Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 46 (2016) 39 – 42

www.elsevier.com/locate/procedia

7th HPC 2016 – CIRP Conference on High Performance Cutting

Influence of Machining Parameters on Heat Generation during Milling of Aluminum Alloys

B. Denkena[a], J. Brüning[a], D. Niederwestberg[a], R. Grabowski[a*]

[a] *Institute of Production Engineering and Machine Tools, Leibniz Universität Hannover, An der Universität 2, D-30823 Garbsen, Germany*

* Corresponding author. Tel.: +49 511/762-18331; fax: +49 511/762-5115. *E-mail address:* grabowksi@ifw.uni-hannover.de

Abstract

Thin-walled components, i.e. fuselage frames of airplanes, are prone to an unstable process behavior during milling. Therefore, tools with a chamfer between the cutting edge and the flank face are often used for such machining tasks. During milling, the chamfered area comes into contact with the just cut surface. This contact leads to process damping forces and the induced heat into the workpiece in this contact zone is increased. Furthermore, the amount of induced heat depends on the process parameters. At certain spots on the machined surface this may lead to a local overheating, which can reduce stiffness significantly. When this occurs during milling of a thin-walled component, the component is often regarded as reject. In this paper, the influence of chamfers and process parameters on the induced heat into the workpiece is investigated experimentally. In addition, a simulation which predict the temperature in the workpiece in dependence of the process parameters is presented.

Peer-review under responsibility of the International Scientific Committee of 7th HPC 2016 in the person of the Conference Chair Prof. Matthias Putz

Keywords: thermal behaviour; simulation; milling; process damping

1.Introduction

The aircraft manufacturer Airbus forecasts that the worldwide air traffic will double in the next 15 years which leads to a demand of more than 30,000 new aircrafts [1]. Modern aircrafts are designed in order to maximize energy efficiency by low weight. Therefore, the structure components are designed with minimal residual material thickness as low as 1 to 2 mm and maximum rigidity. These complex shaped parts are up to 14 m long and typically manufactured from rolled aluminum plates or near-net-shape extruded aluminum profiles. The chosen materials are difficult to machine and challenging for the machining process like distortions.

Thin-walled workpieces have a high compliance, and thus, compared to more solid workpieces, self-excited vibrations may occur more easily during machining [2]. The dynamic displacement between the tool and the workpiece leads to a variation of the chip thickness and a wavy workpiece surface. This phenomenon is known as the regenerative effect [3]. Andrew and Tobias stated that if with every following cut the amplitude of the chip thickness is increasing due to the regenerative effect, the machining process becomes unstable [4]. Tools with cutting edges, which have chamfers on their flank face, are used to increase the process stability [5]. This chamfered areas come into contact with the just cut wavy surface of the workpiece leading to an additional force component known as process damping forces [6]. However, this additional contact also has an influence on heat generation. It is to be expected that this is critical for aluminum alloys with increased tendency for soft spots. These thermal induced structural changes of the material texture lead to a reduced stiffness in the border area of the material [7]. Several experimental investigations showed that this effect could occur in cutting processes [8]. For the detailed simulation and analysis of thermal effects in machining processes, the finite difference method is an approved method [9].

2.Approach

In this paper, experiments to investigate process stability and heat generation when milling thin-walled workpieces are carried out. An end mill with sharp and chamfered cutting

Peer-review under responsibility of the International Scientific Committee of 7th HPC 2016 in the person of the Conference Chair Prof. Matthias Putz
doi:10.1016/j.procir.2016.03.192

edges, is examined in order to analyze differences in heat generation and stability due to the different cutting edge shape. The simulation approach is based on a 2D-sectional view of workpiece and process. Therefore the workpiece is sliced horizontal at half cutting depth. For the determination of the heat input an inverse method was used.

3.Experimental investigations & simulation

3.1.Experimental setup

For the investigation of the influence of chamfered cutting edges on process stability and heat generation, the setup shown in Fig. 1 is used. The workpiece is a small part of a frame with a thickness of 2 mm. A force plate is used to analyze the cutting forces and process stability respectively. The workpiece material is Al-Li 2196, which is commonly used in aerospace applications. A thermal imaging camera is used to measure the heat development on the backside of the workpiece. For a more accurate temperature measurement, the backside is coated with an emissivity spray.

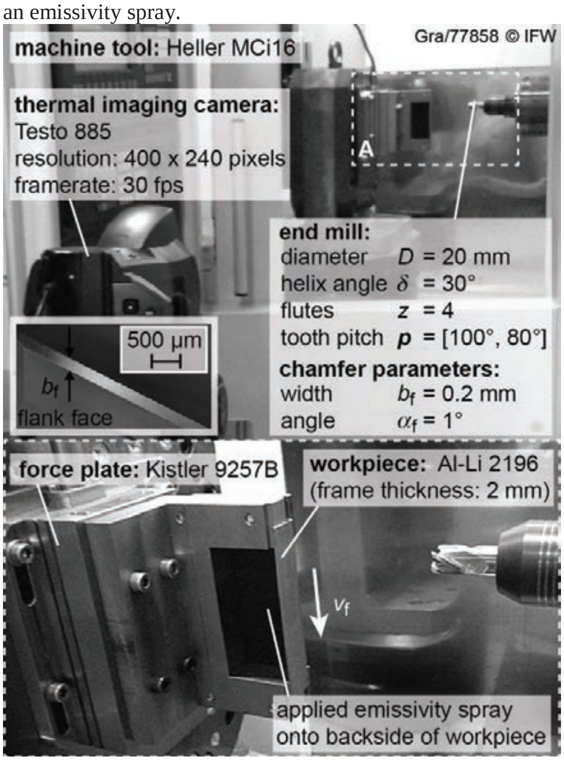

Fig. 1. Experimental configuration

Two similar end mills are used for the experiments. One has sharp cutting edges and the other one has chamfered cutting edges. The chamfer specific values have been chosen based on the experiments by Sellmeier and Denkena [5].

During the milling operation, the axial and radial depth of cut a_p and a_e, respectively, have constant values (see Table 1). The spindle speed n and feed per tooth f_z were varied to investigate the influence on stability and heat development.

Table 1: Experimental process parameters

process parameter	values
spindle speed n	[1,000 … 10,000] min^{-1}
feed per tooth f_z	[0.08 … 0.3] mm
axial depth of cut a_p	25 mm
radial depth of cut a_e	1 mm
milling direction	down milling
coolant	none

3.2.Simulation

The process is simulated by a finite difference method. For the calculation of the heat flux, the domain of the method was divided into cubic elements with an edge length of the feed per tooth f_z. Every element of the domain has several properties which can be defined global if they are homogeneous or local if they are inhomogeneous.

Table 2: Element properties of the simulation model

homogeneous properties	inhomogeneous properties
edge length dx [mm]	heat quantity [J]
thermal conductivity λ [W/mmK]	material removal [-]
mass m [kg]	temperature T [K]
specific heat capacity c_p [J/kgK]	

The heat flux properties are homogeneous. The domain is discretized cubical. Therefore, the local heat quantity of the elements can be stored as matrix Q. The local temperature T can be calculated by the local heat quantity and the specific material properties. An additional matrix A of identical size is used to model the material removal during the process. This matrix is binary-coded to take into account whether there is material or not (Fig. 2).

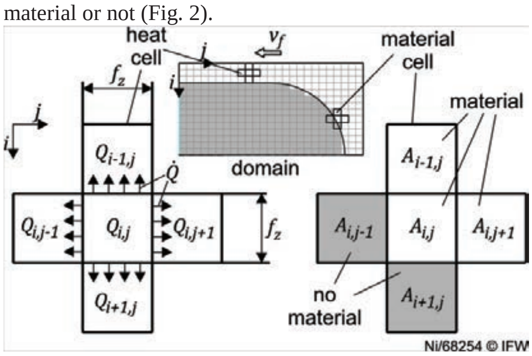

Fig. 2. Domain with single heat and material cell

Based on this description, the heat difference $\Delta Q_{i,j}$ for every element can be calculated by equation 1. The heat difference is depending on the properties of the neighboring elements and the time of a simulation step Δt.

$$\Delta Q_{i,j} = A_{i,j} \cdot \begin{bmatrix} A_{i-1,j} \\ A_{i+1,j} \\ A_{i,j-1} \\ A_{i,j+1} \end{bmatrix}^T \cdot \left(\begin{bmatrix} Q_{i-1,j} \\ Q_{i+1,j} \\ Q_{i,j-1} \\ Q_{i,j+1} \end{bmatrix} - Q_{i,j} \right) \cdot \frac{\lambda \cdot dx}{c_p \cdot m} \cdot \Delta t \qquad (1)$$

Solving this equation for the whole domain, the heat flux in the sliced workpiece can be calculated. The simulation step time Δt is a fraction of the time for a tool rotation. This allows to consider the effect of heat input and propagation for every