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Analysis of lubricant performance in punching and blanking

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Abstract

Punching and blanking processes are characterized by severe tribological conditions due to the creation of virgin surfaces, which are highly prone to develop pick-up of workpiece material on the punch surface. Hazardous forming lubricants are, therefore, commonly used in punching and blanking processes for avoidance of wear induced process deviations such as diminished surface quality, reduced dimensional accuracy and reduced tool life. The present study characterizes the function and performance of lubricants used for punching and blanking operations for assessment of the tribological lubricant properties necessary for adaption of environmentally friendly lubricant alternatives. Analysis of the tribochemical properties of the studied lubricants indicate that an applicable temperature range and a high load bearing capacity are central lubricant properties necessary for ensuring sufficient lubricating ability for punching and blanking operations.

Introduction

Blanking and punching are the most commonly used severing process in sheet metal forming, often combined with other forming operations as an intermediate or finishing production step. Contrary to most common sheet metal forming operations, blanking and punching operations generate new, virgin surfaces during the process, which combined with the frictional stress exerted on the punch stem during the backstroke create severe tribological conditions. Sheet materials with high affinity for adhesion with tool steel, such as stainless steels, are therefore prone to cause local pick-up on the punch stem. The formation of local weld junctions on the punch stem causes scoring of the workpiece material in subsequent strokes and can introduce large tensile stresses in the punch during the backstroke, which can lead to tool failure. Millard and Gasnier [1] evaluated the lubricant performance in punching by determining the coefficient of friction (COF) from measurements of the backstroke force and theoretical analysis of the normal stresses exerted on the punch surface. Pfaff [2] reported that the backstroke force in punching is governed by the accumulation of pick-up of wear particles from the workpiece sheet on the punch stem. No further correlation was however found between the development of the wear mechanism and the measured backstroke force, due to scattering of the force measurements, possibly caused by vibrations stemming from the transducer design. Lind et al. [3] proposed that the wear mechanism occurring in a blanking process is characterized by three distinct phases where abrasive wear, adhesive wear and growth of friction junctions are respectively dominant. Olsson et al. [4–6] conducted extensive investigations on wear and lubrication in punching. The studies showed that the mechanism of lubrication in punching is governed by the lubricant retained on the surface of the punch stem and by the chemical interaction of the lubricant additives with the punch and sheet material. This was evaluated by testing punches with different punch tip geometries and surface topographies combined with different lubricant formulations. It was found that a tangential texture on the punch stem combined with a high viscosity lubricant reduced the amount of wear developed on the punch stem during testing. In case of efficient, additivated lubricants, however, this lubrication mechanism was of no importance. The studies furthermore showed that the development of the backstroke force with number of strokes gave a good indication of the severity of the developed wear on the punch stem and that the punching test requires lubricants with strong boundary films, such as chlorine based additives, to avoid excessive wear on the punch stem [7]. Klocke et al. [8] conducted a series of comparative analyses for characterization of different additives for evaluation of the applicability of non-chlorinated lubricants in fine blanking processes. The study showed that characterization of the tribochemical effect of single and compound additives enables optimization of the tribosystem for fine blanking processes by utilizing the synergy of the different types of additives. Hogmark et al. [9] studied the wear behavior of AISI D2 tool steel punches with sheet material of different steel grades. The study concluded that the material properties of the workpiece materials greatly influence the wear profile of the punch tools. Hogmark et al. highlighted material properties of ductility and hard particle phases to be decisive for promotion of adhesion, fatigue and abrasion. A number of recent investigations [10–15] have furthermore studied the applicability of tool coatings for prolonging the life of punching tools. Klocke and Raedt [16] presented a study, where the formulation and testing of different hard ceramic CVD and PVD coatings were done for cold forging and fine blanking applications. The aim was to minimize the need for hazardous lubricant additives and workpiece pretreatment. Several mechanical and thermal coating properties, such as strong adhesion of the coating to the substrate and a high thermal conductivity, were highlighted as critical coating properties in order to withstand the imposed tribological loads of the fine blanking and cold forging processes. Klocke and Raedt furthermore proposed that a low Young's modulus could increase durability of the tool coating due to reduced tensile stresses in the coating. Kitamura et al. [17] studied the tribological behavior of a micro-dimpled punch, which was evaluated by measuring the backstroke force. They found that a micro-dimpled punch texture made with a pico-second laser could drastically reduce the frictional stress exerted on the punch during the backstroke. The surface texture was optimized in terms of dimple depth, coverage and arrangement.

Many sheet metal forming tribosystems are exposed to high contact temperatures due to the mechanical work and the frictional heat introduced by the forming process. High temperatures can introduce severe tribological loads on the tribosystem due to decomposition of the lubricant additives as well as thinning and evaporation of the lubricant. Analysis of the tribochemical properties of the lubricant additives and the base oil can therefore give valuable information of the lubricant behavior in forming processes. Important properties include thermal stability, volatility and the tribological nature of the film forming additives in the lubricant [18,19]. Differential thermal analysis (DTA) is a commonly used technique for analysis of the influence of temperature on the tribochemical behavior of organic materials by measurement of heat flow and the change in weight at elevated temperatures, from which the occurrence of exothermic and endothermic reactions can be evaluated. Matveevsky [20–24] presented a series of investigations on the performance of different lubricant additives at high temperatures with DTA combined with different simulative tests. Matveevsky furthermore characterized the lubricant action with thermogravimetric (TG) measurements, for quantification of the maximum loss of weight during testing and the weight loss at the temperature of chemical reaction between the lubricant additives and the metal surface. For analysis of the film forming action of different lubricant additives, Matveevsky highlighted the importance of two main transition temperature points. At the first transition, the chemically active lubricant additives react with the metal surface resulting in a sharp decrease in the COF. At the second transition, the chemically modified layer loses its lubricating properties due to desorption of polar molecules or melting of chemically reacted tribofilms, which results in a subsequent increase in the COF.

Matveevsky furthermore highlighted the possibility of using detected exothermic reactions for evaluation of the critical transition temperatures, where the lubricant additives form a surface film on the metal. Kawamura and Fujita [25] studied the performance of organic sulphur and phosphorus compounds with DTA combined with a cross-pin wear tester. The wear scar diameter of the lubricant containing sulphur additives increased with increased reactivity of the lubricant additives. The wear scar diameter generated when lubricating with phosphite based EP additives was however found to decrease linearly with increasing reaction starting temperatures. A similar observation was later made by Wan and Xue [26], who studied the performance of phosphorus based lubricant additives for lubrication of aluminum. They indicated that the tribochemical reaction between the EP additive and the sliding surface was initiated by a flash temperature generated in the rubbing action. Kawamura [27] later presented a similar correlation between additive reactivity and wear scar diameter with ZDDP additives. DTA was similarly used by Møller et al. [28,29] for studying the tribological performance of chlorinated paraffin and diakyl-polysulfide for ironing of stainless steel. The study highlighted that the EP performance of chlorinated paraffins is strongly connected to its high chemical reactivity with the main components of stainless steel, i.e. iron, chromium and nickel.

As mentioned above, blanking processes exhibit severe tribological conditions, where insufficient lubricant quality leads to heavy pick-up of workpiece material on the punch resulting in poor surface quality, reduced dimensional accuracy and a shortened tool life. Hazardous lubricants are therefore often used in order to facilitate stable production conditions. For minimization of the use of hazardous lubricants, the present study aims to evaluate the primary lubricant properties needed to ensure proper lubrication in punching and blanking processes, for assessment of the applicability of alternative environmentally benign lubricants. The study is based on the following individual analyses:

- Punching test
- High temperature pin-on-disc test
- Four-ball test
- Thermo-gravimetric/differential thermal analysis (TG/DTA)
- Analysis of lubricant composition with XRF
- Numerical modeling of the punching process

These tests are described in the following.

Experimental methods

Punching test

A series of punching tests were conducted with a 1 mm EN 1.4301 stainless steel sheet and Ø2mm PM tool steel AISI M3:2 punches with 10µm radial clearance between the punch and the die. The narrow clearance results in a large hydrostatic pressure in the shear band region that induces severe stressing of the lubricant film and promotes a large blank zone similar to the forming conditions in a fine blanking operation. The punches used for the test had a tangential surface texture of Rz = 2.5µm obtained by round grinding. The punch test was conducted on a 320 kN C-frame eccentric press with a stroke rate of 170 RPM and a corresponding punch speed of approximately 45 mm/s during punching. The eccentric press was equipped with an automated pneumatic feeding system that enables continuous drawing of the sheet material from a coil for testing of several consecutive strokes. An overview of the test stand is shown in fig.1. The punch force and the backstroke force were acquired during testing with a piezoelectric load transducer. For the punching tests, lubricant was applied to the surface of the sheet metal by using roller lubricators. Inspection of the surface structure of the punches after testing was done with an FEI Inspect™ S50 SEM.

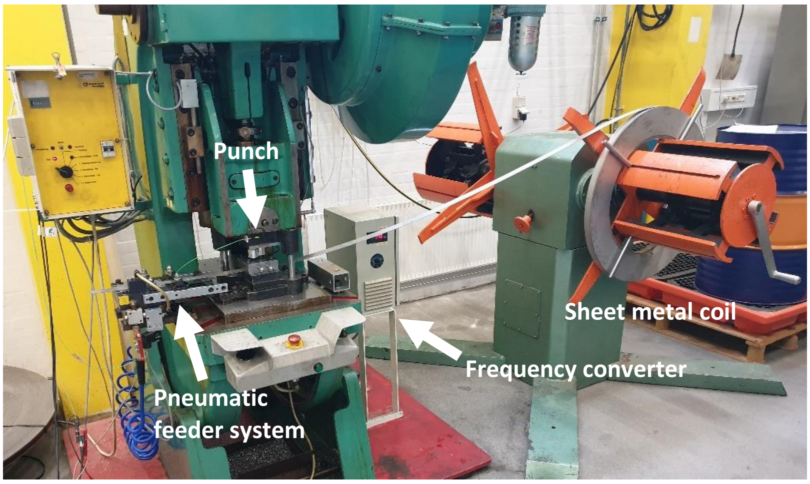


Figure 1: Eccentric press equipped with punching tool, feeder system and a load cell for measurement of the punch force and the backstroke force.

High temperature pin-on-disc test

A high temperature pin-on-disc test was carried out on the Bruker Universal Mechanical Tester Tribolab^{TM}. The Ø69.85mm test disc was made of AISI M3:2, hardened to 64 HRC and polished to a circumferential surface finish of Ra = 0.08 μm. The pin was provided with a Ø6.35 ball in 440-C stainless steel with a hardness of 62 HRC. The test was carried out with a constant load of 16N and a rotational velocity of 0.2mm/s. The sliding contact was fully immersed in lubricant during testing. The test parameters result in an initial maximum Hertzian contact pressure of approximately 1660 MPa. The low sliding velocity used in the test greatly reduces the influence of frictional heating in the sliding contact during testing. An external heat source increased the temperature in the test chamber by 6°C/min to a maximum of 350°C during the test. The slow temperature increase ensured homogenous heating of the workpiece. The temperature in the test chamber was measured with a thermocouple during testing.

Four-ball test

Characterization of the wear behavior and the load bearing capacity of the different lubricants was done with a four-ball test. For evaluation of the wear behavior of the lubricants, the four-ball test test was conducted with a load of 300N, a test duration of 1 hour and a rotational speed of 1420 RPM. Evaluation of the load bearing capacity was done by conducting a series of tests with a 1 minute test duration with increasing test loads until welding of the test specimen was achieved (weld load). The pass load was similarly evaluated with the highest test load applied without welding of the test specimens throughout the test. The load was increased by 200 N per test. Both test series were conducted with Ø12.7mm balls of 100Cr6 and approximately 12 ml of liquid lubricant. The test specimens were cleaned in an ultrasonic bath with a Tickopur TR 13 cleaning agent at 60°C prior to testing. The developed wear scars on the three stationary balls were evaluated with an optical microscope. The average wear scar diameter was determined by measurement of the transversal and the longitudinal wear scar diameter

Thermo-gravimetric/differential thermal analysis (TG/DTA)

The present study takes reference in the tribochemical interaction between the test lubricants and the tool material, as an initial characterization of the function of the lubricant in the tribosystem. The thermal and tribochemical properties of the lubricants were characterized by thermos-gravimetric/differential thermal analysis with a NETZSCH STA 449 C thermo-microbalance. Two test series were carried out. In the first test series, thermal analysis was performed on 500 mg AISI M3:2 tool steel powder mixed with the test lubricants. In the second case, the thermal analysis was carried out with 75 mg of each test lubricant separately. The particle size of the tool steel powder used for the test was in the range of 0.005-0.4 mm. Each sample was transferred into an alumina crucible and heated to 550°C, with a 10°C/min heating rate. The two tests were carried out in an argon atmosphere with a gas flow of 50 ml/min and in dry air with a gas flow of 43 ml/min of nitrogen and 7 ml/min of oxygen, respectively.

Analysis of lubricant composition with XRF

Six commercially available lubricants with different formulations were selected for the presented punching experiment. An overview of the selected lubricants is shown in table 1.

Table 1: General overview of the lubricants used for the blanking experiment.

Name	**Lubricant manufacturer**	**Description**	**Kinematic viscosity at 40°C (cSt)**
Illoform TDN 81	Castrol	Highly chlorinated paraffin oil	170
Illoform PN 226	Castrol	Medium chlorinated paraffin oil with S-, P-, ester-additives and ZDDP	67
SF 125 A	Rhenus	Mineral oil with Ca-, P- and S-additives	125
Montgomery DB 4265	FUCHS	Mineral oil with calcium carbonate and S-additives. Diluted 1:6 with water	2
DROSERA MS 5	Total	Multipurpose machine oil containing triphenyl phosphate	5
Paraffin Oil	Carl Roth	Pure, high viscosity paraffin oil	75

A preliminary evaluation of the elemental composition of the different lubricants was made with X-ray fluorescence (XRF). This was done in order to characterize the overall lubricant content, since the exact lubricant formulation is normally not disclosed by the manufacturer. Detailed knowledge about the specific additive package of the different lubricants is valuable in order to understand the function of the lubricant in metal forming operations. The compositions of the lubricants were evaluated with an Oxford Maxxi 6

X-ray fluorescence analyzer, where the most common elements used in lubricant additives (EP, AW, FM) were surveyed, see table 2.

Table 2: Elemental composition of the lubricants used for the blanking experiment. Values are given in counts per second (CPS) in an X-ray fluorescence analyzer.

Name	Elements (CPS)							
	Ba	**Br**	**Ca**	**Cl**	**P**	**S**	**Mo**	**Zn**
Illoform TDN 81	-	-	-	6631	113	142	-	-
Illoform PN 226	-	-	61	4381	87	153	-	2400
SF 125 A	-	-	4049	-	49	556	-	-
Montgomery DB 4265	-	-	793	-	18	16	-	-
DROSERA MS 5	-	-	-	-	-	-	-	-
Paraffin oil	-	-	-	-	-	-	-	-

No calibration standards were available for the different lubricant additives, meaning that an exact quantification of each lubricant additive was not possible. Evaluation of the counts per second (CPS) for each element allows for a qualitative evaluation of the elemental composition of the lubricants as well as giving a relative comparison of the quantity of each element. The XRF measuring technique has limited applicability for determining the content of elements with low atomic mass. Commonly used lubricant additives such as Mg and B compounds are thus not detectable with XRF. The XRF analysis is therefore used as a preliminary survey method for evaluation of the content of common film forming additives like Cl, P and S in the lubricants.

Numerical modeling of the punching process

FE analysis of the punching operation was made as a coupled thermo-mechanical model with the commercial software LS-DYNA, where the punching operation was modeled with an axisymmetric configuration. An overview of the modeled tool setup is shown in fig. 2, and the input parameters are included in table 3.

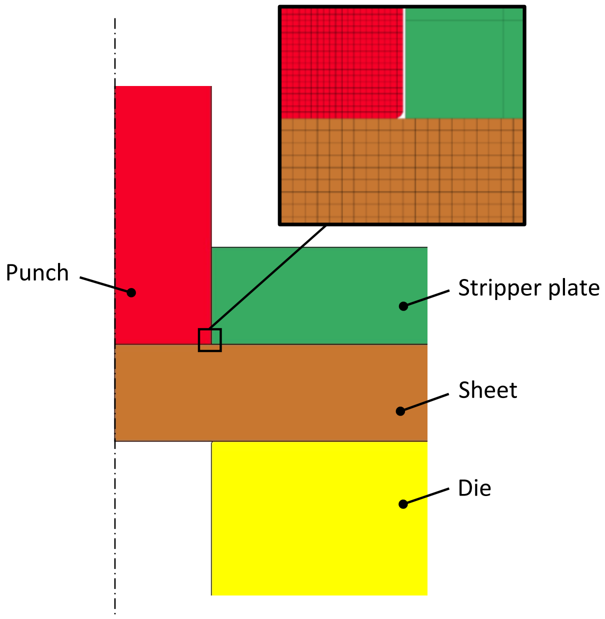


Figure 2: Numerical model with initial mesh shown around the punch corner in the detail.

Table 3: Input parameters for numerical simulation.

	Punch (AISI M3:2)	Blanking Die (1.3343 HSS)	Sheet material (EN 1.4301)
Initial temperature (°C)	20	20	20
Heat capacity (J/(kg·K))	420	460	500
Thermal conductivity (W/(m·K))	24	27	15
Heat transfer coefficient (kW/(m^2·K))	50	50	50
Density (g/cm^3)	7.73	8.12	7.90
Elastic modulus (GPa)	230	217	200
Coefficient of friction	0.1	0.1	0.1
Poisson's ratio	0.3	0.3	0.3

In the FE model, the forming tools were modeled as rigid steel tools, whereas the sheet material was modeled as a plastic material characterized by a Ludwig formulation ($\sigma = 1339\varepsilon^{0.594}+231$ [MPa]), which was determined by tensile testing. The sheet material was discretized with a quadrilateral mesh with an element size of 0.025mm. For the FE analysis of the blanking operation a rounding radius of 0.002mm was applied to the edge of the punch and the edge of the die in order to avoid localized damage due to sharp contacts in the interfaces between tools and the sheet material. A remeshing algorithm was furthermore applied in the numerical model to compensate for the large localized deformation of the mesh in the shear band region. Ductile fracture of the sheet material was modeled with a simple critical shear stress criterion, which by evaluation of the punch force and the morphology of the sheared edge was found to give an accurate description of the ductile fracture occurring in the punching process. Element deletion was initiated at a shear stress of 1300 MPa in the applied fracture model. Thermal coupling is maintained between the punch surface and the sheared surface.

Experimental results

Punching tests

The punching test was conducted with a number of different liquid lubricants for evaluation of the lubricant performance. Fig. 3. shows the results of the punching test by the backstroke force as a function of the number of strokes for the different lubricants. Dry conditions are also included for reference.

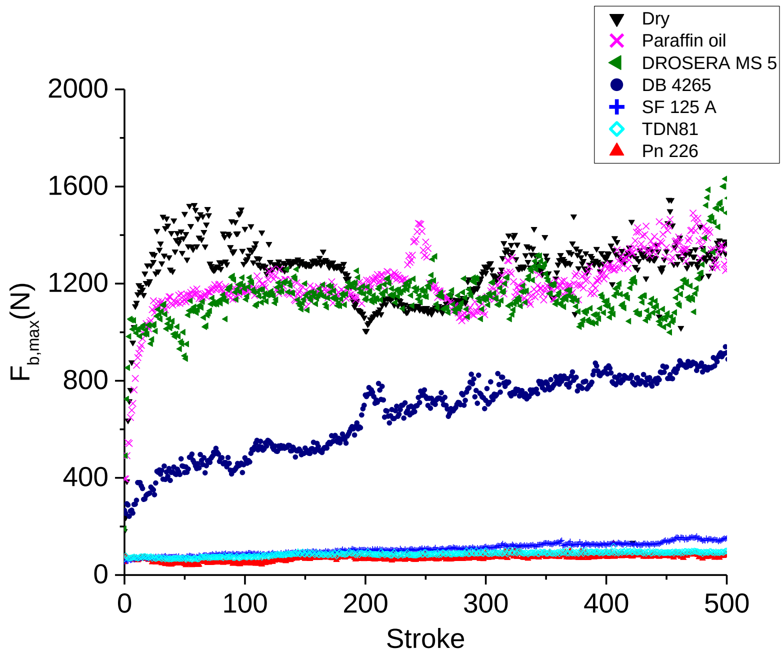


Figure 3: Backstroke force as function of number of strokes for the tested lubricants and under dry conditions.

The development of the backstroke force under dry conditions is found to reach saturation approximately within the first 30 strokes. In the subsequent strokes, the backstroke force is found to fluctuate around an average value of approximately 1300N. The stabilization of the backstroke force is attributed to a saturation of the pickup on the punch surface. The test series conducted with the low viscosity oil Drosera MS 5 and the pure paraffin oil were found to exhibit a similar performance. The DB 4265 lubricant, containing Ca- and S- based lubricant additives, exhibits a gradually increasing backstroke force within the first 500 strokes. The DB 4265 lubricant is based on a suspension of solid particles in the base oil, which inhibits direct metal-to-metal contact between the punch and the sheet material. This mechanism of lubrication retards the adhesive wear that accumulates on the punch stem. A common characteristic of the lubricants, which exhibited poor performance in the punch test, is low viscosities and either a low content of film forming additives or no additives at all, as evaluated with XRF. The two chlorinated paraffin oils, TDN81 and Pn 226, were found to exhibit excellent lubricating ability in the blanking test with a consistently low backstroke force throughout the 500 strokes. The SF 125 A lubricant, containing Ca-, P- and S-additives, is found to have a comparable performance, however, with a small increase in the backstroke force after approximately 250 strokes. An overview of the surface structure of the punches after testing is shown in fig. 4.

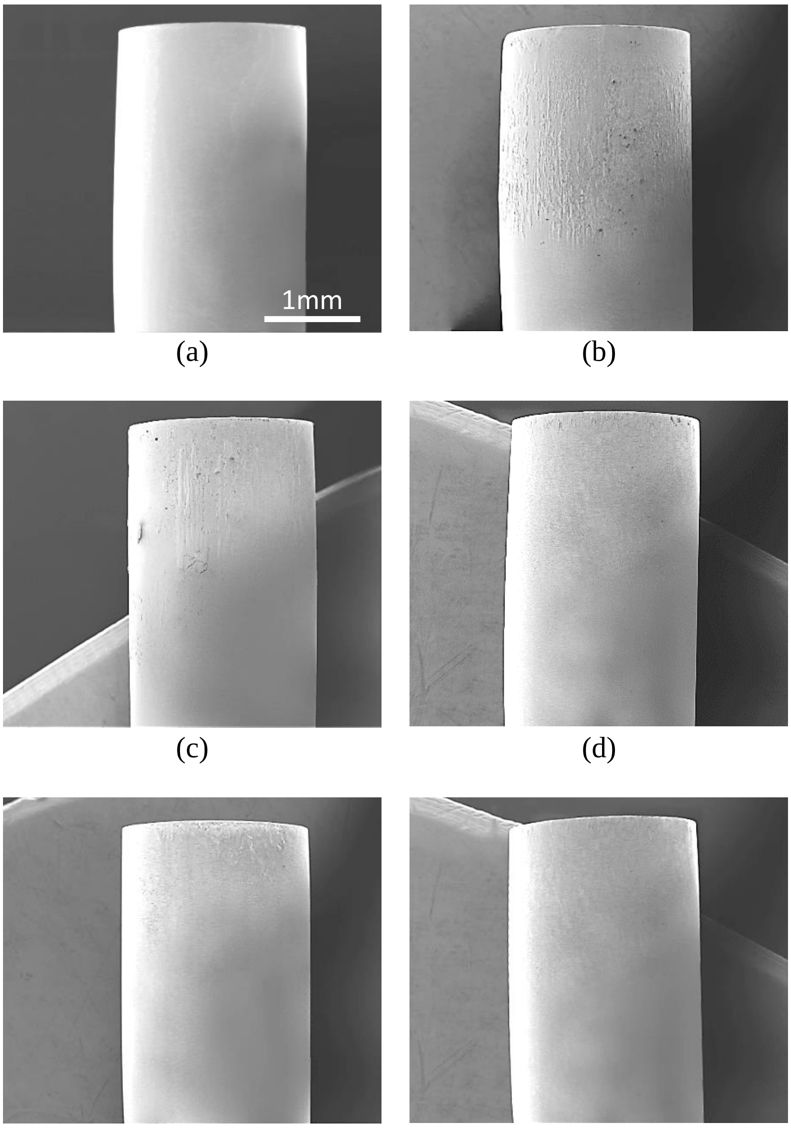
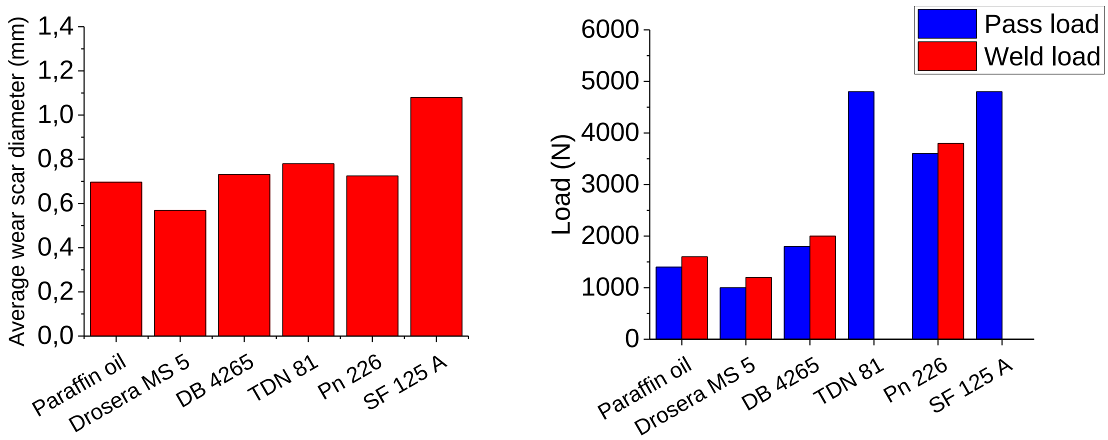


Figure 4: SEM micrographs of the punch surface of (a) a new punch and (b-f) punches after testing with different lubricants: (b) DB 4265, (c) Drosera MS 5, (d) Pn226, (e) SF125 and (f) TDN81.

From inspection of the surface structure of the punches after testing, it is seen that the three highly additivated lubricants, which resulted in low backstroke forces in the punching test, have resulted in minor levels of pickup of workpiece material around the punch tip. In contrast to this the test series conducted with the DB 4265 and the Drosera MS 5 lubricants are found to have a large amount of accumulated pickup of workpiece material on the punch stem, corresponding to a large increase in the measured backstroke force during the test.

Four-ball test

An overview of the wear characteristics and the determined weld load and pass load for the tested lubricants using the four-ball test is shown in fig. 5a and fig. 5b, respectively.



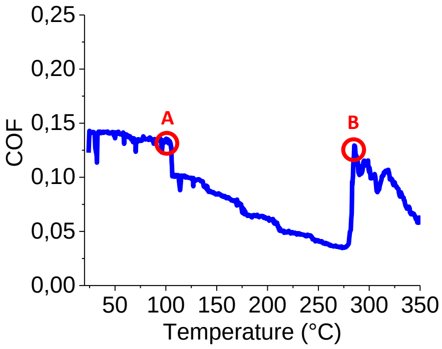
(a) (b)

Figure 5: Characterization of the wear behavior and the load bearing capacity of the tested lubricants in the four-ball test. The results are shown by (a) developed wear scar diameter and (b) weld load and pass load.

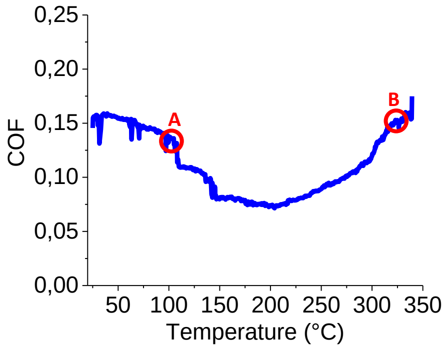
From fig. 5a it is seen that the wear scar diameters generated during the four-ball test ranges from 0.57-0.73 mm for most of the tested lubricants. The test results for SF 125 A are however found to result in a substantially larger wear scar diameter. While the different lubricants exhibited a widely varying performance in the punching test, the developed wear scar diameter indicates a comparable wear performance in the four-ball test. Evaluation of the load bearing capacity however reveals a substantial difference in the tribological properties of the lubricants. The tested lubricants with high weld loads in the four-ball test correspond to the lubricants with excellent results in the punching test; namely those lubricants, which inhibited adhesive wear on the punch stem. Conversely, the lubricants with low weld loads, in the range of 1600-2000 N, are those providing poor lubrication in the punching test. The weld load of TDN 81 and SF 125 A could not be determined for the present study as the loads were found to exceed the maximum capacity of the experimental equipment. The lubricants with high load bearing capacities are found to form tribofilms in the interface between the workpiece and the punch, which retards the mechanism of adhesive wear on the punch surface, as e.g. seen with the chlorinated paraffin oil. The load bearing capacity of the lubricant is therefore identified as one of the primary tribological lubricant properties for blanking processes, where the affinity to adhesion of workpiece material to the punch poses a major tribological issue.

High temperature pin-on-disc test

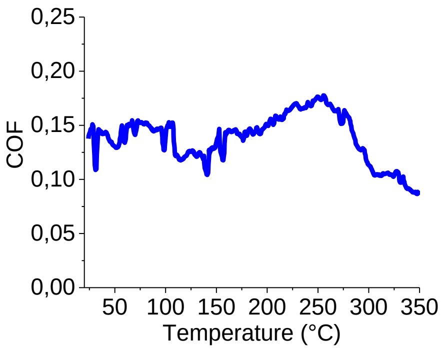
The influence of thermal conditions on the tribological properties of the lubricants was studied with the high temperature pin-on-disc test. The main results are summarized in fig. 6, where an average coefficient of friction of two test repetitions is shown as a function of temperature.



(a)



(b)



(c)

Figure 6: COF as a function of the test temperature in pin-on-disc testing with (a) Pn226, (b) Drosera MS 5 and (c) Paraffin oil.

As examples of the tested lubricants containing film forming additives, the Pn 226 and the Drosera MS 5 lubricants are found to exhibit a temperature interval, where a lower

COF is measured due to thermal activation of the lubricant additives. This temperature interval is defined by point (A), where the active additive species in the lubricant are adsorbed on the surface of the metal, forming a tribofilm that lowers the COF and point (B), where a loss of the lubricating properties occurs due to thermal degradation of the lubricant. These transition temperatures indicate the working range of the lubricant, where properties of boundary lubrication are exhibited. The pure paraffinic base oil is conversely found to have an increasing COF at elevated temperatures due to thinning of the lubricant. After the initial increase in friction, a large decrease in the measured COF is seen at approximately 270°C, when nearing the boiling point of the lubricant, as seen in the following TG/DTA results.

Thermo-gravimetric/differential thermal analysis (TG/DTA)

Evaluation of the lubricant properties at elevated temperatures was furthermore done with TG/DTA, see fig. 7. The TG/DTA was conducted in dry air as well as in an inert argon atmosphere in order to study the influence of oxygen as well as a limitation of oxidative degradation of the lubricants.

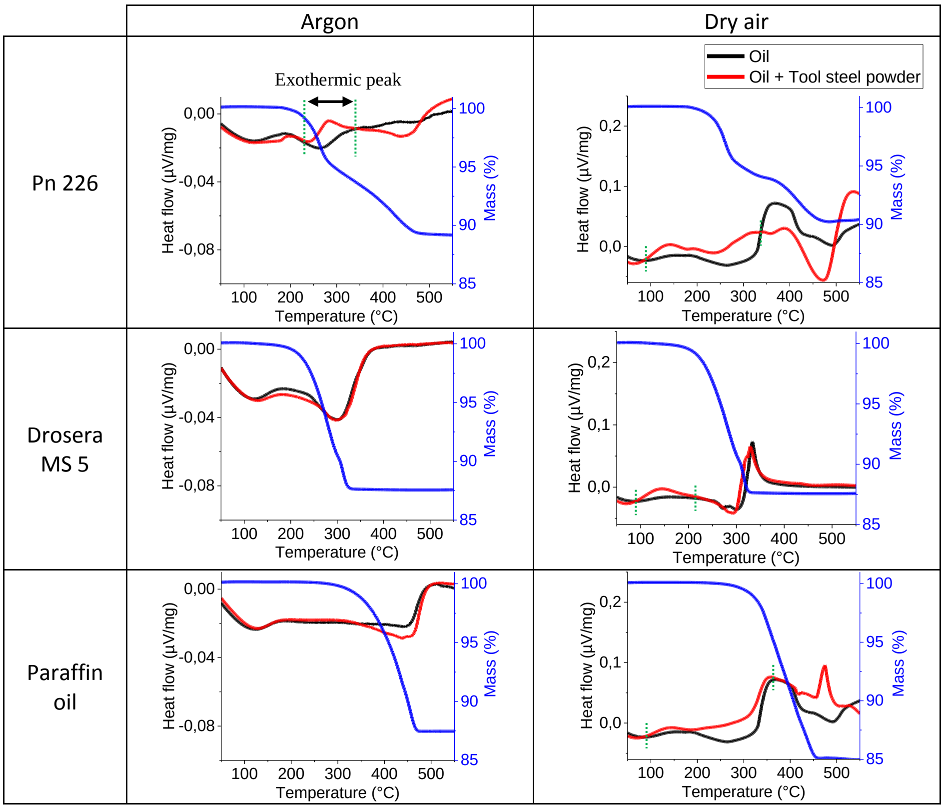


Figure 7: TG/DTA thermograms of the tested lubricants.

The thermograms established from testing of the pure lubricants and testing of mixtures of the tool steel powder and lubricant were used for assessment of the transition temperature, where activation of the lubricant additives was initiated. This was evaluated by superposition of the two thermograms [25]. A summary of the critical transition temperatures is shown in table 4.

Table 4: Overview of the transition temperatures of the tested lubricants

	Temperature of initial chemical reaction [°C]	Temperature of lubricant breakdown [°C]	Temperature interval of first exothermic peak [°C] (Ar)	Temperature interval of first exothermic peak [°C] (dry air)
Illoform TDN 81	101	287	151-256	-
Illoform PN 226	104	285	223-339	89-339
SF 125 A	109	309	125-195	108-212
Montgomery DB 4265	229	-	-	-
DROSERA MS 5	105	319	-	90-226
Paraffin oil	-	-	-	94-369

The thermogram for Pn 226 and tool steel powder mixture reveals an exothermic peak at a temperature of 223-339°C in the inert atmosphere, i.e. Ar. The first exothermic peak in dry air is, however, seen in the temperature range of 89-339°C. The widening of the temperature range of the exothermic peak is possibly due to the influence of oxygen on the compound additive package of the lubricant, as certain groups of lubricant additives, e.g. certain S-based additives, only display a tribological function with the presence of oxygen [8]. The thermogram for pure paraffinic base oil reveals an initial exothermic peak in the temperature range of 94-369°C in dry air, while no major reaction peaks were found in Ar. This behaviour is attributed to the oxidative degradation of the lubricant at elevated temperatures. This is indicative of the sensitivity of the TG/DTA technique towards a range of different physical and chemical phenomena occurring simultaneously during the heating cycle, highlighting the importance of assessing the lubricants in varying atmospheres for evaluation of the thermal stability and the tribological properties of the lubricant. The TG/DTA is therefore used as a supplementary technique for assessment of the lubricant properties at elevated temperatures. This encompasses a supplementary method for determining the transition temperatures of the film forming additives and the thermal stability of the lubricant.

Numerical modelling of the punching test

Punching operations are commonly found to develop highly localized temperature fields and transient temperatures peaks, which makes it difficult to characterize the process temperatures with conventional measurement techniques, e.g. thermocouples or thermographic measurements. Assessment of the temperature development in the forming tool and the sheet material during the punching operation in the present study is therefore done with a coupled thermo-mechanical FE simulation. The simulated temperature field during a punching operation is shown in fig. 8a, where point 1 and point 2 are highlighted. Point 1 is inside the punch 0.3 mm from the tip, while point 2 is in the shear band region at the center of the sheet at the start of the test. The vertical position of point 2 varies during the test as the sheet material is plastically deformed into the blanking die.

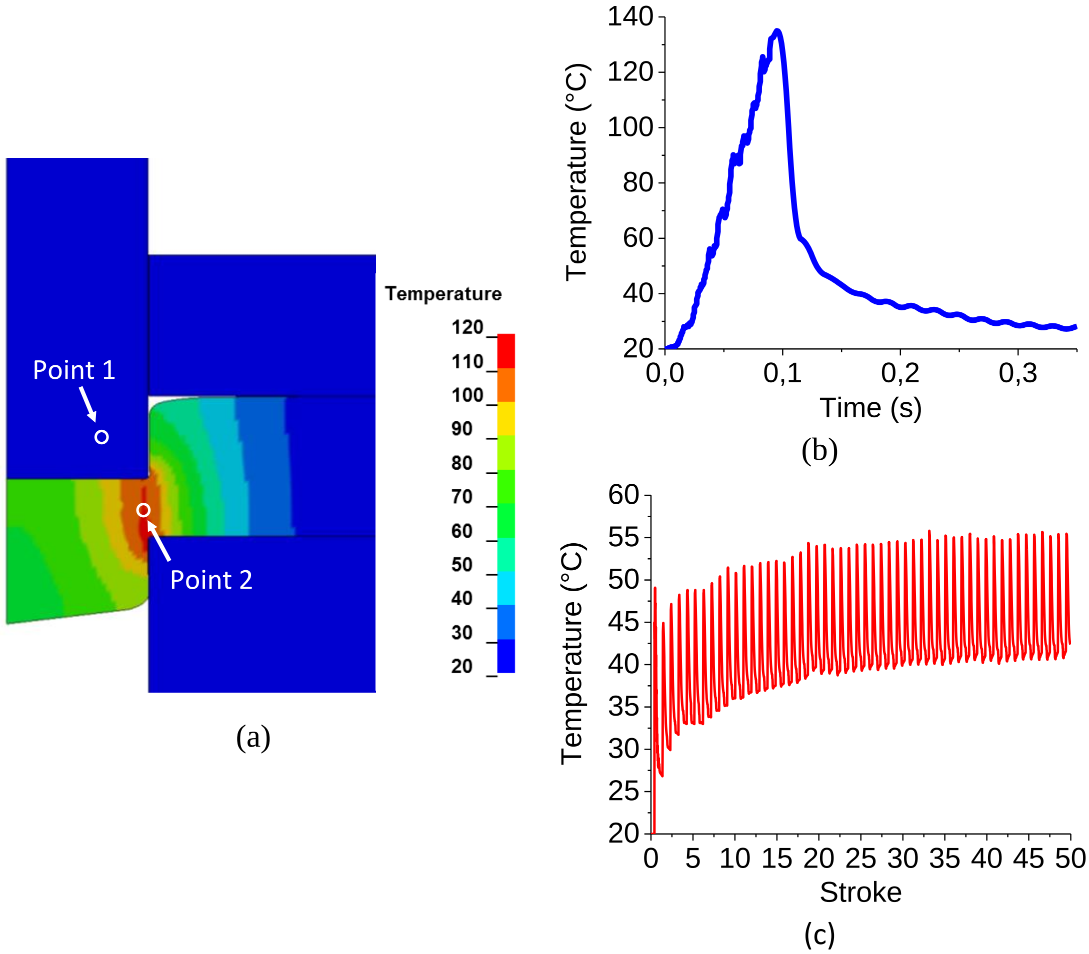


Figure 8: Thermo-mechanical FE simulation of temperature showing (a) the temperature distribution in the tools and workpiece, (b) temperature development in point 2 during stroke number 1, and (c) temperature development in point 1 during the first 50 strokes.

The temperature development in the sheared surface, see fig.8b, shows a high temperature peak during the forward punch stroke, followed by a large dissipation of the generated heat after approximately 0.1s. The peak temperature ranges locally between 135-150°C in the shear band region. Fig. 8c shows development of the punch temperature in point 1 during the first 50 strokes. The transient temperature peak and the short time of contact between the punch and the sheet material result in minor heat transfer to the punch, which is found to stabilize after approximately 40 strokes. The peak temperature in the interface between the punch and the sheet material governs the tribological behaviour of the lubricant, as seen in the pin-on-disc test and the TG/DTA. The lubricants providing excellent lubrication in the punching test are therefore characterized by having high load bearing capacities combined with an applicable thermal working range, where the peak temperature in the punching process ensures the activation of the lubricant additives in the punch/workpiece interface in order to inhibit the development of pickup of workpiece material.

Conclusion

The performance of different lubricants was evaluated with a punching test. A clear correlation between the development of pickup of workpiece material on the punch stem and the measured backstroke force was confirmed in accordance with literature. Process temperatures were characterized by numerical simulation. Combined analysis of the lubricating action of common EP additives was made with TG/DTA and a high temperature pin-on-disc test, which showed that the effective, additivated lubricants exhibit a temperature interval where a low COF is measured. This temperature interval is defined by an initial activation temperature and a second transition temperature, where a loss of the lubricating ability occurs due to thermal degradation. Analysis of the tribochemical properties of the tested lubricants furthermore revealed that an applicable temperature range and a high load bearing capacity are central lubricant properties necessary for ensuring sufficient lubricating ability for punching and blanking operations. Characterization of these essential lubricant properties allows for a selection of alternative, environmentally friendly lubricants suitable for replacing the hazardous chlorinated paraffins often used in tribologicallly severe manufacturing processes. Based on this methodology, the presented study highlighted the possibility to replace chlorinated paraffins for punching and blanking operations with a mineral oil with an additive package based on Ca-, P- and S-additives.

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