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Experimental investigation on the thermoelectric current during embossing of Aluminum EN AW 1050

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Abstract

Aluminum is one of the most important materials for lightweight constructions, which has been leading to a steady increase in its consumption for years. Many parts are manufactured by cold forming or blanking. Due to the strong tendency to adhesion, aluminum processing is a big challenge. Adhesive wear deteriorates quality of the formed parts and shortens service times of tools. Minimizing wear is the main goal and only possible by improving the understanding of all wear causing interactions. Beside temperature, thermoelectric currents influence the occurring adhesive wear significantly. In order to understand the relationship between thermoelectric currents and wear, a precise measurement of the occurring currents during manufacturing processes is necessary. Therefore, lubricated and dry embossing and blanking operations with the aluminum alloy EN AW 1050 are carried out and the occurring thermoelectric currents are measured.

Keywords: Embossing, blanking, thermoelectric current, lubrication, wear

1 Introduction

Cold forming and blanking belong to the most frequently used production processes in sheet metal processing. High surface qualities as well as accuracy grades of the produced parts are feasible. However, increasing wear results in a dramatic drop in the achievable component quality, the process stability and the profitability. [1]

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. [2] During forming and blanking operations, wear is generally a combination of the four wear mechanisms: abrasion, adhesion, surface fatigue and tribochemical reaction. [3] Process forces and tensions as well as energetic interactions between the contact partners trigger abrasion and surface fatigue. On the contrary, material interactions on the micro- and nano-level lead to adhesion and tribochemical reaction. [4]

In case of aluminum processing, adhesion is the dominant wear mechanism. Adhesive wear can occur from the first stroke and is the major challenge in forming and blanking of aluminum alloys. [5] State of the art is an application of lubricants in order to minimize wear and reach a stable process. Nevertheless, the current trend is towards a reduction in the use of lubricants because of economic and ecological reasons. [6] However, only with a fundamental knowledge about all wear causing interactions, processes are realizable with a reduced amount of lubricant or even without any.

One major influential factor on adhesion is temperature. Groche et al. investigated adhesive wear during deep drawing of aluminum. The results show that adhesive wear occurs predominant in areas of local peak stresses where the highest temperatures prevail. [7] Groche and Nitzsche also confirmed a strong influence of temperature on the initiation of adhesive wear with a strip drawing test. They showed that a temperature increase from 15 to 30°C leads to a strong rise of adhesive wear almost from the start. [8] Dasch et al. investigated different coatings in a pin-on-disc test at three different temperatures. With increasing temperatures, more and more coatings failed because of adhesive wear. [9]

However, temperature comes along with side effects having also an impact on wear. For example, increasing temperatures in combination with two connected electrical conductors always result in thermoelectric currents and voltages. [10] Their impact on adhesive wear, especially during forming of aluminum, has been investigated insufficiently because temperature was

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paramount. Inter alia, Opitz and Hehekamp et al. have already proved a connection between electrical currents and adhesive wear in machining of steel. [11; 12] Tröber et al. could confirm this relation during blanking of S355MC. By changing solely the electrical conditions in the tool, adhesive wear significantly increased. A current of 95 mA flowed when a fine-grained steel with a punch made out of PM steel was blanked. The current direction was from sheet metal to punch and the temperature in the shearing zone reached almost 300°C. [13; 14]

The results so far suggest that an improved understanding of the relation between thermoelectric currents and wear behavior of active elements could point to a new approach of minimizing wear. In this report, several blanking and embossing operations are carried out in order to measure occurring thermoelectric currents.

2 Principle of Thermoelectric Measurement

Thermoelectric currents and voltages arise if two different conductors are connected in an electrical circuit and a temperature gradient between the junctions occurs. This induces a thermodiffusion of charge carriers, leading to a quantified voltage respectively current. The value is proportional to the temperature gradient and depends on the Seebeck-coefficients of the conductors. [10]

By an electrical isolation of the active elements, this principle can also be used in a tool. Sheet metal and punch are two electrical conductors, which are connected in the forming zone. This measuring setup enables an instantaneous measurement of thermoelectric currents and voltages in the tool in-situ at the origin of the thermoelectric phenomena. Figure 1 illustrates the principle of the used measuring setup in the tool.

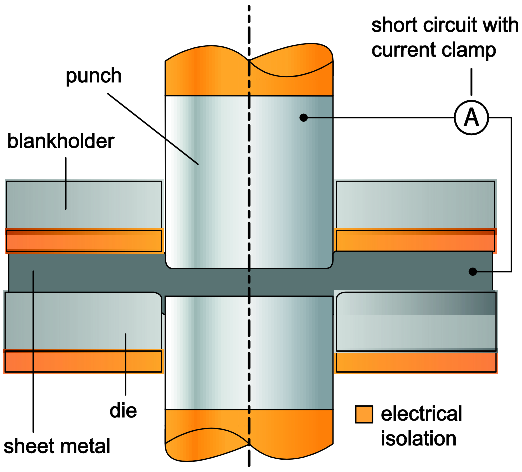

Figure 1. Principle of thermoelectric current measurement in a tool

According to Ohm´s law, currents increase with a decreasing electrical resistance. On this account, a wire connects punch and sheet metal building a short electrical circuit. The current clamp K2 from Chauvin Arnoux (Paris, France) is used for measuring the currents. 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, a directional determination of the flowing current is also possible.

3 Experimental setup

3.1 Materials

The punch is made of 1.2379 (X155CrVMo12-1). Due to its high wear resistance, this steal alloy is typically used for cold metal forming and cutting tools. Sheet metal is the aluminum alloy EN AW 1050 with a thickness of 4 mm. Due to its poor mechanical properties, this alloy is mainly used for electrical applications and housings. Tab. 1 shows the chemical composition of both materials.

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

(a) 1.2379

C	Si	Cr	Mo	V	Fe
1.2	0.32	12,9	0,7	0,6	balance

(b) EN AW 1050

Si	Fe	Al
0,1	0,2	balance

3.2 Lubricant

For lubrication, ZO 3368 from Wisura GmbH (Bremen, Germany) was used. It is a biodegradable lubricant for difficult forming operations of steel, aluminum and stainless steel. For the experimental investigations, lubricants where applied on both sides of the sheet metal by a brush reaching a quantity of about 20 g/m^2 [15].

3.3 Blanking Press

The experiments were carried out on the hydraulic fine blanking press HFA 3200 plus 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 blankholder force. The punch velocity is continuously adjustable between 5 and 70 mm/s.

3.4 Blanking tool

A four-pillar tool is the basis for the experimental investigations. The high stiffness in conjunction with locking bolts, which station the blankholder when touching the sheet metal, provide the use of smallest clearances. A counterpunch improves the size accuracy during the forming process and functions as ejector afterwards.

Punch, counterpunch and blankholder forces are measured by piezoelectric load cells from Kistler Instrumente AG (Winterthur, Switzerland). The punch travel is recorded with a length gauge from Dr. Johannes Heidenhain GmbH (Traunreut, Germany).

4 Results and Discussion

The following experiments were conducted on the experimental setup described above. According to Demmel, the maximum thermoelectric voltage appears with the complete rupture of the sheet metal. [15] Thus, embossing operations have a comparable peak value of the thermoelectric currents. Due to that fact, only blanking operations were carried out, in order to eliminate the danger of chipping which is a well-known problem in embossing operations.

4.1 Influence of punch velocity

The investigated punch velocities 5, 40 and 70 mm/s were chosen in accordance with the possible speed range of the press. These tests were carried out without lubricant and a clearance of 1 % of the sheet thickness.

Figure 2 illustrates the plots of the thermoelectric currents in dependence of the punch velocity. At the beginning, as long as the press, tool and sheet metal deform elastically, no currents are measureable. With the plastic deformation of the sheet metal, punch and sheet metal get into an intemate electrical contact, resulting in measurable thermoelectric currents with a technical current direction from punch to sheet metal. The first slight increase at 3.8 mm before the bottom dead centre (BDC) results from a compensation of potentials which developed before the contact. Afterwards, the plastic deformation continues and the forming zone heatens because of dissipating inelastic work. [15] Simultaniously, thermoelectric currents steadily increase until a maximum is reached. An increasing punch velocity results in a later peak value of the current because the initiation of cracks leads to a decrease of the thermoelectric current. This confirms the results of Demmel et al. who observed a later crack initiation with a higher tempertature of the material. [16] After the initiation of cracks, temperature in the forming zone decreases and thermoelectric currents also decline. The incline depends on the extent of second clean cut. From this stage, thermal convection is stronger than heating because of dissipating work. At the end of the blanking prozess, a last small increase occurs, indicating the total rupture of the sheet metal. Due to the shrinking shearing zone shortly before rapture, the plastic work is concentrated in a small volume, leading to a temperature respectively current rise. Figure 3 illustrates the corresponding cutting surfaces, which are characterized by a rough clean cut and second clean cut. Only the cutting surfaces of 5 mm/s show fracture. However, smearings over the whole surfaces complicate a detailed correlation to the development of thermoelectric current.

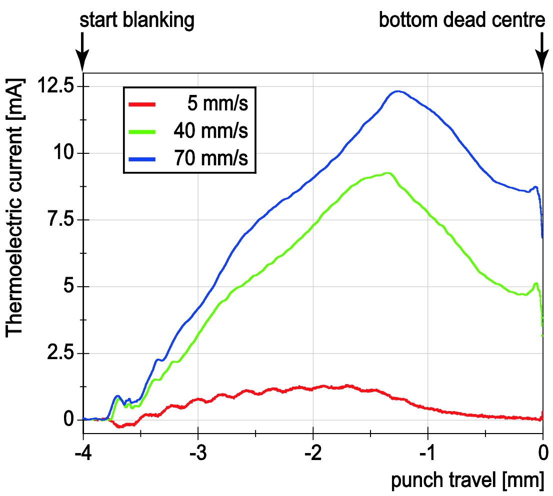

Figure 2. Thermoelectric currents over the punch travel at different punch velocities for a clearance of 1 % of the sheet metal thickness and without lubrication

A punch velocity of 70 mm/s results in a maximum thermoelectric current of 12.6 mA. The peak value falls by 25 % to 9.4 mA when the velocity was lowered from 70 to 40 mm/s. A velocity of 5 mm/s leads to a very low maximum current of 1.4 mA, which can be explained by thermal conduction. If the velocity is slow enough, the rising temperature in the forming zone will be derived equally and will lower the peak values of the thermoelectric currents. For that reason, the measured thermoelectric current in case of 5 mm/s is only 11 % of the maximum value in case of 70 mm/s. This illustrates the high impact of punch velocity on occurring thermoelectric currents.

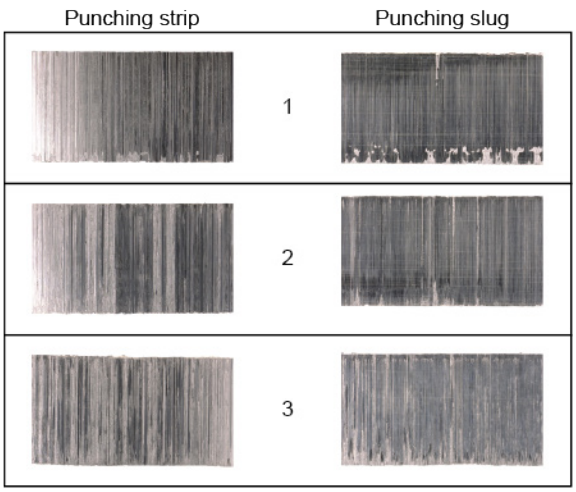

Figure 3. Cutting surfaces (clearance 1 %; no lubrication) with different velocities: (1) 5 mm/s, (2) 40 mm/s, (3) 70 mm/s

4.2 Influence of lubrication

The curves of the lubricated tests show almost the same characteristics as under dry conditions wherefore figure 4 depicts only the maximum values of the thermoelectric currents. In addition, the maximum values of the dry tests are also illustrated.

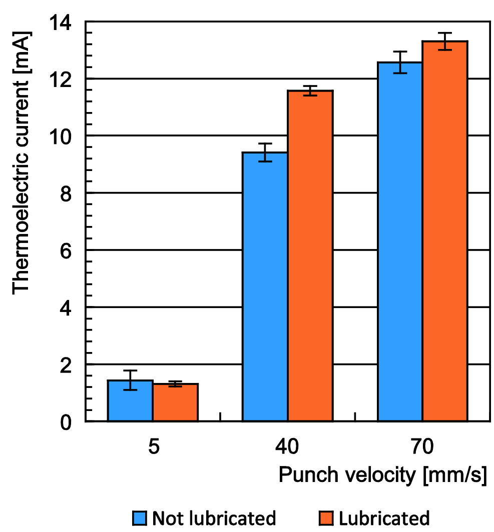

Figure 4. Maximum thermoelectric currents in dependence of the punch velocity during lubricated and dry conditions

The comparison between lubricated and dry blanking operations exhibit that lubrication results in an increase of the maximum value for all punch velocities except 5 mm/s. This result is in accordance to Demmel, who measured the thermoelectric voltage during dry and lubricated blanking operations with a punch velocity of 70 mm/s. [15] This increase is due to the measuring system, which records a mean value over the whole area of contact. Lubricant is not electric conductive which leads to a layer between punch and sheet metal. Consequently, less micro-contacts in the contact zone are in touch and the remaining ones are severely deformed. This results in measuring higher thermoelectric currents. Furthermore, a compensation of potentials by circular currents in the forming zone is hindered. The extent of this effect depends mostly on the appearance of the cutting surfaces and the type of lubricant.

If the punch velocity is slowly enough, there is enough time for heat conduction in the sheet metal. Consequently, an equal temperature distribution lowers peak values and isothermal conditions prevail. Therefore, the maximum value of the lubricated and dry condition is almost the same at 5 mm/s. At higher punch velocities, the heat conduction is not fast enough and the process gets an adiabatic character. [17] In the case of 40 mm/s, lubrication shows the biggest influence on the thermoelectric current with an increase of 19 %. For a velocity of 70 mm/s the increase is about 5 %.

5 Summary and Outlook

In the present report, the influence of punch velocity and lubrication on the thermoelectric current during blanking of EN AW 1050 was investigated. The used experimental setup enabled an instantaneous measurement of the thermoelectric currents arising in the forming zone between sheet metal and punch. Maximum currents up to 12.6 mA were measured under dry conditions and 13.3 mA when lubricant was applied. In both cases, the technical current direction was from punch to sheet metal. The measured peak value with a velocity of 70 mm/s is nine times higher than the maximum value with 5 mm/s. These results prove a significant influence of punch velocity on occurring thermoelectric currents. Furthermore, increasing temperatures lead to a later crack initiation, notable by a later occurrence of the maximum thermoelectric currents. This can also be seen in the cutting surfaces, which show more clean cut when the punch velocity rises.

Currently, more tests are carried out in which thermoelectric currents and voltages are measured. In general, this research project has the goal to improve the understanding of the relation between thermoelectric phenomena and wear in order to handle forming and cutting processes with less or even without lubrication.

Acknowledgements

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