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Investigation of abrasive water jet cutting parameters influence on 6082 aluminium alloy surface roughness

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1. Introduction

Many machining technologies, so-called high speed technologies are included in the category of Non-Traditional Machining Processes (NTMP). These are non-traditional in the sense that traditional tools are not employed; instead, energy in its direct form is utilized [1]. Abrasive Water Jet (AWJ) cutting technology uses a jet of high pressure and abrasive water slurry to cut the material by means of erosion. The impact of single solid particles is the basic event in the material removal by abrasive water jets [2].

In some technological applications the AWJ process has the target of “cold” cutting process [3], but combining the temperature it was observed that the AWJ produces high quality holes free of chipping and gouging [4]. The process uses a fine-bore nozzle to form a coherent, high velocity jet, which has a pressure up to 400 MPa and a velocity of up to 1000 m s^{-1}. AWJ cutting of the workpiece results from failure and micro-machining and comparing with traditional and most NTMP, AWJ cutting technology offers the following advantages [3]:

- no thermal distortion,
- high flexibility,
- high machining versatility,
- small machining force.

Whereas the AWJ technology is well defined but different techniques like numerical study [5, 6] and cutting head oscillation techniques [3, 7, 8] are used for the optimisation of AWJ.

Nevertheless, many aspects of AWJ are still in development. AWJ process investigation overview has showed that process has some limitations on the thickness of material to cut [1, 3, 9]. The cut layer of the material is characterized by two AWJ parameters: 1) cutting zone or smooth roughness zone and 2) deformation zone or rough roughness zone. Smooth roughness and rough roughness zones are limited by critical depth h_{crit}. According to Hashish, the so-called critical depth h_{crit} can be found in each surface [9]. The zone above the critical depth is cutting zone h_c and the zone below it is the deformation zone h_d. Author Valicek [9] also proposed the parameters for surface quality evaluation below the critical zone: the retardation of cutting trace Y_{ret} and the angle δ of deviation. These mentioned parameters are the nozzle effect on surface due the working parameters.

Fig. 1 demonstrates the main parameters in cut-wall surface roughness evaluation. Also, it can be seen, that striations resulting on the cutting surface has a typical structure and are opposite to the direction of cutting. The cutting zone is considered to be of good quality and the deformation zone of poor quality. This critical depth depends on the traverse speed of the cutting head.

The literature analysis [10] of surface roughness profile data showed, that cutting workpiece of 30 mm according to traverse speed can generate the smoother surface roughness comparing to other NTMP techniques. For example, by oxygen cutting with economical working parameters, the surface roughness R_a can be reached in the range of 25-6.3 μm (N11- N9 according to standard ISO 1302). Meanwhile surface roughness using AWJ technique depending on the traverse speed is gained in the range of 6.3-3.2 μm.

It can be concluded that the main parameters of AWJ which describes surface quality are [1-9]: pressure, traverse speed (cutting speed) and abrasive material as well dimension.

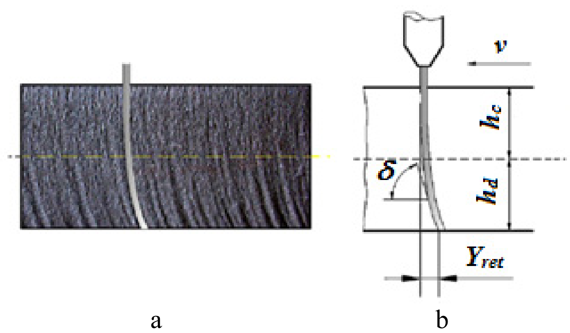


Fig. 1 The main parameters of surface profile, generated by AWJ (adopted from [9]): a) typical surface profile, b) parameters, defining the surface quality

The aim of this work was to investigate traverse speed influence on the surface roughness of 6082-Al alloy, to define the critical depth of AWJ cut and examine the ability to increase maximum smooth surface zone cut depth.

2. The experimental technique

The pentagonal shape workpiece was selected as a test specimen and was cut from 6082-Al alloy with a thickness of 30 mm using a Resato ACM Waterjet machine equipped with a 2.5D cutting head (5-axis) (Fig. 2). The cutting was performed using five different traverse speeds, keeping other cutting parameters constant: e.g. abrasive flow rate (180 g/min), pump pressure (3600 bar) and the inside diameter of the cutting nozzle (0.762 mm).

GMA Garnet MESH80 abrasive type (abrasive dimensions 300-150µm) was chosen, which is ideally suited for all material applications for precision cutting. AWJ cutting program was written to control the nozzle path and traverse speed in order to cut pentagonal specimen with different traverse speed for each pentagon walls (Fig. 3).

Fig. 2 The AWJ cutting machine ACM 3060-2

Samples	v , mm/min
X-ROUGH	163.5
ROUGH	97.2
MEDIUM	68.1
FINE	48.9
X-FINE	37.8

a b

Fig. 3 The object of experiments: a) pentagonal shape specimen of 6082-Al alloy, b) traverse speed applied for concrete experiment

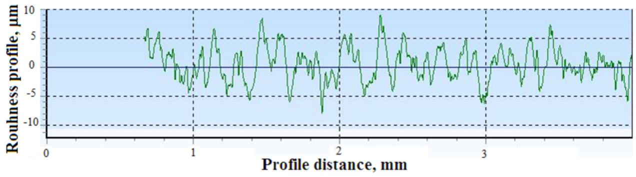
The surface roughness measurements were performed using portable roughness tester *TR200* and special *Time Surf* software.

The surface quality parameter employed to indicate the surface quality in this experimental study was the arithmetic mean roughness R_a.

3. Experimental results

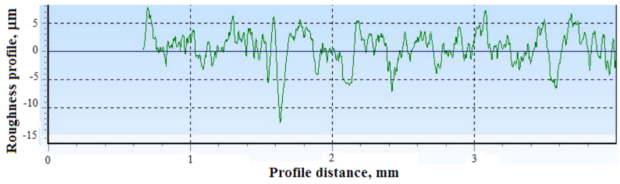
Five straight wall cutting tests were performed with different traverse speed starting from 163.5 mm/min (X-ROUGH wall cut) to 37.8 mm/min (X-FINE wall cut). Total cutting length comprises 300.4 mm and time of cutting 7 min 46 s.

The surface roughness results of generated samples are presented in Fig. 4. The surface profile measurements were performed in so-called smooth roughness zone (or cutting zone). It is seen on the samples that increase of traverse speed can be very effective. Also it is seen that surface profile on surfaces X-ROUGH, ROUGH has clearly defined roughness zones: cutting zone and deformation zone. The striations of tool path are left in the deformation zone, due to the deflection of the nozzle in high cutting speed. Visually, the results of samples MEDIUM, FINE, X-FINE not presents the critical depth, as it seen in samples X-ROUGH and ROUGH. The investigation of surface roughness according to cutting depth was performed.



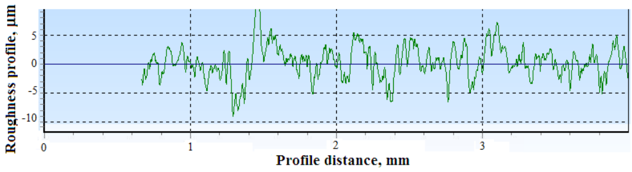
R_a=4.826 µm, R_q=5.954 µm, R_z=27.5 µm, R_t=35.2 µm,
R_p=14.11 µm, RS=0.077 mm, RS_m=0.121 mm, RS_k=0.204, R_v=13.38 µm

a



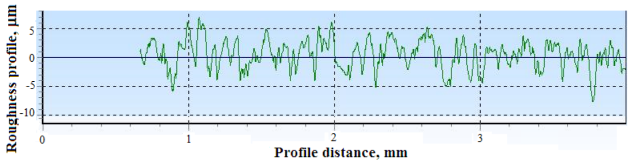
R_a=4.609 µm, R_q=5.927 µm, R_z=27.4 µm, R_t=42.18 µm,
R_p=12.64 µm, RS=0.1 mm, RS_m=0.138 mm, RS_k=-0.57, R_v=14.81 µm

b



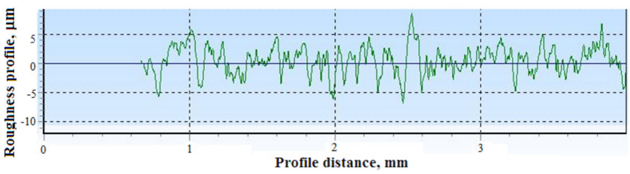
R_a=4.398 µm, R_q=5.816 µm, R_z=28.32 µm, R_t=46.09 µm,
R_p=13.25 µm, RS=0.082 mm, RS_m=0.133 mm, RS_k=0.143, R_v=15.06 µm

c



R_a=3.988 µm, R_q=4.996 µm, R_z=21.86 µm, R_t=30.13 µm,
R_p=9.415 µm, RS=0.074 mm, RS_m=0.1 mm, RS_k=-0.311, R_v=12.44 µm

d



R_a=3.809 µm, R_q=4.808 µm, R_z=23.97 µm, R_t=31.68 µm,
R_p=11.45 µm, RS=0.073 mm, RS_m=0.103 mm, RS_k=-0.082, R_v=12.52 µm

e

Fig. 4 Surface roughness profile, measured in the zone h_c: a) X-ROUGH surface profile, b) ROUGH surface profile, c) MEDIUM surface profile, d) X-FINE surface profile, e) FINE surface profile

In the next stage, the surface roughness measuring in the longitudinal direction was performed with the interval of 2 mm, so 14 measurement positions in total were defined for each specimen wall. The surface evaluation was performed starting from cutting side. Each measurement was performed at least 6 times and then averaged.

The surface roughness measurement results are presented in Fig. 5.

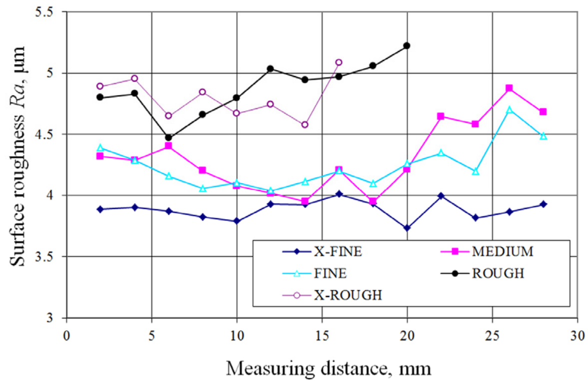


Fig. 5 Surface roughness evolution according to the cutting depth

The surface roughness evolution according to the cutting depth allowed defining the critical depth for concrete traverse speed.

Regarding the results of surface roughness according to the depth of cut it was concluded that in our performed experiment the critical depth for 30 mm 6082-Al alloy specimen varied according to traverse speed.

Summarised surface roughness measurement results are presented in Table 1.

It is seen, that samples X-ROUGH and ROUGH have striations, which are formed in rough cutting (deformation) zone. These striations are formed due to high traverse speed, which causes the deviation of the water jet.

Specimens FINE and MEDIUM in cutting zone are practically of identical surface quality of $R_a = 4.2$ µm. But starting from 26 mm (FINE machining) and 22 mm (MEDIUM machining) of cutting the surface quality differs according to traverse speed. The same tendency is observed in the samples X-ROUGH and ROUGH. In the cutting zone of both mentioned samples the surface roughness is 4.8-4.9 µm.

Only X-FINE (37.8 mm/min) cut showed the same surface results on all specimens' length of 30 mm. So, the decrease of traverse speed on the same workpiece allows increasing the cutting depth.

Finally, it has been demonstrated how surface roughness depends on the traverse speed.

Table 1

Surface roughness measurement results in cutting zone and deformation zone, according to cutting depth

Specimen, traverse speed v, mm/min	Critical depth, mm	Specimen view and critical depth evaluation	Variation of surface roughness in cutting zone, h_c R_a, µm	Averaged surface roughness in cutting zone h_c and h_d, R_a, µm
X-ROUGH: 163.5	16		zone h_c: 4.7-5.2	h_c: R_a=4.8 h_d: no measurements
ROUGH: 97.2	20		zone h_c: 4.5-5.2	h_c: R_a=4.88 h_d: no measurements
MEDIUM: 68.1	22		zone h_c: 4.0-4.6	h_c: R_a=4.16 h_d: R_a=4.7
FINE: 48.9	26		zone h_c: 4.0-4.75	h_c: R_a=4.19 h_d: R_a=4.6
X-FINE: 37.8	30		zone h_c: 3.75-4.0	h_c: R_a=3.88 h_d: absent

Fig. 6 presents the results of cutting depth dependence on cutting speed. The results of surface roughness dependence according to traverse speed in cutting zone are presented in Fig. 7.

Under the critical depth the trajectory of the jet is no more vertical. It has been found that cutting head traverse speed decrease from 163. to 37.8 mm/min calls the decrease of the surface roughness by 1µm. Due to the peculiarities of AWJ technique the main effect on the admissible surface quality the workpiece surface roughness is the thickness.

Data presented in Fig. 7 enable to conclude that surface roughness in the cutting zone in dependence on cutting speed can be expressed by equation:

$$R_a = 2.25\ v^{0.155} \quad (1)$$

Data presented in this study could be used by the manufacturers to predict required surface roughness for water jet cutting considering to the aluminium sheets thickness.

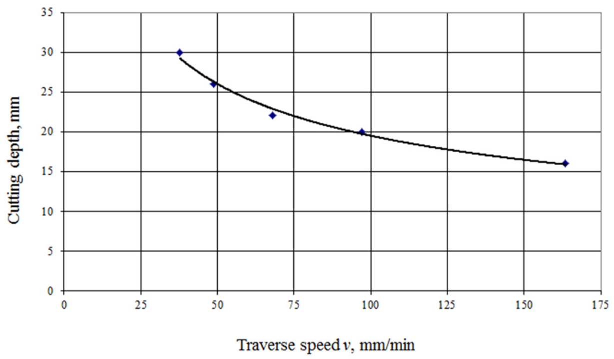


Fig. 6 Cutting depth dependence according to traverse speed

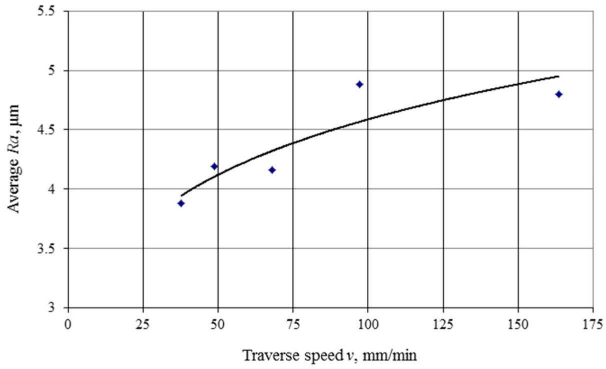


Fig. 7 Surface roughness dependence in cutting zone according to traverse speed

4. Conclusions

1. Abrasive Water Jet experimental research has been performed by cutting 6082-Al alloy specimen of the thickness of 30 mm. Also the influence of the traverse speed on surface roughness was examined.

2. AWJ experimental research has shown that traverse speed is the main factor influencing the cutting depth achieving the admissible surface roughness:

- the use of traverse speed of 37.8 mm/min allows cutting the 30 mm 6082-Al alloy workpiece in the range of surface quality 3.75-4.0 μm,
- the use of traverse speed of 48.9 mm/min allows cutting the 26 mm workpiece in the range of surface quality 4.0-4.75 μm,
- the use of traverse speed of 68.1 mm/min allows cutting the 22 mm workpiece in the range of surface quality 4.0-4.6 μm,
- the use of traverse speed of 97.2 mm/min allows cutting the 20 mm workpiece in the range of surface quality 4.5-5.2 μm,
- the use of traverse speed of 163.5 mm/min allows cutting the 16 mm workpiece in the range of surface quality 4.7-5.2 μm.

3. Finally, it has been concluded that the traverse speed of 37.8 mm/min in cutting 6082-Al alloy allows to achieve the surface roughness of R_a = 3.9 μm for the workpiece with the wall thickness of 30 mm.

4. Also it has been found, that the decrease of traverse speed from 163.5 mm/min to 37.8 mm/min decrease the surface roughness by 1 μm. But here the limitation of cutting depth to 16 mm is achieved, by using the highest traverse speed.

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ALIUMINIO LYDINIO 6082 PJOVIMO ABRAZYVINE VANDENS SROVE PARAMETRŲ ĮTAKOS TYRIMAS PAVIRŠIAUS ŠIURKŠTUMUI

R e z i u m ė

Straipsnyje pateiktas paviršiaus šiurkštumo tyrimas, pjaunant ruošinį abrazyvine vandens čiurkšle. Pateikiami pagrindiniai pjovimo proceso parametrai – abrazyvo tipas, vandens padavimo slėgis, naudotų purkštukų skersmuo ir pjovimo galvutės eiga.

Arazyvinio pjovimo vandens čiurkšle būdingi du pjaunamo paviršiaus atvejai: išbaigiamasis ir rupusis. Išbaigiamojo šiurkštumo paviršius susiformuoja aukščiau kritinio gylio ir pjovimo zonoje, rupusis paviršius susiformuoja žemiau kritinio gylio – deformavimo zonoje. Tyrimo metu atlikti bandymai pjaunant Al-6068 lydinio ruošinį skirtingais pjovimo galvutės eigos greičiais parodė, kad didesnis pjovimo greitis paviršiuje suformuoja pjovimo pėdsakus, kurie yra pastebimi gilesniame, deformaciniame, pjaunamo ruošinio sluoksnyje.

Darbe pateikti rezultatai, parodė, kad parinkus 37.8 mm/min pjovimo galvutės eigos greitį, pasiekiamas paviršiaus šiukštumas R_a gaunamas 3.9 μm visame 30 mm ruošinio storyje. Galvutei judant 48.9 mm/min ir 68.1 mm/min greičiu gautas R_a = 4.2 μm paviršiaus šiurkštumas, tačiau pjovimo zona sudaro 26 mm ir 22 mm atitinkamai viso ruošinio storio. Pjaunant ruošinį didesniu, 97.2 mm/min ir 163.5 mm/min greičiu gautas paviršiaus šiukštumas – R_a = 4.8 μm, tačiau išbaigiamasis pjovimo gylis neviršija 16-20 mm viso ruošinio storio.

Darbe gauti rezultatai bus panaudoti paviršiaus šiurkštumui prognozuoti pjaunant įvairaus storio aliuminio lakštus.

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INVESTIGATION OF ABRASIVE WATER JET CUTTING PARAMETERS ON 6082 ALUMINIUM ALLLOY SURFACE ROUGHNESS

S u m m a r y

The paper provides the analysis of surface roughness of the workpiece cut using abrasive water jet. The main cutting process parameters are presented: the type of abrasive material, water feed pressure, the diameter of the used nozzle and the course of the cutting head.

The abrasive cutting using water jet has two typical cases of the cut surface are: smooth and coarse. In the case of finished cutting the surface of the necessary roughness forms below the critical depth – in so called cutting zone. The coarse surface forms under the critical depth – in so called deformation zone. The performed tests of cutting the Al-6068 alloy workpiece with different cutting head traverse speeds revealed that due to the higher traverse speeds the cutting trace forms on the surface which are noticed in the deeper deformation layer of the workpiece cut.

According to the provided results the selected of the 37.8 mm/min cutting head traverse speed achieves the roughness of the surface of R_a makes 3.9 μm in a whole workpiece thickness of 30 mm.

When the head moves by 48.9 mm/min and 68.1 mm/min speeds the resulted roughness was R_a = 4.2 μm, but the cutting zone makes 26 mm and 22 mm respectively of the whole thickness of the workpiece. When cutting the workpiece the greater speeds such as 97.2 mm/min and 163.5 mm/min the resulted roughness makes R_a = 4.8 μm, but the cutting depth does not exceed 16-20 mm of the whole thickness of the workpiece.

The results of this study will be used for the forecast of possible surface roughness when cutting various workpieces made of aluminium.

Keywords: abrasive water jet, surface roughness.

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