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Press hardening tool integrated thin film temperature sensor

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Abstract
Controlling of process parameters like temperature is crucial in technical applications of all kinds. But there is only a certain amount of processes where detecting of temperatures is even a matter of safety. One is the press hardening of chassis parts in the automotive industry. The simultaneous forming and microstructural transformation requires a temperature rise of at least 27 K per second to fabricate martensitic phase with a tensile strength of more than 1,500 MPa. In terms of quality assurance a 100 % accurate monitoring of this gradient is necessary to guarantee the desired material properties. So far several concepts like optical measurements or tool integrated standard thermocouples have been evaluated. These either influence the thermal transport or don't have the required sensitivity. A possible solution is the use of a thin film sensor on the surface of the forming tool. Its heat capacity is very low, which increases the sensitivity and minimizes the influence on thermal transport. However micro technical approaches of depositing and structuring are usually performed on flat substrates. To fabricate microsystems on top of tools made of steel, different challenges like surface flatness, electrical contacting and abrasion resistance need to be overcome. This work focuses on the manufacturing of temperature sensors on the surface of a press hardening tool's steel by means of thin film deposition and structuring. A combination of photoresist spray coating and laser direct imaging in comparison to direct coating using shadow masks for the thermo resistive and thermocouple sensor were analysed. Both concepts were realized and briefly characterized in terms of reliability and response behaviour.

Hot forming, press hardening, thin film, PVD, temperature sensor, thermocouple, laser direct imaging and spray coating

1. Introduction

Bringing micro technical elements like sensors in or on parts and tools is a promising approach for the acquisition of relevant process data [1]. In this case a rough environment, the surface of a press hardening tool, was chosen for the temperature measurement of press hardened plates. This is crucial for the quality assurance of martensitic phase formation [2]. Known concepts using pyrometers or buried thermocouples either impair the thermal transport or provide imprecise data through a separation from the signals source [3]. In this work thin film sensors will be presented, which are directly applied on the contact area of a tool steel surface using techniques of micro technology. A set of exchangeable sensor carriers with both thermocouple and Pt 100 temperature sensors was manufactured and tested. Figure 1 shows a draft of the result of a transient thermal simulation of the cooling process after seconds in the planned setup.

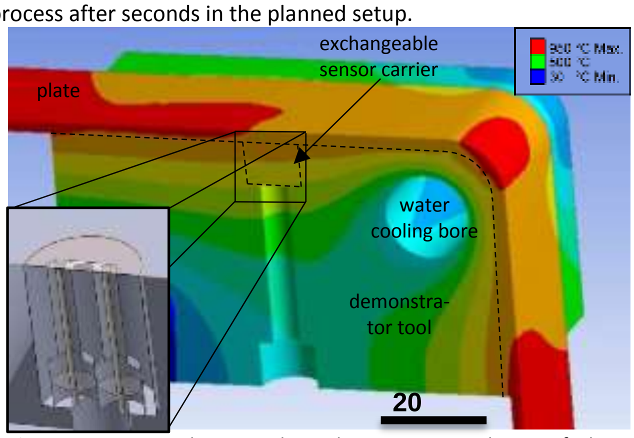


Figure 1. Section drawing: thermal transient simulation of the temperature distribution in plate, demonstrator tool and sensor

2. Manufacturing

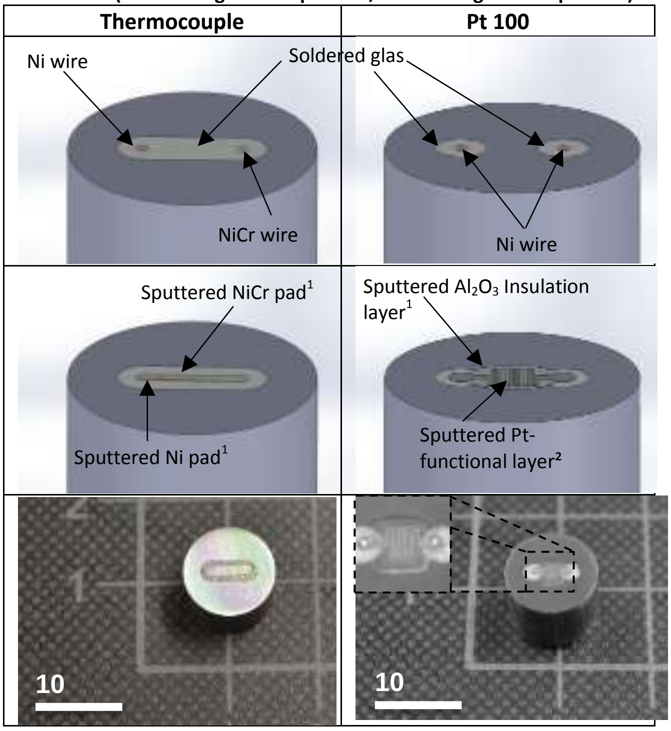
To fabricate both sensor concepts on the polished tool steel (1.2367) surface with vertical interconnections made of soldered glass and metal wires several difficulties had to be overcome [6]. The thermocouple sensor has significantly lower requirements concerning the surface quality (roughness and planarity) then a Pt 100 element. Where the first concept needs a geometrical non defined electrical contact between Ni and NiCr pads, the latter concept responds very sensitive to inhomogeneity's of the substrate. The electrical resistance, which is the measured value, is dependent on the temperature, the length and the sectional area of the Pt meander. Following the results of polishing, the thermocouple can be applied on the fairly polished partly crystalline composite glass (R_a<0.1 µm) and the Pt 100 element has to be applied to the high quality polished steel (R_a<0.01 µm) in the middle of two electrical feed troughs or rather vias. In table 1 the initial state of the different prepared substrates and the main steps of manufacturing are shown.

The thermocouple sensor is properly working by using the correct materials. Using the Pt 100 a further processing (ion mill trimming) is necessary to obtain the characteristic resistance of roughly 100 ohm at 0 °C. After manufacturing of the functional structures an isolation and wear resistant layer was applied to both sensors. A promising material Al_2O_3 [5] was chosen and PVD coated with a total thickness of 3 µm. All PVD coatings where deposited with a Kenotec RF (13,56 MHz) 6,5"magnetron sputter device.

2.1. Direct sputtering using shadow masks

Structured thin films with a pitch of more than 300 µm can be realized by the use of milled sputter masks (Fig. 2). This basic technique allows flexible and cost effective structuring on 3D

Table 1 Main steps of manufacturing thermocouple and Pt 100 sensors. ([1]structuring acc. chapter 2.1, [2]structuring acc. chapter 2.2)



substrates. To overcome the resolution limit laser cut metal sheets or etched silicon substrates can be used [4]

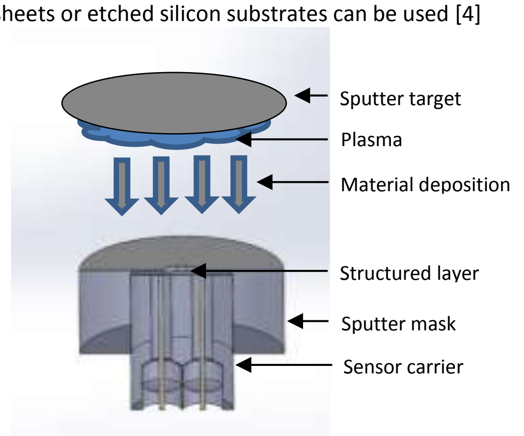


Figure 2. Section drawing: shadow mask direct sputtering on steel substrates

2.2. Spray coating of photoresist and laser direct imaging

For the deposition of structured layers with a pitch down to one µm a spray coating of photoresist (MicroChemicals AZ5214:PGMEA 2:1) with an airbrush system followed by a laser direct imaging using an adapted LPKF ProtoLaser LDI was used. After developing the photoresist with AZ351:H2O 1:4, the functional layer of Pt was applied by sputtering. Afterwards the resist was stripped with acetone and the structure was obtained.

3. Characterisation

A briefly characterisation concerning the response behaviour of both sensors was performed. By means of a thermo-shock test both sensors were manually contacted to a heated steel plate of 950 °C. Both signals where recorded with a data logger and are shown in fig. 2.

4. Results and Discussion

Two typical temperature sensors (thermocouple type-K and Pt 100) have been applied on exchangeable sensor carriers made of tool steel with vertical electrical feedthrough. The different concepts were realized by adaption of micro production techniques to non-flat technical substrates. In thermal contact to a hot steel plate the sensors showed a gradient of more than 15 K / s. Furthermore the maximum temperature at the thermocouple is below the expected value. The low gradient and accuracy are probably caused by the insufficient contact between sensor and plate in the manually performed test. In case of the thermocouple heated contacts could also be a cause. No damage could be observed after the tests.

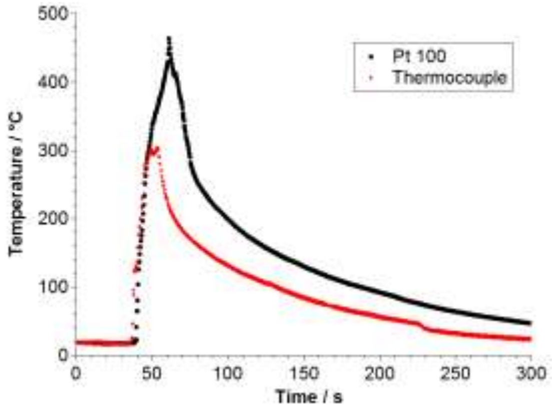


Figure 2. Thermal response of the sensors in contact to heated a steel plate

4. Outlook

Further characterisation will take place in a production environment of press hardening, where the sensors will be tested under real conditions.

Acknowledgements

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