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Enhancement of Surface Integrity in Turning of Particle Reinforced Aluminium Matrix Composites by Tool Design

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Abstract

Particle reinforced aluminium matrix composites (AMCs) are high-strength lightweight materials consisting of a comparatively soft aluminium alloy and hard embedded ceramic particles. The high hardness of the particles results in excellent abrasion resistance. However, this property lends poor machinability involving high tool wear and surface imperfections on the workpieces. For this reason, CVD diamond tipped indexable inserts were used for turning AA2124 with 25 % volume proportion of SiC particles. The surface integrity is influenced by the tool geometry, which affects the stress condition in the shear zone. In the research described the influence of modified corner geometries and the width of flank wear land were investigated. The results showed that surface roughness values can be decreased by using tools with a wiper geometry. An increasing flank wear land width of the inserts led to a reduction of the surface imperfections.

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Keywords: Surface integrity, Tool geometry, Turning, Aluminium matrix composites

1. Introduction

The advancement of operational systems often aims at an improved performance while increasing the resource and energy efficiency. This can be realised by using lightweight materials, for example composites. An important advantage of composites is the opportunity for a predefined creation and combination of specific material properties. One type of composites used increasingly are particle reinforced aluminium matrix composites (AMCs). They are applied for automotive and mechanical engineering, railway vehicle manufacturing and aeronautics. Such AMCs consist of a comparatively soft aluminium alloy and hard embedded ceramic particles. The advantages of AMCs in comparison to

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aluminium alloys are an increased yield, ultimate tensile and fatigue strength. Furthermore, the abrasion resistance is significantly higher. However, these mechanical properties result in low machinability. The high hardness of the ceramic particles causes very high tool wear. Another problem is the heterogeneity of the composite, which leads to changing conditions in the shear zone. Surface imperfections arise in machining of AMCs due to the different mechanical properties of the components. Typical imperfections are voids, cracks and fractured particles [1-3]. The structural durability of mechanical components is influenced by surface roughness and surface imperfections. Consequently, both have to be reduced in order to achieve a high reliability of the components. Dabade et al. showed that a reduction of the roughness values can be obtained by using inserts with wiper geometry [1].

This article presents detailed approaches for generating high-quality surfaces by using tools with different corner geometries and flank wear land widths in turning of particle reinforced AMCs.

Nomenclature

f	feed	Rz	surface roughness depth
l_{te}	length of trailing edge	Rz_{theor}	theoretical surface roughness depth
r_{wg}	radius of wiper geometry	VB	width of flank wear land
r_{ε}	corner radius		

2. Experiment

The aluminium matrix composite used for the investigations consists of the aluminium alloy AA2124 and 25 % volume proportion of SiC particles. The characteristic size of these particles is in the range of two to three microns. The composite is manufactured by a special powder metallurgy route. After a high energy mixing process the powder is compacted by hot isostatic pressing [4]. A subsequent extrusion process and a heat treatment T4 enhance the mechanical properties of the material. Figure 1 shows the microstructure of the AMC in the cross and longitudinal direction. The specimens for turning tests had a diameter of 25 mm and they are 20 mm long.

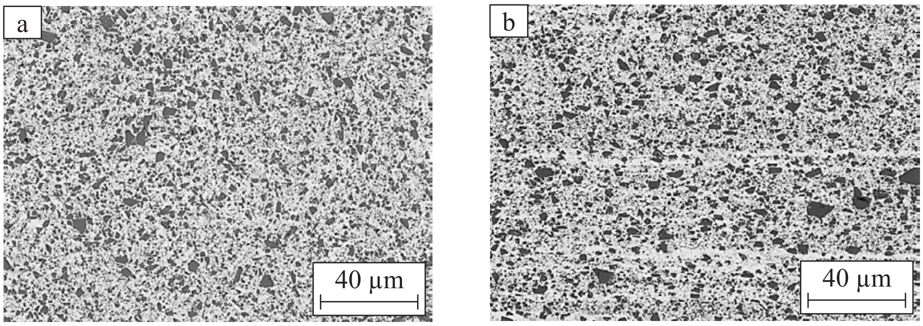

Fig. 1. (a) Microstructure of the AMC in cross direction; (b) Microstructure of the AMC in longitudinal direction

Because of the high hardness of the silica particles, CVD diamond tipped inserts were used. The tips are manufactured by laser beam machining, which results in very sharp cutting edges with an average radius of approximately 2 µm. Inserts of the type CCGW 09T304 were used for the tests. The tools have an included angle of 80° and a clearance angle of 7°. The corner radius is 0.4 mm. The tool cutting edge angle of 95° enables cylindrical and face turning. In turning surface is usually generated by the corner radius of the tool, which leads to the theoretical surface roughness depth

$$Rz_{theor} \approx \frac{f^2}{8 \cdot r_\varepsilon} \quad (1)$$

For small corner radii and high feeds this results in a high surface roughness depth. A reduction of the surface roughness values can be achieved by a smaller feed or a variation of the tool geometry. Because of the specified geometrical form of the workpieces the maximum corner radius is often limited. In order to reduce the roughness values of the machined surface without changing the corner radius inserts with a modified form called wiper geometry were used. There are several variants of a wiper geometry. Figure 2 presents the standard form of the insert and two different variants of the wiper geometry used for the experiments. Inserts with a wiper geometry in the form of a trailing edge have a minor cutting edge, which is angled near the corner radius in order to account a minor cutting edge angle of 0°. This region of the cutting edge generates the surface. For a feed smaller than the length of the trailing edge the theoretical roughness is 0 µm. In the experiments cutting inserts with different lengths of the trailing edge (0.35 mm, 0.5 mm, 0.8 mm) were used. Another variant of the wiper geometry is a comparatively large radius. The advantage of this geometry is a lesser susceptibility to tolerances of the cutting edge angle. Inserts with different radii of the wiper geometry varied in the range of 1.25 mm to 40 mm were applied.

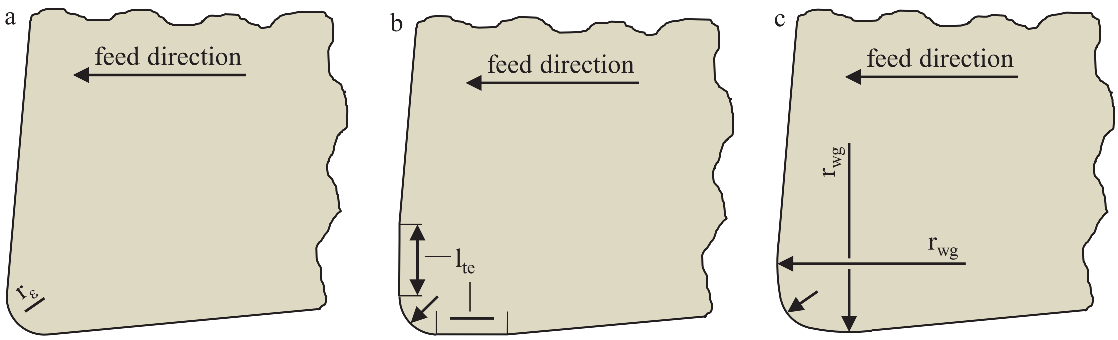

Fig. 2. (a) Standard tool geometry; (b) Wiper geometry with trailing edge; (c) Wiper geometry with large radius

A common problem in cutting of aluminium matrix composites is the formation of surface imperfections, for example voids and microcracks [5]. Object of investigation is the influence of tool wear on surface integrity. The dominant wear form is flank wear by abrasion, which is characterised by the flank wear land width. Its influence on the surface integrity was tested with one tool, beginning with a new tool up to a flank wear land width of approximately 200 µm. In order to achieve a comparatively fast generation of the tool wear, a more abrasive AMC was machined. For the investigations in the surface integrity the AMC described was used.

The cutting tests were carried out on a precision lathe with an integrated three-axis dynamometer. The specimens were clamped on a mandrel in order to machine the complete length. The cutting speed was 200 m/min and the depth of cut 0.5 mm. These parameters were kept constant for all cutting tests. The feed was varied between 0.05 mm and 0.25 mm for the experiments to investigate the influence of different corner geometries on the surface integrity. The investigations in the influence of the tool wear were done with a feed of 0.1 mm. Each parameter combination chosen was tested thrice. The experiments were carried out with emulsion cooling. During the tests cutting force components were recorded. Surface integrity is identified by roughness measurements with a stylus instrument and SEM micrographs. For surfaces generated with an insert with different wear conditions surface imperfections were evaluated by cross sections. Furthermore, for several specimens residual stresses in the aluminium phase of the matrix were determined by an X-ray diffraction analysis.

3. Results and discussion

3.1. Influence of tool corner geometry on surface integrity

The influence of the tool corner geometry and the feed on the surface roughness is represented in Figure 3. This diagram reveals that surface roughness values increased with increasing feed. This result is in agreement with Equation (1). However, the surface roughness values for the specimens machined with the tool with a trailing edge length of approximately 0.8 mm showed an inverse trend. These values decreased slightly with an increase of the feed. This can be explained by an imperfection of the trailing edge of the tool, which was transferred to the specimens' surfaces more often for small feeds.

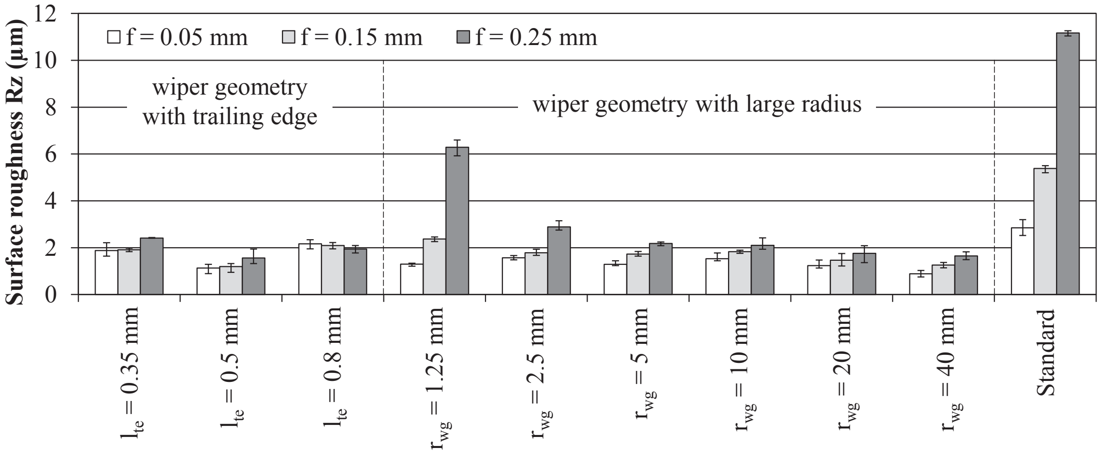

Fig. 3. Influence of tool corner geometry and feed on the surface roughness

The lowest surface roughness values were generated by using tools with a trailing edge and a large wiper radius respectively. In tools with a wiper radius, the intersection of the wiper radius and the straight part of the minor cutting edge is not tangential in order to assure that the surface is only generated by the wiper radius. Consequently, the theoretical surface roughness can be calculated by Equation (1) when corner radius is substituted by the wiper radius. The experimental surface roughness values obtained with the tool which has a wiper radius of 1.25 mm in combination with feeds of 0.15 mm and 0.25 mm are in the range of the theoretical roughness. This applies to the surfaces generated by the tool with a wiper radius of 2.5 mm and a feed of 0.25 mm. For tools with larger wiper radii or trailing edges calculated surface roughness values are significantly smaller than the measured values. This can be attributed to differences between the ideal and the real tool geometry. The imperfections of the inserts are in the range of approximately 2 µm. For the specimens machined with the standard tool and feeds of 0.15 mm as well as 0.25 mm measured surface roughness values are lower than the calculated values. This can be explained by the engagement of the minor cutting edge because of the small minor cutting edge angle of 5°. Figure 4 shows SEM micrographs of surfaces generated with different tools. All surfaces exhibit imperfections in the form of voids or grooves. Surfaces generated by tools with a trailing edge have less voids than the other surfaces. The forces measured during the cutting tests increased with an increase of the feed, but they were almost independent of the specification of the wiper tool geometry. For a feed of 0.15 mm the mean cutting forces were in the range of 97 N to 101 N, the mean passive forces in the range of 25 N to 32 N and the mean feed forces in the range of 33 N to 36 N.

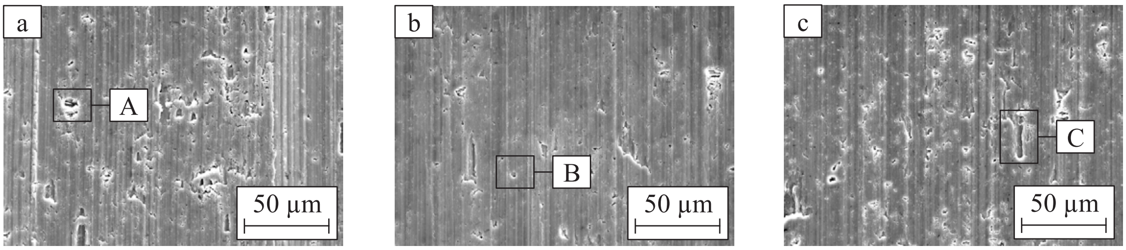

Fig. 4. SEM micrographs of specimens machined with tools with different corner geometries and a feed of 0.25 mm; (a) Standard geometry; (b) Wiper geometry with trailing edge (l_{te} = 0.5 mm); (c) Wiper geometry with large radius (r_{wg} = 10 mm); Examples for surface imperfections: A: Large void; B: Small void; C: Groove

3.2. Influence of tool wear on surface integrity

The dominant wear form was flank wear due to abrasion caused by the hard ceramic particles. Flank wear can be estimated by the width of flank wear land. Furthermore, a displacement of the cutting edge in the direction of the rake and the flank face occurred. The cutting edge radius was not changed markedly by the tool wear. A slight built-up edge formation could be seen on the rake face of the tool.

Investigations in the influence of the tool wear on the surface roughness showed that surface roughness values increase at the beginning of the tests up to a flank wear land width of approximately 50 µm. The increase of the roughness values was caused by a slight microchipping of the cutting edge. As tool wear progressed, displacement of the cutting edge reduced the microchipping due to an increase of the wedge angle, which becomes greater than 90°. Consequently, surface roughness values decreased when using tools with a flank wear land width of more than 50 µm.

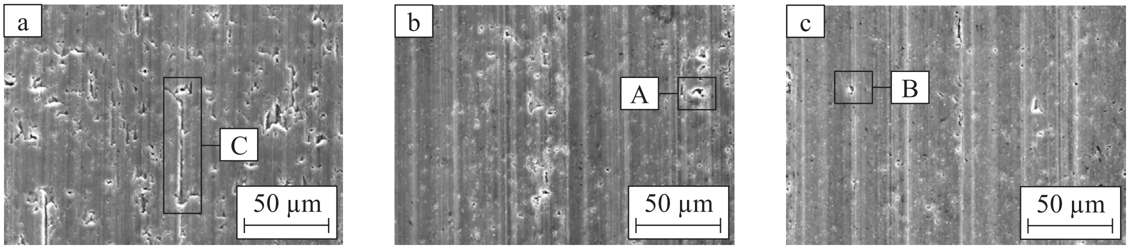

Fig. 5. SEM micrographs of specimens machined with a tool with different widths of flank wear land; (a) VB ≈ 0 µm; (b) VB ≈ 100 µm; (c) VB ≈ 200 µm; Examples for surface imperfections: A: Large void; B: Small void; C: Groove

Figure 5 represents SEM micrographs of the specimens' surfaces generated by a tool with different widths of flank wear land. It can be seen that surface imperfections in the form of voids were reduced markedly with increasing tool wear. This might be explained by an increase of the wedge angle of the tool and higher cutting temperatures, which support the embedding performance of the particles. SEM micrographs of cross sections of the specimens (Figure 6) show that imperfections of the surface layer were more distinctive for surfaces generated with new tools. This confirms the results described.

Investigations in the residual stresses of the specimens showed that turning with a worn tool induces high absolute values for the compressive residual stresses in the longitudinal direction. When turning with a new insert, the measured normal residual stress in longitudinal direction is -14 MPa. For using a tool with a flank wear land width of approximately 200 µm a value of -106 MPa was detected. The residual stresses in the matrix show a similar behaviour like the mean passive force, which increased from approximately 21 N for a new tool to circa 107 N for a worn tool (VB ≈ 200 µm).

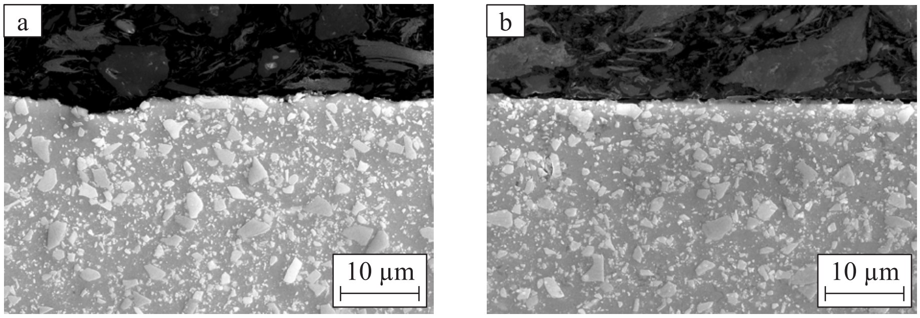

Fig. 6. SEM micrographs of cross sections of specimens machined with a tool with different flank wear land widths;
(a) VB ≈ 0 µm; (b) VB ≈ 200 µm

4. Summary and conclusions

This article describes the influence of different tool modifications on the surface integrity in turning of an AMC with 25 % volume proportion of SiC particles. Surface roughness values can be reduced by using tools with a wiper geometry. Tools with a large wiper radius or a trailing edge are particularly suitable for the generation of surfaces with small roughness values. The achievable surface roughness values are limited by cutting edge quality. Surface imperfections like voids can be reduced significantly by using tools with a flank wear land width of approximately 100 µm or larger. In order to avoid the disadvantages involved with the use of worn tools, other tool modifications have to be investigated.

Acknowledgements

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