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Influence of lubrication on the measured thermoelectric voltage and temperature in the forming zone when embossing S355MC

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Abstract

Cold Metal Forming is one of the most frequently used sheet metal manufacturing processes because of high material efficiency, accuracy grade and surface quality as well as short cycle times of the produced parts. In order to reach the requirements for both quality of the components and process stability, minimizing tool wear is one of the main aims in this field. One of the most influential factors on wear development is the occurring process temperature. The dissipation of more than 80 % of the plastic work as well as frictional heating lead to a severe temperature rise in the forming zone, especially during processes with high tension between tool and workpiece respectively high strain rates like embossing and blanking. Beside the influence on the mechanical properties of the materials, the temperature rise causes thermoelectric voltages and currents. These thermoelectric phenomena in combination with the occurring temperature reinforce the wear mechanisms Adhesion and tribochemical reaction, which determine the tool wear development because they can appear right from the beginning. State of the art is the application of lubricants in order to minimize temperature and consequently wear by reducing friction, removing heat and building reaction layers due to the additives. However, in order to improve the understanding of the interactions between the surfaces of the tool and the sheet metal precise measurements of the temperature as well as the occurring thermoelectric voltages are essential. This report shows the measuring concept and the appearing thermoelectric voltage, current and temperature during blanking S355MC.

Keywords: Embossing, Blanking, Thermoelectricity, Temperature Measurement, Lubrication

1 Introduction

Cold metal forming belong to the most frequently used production processes in sheet metal processing because of a high material efficiency, accuracy grade and surface quality of the produced parts. In addition, cost efficiency, which depends primary on cycle time, process stability and tool service life, plays an important role considering mass production. The predominant factor regarding the manufacturing process is tool wear. Thus, one of the main targets is to minimize wear in order to improve profitableness of the process.

Very susceptible to wear are processes, characterized by high process tensions between tool and workpiece as well as high strain rates, like embossing or blanking. Embossing as described by DIN 8587 consists of the displacement of one zone of the workpiece relative to the adjacent zone, usually by means of the linear movement of a mobile tool relative to the edge of a fixed tool [1]. It is often used together with fine blanking processes, which can be described as an embossing operation beyond the specific shear fracture limit for the material [2].

To reach the aim of wear minimization even in the abovementioned processes state of the art is the application of lubricants. They effect amongst others a reduction of temperature in the forming zone and influence interactions between the tool and the workpiece surface positively. Nevertheless, produced parts have to undergo a complex treatment process in which lubricants are removed. Thus, economic and ecological reasons make it necessary to control forming processes without any application of lubricants [3].

Lubricant free forming results in intense interactions between the surfaces of the tool and the workpiece as well as an increasing temperature [4]. Considerable wear, clearly reducing the reachable durability of the used tools

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and the cost-effectiveness of the process, are consequences. A quantitative prediction of wear development under these circumstances is not possible because wear causing interactions are poorly analyzed. To counteract these consequences, it is unavoidable to improve the understanding of the wear phenomena by investigating also electrical and thermal influences beside mechanical processes [5].

A central issue in this field is the temperature in the forming zone and resulting thermoelectric effects. Adhesion and tribochemical reaction are especially influenced by both parameters [6]. These wear mechanisms can appear right from the beginning and build the basis of the development of other wear mechanism.

For a forming operation, a defined amount of work is needed. The work consists of small part caused by friction and a major part required for plastic deformation of the sheet metal. The dissipation of up to 95 % of the forming work [7] and additional frictional heating cause a significant temperature rise in the forming zone [8]. Several investigations on the temperature were performed during blanking processes. The observed temperature maxima appear before ductile crack initiation, which makes these results very comparable to temperatures occurring during embossing. However, results differ extremely because of the diverse measuring methods. A very precise measurement can be realized by a tool-workpiece-thermocouple as used by Demmel who observed temperatures up to 270 °C. He also investigated the impact of lubricant application stating that the maximum temperature is even higher when lubricants are applied. Only after the temperature maximum, the lubricant lowers the temperature distinctly. [9]

However, not only the thermal factor affects wear but also the occurring thermoelectric phenomena. A relation between thermoelectric effects and tool wear has yet been verified by various reports but only in the field of machining. Opitz et al. investigated amongst others a turning process in which he measured a thermoelectric current of 5 mA. By applying an external electric current in counter direction, he was could more than double the tool life [5]. Awakov and Ritschkin could demonstrate similar results for drills made out of tool-steel and cemented carbide [10]. Other investigations came to contradictory results when investigating the electrical isolation of the tool. Hehenkamp found out that an isolation of the turning tool does not influence the wear development [11] whereas Bobrovskij came to an opposite result during drilling [12]. An electrical insulation prohibit the grounding of the tool, which leads to the flow of thermoelectric currents through the active elements. In various other investigations could be shown that the direction of the thermoelectric current has an enormous impact on tool wear, which can also be the explanation for the differing results when isolating tools. [13; 14; 15]

The abovementioned results suggest that an external manipulation of the thermoelectric currents and voltages could be used in order to minimize tool wear even without any use of lubricants. Nevertheless, before influencing a process externally it is first essential to get to know the values of thermoelectric voltage and current as well as the temperature occurring during the forming process. Thus, this report investigates the temperature development in the forming zone as well as the thermoelectric voltage during blanking with regard to the influence of lubrication

2 Principle of Thermoelectric Measurement

Thermoelectric currents and voltages arise if two different electrical conductors are connected in an open electrical circuit and a temperature gradient between the junctions occurs. This induces a thermodiffusion of charge carriers, which leads to a quantified thermoelectric voltage. The amount of the voltage and current are proportional to the temperature gradient between the ends of the conductors and the contact point. [16]

According to this principle, thermoelectric parameters can also be measured in a forming tool. From the point when the cutting edge of the punch touches the sheet metal an electrical contact arises. This contact persists until the end of the stroke and is similar to the junction of a normal thermocouple. This measuring set-up is called tool-workpiece-thermocouple and enables an instantaneous measurement of thermoelectric voltages during the blanking process in-situ at the origin of the thermoelectric phenomena, the contact point of the punch and sheet metal. The tool-workpiece-thermocouple after Demmel is shown in Figure 1.

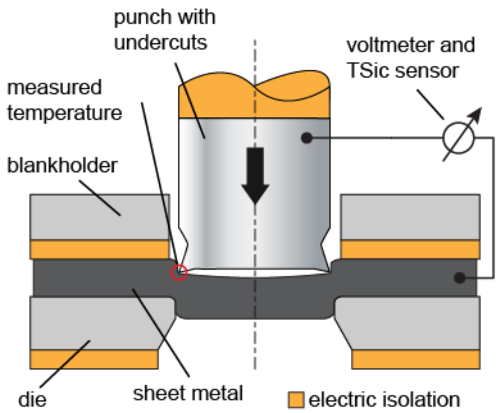

Figure 1. Tool-workpiece-thermocouple for measuring thermoelectric voltage and temperature after [8]

At the area around the cutting edge, the sheet metal is strongly deformed and the dissipation of plastic work heats the punch respectively the sheet metal. Consequently, a temperature gradient emerges in the tool inducing a quantified voltage, which can be measured with a voltmeter built in the tool and connected to the punch and sheet metal. By recording this occurring voltage, it is possible to calculate temperature if the punch and sheet metal materials were calibrated before. This calibration is not part of the paper and can be read in [17]. The quality of the temperature measurement depends on a precise determination of the environmental temperature. For this reason, a TSic sensor measures the surrounding temperature with an accuracy of ± 0.07 °C from IST AG (Ebnat-Kappel, Switzerland).

3 Experimental setup

3.1 Materials

Quality of the measurement with a thermocouple depends on the thermoelectric characteristic of the materials as well as the homogeneity. Materials with a high Seebeck-coefficient generate more thermoelectric voltage when heated and improve temperature measurement. However, the recurrent mechanical strain in the tool limits the choice of materials to such normally used in forming tools.

The punch is made of CF-H40S from Ceratizit Deutschland GmbH (Empfingen, Germany). This cemented carbide meets the mechanic as well as the thermoelectric requirements as tool material. Due to its high resistance to wear, fracture toughness and homogeneity CF-H40S is often used especially in blanking operations.

For the recent investigation a S355MC with a thickness of 4 mm is used as sheet metal material. This microalloyed fine-grained steel has a homogenous structure because of a hot rolling process and is very common in cold metal forming applications. Figure 1 shows the chemical composition of both materials.

Tab.1: Chemical composition of the (a) tool-(b) workpiece-thermocouple-materials in weight-percentage

(a) CF-H40S

WoC	Co
88	12

(b) S355MC 4 mm

C	Si	Mn	P	S	Cr	Ni	Mo	Fe
0.09	0.01	0.47	0.01	<0.01	0.02	0.03	<0.01	balance

3.2 Lubricants

Two different types of lubricants from Wisura GmbH (Bremen, Germany) with the trade names ZO 3368 and AK 3080 are investigated. Both lubricants are commonly used in the field of metal forming especially when blanking Aluminum or stainless steel alloys. AK 3080 is based on fatty alcohols without any additives whereas ZO 3368 has additional additives like phosphor. Both lubricants are free from chlorine and heavy metal. For the experimental investigations, lubricants where applied by a brush which means a quantity of about 20 g/m^2 is applied on each side of the sheet metal [18].

3.3 Blanking Press

The pratical experiments were performed in a hydraulic fine blanking press of the type hfa 3200plus built by Feintool AG (Lyss, Switzerland). The triple action press has a maximum pressing force of 3200 kN and offers an independent controlling of the blankholderforce. The punch velocity is continuously adjustable between 5 and 70 mm/s.

3.4 Blanking tool and process parameters

The tests were carried out on a four-pillar tool with a modular structure offering the possibility of varying die clearances (the distance between the immersed punch and the die), tool materials and other parameters. The high stiffness in conjunction with locking bolts, which station the blankholder when touching the sheet metal, provide the use of very small clearances.

Ceramic components on the die, the blankholder and the punch guarantee an electrical insulation of the active elements and impede contact between the tool-workpiece-thermocouple and the residual tool respectively the press frame. Due to high mechanic forces, zirconium oxide characterized by a high fracture toughness and compressive strength from BCE special ceramics GmbH (Mannheim, Germany), is attached.

Forming and blankholder forces are measured by piezoelectric load cells and the punch as well as the blankholder travel are both measured with a length gauge.

The punch is circular with a diameter of 70 mm and a relative die clearance of 1.5 % (0.06 mm) was adjusted. The Punch velocity was set to 70 mm/s.

3.5 Signal Conditioning

Thermoelectric voltages generated by materials like steel or carbide are in the range of maximal a few millivolts at temperatures of about 400 °C. The experimental environment in the press is full of electromagnetic interfering signals, which disturb the recorded thermoelectric voltages in the tool. Therefore, an amplifier with a gain of 100 is built in the tool as near as possible to the tool-workpiece-thermocouple. The amplifier is based on the LT 1167 from Linear Technology Corporation (Milpitas, USA). To avoid signal disturbance a low noise and hum-free power supply was realized by batteries, which guarantees a high accuracy of the measurement. A low pass filter with a cut-off frequency of 44 kHz and Bessel-characteristic suppresses high frequency interferences after amplification. Finally, a high-accuracy data acquisition board from National Instruments (Austin, USA) records the processed voltage signal with an 18-bit analog input accuracy and a sampling rate up to 625 kHz.

4 Results and Discussion

With the abovementioned measuring setup, several blanking and embossing examinations were carried out. The thermoelectric voltage is measured during blanking operations, which is similar to an embossing operation with the difference that the punch penetrates the sheet metal beyond the specific shear fracture limit for the material. The sheet metal is parted and the slug can fall through the die and no part ejector is needed. Furthermore, the mechanic strain of the cutting edge is less and the durability of the used punch is longer. Temperature profiles until the fracture of the material are the same for both processes. Smallest die clearances typically used for embossing operations are also transferred to the blanking set-up.

Figure 2 depicts the plot of the thermoelectric voltage, the temperature as well as the cutting force during one punch stroke related to the punch travel. The thermoelectric voltages are shown for blanking with both lubrication and without. The experiments showed that the blanking force does not depend on the applied lubricant, which is why only one force plot is illustrated. There is only the lubricant free temperature plot illustrated because of the correlation between thermoelectric voltage and temperature. Relative changes in the thermoelectric voltage are equally transferable on the occurring temperature.

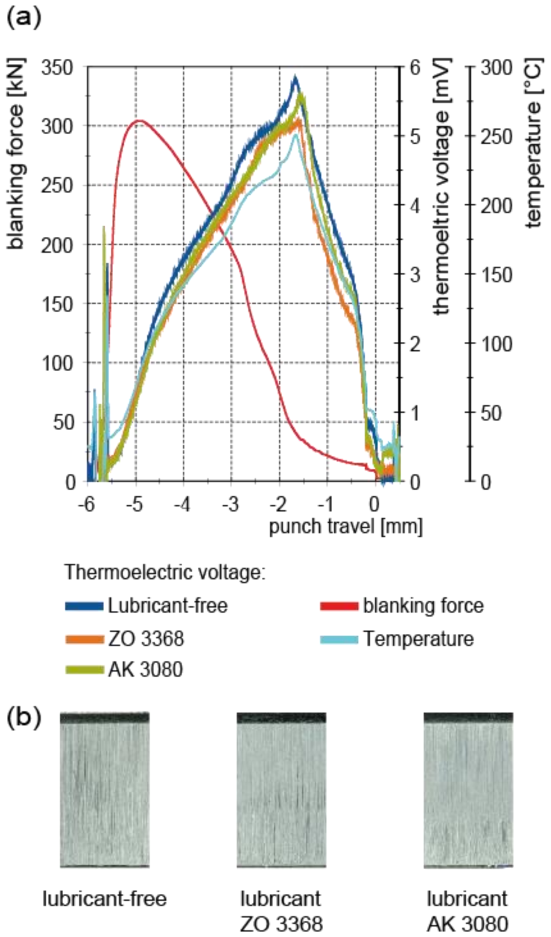

Figure 2. Temperature, thermoelectric voltage and blanking force represented over the punch travel (a) as well as the cutting surfaces of the blanked parts

In the beginning of the blanking operation at 5.9 mm before the bottom dead center, the punch and the sheet metal get into contact. The thermoelectric voltage emerges from different electric potentials of the sheet metal and the punch which results in electrical charge balancing. Therefore, the first maxima do not occur because of a temperature increase.

Following, the characteristic plot of the thermoelectric voltage rises strongly due to the heating of the forming zone by dissipation of the performed forming work. Above all the very small die clearance leads to 100 % clean cut and no fracture of the sheet metal occurs. The cutting surfaces are similar regardless of lubrication is applied or not (Fig. 2, b).

Right before the punch breaks through the sheet metal at -1.5 mm the thermoelectric voltages reach their maxima. The highest value is obtained when blanking without any lubricant. A temperature of 250 °C causes a thermoelectric voltage of 5.8 mV. If the lubricant AK 3080 is applied, the occurring maximum thermoelectric voltage lowers to 5.5 mV implying a temperature of 240 °C. ZO 3368 drops the thermoelectric voltage to 5.2 mV and a measured temperature of about 225 °C. Therefore, the impact of lubrication on the maximum temperature respectively the thermoelectric voltage is about 10 %.

After the maximum peak, the part is separated completely and the temperature drops to starting temperature because no plastic work dissipates anymore and the blanking force is only needed to push the slug deeper into the die. Forces are relatively high because of the small die clearance resulting in high friction between the slug and the die. However, the impact of friction between slug and die as well as punch and sheet metal on the temperature is very low and therefore negligible. Temperature transferred from the sheet metal to the punch leads to a small temperature increase of the cutting edge at the bottom dead center. Due to the high material quantity in relation with a relatively small area on the cutting edge where temperature rises, a full temperature equalization is completed after a short time and the starting temperature is reached except fast continuous stroke processes.

5 Summary and Outlook

In the present research report, the influence of lubrication on the thermoelectric voltage characteristics during a blanking operation was investigated. The thermoelectric voltage was measured based on a tool-workpiece-thermocouple. The use of this principle enables an instantaneous measurement of the thermoelectric voltages arising at the junction between the cutting edge of the punch and the sheet metal. A foregoing thermoelectric calibration of the punch and sheet metal material enables the derivation of the temperature from the voltage characteristics.

A maximum temperature of 250 °C was measured which results in a thermoelectric voltage of 5.8 mV. The impact of lubrication is contrary to the expectations and lowers the temperature negligible by a maximum of 10 %. Heating in the forming zone is caused by plastic work dissipating into heat and frictional heating. About 95 % of the plastic work dissipates into temperature, which makes up the biggest contribution to the temperature development. Lubrication only affects friction and frictional heating causes only a small impact on the temperature development in the forming zone.

Currently, more tests are carried out in order to analyze the relation between thermoelectric phenomena and wear. Furthermore, a stainless steel and an aluminum alloy will be investigated with regard to temperature and thermoelectric parameters. Finally, this research project will analyze the fundamental interactions between the surfaces of the tool and the sheet metal in order to handle forming processes without any use of lubricants.

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