The surface quality of AWJ cut parts as a function of abrasive material reusing rate

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Abstract. Abrasive water jet cutting (AWJ) has been extensively used during the last years to process a large variety of materials since it offers important advantages as a good quality of the processed surface, without heat affected zones, low environmental impact (no emission of dust or other compounds that endanger the health of the user), small induced mechanical stresses etc. The main disadvantage is the high cost of processing (cost of equipment and consumables). In view of this, the effects of reusing the abrasive material on the quality of processed surface are investigated in this paper. Two steel materials were used: OL 37 (S 235) with large applicability in machine building industry and 2P armor steel used in the arms industry. The reusing rate of the garnet abrasive material was: 0%, 20%, 40%, 60%, 80% and 100%. The quality of processed surface was quantified by the following parameters: width at the jet inlet (Li), width at the jet outlet (Lo), inclination angle (α), deviation from perpendicularity (u) and roughness (Ra).

1. Introduction
The need to process different hard and super hard materials that cannot be processed by conventional processing methods led to the appearance of unconventional technologies. These technologies have been developed greatly in recent decades, as they are used at large scale in different industries. A great advantage of the unconventional technology is the lack of contact between the tool and the surface to be processed; the processing is done using agents such as electricity, water, air, chemicals etc [1].

The newest unconventional technology is water jet cutting (the first reliable ultra-high pressure pump was developed in the early 1970s). However, while water jets could easily cut soft materials, they were not effective in cutting harder materials such as metals. This capability was achieved by adding an abrasive to the water jets. In 1979, Dr. Mohamed Hashish, from the Flow International Cooperation Company, introduced for the first time abrasive water jet cutting by adding an abrasive material into a jet of pure water [2]. Therefore, two subcategories of water jet cutting can be considered: (1) water jet cutting without abrasive material, which is used to process non-metallic materials (wood, plastic, glass, leather, etc.) as well as different products in the food industry since it prevents oxidation and (2) water jet cutting with abrasive material, which is used to cut a wide range of materials including hardened tool steel, titanium, all types of alloys, stone, ceramics etc., based on a proper combination of a durable abrasive water jet nozzle and a reliable high pressure pump [3, 4].

Water jet technology has many advantages such as: is an ecological technology; does not emit toxic fumes or dust that are harmful to the environment or machine operator; can process various metallic and non-metallic materials; can process different geometries of parts; there is no heat release during
processing; there is a very low loss of material, having a small cutting width; does not leave burrs or rough surfaces [5, 6].

However, the technology has disadvantages, too: in packet processing cannot be performed; high cost of equipment and replaceable components (water nozzle, focusing tube, cutting head, filter, etc.); large thicknesses cannot be processed accurately, as the shape of cut becomes conic and appears grooves at the bottom of surface; materials that degrade on contact with water cannot be processed [7].

In recent years, many researches have been conducted for process optimization in order to obtain a better quality at a low price. Following this trend, the current paper investigates the effects of reusing abrasive material on the quality of processed surface. In view of this two types of steel were used: OL 37 (S 235) steel, with large applicability in machine building industry and 2P armor steel with low-temperature-tempered martensite structure (Russia), used in the arms industry. Different reusing rates of abrasive material were set for the experiments: 0%, which means only virgin abrasive, 20%, 40%, 60%, 80% and 100% reused abrasive material. The parameters used to quantify the quality of processed surface, according to the ISO/WD/TC44 N 1770 standard were: width of the processed surface at the jet inlet (Li), width of the processed surface at the jet outlet (Lo), inclination angle (α), deviation from perpendicularity (u) and roughness (Ra).

2. Experimental methodology

The experimental tests were performed on a Hydro-Jet Eco 0615 water jet cutting machine using plates made by the above mentioned two materials, with the thickness of 6.5 mm. The mechanical characteristics of materials are presented in table 1 and table 2, respectively. The process parameters were those presented in table 3.

| Table 1. Mechanical characteristics of the OL 37 carbon steel (S 235). |
|------------------|-----------------|-----------------|---------------|
| Steel grade      | Yield stress, Rp0.2 [MPa] | Tensile stress, Rm [MPa] | Elongation, A [%] |
| S 235 (OL 37)    | 240             | 360 - 440       | 25            |

| Table 2. Mechanical characteristics of armor steel with low-temperature-tempered martensite structure (Russia). |
|------------------|-----------------|------------------|-----------------|
| Steel Grade      | Alloy System    | Carbon, % by weight | Tensile stress (average), Rm [MPa] | Hardness, [HB] | Similar standard |
| 2P               | Si-Mn-Mo        | ≤ 0.29            | 1550            | 444 – 514      | (MIL 46100)     |

| Table 3. Process parameters. |
|-------------------------------|
| Parameter                      | Unit      | Value |
| Abrasive mixture quantity, Q   | [g/min]   | 300    |
| Pressure, P                    | [MPa]     | 150    |
| Distance between cutting head and surface, h | [mm] | 3 |
| Feed rate, Vf                  | [mm/min]  | 100    |
| Orifice diameter, Do           | [mm]      | 0.35   |
| Focusing tube diameter, Df     | [mm]      | 1.02   |
| Length of focusing tube, Lf    | [mm]      | 76.2   |

The abrasive material as a function of the reusing rate is presented in figure 1. It can be seen that the dimension of abrasive grains is getting smaller as the reusing rate is higher.

The measurements of width of the processed surface at the jet inlet (Li), width of the processed surface at the jet outlet (Lo), deviation from perpendicularity (u), inclination angle (α) and surface
macrostructure were performed on a Leica MZ75 microscope, with PC interface. The surface roughness (Ra) was measured with a Mitutoyo SJ 201 digital roughness device.

3. Results and discussion
The influence of the reusing rate of abrasive material on the surface quality of plates made by OL 37 (S235) carbon steel and 2P armor steel, cut by abrasive water jet technology, is presented in the graphics below.

The macrostructures of OL 37 (S235) material processed at different percentages of reused abrasive is presented in figure 2. Note that the increasing of reused abrasive percentage leads to a macrostructures without striations. In case of 2P armor steel cut at different rates of reused abrasive material, some small striations resulted on the cut surface when virgin grains of abrasive were used. As the percentage of reused abrasive increased, the striations were getting bigger, the worst surface quality being obtained at a reusing rate of 60%. However, the best quality of processed surface resulted for a reusing rate of abrasive material of 80% (figure 3).

**Figure 1.** The abrasive material used for the experimental tests.

**Figure 2.** Macrostructures of OL 37 (S235) steel processed by AWJ at different rates of reused abrasive.
Figure 3. Macrostructures of 2P armor steel processed by AWJ at different rates of reused abrasive.

The results concerning the influence of abrasive material reusing rate on the width of processed surface at the jet inlet (Li) are graphically shown in figure 4. The graph analysis highlights that a higher percentage of reused abrasive material leads to a smaller value of the Li parameter, in case of both materials, due to the small size of the abrasive grains.

![Graph showing width of the processed surface at the jet inlet (Li) as a function of the reused abrasive.]

Figure 4. Width of the processed surface at the jet inlet (Li) as a function of the reused abrasive.

The influence of abrasive material reusing rate on the width of processed surface at the jet outlet (Lo) is graphically presented in figure 5. It can be seen that the percentage of reused abrasive has an almost insignificant influence on the Lo parameter till the value of 60%. After this value, the width of processed surface at the jet outlet decreases as the percentage of reused abrasive increases.

![Graph showing width of the processed surface at the jet outlet (Lo) as a function of the reused abrasive.]

Figure 5. Width of the processed surface at the jet outlet (Lo) as a function of the reused abrasive.
Figure 6. Deviations from perpendicularity (u) as a function of the reused abrasive.

Figure 7 summarize the results concerning the influence of reused abrasive percentage on the inclination angle of processed surface. It can be noticed that the angle of inclination is constant at 3°, for both materials, up to a reusing rate of abrasive of 80%. Over 80%, the inclination angle increases for both materials, more pronounced in case of OL 37 (S235) carbon steel.

Figure 7. Inclination angle of cut (α) as a function of the reused abrasive.

The influence of abrasive material reusing rate on the surface roughness is presented in figure 8. It can be seen a decreasing trend of roughness as the abrasive is reused in larger percentages, excepting the 40% reusing rate when an increase of roughness is observed for both materials, more pronounced in case of 2P armor steel.

Figure 8. Surface roughness as a function of the reused abrasive.

4. Conclusions
The aim of the current paper was to investigate the effects of using abrasive material on the quality of surfaces cut by AWJ. As result of the study it was found that reusing of abrasive material leads to a good quality of the processed surface, the processing productivity being slightly affected. The best quality of processed surface, quantified in terms of parameters specified by the ISO/WD/TC44 N 1770 standard, was obtained for reusing rates of abrasive material between 60% and 80%. This means a decreased consumption of virgin abrasive material, which in turn results in a lower cost of processing.
per unit length (economic benefits) as well as lower power consumption, lower transport costs and fewer related problems (environmental benefits).

![Figure 8. Roughness of the processed surface (Ra) as a function of the reused abrasive.](image)

As concern the two analysed materials, it was observed that in case of 2P armor steel all parameters that quantify the surface quality had higher values compared to those obtained for OL 37 (S235) carbon steel, excepting the inclination angle that, after a constant value of 3° for both materials, was bigger for carbon steel.

**Acknowledgement**
This paper was performed through the Partnerships program, in PN II priority areas, developed with MEN-UEFISCDI (Romanian National Authority for Scientific Research) support, project no. 294/2014.

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