Available online at www.sciencedirect.com

ScienceDirect

Procedia CIRP 62 (2017) 233 – 238

www.elsevier.com/locate/procedia

10th CIRP Conference on Intelligent Computation in Manufacturing Engineering - CIRP ICME '16

Reverse engineering and scanning electron microscopy applied to the characterization of tool wear in dry milling processes

Marcello Cabibbo[a], Archimede Forcellese[a], Roberto Raffaeli[b], Michela Simoncini[b,*]

[a]*Università Politecnica delle Marche, Via Brecce Bianche, Ancona 60100, Italy*
[b]*Università degli Studi eCampus, Via Isimabrdi 10, Novedrate (Como) 22060, Italy*

* Corresponding author. Tel.: 0039 071 2204798; fax: 0039 071 2204801. E-mail address: michela.simoncini@uniecampus.it

Abstract

An innovative method of tool wear assessment, based on the digitization of the cutting tool performed by a piezoelectric 3D scanner and on the analysis of the surfaces of a 3D model generated using the Reverse Engineering technique, has been developed. To this purpose, face milling experiments were carried out under dry cutting condition on AISI 420 B stainless steel using inserts in cemented carbide, with a two-layers coating (TiN and TiAlN). The time dependence of the insert wear was analysed by interrupting milling at predetermined time values. The proposed approach has been validated by comparing the output provided by the reverse engineering method to that measured experimentally by analysing the worn insert images obtained using a stereo microscope. An excellent agreement between the results given by the two different methodologies has been found. The worn tools have also been analysed using the scanning electron microscopy technique in order to understand the wear mechanisms operating during dry milling.

Peer-review under responsibility of the scientific committee of the 10th CIRP Conference on Intelligent Computation in Manufacturing Engineering

Keywords: Reverse engineering; CAD; dry cutting; milling process; tool wear; FEG-SEM.

1. Introduction

The high temperatures generated at the tool – workpiece interface during machining operations, especially as they are performed under dry cutting condition, strongly affect the tool life [1-4]. Unfortunately, the very high temperatures developed during dry machining can reduce the accuracy and increase the risk of thermal damage of the work-part surface. Moreover, the increase in temperature and friction can strongly influence the tool wear [1-6]. The precise and accurate evaluation of the tool wear is critical to define the tool life, i.e. the time interval during which the tool is able to perform the machining operation by ensuring the obtaining of the desired values of dimensional and form tolerances, and surface quality of the workpiece [6-10].

The international standard ISO 8688-1 specifies recommended procedures for tool-life testing with cemented carbide tools used for face milling of steel and cast iron workpieces by microscopy at low magnification [11]. In order to overcome such drawback, innovative methods of evaluating the tool wear, based on the digitization of the cutting tool and on the analysis of the surface of a 3D model generated using the Reverse Engineering (RE) technique [12], should be developed. Then, the three-dimensional model of the wear cavity can be used to compute the total mass loss, the wear rate and the influence of the operating conditions on them.

Many papers have investigated metrics for quantifying the quality of measurements in order to assess the reconstructed virtual models [13-15]. Same authors have also evaluated the precision of reconstructed surfaces by RE systems by comparing it with the one measured using a CMM machine [16, 17]. The grooving interest towards the RE in inspection of manufactured parts is also demonstrated by the application of such technique in the tolerance control field [18].

In the present work, face milling operations were carried out under dry cutting conditions on blocks in AISI 420B stainless steel using PVD-coated cermet inserts. The analysis of tool wear was carried out by interrupting the milling process at predetermined time values and scanning the inserts

Peer-review under responsibility of the scientific committee of the 10th CIRP Conference on Intelligent Computation in Manufacturing Engineering
doi:10.1016/j.procir.2016.06.087

through a piezoelectric 3D scanner. The small sizes involved required a preliminary validation of the correctness and reliability of the measurement accomplished [19]. Then, repeatable geometric procedures were defined in order to build the nominal shape of the insert and to evaluate the wear behaviour as a function of processing time. The comparison between the results obtained through the RE analysis of the worn inserts and those experimentally measured by stereo-microscopy has shown that the reverse engineering can be effectively used in the tool wear evaluation. Finally, in order to understand the mechanisms leading to the formation of the wear cavity in the inserts during dry milling, the worn tools were analysed using the scanning electron microscopy (SEM) technique.

2. Experimental techniques

2.1. Face milling operations

Face milling operations were performed without any cooling lubricant (dry cutting) using a vertical machining center on blocks in AISI 420B stainless steel (0.16C, 13Cr, 1.05Mn, 1.0Si, 0.04P, 0.03S, wt.%). Blocks with a width of 32 mm, a length (along the feed direction) of 345 mm and a height of 130 mm were used as workpieces. For each condition the tests were repeated different times.

A tool holder with a diameter of 63 mm was used. Five inserts in cemented carbide (R245 12T3 E-ML 2030) with a two layers coating (TiN and TiAlN) [20] were mounted on the tool holder. The face milling operations were carried out with only one tooth – workpiece contact each time. The cutting parameters were selected according to the tool manufacturer recommendations [20]: a cutting speed equal to 230 m/min, a feed rate of 0.14 mm/tooth, and a depth of cut of 0.2 mm were used. The process time on the workpiece for each pass is about 26 s. In order to accurately measure the tool wear, the milling operations were interrupted at fixed time values, equal to 12, 36, 64, 92, 116, 136, 172, 200, 224, 250, 280, 310, 350, 400, 450, 500 e 520 min. At any interruption of the milling process, the inserts were analyzed by means of a stereomicroscope (Leica EZ template 4D). Two supports were made in order to correctly arrange the worn face of the insert parallel to the lens of the stereomicroscope. By superimposing the image of the wear-free insert with that of the worn one, it was possible measure the height of the worn part.

2.2. Scanning by piezoelectric 3D scanner

After each working interval, the tool inserts have been removed from the tool and acquired by 3D scanning devices which are commonly used for Reverse Engineering purposes, i.e. to track the progression of the material erosion.

Preliminarily, different scanning systems were evaluated, i.e. contact and optical types. In particular, an attempt has been performed using a laser scanner (Minolta Range 7). This scanner ensures a high spatial resolution and a good behaviour in minimizing the speckle phenomena typical of optical scanning systems based on laser beam. However, the insert material properties and the deterioration of the surface due to wear has made measurements quite noisy. With this respect, a scanner piezoelectric contact PICZA Roland MDX-15 was used, since it is not affected by reflection phenomena. The sensor is constituted by a needle mounted on a piezoelectric sensor moved along the three coordinate axes resembling a CMM machine. The pointed shape of the needle, the absence of undercuts in the acquired insert area and the simplicity of the machine makes the process rather lean although far slower than optical acquisition systems. The scanner has a working volume of 200x150x60 mm^3.

The inserts were positioned in tilted positions such that the cutting edge were invested by the needle vertically. The measurement resolution was set at a pitch of 0.05x0.05 mm on the XY plane. The choice of scanning the insert from a single direction has required accurate positioning of the insert in order to ensure the absence of undercut areas in the portion of interest, namely the areas adjacent to the cutting zone. However, some undercuts were generated only in other areas leading to fictitious shapes which have been eliminated in a post processing phase. The insert has been acquired from a single point of view, thus errors due to the alignment of multiple views [21] has been avoided.

2.3. CAD elaboration of the digitized models

The scans of the inserts have been elaborated by a software with functionalities oriented to the standard Reverse Engineering process (Fig. 1). The models were processed by using the Rapidform software (Inus Technology, Inc.).

By overlapping the acquisitions of the unused and worn inserts, and by displaying the colour map of the deviations between the two acquisitions, the complexity and three-dimensionality of the worn volume are revealed.

In order to determine the insert degradation, and measurement procedures were developed. The main steps of such procedure are as follows: i) scan of the inserts and model cleaning; ii) scan alignment to the reference model; iii) identification of a reference measuring planes (Fig. 2); iv) monitoring the wear evolution.

Through the digital overlay of the scans obtained for each insert at various time intervals, it was possible to record the evolution of the wear parameter.

3. Results and discussion

The proposed method was validated by comparing the results obtained through RE and those experimentally given by the image analysis of the worn inserts, acquired using the stereomicroscope at predetermined cutting time values. Fig. 3 shows worn inserts, superimposed with the wear-free one at different milling time. It can be qualitatively observed the increase of tool wear as a function of the cutting time.

In order to better correlate the CAD modelling of thecutting edge deterioration with working hours, a systematic scanning electron microscopy (using a Zeiss™ Supra-40® FEGSEM) inspections were carried out. The cutting edge consumption by wear, during dry milling, is evident from the sequence of the electron microscopy documentation of Fig. 4.