Influence of process parameters on the AWJ cutting of the AL-EN AW 2017A (T4) aluminium alloy

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Abstract. Abrasive water jet machining is an emerging non-conventional technology widely used in different industrial sectors due to its multiple economic and environmental benefits. The quality of processed surface depends on process parameters, abrasive material properties and processed material properties and is mainly expressed by surface roughness, shape and dimensional accuracy of cut, presence of striations and/or burr. The current paper aims to present the influence of water jet pressure and traverse speed on the quality of processed surfaces in the case of AL-EN AW 2017A - T4 aluminium alloy abrasive water jet cutting.

1. Introduction

Since 1987, when the World Commission on Environment and Development (the Brundtland Commission), convened to examine the degradation of the global environment, approved the report "Our Common Future", the stated goal of humanity, worldwide, is to promote sustainable development - a strategy to “meet the needs of the present without compromising the ability of future generations to meet their own needs” [1]. To achieve this goal, different initiatives have been adopted. Among them, promoting investment and innovation in clean technologies has been of crucial importance, as industry is increasingly integrated into global value chains.

Abrasive water jet machining (AWJM) is a relatively new, emerging non-conventional technology, widely used in different industrial sectors for processing a wide range of materials, metallic and non-metallic, soft and hard, from aluminium and mild steel [2] to titanium [3, 4], Inconel [5], composites [6, 7] etc. Its large applicability is due to the multiple economic and environmental benefits: it is eco-friendly (no hazardous substances used during processing but only water and non-harmful and recyclable abrasive material, no dust or hazardous emissions released), high productivity, good integrity of processed surfaces compared to other cutting technologies (no thermal affected zones), ability to cut complex shapes, high flexibility etc. [8].

In abrasive water jet cutting (figure 1), the material is removed due to an erosion process, created by the combined effect of the highly pressurised water jet and hard abrasive particles. The process can achieve high productivity, with material removal velocity up to 1000m/s when high water jet pressure, up to 600 [MPa], is used [9, 10]. The quality of processed surface depends on process parameters (water jet pressure, traverse speed, abrasive flow rate, standoff distance, focusing nozzle length and diameter, nozzle diameter), abrasive material properties (mesh size, hardness) and processed material properties (e.g. strength, hardness, modulus of elasticity) and is mainly expressed by surface roughness, shape and dimensional accuracy of cut, presence of striations and burr.

The current paper aims to present the influence of traverse speed and water jet pressure on the quality of processed surfaces in the case of AWJ cutting of an aluminium alloy, largely used in aeronautics industry.
2. Experimental setup

The experimental tests were carried out on the AL-EN AW 2017A (T4), an aluminium alloy used in aviation, whose properties are presented in table 1. This alloy ensures high mechanical strength and it is suitable for aviation parts, where the development of technologies for the manufacture of light armor is desired. The thickness of the used sheet was 1.5 mm, a thickness imposed by the weight reduction of the developed products.

Simple linear cuts through the material thickness were performed on a Hydro-Jet Eco 0615 machine, equipped with a piston pump capable of providing a maximum pressure of 150 MPa. The length of the cut was 40 mm. The stroke of the cutting head started 10mm outside the material to allow a proper homogenization of the water and abrasive material in the mixing chamber (figure 3).

Two process parameters were varied – water jet pressure and traverse speed, while the other parameters were kept constant (table 2). The minimum pressure was correlated with the transverse speed and was chosen to allow a proper cut throughout the material thickness. The maximum pressure was the highest available among the machine parameters.

Each trial was repeated three times to reduce the influence of the random errors. An average value of the results was calculated, and it is presented in this analysis.

In AWJ cutting, the quality parameters are defined by the ISO/WD/TC 44 N 1770 standard [11] (figure 2), and this paper analysis the following: top kerf width (Li), bottom kerf width (Lo), kerf taper angle (α) and surface roughness (Ra). The linear and angular dimensions were measured with a Leica MZ75 microscope while the surface roughness was measured with a Mitutoyo SJ 201 digital roughness device, at the middle of material thickness. Three measurements were performed for each cut and averaged for more accurate results.

### Table 1. Properties of the AL-EN AW 2017A (T4) aluminium alloy [12].

| Property            | Value [MPa] |
|---------------------|-------------|
| Yield strength      | 162*/*/145  |
| Ultimate strength   | 228*/*/225  |
| Elongation          | 14          |
| Hardness            | 59*/*/55    |

*values experimentally determined in the laboratories of the „Vasile Alecsandri” University of Bacau
Figure 3. Abrasive water jet machining: cutting schema and processed part.

Table 2. Process parameters used for the experimental tests.

| Abrasive flow rate, \( (Q) \) [g/min] | Standoff distance, \( (h) \) [mm] | Nozzle diameter, \( (d_0) \) [mm] | Focusing nozzle length, \( (L_f) \) [mm] | Focusing nozzle diameter, \( (L_f) \) [mm] | Abrasive mesh [#] | Varied parameters | Waterjet pressure, \( (P), \) [MPa] | Traverse speed, \( (Vf), \) [mm/min] |
|--------------------------------------|-----------------------------------|----------------------------------|-----------------------------------|-----------------------------------|-----------------|---------------------|-----------------|-----------------|
| 300                                  | 2                                 | 0.35                             | 76                               | 1.02                             | 80              |                      | 130             | 100             |
|                                      |                                   |                                  |                                  |                                  |                 |                     | 140             | 150             |
|                                      |                                   |                                  |                                  |                                  |                 |                     | 150             | 200             |

3. Results and discussion
The quality parameters for the water jet pressure of 130 [MPa] are presented in figure 4, as a function of traverse speed, while the surfaces macrostructure is presented in figure 5.

Figure 4. Influence of traverse speed on the quality parameters of cut when \( P = 130 \) [MPa].

As can be seen from the below graphs, the increase of water jet traverse speed leads to a narrower kerf, both, at the top and bottom (the Li and Lo parameters decreased with approximately 10% and 13%,
respectively). This is because a lower value of the traverse speed allows the water jet to act for increased amount of time which leads to larger values of kerf widths. Meanwhile, the kerf taper increased with $0.7^\circ (\approx 30\%)$ with the increasing of water jet traverse speed. The surface roughness became coarser (with $\approx 40\%$), due to the small number of abrasive particles that collided the processed material.

The quality parameters for the water jet pressure of 140 [MPa] are presented in figure 6, as a function of traverse speed, while the surfaces macrostructure is presented in figure 7.

**Figure 5.** The surfaces macrostructure as a function of traverse speed when $P = 130$ [MPa].

**Figure 6.** Influence of traverse speed on the quality parameters of cut when $P = 140$ [MPa].

In the case of using a higher water jet pressure, the graphs reveal the same tendency of variation for the quality parameters as in the previous case: the kerf width decreased with the increasing of transverse speed (the Li and Lo parameters decreased with 14.53% and 13%, respectively) while the kerf taper increased with $\approx 44\%$ and the surface roughness increased with $\approx 15\%$ with the increasing of transverse speed.
The left side of cut  
Kerf profile  
The right side of cut

**Figure 7.** The surfaces macrostructure as a function of traverse speed when $P = 140$ [MPa].

The quality parameters for the water jet pressure of 150 [MPa] are presented in figure 8, as a function of traverse speed, while the surfaces macrostructure is presented in figure 9.

**Figure 8.** Influence of traverse speed on the quality parameters of cut when $P = 150$ [MPa].
For the water jet pressure of 150 [MPa], the increasing of the traverse speed determined a ≈ 12% decrease of kerf width at the top and ≈ 25% at the bottom. The taper angle of kerf increased with ≈ 49%, while the surface roughness increased with ≈ 16% with the increasing of the traverse speed. Higher water pressure gives an increased kinetic energy to the abrasive particles, which in turn are more capable to erode the material, thus leading to larger kerf widths.

4. Conclusions
The current paper presents a preliminary study in which the influence of water jet pressure and traverse speed on the quality of processed surfaces, expressed in terms of the ISO/WD/TC 44 N 1770 standard, in the case of AL-EN AW 2017A (T4) aluminium alloy abrasive water jet cutting is analysed. Further developments aim to extend the variety of materials, their thickness, the variation intervals for the control process parameters but also the process optimization using various methodologies such as design of experiment (DOE), neural networks, genetic algorithm, fuzzy logic etc.

In the case of AL-EN AW 2017A (T4) aluminium alloy AWJ cutting, within the investigated range of water jet pressure (130 - 150 MPa) and traverse speed (100 – 200 mm/min) and the other considered process parameters, the following aspects were highlighted by the obtained experimental results:

- The increasing of traverse speed led to a narrower kerf. The increasing of water jet pressure did not affect this tendency of variation but did affect the values of the kerf’s width; the largest kerf was obtained for the water jet pressure of 140 MPa while the narrowest kerf resulted for the water jet pressure of 150 MPa.
- The kerf taper increased with increasing the traverse speed for water jet pressures of 130 MPa and 140 MPa; on the contrary, for waterjet pressure of 150 MPa, the kerf taper decreased for higher values of the traverse speed.
- The increasing of traverse speed led to a coarser roughness of the cuts. The water jet pressure has slightly affected the surface roughness, excepting the case when its value was minimum (130 MPa) and it was coupled with the highest traverse speed (200 mm/min) – in this case the coarsest surface roughness resulted.

Therefore, higher traverse speeds led to narrower but tapered kerfs and coarser surfaces. To improve the surface roughness, the tendency is to increase the abrasive flow rate since more abrasive particles would get in contact with the material and the erosion process would be intensified. However, the increasing of the abrasive flow rate would determine an agglomeration of the abrasive particles in the mixing chamber, their collisions would appear which would determine the reduction of their kinetic energy and, implicitly, the processing quality.

Higher traverse speeds coupled with higher water jet pressures (e.g. 150 MPa in this study) led to an improvement quality of the cut: narrower and less tapered kerf and better surface roughness.

Regarding the macrostructure of the processed surfaces, some small striations can be observed when higher values of the traverse speed were used.

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