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Procedia Engineering 149 (2016) 177 – 182

**Procedia  
Engineering**[www.elsevier.com/locate/procedia](http://www.elsevier.com/locate/procedia)

International Conference on Manufacturing Engineering and Materials, ICMEM 2016,  
6-10 June 2016, Nový Smokovec, Slovakia

## Study of the Effect of Material Machinability on Quality of Surface Created by Abrasive Water Jet

Dagmar Klichova\*, Jiri Klich

*Institute of Geonics of the CAS, v. v. i., Studentska 1768, Ostrava, 708 00, Czech Republic*

### Abstract

The paper investigates the effect of material machinability on the quality of cutting surfaces created by abrasive waterjet in selected aluminium alloys. The texture of studied surfaces was measured by an optical profilometer and consequently assessed using the standardized amplitude parameters of the profile roughness  $Ra$ ,  $Rz$  and  $Rq$ . It was found that the quality of a cutting surface is significantly influenced not only by the cutting speed and determined machinability of particular aluminium alloy but also by its strength properties.

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Peer-review under responsibility of the organizing committee of ICMEM 2016

*Keywords:* machinability; surface roughness; abrasive waterjet; study of quality; aluminium alloy; optical profilometer

### 1. Introduction

Abrasive waterjet (AWJ) technology is becoming an increasingly popular machining method due to its unique properties, such as the universality, environmental friendliness and near zero thermal impact on the cutting surface. Water of very high pressure being forced through a small nozzle forms a liquid jet where small abrasive particles are added into. High kinetic energy of the water flow accelerates the abrasive particles which enable destruction of a target material in the area of their interaction with the material. Mechanism of material disintegration can be defined as a continuous grinding process caused by abrasive grains using the water jet as a cooling agent as well as a medium for the transport of new abrasives into the cut and removal of the used abrasive grains from the cut.

There are many factors which determine the final quality of the cutting surface created by the AWJ. In addition to the properties of the water jet as a cutting tool (water pressure at the nozzle inlet, diameter of the water nozzle, abrasive type, size of grains and amount of the abrasive used, cutting speed – i.e. traverse speed of the water jet over the material, stand-off distance of the nozzle from the material, etc.), the final appearance of the cutting surface is also influenced by the properties of the machined material. One of these properties which was studied in the presented paper is material machinability, i.e. the ease with which a material can be machined. The machinability is usually defined as a combined impact of physical properties and chemical composition of material on the progress, economic and qualitative results of the machining process [1]. The knowledge of particular material machinability enables to predict appropriate setting of input technological parameters in order to achieve required quality of a cut and to optimize the production process. Material machinability using the AWJ can be determined by a special method [2] based on the creation of non-through cuts (kerfs) in the studied material by the jet under pre-defined conditions. The machinability is then defined based on the amount of the material removed.

\*Dagmar Klichova. Tel.: +420-596-979-111; fax: +420-596-919-452.

E-mail address: [dagmar.klichova@ugn.cas.cz](mailto:dagmar.klichova@ugn.cas.cz)

## 2. Amplitude parameters of profile roughness

Quantified form of surface texture of studied materials is described by roughness amplitude parameters (parameter  $Ra$ ,  $Rq$  and  $Rz$ ). Rules and procedures for the assessment of surface textures are specified in more details in the standard of CSN EN ISO 4288 [3]. 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. [4]

**$Rq$  – 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 than the parameter  $Ra$ . [4]

**$Rz$  – 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  $lr$ . [4]

## 3. Machinability assessment of materials

Methodology for assessment of material machinability by AWJ [2] is based on the comparison of removal per unit volume of the tested material with the standard (etalon) material. The weight of the material  $m_1$  is measured with an accuracy of  $\pm 0.01$  g and the volume  $V$  is determined. The specific weight  $\rho$  of the tested material is calculated using the relation (1)

$$\rho = \frac{m_1}{V} \left[ \text{kg} \cdot \text{m}^{-3} \right] \quad (1)$$

Consequently, a kerf is done in the tested material during test cutting. The material should not be cut through the entire width. Three kerfs are finally created in all tested materials to ensure higher stability of material removal. The so-created kerfs determine the volume of material removed. The testing sample with kerfs is then dried with a stream of air. The final weight  $m_2$  of the tested material is measured. The weight removal  $\Delta m$  and volume removal  $\Delta V$  of the material are calculated according to the equations (2) and (3):

$$\Delta m = m_1 - m_2 \left[ \text{kg} \right] \quad (2)$$

$$\Delta V = \frac{\Delta m}{\rho} \left[ \text{m}^3 \right] \quad (3)$$

Removal per unit volume of the tested material is determined using the relation (4) where  $L$  is the length of the testing kerf. When the removal per unit volume  $\Delta V_U$  is known, the machinability index is calculated according to the equation (5) where  $\Delta V_{Uet}$  is the removal per unit volume of the standard (etalon) material.

$$\Delta V_U = \frac{\Delta V}{L} \left[ \text{m}^2 \right] \quad (4)$$

$$M_1 = \frac{\Delta V_U}{\Delta V_{Uet}} \left[ - \right] \quad (5)$$

Materials with the machinability index lower than one show worse machinability than the standard (etalon) material. On the contrary, materials with the machinability index higher than one have better machinability than the standard (etalon) material. The standard (etalon) material is aluminium alloy EN AW-1050.

#### 4. Experimental setting

Equipment for waterjet cutting available at the Institute of Geonics of the CAS, v. v. i. was used for preparation of testing samples. The testing assembly consisted of the PTV 75-60 high pressure pump (2 multipliers, max. operating pressure of 415 MPa, max. flow rate of  $7.8 \text{ l}\cdot\text{min}^{-1}$ , power of 67 kW) and the X-Y cutting table PTV WJ2020-1Z-D (operating area of  $2000 \times 2000 \text{ mm}$ , cutting speed continuously adjustable in the range of  $0 - 20 \text{ m}\cdot\text{min}^{-1}$ ). The commercially available Australian garnet with MESH 80 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 traverse speed was set at 100, 200, 300, 400, 500 and  $600 \text{ mm}\cdot\text{min}^{-1}$ .

Selected roughness amplitude parameters of the cutting surface were evaluated on testing samples prepared by the abrasive waterjet technology with dimensions required according to the standard of CSN EN ISO 4288 [3]. For the experiment, the following types of the aluminium alloy were selected: EN AW-2017, EN AW-5083, EN AW-6060, EN AW-7075. From these materials, 24 testing samples of  $60 \times 20 \times 3 \text{ mm}$  were prepared.

Cutting surfaces were measured 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. Surface topography was assessed by means of an optical profilometer MicroProf FRT. The obtained data were analyzed with the SPIP software. Measurement and consequent evaluation of surfaces were done according to the standards [3, 4, 5].

The aforementioned aluminium alloys were also used for preparation of testing samples cuboid in shape and measuring  $20 \times 60 \times 100 \text{ mm}$  which were then subjected to the tests of machinability. The standard (etalon) material was the aluminium alloy EN AW-1050. The testing block from the nearly pure aluminium Al 99.5% measured  $5 \times 50 \times 80 \text{ mm}$ .

#### 5. Results and discussion

As regards the stress-strain deformation state, rather high deformation stress occurs at the inlet of the jet to the material. Therefore, the separating cut is relatively smooth at the start. However, the deformation stress (i.e. cuttability of the tool) which is significantly influenced by the traverse speed decreases with the increasing depth of the cut [6]. The surface topography of analyzed samples of aluminium alloys (EN AW-2017, EN AW-5083, EN AW-6060, EN AW-7075) created by the AWJ technology differ then with the increasing depth of the cut and traverse speed. A comparison of photographs of cutting walls of individual aluminium alloys which were cut at the traverse speeds of 100, 200, 300, 400, 500 and  $600 \text{ mm}\cdot\text{min}^{-1}$  is presented in Fig 1.

Material designation	Traverse speed [ $\text{mm}\cdot\text{min}^{-1}$ ]					
	100	200	300	400	500	600
EN AW- 2017						
EN AW- 5083						
EN AW- 6060						
EN AW- 7075						

Fig. 1. Comparison of photographs of cutting walls of individual aluminium alloys cut at various traverse speeds

During evaluation, specific texture of the newly-created surface must be considered. The texture is divided into elements based on the spacing between particular inequalities which vary significantly depending on the depth of cut. The values of roughness parameters in the upper part of the separating cut are generally lower than the values in the lower part. For this reason, the values of roughness parameters in the line no. 19 were selected from 20 lines measured in the sample. 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 a surface profile. Therefore, the parameters  $Rq$  and  $Rz$  were observed as the amplitude parameters for more detailed surface evaluation since they reacted more sensitively to local inequalities of the assessed surface. They provided with more precise information about the studied surface texture. The amplitude parameters of roughness  $Ra$ ,  $Rq$  and  $Rz$  were increased with the increasing traverse speed, as can be seen in Fig. 2.

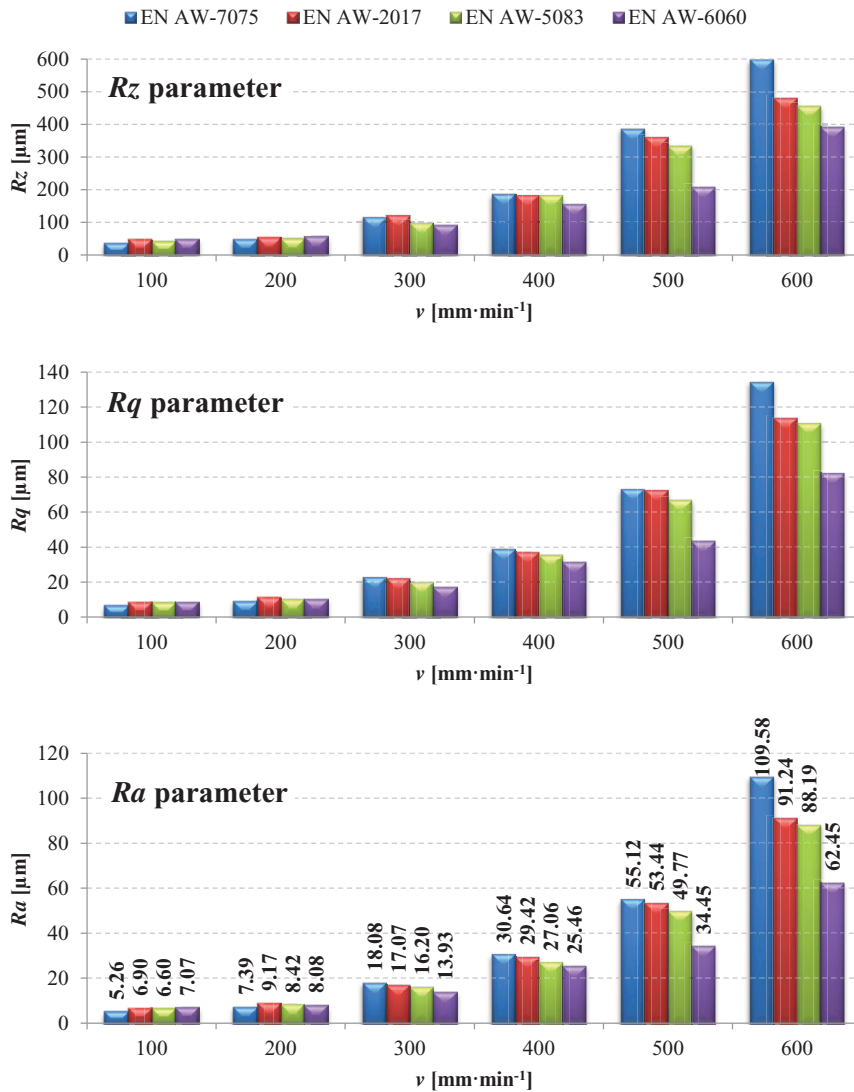


Fig. 2. Effects of traverse speed on roughness amplitude parameters  $Ra$ ,  $Rq$  and  $Rz$

Graphs of the parameters  $Ra$ ,  $Rq$  and  $Rz$  measured in the line no. 19 in four types of aluminium alloys and their dependence on the traverse speed are compared in Fig. 2. It can be seen that the character of changes in roughness parameters  $Ra$ ,  $Rq$  and  $Rz$  caused by the effect of traverse speed is similar in all materials. It is therefore concluded that the measured samples are not affected by local height inequalities.

At the traverse speed of 100 and 200  $\text{mm} \cdot \text{min}^{-1}$ , deformation stress of the abrasive waterjet is sufficiently high to create rather smooth separating cut throughout the whole thickness of the material, see Fig. 1. Deformation stress decreases with the increasing traverse speed during the material cutting. In the lower part, the abrasive waterjet leaves kerfs 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  $\text{mm} \cdot \text{min}^{-1}$ .

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. The effect of machinability of materials generally increases at higher values of the traverse speed.

For example, the aluminium alloy EN AW-7075 achieves the lowest value of the parameter  $Ra$  at 100 and 200  $\text{mm} \cdot \text{min}^{-1}$ . However, at the traverse speed of 300  $\text{mm} \cdot \text{min}^{-1}$ , physical and mechanical properties of the material start affecting the process and the value of the parameter  $Ra$  is increased. At this traverse speed, the material EN AW-7075 demonstrates the worst machined surface quality of all investigated aluminium alloys.

The aluminium alloy EN AW-6060 is another material of the investigated materials, the surface quality of which changes with the increasing traverse speed. At the traverse speed of 100  $\text{mm} \cdot \text{min}^{-1}$ , the highest value of the parameter  $Ra = 7.07 \mu\text{m}$  is measured. The increase in the parameter  $Ra$  of this machined surface at higher traverse speed is, however, slower than by other materials. Already at the traverse speed of 200  $\text{mm} \cdot \text{min}^{-1}$ , EN AW-6060 achieves the lowest  $Ra$  value of all studied aluminium alloys, i.e.  $Ra = 8.08 \mu\text{m}$ . This trend continues and differences in the surface quality caused by the increasing traverse speed are distinct in comparison to other analyzed aluminium alloys, see Fig. 1 and Fig. 2.

The results show that the effect of material machinability on the quality of surfaces created by AWJ varies depending on the used traverse speeds. When evaluating the surface quality at the highest traverse speed, the aluminium alloy EN AW-7075 is the worst machinable of all tested materials. On the contrary, EN AW-6060 demonstrates the best machinability. However, when evaluating the surface quality at the lowest traverse speed, EN AW-7075 is the best material to be machined. For this reason, tests of machinability were done on all studied materials. The machinability index was determined according to the author [2]. The evaluation method was already described in the previous part of the paper. Fig. 3 provides a graphical overview of the obtained results.

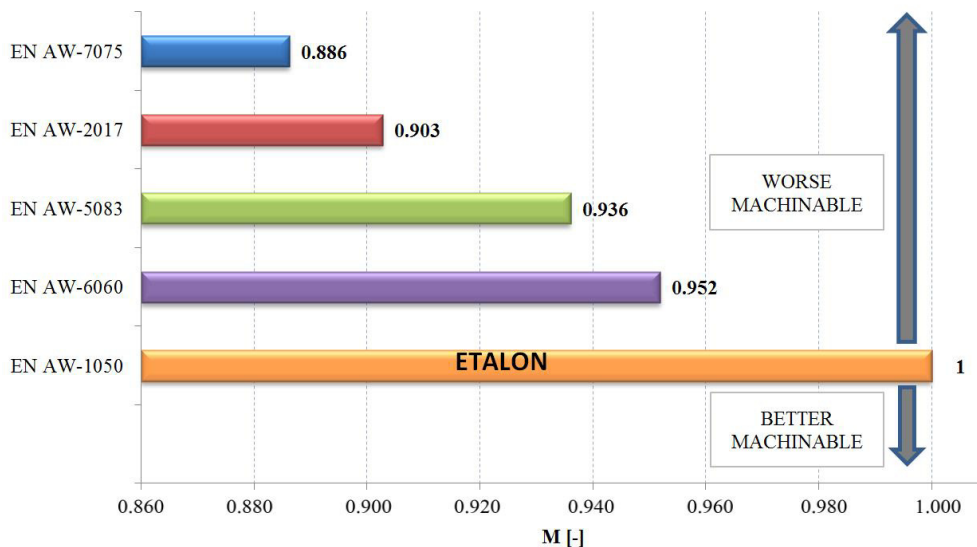


Fig. 3. Values of machinability index  $M$

EN AW-1050 was selected as the standard (etalon) material with the value of  $M = 1$ . If the machinability index of the tested aluminium alloys is lower than 1, their machinability is worse than the machinability of the standard (etalon) material. EN AW-7075 has the lowest machinability index of  $M = 0.886$ . EN AW-2017 has  $M = 0.903$ . EN AW-5083 has  $M = 0.936$ . EN AW-6060 has the highest value of the machinability index of all tested materials ( $M = 0.952$ ). So-defined level of machinability corresponds to the values of surface roughness at the traverse speed of  $300 \text{ mm} \cdot \text{min}^{-1}$  and higher, see Fig. 2. Material machinability is influenced by physical properties, chemical composition, economic and qualitative results of the machining process. Differences in the machinability index  $M$  of the studied materials are low. It is therefore concluded that the effect of machinability is only significant at higher traverse speeds as the impact of physical and mechanical properties on the final quality of the cutting surface is increasing.

## 6. Conclusion

Surface of a material machined using the AWJ technology has a specific texture. 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. Objective measurement of values of the R-parameters is determined by the conditions established in particular standards. Four different types of aluminium alloys were studied in the experiment in order to investigate the effect of the traverse speed on the final surface quality. It was found that the observed amplitude parameters of roughness  $Ra$ ,  $Rq$  and  $Rz$  increased with the increasing traverse speed.

Machinability tests were carried out on the selected aluminium alloys. EN AW-1050 was assigned as a standard (etalon) material with the machinability index of  $M = 1$ . Machinability index  $M$  for EN AW-7075, EN AW-6060, EN AW-5083 and EN AW-2017 was determined to be lower than 1. Machinability of these materials was worse than the machinability of the standard (etalon) material. It was found that particular physical and mechanical properties of the tested materials started affecting the machining process at the traverse speed of  $300 \text{ mm} \cdot \text{min}^{-1}$ . Effects of the material machinability also increased at higher values of the traverse speed.

## Acknowledgements

The article was prepared in the frame of the project for the support of long-term strategic development of research organization, RVO: 68145535 and the project of the Institute of Clean Technologies for Mining and Utilization of Raw Materials for Energy Use – Sustainability Program, Reg. No. LO1406, which is supported by the Research and Development for Innovations Operational Programme financed by the Structural Funds of the European Union and the State Budget of the Czech Republic. The authors are very appreciative and thankful for the support.

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