TAPER OF CUT AT ABRASIVE WATERJET CUTTING OF AN ALUMINIUM ALLOY

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Abstract
Abrasive waterjet cutting is usually the first machining operation of different aluminium alloys from sheet metal. Quality of the machined parts and their later machining operations are determined by the accuracy of the cut, which highly depends on the taper of the cutting gap. Taper of the cutting kerf is one of the most important accuracy problems at abrasive waterjet cutting operations. Taper can be different at different materials and depends on the applied technological parameters (feed rate, pressure, abrasive flow rate etc.). Some results of cutting experiments for investigation of cutting kerf geometry are summarized in the paper when machining aluminium alloy material by abrasive waterjet cutting.

Keywords: abrasive waterjet cutting, form of the cutting kerf, aluminium alloy

1. Introduction

Ultra high-pressure abrasive water jet cutting has for the last few years become a competitor to various procedures that generate heat. The new technique has become popular because the heat of cutting does not deform the material and the cut surface is of high quality. The fact that almost every type of material (both soft and hard) can be cut by the method and that the thickness of the cut is less limited, are two of the several important advantages of the abrasive water jet technology. Comparing to thermal cutting processes, abrasive water jet cutting is a relatively a clean technology. Nevertheless it consumes energy, water and abrasive powder. Choosing optimal cutting parameters abrasive water jet methods become a cleaner technology.

High pressure waterjet cutting (WJC) is one of the so-called non-traditional machining methods using a very high energy density to dissipate material from the workpiece. Abrasive waterjet (AWJC) systems have been commercially available since 80th. This process relies on erosion caused by liquid or solid particle impact, giving the possibility of machining almost all kind of material. The utilisation of the energy of a supersonic liquid jet outflowing from a small-diameter hole under high pressure is a progressive direction in material cutting.

One of the limit of application of waterjet cutting are the different accuracy problems of this machining method. Usually the form of the cutting kerf causes difficulties in the assurance of the prescribed accuracy.
2. Form of the cutting kerf at abrasive waterjet cutting

Form of cutting kerf is one of the main problems effecting on the accuracy of abrasive waterjet cutting. Form of the kerf (Fig. 1.) is always very complex, but basically it can be considered like two tapered plains.

**Figure 1. Through-cut kerf characteristics**

Kerf characteristics refer to the kerf geometrical features as kerf width, kerf taper and kerf depth. The surface topological features as represented by surface roughness and striation (or waviness) are also to as kerf characteristics. Generally there are two types of kerfs, through cut and non-through cut. The typical geometry of a through cut kerf is shown in Fig. 2. It has a wider entry and its width decreases as the jet cuts into the material, so that a kerf taper is produced. In most cases the kerf is wider at the upper side (entering) then the lower side, where the jet goes out from the workpiece, so the taper can be convergent \( (w_t > w_b) \), divergent \( (w_t < w_b) \) or even divergent-convergent.

**Figure 2. Taper of the kerf**

Kerf taper is normally expressed by kerf taper angle as [1]:

\[
\theta = \frac{w_{b,max} - w_{b,min}}{W_{top} - W_{min}} \times 100\%
\]
\[ \theta = \arctan \left( \frac{w_t - w_b}{2t_w} \right) \]  

where \( w_t \) is the top kerf width, \( w_b \) is bottom kerf width, \( t_w \) is workpiece thickness for through cuts.

Taper of the kerf causes accuracy problems at the waterjet cutting. Elimination of this error is very difficult because of the great number of effecting cutting parameters, especially if we consider the economy of the machining. Error caused by the taper can be reached the extent of 0.3 mm at cutting through a 20-25 mm thick workpiece, which is a very hard limitation of this machining method.

Form of cutting kerf was investigated by more authors. Öjmertz [2] establishes that form of the gap depends on lot of cutting parameters, and gives the characteristics of them, but doesn’t gives any mathematical relation for express of their effects.

In an investigation of ductile materials conducted by Chung at al [3], the taper of the cut is inversely proportional to nozzle traverse speed. They also noticed, that kerf taper increases with an increase in standoff distance because the bottom kerf width has no correlation with standoff distance but the top kerf width of the kerf is directly proportional to it. In addition they found no clear relation between the kerf taper and abrasive mass flow rate.

Arola and Ramulu [4] investigated the taper formation and influential factors using AWJ cutting graphite/epoxy composite. They noticed that kerf taper has close relation with material thickness. At cutting depth greater than 15 mm, no single parameter clearly dominates the kerf taper as it is affected by a combination of all the independent variables.

Aim of recent research work was to get connections between the technological parameters and the taper of the kerf in order to find cutting parameters with which we can get parallel cut surface.

3. Experimental conditions

Cutting tests were carried out for investigation of kerf taper on AlMgSi0.5 aluminium alloy. This material is a widely used light metal in machine industry.

Cutting experiments were carried out on a two dimensional waterjet cutting machine type INNO PUMP-36HD. Main technical data of the devices are as follows:

- maximum water pressure: 360 MPa
- working space: 2100x1900x210 mm
- positioning accuracy: ±0.15 mm
- type of abrasive federate: vibration
- electric power: 30 kW
- water flow rate: 1.5 l/min
- control system: Messer-Griesheim

During the cutting experiments the water pressure (p), the abrasive mass flow rate (ma) and the federate (f) were changed in different levels. Applied technological parameters are shown in 1. Table.

Abrasive powder was a Barton Garnet type #80 size powder, which ha 200μm average size abrasive grains.
Table 1. Parameters of the cutting experiments

<table>
<thead>
<tr>
<th>Constant parameters</th>
<th></th>
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</thead>
<tbody>
<tr>
<td>Material</td>
<td>AlMgSi0.5</td>
</tr>
<tr>
<td>Material thickness</td>
<td>10 mm</td>
</tr>
<tr>
<td>Diameter of primary nozzle</td>
<td>0,25 mm</td>
</tr>
<tr>
<td>Diameter of abrasive nozzle</td>
<td>0,8 mm</td>
</tr>
<tr>
<td>Length of abrasive nozzle</td>
<td>70 mm</td>
</tr>
<tr>
<td>Standoff distance</td>
<td>2 mm</td>
</tr>
<tr>
<td>Abrasive material</td>
<td>GARNET #80</td>
</tr>
</tbody>
</table>

| Changing parameters AlMgSi0.6             |       |
| Water pressure, MPa                      | 350; 300; 350 |
| Abrasive mass flow rate, g/min           | 200; 400 |
| Feedrate, mm/min                         | 50; 100; 150; 200; 250; 300 |

After the cutting experiments upper width ($w_t$) and lower width ($w_b$) were measured for determination of the taper of the kerf.
Measurements of the kerf width were accomplished on an optical length measuring machine type MF-1030 TH.

4. Effect of the technological parameters on the taper of the kerf

Effect of the different technological parameters on the taper of the cut can be followed on figures 3-5.

Figure 3. Change of the upper ($w_t$) and lower with ($w_b$) of the cutting kerf in function of the federate and the water pressure
Figure 3 shows the change of the upper and the lower width of the kerf in function of the federate, at different pressures. Effect of the federate on the form of the cutting kerf is very typical. Width of the cutting kerf decreases highly in function of the federate at the bottom side, but at the upper side it is almost constant when the federate higher than 150 mm/min. Similar tendencies cab be read from Fig. 4.

![Figure 4. Change of the taper angle of the cutting kerf in function of the federate at different water pressure](image)

The taper angle increases clearly in function of the federate. At higher pressures the taper angles are smaller. This can be seen on Fig. 5, where the taper angle is described in function of the water pressure at different feed rates.

![Figure 5. Change of the taper angle of the cutting kerf in function of the water pressure at different feed rates](image)

By increasing the pressure, the taper angle is decreasing. There is a clear correlation between the pressure and the taper angle mainly at higher pressures. This phenomenon could be explained that at high pressures the particles of the jet have enough kinetic energy for material removal even at the bottom side of the cut.
Effect of the abrasive mass flow rate is dominant mainly at application of small federates. In this case there are enough loading time for the abrasive grains to remove the materials from the cutting kerf.

5. Summary of the results

On base of the cutting experiments we can point out that the accuracy of the cut surface is basically defined by the size and form of the cutting kerf. Cutting kerf is usually tapered, orientation of the taper is mainly depends on the quality of machined material, at metals it is usually convergent.

It can be established, that the extent of taper of the cutting kerf basically depends on the technological parameters. The federate ($f$) clearly increases the taper angle. The effect of the water pressure ($p$) and the abrasive mass flow rate ($ma$) could strongly effect on the taper mainly at lower federates, when there is enough loading time for the abrasive particles to remove the material from the workpiece.

In this case increasing the pressure decreases the taper angle of the kerf because of the fact that at lower federates the abrasive jet is able cut through more wide the material at the bottom side as well.

Increase of the abrasive mass flow rate decreases the taper too. By increasing the number of abrasive grains acting in the jet, increases the energy of the jet, which results a wider kerf width at the bottom side of the cut.

From the results it can be established that the extent of tapering of the kerf basically depends on the quantity of the energy-input, and can be controlled by it. So future researches will oriented to describe connections between the loading energy and the cutting kerf geometry.

6. Acknowledgements

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References


