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In situ strain measurement during a grinding process using a sensor-integrated workpiece

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Abstract

Experimental results of successfully using a sensor-integrated workpiece for in situ measurement of strain during a grinding process are presented. This way the internal process parameters is measured in situ and by doing so the internal loads specific to a machining process can be correlated with the modifications made on the workpiece material due to the process. Integrating sensors directly on the workpiece at the material level for such measurements is a novel concept. The sensors are resistive structures in the form of meanders that were fabricated on wafers made of 42CrMo4 steel (AISI 4140) using standard microtechnology processes. The wafers are cut and rectangular sensor-integrated steel pieces are obtained. Such a piece is embedded into a groove on the top surface of a workpiece using epoxy adhesive. The workpiece is also made of the same steel as the sensor wafers and has a similar metallographic structure due to a pre-defined heat treatment process thereby maintaining the homogeneity of the material. The fabricated sensors are characterized by measuring its temperature co-efficient of resistance and gauge factor. Using the sensor integrated workpiece, grinding experiments were carried out in a Blohm Profimat 412 HSG surface grinding machine and the sensor signal measuring the total strain on the workpiece at various depths was obtained. The signals were later decomposed and the temperature effect was eliminated to obtain the mechanical strain values. An integrated thermocouple was used for reference temperature measurements. The sensor signal is converted into strain using the calibrated gauge factor. Such an application of sensor integration in materials for in situ process monitoring can be used to observe internal mechanical and thermal loads in other manufacturing processes as well

sensor integration in metals, sensor fabrication on steel, sensors for in situ measurement, sensors in manufacturing, process signatures, surface integrity

1. Introduction

The motivation of this work is to integrate sensors in a workpiece for measuring in situ strain and temperature in a manufacturing process. In this way internal loads that are specific for each manufacturing process can be correlated with the corresponding material modifications that are introduced by the various internal loads on the machined workpiece. This concept is termed as *Process Signatures* of manufacturing processes [1]. To create such a workpiece, thin film sensors are fabricated on steel wafers and a so called sensor inlay is obtained from it which is embedded in a workpiece using epoxy glue. The schematic of the process is shown in figure 1. In this paper, such a sensor-integrated workpiece has been used for measuring strain in a surface-grinding process. Previously such a sensor integrated workpiece was used for measuring temperature in a grinding process [2]. In this work a new method of sensor fabrication has been adopted and experiments were conducted to measure strain during the process.

2. Sensor Fabrication and Process Development

Fabrication of the sensor layer on steel wafers was done in a clean room. The wafer material is 42CrMo4 steel and wafers of 150mm in diameter were polished using chemical mechanical polishing. The fabrication process involves sputtering a Ti layer as adhesion promoter between the steel wafer and a bottom isolation layer of Al_2O_3 to protect the sensor layer from the conductive steel substrate. The sensor layer is made of Aluminium film which is 1 µm thick. This layer is structured using photolithography and wet chemical etching to form the shape of meanders. This forms the sensor layer. A top isolation layer of Al_2O_3 is then deposited over the sensor layer for protection from the outside environment. This completes the fabrication process. Rectangular sensor inlays as shown in figure 2 are diced from the fabricated wafers and are embedded in the workpiece as shown in figure 3 for carrying out grinding experiments.

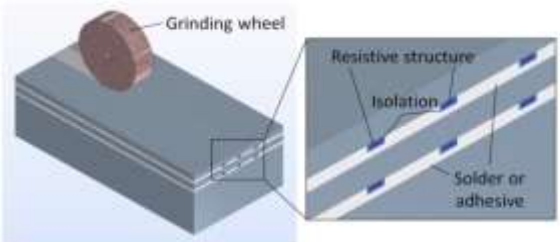

Figure 1. Schematic illustration of in situ measurement with a sensor integrated workpiece in a surface grinding process [2]

The senor pads are connected to an external three-wire quarter bridge circuit for measuring strain and a NI-6009 measurement card from National Instruments is used for data acquisition.

The workpiece is also made of the same steel as the wafers. An additional heat treatment process was utilised to make the workpiece material similar to the sensor inlay material. For embedding the sensor on the workpiece a groove is machined on the top surface (machining surface) of the workpiece so that the inlay fits into it.

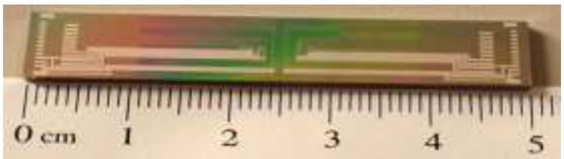

Figure 2. Sensor inlay obtained from fabricated wafers

The sensor inlay was embedded using epoxy adhesive OMEGABOND-200 from Omega Technologies. It has a high thermal conductivity which creates a heat sink between the sensor inlay and the workpiece and the heat can be evenly distributed. This is important because the workpiece is supposed to have a continuous distribution of thermal and mechanical energy at the location where the sensor inlay is embedded and the measurements are taken.

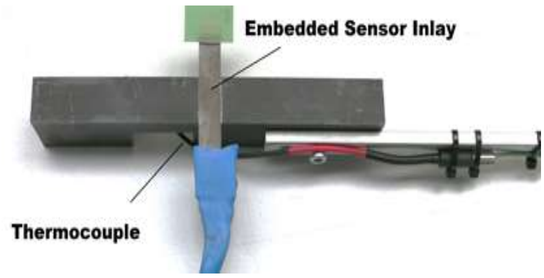

Figure 3. Sensor inlay embedded on the groove upside down. Only the sensing part is connected to the workpiece and the electronics are free from the contact zone. Thermocouple used for reference temperature measurement

3. Grinding Experiment

The experiments were carried out on a surface grinding process with grinding parameters as shown in table 1. Grinding was done on the workpiece at 2mm above the sensor layer taking off the depth of cut a_e at every step. Measured data from the sensor layer was acquired with a decreasing distance from the contact zone until the substrate was ground down and the sensor layer was destroyed.

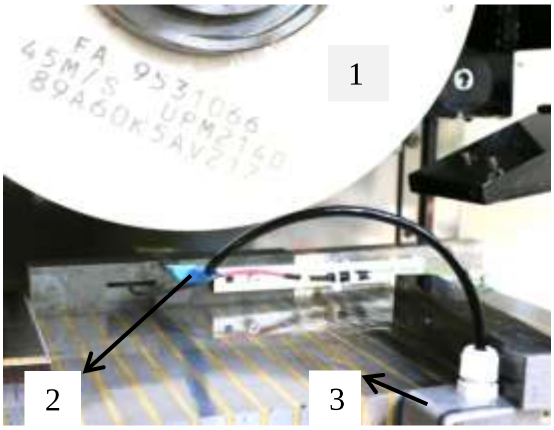

Figure 4. Experimental set-up: 1) Grinding wheel, 2) Workpiece with embedded sensor inlay, 3) Box with measurement electronics

The grinding machine is equipped with a three-component piezoelectric force measurement system to record the process forces as external loads during the grinding process. The process time is about 10s with the tangential workpiece feed speed of 1m/min and a total workpiece length of 160 mm. The sensor inlay is positioned in the middle of the workpiece and is run over after about 4.5 s until about 5.1 s after establishing contact of workpiece and grinding wheel. The experimental set-up is shown in figure 4.

Table 1 Grinding parameters

material	AISI 4140 (224HV1)	**cutting speed**	v_c = 30 m/s
process	Surface grinding	**feed speed**	v_{ft} = 1 m/min
tool	89A60K5AV	**depth of cut**	a_e = 50 µm

4. Results

At every grinding step the sensor response is recorded at a sampling rate of 10 Hz. Simultaneously thermocouple data is recorded. The sensor output consists of both the effect of mechanical strain and temperature. The temperature effect is corrected using the calibrated temperature co-efficient of resistance of the sensor layer. The strain measured is the process induced strain in the workpiece. In figure 5 the maximum value of the measured strain at every grinding step is shown along with the maximum value of the externally measured force on the sensor inlay. From the result it can be seen that the internal strain increases as the tool comes closer to the sensor layer but the external forces remain relatively constant. An outlier in step 7 can be seen in both curves indicating that a change in the process was measured simultaneously by both methods.

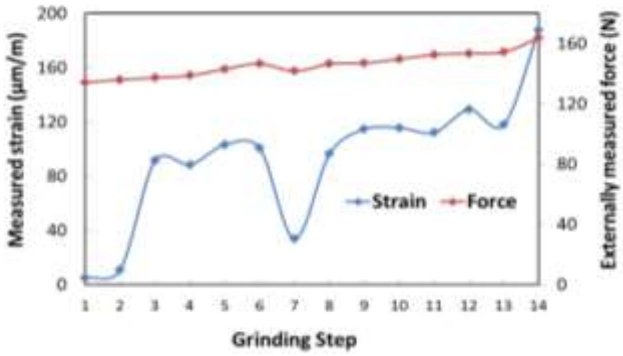

Figure 5. Measured data showing maximum strain and maximum normal force measured externally at the sensor inlay during every grinding step.

5. Conclusion

In this work it has been shown that it is possible to measure in situ strain with the use of a sensor-integrated workpiece. The significance of the measurements was obtaining the internal loads (mechanical strain) during the process. To generate transfer functions of internal loads that results in identifying material modifications independently from the process, the measurement technique needs to be validated in the future.

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