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TEMPERATURE VARIATION IN RADIAL TURNING

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Abstract. *Hard turning has become an alternative to grinding as a finishing process for hardened steel since the early 80s. Since then, there is a need to better understand the hard turning process. Recent hard turning studies reported a decrease in forces and an increase in white layer formation as the tool approached the workpiece center during radial turning, which indicates a temperature increase along the process. This increase occurred with constant process parameters, with the only variation during the process being the lathe spindle rotation. The objective of this study is to determine if there is an increase in temperature during radial turning and to investigate a possible cause for this increase. To do this a prototype of a temperature measuring device was used to measure the temperature in fixed points of the workpieces. The temperature was measured with a sample rate of 1 kHz. The experiments consisted of the radial turning of SAE 1040 steel with cutting speed of 150 m/min, feed of 0.08 mm/rev, and depth of cut of 0.2 mm using new and worn tools. Each workpiece was a 100 mm diameter disc with a central hole of 24 mm in diameter. Three thermocouples were embedded and positioned radially at 15 mm, 30 mm, and 45 mm. The thermocouples were 2.3 mm from the surface in the first pass of each experiment and would become closer to the surface in each successive pass. As the device used to measure temperature was a prototype, only qualitative analysis was made. The temperature measurements have shown that the centermost thermocouple had always a higher temperature than the outermost thermocouple. In the later passes pulsed signals with a frequency close to the instant spindle rotation when the tool was above the specific thermocouple were detected. These pulsed signals were identified as the tool passage, creating a sudden increase in temperature followed by a cooling curve. These results confirm that there is an increase in temperature as the tool approaches the center of the workpiece and that this increase occurs at least partly because of a diminishing in the cooling time of the region due to the increase of tool passage frequency.*

Keywords: *machining; radial turning; temperature measurement.*

1. INTRODUCTION

Injection and conformation molds as well as many high performance parts are fabricated of materials with elevated hardness (Mohruni et al., 2018). The classic finishing process applied to materials of elevated hardness is grinding but beginning in the 1980’s hard turning started to be used for many parts. This happens due to hard turning presents advantages related to cost, preparation time, flexibility to part geometry, removal rate, and can be done without cutting fluid (Mohruni et al., 2018). Although hard turning presents many advantages compared with grinding it still presents disadvantages in relation to reliability, surface quality, and generation of tensile residual stress (Klocke et al., 2005).

Works in radial turning of AISI 52100 HC60 with PCBN tools done recently obtained signs of temperature phenomena in radial turning. Camargo (2019) noticed a decrease in machining forces as the cutting tool approached the center of the workpiece. The initial force at each pass would increase in relation to the initial force of the previous pass, due to tool wear, but along the pass, the force would decrease, and this was exacerbated with tool wear. Bortoli (2019) analyzed white layer formation for the same process and found that there was an increase in white layer formation closer to the workpiece center. Both a decrease in machining forces and an increase in white layer formation pointed to an increase in temperature as the cutting tool approached the center of the workpiece (Griffiths, 2001; Klocke, 2011). As neither research involved the measurement of temperature it was necessary to repeat the experiments measuring the temperature to confirm that there was a temperature increase.

One of the suspected causes for this proposed temperature increase was the increase of the lathe spindle rotation as the cutting tool approaches the workpiece center, necessary to maintain the cutting speed constant in radial turning, with the increase of rotation, the frequency of passage of the cutting tool close to a region of the workpiece would increase.

As the cutting tool acts as a heat source, this increase in frequency would decrease the cooling time between each passage and increase the heat build-up, increasing the temperature. For this reason, measuring the temperature in fixed points of the workpiece might reveal more about the phenomena than measuring the temperature in the cutting tool.

This research has the objective of measuring the temperature in the workpiece to verify if there is a temperature increase during radial turning. To measure the temperature a prototype of a device developed for this purpose was used. As the used device is still in the prototype stage and due to the cost of materials and tools, this research will use stand-in materials for the workpiece and tools with the intention of repeating these experiments using the original materials and tools used by Camargo (2019) and Bortoli (2019) in future experiments.

2. METHODOLOGY

This section will describe the methodology used to obtain and analyze the results obtained in this research.

2.1 Temperature measurement

The temperature measuring device was developed by van Caspel (2022) specifically for this application. The device prototype uses a sample rate of 1 kHz in four channels. Three channels acquire signals from thermocouples embedded in the workpiece and one channel acquires the signal from a thermistor that is located with the thermocouples' cold junction to provide compensation.

As a prototype, the number of experiments done was limited and the analysis used in this research will be only qualitative. Validation of the prototype was done using an oven to determine systematic and random errors. Systematic errors stayed below 20 ºC when measuring temperatures below 300 ºC and below 50 ºC when measuring temperatures up to 1100 ºC. Random errors stayed below 3 ºC for all temperatures. One thermocouple data was not used in the results due to a failure that limited its temperature measuring range between 200 and 800 ºC. The other two thermocouples were able to measure temperatures from 10 to 950 ºC above their compensation temperature.

With the random errors defined in the validation, the minimum temperature difference was calculated which would mean a hypothesis test would confirm the temperature difference between two measurements. It was determined that with the standard deviations presented by the channels a temperature difference of 5 ºC would be enough to be reasonably sure that the temperature difference was real and not due to random error.

2.2 Workpiece and tools

The workpieces, seen in used were 100 mm diameter discs with a 24 mm hole in their centers and with 15 mm width made of AISI 1040 steel. In each disc three holes were machined using Electrical Discharge Machining (EDM) with a 1.6 mm copper electrode and 12.7 mm depth, these holes were located at 15, 30, and 45 mm from the workpiece center. Figure 1 shows the workpiece dimensions. In each hole, a type K thermocouple was embedded.

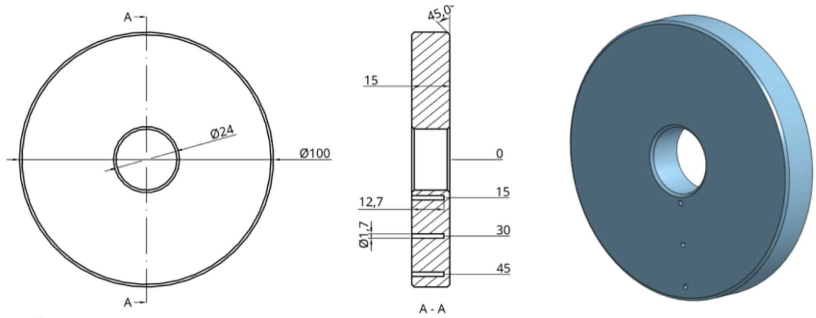

Figure 1. Workpiece dimensions.

The cutting tool used was the Sandvik SNMG 12 04 08-QM 525. This is an uncoated carbide tool with a corner radius of 0.794 mm and a clearance angle of zero degrees. The tool holder used was the Sandvik DSBNL 2020K 12 with a cutting tool edge angle of 75 degrees and a tool lead angle of 15 degrees. Tools with new and worn edges were used.

2.3 Process parameters

As this research has the main objective to verify the existence of the temperature increase phenomena and a secondary objective to test the temperature measuring device for application in hard turning, the process parameters was chosen not to be the usual parameters for radial turning of AISI 1040 steel with a carbide tool, but parameters that would better attain the objectives.

A higher cutting speed would generate more heat (Klocke, 2011) and increase the lathe rotations, both would increase the intensity of the suspected phenomena. A low feed rate would mean that the tool would pass a greater number of times close to the same area, increasing the number of heating and cooling cycles suffered by that area. A small cutting depth would reduce the total heat generated but would result in a greater number of passes before the thermocouples are revealed and would enable the analysis of the benefits of measuring the temperature at varied distances from the machined surface.

Because of these factors and to test the acquisition of signal in a sample rate closer to those that will be used in possible future research, it was decided that the parameters used would be the same as those used by Camargo (2019). The cutting speed used was 150 m/min, the feed was 0.08 mm/rev and the cutting depth was 0.2 mm. Each experiment was composed of multiple passes and in each subsequent pass the machined surface would become closer to the embedded thermocouples and the experiment continued until the thermocouples were completely cut.

With the sample frequency of 1 kHz and cutting speed of 150 m/min, the tool moved 2.5 mm between samples. With these parameters, the total cutting time was approximately 37 s, taking 7.4 s to move from the workpiece outer edge of the workpiece to the outermost thermocouple, 17.7 s from the outermost thermocouple to the middle thermocouple, 10.6 s to move from the middle thermocouple to the centermost thermocouple and another 1.3 s to reach the workpiece inner edge.

3. RESULTS

Although six experiments were conducted, only two were able to acquire adequate data. The other four experiments were important for failure analysis which will not be discussed in this research. The two experiments with adequate data will be referred to as worn tool experiment and new tool experiment, each one composed of 16 passes.

3.1 Temperature increase

The two successful experiments presented similar results with different intensities. The experiment with the worn tool acquired a signal peak above saturation in the centermost thermocouple since the first pass while the middle thermocouple is still below saturation (Figure 2). In the third pass, the middle thermocouple already shows a peak above saturation. In all passes, the centermost thermocouple presents a peak with a temperature above the peak temperature of the middle thermocouple. The measured temperature also increased from one pass to another. The experiment with the new tool had a similar behavior, but with signals above saturation appearing only in later passes. This is probably due to tool wear increasing the heat generation during the process (Klocke, 2011).

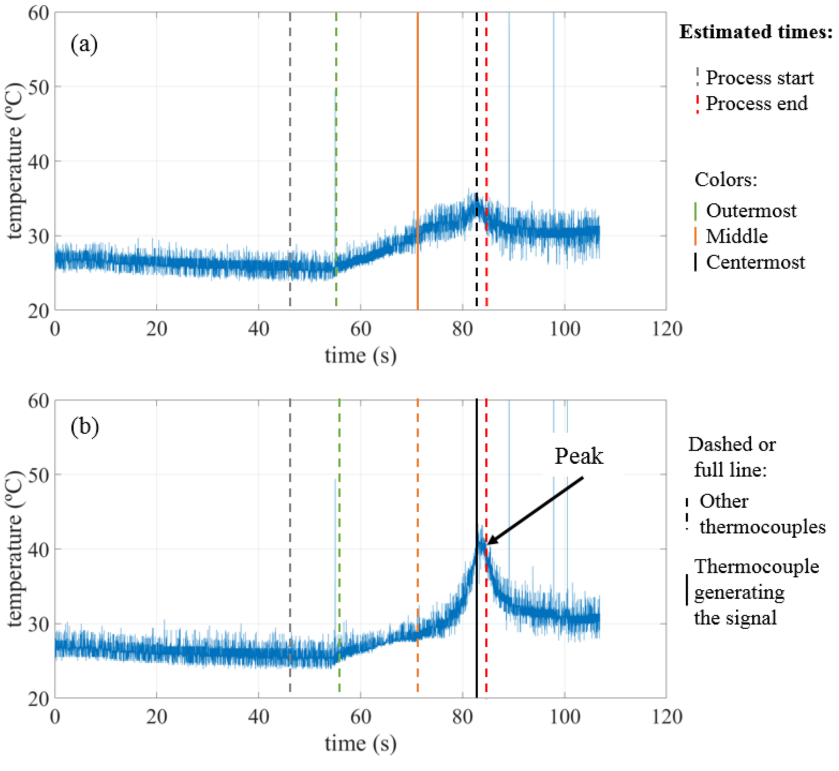

Figure 2. Temperature signal from the first pass of the worn tool experiment. (a) Signal from the middle thermocouple. (b) Signal from the centermost thermocouple.

These results confirm the propositions made by Camargo (2019) and Bortoli (2019). In this work it was not possible to obtain more quantitative results that would enable the use of the data for modeling and simulation.

3.2 Pulsed signals

After the eighth pass of the worn tool experiment, the centermost started to show a different type of signal with the temperature peaks, a pulsed signal. The same type of signal was acquired in the middle thermocouple after the tenth pass of the worn tool experiment and in the new tool experiment, the same type of signal was only acquired in the centermost thermocouple in the sixteenth pass.

Figure 3 shows the signal from the middle (a) and centermost (b) thermocouples of pass 16 of the worn tool experiment. These pulsed signals were much greater in magnitude that the peaks of the non-pulsed signals. It was suspected that these signals represented the heat delivered by the tool passage because they wore only acquired when the thermocouples were close to the machined surface.

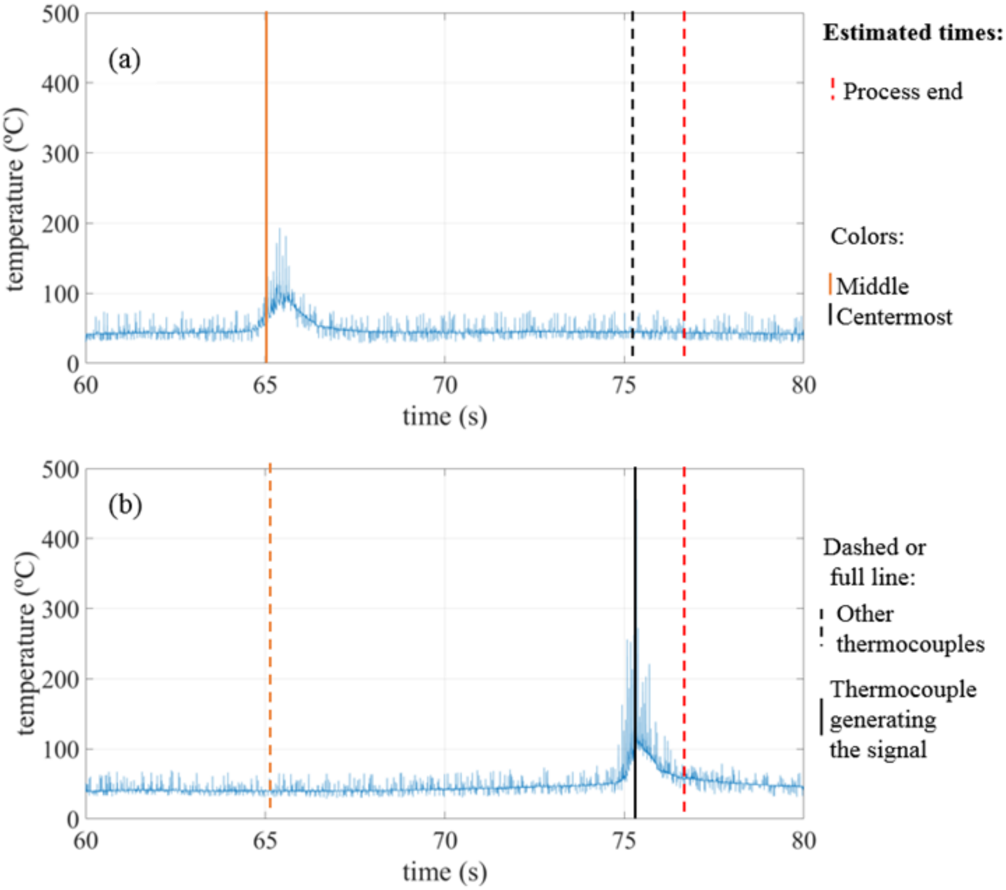

Figure 3. Pulsed signals from pass 16 of the worn tool experiment. (a) Middle thermocouple. (b) Centermost thermocouple.

Figure 4 shows zoomed-in sections of the pulsed signals seen previously. It can be seen that the pulsed signals are composed of a very sudden temperature increase followed by a cooling curve. It should be noted that the pulsed signal also has a higher temperature in the centermost thermocouple than in the middle thermocouple.

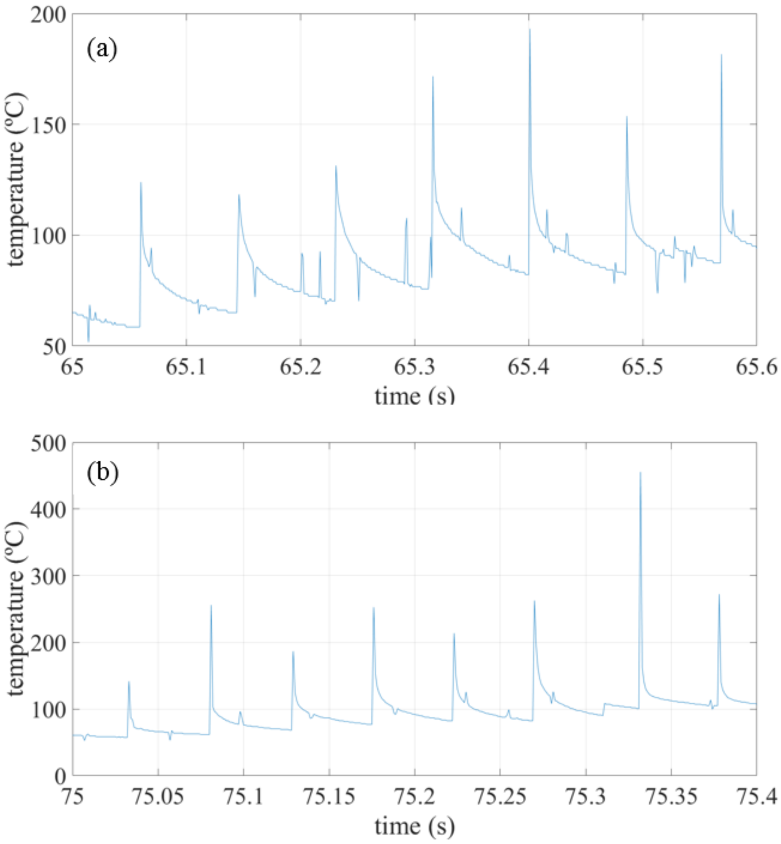

Figure 4. Zoomed in pulsed signals from pass 16.

A Fast Fourier Transform (FFT) was applied to the pulsed signals. The analysis of the FFTs revealed that the pulsed signals had frequencies very close to the theoretical frequencies of the lathe spindle rotation when the tool was above the thermocouples, approximately 13 Hz for the middle thermocouple and 26 Hz for the centermost thermocouple. This is a confirmation that the pulsed signals are caused due to the tool passage.

While the previous signals already confirmed that there was an increase in temperature as the tool approached the workpiece center in radial turning, the pulsed signals show an indication of how the phenomena occur. One probable cause for the phenomena is that with the increase of rotation, the cooling period of an area of the workpiece between the tool passage is shortened. This shortening means a greater heat built-up and results in a temperature increase.

4. CONCLUSION

This research was able to confirm that in radial turning there is an increase in temperature as the tool approaches the workpiece center. Although the results obtained are not enough to develop a model for this increase, one possible mechanism responsible for the increase was identified as being the shortening of cooling time due to the lathe spindle rotation increase needed to maintain the cutting speed constant in radial turning.

The identified cause would mean that an increase in delivered heat, an increase in cutting speed, a decrease in the workpiece's internal radius, or a decrease in heat diffusivity would intensify the phenomena. More research will be necessary to be able to model and identify any other causes for the phenomena.

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6. RESPONSIBILITY NOTICE

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