The quality of water jet cutting of selected construction materials

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Abstract. The article presents examinations of the quality of water jet cutting process four different construction materials. The study was conducted on selected materials: aluminium alloy (AlCu4MgSi), brass (CuZn37), stainless steel (X5CrNi18-10) and non-alloy steel (S235JR). All these materials had the same thickness of 10mm. Sample geometry has been designed to be able to obtain five different surfaces and slit. During the water jet cutting process parameters were being changed to obtain five surfaces and to compare parameters. The water jet cutting process for this tests was carried out on one-head waterjet machine produced by PTV, designed for 2D and 3D cutting. Quality of all surfaces of samples was then evaluated including: surface roughness, deviation perpendicularity, bevel angle, the width of the cut and the bore. Because there are no standard describing quality tests of water jet cut surfaces, during this study standard ISO 9013:2017 for thermal cutting process was used. Basing on this standard tests of surface roughness and perpendicular deviation or slanting of cut edges were made. The other parameters were tested for information only. In this article results of this test were presented. Quality of surfaces, possibility of using this cutting method for tested construction materials were analysed. The test results have shown usability of water jet cutting process for 10mm thick aluminium alloy AlCu4MgSi, brass CuZn37, stainless steel X5CrNi18-10 and non-alloy steel S235JR. The surface quality obtained after cutting compared to construction materials is sufficient and profitable in Q3 average quality. For the better quality, of course better results, but the cost of cutting increases significantly. Therefore, the details can be cut at a lower quality, and then subjected to further mechanical processing, which is less expensive.

1. Introduction

Technological process of cutting is commonly used for metals [1-8]. During the process there is created stress state in cutting location that propagates the crack which is frequently preceded by plastic deformation. Mechanical cutting is one of the oldest methods of this process which uses for example guillotine to cut material on straight lines. This method, however, can cause deformation and cracks of the cutting edge as a result of crush. As an alternative to this process there are used processes of thermal cutting such as: oxygen cutting, plasma cutting, laser cutting and also the process of water jet cutting [9-13]. Water jet cutting technology uses high-pressure water (up to 700MPa) or mixture of water and an abrasive substance to remove metal from the cutting gap. Water jet is generated in high-pressure pomp with hydraulic multiplier, then it gets out through a small hole in the nozzle and operate the cutting process by erosion. Process of water jet cutting, depending on treated materials, can be divided into pure waterjet and abrasive waterjet (AWJ). This method of cutting proceeds as fully
automated. By using computer control of the machine there are no restrictions as object shape and material type. Of course, it is important to set the appropriate head and water jet parameters. Due to safety reasons, cutting may be proceeded with head inclination up to 45° from cutting material surface (3D cutting). This process is mainly applied for materials that are difficult, expensive or impossible to cut with other methods [14-18]. Water jet cutting is particularly profitable in small and medium productions. Pure waterjet is process that allows to cut almost all soft materials such as insulation materials, puzzles etc. For hard materials (eg. metals, glass, stones) water jet contains abrasive particles what causes increase of cutting force. That is why using abrasive waterjet there can be cut materials with thickness up to 300mm. Main advantages of this process are: high quality of cutting surface, no structural changes in the material, no thermal deformations, high purity of cutting surface, high precision, short preparatory-finishing time, high speed of cutting and high efficiency of the process. For many applications water jet cut materials do not require any additional treatment or processing after cutting.

2. Experimental procedure

The aim of research was to evaluate the quality of abrasive water jet cut surfaces of different construction materials. The study included: surface roughness, deviation perpendicularity, bevel angle, the width of the cut and the bore. For the research there were used 4 types of materials: aluminum alloy (AlCu4MgSi), brass (CuZn37), stainless steel (X5CrNi18-10 ) and non-alloy steel (S235JR). Each of tested materials was 10mm thick. The abrasive water jet cutting process was carried out on one-head waterjet machine produced by PTV, designed for 2D and 3D cutting.

2.1. Cutting process

The goal of the research was to obtain after cutting five surfaces with different quality (Q1 – very coarse, Q2 – coarse, Q3 – average, Q4 – fine, Q5 – very fine) due to changing parameters during process. For this reason, special shape of sample was designed. It was pentagon with bore and additional cut to test its width. The drawing of cut object was made in AutoCad 2014 (figure 1) and then saved in *.dxf format in order to use it by machine systems. Nextly, parameters (table 1) of each edge have been selected to get the right surface quality after the cutting process.
Material | Non-alloy steel | Stainless steel | Brass | Aluminum alloy
--- | --- | --- | --- | ---
Grade | S235 | X5CrN18-10 | CuZn37 | AlCu4MgSi
Thickness, g [mm] | 10 | 10 | 10 | 10
Treatability | 87 | 80 | 114 | 220
Punching time, t, [s] | 4 | 4 | 4 | 4
Punching pressure, $P_p$ [bar] | 4130 | 4130 | 4130 | 4130
Abrasive amount while punching, $[g/min]$ | 350 | 350 | 350 | 350
Cutting pressure, $P_c$ [bar] | 4130 | 4130 | 4130 | 4130
Abrasive amount while cutting, $[g/min]$ | 320 | 320 | 320 | 320

Cut feed $f [mm/min]$ for different surface quality $Q$

| Surface quality $Q$ | Very coarse Q1 | Coarse Q2 | Average Q3 | Fine Q4 | Very fine Q5 |
| --- | --- | --- | --- | --- | --- |
| $f$ [mm/min] | 410.6 | 372.9 | 560.3 | 1193.4 | 276.1 | 496.8 |

After abrasive water jet cutting four samples, each with the same geometry and size, were received. Due to change of parameters during cutting process as a result there can be observed surfaces with different quality (figures 2-5). Both external and internal cutting edges are very well visible.

**Figure 2.** Non-alloy steel S235 cut sample and surfaces Q1-Q5.
Figure 3. Stainless steel X5CrN18-10 cut sample and surfaces Q1-Q5.

Figure 4. Brass CuZn37 cut sample and surfaces Q1-Q5.
2.2. Cutting surfaces quality evaluation

Quality evaluation of surface roughness, deviation perpendicularity and bevel angle was done using ISO 9013:2017 standard. Measuring of roughness “Rz” was made in the direction of cutting line in five locations of the samples with the length of measuring distance of 12.5mm and elementary length 2.5mm (table 2). In roughness test, profilometer SJ-201 Mitutoyo was used. Measuring of deviation perpendicularity “u” was made in three locations with interspace 20mm. Bevel angle was measured using optical protractor (table 2).

| Surface quality | Deviation perpendicularity “u” [mm] | Area “Rz” ISO 9013:2017 [μm] | Surface roughness by ISO 9013:2017 [μm] | Bevel angle [°]
|-----------------|------------------------------------|-------------------------------|-----------------------------------------|----------------|
| Non-alloy steel S235 |                                    |                               |                                         |                |
| Very coarse Q1 | 0.52                               | 4                             | -                                       | 3° 20’         |
| Coarse Q2      | 0.23                               | 3                             | 13.30                                   | 1° 30’         |
| Average Q3     | 0.16                               | 2                             | 10.78                                   | 1° 03’         |
| Fine Q4        | 0.12                               | 2                             | 10.37                                   | 1° 45’         |
| Very fine Q5   | 0.11                               | 1                             | 6.78                                    | 1° 42’         |
| Stainless steel X5CrN18-10 |                      |                               |                                         |                |
| Very coarse Q1 | 0.56                               | 4                             | -                                       | 3° 37’         |
| Coarse Q2      | 0.21                               | 3                             | 11.06                                   | 1° 23’         |
| Average Q3     | 0.22                               | 2                             | 8.58                                    | 1° 27’         |
| Fine Q4        | 0.20                               | 2                             | 6.66                                    | 1° 18’         |
| Very fine Q5   | 0.19                               | 2                             | 6.46                                    | 1° 15’         |
On the cut objects there was made 50mm length cut in order to test its geometry. It was tested by measure top and bottom kerf width and also by measure top and bottom bore diameter. Results of this measurements are shown in table 3. Cut and bore were made using parameters for quality Q3 in each of tested materials.

| Material                  | Top kerf width [mm] | Bottom kerf width [mm] | Top bore diameter [mm] | Bottom bore diameter [mm] |
|---------------------------|---------------------|------------------------|------------------------|--------------------------|
| Non-alloy steel S235      | 1.25                | 0.73                   | 50.17                  | 49.78                    |
| Stainless steel X5CrNi18-10 | 1.26                | 0.74                   | 50.19                  | 49.76                    |
| Brass CuZn37              | 1.32                | 0.79                   | 50.17                  | 49.84                    |
| Aluminum alloy AlCu4MgSi  | 1.37                | 0.67                   | 50.21                  | 49.75                    |

3. Results and discussion
The aim of research was to compare the quality of cut edges four different construction materials with thickness of 10mm (aluminium alloy AlCu4MgSi, brass CuZn37, stainless steel X5CrN18-10 and non-alloy steel S235JR) using an abrasive water jet cutting process. Each cut edge was done using different parameters shown in table 1. In the middle of each sample bores and cuts were made in order to analyse their geometry. All surfaces were evaluated using ISO 9013:2017 standard (“Thermal cutting - Classification of thermal cuts - Geometrical product specification and quality tolerances”). This standard was used because there is no standard for quality assessment of water jet cut materials. ISO 9013:2017 standard for quality evaluation of thermal cut surfaces takes into consideration roughness of surface and deviation perpendicularity. Other tested geometrical parameters: bevel angle, kerf width and bore diameter are additional in this research. Quality of surfaces has been evaluated also using this standard.

3.1. Cut surface quality analysis
Taking into account results of the research of selected construction materials, each thick 10mm, using ISO 9013:2017 standard: surface roughness and averaged deviation perpendicularity, it can be determined that by selecting appropriate parameters of the abrasive water jet cutting process it is possible to control surface quality and also manufacturing costs. Non-alloy steel S235 and stainless steel X5CrNi18-10 had the biggest averaged deviation perpendicularity of all tested materials. This is particularly noticeable in very coarse cutting. Aluminium alloy AlCu4MgSi and brass CuZn37 shown
more apparent similarity between each cutting quality. In this case the averaged deviation perpendicularities do not show large differences. Figure 8 shows comparison of averaged deviation perpendicularities for tested materials cut in the abrasive water jet cutting process.

![Figure 6](image1.png)

**Figure 6.** Averaged deviation perpendicularities comparison for cut surfaces in the abrasive water jet cutting process.

The research showed that after abrasive water jet cutting process S235 non-alloy steel and X5CrNi18-10 stainless steel have lower surface roughness comparing to AlCu4MgSi aluminium alloy and brass CuZn37. Considering this cutting process, for softer materials abrasive particles reflect and remove more material from cut surface. In harder materials abrasive water jet is more concentrated. Figure 9 shows comparison of surface roughness test results for tested materials.

![Figure 7](image2.png)

**Figure 7.** Abrasive water jet cut surfaces roughness comparison.

### 3.2. Geometry of groove and bore analysis

Comparing kerf width and diameter of the bore for each tested construction material: S235 non-alloy steel, X5CrNi18-10 stainless steel, AlCu4MgSi aluminium alloy and brass CuZn37, results are similar in all materials. Steels, however, shows better dimensional stability comparing to non-ferrous metal, the same as in averaged deviation perpendicularity test. Figures 10 and 11 show comparison of kerf width and bore diameter for tested materials.
4. Conclusions

The test presented in this article have proved usefulness of the abrasive water jet cutting process for all selected construction materials with thickness of 10mm (AlCu4MgSi aluminium alloy, brass CuZn37, X5CrNi18-10 stainless steel and S235JR non-alloy steel). Results do not show significant differences of deviation perpendicularities in each tested material. The surface roughness analysis showed better quality of cut surface for harder materials such as non-alloy steel and stainless steel. Differences between surface roughness are similar for aluminium alloy and brass with quality Q3 – Q5. It is caused by easier material loss during cutting process, because in harder materials abrasive particle gets blunt much faster than in softer materials. Roughness of surfaces of tested materials cut in abrasive water jet cutting process is sufficient and profitable in medium quality Q3. Results are of course better for fine and very fine quality, but the process costs increase. Therefore, it is economically advantageous to cut in lower quality and then use additional, cheaper mechanical processing. Cut surfaces evaluation showed that most of tested cut edges are in 1 – 3 accuracy classes according to
ISO 9013:2017 standard. Water jet cutting process is constantly growing technology which enables cutting materials with good quality and can be applied even in single production. This cutting process can be applied for materials which cannot be cut using other technologies.

5. References

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