Study on the influence of the working regime on the quality of cut in the case waterjet processing of S 235 steel

E Herghelegiu, M C Radu, C Schnakovszky, B A Chirita and N C Tampu
“Vasile Alecsandri” University of Bacau, Faculty of Engineering, The Department of Industrial Systems Engineering and Management, Calea Marasesti 157, 600115, Bacau, Romania
E-mail: eugen.herghelegiu@ub.ro

Abstract. The current paper presents the influence of different working regimes on the quality of cuts performed by abrasive water jet processing on S 235 steel. Four process parameters were varied: pressure (P), feed rate (Vf), quantity of abrasive material (Q) and distance between the cutting head and workpiece (h). Four quality parameters were analysed: width of the processed surface at the jet inlet (Li), width of the processed surface at the jet outlet (Lo), inclination angle of cut (α) and surface roughness (Ra). The analysis was done for three material thicknesses: 1mm, 6.5mm and 10mm.

1. Introduction
Abrasive water jet is a relatively new technology, widely used when it comes to process, especially by cutting, hard materials as stainless steel, titanium, etc. but also softer materials, as aluminium alloys, due to the gains in quality (e.g. no heat affected zones, no thermal distortions), environmental impact (e.g. no dust; non-toxic, easily disposed water; reduced wastes due to narrow cuts; no fire hazards) and capital (e.g. lower cost of equipment compared to laser or plasma machines) [1, 2]. However, the process has some limitations, especially when thick materials have to be cut. In this case, the cutting rate has to be reduced, determining the increasing of cutting time which, in turn, makes the process costlier. Besides, the accuracy of cuts is decreased, often resulting in a tilt cross section, due to the dissipation of the abrasive water jet towards the bottom surface of material. Another defect that usually appears at abrasive water jet cutting of thick material is the striations occurrence. To reduce the two main disadvantages – taper cross section (kerf taper) and striations - different solutions have been proposed by researchers as nozzle tilted-jet cutting [3], nozzle oscillation [4], proper selection of process parameters [5], compensation models [6], multipass abrasive water jet cutting [7], optimization algorithms [8].

The scope of the paper is to investigate the quality of cuts performed by abrasive water jet cutting of S 235 steel (three thicknesses considered), as a function of different working regime.

2. Experimental methodology
The experimental study was performed on the S 235 steel. This material is widely used in construction industry (for metal structures, elements for gates and fences, etc.) due to its good properties and purchase accessibility. Three material thicknesses were used: 1mm, 6.5 mm and 10 mm. The material chemical composition and its mechanical properties are shown in table 1 and table 2.
Table 1. Chemical composition of the S 235 steel.

| Steel grade | C  | Si  | Mn  | P  | S  | N  | Cu  | Cr  | Ni  | Mo  | Al  | V   |
|-------------|----|-----|-----|----|----|----|-----|-----|-----|-----|-----|-----|
| S 235 (OL 37) | 0.13 | 0.25 | 0.58 | 0.013 | 0.008 | 0.01 | 0.32 | 0.08 | 0.10 | 0.013 | 0.033 | 0.001 |

Table 2. Mechanical properties of the S 235 steel.

| Steel grade | Yield strength [N/mm²] | Ultimate strength [N/mm²] | Elongation [%] | Resilience KCU J/cm |
|-------------|------------------------|---------------------------|----------------|---------------------|
| S 235 (OL 37) | 240 | 360 - 440 | 25 | 69 |

The experiments were conducted on a Hydro jet Eco 0615 water jet cutting machine, whose main technical features are as follows: the cutting range: 1510 x 610mm; operating pressure: 150MPa; water jet cutting mode: without and with abrasive mix; displacement mode: on x and y axis- automatically, on the z axis - manually; maximum feed rate: 4m/min; displacement precision on x axis: ± 0.03/300mm; displacement precision on y axis: ± 0.02/300mm; repeatability on x axis: ±0.02/300mm; repeatability on y axis: ± 0.02/300mm; the power of motor acting the high pressure pump: 7.5kW; water flow: 2.4 l/min.

The used abrasive material was garnet, with granulation #80.

Four process parameters were varied in order to determine their influence on the quality of cuts performed by abrasive water jet cutting: pressure (P), feed rate (Vf), quantity of abrasive material (Q) and the distance between the cutting head and work piece (h).

The parameters considered to quantify the quality of cut were figure 1: width of the processed surface at the jet inlet (Li), width of the processed surface at the jet outlet (Lo), inclination angle of cut (α) and surface roughness (Ra). The measurement of the Li, Lo and α parameters was performed on a Leica MZ75 microscope, while the measurement of the Ra parameters was performed with a Mitutoyo SJ 201 roughness device.

Figure 1. The quality parameters of cut [9, 10].

3. Results and discussions
The results obtained from the experiments are presented in this section.

3.1. Influence of pressure (P) on the quality of cut
The influence of pressure on the quality of cut, for the three thicknesses of material, is presented in figure 2. It is noticed that the water jet pressure of 110MPa was not sufficient to erode the 10mm thick material (as it is shown in figure 3, too). Figure 2(a) reveals that the increase of pressure leads to the
increase of width $L_i$. The width $L_o$, also increases when higher values of pressure are used. Increasing the thickness of material results in lowering the width of the processed surface at the jet outlet, even at high pressure; this fact is due to the narrowing of the active part of the jet as the material thickness increases.

![Figure 2](image)

**Figure 2.** Influence of pressure on the: (a) width $L_i$; (b) width $L_o$; (c) inclination angle ($\alpha$); (d) surface roughness (Ra).

The inclination angle ($\alpha$) decreases when a higher pressure is used (figure 2(c)). Related to the material thickness, the highest inclination of cut was obtained for the 1mm thick material. The influence of pressure on the surface roughness (Ra) results from figure 2(d): in case of 1mm thick material the surface roughness increases with the water jet pressure, while for the other two thicknesses – 6.5mm and 10mm – the surface roughness decreases with the increases of water jet pressure.

![Figure 3](image)

**Figure 3.** Cut through the 10mm thick material, when 110MPa pressure was used.
3.2. Influence of feed rate (Vf) on the quality of cut

The graphic representation of the influence of feed rate on the quality of cut is presented in figure 4. It can be observed that the width Li decreases as the feed rate increases; this evolution is more evident in case of 1mm thick material (figure 4(a)). The width Lo also decreases as the feed rate increases (figure 4(b)); this is due to the fact that fewer abrasive particles come in contact with the processed material and the active part of the water jet is narrowed. The inclination angle (α) increases as the feed rate increases, for all the three material thicknesses analysed. Thus, a lower feed rate must be adopted in order to obtain a perpendicular cut (figure 4(c)). An increase of roughness also occurs when increasing the feed rate (figure 4(d)). In case of thicker materials, it also leads to the appearance of striations on the processed surface.

![Influence of feed rate on the quality of cut](image)

**Figure 4.** Influence of feed rate on the: (a) width Li; (b) width Lo; (c) inclination angle (α); (d) surface roughness (Ra).

3.3. Influence of abrasive material quantity (Q) on the quality of cut

The influence of the abrasive material on the quality of cut, for the three thicknesses of material, is presented in figure 5. It can be noticed that the width Li decreases as the quantity of the abrasive material increases (figure 5(a)). A similar tendency is observed for the width Lo, for all the three material thicknesses (figure 5(b)). The inclination angle (α) and the surface roughness (Ra) increases as the quantity of abrasive material increases (figure 5(c) and (d)). This variation is due to the agglomeration of abrasive particles in the mixing chamber, which lead to the decrease of the kinetic energy of the water jet. At the same time, the collision of the particles with the focusing tube leads to the decrease of the kinetic energy of the cutting jet and, implicitly, to a poor quality of cut.
3.4. Influence of distance between the cutting head and workpiece (h) on the quality of cut

The influence of distance between the cutting head and workpiece (h) on the quality of cut, for the three thicknesses of material, is presented in figure 6. It can be noticed that, for the material thickness of 1mm and 6.5mm, the width Li increases with the distance between the cutting head and workpiece.

For the material thickness of 10mm, to the smallest width Li was obtained for the distance between the cutting head and workpiece of 3mm (figure 6(a)). The width Lo increases as the distance between the cutting head and workpiece increases (figure 6(b)).

![Figure 5](image_url)

**Figure 5.** Influence of the quantity of abrasive material on the: (a) width Li; (b) width Lo; (c) inclination angle (α); (d) surface roughness (Ra).

The variation of the inclination angle (α) with the distance between the cutting head and workpiece is different for the three thicknesses of material. Thus, for the 1mm thick material, the inclination angle is getting bigger as the distance between the cutting head and workpiece increases (more pronounced for h = 5mm). In case of 6.5mm thick material, the increase of inclination angle occurs only for the biggest distance between the cutting head and workpiece (h = 5mm). For 10mm thick material, the smallest inclination angle is obtained when a distance of 3mm between the cutting head and workpiece is used (figure 6(c)). The variation of surface roughness (Ra) with the distance between the cutting head and workpiece is similar for all the three analysed thicknesses of material (figure 6(d)).

The smallest surface roughness is obtained for the distance between the cutting head and worpiece equal to 3mm.

The above presented results can be explained by the fact that, in case of a too small distance between the cutting head and workpiece (e.g. 1mm), the abrasive material and the eroded material are very hard removed from the working area, which makes difficult the machining process and, besides,
the abrasive material is blocked in the mixing chamber of the cutting head. At the distance of 5mm between the cutting head and workpiece, the cutting jet tends to evade at the exit of the focusing tube and the active part of the jet is conical. Therefore, for the Hydro jet Eco 0615 machine and for the considered material, the optimum distance between the cutting head and workpiece is 3mm, in terms of cut quality.

![Graphs](image_url)

**Figure 6.** Influence of the distance between the cutting head and workpiece on the: (a) width Li; (b) width Lo; (c) inclination angle (α); (d) surface roughness (Ra)

### 4. Conclusions

The experimental results revealed that, for the used material and waterjet cutting machine, a good quality of cut - in terms of the kerf width at the jet inlet/outlet and perpendicularity of cut - is obtained for lower values of pressure, higher values of feed rate and quantity of the abrasive material and a distance between the cutting head and worpiece of 3mm, for all the three analysed thicknesses of material.

As concern the cut surface roughness, the influence of the process parameters is opposite. A special attention must be paid to the used pressure when thicker materials need to be cut because it is possible that the jet cannot completely erode the material and the cutting process fails (as was the case of 10mm thick material when a 110MPa pressure was used).

### 5. References

[1] Zhang S, Wu Y and Wang S 2015 *Int. J. Adv. Manuf. Technol.* **80** 1685–1688

[2] Muthuramalingam T, Vasanth S, Vinothkumar P, Geethapriyan T and Mohamed Rabik M 2018 *Silicon* **10** 2015–2021
[3] Hlavac L B, Hlavacova I M, Arleo F, Vigano F, Annoni M P G and Geryk V 2018 Precis. Eng. 53 194–202
[4] Lemma E, Chen L, Siores E and Wang J 2002 Int. J. Mach. Tool. Manu. 42 781–789
[5] Zhang S J, Wu Y Q and Wang Y L 2011 Open Mech. Eng. J. 5 166–177
[6] Wang S, Zhang S J and Wu Y Q 2017 Int. J. Adv. Manuf. Technol. 90 1265–1275
[7] Miao X, Qiang Z, Wu M, Song L and Ye F 2018, Int. J. Adv. Manuf. Technol. 97 71–80
[8] Gostimirovic M, Pucovsky V, Sekulic M, Rodic D and Pejic V 2018 Int. J. Adv. Manuf. Technol. 1-11
[9] ISO/ WD/ TC 44 N 1770 - 2010.
[10] Herghelegiu E, Radu C, Schnakovszky C and Zichil V 2015, Appl. Mech. Mater. 809-810 207-212

Acknowledgements
This work was supported by a grant of the Romanian Ministry of research and Innovation, CCCDI – UEFISCDI, project number PNIII-P1-1.2-PCCDI-2017-0446 / 82PCCDI / 2018, within PNCDI III.