STUDY OF QUALITY OF NINE ALUMINIUM ALLOYS SURFACES CREATED USING ABRASIV WATERJET

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The article focuses on the normalized method of measurement and evaluation of a surface texture created using the abrasive waterjet. It detects selected amplitude parameters of a roughness profile providing a form of a quantified description of properties of a surface topography. It studies the change in quality of machined surfaces created by the abrasive waterjet in nine selected materials of aluminium alloys when changing the traverse speed. Studied samples were measured by an optical profilometer MicroProf FRT and further analyzed with the Scanning Probe Image Processor software (SPIP). The results of experiments show that the observed amplitude parameters of roughness are influenced by the increasing traverse speed.

KEYWORDS
surface roughness, abrasive waterjet, study of quality, aluminium alloy, optical profilometer

1. INTRODUCTION

Assessment of the surface topography of materials was previously used in the engineering industry exclusively. The present brings new design trends and requirements for functional surface properties with emphasis on the quality and the overall economic requirements while reducing the environmental impact. All this influences the recent developments in manufacturing technologies, as well as in the equipment. New manufacturing processes and measurement methods which provide with new and improved surface properties and extensive information about the newly-created surfaces are implemented into practice. At present, the industry of electronics and optoelectronics are interested in this area. Due to the possibility of monitoring properties of the surface topography in nanometers, it also becomes a promising area in biomedicine.

The current trends in environmental protection contribute to the development of non-conventional machining methods which include the abrasive waterjet technology. The main advantage of this technology is the elimination of overheating of the machined material due to the cutting process using the medium formed by an abrasive material and water. The AWJ (abrasive waterjet) technology has a wide range of applications. In principle, it can disintegrate all industrial materials, such as paper, plastic, metal, alloys, composite material, hard metal, and others. This technology creates a specific surface on the machined material which should be studied more precisely when assessing parameters of the surface topography.

2. PARAMETERS OF ROUGHNESS PROFILE

Parameters of a roughness profile provide a quantified form of a description of properties of the surface topography. The surface texture is assessed according to a profile of the surface which results from the intersection of the real surface by a suitably selected plane. In practice, the plane perpendicular to the plane parallel to the real surface in an appropriate direction is usually selected.

Analysis of the surface profile is performed by separating individual components using the procedure of filtering. A profile filter separates profiles into longwave and shortwave components [CSN ISO 16610-21, 2012]. Rules and procedures for the assessment of surface textures are specified in more details in the standard of CSN EN ISO 4288. This standard establishes the basic roughness sampling length *lr* and the evaluation length ln needed for the measurements of R-parameters of periodic and non-periodic surfaces.

***Ra* – arithmetical mean deviation of the assessed profile** is the arithmetical mean of the absolute values of *Z(x)* in a sampling length *lr*. It is one of the commonly-used roughness parameters in the engineering practice. However, the qualitative value of the parameter Ra is low as it is not sensitive to the extreme heights of profile peaks and depths of profile valleys. [CSN EN ISO 4287, 1999]

***Rq* – root mean square deviation of the assessed profile (RMS)** is the root mean squared of *Z(x)* in a sampling length *lr*. Parameter *Rq* is more sensitive to unwanted peaks and valleys of the assessed surface. Therefore, it reaches higher values that the parameter *Ra*. [CSN EN ISO 4287, 1999]

***Rz* – maximum height of profile** expresses the sum of the maximum value of profile peak height *Zp* on the profile curve, and the maximum value of profile valley depth *Zv* in a sampling length *lr*. [CSN EN ISO 4287, 1999]

***Rsk* – skewness of the assessed profile** expresses the cubic mean of *Z(x)* in a sampling length *lr* rendered dimensionless as the cube of the root mean squared height *Rq*. This value indicates the offset of the probability density function in comparison to the Gaussian normal distribution, allowing better detection of surfaces with the same value of *Ra* in terms of the profile shape. If the peak of this function is shifted toward the peaks of inequalities ($Rsk < 0$), it indicates larger and deeper valleys on the surface; whereas the peak shifted toward the valleys ($Rsk > 0$) indicates a surface with many and more rugged peaks. Negative deviation of the parameter *Rsk* corresponds to good load capacity properties of a profile. [CSN EN ISO 4287, 1999]

***Rku* – kurtosis of the assessed profile** expresses the biquadratic mean of *Z(x)* in a sampling length *lr* rendered dimensionless as the biquadratic of the root mean squared height *Rq*. It indicates widths or narrows of the probability density function in comparison to the Gaussian normal distribution of coordinates of a profile, where parameter $Rku = 3$. A profile with sharper peaks has the value of $Rku > 3$. On the contrary, $Rku < 3$ indicates a profile with round and less frequent peaks. [CSN EN ISO 4287, 1999]

3. TESTING ASSEMBLY

Equipment for the abrasive waterjet cutting of the Department of Material Disintegration at the Institute of Geonics of the CAS, v.v.i. was used for testing. The testing assembly consisted of the PTV 75-60 high pressure pump (2 multiplicators, max. operating pressure of 415 MPa, max. flow rate of 7.8 $l \cdot min^{-1}$, power of 67 kW) and the X-Y cutting table PTV WJ2020–1Z-D (operating area of 2000 x 2000 mm, cutting speed continuously adjustable in the range of 0 – 20 $m \cdot min^{-1}$). [PTV 2009]

The commercially available Australian garnet with MESH 80 [Martinec et al. 2002] was used as an abrasive material. The water pressure was set at 400 MPa and the standard cutting head for the abrasive waterjet generation (PTV 301022-X) with the diamond water nozzle of the diameter of 0.33 mm was used. The diameter of the focusing tube was 1.02 mm, length of the focusing tube 76 mm, stand-off distance of the focusing tube orifice from the surface of the cut sample 4 mm. The cutting speed was set at 100, 200, 300, 400, 500 and 600 $mm \cdot min^{-1}$.

Selected roughness parameters of the cutting surface were evaluated on test samples prepared by the abrasive waterjet technology with dimensions required according to the standard of CSN EN ISO 4288. For the experiment, nine types of the aluminium alloy were selected, namely: EN AW 2017, EN AW 2024, EN AW 5083, EN AW 5754, EN

AW 6060, EN AW 6061, EN AW 6082, EN AW 7022, EN AW 7075. From these materials, 54 test samples of 60x20x3 mm were prepared.

Measurements of topography of cutting surfaces were realized by means of an optical profilometer MicroProf FRT in 20 lines starting at the distance of 0.5 mm from the edge of the jet penetration into the material and ending at the distance of 0.5 mm from the edge of the jet exit from the cut material. The total length of the measured line was 42 mm. The evaluation length was 40 mm, the dot pitch was 1.5 μm. The measured data were analyzed with the SPIP software. Measurement and consequent evaluation of surfaces were done according to the standard [CSN EN ISO 4287, 1999], [CSN EN ISO 4288, 1999], [CSN EN ISO 16610-21, 2012].

For analysis of the surface topography created by the abrasive waterjet technology, a NIKON D700 camera (lens of Micro Nikon 60 mm) was used and photographs of the topography of surfaces of machined materials were made, see Fig. 1.

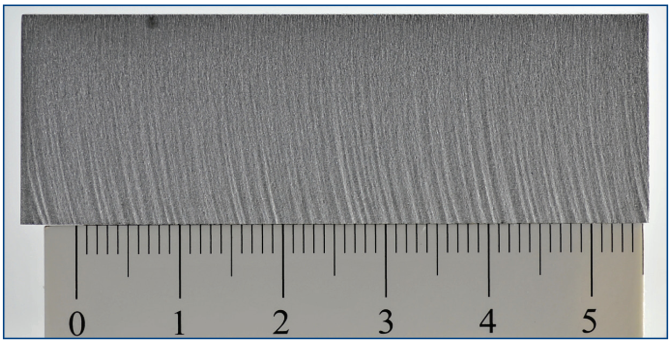

Figure 1. Photograph of aluminium alloy EN AW 2024 sample of dimensions of 60 x 20 x 3 mm (water pressure of 400 MPa, traverse speed of 300 mm·min^{-1}, water nozzle diameter of 0.33 mm, focusing tube diameter of 1.02 mm, stand-off distance of 4 mm, angle of incidence of 90°, Australian garnet with MESH 80, abrasive flow rate of 400 g.min^{-1})

4. RESULTS AND DISCUSSION

The surface topography of analyzed samples from the aluminium alloy materials created by the AWJ technology differ with the increasing depth of cut and traverse speed. Fig. 2 presents a comparison of photographs of cutting walls of the individual aluminium alloys cut at traverse speeds of 100, 200, 300, 400, 500 and 600 mm·min^{-1}. In terms of the stress-strain deformation state, the deformation stress is relatively high at the inlet of the jet to the material. Therefore, the separating cut is rather smooth at the beginning. With the increasing depth of cut, the deformation stress (cuttability of the tool) which is influenced by the traverse speed decreases.

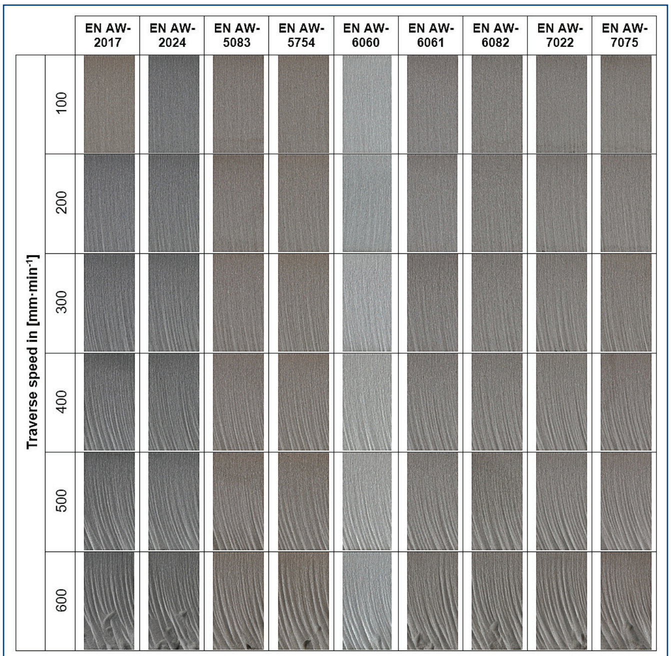

Figure 2. Comparison of photographs of cutting walls of individual aluminium alloys at various traverse speeds

The most commonly-used roughness parameter applied for the evaluation of surfaces of machined materials is the amplitude parameter *Ra* – the arithmetical mean deviation of the roughness profile. However, the parameter *Ra* does not react sensitively to height variations of the assessed surface profile. For this reason, the parameters *Rq* and *Rz* were observed as the amplitude parameters for more detailed surface evaluation since they react more sensitively to local inequalities of the assessed surface. They provide with more precise information about the studied surface texture. The observed amplitude parameters of roughness *Ra*, *Rq* and *Rz* increase with the increasing traverse speed, as can be seen in Fig. 3.

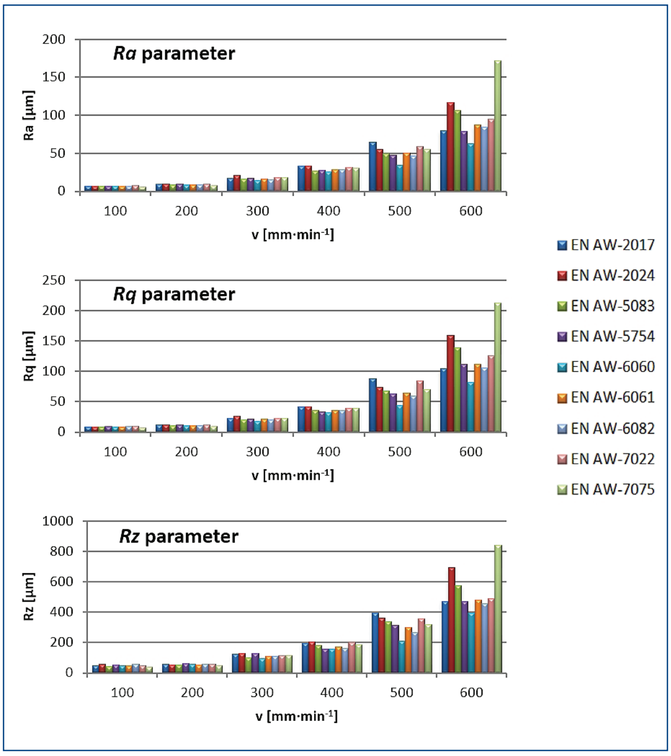

Figure 3. Effects of traverse speed on roughness parameters *Ra*, *Rq*, *Rz* measured in line no. 19

During evaluation, specificities of the newly-created surface texture should be taken into account. The texture is divided into elements based on the spacing between particular inequalities which differ with the depth of cut. The values of roughness parameters in the upper part of the separating cut are lower than the values in the lower part. For this reason, the values of roughness parameters *Ra*, *Rq* and *Rz* in the line no. 19 of the sample with 20 measured lines were selected. In Fig. 3, graphs of the parameters *Ra*, *Rq* and *Rz* in the line no. 19 of nine types of aluminium alloys and their relations to the traverse speed are compared. It can be seen that the effect of the traverse speed causes similar character of changes in roughness parameters *Ra*, *Rq* and *Rz* in all materials. It can be stated that the measured samples are not affected by local height inequalities.

At the traverse speed of 100 and 200 mm·min^{-1}, the abrasive waterjet generates sufficiently high deformation stress and therefore creates rather smooth separating cut throughout the whole thickness of the material, see Fig. 2 and Fig. 3. Deformation stress decreases with the increasing traverse speed throughout the material cut. In the lower part, the abrasive waterjet leaves traces and the surface roughness increases accordingly. Particular physical and mechanical properties of the tested materials start affecting the process at the traverse speed of 300 mm·min^{-1} and more because the effect of machinability of materials generally increases at higher values of the traverse speed.

In all investigated materials, increase in the traverse speed v results in deterioration of the surface quality and the value of the parameter *Ra* is increasing. However, in some materials, the values of the parameters *Ra*, *Rq* and *Rz* are decreasing at higher traverse speeds compared to other studied aluminium alloys and vice-versa.

For example, the aluminium alloy EN AW-7075 achieves the lowest value of the parameter Ra at 100 and 200 mm·min^{-1}. At the traverse speed of 300 mm·min^{-1}, physical and mechanical properties of the material start affecting the process and the value of the parameter *Ra* increases. At this traverse speed, the material EN AW-7075 demonstrates the third worst machined surface quality of the investigated aluminium alloys. At the traverse speed of 600 mm·min^{-1}, the highest value of the parameter *Ra* of all studied materials is measured for the material EN AW-7075, i.e. it is of 50 µm higher.

The aluminium alloy EN AW-6060 is another material which changes in surface quality at the increasing traverse speed compared to other investigated materials. At the traverse speed of 100 mm·min^{-1}, the second highest value of the parameter Ra = 7.07 µm is measured. The increase in the parameter *Ra* of this machined surface at higher traverse speed is slower than by other materials. Already at the traverse speed of 300 mm·min^{-1}, the material EN AW-6060 achieves the lowest *Ra* value of all studied aluminium alloys, i.e. Ra = 13.93 µm. This continues and differences in the quality of the machined surface in comparison to other analyzed aluminium alloys are distinct at the increasing traverse speed, see Fig. 2 and Fig. 3.

When evaluating the surface quality of all investigated materials at the highest traverse speed, the worst-to-machine material is the aluminium alloy EN AW-7075 and the best-to-machine material is EN AW-6060. In terms of the evaluation of the surface quality at the lowest traverse speed, the material EN AW-7075 is, on the contrary, the best material to be machined.

More of the normalized R-parameters should be used for the evaluation of the surface quality. Only one studied parameter provides with partial insight into the surface quality, which can lead to incorrect conclusions about the total quality of the workpiece. Appropriate selection of the investigated parameters should reflect the requirements for the monitoring of aspects of surfaces. Multi-parameter evaluation ensures more comprehensive approach to the behavior of surfaces.

Other studied amplitude parameters are the skewness *Rsk* and the kurtosis *Rku*. The skewness of the assessed profile expresses the level of symmetry of peaks and valleys from the central line. It is a specific measure which compares the degree of distribution of amplitude values with the degree of density of other values.

When evaluating the parameters *Rsk* and *Rku*, two lines both from the upper part and from the lower part of the cutting wall were removed in order to eliminate the effect of penetration and exit of the cutting tool (i.e. abrasive waterjet) into and from the cut material. Values of the parameters *Rsk* and *Rku* from 16 lines were calculated for each material type at various cutting speeds.

Fig. 4 shows the distribution of the parameter *Rsk* in particular depths of cut in studied aluminium alloys. At the traverse speed of 100 and 200 mm·min^{-1}, the values of $Rsk < 0$ mean larger and deeper profile valleys in the entire cutting thickness of almost all investigated materials. This reflects good load capacity properties of the surface. At increasing traverse speed, the parameter *Rsk* in the lower half of the cutting thickness of almost all studied materials is $Rsk > 0$. This indicates profiles with more frequent and more rugged peaks.

The distribution of the parameter *Rku* in particular depths of cut in studied aluminium alloys is presented in graphs in Fig. 5. It is obvious that neither the traverse speed nor the depth of cut have influence on the parameter *Rku* which approaches the value of $Rku = 3$ or $Rku > 3$. This indicates profiles with sharper peaks and valleys.

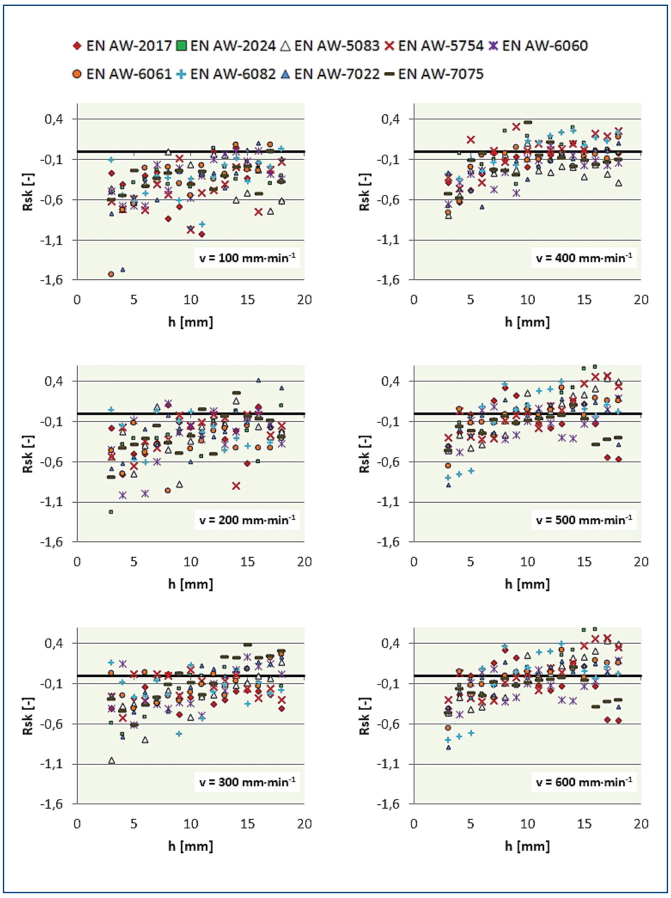

Figure 4. Effect of traverse speed on parameter *Rsk* in relation to depth of cut

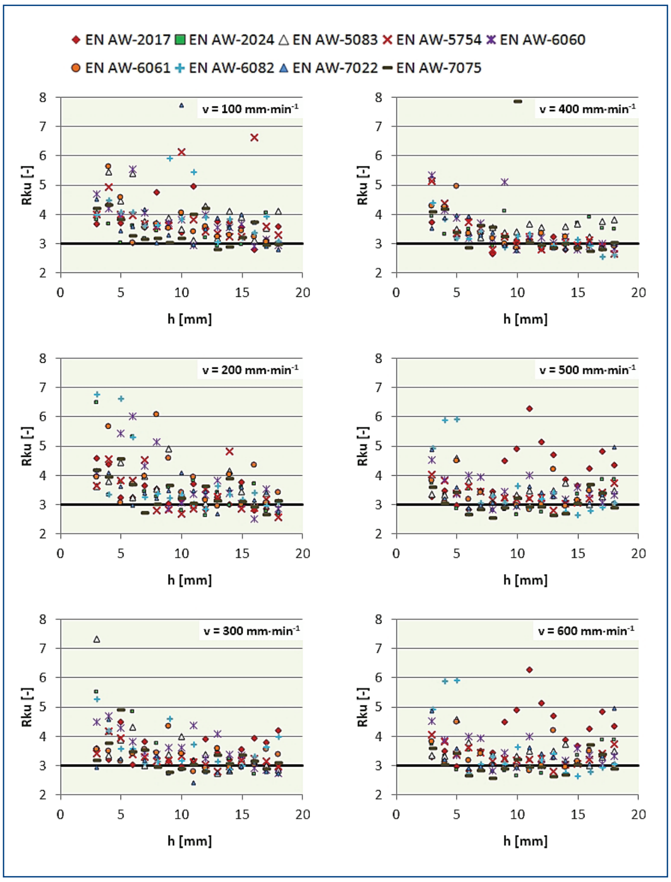

Figure 5. Effect of traverse speed on parameter *Rku* in relation to depth of cut

6. CONCLUSION

Surface of a material machined using the AWJ technology has a specific texture. Objective of measurement of values of the R-parameters is determined by the conditions established in particular standards. More of the normalized R-parameters should be measured for the evaluation of the surface quality, as only one studied parameter provides with partial insight into the surface quality, which can lead to incorrect conclusions about the total quality of the workpiece. Suitable selection of the analyzed parameters should reflect the requirements for the monitoring of aspects of surfaces. Multi-parameter evaluation ensures more comprehensive approach to the behavior of surfaces.

Nine different types of aluminium alloys were studied. The results show the effects of the traverse speed on the final surface quality. The observed amplitude parameters of roughness Ra, Rq and Rz increase with the increasing traverse speed. Particular physical and mechanical properties of the tested materials start affecting the process at the traverse speed of 300 $mm \cdot min^{-1}$. Effects of the machinability of materials also increase at higher values of the traverse speed. For the studied materials, the machinability should be tested and compared with the measured parameters of the surface roughness in order to better analyze the relation of machinability of materials and the traverse speed.

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