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3D modelling and analysis of the cut layer used a numerical direct CAD method regarding torus milling cutter wear in multi-axis milling

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ABSTRACT: The aim of the present study was to develop model dependencies of the cut layer and adapt them for 3D analysis using a numerical direct CAD method. This made it possible to obtain a 3D model of the machined layer as a function of the instantaneous contact angle between the torus cutter and the machined surface and to carry out simulation studies of the distribution of the maximum thickness of the machined layer on the base surface of the cutter blade. Then, experimental studies were carried out to verify this distribution and its comparability with the formation of blade wear forms for the declared threshold values, based on the wear curves obtained. From the results obtained, it was found that the distribution of the maximum thickness of the cut layer is influenced by the inclination angle of the torus milling cutter axis. In addition, this decomposition can be successfully used to predict the wear zone in multi-axis machining and, furthermore, the formation of the notching wear form.

KEY WORDS: multi-axis machining, torus milling cutter, working angle of the cutter blade, cut leyer thickness, tool wear

1. Introduction

Multi-axis milling is now one of the main machining techniques for geometrically complex parts, and is widely used in precision finish machining of sculptured surfaces [1–3]. For machining these surfaces, torus milling cutters are increasingly being used. Tools with this geometry type allow for better surface quality and dimensional-shaped accuracy through, among other things: the lack of zero cutting speed during machining and less deflection due to the cutting forces acting on the cutter body. [2, 4–6]. In multi-axis milling, the state of geometrical-kinematic cutter-workpiece (CWE) directly determines the instantaneous cutter blade interactions with the workpiece in the contact zone, including cutter-workpiece conditions, cut layer geometry, and instantaneous undeformed cut layer thickness (IUCT). It is therefore currently one of the most important areas of research in the field of machining, especially multi-axis regarding of tool wear [1, 2].

2. Modelling of the cut layer in the CWE zone taking into account the instantaneous position of the contact point

In the multi-axis torus cutter milling process, the cut layer in the CWE zone depends on the axial depth of cut a_p. When the edge of the round cutting insert is in direct contact with the machined surface at the CP_i point, its geometry was found to be essentially influenced by the radius of the round cutting insert r_p, the feed per tooth f_z and the depth of cut a_p, as shown schematically in Fig 1.

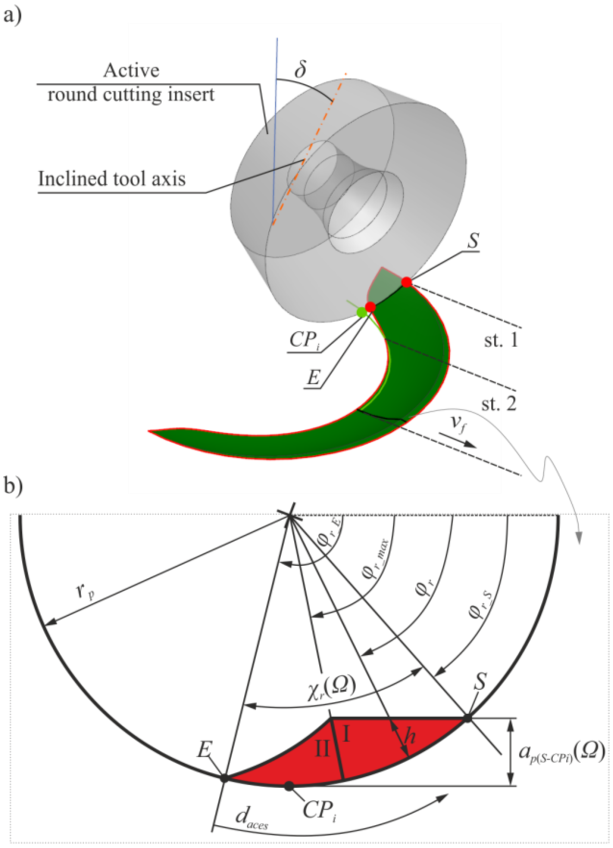

Fig. 1. Geometry of the cut layer: a) model 3D, b) parameters in the feed plane. Own elaboration.

In the mathematical description of the discontinuous cross sectional geometry of the cut layer, it is divided into two areas (I and II in Fig. 1). Such a division results from the adopted parameter of maximum cut layer thickness h_{max} in the cross section, which separates the two areas. The boundaries of these two areas and the characteristic points of the cross section were defined by determining the boundary angles: φ_{r_S}, φ_{r_max}, φ_r, φ_{r_E}. Using the above angles, the thickness of the cut layer h in area I can be calculated as a function of the angle φ_r, according to relationship (1).

Thickness of cut layer h_I in area I (range from φ_{r_S} to φ_{r_max}):

$$h_I\left(\varphi_r\right)=r_p-\left(\frac{r_p-a_{p(S-CP_i)}(\Omega)}{\sin\varphi_r}\right) \tag{1}$$

Furthermore, using the angles φ_{r_S} oraz φ_{r_E} it is possible to calculate the working angle of the cutter blade in the base plane, denoted by $\chi_r(\Omega)$ and dependent on the tool rotation angle Ω, expressed by the relationship:

$$\chi_r(\Omega)=\frac{\pi}{2}+\sin^{-1}\left(1-\frac{f_z}{2\cdot r_p}\right)-\sin^{-1}\left(1-\frac{a_{p(S-CP_i)}(\Omega)}{r_p}\right) \tag{2}$$

In the case under consideration, in order to solve relaionship (2), it is necessary to determine the value of the instantaneous depth of cut $a_{p(S\text{-}CPi)}(\Omega)$ which depends on the tool rotation angle Ω and is measured between the characteristic points S and CP_i. The determination of $a_{p(S\text{-}CPi)}(\Omega)$ was carried out using the numerical direct CAD method and represents an original approach developed by the author of this paper.

3. Research conditions

The research was carried out in two stages. The first stage was a simulation study based on the developed model dependencies of the cut layer while the numerical direct CAD method was used. The second stage was an experimental study, which was carried out in the aspect of torus cutter wear in multi-axis milling.

The variable quantities and parameters for multi-axis milling are shown in Table 1.

Table 1. Multi-axis milling parameters

Experiment No.	Inclination angle δ [°]	Cutting speed v_c [m/min]	Feed per tooth f_z [mm/z]	Axial depth of cut a_p [mm]
1	1.37	100	0.25	0.5
2	10.00			
3	18.62			

4. Research results and analysis

The tool life of the torus milling cutter increases significantly with increasing values of the tool axis inclination angle. There is an increase in the angle of the circle cutout within the boundaries outline of the round cutting insert edge of the torus milling cutter (Fig. 2d), which indicates an extension of the arc delimiting the zone of distribution of the maximum thickness of the cut layer on the base plane P_r of the cutter blade. Thus, the values of the maximum thickness of the cut layer as a result of the tool axis inclination angle and as a function of the contact angle become increasingly dispersed along the arc of the wear zone (Fig. 2a and 2b). This has the effect of extending tool life by progressively loading the cutting edge with stresses. The nature of the changes the distribution of the maximum thickness of the machined layer is comparable to the shape and form of the resulting notching wear (Fig. 2c).

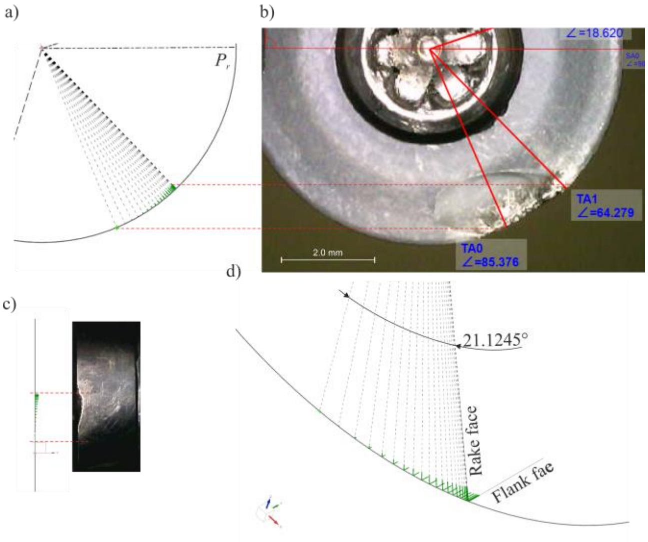

Fig. 2. Distribution h_{max}: a) on the rake face, c) on the flank face, d) in 3D and images of wear: b) on the rake face, c) on the flank face

5. Summary

Based on the analysis of the results obtained, the following conclusions were drawn.

1) The inclination angle of the torus milling cutter axis influences the cutter-workpiece coupling conditions in the CWE zone.
2) The developed 3D model of the cut layer can be successfully applied to the studies of the multi-axis milling process and, in particular, to the initial prediction of the wear zone taking into account the notching form.

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