EVALUATION OF GEOMETRIC AND QUALITATIVE CHARACTERISTICS OF THE ALUMINIUM ALLOY AFTER CUTTING BY ABRASIVE WATER JET

DOMINIKA BOTKOVA[1], FRANTISEK BOTKO[1], DAGMAR KLICHOVA[1], RADOSLAV VANDZURA[1], MATUS GELATKO[1]

[1]Technical University of Kosice, Faculty of Manufacturing Technologies with a seat in Presov, Slovakia

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frantisek.botko@tuke.sk

Presented article is aimed on the evaluation of geometric and qualitative characteristics of the surface created abrasive water jet cutting of EN AW 2024 aluminium alloy with traverse speed change in values from 100 to 600 mm.min^{-1}. The resulting surfaces were evaluated according to the Swiss standard SN 214001 and ISO/TC 44 N 1770 which describes the parameters of the machined surface and evaluates the final quality of the created surface. A surface with the best properties was created at the traverse speed of 100 mm per minute**.** The methodology included geometric evaluation, including measurements of perpendicularity and flatness, and dimensional evaluation of the accuracy of the cut width. Qualitative characteristics included analysis of surface roughness (Ra) and visual inspection of cut marks. The surfaces were classified into quality classes (Q1–Q5) according to the measured values.

KEYWORDS

cutting, abrasive water jet, surface quality, aluminium alloy

1 INTRODUCTION

The technology of cutting and disintegration of materials by water jet is currently used in various industries [Hutyrova 2016, Michalik 2014, Hloch 2018, Carach 2018]. Water jet [Perec 2018] is one of the progressive energy beam technologies for cutting and machining materials [Klichova 2016]. The effects of the technology on materials of various kinds and properties are constantly being investigated. Several modifications of the water jet are known. Each modification being characterized by a specific effect on the surface [Lehocka 2018 &2019a, Kascak 2019] or the cutting edge of the cut or machined material. The basic modification is a pure continuous water jet without abrasive [Hlavac 2012]. The most commonly used modification is an abrasive water jet [Ganovska 2016], where a mixture of abrasives in various forms [Carach 2019] is added to the water. In this modification, the abrasive and suspension water jet are known and their effects on the material are comparable. The main difference is the mechanism of adding the abrasive to the water [Hloch 2006]. The abrasive is most often fine sand, but the use of fine ice particles (cryogenic water jet) is also known [Jerman 2021]. Other modifications include a discontinuous pulsating water jet [Klich 2011, Kusnerova 2012], which can be generated using a specially designed self-resonating nozzle or using ultrasonic excitation [Lehocka 2019b, Hloch 2019] to provide flow discontinuity [Lehocka 2020, Klich 2017].

The continuous abrasive water jet technology (AWJ) was used for the experimental investigation described in this article. This modification of the water jet is characterized by mixing the abrasive with the liquid in the mixing chamber from which a high-pressure abrasive mixture of liquid and abrasive subsequently flows out through the nozzle orifice. The flow impinges on the target material and cutting it. Flow efficiency is increased by adding abrasive.

The main aim of the presented article is to evaluate the qualitative and geometrical characteristics of the surface of aluminium alloy EN AW 2024, which was cutting by abrasive water jet with different traverse speed v [mm.min^{-1}] based on the Swiss standard [SN 214001 2010]. Based on this standard, a working draft [ISO/TC 44 N 1770 2010] was formulated and should be accepted as a new valid ISO standard in the near future [SN 214001 2010, ISO/TC 44 N 1770 2010, VDI 1994]. Based on mentioned standard, data in this article were processed and the results were evaluated.

Swiss standard SN 214001 and a working draft ISO/TC 44 N 1770 are designed for the evaluation of surfaces of materials created by water jet cutting with a maximum thickness of the cut material of 300 mm.

The final state of the cutting surface is evaluated based on geometric, dimensional and qualitative properties of the created surface [Krenicky 2022]. Based on the results, it is possible to classify the resulting surface into one of the quality classes and determine the area of water jet possible use.

2 EXPERIMENTAL METHODOLOGY

2.1 *Experimental material*

The experimental material was aluminium alloy EN AW 2024. It belongs to the alloys with higher copper content, therefore it is also known under the trade name dural, dural aluminium or superdural. It is characterized by high strength after heat treatment, but lower corrosion resistance and is not suitable for welding. After curing it is characterized by good machinability, after annealing the machinability is bad. Higher copper content (Tab. 1) Causes lower chemical resistance. It is most often used for forming.

Table 1. Chemical composition, physical and mechanical properties of aluminium alloy EN AW 2024

Chemical properties [%]	
Copper (Cu)	3.80 – 4.90
Magnesium (Mg)	1.20 – 1.80
Manganese (Mn)	0.00 – 0.90
Iron (Fe)	0.00 – 0.50
Silicon (Si)	0.00 – 0.50
Zinc (Zn)	0.00 – 0.25
Titanium (Ti)	0.00 – 0.20
Chromium (Cr)	0.00 – 0.10
Aluminium (Al)	Rest
Physical and mechanical properties	
Density	2.78 g.cm^{-3}
Proof strength	455 MPa
Yield strength	483 MPa
Shear strength	310 MPa
Elongation $A_{50\ mm}$	5 %
Modulus of elasticity	71 GPa

EN AW 2024 is used to produce medium and heavily stressed components, it is widely used in the aerospace industry in the production of aircraft fuselages, beams and structural elements for tensioning the wings in aircraft. It is also used in the production of vehicles such as rail vehicles, cars, cranes and the construction industry in the production of structural elements of bridges. Six samples were cut with an abrasive water jet in the experimental investigation, the material thickness was 20 mm.

2.2 Technological parameters of the experiment

Experimental cutting was realized on a technological device Water jet 3015 RT 3D. Australian garnet (Mesh 80) was used and mass flow of abrasive was 400 g.min^{-1}. The water pressure was produced using pump PTV Jets 3.8/60 Classic. Working pressure was 400 MPa. The stand-off distance between the focus tube and the experimental material was 4 mm. The diameter of the water nozzle orifice was 0.33 mm and the focusing tube diameter was 1.02 mm. (Tab. 2)

Aluminum alloy EN AW 2024 was cutting at various AWJ traverse speed of values 100, 200, 300, 400, 500 and 600 mm.min^{-1}.

Table 2. Experimental technological set-up of AWJ

Technological factors of experiment	
Pressure of pump	p = 400 MPa
Water nozzle diameter	d_w = 0.33 mm
Focusing tube diameter	d_f =1.02 mm
Length of focusing tube	l = 76.2 mm
Stand-off	z = 4 mm
Angle of impact	φ = 90°
Abrasive material	Australian garnet
Abrasive size	80 MESH
Abrasive mass flow	m_a = 400 g.min^{-1}
Traverse speed	v = 100 - 600 mm.min^{-1}

2.3 Experimental methods of evaluation

Surfaces created by AWJ cutting at varying traverse speeds were evaluated based on the Swiss standard [SN 214001 2010]. The terms and definitions are given in ISO 21920-1 [ISO 21920-1 2022] and ISO 9013: 2017 [ISO 9013 2017] are used. The standard applies to materials that are suitable for water jet cutting up to a thickness of 300 mm. The standard applies to materials up to a thickness of 300 mm, which can be cut by water jet technology.

The Swiss standard SN 214001 and working draft ISO/TC 44 N 1770 defines individual quality levels (Q1, Q2, Q3, Q4, Q5) based on the measured roughness profile parameter Ra [µm] and parameter u [mm] (perpendicularity or angularity deviation) (Tab. 3). According to [SN 214001 2010] and [ISO/TC 44 N 1770 2010], the quality of the machined cut surface can be divided into a fine cut zone h_f [mm] and a zone with a lower cut quality (remaining surface) h_r [mm].

Table 3. Quality levels for water jet cutting according to ISO/TC 44 N 1770 standard

Quality levels for water jet cutting		
Q-level	Roughness *Ra* [µm]	Perpendicularity or angularity tolerance *u* [mm]
Q5	< 3.20	< 0.05
Q4	3.21 to ≤ 6.30	< 0.10
Q3	6.31 to ≤ 12.50	< 0.20
Q2	6.31 to ≤ 12.50	< 0.30
Q1	25.10 to ≤ 50.00	> 0.30

The surface of the experimental samples was measured with an optical profilometer MicroProf FRT. The values of the profile parameters Ra [µm] defined by ISO 21920-2 [ISO 21920-2 2021] were measured in the program Mountains SPIP Academic.

2.4 Measuring of roughness Ra

Based on the SN 214001 standard and ISO/TC 44 N 1770, it is determined that the measurement of the Ra profile parameter for determining the quality of the cut surface (Q-level, Tab. 3) must be at the point where the surface fragmentation is highest. For material thicknesses >2 mm, the measurement is made at the bottom of the sample 10% above the bottom edge, but at least 1 mm above the bottom edge. In this case, it is a value 2 mm above the lower edge, which corresponds to the measurement of Ra profile parameter number 18 (line 18 - depth of the evaluated profile = 18 mm) (Fig. 1).

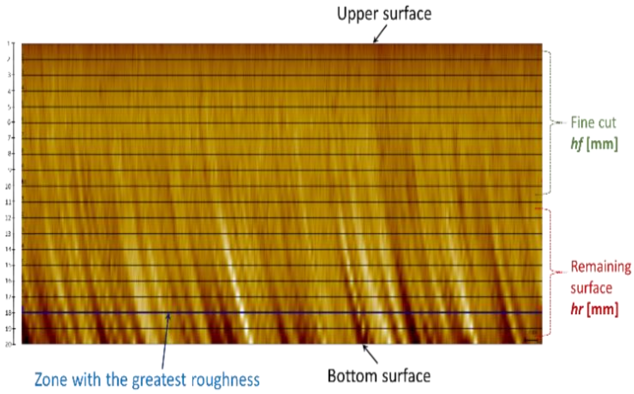


Figure 2. Example of measurement settings in the program SPIP 6.4.1. on a sample cut at v = 400 mm.min^{-1}

2.5 Evaluation of kerf on cutting surface

Each sample was 20 mm thick. The surface of the sample was measured from the upper edge of the sample (the point of the first contact of the AWJ with the surface) to the lower edge (the point where the walls of the sample separated). It was measured at 20 points with a spacing of 1 mm. The limit Ra = 11 µm was chosen for the evaluation of fine cut h_f [mm] and remaining surface hr [mm]; Ra < 11 µm → fine cut h_f [mm] and Ra > 11 µm → remaining surface hr [mm] (Fig. 1).

Perpendicularity or angularity tolerance u [mm] and edge radius r_K [µm] was measured by a profile projector Mitutoyo PH-A14 (Fig. 2).

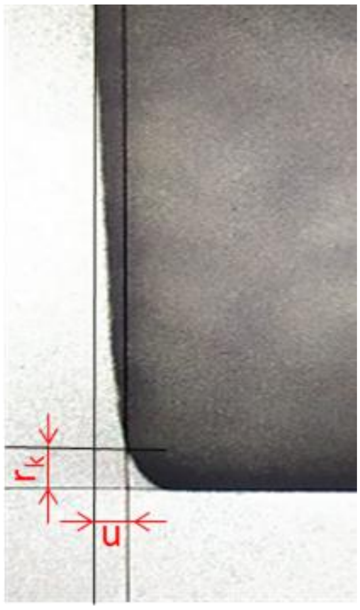


Figure 2. Measurement of perpendicularity or angularity tolerance u [mm] and edge radius r_K [mm] parameter

Drag line n [mm] was evaluated using a Dino-Lite digital microscope. The pitch of drag line f [mm] was evaluated in Gwyddion 2.59 program.

The surface of the cutting samples was uneven and measurement in only one place would not be sufficient (Fig. 3). For this reason, 7 measurements were performed on both evaluated parameters in various places. An average value was calculated from the measured values (table 4 shows the range of measured values with the calculated average value). The measurement was performed in places where the surface quality was lower - in the zone of remaining surface h_r.

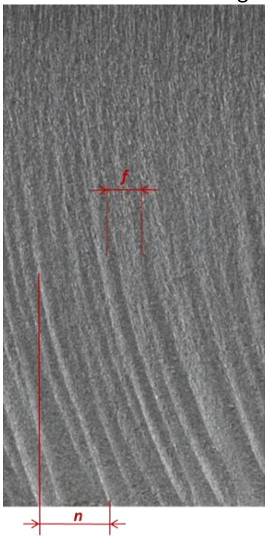


Figure 3. Measurement of pitch of drag line f [mm] and drag line n [mm] parameters

3 RESULTS

Table 4 shows the measured geometric and qualitative characteristics of EN AW 2024 aluminium alloy surfaces cut by abrasive water jet at increasing traverse speed v [$mm.min^{-1}$]. The measured values show that the quality of the cut surface significantly decreases with increasing traverse speed v [$mm.min^{-1}$]. The created surfaces were evaluated according to 5 quality classes (Q5 to Q1) according to Swiss standard SN 214001 and ISO/TC 44 N 1770 (Tab. 3). A surface roughness parameter Ra = 6.31 µm was measured at a traverse speed of 100 $mm.min^{-1}$, which corresponds to quality class Q4 (Tab. 5). Based on the evaluation of the roughness profile parameter Ra, no Q5 quality surface was created in this experimental investigation. However, it can be assumed that if the material were cut at a lower traverse speed v [$mm.min^{-1}$], the surface quality would be higher.

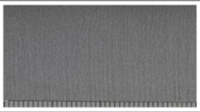
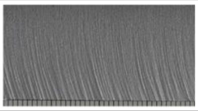
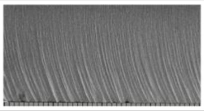
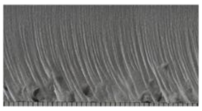
Table 4. Measured geometric and qualitative characteristics of EN AW 2024 aluminium alloy (workpiece thickness t = 20 mm)

Sample no.	1	2	2	4	5	6
Traverse speed v [$mm.min^{-1}$]	100	200	300	400	500	600
Fine cut h_f [mm]	20	19	13	11	8	6
Remaining surface h_r [mm]	0	1	7	9	12	14
Edge radius r_K [mm]	0.295	0.320	0.295	0.330	0.365	0.265
Pitch of drag line f [mm]	-	-	0.57 (0.38 – 0.73)	0.70 (0.52 – 0.99)	1.08 (0.65 – 1.52)	1.11 (0.92 – 1.37)
Drag line n [mm]	-	0.615 (0.466 – 0.787)	1.622 (1.393 – 2.107)	2.246 (1.822 – 2.500)	2.823 (2.324 – 3.250)	4.215 (3.357 – 4.714)
Roughness Ra [µm] (in 18 line)	6.31	8.27	19.98	27.47	45.18	95.89
Perpendicular. or angularity tolerance u [mm]	0.125	0.085	0.150	0.210	0.155	0.380
Q-level	4	3	2	1	1	1

The increasing traverse speed v [$mm.min^{-1}$] also significantly affected the kerfs on the cut surface. The parameters: fine cut h_f [mm], remaining surface h_r [mm], pitch of drag line f [mm], drag line n [mm], edge radius r_K [mm] and perpendicularity or angularity tolerance u [mm] were evaluated for the evaluation of kerfs on the cut surface. The highest surface quality was detected at a traverse speed of 100 $mm.min^{-1}$. The surface of this sample is characterized by a fine cut h_f [mm] on the entire thickness of the material - 20 mm, the surface is regular and there is no measurable creasing or drag of water flow. A lower but the comparable surface quality was also achieved with the sample cut at a traverse speed v = 200 $mm.min^{-1}$. The fine cut zone was measured at 19 mm. On the sample, it is possible to observe the beginning of the formation of a slight grooving with an average drag line of 0.615 mm. As the traverse speed v [$mm.min^{-1}$] increases, it is already possible to observe a decrease in the quality of the machined surface (Tab. 5), as the fine cut zone hf [mm] shortens and the average drag line n [mm] increases. On surfaces cut at a higher traverse speed, it is possible to observe a decreasing quality, a significant dragging of water flow and a visible grooving. Defects such as coarse grooves, gouging, interrupted cuts and scouring were created on the observed surface, which significantly reduces the quality and accuracy of the machined surface. At a traverse speed v = 600 $mm.min^{-1}$, the zone of remaining surface hr [mm] was very marked (measured 14 mm from the bottom edge of the sample) and the pitch of drag line f [mm] can no longer be measured at the bottom of the sample (Tab. 5). When used in industrial applications requiring machining accuracy, additional surface treatment will be required.

The influence of the change in traverse speed v [$mm.min^{-1}$] on the size and formation of perpendicularity or angularity tolerance u [mm] and edge radius r_K [mm] cannot be unambiguously evaluated in this experimental investigation.

Table 5. Quality levels of machined EN AW 2024 aluminium alloy

Sample No.	Cutting surface	Description	Q - level
1		• High precision of the machined surface • Slight surface roughness • Slight grooving on the surface are visible	Q4
2		• Good quality of surface • Slight grooving is visible	Q3
3		• Lower surface quality • Rough cut • Regular grooving without gouging	Q2
4			
5		• Low surface quality • Defects in the form of coarse grooves, gouging, interrupted cuts and scouring are detected on the surface	Q1
6			

4 CONCLUSIONS

The evaluation of the quality and geometric characteristics of the EN AW 2024 aluminium alloy surface, cutting by abrasive water jet at traverse speeds of 100; 200; 300; 400; 500 and 600 mm.min-1 according to the Swiss standard SN 214001 and working draft ISO/TC 44 N 1770 demonstrated the significant effect of traverse speed v [mm.min^{-1}] on the quality of the created surface. The increasing traverse speed v [mm.min^{-1}] negatively affected the quality of the created surface. The geometrical and qualitative characteristics obtained at a traverse speed of 100 mm.min^{-1} suggest that when cutting with an abrasive water jet at a traverse speed lower than 100 mm.min^{-1}, a higher surface quality after cutting could be achieved. However, this claim still needs to be experimentally verified and evaluated.

The surface with the best properties was created at a feed rate of 100 mm min^{-1}, when the highest surface quality was achieved with minimal roughness and cut accuracy corresponding to higher quality classes.

The results of the presented experimental research can be used in the evaluation and prediction of geometric and qualitative characteristics of materials of various kinds cutting by abrasive water jet.

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CONTACTS:

MSc. Dominika Botkova, PhD.

Assoc. prof. MSc. Frantisek Botko, PhD.

MSc. Dagmar Klichova, Ph.D.

Eng. MSc. Radoslav Vandzura, PhD.

Eng. MSc. Matus Gelatko, PhD.

Technical University of Kosice, Faculty of Manufacturing Technologies with a seat in Presov

Bayerova 1, 080 01 Presov, Slovakia

dominika.botkova@tuke.sk

frantisek.botko@tuke.sk

dagmar.klichova@tuke.sk

radoslav.vandzura@tuke.sk

matus.gelatko@tuke.sk