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Adhesive Wear Initiation during Blanking of Austenitic Stainless Steel, with regard to Thermoelectricity

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Abstract

Blanking and cold metal forming are two important large-scale manufacturing processes, and therefore have to be cost-efficient whilst allowing for the production of parts subject to the highest of quality requirements. These conditions require long tool service life, which necessitates a reduction of adhesive wear, especially when processing materials with a high tendency to bond adhesively, like aluminum or stainless steel. To meet this objective, all wear-causing interactions have to be understood. One key aspect in this context is thermoelectricity, a phenomenon that occurs when two connected electric conductors are subject to a temperature gradient. This constellation causes a thermoelectric current to flow, which influences adhesive bonding and entails processes like local melting of the sheet metal. This paper deals with the comparison of two continuous stroke blanking processes with regard to adhesive wear development. One process represents an ordinary blanking tool configuration, and one is performed with externally influenced thermoelectric currents. The results show a significant impact between the initial development of adhesive wear and tool configuration, with regard to thermoelectricity.

Keywords: Adhesive wear, Blanking, Cold forming, Thermoelectricity, Stainless steel

1 Introduction

High part quality and cost-efficient production are two of the main goals when processing metal parts. Blanking and cold metal forming are the two most common manufacturing processes for large-scale metal production goods, and thus have to meet these requirements, which are determined by tool wear. Important wear mechanisms include abrasive wear, tribochemical reactions, tool surface breakdown and adhesive wear, which is the subject of research in this paper.

Adhesive wear means a transfer of sheet metal to active elements of tools. This mechanism takes effect as early as the very first strokes and causes bad surface quality of the workpieces. [1] This leads to short service intervals and thus raises tool downtime and costs. Furthermore, detaching adhesions form tinsel [2], which can lead to surface damage to the workpiece and tool and trigger short circuits in electrical installations. With this in mind, it is necessary to prevent or at least reduce adhesive wear. [3] To do so, a profound knowledge about wear-causing mechanisms and the development of adhesions is indispensable.

Local stress peaks at roughness elevations cause the first initiation of adhesions. In these areas plastic deformation causes cracks in the passivating oxide layer, and the highly reactive surfaces of the tool and workpiece weld together. [4] Further relative movement breaks the cohesive bonds. As the separation takes place in the sheet metal, a material transfer occurs.

Macroscopic friction, microscopic friction at the atomic level and the dissipation of up to 95 % of the plastic work [5] increase the temperature in the forming zone, which can reach more than 200 °C. [6] The maximum temperature mainly depends on the work necessary to separate the sheet material, and on process parameters like die clearance, cutting edge wear and punch speed. Die clearance and wear influence the dimensions of the forming zone and punch speed determines the time required for heat equalization processes. With regard to Groche and Nietzsche, who found out that even small temperature changes of 15 °C have a relevant influence on the development of adhesive wear those temperature rises strongly affect the formation of adhesion. [1]

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A further key influencing factor for the development of adhesive wear is thermoelectricity. [7] Due to the Seebeck effect the various materials of the active elements and the sheet metal, as well as the heating in the forming zone, form the tool-workpiece thermocouple that establishes thermoelectric voltages and currents. The difference between the Seebeck coefficients of sheet metal and of the tool, as well as the temperature gradient determine the voltage level. Current strength is proportional to the voltage level, with the resistance as the proportional factor. [8]

Previous investigations showed that influencing thermocurrents externally is an option for reducing the amount of adhesive wear. [9] The investigations in this paper compare the initial development of adhesive wear and its influence on the force curve between blanking under normal conditions and influenced thermocurrent based on continuous stroke experiments.

2 Experimental Setup

2.1 Blanking tool and press

A Bruderer BSTA-1600 high-performance mechanical stamping press with a maximum press force of 1600 kN was used for these investigations.

The blanking tool is a four pillar construction with high stiffness, which guarantees reliable results despite using very small die clearances. In the experiments, two of the four available cutting units are used for parallel blanking of two holes. The active elements and the blankholder of every unit as well as the sheet metal, are electrically insulated using zirconium oxide panels. Piezoelectric load cells in a force-shunt configuration measure the punch force.

The punch diameter is 15 mm, the cutting edge radius 50 µm and the immersion depth 4.25 mm. Cutting is performed without lubricant, and a punch impact speed of 50 mm/s. The die clearance amounts to 25 µm which corresponds to 1 % of the sheet metal thickness.

One of the two cutting units is wired in a short circuit-configuration, representing the conditions in an ordinary blanking tool. The thermoelectric current is recorded indirectly via a current clamp, in order to exclude retroactive effects from the measurement. Thermoelectricity occurring in the second cutting operation is externally compensated via a source-measure unit that generates a regulated current opposed to the thermocurrent. It provides a sourcing accuracy of 20 µA and has a response time of less than 80 µs. The countercurrent strength is set to 25 mA.

2.2 Investigated materials

The sheet material chosen for this investigation is a 1.4301(X5CrNi18-10) austenitic stainless steel with a thickness of 2.5 mm and a tensile strength of 720 MPa, selected due to its high adhesion tendency. The punches are made of the high-speed steel 1.3343 (X82WMoV65) hardened to 62 HRC. The chemical compositions of the two materials are shown in Table 1.

Tab. 1: Chemical composition of the materials used, given as a percentage of the weight

Material	Fe	C	Cr	Ni	Mo	V	W
1.3343	bal.	0.8	4.2	0.3	8.3	2.2	5.7
1.4301	bal.	0.1	0.3	1.3	13.8	-	-

3 Thermoelectricity

In an electric conductive material that is subject to a temperature gradient a thermodiffusion effect is initiated. Caused by the overall velocity vector of the charge carriers, electrons head to the cold end. This electron movement triggers a contrarily oriented electric field resulting in a state of balance in which thermodiffusion stops. The resulting charge-carrier displacement is the basic phenomenon for thermoelectricity. [8]

Measurable electricity occurs only when at least two conductors are combined. In case of an open circuit, a thermoelectric voltage arises, leading to a thermocurrent upon closing the circuit. The difference between the Seebeck coefficients of the connected materials determines the direction and strength. This factor is a material-specific, temperature-depend value that describes the thermoelectric properties. [7]

4 Adhesive Wear

Adhesive wear initiation starts at contacting surface asperities between sheet metal and punch. [10] Due to the small contact areas, high stress levels occur which break the passivating oxide layer of the stainless steel. [11] This leads to contact between highly reactive metal surfaces, and thus enables charge carrier exchange. Consequently, a strong chemical compound emerges. Furthermore, the above described thermoelectric currents in combination with the micro contact areas lead to high current densities, and influence adhesive wear development in two ways. First is the local exceedance of the melting temperature of the sheet metal due to Joule heating and the subsequent resolidification at the active elements. This phenomenon depends solely on current strength and not on current direction. In contrast, the second mechanism is a material movement in the direction of the current flow, caused by impacts of charge carriers and the transfer of kinetic energy from electrons to metal ions. This mechanism is comparable to electromigration, which is well known in the field of microelectronics, whereby small wire cross-sections trigger high current densities. [12]

Beside these influences, there is strong adhesive material bonding of the sheet material to the punch. The cohesive bonds in the stainless steel break due to further movement and result in a material transfer to the punch surface.

5 Results

This section is separated in two parts for the sake of clarity. First the force profiles are described in Section 5.1, and afterwards the relation to adhesive wear is investigated in Section 5.2.

5.1 Force profiles

Characteristic force profiles of a blanking process are illustrated in Figure 1. Negative punch travel values represent movement towards the bottom dead center. The graphs can be divided into five sections that show characteristic shapes. In the first part, starting at -6.75 mm, the punch hits the sheet metal and deforms it elastically. Hence, the force profile shows a linear increase. At -6.5 mm the second section starts, in which the sheet metal is plastically deformed. The clean cut is formed out up to -4.7 mm, with the force maximum being reached at -5.75 mm. After the point of maximum force, micro cracks occur before the material is completely separated at about -4 mm. Afterwards the slug is pushed out through the die in the fourth section until the bottom dead center (BDC) is reached at 0 mm. Here the direction of the punch movement changes and the last part of the force profile, the return stroke, takes place.

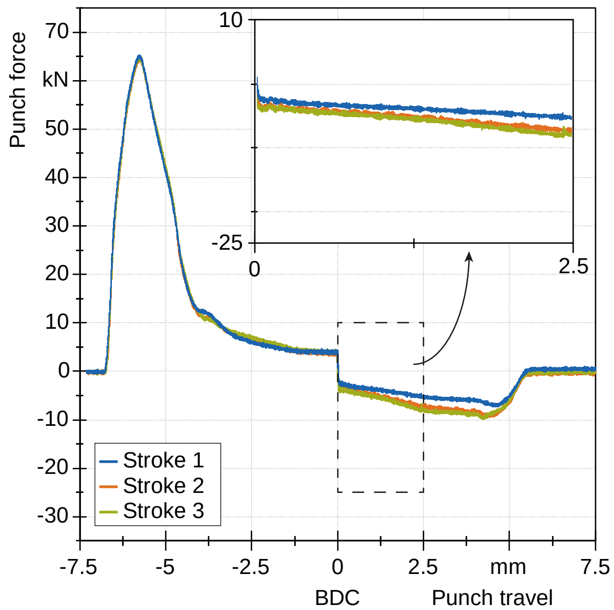

Fig. 1: Reference experiment force curves of Strokes 1 to 3, with respect to punch travel.

5.1.1 Reference profiles

Results of the experiments under ordinary blanking conditions are shown in Figures 1 to 4, illustrating three strokes per picture. In Section I and II, all force profiles show the same behavior until complete separation. Strokes 1 to 3 end at a level of 12 kN. Whereas in Strokes 4 to 12, material separation is delayed and the force level rises to 18 kN. The push-out force grows with every stroke and has the highest increase between operations 4, 5 and 6. The return strokes 1 to 3 show a slight force raise but a smooth slope. The behavior of the subsequent strokes is quite different: After a short linear increase in force, a sudden decrease with a high overshoot follows and thereupon a linear slope and again an abrupt discharge. This happens three times in Stroke 4, 16 times in Stroke 5 and five times in Stroke 6. Strokes 7 and 8 do not exhibit sudden force changes, although the amount of the maximum return stroke force of -25 kN is significantly higher compared to -16 kN of the previous strokes. Strokes 9 to 12 show a higher force of about -31 kN and again an abrupt discharge - number 9 two times and numbers 10 to 12 one time.

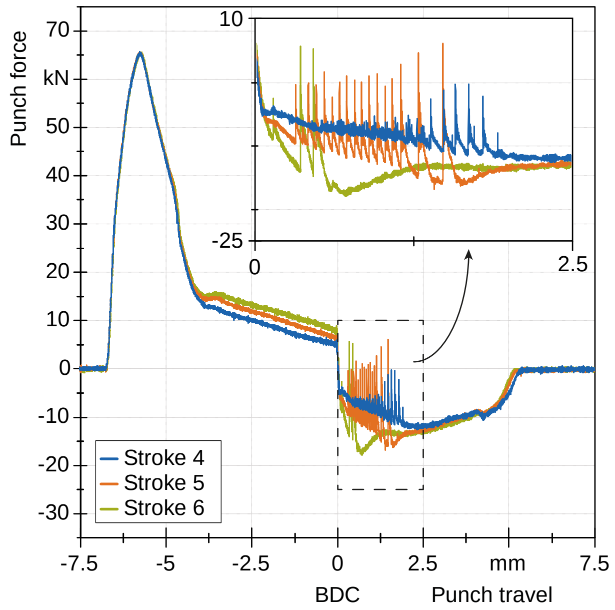

Fig. 2: Reference experiment force curves of Strokes 4 to 6, with respect to punch travel.

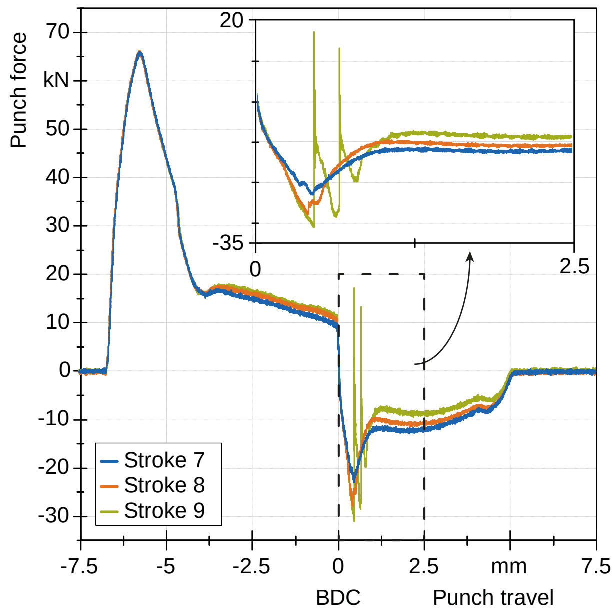

Fig. 3: Reference experiment force curves of Strokes 7 to 9, with respect to punch travel.

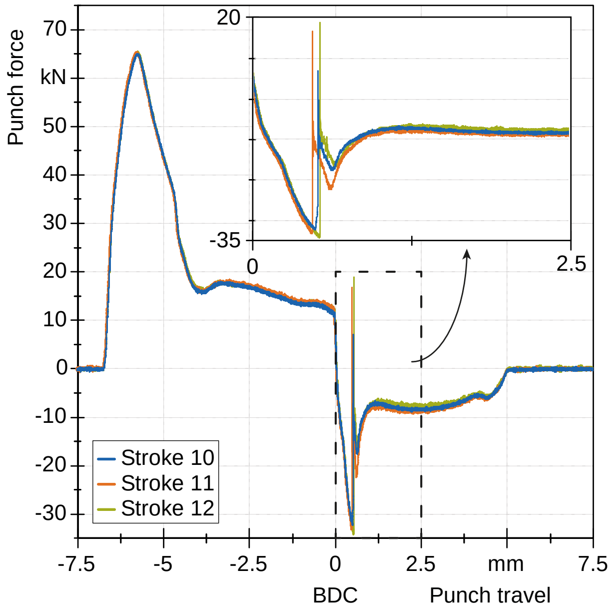

Fig. 4: Reference experiment force curves of Strokes 10 to 12, with respect to punch travel.

5.1.2 Profiles with countercurrent

Figures 5 to 8 illustrate the force profiles of the countercurrent investigations. In Section III the maximum force rises slightly from 65 kN to 67 kN, and the gradient of the curve in the clean cut formation area flattens with an increasing number of strokes. Subsequently, the force level at the end of the clean cut formation rises from 35 kN to 41 kN. In Phase IV, the push out force increases with every stroke, from about 5 kN in Stroke 1 to 18 kN in Stroke 12. The return stroke force acts similarly, with an increase from -3 kN up to -22 kN. The sudden discharge with a force overshoot, which occurs from Stroke 4 in the reference profiles, appears in the countercurrent experiments at Stroke 9 and increases in the three subsequent strokes. In contrast to the reference experiments, the abrupt force change happens only once per stroke.

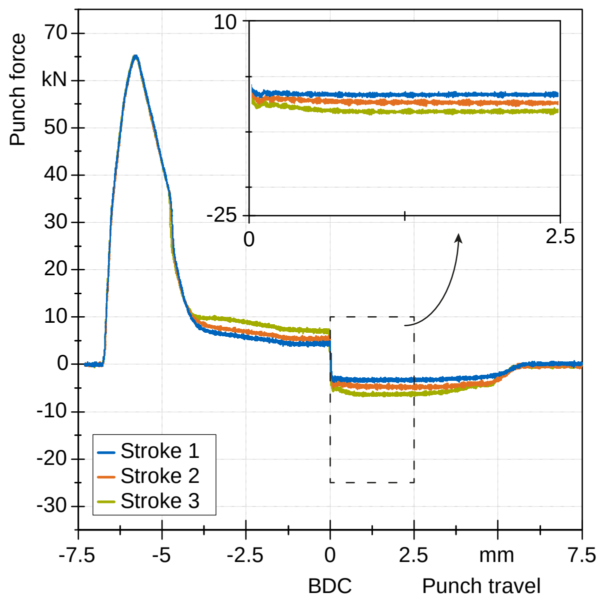

Fig. 5: Countercurrent experiment force curves of Strokes 1 to 3, with respect to punch travel.

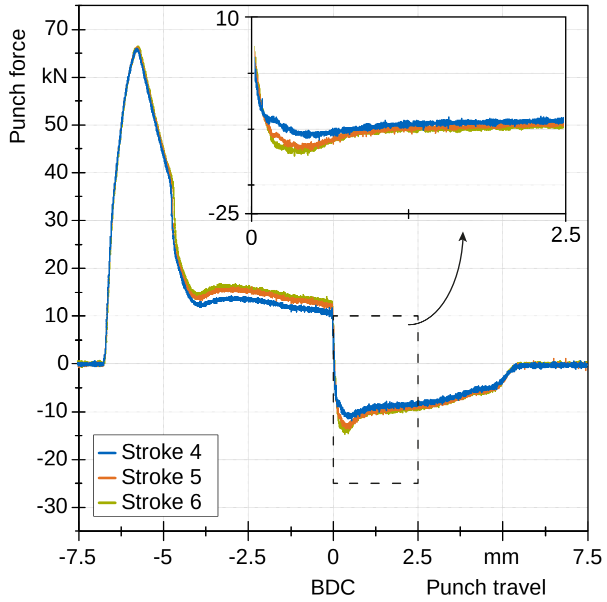

Fig. 6: Countercurrent experiment force curves of Strokes 4 to 6, with respect to punch travel.

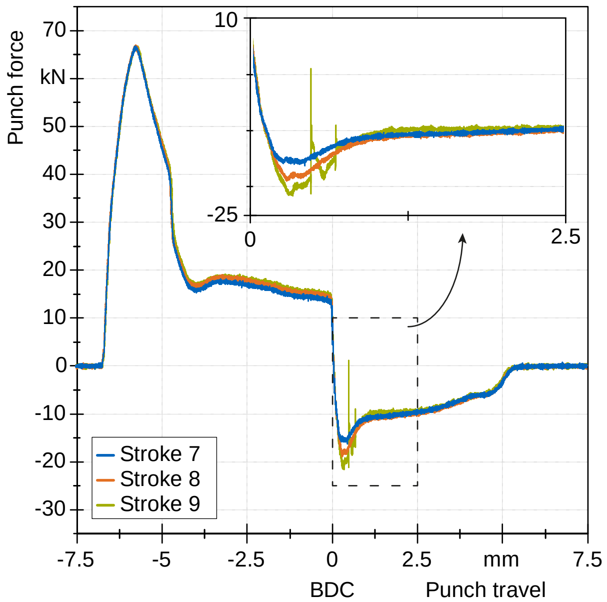

Fig. 7: Countercurrent experiment force curves of Strokes 7 to 9, with respect to punch travel.

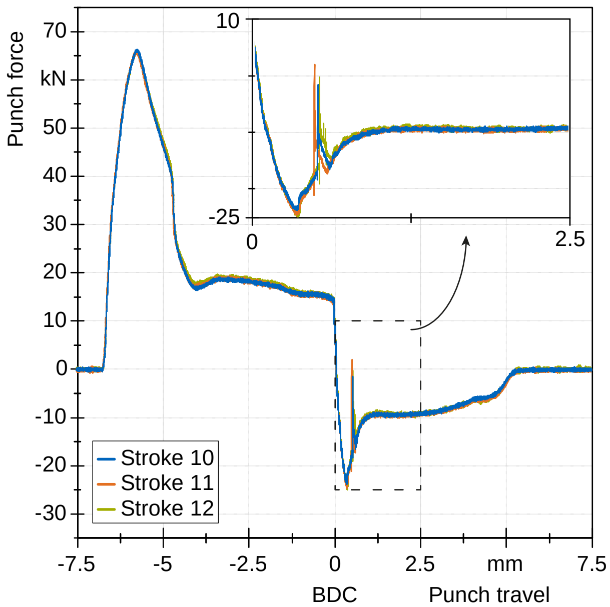

Fig. 8: Countercurrent experiment force curves of Strokes 10 to 12, with respect to punch travel.

5.2 Adhesive wear development

5.2.1 Reference experiments

The constant force in Section II over all strokes indicates that no material adheres near the cutting edge. A smaller die clearance entails delayed crack initiation and thus a slightly bigger clean cut area. This can be traced back to a permanent accumulation of the sheet metal to the punch shell surface above the cutting edge with every stroke. This also causes the higher push-out forces, because of higher friction between the stamping grid and punch, as well as the punching slug and die. In addition, more plastic work to equalize roughness asperities is needed. On the return stroke, those elevations and a strong spring-back effect of 1.4301 increases the force needed. Due to high tensions, adhesions are periodically removed during the return stroke. This is the reason for the sudden force changes and the origin of tinsel formation. Stroke 7 and 8 without sudden rupture confirm such a cyclic process of the formation and removal of adhesive wear. The fact that the force overshoot increases with a higher stroke number indicates progressive wear accumulation, even though parts of the adhesions are torn away.

5.2.2 Countercurrent experiments

In the instant that the punch makes electric contact with the sheet metal, the external current flows from the source-measure unit. Due to the very small contact area between the cutting edge and the sheet metal the current density becomes very high. This entails melting processes and strong adhesive bonding which causes an accumulation of adhesions directly at the cutting edge, and subsequently an increase in the maximum force. Afterwards, the external current counteracts the thermoelectric current and thus reduces the formation of adhesive wear. [7] This can be seen in the force increase in Section III, which is not as strong as in the reference experiments. Hence, the amount of adhesive wear that accumulates at the punch shell surface is lower. During the return stroke, fewer adhesions cause smaller force increases, and the clamping effect with sudden rupture of the punch occurs later, at Stroke 9 in contrast to Stroke 4 in the reference experiments. A differing cycle time for adhesive wear development can be concluded. Furthermore, the quantity and amount of the force overshoots is lower. Less adhesive wear occurs at the punch shell surface due to reduced friction and fewer bondings that have to be cracked.

6 Conclusion

The results described in this paper show the development of adhesive wear on the basis of its impact on the punch force. Lubricant-free cutting with small die clearance provokes the fast development of wear. Therefore, changes in the force, triggered by adhesions, during the first 12 strokes occur. Different wear formation was indicated by continuous force changes across all investigations due to a reduction of the die clearance. Furthermore, sudden force changes - caused by the tearing off of parts of the adhesions and pieces from the work-hardened area of the sheet metal.

An externally generated countercurrent influenced adhesive wear distribution as well as the amount thereof. Adhesions at the cutting edge were strengthened whereas the amount at the punch shell surface was reduced compared to reference experiments without external current. Furthermore, the sudden material rupture during the return stroke was delayed from Stroke 4 to Stroke 9.

In conclusion, the force profiles show that the amount of adhesive wear raises fast with every stroke during blanking under normal conditions. The countercurrent provokes an accumulation of adhesions at the cutting edge, but overall, a lower development of adhesive wear, especially at the punch shell surface.

Acknowledgements

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References

[1] P. Groche, G. Nitzsche, and A. Elsen: "Adhesive wear in deep drawing of aluminum sheets," CIRP Annals, 57 (1), (2008), 295–298,

[2] T. Sasada, S. Norose, and H. Mishina: "The Behavior of Adhered Fragments Interposed Between Sliding Surfaces and the Formation Process of Wear Particles," Journal of Lubrication Technology, 103 (2), (1981), 195–202

[3] R. Hambli: "Blanking tool wear modeling using the finite element method," International Journal of Machine Tools and Manufacture, 41 (12), (2001), 1815–1829

[4] G. W. Stachowiak, and A. W. Batchelor, Engineering tribology (2014)

[5] P. Demmel, H. Hoffmann, R. Golle, C. Intra, and W. Volk: "Interaction of heat generation and material behaviour in sheet metal blanking," CIRP Annals, 64 (1), (2015), 249–252

[6] P. Tröber, M. Welm, H. A. Weiss, P. Demmel, R. Golle, and W. Volk: "The influence of process parameters on the temperature development in the forming zone," MATEC Web of Conferences, 190, (2018), 14004

[7] P. Tröber, H. A. Weiss, T. Kopp, R. Golle, and W. Volk: "On the correlation between thermoelectricity and adhesive tool wear during blanking of aluminum sheets," International Journal of Machine Tools and Manufacture, 118-119, (2017), 91–97

[8] R. Pelster, I. Hüttl, and R. Pieper, "Thermospannungen - viel genutzt und fast immer falsch erklärt" PhyDid, (2005), 1

[9] P. Tröber, P. Demmel, H. Hoffmann, R. Golle, and W. Volk: "On the influence of Seebeck coefficients on adhesive tool wear during sheet metal processing," CIRP Annals, 66 (1), (2017), 293–296

[10] P. Groche, and F. Resch: "Dry forming of aluminum alloys – Wear mechanisms and influencing factors," Materialwissenschaft und Werkstofftechnik, 46 (8), (2015), 813–828

[11] D. H. Buckley, Surface effects in adhesion, friction, wear, and lubrication, Tribology series, vol. 5, Elsevier Scientific Pub. Co, (2010)

[12] A. S. Budiman, C. S. Hau-Riege, W. C. Baek, C. Lor, A. Huang, H. S. Kim, G. Neubauer, J. Pak, P. R. Besser, and W. D. Nix: "Electromigration-Induced Plastic Deformation in Cu Interconnects: Effects on Current Density Exponent, n, and Implications for EM Reliability Assessment," Journal of Electronic Materials, 39 (11), (2010), 2483–2488