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Continuous Strip Reduction Test Simulating Tribological Conditions in Ironing

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Abstract

Laboratory testing of tribo-systems for sheet metal forming applications must ensure similar conditions with the tribo-parameters that are commonly utilized in real production in order to generate data that is meaningful for industry. The main parameters to consider are the tool and workpiece materials, surface roughnesses, normal pressure, sliding length, sliding speed, interface temperature and lubrication. This paper proposes a new Strip Reduction Test (SRT) for industrial ironing processes that is capable of replicating the highly severe tribological conditions that are experienced during both the forward stroke and the backward retraction of the punch. The new SRT tool design is implemented in a new Universal Sheet Tribo-Tester (UST), which can run multiple tests continuously from a coil. The test is capable of simulating various process parameters such as reduction, drawing speed, tool temperature, sliding length and quantifying the onset of breakdown of the lubricant film and subsequent galling after several strokes not only when emulating the forward strokes but also the backward strokes. Preliminary tests disclose promising results as regards the identification of lubricant film breakdown by detecting changes in measured force, surface roughness and/or torque values.

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Keywords: *Simulative test; sheet metal forming; ironing; tribology*

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1. Introduction

Among sheet metal forming processes, ironing (Fig. 1) is considered as one of the most severe due to the occurrence of high localized pressures and large surface expansion. Fig. 1 shows ironing in a tribologically critical production operation at the Danish company Grundfos. Unless very efficient boundary lubricants are applied the combination of high localized pressures and stretching of the lubricant along the tool-workpiece contact interface give rise to lubricant breakdown, pick-up and galling, which results in a poor surface finish. Chlorinated paraffin oils have been commonly utilized to prevent the galling, but legislative initiatives and environmental concerns are forcing the need for replacing such hazardous lubricants by new environmentally friendly ones [1].

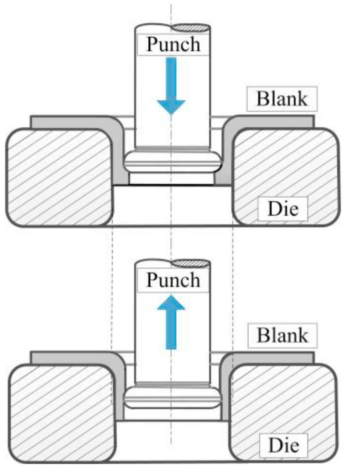

Fig. 1. Schematic of the ironing process during forward and backward strokes.

The Strip Reduction Test (SRT) is a simulative test in which the process conditions of ironing can be replicated by reducing the thickness of a plane sheet strip. One of the first experimental setups developed for this purpose is due to Fukui et al. [2] who performed direct measurements of the friction force in metal-strip drawing with a strip being reduced between two stationary dies. Dohda and Kawai [3] proposed an alternative design consisting of a bottom plate that is drawn together with the strip through a wedge shaped ironing die. Andreasen and Bay [4] introduced a new design that makes use of a circular tool pin, which is easy to polish and furthermore has the advantage of using the same tool four times before repolishing by rotating it 90º. More recently, Aleksandrović at al. [5] proposed a new setup in which the strip is reduced from both sides through a wedge shaped die.

Despite the variety of SRT setups proposed in literature, they all have either limited sliding length or lack of control for enforcing a large number of strokes with idle time in between. These are two critical issues when using the SRT to replicate the tribological conditions in ironing. Attention should also be paid to the influence of temperature in case of modelling high production rates because an increase in temperature results in a smaller lubricant film thickness due to lowering of the viscosity and pick-up, thereby damaging the tools. Furthermore, none of the proposed designs include replication of the back-stroke, which is typically the tribologically most critical phase, since the lubricant film is thinned to a minimum during this part of the operation.

The objective of this paper is to evaluate the potential of a new SRT tool design installed in a Universal Sheet Tribo-Tester (UST) to replicate the operating conditions of high, localized contact pressures, large surface expansions and temperature increase that are commonly found in ironing. The proposed setup allows investigating the performance of lubricants in both the forward and backward ironing stroke and its overall design can easily accommodate changes to account for different processes. The importance of modelling both forward and backward strokes is due to the fact that in some industrial operating conditions the elastic expansion of the ironing die during forward stroke helps maintaining the lubricant film on the contact surface whereas the elastic contraction of the die before the backward unloading stroke (Fig. 1) results in severe contact conditions, lubricant film breakdown and heavy pick-up.

2. Strip Reduction Test

2.1. Tool design

Fig. 2 shows the new SRT tool design and a schematic cross-sectional view of its main components. With numbering according to Fig. 2b, the forward stroke of the ironing process is replicated by drawing a strip (1) from right to left while its thickness is reduced in 'Station A' by means of two stationary cylindrical tool pins (2, 3). The upper cylindrical tool pin is located in a housing (4), which is placed on the base (5), and the base is mounted to the UST by means of guiding keys (6). The desired thickness reduction can be adjusted by changing the thickness of the shims (7), which are placed between the housing legs and the base. The lower cylindrical tool pin is mounted on a heater block (8), by which the tool temperature can be adjusted by an electric cartridge placed in the center hole. The backward stroke of the ironing process is replicated in 'Station B'. Like in 'Station A', this second set of tools includes two stationary cylindrical tool pins (9, 10), a housing (11) and a heater block (12). In practical terms, 'Station B' provides further reduction in strip thickness by adjusting the gap between the two stationary cylindrical tool pins to a value slightly smaller than that utilized in 'Station A'. A torque transducer (13) is connected to the upper cylindrical tool pin in 'Station B'.

a **b**

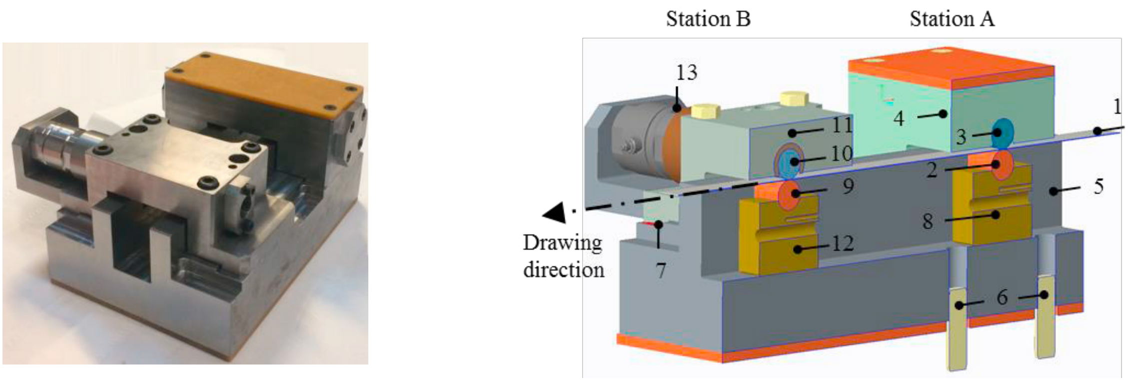

Fig. 2. (a) Photograph of the new SRT tool design and (b) schematic cross-sectional view of its main components.

The new SRT tool design allows use of each of the tool pins in several tests by turning the pins after use, which is an important feature for investigating lubricant breakdown and pick up under several different operating conditions. The capabilities of the new SRT tool are summarized in Table 1.

Table 1. General specifications of the new SRT tool.

Parameter	**Value**
Reduction (for 1 mm thick sheet) [%]	0-65
Drawing speed *[mm/s]*	0-150
Sliding length per stroke *[mm]*	0-500
Strip dimensions [width]x[thickness]x[length] *[mm]*	[0-30]x[0-2]x[limited by the coil length]
Number of strokes	Limited by the coil length

2.2. Installation and operation in the UST

Fig. 3 shows the new proposed SRT tool setup installed in the UST at the Technical University of Denmark. The operation of the SRT makes use of two axes. The horizontal axis draws the strip up to 500 mm before returning to its original position (homing) to continue drawing the strip and includes a clamping system to hold the strip and a force transducer. The vertical axis supplies the force necessary to keep the tool in position for the given reduction. Automatic cutting of the strip at the exit of the working region is performed by the ‘Cutting Station’, and the ‘Holding Station’ located next to is for holding the strip during cutting and homing of the horizontal axis. The strip passes through a guiding tool for accurately feeding the strip into the SRT tool and through the lubrication rolls before entering ‘Station A’. The strip is drawn for a specified sliding length stepwise until reaching the desired number of strokes.

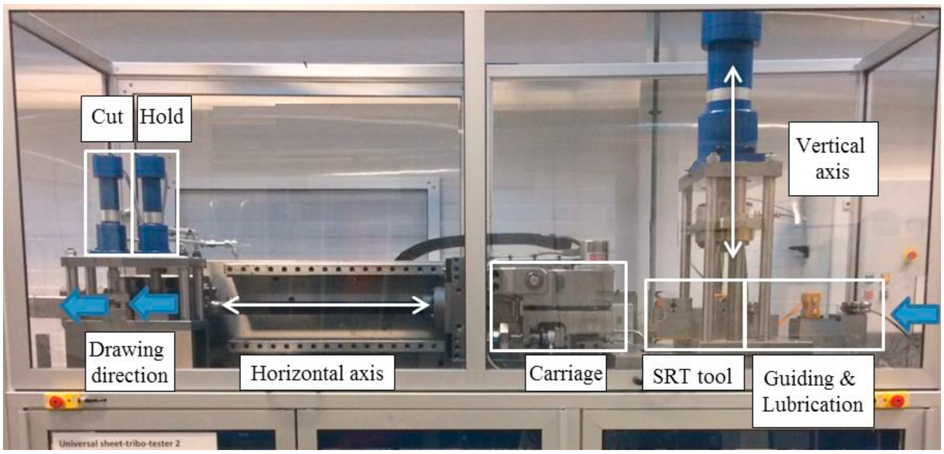

Fig. 3. The UST equipped with the new proposed SRT tool setup.

2.3. Utilization for a production platform

Finite element analysis of strip reduction with 20% thickness reduction was carried out to determine the distribution of contact pressure at ‘Station A’ where the main reduction takes place (Fig. 4). This information can be further utilized to adjust the operating conditions of the SRT tool so that testing in a laboratory controlled environment is able to replicate the conditions found in the production platform. Additional parameters such as the coating and the roughness of the cylindrical tool pins, sliding length and sliding speed must be adjusted according to those in the real ironing process in order to ensure testing conditions identical to the industrial process.

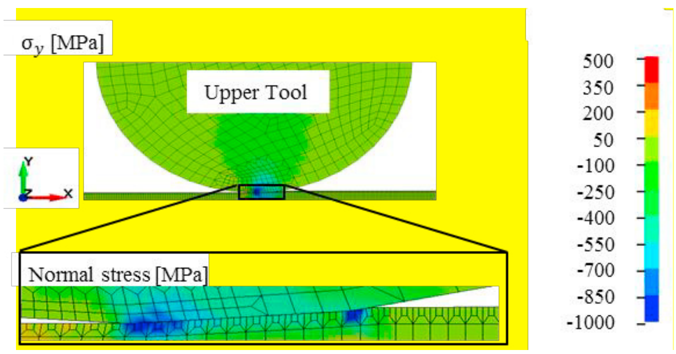

Fig. 4. Finite element distribution of σ_y for ‘Station A’ of the SRT tool setup with the detail of contact pressure.

3. Results and Discussion

The potential and performance of the new SRT tool setup were investigated by means of preliminary experiments performed in stainless steel strips with 1 mm thickness and 30 mm width. Before testing, the cylindrical tool pins were cleaned with alcohol using a soft tissue after which they were placed in the test tool. The desired strip thickness reduction was achieved by adjusting the tool setup with shims. During the entire investigation, Rhenus base oil with additives (LA 722086) was used and the remaining testing parameters are given in Table 2.

Table 2. Test conditions.

Parameter	**Value**
Upper and lower tool diameter *[mm]*	15
Upper and lower tool material	Powder metallurgy chromium-molybdenum-vanadium alloyed cold work tool steel, hardened and tempered to 63 HRC and polished to Ra=0.06 mm (Commercial designation: VANADIS 4)
Strip material	Stainless steel (Euronorm: EN 1.4307, AISI 304L)
Sliding length [mm]	10
Sliding speed [mm/s]	50
Number of strokes	80

The first set of tests was aimed to replicate a thickness reduction of 20 % during the forward ironing stroke and, therefore, only 'Station A' was utilized. The second set of tests was aimed at replicating the combined forward and backward ironing stroke. For this purpose, after performing the 20 % thickness reduction in 'Station A', the resulting thickness was further reduced 4% in 'Station B'. A few number of tests have been performed and a representative set of data has been presented in the paper.

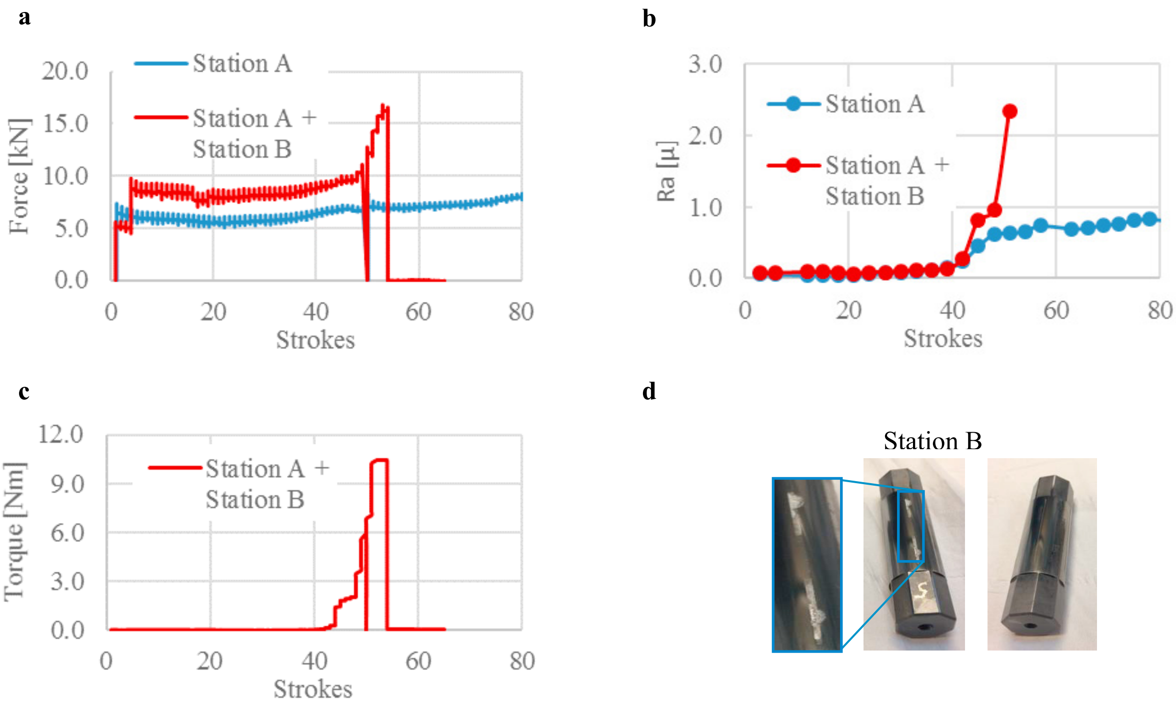

Fig. 5. Evolution of the (a) drawing force, (b) average strip surface roughness and (c) torque as function of the number of strokes, and (d) photographs showing pick-up formation on the tool surface.

Fig. 5a shows the experimental evolution of the drawing force F_d with the number of strokes. As seen, F_d is larger for the second set of tests involving both 'Station A' and 'Station B' because the total thickness reduction is larger. However, Fig. 5a also reveals an increase of F_d after 40 strokes for both set of tests and that this increase is very steep in case of the second test. By comparing these results with the strip surface roughness measurements shown in Fig. 5b, it is concluded that the onset of galling takes place after 40 strokes for both set of tests. The second set of tests experiences a sudden growth of pick-up on the tools in the last five strokes, which leads to the abrupt increase in torque T as shown in Fig. 5c. Fig. 5d discloses the differences in pick up on the surfaces of the lower cylindrical tools of 'Station A' and 'Station B', where heavy pick-up is observed in 'Station B' despite the small reduction. It should be noted that the paper does not focus on repeatability and sensitivity of the set-up at this stage. However, the drawing force, torque and roughness measurements are in good agreement with each other showing that the new continuous SRT tool design is capable of determination of onset of galling.

4. Summary

In this study, the design and the implementation of a new strip reduction test tool is introduced. The design consists of two stations replicating not only the main ironing process but also the back stroke, where the lubricant is scraped off, and the additional reduction due to elastic contraction of the die may cause pick-up on the punch. The UST enables to run the test repetitively with numerous number of strokes, which provides the possibility of replicating individual industrial ironing production in the laboratory. Various tribo-systems can be tested and consequently an optimum tribo-system can be proposed for the production. Preliminary tests have shown promising results as regards the identification of lubricant film breakdown. Further testing will follow to emulate the test conditions in real production while investigating various tribo-systems.

Acknowledgements

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