Optimization of working parameters in case of aluminium alloy abrasive water jet cutting (AWJC)

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Abstract. Aluminium alloys are increasingly important in the aeronautical industry, since they have low weight, good workability, good corrosion and wear resistance, etc. The AL-EN AW 2017A (T4) is such an aluminium alloy, used to manufacture various components of the aircrafts. Processing the alloy by various classical technologies leads to degradation of superficial surface, which is why new technologies are being proposed. The aim of this paper is to optimize the working parameters for abrasive water jet cutting of AL-EN AW 2017A (T4) aluminium alloy, so that to obtain good surface quality according to the ISO/WD/TC 44 N 1770 – 2010 standard (width of the processed surface at the jet input, width of the processed surface at the jet output, deviation from perpendicularity, inclination angle of the processed surface and surface roughness - being the parameters of interest) and economic efficiency.

1. Introduction
Innovation is a key word in all fields of our life. Higher requirements for quality and customization, lower production costs, sustainable manufacturing, lead-time minimization are some of the driving forces behind innovation. Developing innovative manufacturing processes to face these challenges has become an imperative target of the academic and industrial world [1].

Abrasive water jet cutting (AWJC) technology has been one of the mostly worldwide researched, perfected and used unconventional technologies during the last decades due to its benefits related to applicability (different materials - from soft to very hard - for different industrial fields), processed surface quality (no heat affected layers, no thermal stress), ecological impact (no toxic fumes, no dust), high flexibility, reduces cutting forces etc. [2, 3].

By following this development line, the aim of the current paper is to optimize the abrasive water jet cutting process of AL-EN AW 2017A (T4) aluminium alloy. The surface quality (quantified according to the specifications of the ISO/WD/TC 44 N 1770 – 2010 standard) and the economic efficiency are the outputs of interest.

2. Experimental methodology
In this study, the aluminium alloy AL-EN AW 2017A (T4) is analysed due to its large applicability in the aeronautical industry for manufacturing of various aircraft components. The alloy has a high mechanical strength and provides a very good protection reported to the material mass. Its mechanical and chemical properties are shown in table 1 and table 2.
Table 1. Chemical properties of the AL-EN AW 2017A (T4) aluminium alloy [4].

| Cr  | Cu  | Fe  | Mg  | Mn  | Ni  | Si  | Ti  | Ti + Zr | Zn  | Others | Al  |
|-----|-----|-----|-----|-----|-----|-----|-----|---------|-----|--------|-----|
| (%) | (%) | (%) | (%) | (%) | (%) | (%) | (%) | (%)     | (%) | (%)    | (%) |
| 0.10| 5   | 0.50| 0.80| 1.20| 0.10| 0.90| 0.15| 0.20    | 0.25| 0.15   | Rest|

Table 2. Mechanical properties of the AL-EN AW 2017A (T4) aluminium alloy [4].

| Tensile strength, Rm (MPa) | Proof stress, Rp0,2 (MPa) | Elongation A50mm (% min) | Bend radius 180° | Bend radius 90° | Brinell Hardness | Elastic modulus (KN/mm²) |
|---------------------------|---------------------------|--------------------------|-------------------|-----------------|------------------|------------------------|
| 390                       | 245                       | 15                       | 5                 | 5               | 110              | 72500                  |

Optimization of the working parameters in case of abrasive water jet cutting of AL-EN AW 2017A (T4) aluminium alloy was made by using an experimental design of 81 experiments (table 3). The input variables were:
- \( A \) = pressure, \( P \) [MPa]: 130MPa, 140MPa, 150MPa;
- \( B \) = feed rate, \( v \) [mm/min]: 100 mm/min, 200 mm/min, 300 mm/min;
- \( C \) = abrasive flow rate, \( Q \) [g/min]: 100 g/min, 150 g/min, 200 g/min;
- \( D \) = distance between the cutting head and material, \( h \) [mm]: 1.2 mm, 2.4 mm, 3.6 mm.

The parameters used to quantify the cuts’ quality were chosen according to the ISO/WD/TC 44 N 1770 – 2010 standard: width of the processed surface at the jet input (Li), width of the processed surface at the jet output (Lo), deviation from perpendicularity (u), inclination angle of the processed surface (\( \alpha \)) and surface roughness (Ra).

Table 3. Experimental design.

|          | B1     | B2     | B3     |
|----------|--------|--------|--------|
| A1       | C1D1   | C1D2   | C1D3   |
|          | C1D1   | C1D2   | C1D3   |
| A2       | C2D1   | C2D2   | C3D3   |
|          | C2D1   | C2D2   | C3D3   |
| A3       | C2D1   | C2D2   | C3D3   |
|          | C2D1   | C2D2   | C3D3   |
|          | C3D1   | C3D2   | C3D3   |
|          | C3D1   | C3D2   | C3D3   |

3. Results and discussions

The statistical processing of the experimental data was carried out by using the DOE++ software from ReliaSoft. It allows performing ANOVA analysis, determination of significant factors, interactions analysis, factor effects analysis, etc.

3.1. Presentation of the significant factors that affect the quality parameters, based on the Pareto-ANOVA graphs and interactions diagrams

The significant factors for each of the six parameters that quantify the quality of cuts were emphasised by drawing the Pareto-ANOVA graphs and interactions diagrams and are presented in figure 1. It can be observed that the Li parameter is significantly affected by the distance between the cutting head and material (D) and feed rate (B). Abrasive flow rate is not significant in case of processing soft materials because its value is reduced compared to that used for hard materials cutting. The Lo parameter is significantly influenced by the feed rate (B), distance between the cutting head and material (D) and
jet pressure (A). Again the abrasive flow rate has not a significant influence. The inclination angle of cut, \( \alpha \), and the deviation from perpendicularity, \( u \), have a similar behaviour as response to the influence of working parameters because of their dependency on each other. Thus, they are significantly affected by the distance between the cutting head and material (D) and pressure (A). The surface roughness is significantly influenced by the feed rate (B) and the abrasive flow rate (C). The hardness of the superficial layer depends on the feed rate (B) and pressure (A); the stronger and the longer the abrasive particles hit the material, the harder the superficial layer becomes. The way the final results are affected can be also seen on the interactions diagrams.
Figure 1. Pareto-ANOVA graphs and interactions diagrams.

3.2 Influence of the working parameters on the quality of cuts
The influence of the working parameters on the quality of cuts is presented in figure 2. The width of the processed surface at the jet inlet (Li) is strongly affected by the distance between the cutting head and material, the value of 2 mm leading to the best results. Also, higher feed rates lead to an approximately linear increasing of the Li parameter.
The width of the processed surface at the jet outlet (Lo) is strongly affected by the distance between the cutting head and material as well as the feed rate. Also, good results are obtained for high value of the jet pressure. The influence of the abrasive flow rate on the Lo is reduced.

The inclination angle of cut (α) and the deviation from perpendicularity (μ) are negatively influenced by the increase of the cutting head distance and the jet pressure. The recommended value for the cutting head distance remains 2 mm; as concern the pressure, even if smaller values of it lead to better results in term of α and μ parameters, other parameters as Li, Lo and Ra are negatively affected. Therefore, the two quality parameters must often be sacrificed to the detriment of the others in order to achieve a better productivity in relation to the pursued quality indices.

The surface roughness (Ra) strongly depends on the feed rate, its increase decreasing the roughness value. The other technological factors (pressure and distance of the cutting head) have an insignificant influence on the processing, their modification affecting slightly the surface quality. Increasing the abrasive flow rate leads to worsening of the roughness due to the additional kinetic effects that occur by multiplying the number of abrasive particles that affect the processed surface.

The hardness of the superficial layer is strongly affected by the increase of feed rate and jet pressure which lead to a pronounced hardening. As the distance between the cutting head and material to be processed is higher, its effect on the surface hardness is smaller, the impact energy of the abrasive particles being lower.

3.3. Optimization of the working parameters in case of AL-EN AW 2017A (T4) aluminium alloy AWJ cutting

For the analysed process of abrasive water jet cutting of AL-EN AW 2017A (T4) aluminium alloy, the optimum solution proposed by the system is shown in figure 3.
Figure 3. The optimum solution for obtaining the target quality parameters for the aluminium alloy.

The values of the optimum resulting factors that influence the quality of the processed surface (P = 150MPa; v = 300mm/min, Q = 200g/min and h = 2mm) are also those that ensure the maximum productivity. From the economic efficiency point of view, a single problem raises the abrasive flow rate which is at maximum value, which means additional costs with the abrasive material.

The values of quality parameters obtained as result of using the optimized working parameters are shown in table 4.

| Quality parameters | Li (mm) | Lo (mm) | α (°) | u (mm) | Ra (µm) |
|--------------------|--------|--------|-------|--------|---------|
| Values             | 0.953  | 0.804  | 0.059 | 1.403  | 4.830   |

To reduce costs, an amount of abrasive material as small as possible per unit of length is necessary to be used. Thus, in table 4, a solution to ensure the economic efficiency is presented (Q = 100g/min), as well as the differences related to the proposed quality parameters. In this case, the quality factors mostly affected by the increase in productivity are the inclination angle of the processed surface (α) and deviation from perpendicularity (u).

4. Conclusions
Optimization of the abrasive water jet cutting process of the AL-EN AW 2017A (T4) aluminium alloy was addressed within the present study, in order to obtain a good quality of the processed surface. The found solution involved high amounts of abrasive material to be used; consequently, to meet the economic efficiency requirements, an alternative solution was proposed and tested. The obtained results highlighted an overall better surface quality.
Table 5. Comparison between the optimum value for economic efficiency and that for quality, for the AL-EN AW 2017A (T4) Aluminium Alloy.

| Working parameters | Li (mm) | Lo (mm) | α (°) | u (mm) | Ra (µm) |
|--------------------|--------|--------|-------|--------|--------|
| P [MPa]            | 150    |        |       |        |        |
| v [mm/min]         | 300    |        |       |        |        |
| Q [g/min]          | 100    |        |       |        |        |
| h [mm]             | 2      |        |       |        |        |
| OPTIMUM            | 0.953  | 0.804  | 0.059 | 1.403  | 4.830  |
| Difference [%]     | -2%    | -21%   | 163%  | 315%   | -10%   |

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