Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 46 (2016) 234 – 237

www.elsevier.com/locate/procedia

7th HPC 2016 – CIRP Conference on High Performance Cutting

Thermal finite-difference modeling of machining operations in polymers

Frédéric Rossi[a]*, Thomas Baizeau[a], Carole Moureaux[a]

[a]*Arts et Metiers ParisTech, LaBoMaP, rue porte de Paris, 71250 Cluny, France*

* Corresponding author. Tel.: +33385595344; fax: +3385595350. *E-mail address:* frederic.rossi@ensam.eu

Abstract

Polymer materials are known to be easily damaged by temperature reached during machining operations. A two-dimensional finite-difference model is established to predict the temperature in orthogonal cutting. Calculations are validated with experiments carried out on polyurethane samples with various cutting speeds and depths of cut. The cutting temperatures are measured by thermocouples embedded within the workpiece and the tool cutting edge. The model provides a three dimensional thermal field of the workpiece with an accuracy of 20 K.

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

Keywords: Temperature; Simulation; Measurement.

1. Introduction

The temperature at the cutting zone is investigated since the beginning of machining researches and is one of the main affecting parameters for surface integrity and lifetime of tools [1,2]. The heat produced both by shearing and by friction, at the tool tip, may leads, in the case of polymers, to temperatures that can damage the material [3]. Most research works have been conducted on metals and composite materials [4,5] with both the experimental and numerical point of views. Only few papers study the thermal aspect of the cut in thermoplastics [6].

As presented by Arrazola [7],and Klocke [8] most thermal model are performed through an analytical approach. The aim of this study is to establish a model of temperature of the tool, the chip and the piece during planing operations. The limit cutting conditions are estimated by the modelled temperature in the workpiece.

A two dimensional thermal finite difference methodology is developed to model the temperature. In order to improve the accuracy of results, the experimental mechanics data are used as input in the modelling.

Finally, the validation of the model is done with temperature measurements at the tool edge.

2. Experimental set-up

The thermal model needs to be validated with experimental data. Most of the machining involve 3D cutting operations. To simplify the analysis, the problem is reduced to orthogonal cutting configuration. The tool edge–material pair can then be used by recomposing parts of the thermal load for the whole edge on the machined surface.

The experiments are performed in planing operations. The cutting motion is obtained with the longitudinal axis of a DMG DMC85V 3 axis milling machine [9] driven by linear motors. Figure 1 shows the experimental set-up with the cutting tool on the translating x-axis. The machined part is clamped on a Kistler 9119AA2 piezoelectric dynamometer for cutting forces measurements (F_c) and thrust force (F_D). The thermoplastic polymer samples were 4 mm width (b) and 55 mm long. The temperature is measured when the cutting edge cuts and closes the electrical circuit of the two K type thermocouples wires embedded in the workpieces as presented in Figure 2. Five thermocouples are positioned every 10 mm to get the transient temperature elevation. The mechanical and thermal data are recorded thanks to a NI9205 and a NI9219 cards synchronized with a NI CompacDAQ 9188 board [7].

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.2016.04.017

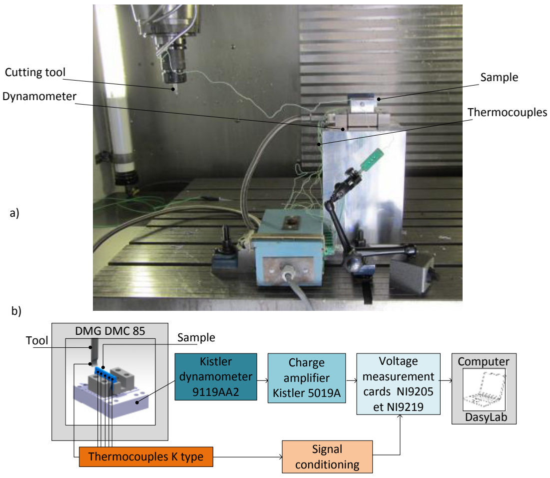

Figure 1. a) view and b) schematic of the experimental set-up.

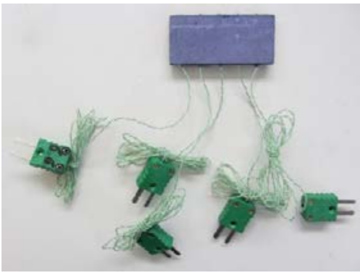

Figure 2. Thermoplastic sample with the five embedded thermocouples.

Figure 3 shows the force disturbances in the direction of the cutting speed due to the five K type thermocouples when they are cut by the tool. The force peaks are removed from the collected data to get only the values due to the studied thermoplastic material.

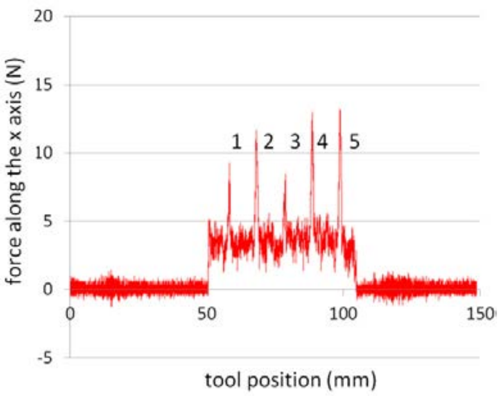

Figure 3. Disturbance on the force (F_c) along the x-axis (cutting direction) due to the cut of the thermocouples (V_c = 5m/min, h = 0.3 mm).

The cutting tool, exposed in the Figure 4 is a single edge made with K20 sintered tungsten carbide. The rake and flank angles, respectively 20° and 20°, are chosen accordingly to the industrially optimized geometry. The tool edge radius is controlled thanks to a contact profilometer to evaluate the wear and thus guaranty the results homogeneity. The parameter evolve from 4±2 µm (before the first cut) to 5±2 µm (at the end of the whole experimentation). The wear was therefore considered irrelevant.

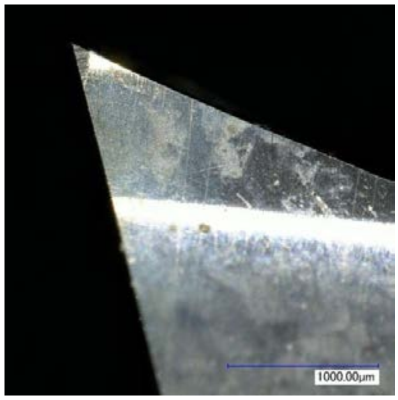

Figure 4. Side view of the tool edge.

3. Model

The model of temperature in orthogonal cutting is obtained by solving the heat equation (1) with a finite difference method coded in C++. Thanks to the spatial and temporal decomposition, equation (2) gives the temperatures on each cell thanks to the temperatures of the adjacent cells on the previous time step.

$$div(-\vec{\varphi}) + q = \rho \cdot C_p \cdot \frac{\partial T}{\partial t} \quad (1)$$

With φ the heat flux (W/m^2)
q the volumetric heat flux (W/m^3)
ρ the density (kg/m^3)
C_p the specific heat capacity (J/(kg K))
T the temperature (K)

$$(T_{i,j})_{t_{i+1}} = (T_{i,j})_{t_i} + \frac{\Delta t}{\rho\, C_p}[div(-\vec{\varphi}) + q] \quad (2)$$

The figure 5 describes the mesh used to solve the problem. The tool is set as fixed and the workpiece cells are continuously moving along the x direction at the cutting speed (V_c). When the chip is losing its contact with the rake face, the thermal exchange with the tool will achieve zero. The cells corresponding to the chip are thus numerically insulated from the others. In the workpiece base, as long as the tool is progressing on the sample, the material cells are ignored on the mesh. The tool removes thus a given uncut chip thickness (h). Finally cell sizes were chosen to be one sixth of the uncut chip thickness.