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Interaction of heat generation and material behaviour in sheet metal blanking

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ABSTRACT

A temperature rise occurs in the sheet metal and tool parts due to the dissipation of a large part of plastic work during blanking. The resulting temperature in the shearing zone has various impacts on the process. The correlation between the temperature rise and sheet metal behaviour under varying process parameters is investigated. Causal associations can be shown by in-situ measurements of the dynamic temperature development at the cutting edge of the punch and analyses of the sheet metal behaviour. The presented results provide essential knowledge for further experimental, analytical and numerical blanking investigations.

1. Introduction

During sheet metal blanking, the workpiece material is exposed to different stress conditions. Through these stresses, the material undergoes elastic and plastic deformations until crack formation results in a complete separation of the material. Therefore, a defined amount of blanking work is needed. Most of the work is expended for the macroscopic plastic deformation of the sheet metal. Up to 95% of plastic deformation work is converted into heat [1] and only a small fraction is stored in the structure of the material [2]. Thus, the dissipation of inelastic deformation work provokes a noticeable temperature rise in the shearing zone and the contacting tool parts.

There is a great deal of interest to know details about the heat generation due to its diverse effects on the blanking process. The heating of the sheet metal and tool parts during blanking may directly affect the material behaviour and, therefore, the workpiece quality and tool life. In addition, the temperature is an essential selection criterion for the choice of the right lubricant and tool coating. Thus, a comprehensive understanding is crucial for progress as well as to avoid economic losses.

Numerous investigations on the heat generation have been conducted since the 1960s. Experimental studies were carried out using different measurement techniques. Besides embedded thermocouple, tool-workpiece-thermocouple and radiation thermometry, metallographic analyses of the blanked surface were performed. The reported measured maximum temperature occurring during blanking in the sheet metal and tool parts differs between the studies within the range of 50 °C [3] and 600 °C [4]. The heat generation in the shearing zone during blanking was also analyzed in various numerical simulations, e.g. in [5]. Maximum temperatures in similar order of magnitude as those observed in the experimental studies were presented.

The large variances in measured temperatures can be mainly traced back to the commonly missing of a clear geometric and temporal evaluation of the temperature data, an insufficient measuring methodology as well as the disregarding of measurement uncertainties. In addition, many studies reported only maximum temperature values instead of a detailed temperature progress. Temperature values derived from numerical simulations highly dependent on the selected input parameters and material models. Thus, mistaken assumptions and boundary conditions may lead to significant deviations of calculated absolute temperature values. Furthermore, studies involving process parameter variations are often limited to experiments with different sheet metals. Based on the literature, a reliable statement about the influence of the temperature rise on the blanking process cannot be currently taken due to the large variances of reported temperature values.

Hence, the dynamic temperature development at a precise defined measurement point under varying process parameters is experimentally investigated in this paper. In combination with numerical and experimental analyses of the sheet metal behaviour, a detailed evaluation of the recorded temperature profiles is possible. In addition, causal associations can be derived.

2. Experimental setup

2.1. Principle of temperature measurement

The measuring system has to meet several requirements in order to get reliable results. Besides a defined geometric measurement point, a small time constant of just a few milliseconds is necessary. The temperature sensor also must be

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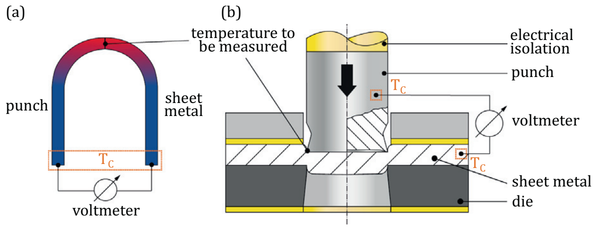

Fig. 1. (a) Schematic thermocouple circuit and (b) tool-workpiece-thermocouple principle for in-situ temperature measurement in blanking.

able to withstand cyclic loads and should not disturb the process, in particular the tribology. Thus, commercially available sensor systems are of limited use in precise temperature measurement during blanking. A measuring system based on a tool-workpiece-thermocouple principle fulfils all these requirements and was therefore developed and implemented in a blanking tool. Its functional principle results from the different thermoelectric properties of the tool and the sheet material [6]. The punch and the sheet metal build the pair of conductors of the thermocouple, which are connected by wires with a voltmeter, as schematically illustrated in Fig. 1a.

During blanking, the cutting edge of the punch and the sheet metal build the measurement junction due to their intimate mechanical as well as electrical contact. Undercuts on the lateral and the face area of the punch guarantee a defined and localized contact (Fig. 1b). Right to this contact, the deformation of the sheet metal is at a maximum and a huge amount of the plastic work dissipates. The cutting edge and the sheet metal respectively are locally heated and a thermodiffusion of charge carriers in the punch and sheet metal is induced. As a result, a potential difference can be measured with a high-resistance voltmeter. The potential difference represents an accurate measure of temperature difference between the measurement junction and the contacting of the connecting wires. To avoid spurious electric contacts and disturbing offset voltages of fluctuating ground potentials, the pair of conductors is completely electrically insulated from the surrounding blanking tool and press frame by ceramic parts (see Fig. 1b electrical isolation). In order to derive a correlation between the measured thermoelectric voltage and the prevailing temperature, a calibration of the tool-workpiece-thermocouple is required. A detailed description of the calibration setup and procedure can be found in Demmel et al. [7].

This measuring system can practically measure the temperature change without any time delay. Due to the not required heat transfer from the measuring object to the sensor and the very high dynamic of thermodiffusion, with a response of just a few femtoseconds, an instantaneous detection of the temperature is possible. The geometric resolution is defined by the contact area between the punch cutting edge and the sheet metal. This contact area amounts just a few square micrometres.

2.2. Investigated materials

For reliable temperature measurements, a punch material with uniformly metallurgical and consequently constant thermoelectric properties has to be chosen. The punch is manufactured of the hard metal grade CF-H40S from Ceratizit Deutschland GmbH. CF-H40S is a powder metallurgical two-phase material with high homogeneity and a hardness of 1400 HV10.

The uncoated hot rolled fine grained steel S355MC with a thickness of 6.0 mm was used as sheet material. It is typical steel for cold forming and blanking operations with a yield strength of 430 MPa and a tensile strength of 480 MPa.

2.3. Blanking conditions

The tool-workpiece-thermocouple was built up in an extremely stiff and modular blanking tool with four-pillar construction. A circular punch with a diameter of 70 mm achieves a rotationally symmetrical homogenous deformation as well as dissipation in the shearing zone. The cutting edge of the punch was chamfered to a radius of 20 μm by grinding. By changing the dies, clearances of 0.06, 0.24 and 0.48 mm can be easily adjusted. The die cutting edges were manufactured with a radius of 0.2 mm. All tests are performed without the use of lubricants.

Blanking experiments were carried out on a hydraulic fine-blanking press of the type HFA 3200plus from Feintool AG. Blanking examinations were conducted in single stroke modus at adjusted punch velocities of 10, 40 and 70 mm/s.

The blanking simulation was performed at the commercial FE program Abaqus/explicit v6.12. Temperature, strain and strain rate dependent mechanical sheet metal properties for the elastic–plastic material model were recorded in compression tests.

2.4. Measurement technology

Several sensors are integrated in the blanking tool for monitoring important process data. Piezoelectric load washers enable the acquisition of the punch force and a length gauge is used to measure the punch travel during blanking. In order to obtain an absolute temperature value from the thermoelectric measurement, the temperatures T_C at the contacting of the connecting wires (Fig. 1b) have to be measured. Calibrated high-precision temperature sensors with an accuracy of ±0.1 °C detect these temperatures and guarantee a high repeatability of the tool-workpiece-thermocouple measurements.

A pre-amplification and filtering close to the tool-workpiece-thermocouple are essential due to the harsh environment in the test area and very low thermoelectric voltages. Therefore, a precision instrumentation amplifier was build up with a gain of 100. At the output of the amplifier, a built-in active low pass filter with a cut-off frequency of 44 kHz and Bessel-characteristic is integrated to minimize noise. The gain of the active low pass filter accounts 10. The analogue to digital conversion of the thermoelectric signal is performed by a high-accuracy data acquisition board with 18-bit analogue input accuracy and a sampling rate of 625 kHz. The expanded uncertainty for a confidence level of 95% is less than 6 °C for the whole tool-workpiece-thermocouple measurement system up to a measuring temperature of 400 °C.

3. Results and discussion

3.1. Characteristic interaction of sheet metal behaviour and heating during blanking

The heat generation during blanking, represented by measured temperature profiles, has similar characteristic features regardless of the chosen process parameters. Five phases can be distinguished with increasing punch penetration into the sheet metal until reaching the bottom dead centre (Fig. 2a). Important steps in the blanking process are illustrated in Fig. 2c.

At the beginning of the blanking process, the sheet metal is elastically deformed. The elastic deformation is induced by a sharp rise of the blanking force. In the first phase, a defined electrical contact is made between the punch and the sheet (Fig. 2a, phase 1). Measured temperatures in this phase do not display real temperatures and are therefore hidden. After an excellent electrical contact is guaranteed, the temperature starts in phase 2 at an elevated temperature to room temperature (22 °C) due to frictional heating between the cutting edge of the punch and the sheet metal surface.

In the following phase 3, the elasticity limit is exceeded and the sheet metal is plastically deformed. First rollover and then clean-cut is formed at the blanked part and the punching scrap. The transition from elastic to plastic deformation is accompanied by a degressive increase of the blanking force. Due to the plastic deformation of the sheet metal, the blanking work as well as the dissipative portion increases. The expended blanking work in this