THE EFFECT OF THE TRAVERSE SPEED ON THE ROUGHNESS PARAMETERS AND KERF WIDTH IN THE AWJ CUTTING OF COPPER

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Abstract

This article describes experiments performed to assess the effectiveness of abrasive waterjet (AWJ) cutting used to cut copper. The roughness parameters of the cut surface and the kerf widths were measured using a TOPO L120 contact profilometer and a Nikon Eclipse MA 200 optical microscope. The experiments revealed that the traverse speed of the jet was a significant parameter affecting the surface roughness parameters and the kerf width. An increase in the traverse speed caused an increase in the surface roughness parameters. This was particularly visible along the bottom edge of the workpiece. Higher cutting speeds were also responsible for a reduction in the smooth cutting region on the cut surface. An increase in the traverse speed caused the kerf to narrow, with the kerf width decreasing both at the top and the bottom. It is thus important to select the correct traverse speed to obtain the required surface quality while keeping the efficiency of the cutting process high.

Keywords: Waterjet cutting, copper, surface roughness, kerf width

1. INTRODUCTION

Copper, which is reddish brown in color, is one of the most electrically conductive metal elements. Because of its excellent electrical properties, ductility and malleability, it is widely used in telecommunication applications. The metal has a tensile strength about half that of mild carbon steel. Copper is easily formed by hand, which does not make it unsuitable for structural applications. It is frequently used in piping and tubes because of high fracture toughness.

Abrasive waterjet (AWJ) cutting has various distinct advantages over the other non-traditional cutting technologies including no thermal distortion, small cutting forces, high machining versatility, high flexibility and minimum stresses on the workpiece [1-3]. Benefits of abrasive waterjet cutting are numerous. Because of its universality, the method can be used to cut most materials, both thin and thick, into any complex shape; hence its wide range of applications. As such, it can easily compete with the conventional material cutting methods [4] or non-traditional processes such as electrical discharge machining (EDM) [5-6] and laser cutting [7-8].

AWJ cutting uses a small-diameter water stream. The main role of water is to accelerate abrasive particles to a high velocity and to produce a high coherent jet [9]. Abrasive particles are added to water to intensify the machining process [10]. Erosion of the material is dependent on the hydraulic energy of the waterjet and the kinetic energy of the abrasive grains in the waterjet. This jet is then directed towards the working area to perform cutting [11].

In the area close to the workpiece surface, the structure of the material is formed by microcutting. The cutting of the area further from the surface is a result of abrasive wear or mechanical erosion [12]. When the penetration of the waterjet into the material is deeper, the waterjet energy is smaller. When the energy of the waterjet is too low, the cut surface is not a straight but a curved line down through the material [13-14]. An increase in the traverse speed [15-16] causes a decrease in the smooth cut zone and a proportional increase in the lower quality zone. There is also an increase in the surface roughness.

Surface roughness parameters are one of the most important requirements of surface quality in machining. In AWJ cutting, surface finish varies according to the depth of measurement [17]. The studies on this issue were conducted by several separate research teams [18-19]. However, still a lot of work is necessary for preparation of a sufficiently complex system describing the effect of traverse speed on the surface quality in AWJ cutting. The latest research shows that the traverse speed of the waterjet has a strong influence on the surface finish of the workpiece and the material removal rate [20]. However, the degree of influence of selected process conditions depends on the magnitude of parametric variation and the machinability of a target material [2].

The aim of this study was to measure the roughness parameters of the machined surface and the kerf geometry for copper AWJ-machined at different traverse speeds. The study of roughness parameters involve the complete the cut surface from the data recorded along the thickness of the machined surface from the entry to the exit. In this paper surface quality is considered as the performance measure as in many industrial application it is the main constraint on the process applicability. Further detailed research is required to better understand the influence of the important process parameter such as traverse speed on surface quality of copper after AWJ cutting.

2. MATERIALS AND METHODS

The tests were carried out on copper specimens. **Figure 1** presents the views of the finished samples.

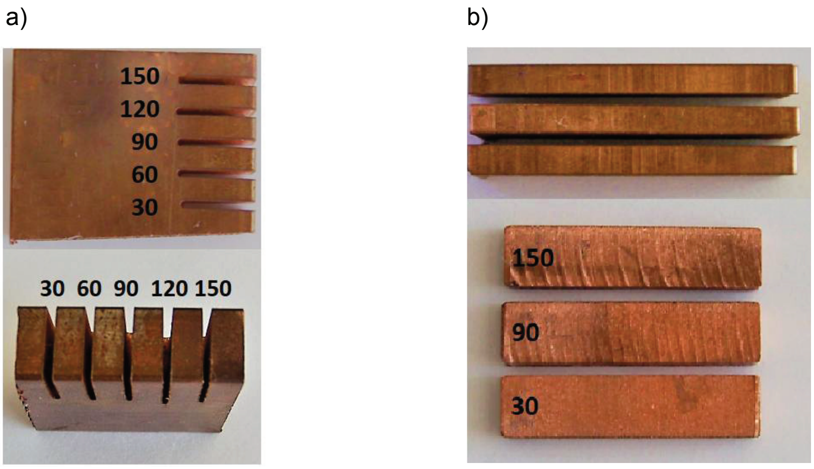

Figure 1 Views of the finished samples with marked traverse speed: a) sample for measuring kerf width; b) selected samples for measuring roughness parameters.

The samples were cut from copper plate with a thickness of 10 mm. First, the sample was cut every 5 mm. Each cut was at a different traverse speed. Each cut had a length of 55 mm (then 40 mm in length was cut off for roughness parameters measuring and the rest of the sample was used for kerf width tests).The chemical composition of material is presented in **Table 1**.

Table 1 Chemical composition of copper EN-AW CW020A (wt.%)

Cu	Bi	O	Pb
≥99.9	≤0.0005	≤0.04	≤0.005

All the experiments were performed at the Laboratory of Electrical Discharge Machining and Finishing of the Kielce University of Technology. The variable process parameter was traverse speed. The tests were performed at five different traverse speeds: 30, 60, 90, 120 and 150 mm/min. The constant process parameters are provided in **Table 2**.

Table 2 Constant process parameters for abrasive waterjet cutting.

Parameter	Value
Water pressure	280 MPa
Stand-off distance	4 mm
Water orifice diameter	0.3 mm
Focusing tube diameter	1.02 mm
Focusing tube length	76 mm
Abrasive mass flow rate	4 g/s
Average grain size	80 mesh
Abrasive type	Indian garnet
Impact angle	0 (normal to the sample surface)

3. RESULTS AND DISCUSION

3.1. The effect of the traverse speed on the surface roughness parameters

The roughness parameters was calculated from the data recorded every 2 mm along the thickness of the machined surface from the entry to the exit of the jet using a TOPO L120 contact stylus profilometer. The first measurement was taken 1 mm from the jet entry surface. Following roughness parameters were measured and compared: R_a (arithmetical average profile height), R_q (standard deviation of distribution in profile heights), R_z (ten-point height), R_t (maximum profile height). These parameters were selected in response to suggestions from the industry and due to their common use for evaluation of surface quality in both research and industrial applications.

The roughness of the cut surface changes with changing traverse speed. The relationship between the traverse speed and the surface roughness parameters in the AWJ cutting is shown in **Figure 2**.

Basing on the analysis of graphs it can be stated that the traverse speed has a significant influence on surface roughness of cut surfaces. Also, the distance from the upper cut surface edge directly affects surface quality and measurement results especially for cutting with faster traverse speed.

It can be seen that when the traverse speed was 30 mm/min, the average surface roughness R_a increased with increasing depth of measurement. At a depth of 1 mm it was 4.71 μm, at a depth of 5 mm, it amounted to 4.78 μm and at a depth of 9 mm it reached 5.14 μm. The changes in roughness observed along the thickness of the cut surface at a traverse speed of 30 mm/min (from 1 mm to 9 mm from the entry of the jet) were relatively small (+9.1 %). It is important to note that this phenomenon did not occur at other traverse speeds.

An increase in the traverse speed resulted in a lower surface quality, which was due to less overlap and fewer abrasive particles impinging the cut surface. A higher traverse speed increased the jet deflection, which was responsible for higher values of surface roughness. According to this model, the highest surface roughness was observed for a traverse speed of 150 mm/min and a depth of measurement of 9 mm (R_a = 19.7 μm), where there was an increase of 242.9 % in respect of depth of measurement of 1 mm for the same traverse speed.

Very similar percentage changes were reported for R_q parameter. Although the relative value of the R_q parameter was greater than R_a each time, the percent increments were the same. When the traverse speed was 30 mm/min and a depth of 1 mm R_q was 6.13 µm, at a depth of 5 mm, it amounted to 6.43 µm and at a depth of 9 mm it reached 6.75 µm. The changes in roughness observed along the thickness of the cut surface at a traverse speed of 30 mm/min (from 1 mm to 9 mm from the entry of the jet) were relatively small (+10.1%). The highest traverse speed according to the depth of measurement caused the R_q parameter increase by 261.1 % which was the biggest increase among the tested parameters.

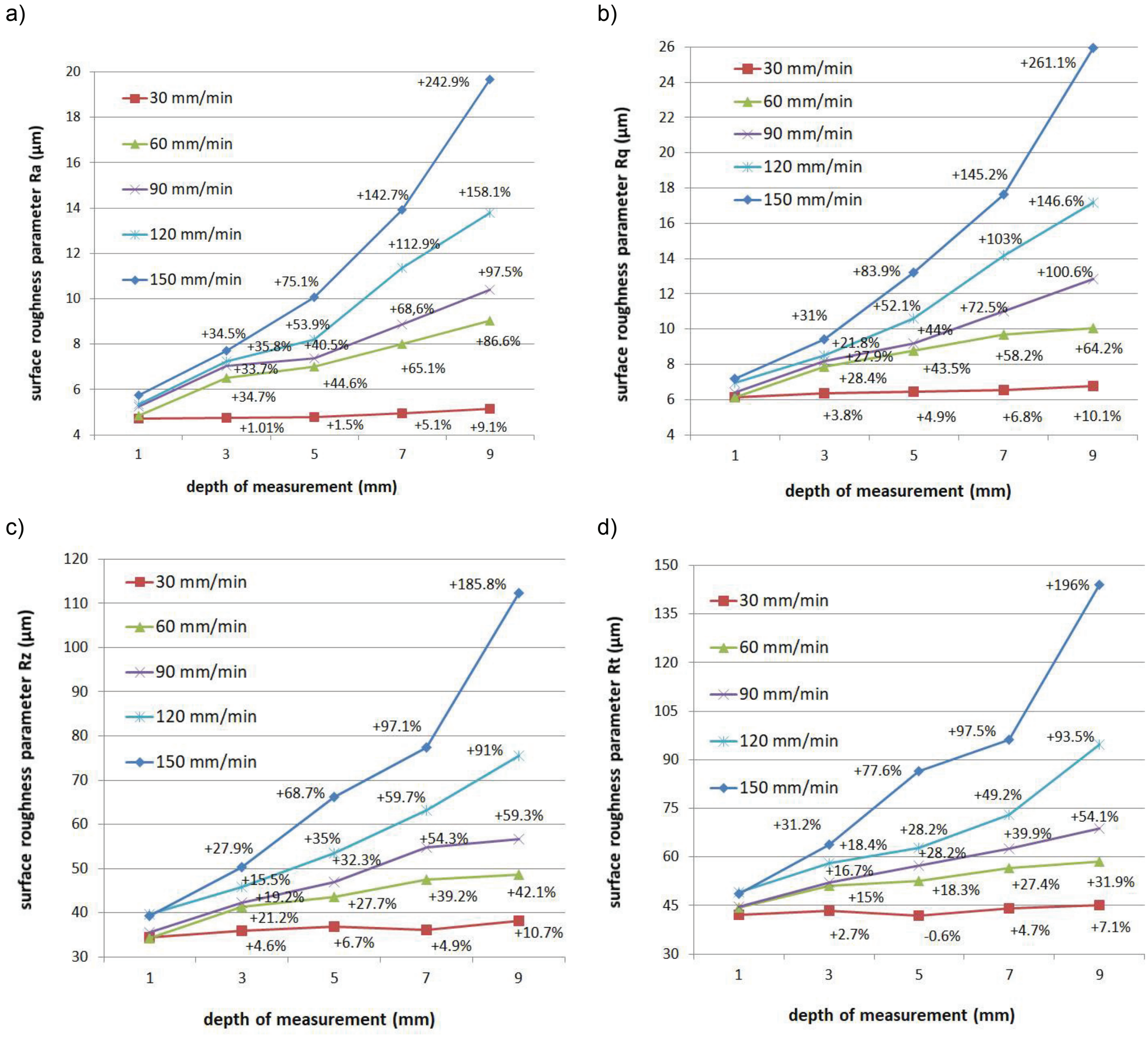

Figure 2 Depth of measurement versus surface roughness parameters (percentile increase)

It was also observed that the sensitivity to changes in cutting speed and distance from top cut edge differs between parameters. R_z and R_t are less sensitive to those changes than R_a and R_q parameters. For depth of measurement of 9 mm and traverse speed 150 mm changes in values of R_z amount 185.8% and of R_t 196% and they are much lower in comparison to R_a and R_q. Relative values of surface roughness R_z i R_t parameters are much higher than R_a and R_q parameters, but each time their increments, depending on the traverse speed and depth of measurement, were percentage smaller.

3.2. The effect of the traverse speed on the kerf width

Further measurements were required to determine how the traverse speed influenced the kerf width. Two profiles were analyzed. One measurement was taken at the point of entry of the water jet (top kerf width), while the other at the point of waterjet exit (bottom kerf width). The measurements were performed using a Nikon Eclipse MA200 optical microscope equipped with an NIS 4.20 image analyzer. **Figure 3** shows the effects of the cutting speed on the kerf width for the material studied.

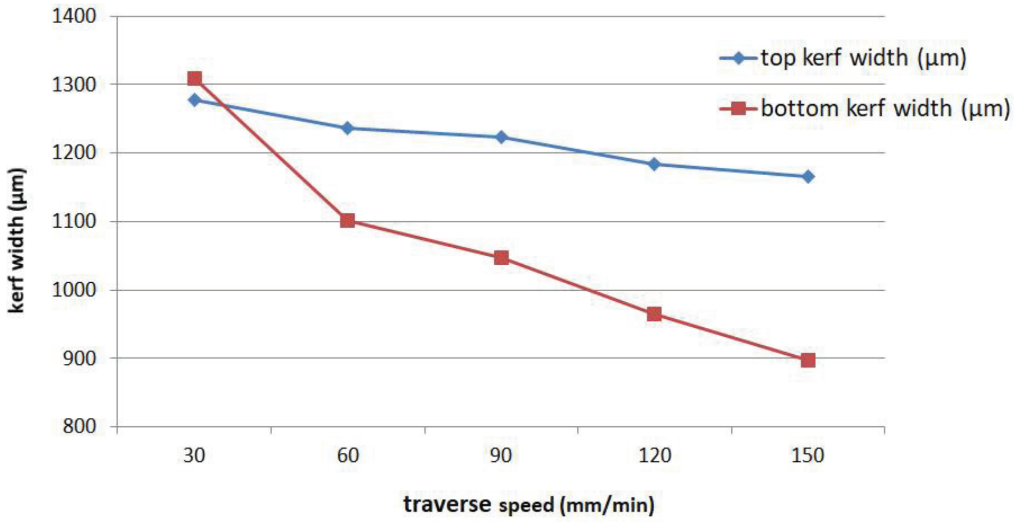

Figure 3 Traverse speed versus kerf width.

The shape of the plot indicates a substantial influence of the cutting speed on the top and bottom kerf widths. As the traverse speed increases, the top and bottom kerf widths decrease. Despite this, the kerf wall slope increases slightly. An increase in the kerf taper angle is directly due to a shorter exposure time. At higher traverse speeds, less time is available for cutting, which results in overlapping passes. The decrease in the bottom kerf width is much greater because the jet loses energy while penetrating into the workpiece.

At a cutting speed of 30 mm/min, the taper was correct, i.e. the top and bottom kerf widths were similar. An increase in the cutting speed to 60 mm/min caused changes in the shape of the kerf with the difference between the top and bottom kerf widths reaching 65 μm. An increase in the cutting speed to 150 mm/min led to a significant narrowing of the bottom kerf; the difference in this case was 268 μm.

4. CONCLUSIONS

The experimental results obtained for copper indicate that the traverse speed of the waterjet has a significant effect on the surface roughness parameters and the kerf width.

The surface roughness parameters of the cut changes with changing traverse speed. Lower traverse speeds result in a better surface finish. An increase in the traverse speed leads to a slightly higher surface roughness parameters at the top edge of the cut. At the bottom edge of the cut, the surface roughness parameters increase considerably with increasing traverse speed. Cutting with a traverse speed of 30 mm/min allowed us to generate a surface with similar roughness parameters along the whole thickness. The change in the surface roughness parameters was very small. This phenomenon was not observed at any other traverse speeds studied. It was also observed that the sensitivity to changes in traverse speed and depth of measurement differs between parameters R_z and R_t are less sensitive to those changes than R_a, R_q parameters. These are parameters with much higher values that exceed R_a and R_q parameters several times.

At a cutting speed of 30 mm/min, a small difference in the kerf width was observed. The kerf width was slightly narrower at the bottom with the difference being several micrometres. An increase in the traverse speed caused the kerf to narrow both at the top and the bottom. The experimental data indicated that, at higher traverse speeds, the bottom kerf width was much smaller than the top kerf width. A greater difference between the top and bottom kerf widths at higher values of the cutting speed suggested that the cut surface tapered.

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