EFFECTS OF SELECTED CUTTING PARAMETERS ON SURFACE ROUGHNESS IN SIDE MILLING

The aim of this contribution is an analysis of the influence of selected cutting parameters on resulted surface integrity of aluminium alloy machined by side milling. The observations and conclusions are mainly concentrated on the effect of depth of cut and cutting speed with a set of constant parameters, such as feed rate, workpiece material and the tool. The experiments were carried out by two methods of milling: the down-milling and up-milling. The resulted values were compared. This knowledge can help in further optimization of cutting parameters in the side milling of aluminium alloys.

Key words: cutting parameters, surface roughness, side milling, aluminium

1. INTRODUCTION

Development of new metal materials, improvement of cutting tools geometry, growing cutting speeds and increased requirements for better quality and integrity of the finished surface as well as stringent environmental regulations expressively influence the development trends in metal machining.

Milling operations are one of the most widely used processes in the machining of metals. Like face milling, end milling can easily machine a workpiece surface into a flat surface. One machining method of the end milling operations, widely used for mold die and machine parts, is side milling. It uses a peripheral cutting edge of an end mill to achieve a relatively broad-range face milling on the vertical wall of a workpiece.

The process of generating a milled surface is affected by several factors, some of them, namely the cutting conditions and tool geometry, are of primary importance in determining the quality of a milled surface.

Past research studies on milling have focused on the different aspects of tool performance, forces involved in the process and the influence of cutting parame-

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ters on the resulting surface roughness [e.g. 1, 3, 5]. In this contribution, the influence of two main cutting characteristics on resulted surface roughness in side milling of an aluminium alloy has been investigated.

2. SURFACE ROUGHNESS IN MILLING

One of the important factors to evaluate the machining quality for the machining process is surface roughness. Roughness plays a significant role in determining and evaluating the surface quality of a product. Because of the fact that surface roughness affects the functional characteristics of products such as resisting fatigue, friction, wearing, light reflection, heat transmission, and lubrication, the product quality is required to be at the high level [4].

Surfaces produced by a given type of machining or finishing operation vary widely in their roughness. Fig. 1 shows the typical range of the roughness average values that can be produced by common manufacturing processes.

![Roughness Chart]

Fig. 1. Surface finish roughness in machining [2]
Rys. 1. Chropowatość powierzchni po obróbce skrawaniem [2]

The quality of a machined surface is becoming increasingly more critical for satisfying the demands for superior component performance and reliability. Surface integrity must be considered in the manufacture of highly stressed components used in applications involving human safety, high cost and predictable component life.

The final surface roughness in milling is influenced by many factors [6]:

a) machine tool (stability, machining environment, cutting fluid, technical conditions, power, stiffness),

b) cutting tool (stability, cutter geometry, tool wear, cutting material, chips formation, tool temperature),
c) workpiece (clamping, workpiece material and character, machinability, tolerances),
d) stiffness and strength of machine tool – cutting tool – workpiece – fixture system,
e) cutting parameters (cutting speed, feed, depth of cut),
f) milling method and others.

3. MATERIALS AND METHODS

In order to study the effects of cutting parameters on surface roughness, series of experiments over a range of cutting conditions are conducted.

The test specimens of 6 pieces were cut according to the drawing in Fig. 2. The opposite sides of each specimen were machined flat, one side by up-milling operation and the second one by down-milling operation.

The selected workpiece material is aluminium alloy AlMgSi1. Aluminium alloys with magnesium and silicon are complex alloys with small amount of manganese, iron and copper [7].

This type of material is suitable for forming and welding operations and has good corrosion resistance. It has been selected for study due to its extensive use in the manufacturing industry, such as aircraft parts, automobile parts, and small
engine parts. The chemical composition of specimen material (DIN 1725-3.2315) is described in Table 1.

<table>
<thead>
<tr>
<th>Si</th>
<th>Mg</th>
<th>Mn</th>
<th>Fe</th>
<th>Cr</th>
<th>Zn</th>
<th>Cu</th>
<th>Ti</th>
<th>Other</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.7–1.3</td>
<td>0.6–1.2</td>
<td>0.4–1</td>
<td>0.5</td>
<td>0.25</td>
<td>0.2</td>
<td>0.1</td>
<td>0.1</td>
<td>0.05</td>
</tr>
</tbody>
</table>

The end mill applied as the cutting tool is tungsten carbide with its major specification as: diameter of 16 mm, 4 flutes and tool length of 42 mm. Fig. 3 shows the schematic diagram and diagram and the image of the side of the side milling operation. The tests have been carried out on a CNC machining centre using the up and down milling operation with a cutting fluid (TRIM C370).

![CNC Machine](image)

**Fig. 3. Clamping and side milling of the specimen**

**Rys. 3. Mocowanie i frezowanie próbki**

The equipment applied to surface roughness measurement is a Mahr Perthometer S2 surface roughness tester. The quantitative evaluation of surface roughness in this study is made by choosing the average surface roughness $Ra$ as the surface finish parameter due to its popularity in industry.

Variable values of cutting parameters are described in Table 2. Constant values are: radial depth of cut $a_r = 5$ mm, feed per tooth $f_z = 0.05$ mm.
Table 2

Cutting parameters of machined specimens
Parametry skrawania obrabianych próbek

<table>
<thead>
<tr>
<th>Specimen</th>
<th>S 1</th>
<th>S 2</th>
<th>S 3</th>
<th>S 4</th>
<th>S 5</th>
<th>S 6</th>
</tr>
</thead>
<tbody>
<tr>
<td>$a_p$ [mm]</td>
<td>20</td>
<td>25</td>
<td>30</td>
<td>20</td>
<td>25</td>
<td>30</td>
</tr>
<tr>
<td>$n$ [min$^{-1}$]</td>
<td>4000</td>
<td>4000</td>
<td>4000</td>
<td>6000</td>
<td>6000</td>
<td>6000</td>
</tr>
</tbody>
</table>

4. RESULTS AND DISCUSSION

Experimentally determined values of surface roughness expressly showed, that according to given circumstances, the down-milling is more accurate method than up-milling. This fact has been verified by the values in F-test.

![Graph showing roughness Ra for up and down milling](image)

Fig. 4. Relation between surface roughness and type of milling
Rys. 4. Zależność chropowatości powierzchni od metody frezowania

As shown in Fig. 5, the influence of depth of cut on surface roughness had an expected behaviour. The roughness increases with increasing depth of cut by the both milling methods. But there are some irregularities. Although, the confidence bars are by up-milling crossed over by each value of depth of cut, the average values are in sufficient distance from each other.
The values by the depth of 20 mm signify the difference. By the next two values are the confidence bars expressively crossed over. This fact is markedly influenced by the measurement of surface roughness on specimen 2.

The graph in Fig. 6 presents incongruited results. It confirms the fact, that optimal selected cutting speed importantly influences the quality of finished surface.

By the cutting speed of 200 m-min⁻¹, the confidence bars are crossed over, but average value of down-milling is on the edge of interval of up-milling. Machining of aluminium alloy by this cutting speed is very unstable and by this type of tool, material and feed rate also very unsuitable. The cutting speed of 300 m-min⁻¹ improves the surface integrity.
Fig. 7. Relation between surface roughness and type of milling, depth of cut and cutting speed
Rys. 7. Zależność chropowatości powierzchni od metody frezowania, głębokości frezowania i prędkości skrawania

Fig. 7 represents a complex analysis of the influence of each factor onto resulted surface integrity. It demonstrates the fact, that a lower cutting speed unfavourably influences the quality of surface finish by the both types of milling.

Moreover, the values in up-milling in depth of 25 mm shows better surface quality than in down-milling, so we can conclude that the cutting parameters by this specimen are chosen inappropriately. By cutting speed of 300 m-min⁻¹ we can fully benefit from advantages of down milling, where resulted surface quality is more then 46% higher than in up milling.

5. CONCLUSION

The result of the experiments has shown the importance of proper cutting parameters selection in machining of aluminium alloys. The parameters should be designed optimally in order to reach the prescribed quality of surface finish by minimal costs. In the contribution, the influence of selected cutting parameters on surface integrity after side milling of aluminium alloy has been analyzed. Surface roughness measurements showed that increasing cutting speed resulted in lower roughness values, and increasing depth of cut in higher roughness values.

Down-milling operation is more suitable for this type of tool, workpiece material and cutting parameters, because we achieved better surface integrity. Average roughness achieved by the experiment was ranging from 0,261 µm to 1,931 µm.
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