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Characterizing precision cutting process by workpiece integrated printed thermocouples

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Abstract

We present a new approach using workpiece integrated thermocouples for measuring low but highly dynamic thermal loads during precision cutting. The manufactured workpiece itself is set as one electrode. A second electrode is printed on the workpiece setting up a thermocouple with it. The workpiece is then characterized in a fly-cutting process while the voltage drop of the thermocouple is recorded. The results show, that measuring the relatively low but most dynamic temperature changes in the millisecond range in the workpiece of each single cut is possible with our approach. The occurring temperatures are much lower than $T = 100$ °C and therefore, do not cause thermal damage to the surface or subsurface zone.

Keywords: Precision cutting, Temperature measurement, Printed thermocouples, Sensory workpiece

1. Introduction

Analysing the thermal impact on workpiece materials is of high interest because it strongly influences the material behaviour, respectively shearing and deformation during machining. This is particularly important in precision cutting, which is a finishing process, giving the part its final shape and defining the final properties of the surface and subsurface. Since the thermal load occurring in precision cutting is low and highly dynamic measuring these thermal energies is a challenging task. Especially the energy flowing into the workpiece is quite low and dissipates fast. Measuring temperatures during manufacturing is mostly done by infrared cameras [1] or commercially available thermo-couples [2]. In case of precision cutting both approaches will not lead to a satisficing measurement because their dynamic response time as well as the local resolution are not high enough. Both cannot monitor the temperatures in precision cutting accurately.

To measure process temperature in precision cutting, our approach is the use of a workpiece with integrated thermo-couples.

2. Experimental setup

The concept provides a sensory workpiece, which is a two-part workpiece with printed thermocouples. The workpiece itself consists of two identical parts, which are adhesively joined. One half of the workpiece itself is one of the two electrodes. Consequently, an increase in the local temperature in the workpiece will directly be detected by a voltage drop at the thermocouple. This enables the measurement of the local temperature within the workpiece with high dynamic response, being able to measure the thermal impact of individual cuts in the workpiece.

As substrate we use the quenched and tempered steel 42CrMo4 (AISI/SAE 4140, sheet material with 1 mm thickness), cut in small plates with a size of 15 mm x 33 mm. Five thermocouples are printed in parallel to ensure measurement repeatability.

2.1. Fabrication of the thermocouples

The fabrication of the thermocouples is shown in Figure 1. For the printing a manual screen printer with commercially available screen (*SEFAR PCF FC*) is used. In the first step epoxy resin (*UHU Endfest 300*) is printed with a thickness of around 5 µm on the workpiece.

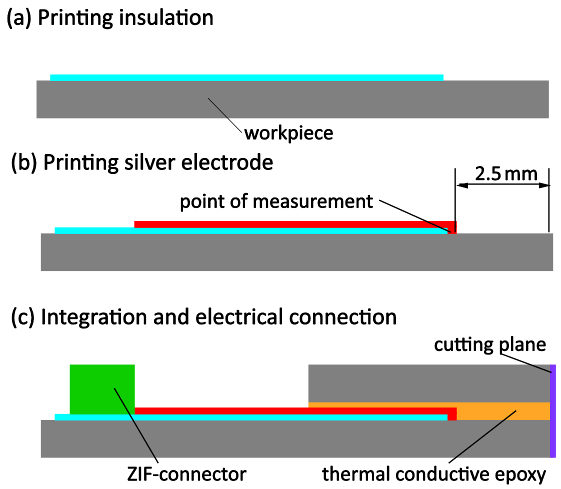

Figure 1. Fabrication process of the sensory workpiece

Afterwards the electrode is printed as shown in Fig. 1(b). At the front of the workpiece (in Fig. 1(b) on the right), where the actual cutting process takes place, the electrode slightly protrudes the insulation, setting up a thermocouple with the workpiece. The thermocouple is printed with a distance of 2.5 mm from the cutting plane (see Fig. 1(b) and (c)). Thus, finally after machining these 2.5 mm, the thermocouple is destroyed. The final workpiece integration is done by joining two steel workpieces (42CrMo4) with thermal conductive adhesive. To read out the thermocouples a ZIF Connector is attached by electrical conductive adhesive. The final workpiece is fixed on a PCB (cf. Fig. 2) for mounting within the machine tool. The sensitivity of the thermocouple is $S = 6$ µV/K.

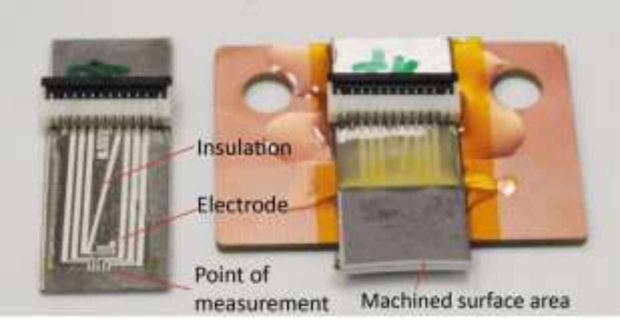

Figure 2. Workpiece during fabrication (left) and the final workpiece after machining (right)

2.2. Precision cutting of the sensory workpiece

The characterization of the sensory workpiece is carried out as a fly-cutting process with free quasi-orthogonal cuts. The machining is performed on an ultra-precision machining system (Precitech Freeform 3000) with an integrated milling spindle (cf. Fig. 3). A coated cemented carbide tool with a cutting edge radius of $r_\beta = 9.3$ µm ± 0.15 µm is applied. The feed rate is $f = 18$ µm at a cutting speed of $v_c = 230$ m/min, according to a spindle speed of 500 rpm and a fly cut radius of 146 mm.

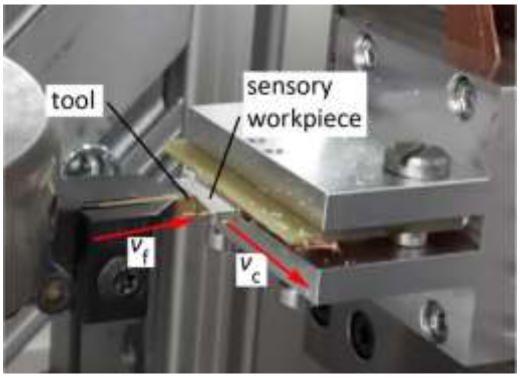

Figure 3. Workpiece during precision cutting

3. Results and Discussion

The result of the characterization is exemplary shown in Fig. 4 for one single thermocouple. In the beginning at $t = 2$ s the tool starts cutting the workpiece and the temperature in the workpiece increases. The shape of the measurement curve between $t = 2$ s and $t = 12$ s is characteristic for a thermal charging process. When the tool is approaching the thermocouple ($t > 12$ s), the shape of the curve changes as seen in detail in Fig. 4. At each engagement of the tool, the temperature rapidly increases to a peak. After every single cut, when the tool is disengaged from the workpiece, the temperature decreases as in thermal discharging process. While the cutting tool moves closer towards the thermocouple, the peak increases until the thermocouple is destroyed at $t = 17.7$ s. The occurring temperatures are quite low for a precision cutting process.

After precision cutting, the machined surface area is blank, without any colour changes due to temperature loads. This is proven with our measurement as the occurring temperatures are much lower than $T = 100$ °C and thus, far away from any tempering or annealing temperature.

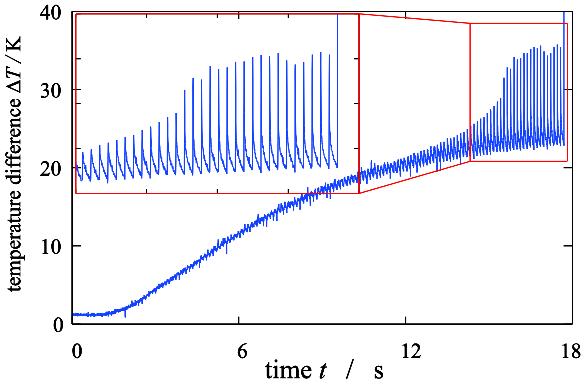

Figure 4. Temperature difference over time after filtering with a low pass with a cut of frequency of $f = 100$ Hz.

4. Conclusion and Outlook

We have presented a sensory workpiece with integrated thermocouples. The workpiece was machined by a fly-cutting process to measure the temperature in the workpiece during precision cutting. With our setup we could successfully characterize the thermal impact on the workpiece. The occurring temperatures are much lower than $T = 100$ °C and therefore, do not cause thermal damage to the surface or subsurface zone.

Our work is the basis for calibrating process models and thus a first step to get further knowledge about precision cutting processes and its energy dissipation in the workpiece. Furthermore these measurements will help to validate process models.

To extend the measurement setup the combination of temperature and force measurement can help to understand the effective mechanisms when the feed rate is in the range of the cutting edge radius of the tool. Our idea of workpiece integrated thermocouple is not limited for the characterization of precision cutting. Further manufacturing processes like laser processing or electrical discharge machining and their thermal impact on the workpiece can be determined.

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References

[1] Ma Y, Feng P, Zhang J, Wu Z, and Yu D 2016 Prediction of surface residual stress after end milling based on cutting force and temperature *J. Mater. Process. Technol.* **235** 41-48

[2] Zäh M F, Brinksmeier E, Heinzel C, Huntemann J W and Föckerer T 2009 Experimental and numerical identification of process parameters of grind-hardening and resulting part distortions *Production Engineering* **3(3)** 271-279