EXPERIMENTAL INVESTIGATION ON MACHINED SURFACE OF ALUMINIUM ALLOY DURING SKIVING

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ABSTRACT

Our first approach in the research of rotational turning was the mathematical definition of the machined surface. The main requirement for the equation was that it should be able to describe both investigated cases (rotational turning and skiving) with the proper changes of the parameters. In order to validate the equation experiments were carried out using the simpler method. The following preparations were made: designing the tool, choosing the workpiece and the measurement method. Finally the measured and the theoretical two dimensional curve of the surface were compared.

Keywords: rotational turning, skiving, mathematical model, machined surface

1. INTRODUCTION

Rotational turning [1] is a special type of hard turning. In this method the cutting edge of the tool is a helical curve and the chip formation is different from the ordinary turning due to the circular feed of the tool [2]. Therefore the cutting conditions will be better than in case of other widely used hard turning methods. Due to the helix angle of the cutting edge the rotational turning shows similarities to skiving in the contact point [3].

One approach of our investigations is the definition of the theoretical equation of machined surface and the cross section of the chip [4]. After the definition of the machined surface, experiments were carried out to validate the equation. Therefore we machined an aluminium workpiece with tools of different inclination angle. After measuring them the theoretical and experimental results can be compared.

1.1. Defining the equation of the machined surface

To define the machined surface’s two-dimensional equation the method used by Vasliko [5] was applied. The purpose of the method is to calculate the generated surface after giving the proper definition of the coordinate systems. In order to do this the transformational equations must be defined between the coordinate systems. These equations contain two parts matrix of rotation and the vector of translation. The used symbols of the parameters in the equations are the following:

- \( \omega_w \) – angular frequency of the workpiece
- \( \omega_t \) – angular frequency of the tool
- \( v_t \) – axial feed rate of the tool
- \( a_w \) – centre distance
- \( r_t \) – \( \xi \) offset of the linear edge / radius of the helical curve
The value of the $\zeta$ variable is calculated in function of $\zeta$ (the coordinate-axis) by the described equation. Therefore the two-dimensional equation of the machined surface cut by linear cutting edge can be described as the following [6]:

$$
\tilde{r}_{i,j}(\xi,\zeta) = (Ar_i - B(\zeta - \nu_i)t)\tan(\alpha_i) - a_w \cos \alpha_i t \cos C_i +
+ (Br_i + A(\zeta - \nu_i)t)\tan(\alpha_i) + a_w \sin \alpha_i t \sin C_i
$$

(1)

In equation (1) the following simplifications were made for a better description [6]:

$$
A = \cos \omega_j t \cdot \cos \omega_w t + \sin \omega_j t \cdot \sin \omega_w = \cos(\omega_j t - \omega_w t)
$$

$$
B = \sin \omega_j t \cdot \cos \omega_w t - \cos \omega_j t \cdot \sin \omega_w t = \sin(\omega_j t - \omega_w t)
$$

$$
C_i = a \tan \left[ \frac{(Br_i + A\zeta \tan(\alpha_i) + a_w \sin \alpha_i t)}{(Ar_i - B\zeta \tan(\alpha_i) - a_w \cos \alpha_i t)} \right]
$$

(2)

2. PREPARATIONS FOR THE EXPERIMENTS

2.1. Selecting the workpiece and the tool

As the workpiece material an Al Si1MgMn grade aluminium alloy was chosen. It has good cutting attributes, corrosion resistance, and due to its mechanical parameters the machined surface can be easily observed [7,8].

To select the tool it is relevant to know the minimal length of the cutting edge, which performs the cutting of different inclination angles. This value can be seen in the graph in Figure 1. [4].

We can see that if the workpiece diameter is 100 mm, the inclinational angle of the cutting edge is 60°, the depth of cut is 1 mm the minimal length of the cutting edge is about 20 mm. In case of lower workpiece diameters this value is smaller. Therefore the most suitable tool for the experiments is an offset face turning tool as
described in the ISO 5 standard [9]. The main parameters of the chosen tool are: cutting edge length: 25 mm, rake angle: 12°, flank angle: 3°. The tool holder was re-designed and machined to get the suitable inclinational angle.

2.2. Experiment conditions

The technological parameters of the cutting process were defined before the experiments. The aim of the experiments is to validate the equation of the machined surface during skiving. Therefore cutting tools with different inclination angles are needed. After consideration three tools were designed and made: inclination with 30°, 45° and 60° angles. This way the behaviour of the equation can be observed with low, medium and high inclination angles. It is practical to have different depth of cuts, therefore we chose 1.0 and 0.5 mm. The feed rate of the tool was 0.05 mm/rev, the revolution frequency was 900 rev/min. In Table 1. the experimental conditions are summarized. The measurement of the machined surface was carried out with an indicator with 0.001 mm resolution. The value of ζ (the linear translation in the direction of the workpiece’s axis of symmetry) was measured with the machine built in 0.01 mm resolution measurement system. This way the value of ξ was measured after every 0.1 millimetre.

Figure 2. shows the layout of the workpiece and tool holding systems (a) and the layout of the measurement system (b).

Table 1. Cutting conditions and technological parameters:
inclination angle, workpiece diameter, depth of cut, feed rate, rotation frequency

<table>
<thead>
<tr>
<th>Condition</th>
<th>λs [°]</th>
<th>dw [mm]</th>
<th>ap [mm]</th>
<th>f [mm/for]</th>
<th>n [for/min]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>30</td>
<td>69</td>
<td>1,0</td>
<td>0,05</td>
<td>900</td>
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<tr>
<td>2.</td>
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<td>63</td>
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<td>3.</td>
<td>45</td>
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Fig. 2. Workpiece- and tool-holder system (a) and measurement method (b)
3. EXPERIMENTAL RESULTS AND DISCUSSION

The resulted surfaces of the cutting experiments are shown in Figure 3. To achieve proper observation after the axial feed of the tool was stopped while the spindle speed remained the same for 5 sec. After this method the surface is ready to be measured.

As it was expected when the inclination angle is higher the length of the surface in the direction of ζ is lower. Further experiments are needed to analyse the quality of the machined surface. However, we can see that the roughness of the surface is better if the tool had a lower inclination angle.

![Fig. 3. Machined surface (depth of cut: 1 mm. inclination angle: a) 30°, b) 45°, c) 60°)](image)

To compare the theoretical and the real surface, the measurements were made on three curves of each surface. Therefore the random differing values of the measurement can be avoided. The comparison graphs can be seen in Figure 4. The theoretical curves are plotted by a continuous line; the measured points are illustrated as discrete points. Not all of the measured points are shown for better comparison. The plotted points are shown evenly divided on the measured length.

To plot the theoretical curve the following values were given for the parameters in equation (1): the angular frequencies of the tool and workpiece is zero; the value of r parameter is zero, because the cutting tool has a linear edge; therefore the centre distance of the tool and the workpiece is equal to the half of the workpiece’s diameter.

The ζ directional translation of the theoretical curve was determined therefore the theoretical and experimental values can be plotted in one graph for comparison. These values were gained by fitting the theoretical curves to the measured values by minimalizing residual errors.
Fig. 4
Diameter change of machined surface: theoretical and measured curves (angles: $a$: 30°, $b$: 45°, $c$: 60°; depth of cuts: 1: 1.00 mm, 2: 0.50 mm)
4. CONCLUSIONS

Based on the comparison of the theoretical curves and the measured values we can state that the curve almost perfectly fits the surface generated by the cutting process (the deviation is below the resolution of the measure). Therefore we can continue further our investigations by describing more complex cases. By using the equation the theoretical values of the surface roughness can be defined and the theoretical cross-section of the chip can be described. After that the optimal inclinational angle for skiving or the optimal helix angle for rotational turning can be determined. Furthermore, we can say that the machining of shaft shoulders is not possible in skiving, however with the application of rotational turning it can be achieved.

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