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STUDY OF SURFACE TOPOGRAPHY GENERATED BY THE ACTION OF PULSATING WATER JET

J. Klich*, J. Valíček*, L. Sitek*, J. Foldyna*, M. Harničárová** P. Hlaváček*

Abstract: *The paper is dealing with study of the surface topography created by the pulsating water jet. Topography is evaluated by height characteristics of the surface roughness (average roughness Ra and average maximum height of the profile Rz). The data obtained from surface texture are analyzed and interpreted in relation to the stand-off distance between the nozzle and the surface.*

Keywords: ***Pulsating water jet, surface roughness, surface topography.***

1. Introduction

During more than 30 years of intensive development, high-speed water jet has gained a steady place in many fields of human activity. In addition to typical applications such as cutting of various materials by both water jet and abrasive water jet, removal of coatings and deposits from surfaces and utilisation of the jet in repair of concrete structures and buildings, the possibility of using of water-jet for surface treatment is investigated in recent years. The objective is to induce changes in surface topography (Borkowski, 2009; Frenzel, 1997; Toutanji & Ortiz, 2001) or to affect properties of surface layers e.g. by residual stress removal or peening (Colosimo & Monno, 1999; Gumkowski, 2003; Ju & Han, 2009).

Efficiency of conventional continuous jets can be significantly increased by using high-frequency pulsating water jets, which break up in air to separate water flow into water bunches (Foldyna et al., 2009). The impact pressure (so-called water-hammer pressure) generated by an impact of bunch of water on the target material is considerably higher than the stagnation pressure generated by corresponding continuous jet. In addition, the action of pulsating jet induces also fatigue and shear stresses in the target material due to the cyclic loading of the target surface and tangential high speed flow across the surface, respectively. Based on these effects one can expect even wider use of pulsating jets in surface treatment applications than in the case of conventional continuous ones.

The paper presents study of topography of surface created during experiments by the pulsating water jet impact on aluminum at different distances from the nozzle exit. Fan pulsating jet that enables to spread the jet energy to greater width (depending on inner geometry of the nozzle) was used in the experiments.

2. Material disintegration by pulsating water jet

Disintegration effects of the pulsating jet can be, depending on the stand-off distance from the nozzle, divided into three regions. In the first region the pulsating jet escapes from the nozzle as a continuous jet and due to uneven flow velocity it breaks up in air into separate bunches of water at some distance (in order of centimetres). In this region, the effects of the jet on material are similar to that of continuous one, i.e. insignificant when operating water pressure is of tens of MPa. The best performance of pulsed jet can be observed in the second region – after breaking up of the continuous jet to bunches. In this disintegration region, the jet easily disintegrates very hard materials (like metals,

* Ing. Jiří Klich, assoc. prof. Ing. Jan Valíček, Ph.D., Ing. Libor Sitek, Ph.D., Ing. Josef Foldyna, CSc. and Ing. Petr Hlaváček: Institute of Geonics of the AS CR, v. v. i., Studentská 1768; 708 00, Ostrava; CZ, e-mails: jiri.klich@ugn.cas.cz, jan.valicek@ugn.cas.cz, libor.sitek@ugn.cas.cz, josef.foldyna@ugn.cas.cz, petr.hlavacek@ugn.cas.cz

** Ing. Marta Harničárová: Faculty of Manufacturing Technologies of Technical University of Košice with a seat in Prešov, Bayerova 1, 080 01 Prešov, SK, e-mail: marta.harnicarova@tuke.sk

rocks, ceramics, etc.). The third, final region is characterized by breaking of bunches of water to small droplets at higher stand-off distances due to air friction (jet breakage region). The jet ability to disintegrate material significantly decreases, only droplet erosion occurs.

The surfaces of various materials exposed to the action of pulsating water jets are generally quite irregular and rough with larger true surface area compared to continuous jet. This is due to a combination of several failure mechanisms affecting the surface in disintegration region of the jet. Subsequent use of such surfaces could be interesting from the point of view of their friction characteristics and/or aesthetic appearance. However, they could be also used in applications where good adhesion of coating layer or new overlay material to substrate surface both in tension and shear is needed. Adequate macroscopic substrate roughness provides good mechanical locking and a large surface area for bonding. Thus, the overlay is properly mechanically linked with the substrate. Commonly used characteristics of the surface indicating the surface adhesion ability are roughness parameters *Ra* (average roughness) and *Rz* (average maximum height of the profile). Ratio of *Ra/Rz* then can provide information about properties of a new surface of the given material for application of specific coating.

In order to study even small disintegration effects of pulsating jet during the surface treatment, it was necessary to select appropriate material for testing. Aluminum appears to be one of suitable technical materials for these purposes due to its properties (soft, homogeneous and isotropic).

3. Experimental setup

Scheme of experimental arrangement for treatment of material surface by pulsating water jet is shown in Fig. 1. Test samples were prepared from 50 mm wide and 5 mm thick cold rolled aluminum strip (99.5% of aluminum). High-pressure water was supplied to the nozzle by a plunger pump; operating pressure was maintained at 30 MPa. High-pressure water was then fed into the acoustic generator of pressure pulsations equipped with fan nozzle (equivalent nozzle diameter of 2.05 mm, spraying angle of 15°). Pressure pulses in high-pressure fluid were generated at frequency 20 kHz with amplitude of vibration 3 μm. Pressure pulsations before the nozzle exit were changed to velocity pulsations in the nozzle and thus flat pulsating jet was created. The jet was moved over the test sample at feed rate of 0.1 $m.min^{-1}$. The stand-off distance *L* was progressively changed during the experiments (*L* = 30, 35, 40, 50, 60, 70, 80 and 90 mm). Fig. 1 shows arrangement of experiments.

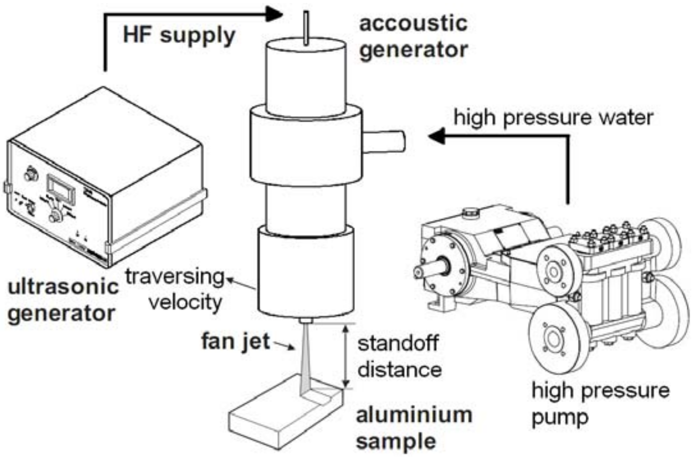

Fig. 1: Schematic diagram of experimental setup.

Slots created by the jet in the test aluminum sample were studied using optical profilometer FRT MicroProf (see example of slot reconstruction on Fig. 2). Ten profiles of the surface in the x-axis direction (perpendicular to the movement of the jet) and ten profiles in the y-axis direction (along the movement of the jet) were measured on the square area of 5x5 mm. Measured data were processed using Mark III firmware and characteristics of surface roughness *Ra* and *Rz* were determined.

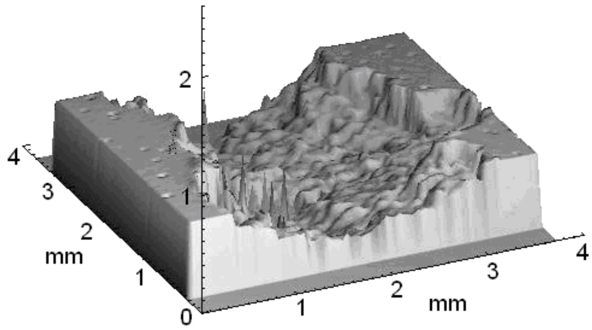

Fig. 2: 3D topography reconstruction of new surface created by the action of fan pulsating water jet.

4. Results and discussion

The values of surface roughness (*Ra* and *Rz*) in both directions (x and y) obtained under the same working conditions were compared to each other. Statistical analysis proved that the surface created by pulsating jet is not influenced by the direction of motion of the jet above tested material (as in the case of many conventional machining methods).

Graphs of surface roughness parameters *Ra* and *Rz* in relation to the stand-off distance *L* are presented in Figs. 3 and 4. It can be seen that values of both *Ra* and *Rz* increase with increasing stand-off distance *L* up to approximately *L* = 80 mm. At higher stand-off distances, values of *Ra* and *Rz* drop down significantly due to the fact that at the stand-off distance of approximately 90 mm the pulsating jet breaks up already into small droplets that do not have enough energy to erode aluminum surface (the stand-off distance is situated in the jet breakage region). The dependence of the roughness of surface treated by fan pulsating jet at stand-off distances from 30 to 80 mm (i.e. at disintegration region of the pulsating jet) can be roughly approximated by the regression line (shown in Figs. 3 and 4).

Next step was to determine the ratio of surface roughness parameters *Ra/Rz* (Fig. 5). The graph clearly shows that the stand-off distance has negligible effect to the ratio *Ra/Rz* and the ratio values are roughly the same in disintegration region. It can be stated that pulsating jet operating within the disintegration region creates surfaces with the same ability to mechanically lock paintings and other coatings applied to treated substrate. Another situation occurs in the jet breakage region, where the ratio *Ra/Rz* decreases significantly due to change in jet acting and thus also mechanism of material failure.

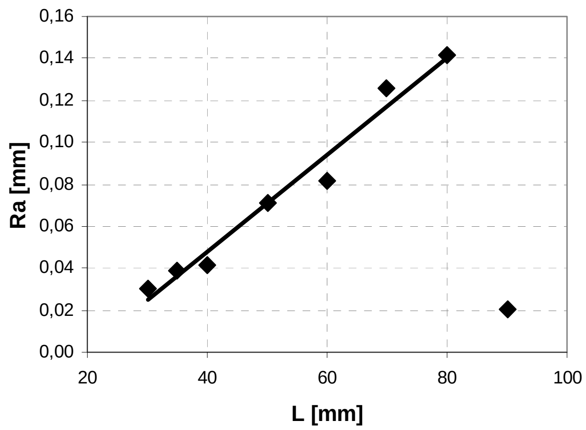

Fig. 3: Average roughness Ra depending on the stand-off distance L from the nozzle exit.

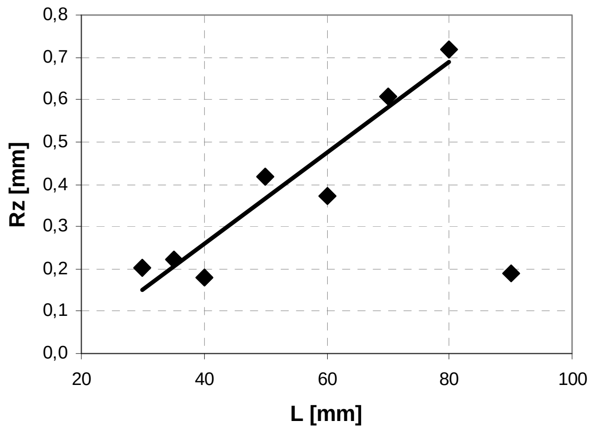

Fig. 4: Average maximum height of profile Rz depending on the stand-off distance L from the nozzle exit.

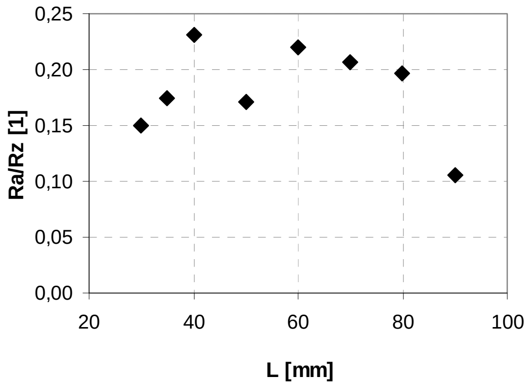

Fig. 5: Ratio Ra/Rz depending on the stand-off distance L from the nozzle exit.

5. Conclusions

This paper has focused attention on determination of basic surface profile parameters of aluminum surface newly created by pulsating water jet and their description. Surface profile parameters *Ra* and *Rz* were evaluated with respect to stand-off distance from the nozzle exit. In the disintegration region of pulsating jet both parameters *Ra* and *Rz* increase with increasing of stand-off distance, however, their ratio remains roughly constant. Because of change of failure mechanisms of material exposed to the pulsating jet in jet breakage region, not only decrease in *Ra* and *Rz* parameters but also decrease of their ratio can be observed.

The knowledge of surface description is very important in terms of adjustment of optimum technological parameters of pulsating water jet in relation to work-piece material and required quality of finished surface. Apart from stand-off distance, the ability of pulsating jet to disintegrate material may be influenced by many other parameters (such as water pressure, type, diameter and internal geometry of the nozzle, feed rate of the jet, frequency and amplitude of acoustic pulses, etc.). These factors will probably also affect the final texture of newly formed surface. Study of influence of these factors on surface texture will represent next step of our research.

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