area decreases, which in turn reduces the initial zone width from 1,25 mm to 1 mm. The width smooth zone decreases with the increase of traverse speed, because the depth of penetration decreases.

5. Prediction model proposal

A nonlinear multiple regression analysis was applied on the experimental data obtained from the measurement traces to gauge the effects of the operating factors used in the study of the detection the smooth zone where the number values of surface parameters are Ra < 10 µm. The results of that factor analyis in addition to the evaluating of factors pressure, abrasive mass flow rate, traverse speed and J/T abbreviation, which also included the change of depth of smooth zone values with the distance from the top edge of the cut-wall surface, were of the following equation:

$$h_{HZ} = \frac{m_a^{0,543} . p^{0,969}}{19,143 . d_f^{1,478} . v^{0,827}}$$

where d_f is diameter of the focusing tube [mm], m_a is abrasive mass flow rate [g.min^{-1}], p is pressure [P] and v is traverse speed [mm.min^{-1}]. The model has been checked by several criteria. The fit of the model has been expressed by the coefficient of determination $R^2 = 0,95414$ which was found to be for equation indicating 95.41% for the model of the variability in the response can be explained by the models. The value also indicates that only 4,59 % of the total variation is not explained by the model. This shows that equation is a suitable model for describing to the response of the maximal depth of the. The value of adjusted determination coefficient $R_{adj} = 0.87781$ is high to advocate for a high significance of the model. Statistical testing of the model has been tested by the Fisher's statistical test for analysis of variance. The statistical testing shows that the model is adequate.

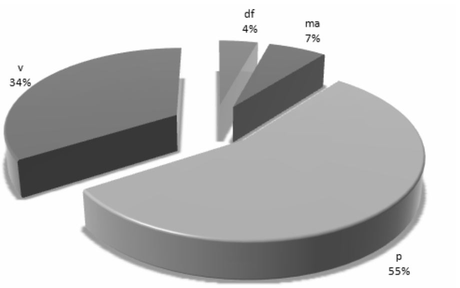

Fig. 4 Factors significance that affects the maximal depth of the smooth zone

Figure 4b show the prediction of the maximal depth of smooth zone, which is mathematically modelled border that divide the surface with Ra values that are < 10 µm. The results obtained indicate that improvements in surface quality as measured by Ra values can be achieved by optimal set up of the AWJ regime factors. According to expectation the smooth cutting zone is changing with change of the traverse speed. Overplap of the zone relate with the factors combination set up. If the traverse speed increases the number of the particles impinging on a given exposed target area decreases. The width of the smooth zone increases as the e.g. traverse speed decreases. The experimental results indicate that the traverse speed of the jet is one of the significant factors after the pressure that affects the surface morphology, and the widths and features of different regions formed in the cutting surface change according to the traverse speed (Fig.4). It is also observed that the surface roughness increase with increasing traverse speed in selected conditions (Fig. 4).

6. Conclusions

Surface irregularities on workpiece surfaces produced by abrasive waterjet (AWJ) have been the most persistent problems that stand in the way of wider applications of the technology in industry. The main task of the paper was to bring the detailed knowledge about the interaction of abrasive waterjet with cutting material. In order to describe the basic geometrical properties of topography of surfaces produced by the AWJ technology, an optical commercial profilometer MicroProf (FRT) has been used. On the basis of optical measurements the values of Ra, Rq and Rz roughness in relation to the depth of cut h, have been evaluated. It has been proved the existence of initial zone. Further the surface profile parameter will be statistically and analytically processed for optimising the technology, improving the quality of output control and studying the mechanism of disintegration interaction between the high-speed abrasive waterjet and the material machined. Therefore, further research work is needed to establish the total depth that can be achieved by each of these cutting techniques under given sets of operating factors.

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7. References

[1] Bátora, B., Vasilko, K. (2000) Machined surfaces: technological heredity, functionality. Trenčín : pp. -183.

[2] Cebalo, R., Stoić, A. (2003) Optimisation of the roughness of the ground surface by diamond roller dressing, Tehnički vjesnik 3, 4; pp. 3-8.

[3] Gombár, M. Statistical model of surface roughness. In: Electrotechnics in practise. 2006, vol. 16, no. 11-12, pp. 26-28.

[4] Hloch, S., Gombár, M., Fabian, S., Straka, L., (2006) Factor analysis of abrasive waterjet process factors influencing the cast aluminum surface roughness, In: Manufacturing Science and Technology. Malaysia, pp. 145–149.

[5] Kozak, D., Vojvodica, J., Gubeljak, N., Semenski, D. Factors influencing the yielding constraint by cracked welded components // Program and book of abstracts of 12th Conference on Materials and Technology / Jenko, Monika, editor(s). Ljubljana: Institut za kovinske materiale in tehnologije, 2004. Pp. 79-79

[6] Kušnerová, M., Hlaváč, L. M. Self vibrating chambers with continuous passage of liquid. Sborník vědeckých prací VŠB - TUO. Řada strojní č. 1/2006, roč. LII. VŠB-TUO, Ostrava, 2006, s. 127- 134. ISSN 1210-0471.

[7] Ohlídal, M., Páleníková, K. Možnosti optického profilometru MicroProf FRT při 3D hodnocení kvality povrchu, Jemná mechanika a optika, Vol.49, (2004), No.9, pp.251-255, ISSN 0447-6411

[8] Páleníková, K., Ohlídal, M. Potentialities of optical profilometer MicroProf FRT for surface quality measurement, 14 th Slovak-Czech Polish Conference on Wave and Quantum Aspects of Contemporary Optics, pp.59451O-1-59456, ISBN 0-8194-5951-8, (2005), SPIE - The internationalSociety for Optical Engineering.

[9] Stoić, A., Lucić, M., Kopač, J. (2006) Evaluation of the Stability During Hard Turning, Strojniški vestnik 52, 11; pp. 723-737.

[10] Stoic, A., Samardzic, I., Klaric, S. Cutting errors in abrasive water jet cutting // CIM 2007 Computer Integrated Manufacturing and High Speed Machining / Aberle, Eberhard ; Udiljak, Toma ; Ciglar, Damir, editor(s). Zagreb : Croatian Association of Production Engineering, 2007. pp. 333-338

[11] Valíček, J., Držík, M., Ohlídal, M., Mádr, V., Hlaváč, L., M., (2001) Optical method for surface analyses and their utilization for abrasive liquid jet automation. In: Proc. of the 2001 WJTA American Waterjet Conference, M. Hashish (ed.), WJTA, Minneapolis, Minnesota, pp. 1–11, 2001.

[12] Valíček, J., Hloch, S. (2006) Surface topography optical identification generated by abrasive waterjet. In: Fine Mechanics and Optics. vol. 51, no. 11-12, pp. 320-322.

[13] Vasilko, K., Lipták, J., Kozáková, D., Modrák, V. (1990) New materials and technologies of their machining. Alfa, pp-365.

[14] Hascalik, A., Caydas, U., Gurun, H. Effect of traverse speed on abrasive waterjet machining of Ti–6Al–4V alloy. In. Materials & Design, Volume 28, Issue 6, 2007, pp. 1953-1957.

[15] Kulekci, K., M. Processes and apparatus developments in industrial waterjet applications. International Journal of Machine Tools & Manufacture 42 (2002) 1297–1306.

[16] Lemma, E. et al. / International Journal of Machine Tools & Manufacture 42 (2002) 781–789 787.

[17] Strážovec, I., Benčíková, J. Research of Dynamic Properties of Hydraulic Drives, International conference of PHD students, University of Hungari 11-17 august 1997, s.201-209

[18] Panda, A., Pandová, I. Statistical process control (SPC) computer aided SPC. In: Transactions of the Universities of Košice : Research reports from the Universities of Košice. č. 2 (2000), s. 24-26. ISSN 1335-2334.

[19] Vasilko, K., Gombár, M. The influence of machining parameters on the machined surface quality. In: Modern Metrology in Quality Management Systems : CEEPUS : Science report Projects PL-0007. Kielce : Wydawnictwo Politechniki Swietokryzskiej, 2006. p. 275-284. ISBN 978-83-88906-66-4.

[20] Molnárová M., Leško A., Vlado M.:Stanovenie kritickej hrúbky obalového plechu pre prienik zavalcovaných oxidov na jeho povrch. Acta Metallurgica Slovaca, 2006, p.59-69.

[21] Milly, D., Maxim, V.: " Simulation And Analysis Of Power Converter Input Currents", MicroCAD'98, International Computer Science Conference, February 25-26, 1998, str. 63 – 68.

[22] Valíček, J. et al. Method of the determination of superposition relation of changes in surface geometry to mechanical parameters of material due to corrosion. In: Acta Mechanica Slovaca. roč. 9, č. 3-a 2005 interantikor 2005 (2005), s. 171-176. ISSN 1335-2393.

[23] Valíček, J., Lupták, M. Study of the roughness of material treated by a liquid jet. In: 10th Conference on Environment and Mineral Processing : 22.6.-24.6.2006 VŠB-TU Ostrava, Czech Republic. Ostrava : VŠB-TU, 2006. p. 239-242. ISBN 80-248-1089-1.