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TESTING AND PREDICTION OF LIMITS OF LUBRICATION IN SHEET METAL FORMING

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Abstract. Increasing focus on environmental issues in industrial production has urged a number of sheet metal forming companies to look for new tribo-systems, here meaning the combination of tool_material/workpiece_material/lubricant, in order to substitute hazardous lubricants such as chlorinated paraffin oils. Testing of new tribo-systems under production conditions is, however, very costly. For preliminary testing it is more feasible to introduce laboratory tests. In this paper a new methodology for testing new tribo-systems is presented. The methodology describes a series of investigations combining laboratory and production tests as well as numerical analyses in order to evaluate and compare performance of the new tribo-systems. A part is selected from industrial production and analyzed by this methodology in order to substitute the existing tribo-system with a new one.

Introduction

New, stricter regulations on handling of chemical products, such as REACH [1], and a new, “green” trend in some companies have forced industries to shift from hazardous lubricants, such as chlorinated paraffin oil to more environmentally friendly ones [2]. However, this implies some drawbacks, like possible poorer performance and high costs related to production tests with lubricant failure due to lack of experience with the new lubricants [3].

Usually a new tribo-system is evaluated performing a few laboratory tests and comparing the results with the old lubrication system. In sheet metal forming, realistic laboratory simulation of production conditions can be difficult to achieve and special, custom built tests have been developed for simulation of deep drawing and ironing operations [4]. If the results are satisfactory, the new tribo-system may be tested in production. It has, however turned out that this procedure does not take in account long term temperature development and gradual build-up of pick-up, which have important influence on the limits of lubrication [5]. In fact most of the laboratory equipments are designed for controlling the main parameters of the process but lacking automated, repetitive testing, which is essential for quantification of limits of lubrication.

New methodology for off-line testing of tribo-systems

Figure 1 presents a schematic outline of the proposed methodology for off-line testing and improving of tribo-conditions, starting with an existing component, which is produced in a defined production platform. Workpiece and tool material, lubricant and production speed are known. The tribo-parameters (normal pressure, surface expansion, sliding length, sliding speed and tool/workpiece interface temperature) in the production process can be determined by means of numerical simulation. After this process characterization, a suitable laboratory test is chosen and the test is numerically analyzed in order to plan the test parameters according to the production conditions including parameter range, possible preheating of tool, number of repetitions and cycle time. A tribo-system is then selected and an initial screening is carried out to clarify, whether the tribo-system is promising or not.

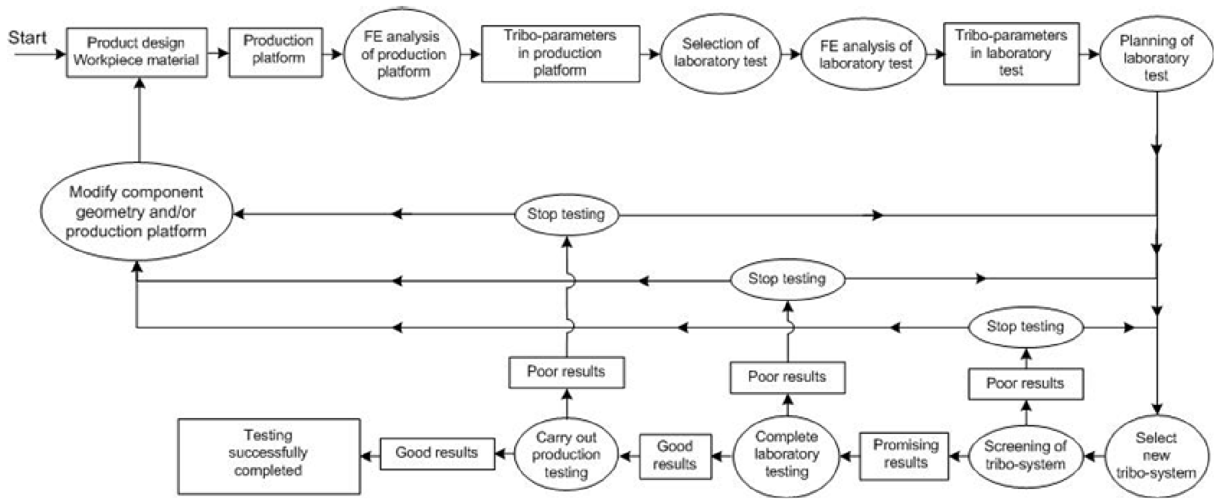

Figure 1. Schematic outline of proposed methodology

In case of poor results the test is stopped and a new tribo-system is selected. Another option can be to modify the component geometry and/or the production conditions (for instance the production speed) without changing the tribo-system. This particular case applies when the tests results are close to acceptable.

The performance of a tribo-system is evaluated by simulative testing under conditions similar to those in the production. The aim of the laboratory tests is to identify the limit of lubrication as a function of the main parameters governing the production process. Exemplification follows here for a deep drawing process. The limit of lubrication in deep drawing is believed to be governed by three main parameters: die radius, normal pressure and production rate. A series of laboratory tests is carried out in order to define a threshold surface, which characterizes the limit of lubrication of the tribo-system. When the surface is known, the production condition can be identified as a point in the graph, which can lie beneath or above the surface as shown in figure 2a and b. The good tribo-system should be able to withstand the production conditions implying that the point lies beneath the threshold surface. On the contrary, a poor tribo-system would imply a point lying above the surface. In case of promising results, a complete and thorough test campaign is carried out. The final conclusion will be either a good (promising) or poor result. In the latter case the same procedure as previously described is followed: either the tribo-system is changed or the component geometry or production conditions are changed. If good results are observed, then the laboratory analysis is concluded and the potentially good tribo-system is tested in production.

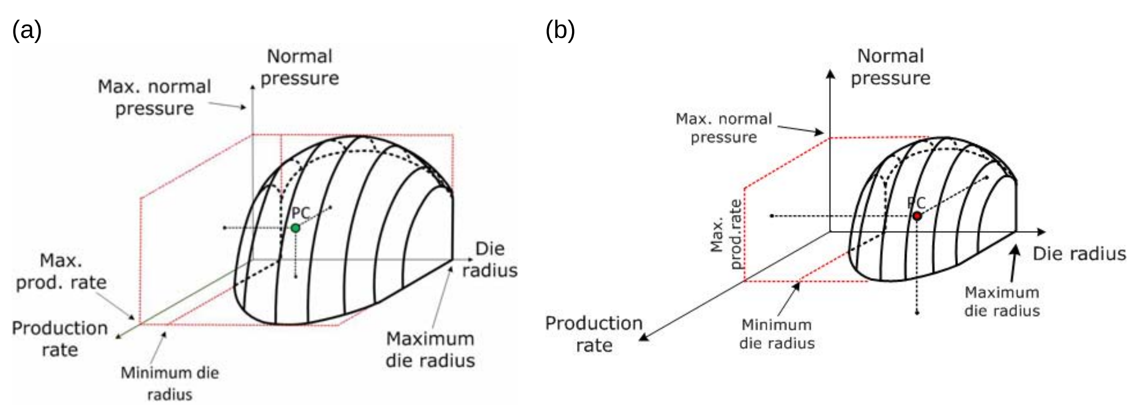

Figure 2. Schematic outline of limits of lubrication in deep drawing with inserted production conditions: (a) good tribo-system – production point lies beneath threshold surface, (b) poor tribo-system – production point lies above threshold surface

Since it is very difficult to ensure that the laboratory test conditions are exactly the same as those in production, the production tests may give a poor result even though the laboratory tests were satisfactory. Thus, as indicated in figure 1, the production tests may lead to two possible outcomes, namely poor or good result. In case of good results the methodology is verified, and the old tribo-system can be replaced with the new one.

New universal tribo-test machine

As mentioned before the long term temperature effect is difficult to assess in most of the laboratory test machines, because the amount of time required between two consecutive tests implies excessive cooling of the tool if heating of the tool is not applied to ensure the typical working temperature. Moreover a slow build-up of pick-up, which only becomes significant after several meters of accumulated sliding length or several hundred strokes, is often seen in industrial production. In order to improve the laboratory tests with regard to these points, a new universal tribo-test machine is built in the authors' laboratory.

The test rig is developed for performing Bending Under tension test (BUT), Draw Bead test (DBT) and Strip Reduction test (SRT). These three tests have proven feasible to simulate normal sheet forming operations e.g. deep drawing, stretch forming and ironing [5]. The special feature of the new machine is the possibility to run the aforementioned tests repeatedly, automatically from coil with a length of more than 1000 m. This allows the user to perform thousands of repetitions at relatively high speed, thus simulating real production conditions.

Figure 3a shows a 3D model of the machine. The workpiece is fed from the right side by means of a coil reel. Figure 3b shows the three axes, which are hydraulically controlled by means of sophisticated proportional electromechanical valves, which enable fast and accurate speed and load control. Axis 1 and 2 are activated when BUT test is performed. Axis 1 and 3 are activated when SRT and DBT are performed.

Industrial case study

In an ongoing project at the authors' laboratory the methodology described above is applied to an industrial case. Figure 4 shows the operations in a progressive tool for manufacturing of a cup by deep drawing followed by two re-drawings and subsequent sharp pressing of the flange.

Workpiece material is stainless steel EN 1.4301, and the production speed is 40 strokes/min.

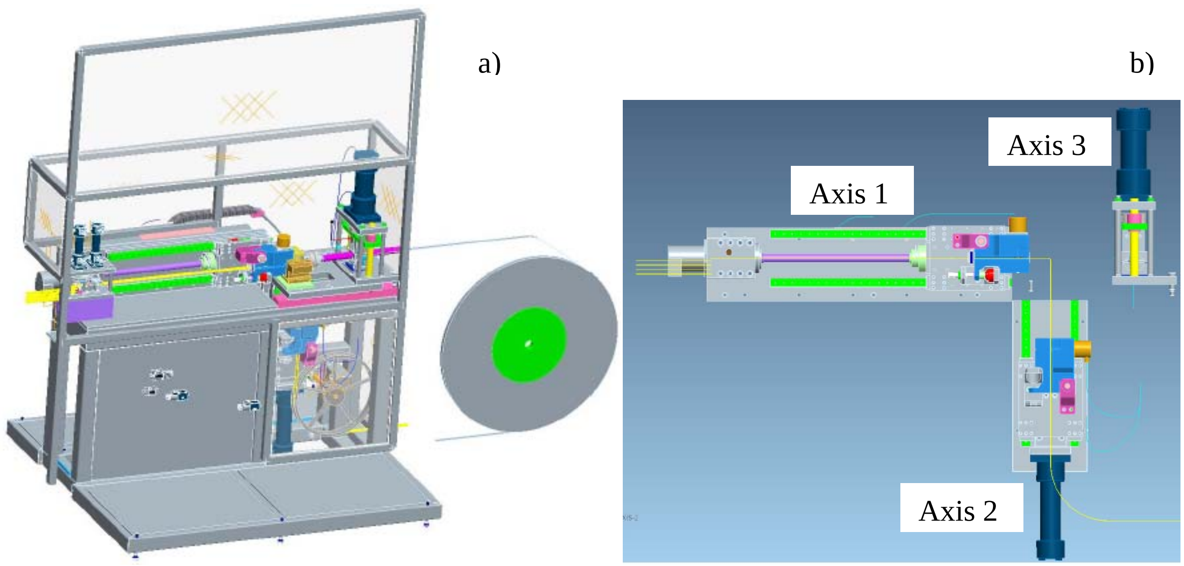

Figure 3. a) 3D model of the new tribo-test machine, b) set-up of the three axes.

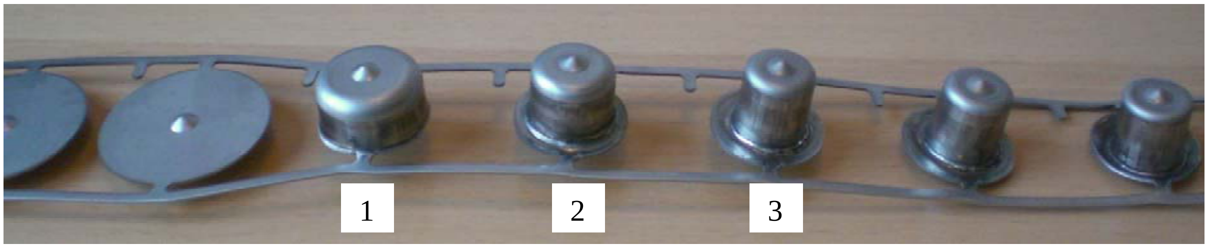

Figure 4. Industrial part produced in a progressive tool. Operation 1 is a deep drawing. Operation 2 and 3 are subsequent re-drawings.

The tool material is PM HSS Vanadis 6 (hardness 62 HRC) from the Swedish company Uddeholm. The most critical operation is No. 3, the second re-draw, where normal pressure and temperature are very high. Experience from production shows that lubrication first break down at this stage, leading to severe galling. Best performance is obtained using chlorinated paraffin oil. The aim is to introduce a new tribo-system replacing the chlorinated paraffin oil. The production condition, tool geometry and production speed are fixed and known. The normal pressure at the die/workpiece interface can be estimated by means of FEA.

Conventional deep drawing can be simulated with the BUT test. In this test a strip of workpiece material is bended 90° around a tool pin. The strip is pulled over the tool pin with constant back tension force controlling the normal pressure at the tool/workpiece interface. Adopting this procedure a laboratory test campaign can be performed selecting new potential tribo-systems and characterizing their performances.

Numerical analysis

Industrial part. Operations 1, 2 and 3, shown in figure 4, were all analyzed with FEM software LSDYNA®. A 2D axisymmetric model of each operation was developed. In figure 5 the models are shown with the punch at the start of deformation. The resulting, formed part is transferred from one operation to the next, importing flow stress and equivalent strain of each element. In the following the results for the critical operation No. 3, the second re-draw, are focused upon.

The coefficient of friction was simulated with three different values: $\mu = 0.1$, 0.05 and frictionless (figure 6a). The punch force was acquired in the third operation by means of a load cell and compared with the simulation in order to calibrate the coefficient of friction. Figure 6b shows the comparison between experimental and numerical punch force. The accordance is good when $\mu = 0.1$ is used.

In figure 7 the normal pressure is shown at the die/workpiece interface. When calculating the normal pressure, the die was assumed to be purely elastic, and the results displayed represent the stresses, on each element, in the direction perpendicular to the curvature. The normal pressure is noticed to be very high for a drawing process, the peak value reaching 900 MPa, which generates a critical condition for the lubrication. The reason for this high normal pressure is the heavy strain hardening due to the successive drawing operations combined with the very small contact area between die and workpiece as seen in figure 7.

BUT test. 2D plain strain numerical analysis of the BUT test was done to calibrate the back tension in order to have the same normal pressure at the interface workpiece/tool as in the industrial process. Due to the high normal pressure seen in the redrawing process, a 90° curvature cannot be used in the BUT tool because this gives too low normal pressure, since the contact surface is much larger than in the redrawing.

A new geometry was adopted, which consist in a 1/8 of a circle as shown in figure 8a. This creates an abrupt exit of the strip causing the normal pressure to suddenly rise at the edge. Figure 8b shows that the normal pressure can reach 1000 MPa applying a back tension of 300 MPa.

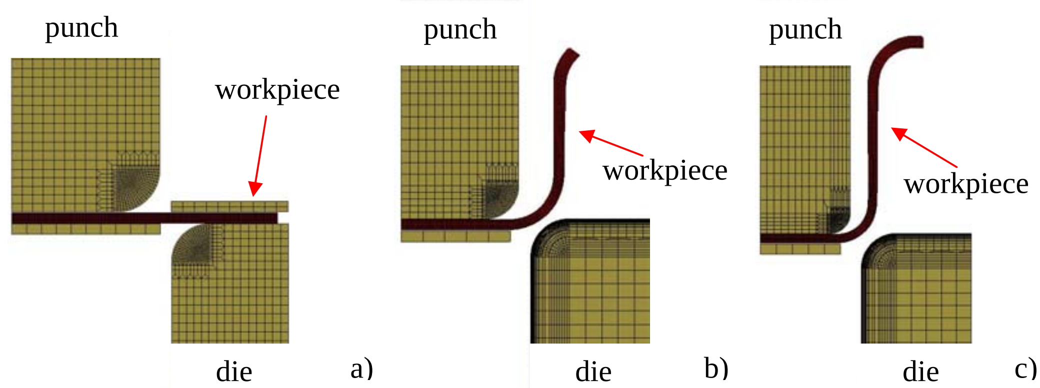

Figure 5. FEM axisymmetric models: a) operation 1, b) operation 2, c) operation 3

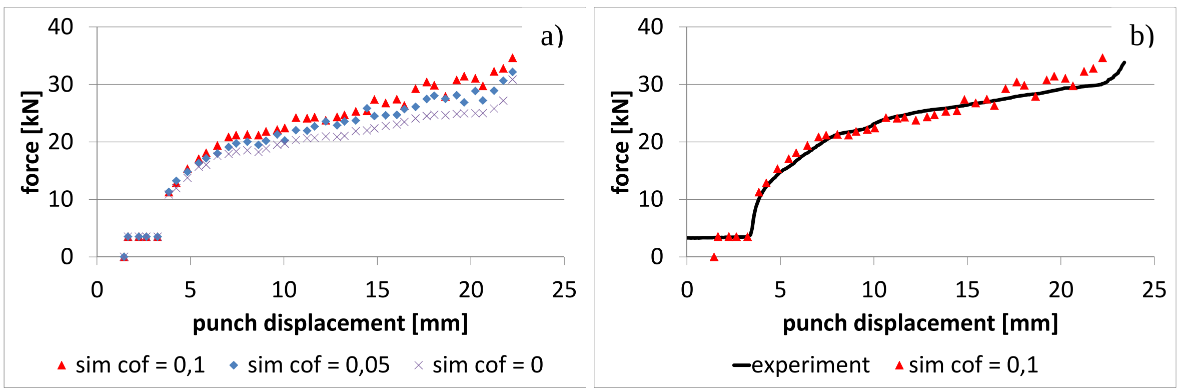

Figure 6. Punch force – displacement curve in operation 3: a) comparison between three coefficients of friction, b) comparison between experimental and numerical analysis (μ = 0.1).

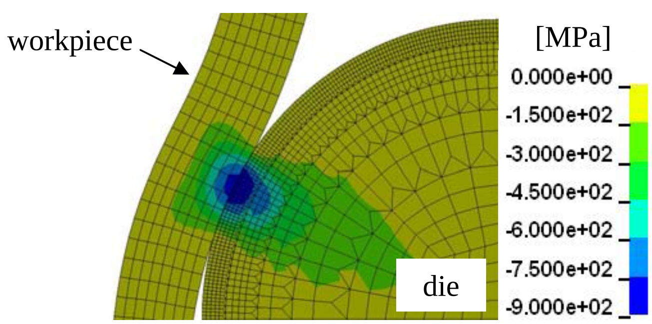

Figure 7. Normal pressure at the interface workpiece/die. Operation 3.

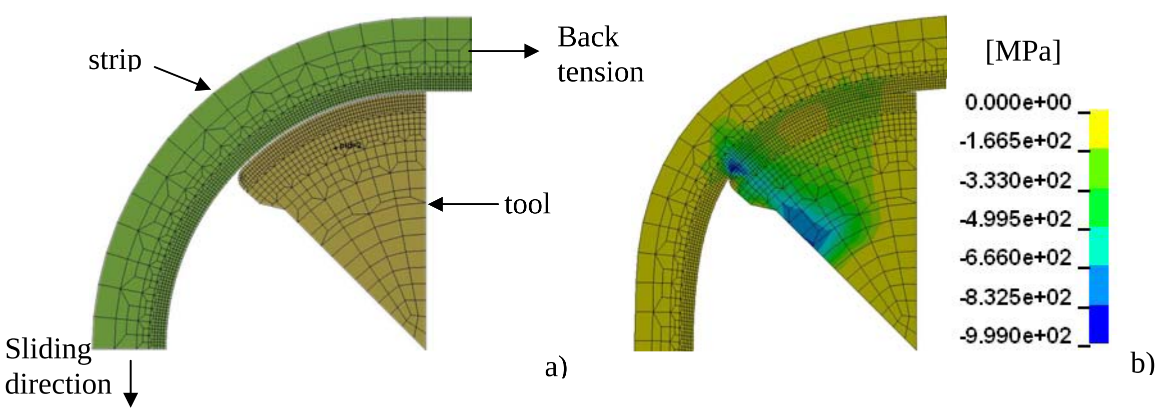

Figure 8. a) BUT numerical model, b) normal pressure at the interface.

Preliminary tests on the new tribo-test machine

Preliminary tests have been done on the new tribo-test machine in order to verify the functionality of the whole system. The first test was conducted on DP 800 workpiece material lubricated with Shell PQ 144 corrosion protective oil. The strip of cross section 1x30 mm was tested at 30mm/s sliding speed, with a sliding length of 20 mm for each draw. Back tension was kept constant at 300 MPa. 700 consecutive strokes were carried out with idle time between two strokes less than 1s. The torque acting on the tool was acquired by means of a torque transducer and figure 9 shows the gradual increase due to build-up of pick-up.

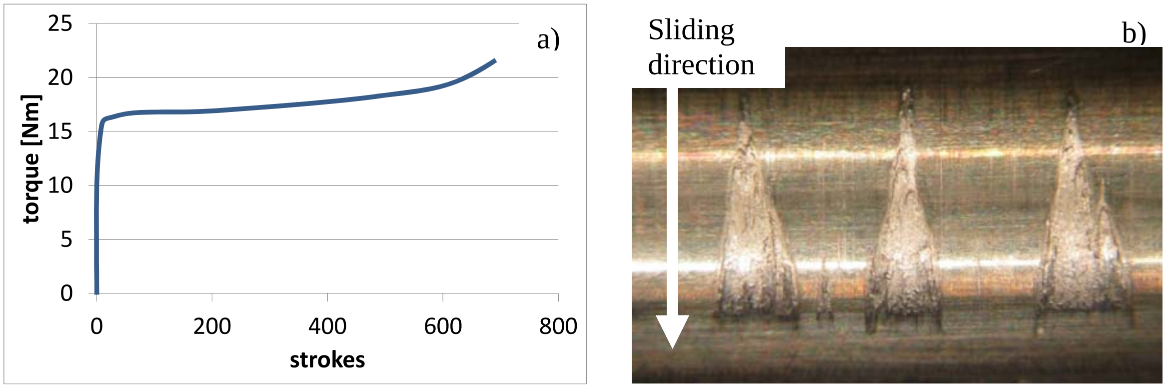

Figure 9. a) torque as a function of number of simulated stroke, b) pick-up formation on the tool.

Conclusion

A new methodology for off-line testing of tribo-systems for industrial sheet metal forming has been presented. The aim is to limit costly production trials to a minimum, when introducing new tribo-systems. The methodology follows a logic path including numerical analysis of the tribo-parameters in the production process, selection and numerical analysis of a suitable laboratory test simulating the production process, laboratory testing of selected tribo-system(s) and, in case of promising results, further testing in the production. A new tribo-test machine was presented, which can simulate real production conditions. Preliminary tests have shown promising results as regards the identification of limit of lubrication for a defined tribo-system. Further test campaigns will follow, where new, environmentally benign tribo-systems will be investigated.

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