EFFECT OF CUTTING TOOL MICROGEOMETRY ON THE ALUMINIUM ALLOY MACHINING PROCESS

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The paper deals with the determination of the effect of controlled tool cutting edge preparation on AlCu4SiMg (EN AW - 2014) aluminium alloy machining process as well as on tool wear. To conduct the experiment, the authors have chosen longitudinal turning technology and cutting geometry of indexable cutting inserts marked CCGT 120408F-AL, and proposed suitable cutting conditions. By controlled tool cutting edge preparation (brushing), the desired edge rounding of indexable cutting inserts of 0–5 µm, 10–15 µm and 20–25 µm has been achieved. Depending on the radius r_n and the roughness of the cutting edge, the course of wear of the cutting inserts, the flow direction of the shaped material and its effect on the formation and size of the build-up were monitored during machining of the aluminium alloy.

KEYWORDS

Aluminium Alloys; Machining; Microgeometry; Cutting Edge; Build Up Edge.

1 INTRODUCTION

The term "cutting tool microgeometry" has been increasingly used in the production of tools. This term includes geometric shapes that characterize the tool edge, tool surface roughness, as well as microscopic defects. Typical defects such as burrs, micro cracks, surface defects, and stresses that occur during the production of cutting tools can cause premature edge chipping, machining instability and wear, and can negatively affect the cutting tool function during machining. The cutting tool is subjected to intense mechanical and thermal loading during machining, especially on surfaces that are in direct contact with the machined material. For this reason, the design of precision cutting tools must particularly focus on the cutting edge and its vicinity. Contribution by Hronek et al. [Hronek 2017] – full text deals with the issue of microgeometry of the cutting tool and its influence on the machining process, especially for aluminum alloys.

One of the most commonly used cutting edge preparation is cutting edge rounding. This preparation allows for increased strength and resistance of the cutting edge to stress, reducing inequalities on its surface and preventing micro cracks and pores. Depending on the selected rounding method, a cutting edge radius of up to several tens of micrometres can be achieved. Thus, the rounding of the cutting edge affects the machining process, the amount of heat generated and the force stress, the cutting ability of the tool, the formation of chips and their discharge, and the integrity of the new surface (surface roughness, reinforcement and residual stresses in surface and sub-surface layers). Publication *Cutting edge preparation of precision cutting tools by the application of micro-abrasive jet machining and brushing* by C. J. Rodriguez describes in more detail the field of cutting geometry, its modification and factors affecting the durability of the cutting tool. [Rodríguez 2009] – full text

The technology of controlled cutting edge preparation should also be in line with the cutting tool macrogeometry. The machining process, the cutting ability of the tool, and the integrity of the machined material are affected to a certain extent by the angles of the rake, flank and cutting edge, the angle of the main cutting edge and their sizes. For this reason, when designing a new cutting tool geometry, additional edge preparation technology and coating, it is important to adopt a comprehensive approach and take into account multiple effects simultaneously influencing the machining process. [Hronek 2017, Mrkvica 2015] – full text

2 EFFECT OF THE CUTTING EDGE ROUNDING ON THE MACHINING PROCESS

The technology of controlled cutting edge preparation is currently an integral part of the manufacturing process of precision tools in order to increase their utility. In terms of machining, it involves the ability to efficiently remove the chip from the surface of the machined material, achieving resistance to mechanical stress, brittle fracture, and tool edge durability. To determine the effect of the cutting tool geometry on the machining process, the magnitude of wear and its course are among the basic indicators.[List 2005] – full text

The rounded edge has a significant effect not only on the tool, but its size also affects the machining process. Rounding the cutting edge results in a negative angle of the rake on the tool edge. Therefore, the final surface of the machined surface is not cut but formed. In addition, the rounded edge also affects the formation of chips, causes increase in temperature and cutting forces, influences the integrity of the machined surface (roughness, hardening and residual stress), and wear resistance of the tool (see Fig. 1). These changes during machining are related to the change in the magnitude of plastic deformations, especially tertiary plastic deformations. [Náprstková 2016] – full text

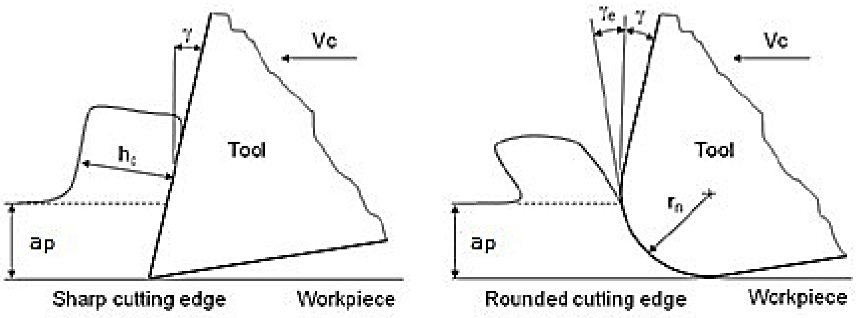


Figure 1. Theoretical assumption of cutting edge geometry design [Rodríguez 2009] – full text

The intensity of tertiary plastic deformation during machining is affected by cutting edge radius r_n and position of the stagnation point S. The existence of this point in the cutting zone determines the flow direction and the volume of material that goes over the tool edge and transforms into a chip, as well as the amount of material which goes under the tool edge and becomes deformed into the newly machined surface of the material, see Fig. 2. When machining plastic and tough materials (non-ferrous metals, stainless steels and special alloys), the intensity of plastic deformation is together with the position of the stagnation point S affects the volume of material that sticks to the cutting edge (BUE).

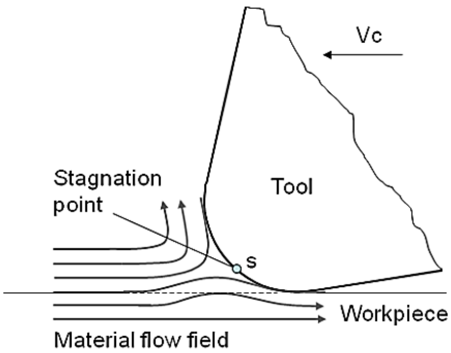


Figure 2. Concept of stagnation point [Rodríguez 2009] – full text

3 EXPERIMENTAL PART

The experimental part aims to determine the effect of the tool edge rounding on the machining process of the AlCu4SiMg – EN AW-2014 aluminium alloy. CCGT 120408F-AL indexable cutting inserts with varying edge radius were chosen as the cutting tool (see Fig. 3). By means of mechanical preparation of the "Nylon Abrasive Filaments" cutting edge, a cutting insert radius of 0–5 µm, 10–15 µm and 20–25 µm was achieved. The preparation was carried out by brushing, a method that uses nylon cylindrical brushes with a circular cross-section of fibres to modify the tool edge. Osborn brushes with a SiC abrasive (120 µm grain size) were used for rounding the cutting edge with this method. This grain size is used for smaller rounding and also where it is necessary to achieve a low surface roughness without defects. [Hronek 2016] – full text

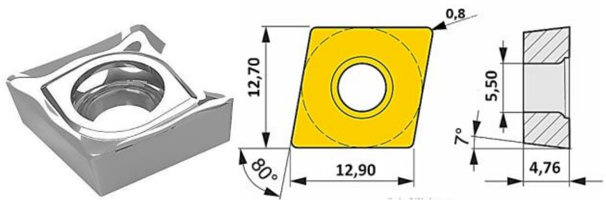


Figure 3. Geometry of cutting insert CCGT 120408F-AL [PRAMET TOOLS 2016] – full text

Rounding of 0–5 µm is considered a sharp cutting edge and is intended for tools suitable for machining non-ferrous metals and their alloys. The sharp edge achieves minimal deformation of the cut-out layer, reduces build-up and decreases the cutting forces. However, its disadvantage is the low relative strength and the possibility of spontaneous preparation or chipping upon first contact with the material. For tools with rectified cutting edge, (see Fig. 4, Table 1.)

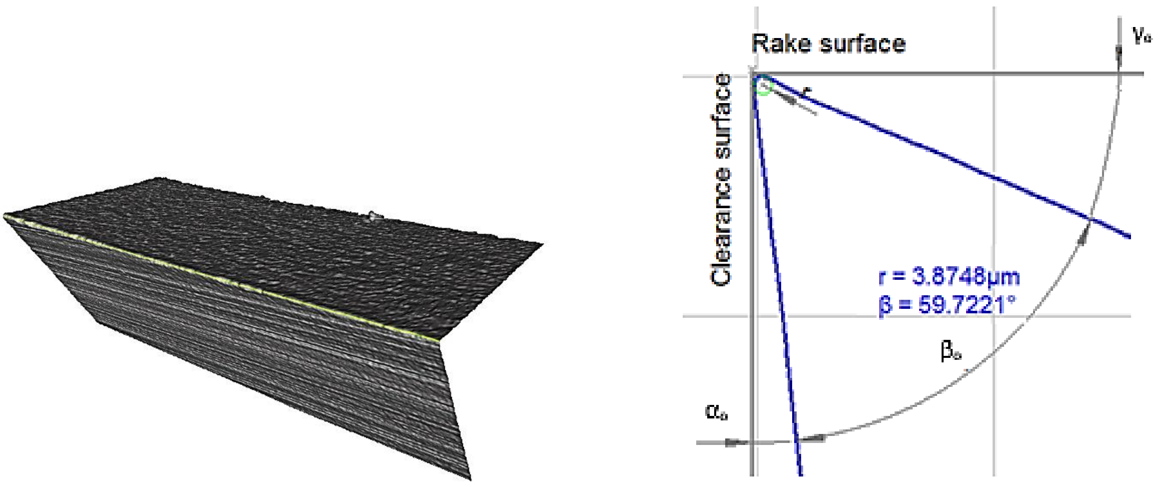


Figure 4. Cutting edge of used inserts

Edge radius		
0–5 µm	10-15 µm	20-25 µm
r_n = 3.87 µm	r_n = 10.91 µm	r_n = 21.01 µm
α_o = 7.02 °	α_o = 6.98 °	α_o = 6.94 °
β_o = 59.72 °	β_o = 61.36 °	β_o = 59.99 °
γ_o = 23.25 °	γ_o = 21.65 °	γ_o = 23.06 °
K = 0.65	K = 1.20	K = 1.31
Ra = 0.73 µm	Ra = 0.17 µm	Ra = 0.28 µm
Rz = 3.66 µm	Rz = 1.06 µm	Rz = 1.01 µm

Table 1. Cutting edge parameters

In order to assess the impact of cutting edge microgeometry on the machining process of AlCu4SiMg (EN AW - 2014) aluminium alloy, the cutting conditions were chosen to meet the requirements for easy chip formation and removal, cutting tool durability, high material removal, and the precision and quality of the machined surface, see Table 2. The aluminium alloy AlCu4SiMg (EN AW - 2014) is used for high-strength structural elements with a strength limit R_m = 440 MPa, yield strength $R_{p0,2}$ = 380 MPa, elongation A_5 = 6 % and Brinell hardness HB = 135.

v_c [m.min^{-1}]	f [mm]	a_p [mm]
1 000	0.2	2

Table 2. Cutting conditions chosen for machining the alloy

Aluminium alloy machining took place under constant cutting conditions, with great emphasis on cutting speed and feed rate. For the machining of this type of material, it is common to choose a high cutting speed with respect to the course of wear of the cutting tool, chip formation as well as feed rate. The selected feed rate is smaller than the cutting tool tip radius r_ε, which had a positive effect on the roughness of the machined surface during the experimental machining. On the other hand, the feed rate is several times greater than the range of the rounded edge radii. Still, based on the wear measurement and the multiple magnification of the tool edge by electron microscopy (EDX), we can determine the effect of the radius of the radius on the course of the tool wear, see Table 3.

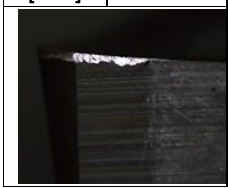
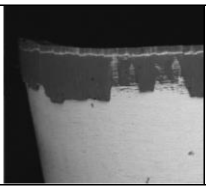
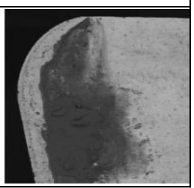
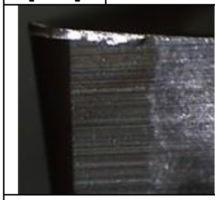
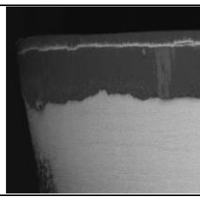
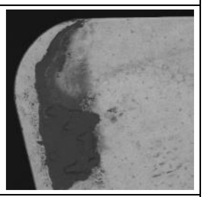
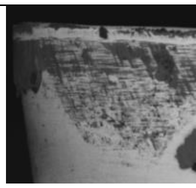
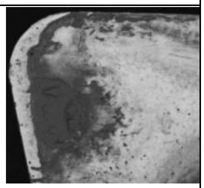
Cutting insert geometry		CCGT 120408F-AL	
Edge radius r_n = (0 – 5) µm			
Clearance A_α			Rake face A_γ
$VB_{b\,max}$ [mm]	0.18	Enlarge 500x	
			
Edge radius r_n = (10 – 15) µm			
Clearance A_α			Rake face A_γ
$VB_{b\,max}$ [mm]	0.22	Enlarge 500x	
			
Edge radius r_n = (20 – 25) µm			
Clearance A_α			Rake face A_γ
$VB_{b\,max}$ [mm]	0.21	Enlarge 500x	
			

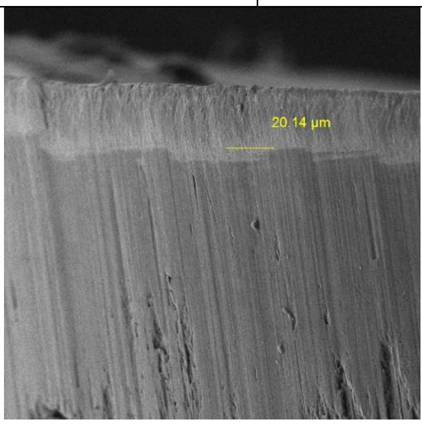
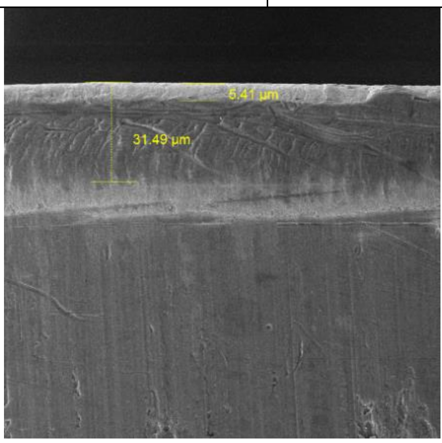
Table 3. Cutting tool wear inserts after machining

4 EVALUATION OF THE MACHINING PROCESS

Aluminium alloy machining was very problematic under the given cutting conditions. The high thermal conductivity and the adhesion tendencies of the material were the cause of a change in chip formation and the formation of build-up on the tool edge. The build-up formed along the entire main edge at a distance corresponding to the depth of cut, and also adhered to the rake and flank of the tool in the form of thin glossy layers. The nature and intensity of the built-up layers of the deformed material on the tool can be seen in the individual pictures, see Table 4.

To further determine the effect of the rounded edge radius on the aluminium alloy machining process, chip formation during machining was studied. The study was based on stress-strain relations and the size of the contact zone between the tool edge and the material layer. The existence of a rounded cutting edge resulted in "current field" and "stagnation point" in the place of chip formation. Around this point, there was a controlled flow of material in two directions. The flow direction was affected not only by the radius of the rounded edge but also by the K- factor determining its symmetry. By determining the K-factor for the cutting inserts tested, it was found that in the case of a sharp radius the shape is "WATERFALL" while in the other two cases the shape is "TRUMPET". For the TRUMPET shape (K<1), the curvature was bigger at the end the profile that connects with the clearance surface and the curvature was smaller at the end of the profile that connects with the rake surface. In the case of WATERFALL geometry (K>1), the curvature was bigger at the end of the profile that connects with rake surface and the curvature was smaller at the end that connects the clearance surface. The radius and its symmetry therefore significantly affected the direction of material flow, the intensity and direction of force, the number of deformed layers, the residual stresses in the surface layers of the material and finally the durability of the tool.

By enlarging the cutting edge using EDX microscopy (see Table 4), it has been shown that the size of the deformed layers of the machined material and their character for the individual cutting inserts is different. For cutting inserts with edge radius of 0–5 µm, the layers were building up until a continuous thin layer of deformed material was formed across the entire tool edge. However, based on the assumptions for a very sharp tool geometry, the material should have built up very rarely. Possible causes could include the symmetry of the radius and the factor K<1 influencing the force effect and the material flow direction under the tool flank. The second reason for adhesion of the layers of machined material was that edge that was not rectified had a rougher surface, as evidenced by higher measured values of roughness parameters, and such a rough surface became a suitable base for the adhesion of deformed layers of machined material. For cutting inserts with a larger radius, the material flow area narrowed and the outgoing material began to accumulate in particular in front of the cutting edge. With the radius of 10–15 µm, the material stuck to the cutting edge was at two levels separated by a thin light line. This is the transition from the edge radius to the flank. The light area marks the base substrate of the tool material, to which less machined material gets stuck due to radius symmetry, uniform distribution of force, and better surface roughness. The bottom built-up layers of the material are the result of deformation after spring-back of the material and the abrasion of the tool flank against the machined surface. A visible change in the nature of the adhesion of the machined material occurred with the use of a cutting insert with a radius of 20–25 µm. In this case, individual layers were welded on each other on the edge radius and formed a build-up. The formation of build-up in this point is evidenced by the presence of the stagnation point S and a current field that determines the direction of material flow in the cutting zone.

<table>
<tr><th colspan="2">Major flank A_α – magnified 2000x</th></tr>
<tr><td>r_n [µm]</td><td>(0–5)</td></tr>
<tr><td>width of built-up layer [µm]</td><td>20.14</td></tr>
<tr><td colspan="2">
</td></tr>
<tr><td>r_n [µm]</td><td>(10–15)</td></tr>
<tr><td>width of built-up layer [µm]</td><td>31.49</td></tr>
<tr><td colspan="2">
</td></tr>
<tr><td>r_n [µm]</td><td>(20–25)</td></tr>
<tr><td>width of built-up layer [µm]</td><td>20.14</td></tr>
</table>

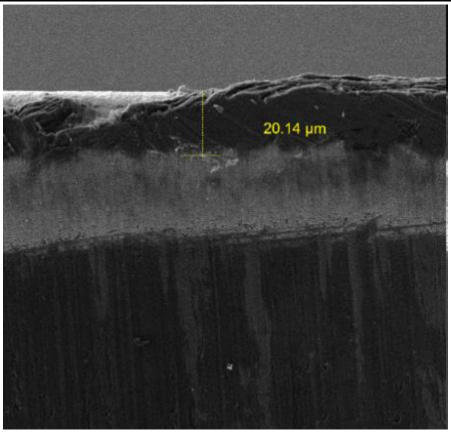


Table 4. Formation of a build-up on the tool cutting edge

5 CONCLUSIONS

The aim of the experimental activity was to determine the effect of the tool cutting edge radius on the process of aluminium alloy machining. Aluminium alloy designated AlCu4 SiMg (EN AW - 2014) was proposed for this purpose. This alloy has specific properties that make it suitable for the manufacture of high-strength structural elements used especially in industry. However, the process of machining aluminium and aluminium alloys is accompanied by a number of undesirable phenomena. One of them is the strong adhesion of material and the formation of build-ups. The ability of material to adhere to the surface of tools and form a build-up affects cutting tool geometry, chip formation, the extent of wear and life of the tool, and the quality of the machined surface.

As the cutting tool, non-coated cutting inserts designated CCGT 120408F-AL were selected for the machining of the aluminium alloy. These cutting inserts have a very sharp cutting geometry suitable especially for the machining of non-ferrous metals. In order to increase the cutting properties, a controlled preparation of the cutting edge microgeometry was carried out by brushing the cutting inserts. The aim was to achieve a higher cutting edge strength, chipping resistance, and lower surface roughness due to adhesion of machined material. The use of nylon brushes with circular cross-section and SiC abrasive with a 120 µm grain size resulted in cutting edge radius of 0–5 µm, 10–15 µm and 20–25 µm in the selected cutting inserts. Using an optical microscope, the nominal edge radius, edge angles and surface roughness parameters of the cutting edge were measured. At the same time, in order to determine the position of the stagnation point *S*, material flow and the force effect distribution, the K-factor indicating the symmetry of the edge radius was determined.

The experimental part of the alloy machining was carried out under predetermined cutting conditions. Emphasis was placed on the cutting speed due to its effect on the intense creation of build-up in machining and change of chip formation. Photographic documentation of wear and multiple magnification of tool edges using electron microscopy have been used to perform a detailed study of the chip and build-up formation. Based on this study, the effect of the edge radius on the machining process and the wear of the cutting tool was determined.

As a result, it was found that a very sharp radius was unsuitable, contrary to the initial assumption. In this case, the cutting edge was covered with a continuous layer of deformed material, which protected the cutting edge from wear until a certain point, but its unstable part could cause premature chipping of a very sharp edge. A significant role in the formation of built-up layers of machined material was played by the cutting edge's WATERFALL shape that curved the material flow lines under the tool flank, and by the roughness of the surface of the cutting edge allowing for their easy adhesion. Partial changes in the nature of adhesion of the deformed layers of machined material were observed in cutting inserts with a radius of 10–15 µm. The edge with this radius has a higher relative strength and the radius symmetry with better surface roughness had a positive effect on the amount and size of the built-up layers. For cutting inserts with a radius of 20–25 µm, the position of the stagnation point S and the nature of build-up of deformed material layers is evident from the machining process and the photo-documentation of the tool edge. With the increasing radius of the cutting edge, the area for the flow of material changed and the material began to accumulate in front of the tool edge. This is also evidenced by the fact that in the case of a cutting insert with a radius of 20–25 µm, it is not a continuous layer, but rather several welded layers of machined material.

The study of chip and build-up formation is a very problematic area, both in terms of machined material and the setting of cutting conditions. However, by properly preparing the cutting edge microgeometry, this process can be affected to a certain extent. Nevertheless, it is also necessary to take into account other accompanying machining phenomena that may be affected by the preparation of the cutting edge microgeometry. In particular, these include a change in chip formation, the extent of plastic deformations, the force and heat load, wear and durability of the tool, the parameters of the integrity of the machined surface such as surface roughness and hardening, the size and nature of residual stress, etc. In most cases, however, the preparation of the cutting edge microgeometry has a positive effect, which implies its justification and importance.

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