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Thermoelectric currents and their impact on wear behavior of punches during embossing operations

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Abstract

The profitability of forming processes strongly depends on tool life. On this account, the main goal is to minimize tool wear. During forming operations, the four main wear mechanisms adhesion, abrasion, tribochemical reaction and surface breakdown appear. Abrasion and surface breakdown depend on the stress conditions and normally occur after several strokes. Adhesion and tribochemical reaction can appear right from the first stroke and are mainly triggered by temperature. Beside the known mechanic parameters influencing wear behavior like the die clearance, there are other aspects insufficiently examined. Thermoelectric currents and voltages occur in every forming tool and their influence on wear behavior has already been proven in the field of machining. However, there are no investigations on these currents and their impact on wear behavior in a forming tool. In this report, thermoelectric currents during lubricated and dry embossing respectively blanking operations were measured. Furthermore, their impact on adhesion and tribochemical reaction was examined.

Keywords: Embossing, Blanking, Thermoelectric currents, Wear, Adhesion

1 Introduction

Wear is the progressive loss of material from the surface of a solid body, caused by mechanical reasons like contact and relative movement of a solid, liquid or gaseous counter body [1]. It is the determining factor regarding tool´s life cycle time and therefore it should be minimized in order to maximize profitability. There are four different wear mechanisms determining wear behavior of the active elements in a forming tool: Adhesion, tribochemical reaction, abrasion and surface breakdown [2]. Occurring wear is always an interaction of all mechanisms but which of the mechanisms is paramount depends on the boundary conditions in the tool. Abrasion and surface breakdown are triggered by stress conditions. They normally occur after several strokes. Adhesion and tribochemical reaction are temperature-induced wear mechanisms, which can appear right from the first stroke. [3] However, beside temperature itself there are electric effects caused by temperature and having a strong influence on wear behavior of the tool [4].

Temperature development in a forming tool strongly depends on the forming process. High process tensions between tool and workpiece as well as high strain rates result in high temperatures in the forming zone. In turn, such processes are very susceptible to adhesion and tribochemical reaction [5]. Embossing respectively blanking processes belong to this category of manufacturing processes. Embossing is defined as 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 [6]. Blanking belongs to the separation processes. It can be described as an embossing operation beyond the specific shear fracture limit of the material [7].

Temperature development depends primarily on the amount of forming and macroscopic friction work per stroke. According to the material, up to 95 % of the plastic work can dissipate into heat [8]. Additionally, friction on the atomic scale also produces heat [9]. Demmel measured up to 300°C with a tool-workpiece-thermocouple when blanking normal deep-drawing steel. With an undercut around the cutting edge of the punch, he was able to minimize the contact zone between tool and workpiece guaranteeing a precise temperature measurement at the cutting edge. The highest temperature arises at the maximum embossing depth, right before crack initiation

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in the sheet metal [10; 22]. On this account, similar maximum temperatures occur during blanking and embossing processes under the same conditions.

However, these operations are only profitable if the process is stable and the service life of the active elements is as long as possible. Thus, embossing and blanking operations are only feasible with applied lubricants. They reduce temperature in the tool by removing it out of the forming zone and lowering the friction coefficient between tool and workpiece. Furthermore, additives build a reaction layer, which minimizes interactions between the surfaces resulting in less wear [9].

In 2004, more than 37 million tons of lubricants were consumed worldwide and about 50 % of them end in and thus pollute the environment [11]. The high price of lubricants in conjunction with an expensive environmental friendly disposal of the additives lead to a high economic and ecological improvement potential. The aim should be a reduction or even total removal of lubricants in cold forming processes. [12] In order to reach that goal it is unavoidable to understand the wear causing interactions and to find a method replacing lubricants without impairing the wear behavior.

Opitz has already stated that there are other wear causing interactions beside temperature and tensions. He mentioned electrochemical and thermal influences evoked by temperature. [4] Thermoelectricity is one issue in this context. According to the Seebeck-effect, electric currents and voltages arise in a circuit consisting of two different electric conductors impinged with a temperature gradient [13].

The basic relationship between thermoelectricity has been investigated several times but mainly in the field of machining. Opitz et al. investigated tool life during turning processes in which a thermoelectric current of 5 mA was measured. By changing the current direction, a doubling lifetime was reached [4]. Awakov and Ritschkin confirmed these results in drilling operations [14]. Bobrovskij was able to extend the tool´s live only by electrically insulating the active elements [15]. In contrary, Hehenkamp could not prove the abovementioned results. He found no difference between a normal tool and an isolated tool. [16] Other reports show that the direction of currents play an important role in the context of wear behavior [17; 18; 19]. An explanation for the differing results could be the lack of a material characterization by means of the thermoelectric properties and a poor understanding of the interactions between the surfaces.

One important issue in this context is the impact of lubrication on the arising thermoelectric voltages. Demmel showed that the application of lubricant results in even higher thermoelectric voltages. In his opinion, the lubricant builds a layer between the surfaces of tool and workpiece reducing the direct contact points. Due to the measuring setup, the temperature rises if only microscopic contact points deforming plastically are in contact. After reaching the maximum voltage, lubricants lower the temperature and thus the thermoelectric voltage. [10] Tröber et al. used the same setup and found out, that the use of lubricants results in a decrease of about 10 % of the peak value. This is explained by the reduction of friction and the cooling effect of the lubricants [20]. Dies stated that the application of lubricants makes no difference in the thermal stress to the punch [21].

In the following report, occurring thermoelectric currents in the tool will be measured under dry and lubricated conditions when embossing respectively blanking S355MC. Furthermore, the impact of thermoelectricity and different electric conditions on punch wear behavior will be shown.

2 Thermoelectric voltages and currents

In principle, thermoelectric voltages and currents arise if two electric conductors impinged by a temperature gradient are in contact. This induces a thermodiffusion of charge carriers leading to a quantified thermoelectric voltage. If the conductors are connected in an open circuit, only thermoelectric voltages occur. By building a short circuit, potentials are able to balance and electric currents flow. [13]

The value of the occurring thermoelectric currents is determined by three parameters. One is the occurring temperature gradient of the active elements and the sheet metal in the tool. Second, the currents depend on the Seebeck-coefficent of the used materials. If the Seebeck-coefficent of both sheet metal and tool material were the same, no thermoelectric currents or voltages would occur [24]. Third, the value of the occurring currents depends on the electric resistance between tool and workpiece material. Although thermoelectric voltages are normally weak, electric currents may become very high due to low resistance of the circuit. Pelster et al. stated that thermoelectric currents could easily reach values of about 100 A. [13]

According to the mentioned electric circuits, a measurement of thermoelectric currents and voltages is also possible in a forming respectively blanking tool. Basis is a so-called tool-workpiece-thermocouple consisting of the tool and the workpiece material. The junction of this thermocouple is the contact area of punch and sheet metal in the forming zone. Temperatures could also be derived from thermoelectric voltages if materials are calibrated before. This setup enables an instantaneous and in-situ measurement of thermoelectric voltages and temperatures. [10]

For measuring thermoelectric currents, some adaptions on the setup are necessary. With consistent voltages, the value of the flowing currents depend on the electric resistance of the circuit. On this account, the quality of a current measurement is best in a short circuit. In this case, a current clamp is attached on the wire of the circuit. This guarantees a measurement without distorting the signal because the clamp is not in direct contact with the thermocouple circuit. By measuring changes of the electric field, resulting from the current flowing in the wire the clamp derives the value of this current. In these examinations, the current clamp K2 from Chauvin Arnoux (Paris, France) is used. It has a measuring range from 0.1 to 450 mA for direct current with an accuracy of ± 1 % of the signal and a response time smaller than 200 µs. Furthermore, the clamp offers the possibility of measuring the flow direction of the currents. Figure 1 shows the tool setup for measuring thermoelectric currents:

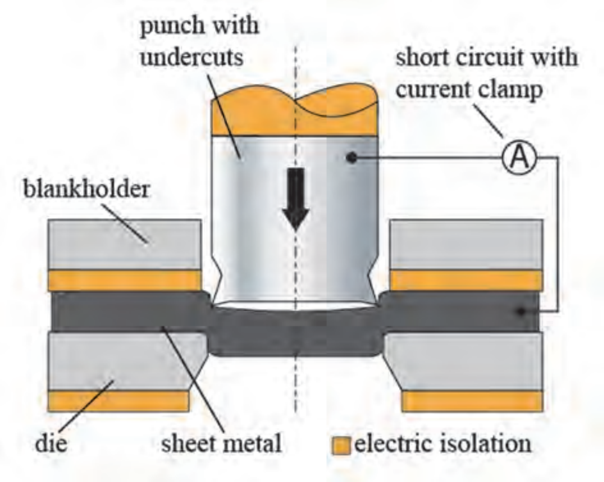

Figure 1. Experimental tool setup for measuring thermoelectric currents

2.1 Materials

In the following examinations, two punch materials were investigated. The cemented carbide CF-H40S from Ceratizit Deutschland GmbH (Empfingen, Germany) is an often-used material for active elements due to its high resistance to wear, fracture toughness and homogeneity. The other material is the powder metallurgical high-speed steel S390MICROCLEAN from Böhler Edelstahl GmbH & Co KG (Kapfenberg, Austria). This material has a Rockwell hardness of 63 HRC.

As sheet metal, the hot rolled fine-grained steel S355MC was used. This representative steel for cold forming operations has a thickness of 4 mm. Table 1 shows the chemical composition of all materials.

Tab.1: Chemical composition of the tool materials (a) CF-H40S and (b) S390MICROCLEAN as well as the workpiece material (c) S355MC in weight-%

(a) CF-H40S

WoC	Co
88	12

(b) S390MICROCLEAN

C	Cr	Mo	V	Co	Fe
1.60	4.80	2.00	5.00	8.00	balance

(c) 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

2.2 Lubricants

In order to investigate the impact of lubrication on the thermoelectric currents measured in the tool, two different types of lubricants from Wisura GmbH (Bremen, Germany) were used. ZO 3368 as well as AK 3080 are commonly used in the field of metal forming especially when forming Aluminum and stainless steel alloys. While AK 3080 is based on fatty alcohols without any additives, 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 results in a quantity of about 20 g/m^2 on each side of the sheet metal [23].

2.3 Blanking Press

The investigations were carried out on the hydraulic, triple acting press HFA 3200plus built by Feintool AG (Lyss, Switzerland). This fine blanking press has a maximum capacity of 3200 kN. An independent controlling of the blankholder force as well as an infinitely variable velocity between 5 and 70 mm/s are also features of this press.

2.4 Blanking tool and process parameters

For investigating the thermoelectric currents and their influence on wear, a modular four-pillar tool was used. This tool offers the possibility of changing tool materials and varying die clearances. Furthermore, the electric conditions could be changed by different isolation configurations. Therefore, ceramic components are attached on the die, the blankholder and the punch. By changing these parts, it is possible to generate an electric contact between individual active elements and the sheet metal.

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

In these examinations, two different punches were used. The punch made out of CF-H40S has undercuts reducing the contact area between punch and sheet metal to that around the punch edge where the highest temperatures in the tool are located. The other punch (S390MICROCLEAN) has a normal lateral and front surface. This leads to larger contact area and therefore smaller thermoelectric currents because colder areas are in connection, too. However, this punch is more favorable when investigating wear behavior. Both punches are circular with a diameter of 70 mm. Examinations are carried out with a die clearance of 1.5 % (0,06 mm) of the sheet metal thickness and a punch velocity of 70 mm/s.

3 Results and Discussion

With the abovementioned measuring setup embossing and blanking examinations were performed. Because of the comparability of these manufacturing processes in terms of temperature and thermoelectric currents, blanking operation were carried out. During embossing operations, high friction forces work on the punch when it is pulled out due to the elastic deformation of the sheet metal. These forces could lead to outbreaks on the edge of the punch disturbing the measurement. In blanking operations, the risk of outbreaks is less because tensile forces act distributed over the lateral surface and not local on the edge of the punch. Furthermore, there is no part ejector needed and the slug can fall through the die. The tool setup in combination with the sheet metal S355MC lead to almost 100 % clean cut on the cutting surface.

3.1 Thermoelectric Currents and lubricants

The first part of this report deals with the influence of lubrication on the occurring thermoelectric currents. Therefore, three different experimental conditions were chosen: One operation dry and the others with application of the mentioned lubricants (cf. chapter 3.2).Figure 2 depicts the plot of the thermoelectric currents as well as the punch force over the punch travel. The blanking process starts at about 5.8 mm before the bottom dead center because the immersion depth is 2 mm. Differences in the blanking force are negligible wherefore only one force plot is illustrated in order to improve comprehension.

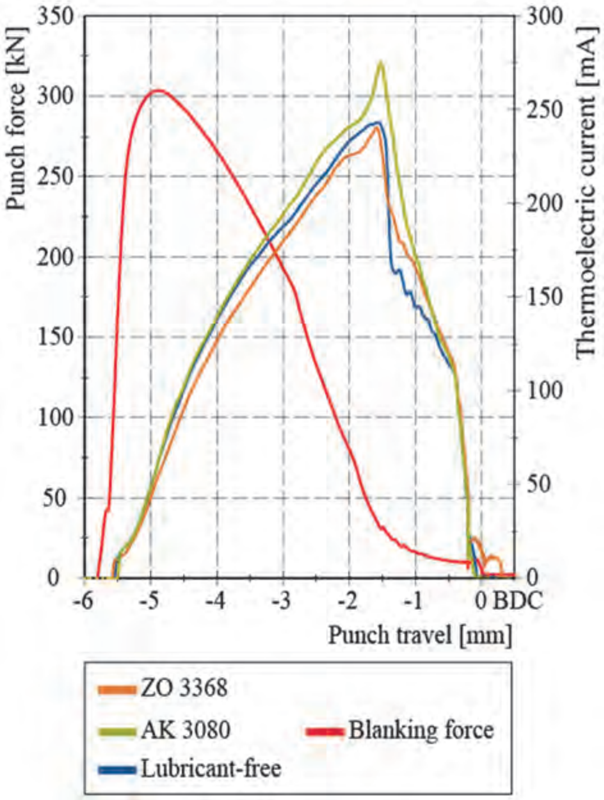

Figure 2: Occurring thermoelectric currents and the punch force when blanking S355MC with a punch made out of CF-H40S with undercuts under dry and lubricated conditions

The thermoelectric currents show almost the same signal path as the voltages and temperatures already investigated in [20]. The technical current direction is from the sheet metal to the punch when the material combination S355MC and CF-H40S is used.

At the beginning, punch and sheet metal get into contact. Afterwards, sheet metal as well as punch and press frame deform elastically. The rise of the thermoelectric currents start with the plastic deformation of the sheet metal beginning at 5.6 mm before the bottom dead center. Due to the dissipating plastic work, currents increase with the temperature in the shear zone. Until the maximum punch force, the rise of the thermoelectric current is almost equal. Right before the peak value, signal paths spread. Without application of lubricants, a maximum value of 276.8 mA was measured. With lubricants, a reduction of the maximum value about 10 % is reached. After [20] this decrease is because of the diminished friction. Additionally, lubricants have a cooling effect in the forming zone [11]. Interesting is the fact that the operations with different lubricants have almost the same maximum value of 247.9 mA.

The peak value normally occurs with crack initiation in the sheet metal. If no crack initiation is observable the maximum shifts backwards at the point where heat compensation is bigger than heat generation by the dissipated plastic work. The fall of all measured thermoelectric currents are again almost congruent.

3.2 Thermoelectric currents and wear

The impact of thermoelectric currents on wear has been worked out by varying the electric surrounding conditions in the tool without changing other forming parameters. In these examinations, the punch made out of S390MICROCLEAN without undercuts was used. The larger contact area increases the potential area in which wear occurs. Furthermore, the measureable thermoelectric currents get lower because of the huge amount of Iron in the punch and sheet materials. When cutting S355MC the measured thermoelectric currents had a peak value of 95 mA. The technical current direction is from the punch to the sheet metal and consequently, electrons flow in the other direction.

First, punch and sheet metal were contacted and grounded by wires (Fig. 3a). This setup represents a tool with a perfect electric contact to the press frame. Commonly used tools normally got a high resistance to the press frame because on the one hand, steel is a poor conductor and on the other hand, lubricants cause an additional isolation. After 10 strokes in the grounded setup, no wear occurs on the lateral surface of the punch. Even more strokes were made without any wear occurring on the punch.

Second, the electric conditions in the tool were changed and the active elements as well as the sheet metal were isolated (Fig. 3b). In this electric setup, wear occurs within a very short time and the results were visible after less than 10 strokes.

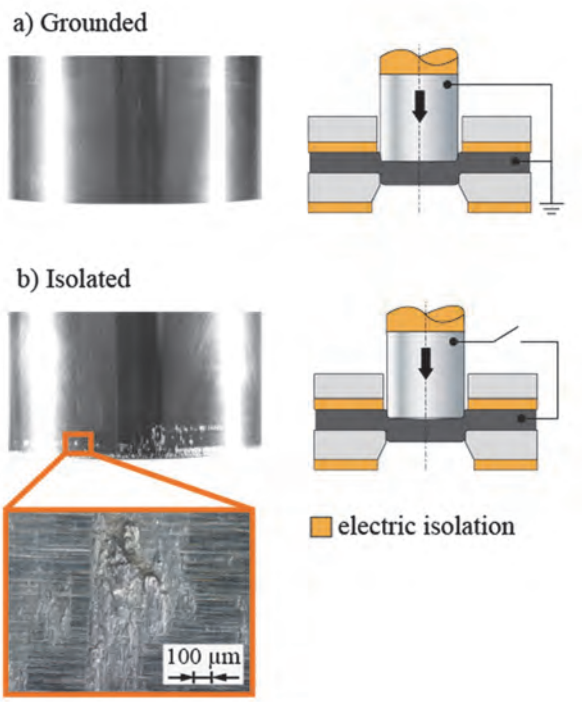

Figure 3: Electric conditions in the tool and the respective lateral surface of the punch after 10 strokes with (a) grounded and (b) isolated active elements and sheet metal

The differing signs of wear are explainable by the current and electron flow. While the active elements are grounded, currents resulting from the temperature gradient are able to balance over the short circuit. On this account, almost no currents flow in the contact zone between punch and die because this is their origin. If the electric conditions were changed to isolation, currents could only balance over the contacts between punch and sheet metal in the forming zone. After Uehara et al. cyclic currents arise in the contact zone resulting in high currents on the micro contacts. Consequently, the materials can reach their melting point due to the current heating, which leads to a huge amount of adhesion. Moreover, the direction of material transfer is also supported by the electron current direction. [19]

Finally, the examinations show that thermoelectric currents have a strong impact on the temperature induced wear mechanisms. Beside the electric conditions in the tool, the amount of material transfer depends on the current strength and the direction of electrons.

4 Summary and Outlook

In the present research report, two main examinations were carried out. First, the influence of different lubricants on the occurring thermoelectric currents in a forming tool was investigated. It could be shown, that thermoelectric currents have almost the same signal path as the thermoelectric voltages measured in [20]. Thus, there is no strong change of the electric resistance between tool and sheet metal during the forming process. Under dry conditions, a maximum current of 276.8 mA occurs when using the punch with undercuts made out of CF-H40S and S355MC as sheet metal. This peak value decreases by about 10 % when applying lubricant because of the cooling effect of the lubricant and a reduction of friction.

An analysis on the relation between thermoelectric conditions in a tool and the occurring wear was also carried out. It could be proven that thermoelectricity and electric conditions in a tool have a strong impact on the wear development of the punch. Due to the arising thermoelectricity, the punch as well as the sheet metal have different electric potentials inclining to balance. If the punch and the sheet metal is only connected in the forming zone (isolated condition), currents are only able to balance between the micro contacts. This leads to cyclic currents heating the contacts over melting temperature, which ends in adhesive wear. Beside current strength determined by the material combination and the temperature gradient in the tool, the flow direction of electrons has also an influence on the amount of material transfer.

Currently, further tests are carried out in which a more precise examination on the relation between thermoelectric currents and wear is done. Questions like what happens when the current direction changes or how does the value of the electric current influence adhesion will be answered. Additionally, the results will be proven for other materials like stainless steels or an aluminum alloys. 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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