Experimental studies on the effect of application methods on the lubricant performance during serial production in automotive industry

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Abstract. Lubricant breakdown and galling phenomena are widely observed at the tooling surface during the stamping of aluminium components for the automotive industry, which compromise the formed surface quality and reduce tool-life. The lubricant performance has been found to be significantly influenced by its method of application. In the present research, a dedicated lubricant was evaluated by utilizing an advanced lab-scale friction testing system, TriboMate, and the effects of lubricant application method and lubricant quantity on the coefficient of friction evolution were investigated. It has been found that lubricant performance was significantly improved when the lubricant was applied on the hot workpiece blank, compared to the cold tooling surface, and when the lubricant quantity was increased. The gradual increase of friction evolution despite lubricant application on the workpiece blank was found to be due to the formation of an aluminium transfer layer at the tooling surface.

Keywords: lubricant performance; application methods; metal forming; lubricant breakdown; galling.

1 Introduction

Sheet metal forming processes have been widely adopted in the automotive and aviation industry for the purpose of producing lightweight components, such as high strength aluminium alloy components [1]. A serial production line for metal stamping processes can produce over 2 million parts per year, indicating the requirement for a continuous production without interruption for at least 8 hours [2]. Lubricant is usually applied at the tool or workpiece surfaces prior to each forming cycle to protect the contacting counterparts and reduce friction [3]. However, Galling, a material transfer layer generated on the tooling surface, is still inevitable and usually observed during stamping processes for aluminium components, which will deteriorate the surface quality of the formed part and reduce the tooling life, especially considering the serial mass production [4], [5]. The conventional pin-

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on-disc test with a continuous lubricant feeding system is usually used to investigate the lubricant performance when applied in a mechanical system or engine. However, this is not representative of the contact condition during the metal forming process where lubricant is applied before the forming initiates and lubricant breakdown may occur afterwards due to consumption and starvation of lubricant [6], [7].

In this paper, the effects of lubricant application methods, i.e., application on the tool or workpiece blank, and lubricant quantity on the coefficient of friction evolution were investigated by a lab-scale friction testing system, TriboMate, to simulate the contact conditions during the real forming production of aluminium stamped components.

2 Methodology

A lab-scale friction testing system, TriboMate [3], [8] (schematic diagram shown in Figure 1), was used to conduct friction tests (pin-on-strip test) to study the effect of lubricant application methods. Pin-on-strip tests were conducted between AA6111 blank strip with a thickness of 2 mm as the workpiece material, which was provided under T4 condition by Novelis, and P20 tool steel pin with a hardness of approximately 320 HV as the die material, which was provided by West Yorkshire Steel. The diameter of the spherical pin was 6 mm with an average surface roughness of 0.8 µm. A dedicated lubricant developed for the hot stamping process was applied at the tool-workpiece interface for testing purposes. The kinematic viscosity of the lubricant was 50.5 cSt at 40°C and the specific gravity was 0.99 at 15°C.

The TriboMate testing system is composed of a flexible robotic arm and a precision thermal box, which enables precise motion, load and temperature implementation during testing. A dedicated tool with precisely machined pockets (lubricant reservoirs) was utilized for the lubricant application on the pin specimen. A spray gun with precise air control for the uniform distribution of lubricant drops was utilized for the lubricant application on the hot blank. In each test, the workpiece blank was heated up to the target temperature followed by lubricant application either on the cold pin or the hot blank. Then the cold pin slid against the hot blank. Each testing condition was conducted at least three times and the coefficient of friction evolution as the function of sliding distance was recorded.

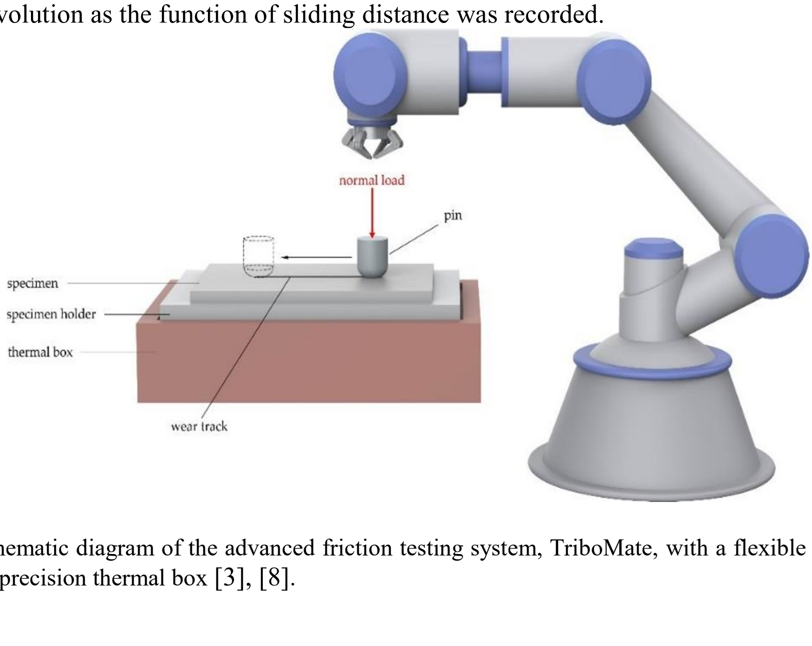

Fig. 1. Schematic diagram of the advanced friction testing system, TriboMate, with a flexible robotic arm and a precision thermal box [3], [8].

3 Results and discussions

3.1 Effect of lubricant application method on coefficient of friction evolution

There are two lubrication application methods usually utilized in industrial hot stamping processes, i.e., application on the forming tool or application on the hot workpiece blank. The application method was found to have a significant effect on the lubricant behaviour and thus coefficient of friction (COF) evolution. Besides the application method, the testing contact conditions remained unchanged, e.g., under the temperature of 250°C, contact load of 6 N and relative sliding speed of 30 mm/s, as shown in Figure 2a.

When the lubricant was applied on the tool (pin head), a rapid increase of COF was observed after a sliding distance of only 10 mm, indicating the lubricant breakdown occurred and it started to lose its efficacy. As the sliding distance continued to increase to around 50 mm, the COF reached a high plateau of approximately 1.1 and a large fluctuation was observed at this level. This means the lubricant completely broke down and lost its lubricity. In contrast, when the lubricant was applied on the workpiece blank (after heating stage), a relatively stable COF was observed during the whole sliding distance of 75 mm with an average COF value of approximately 0.21.

The significantly different lubricant behaviours introduced depending on lubrication application method is due to the discrepancy of the entrapped lubrication volume/film thickness at the contact interface. When the lubricant is applied on the tool, the entrapped lubricant film thickness diminishes rapidly as the sliding distance increases, which results from being smeared on the wear track or squeezed out from the interface. However, during the application on the hot blank, although the film thickness reduces due to the evaporation of lubricant at elevated temperature (250°C in this case), there is negligible reduction due to the increase of sliding distance.

A similar trend can be observed under the higher temperatures of 300°C and 350°C, where the lubricant performance has been significantly improved when applied on the hot workpiece blank (shown in Figures 2b and 2c). It was observed that the lubricant breakdown occurred earlier, and the transformation to dry sliding condition was accelerated as temperature increased when the lubricant was applied onto the tool, e.g., breakdown distance decreased from 10 mm at the temperature of 250°C to 2 mm at the temperature of 300°C, while breakdown immediately occurred at 350°C.

It was also found that when the lubricant was applied on the hot blank, the average COF value increased from 0.21 at the temperature of 250°C to 0.32 at the temperature of 300°C, and 0.82 at 350°C, indicating a reduced lubricity of the lubricant when the temperature increased. This reduction was due to the decrease of lubricant viscosity and degradation of friction modifier additives, leading to a thinner film between the contact counterparts. When the temperature further increased to 400°C, there was no significant improvement on the lubricant performance even when it was applied onto the hot blank (as shown in Figure 2d), indicating a complete failure of the lubricant similar to the dry sliding condition at such high temperature.

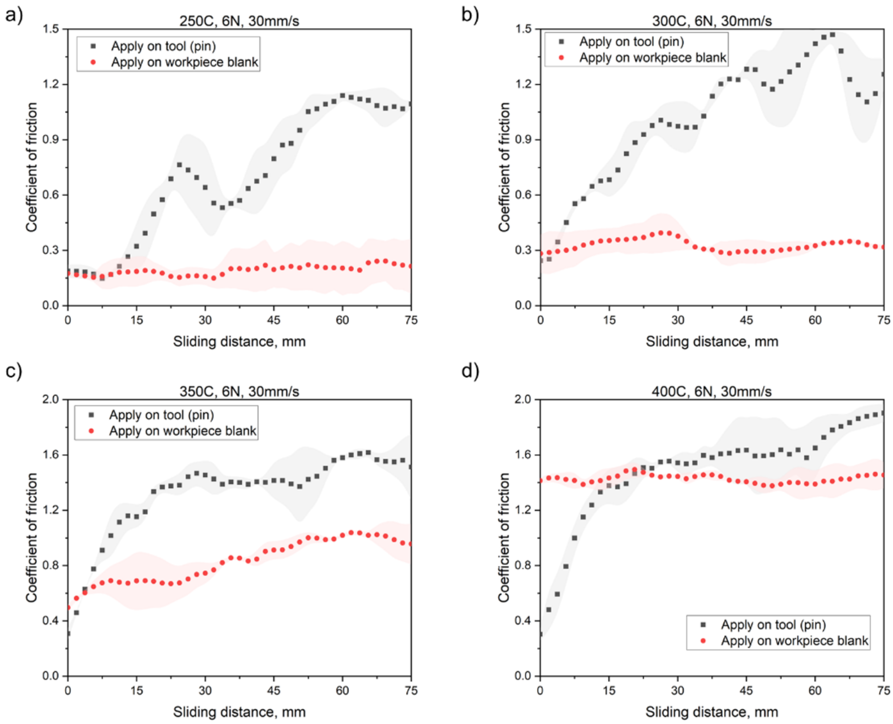

Fig. 2. Comparisons of coefficient of friction evolution between different lubricant application methods (tool or workpiece) under a) 250°C, b) 300°C, c) 350C and d) 400C.

3.2 Effect of lubricant application quantity on coefficient of friction evolution

It has been reported in some literature that when the lubricant was applied onto the tool, the increase in the lubricant application quantity would lead to an increased sliding distance before lubricant breakdown occurred, thus resulting in better lubricity [3], [9]. In the present study, the effect of lubricant quantity on the coefficient of friction was investigated, where the lubricant was applied onto the hot blank surface. A general increase of the lubricity was observed when the lubrication quantity increased. Besides the lubricant quantity, the testing contact conditions remained unchanged, e.g., under the temperature of 350°C, contact load of 6 N and relative sliding speed of 30 mm/s, as shown in Figure 3a.

As the lubricant quantity on the hot blank increased from 37.6 g/m^2 to 81.6 g/m^2, the average COF decreased from approximately 0.82 to 0.25 at the temperature of 350°C. If the temperature was elevated to 400°C, the increase of the lubricant quantity from 37.6 g/m^2 to 81.6 g/m^2 would result in a less evident decrease of the average COF from 1.43 to 1.15. As more lubricant was entrapped at the contact interface and thicker lubricant film thickness, the actual contact area decreased and thus reduced frictional forces.

In addition, during the one sliding cycle, the coefficient of friction was not constant but presented a gradual increasing trend, especially at the temperature of 350°C and 400°C. The gradual increase of the COF value was due to the galling formation on the surface of the tools during the sliding wear although lubricant was applied. During the sliding process, aluminium wear particles were generated due to: 1) frictional stress exceeded the shear flow stress of the workpiece material locally, and 2) ploughing of the hard asperities on the tooling. These loose wear particles would easily adhere onto the cold tooling surface under the locally high contact pressure and significant temperature difference between the tool and workpiece, thus, forming a material transfer layer on the tooling surface. This transfer layer, i.e., galling, would roughen the contact interface, causing increased friction compared to the initial smooth tooling interface. Once the galling occurred, more wear particles would be generated and facilitate the growth of the galling layer. The formation of a galling layer on the tooling surface was also reported in the literature [4], [10].

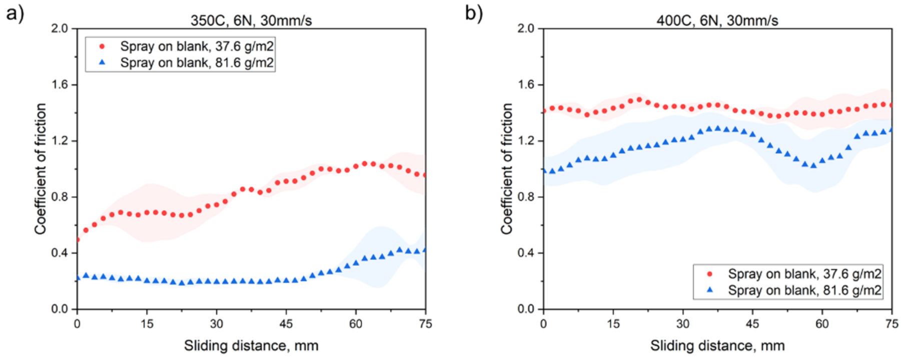

Fig. 3. Effect of the lubricant application quantity on coefficient of friction evolution under the temperature of a) 350°C and b) 400°C.

4 Conclusions

In the present research, friction testing and lubricant performance evaluation under different lubricant application methods and quantities were conducted by implementing an advanced testing system, TriboMate, to reproduce the contact conditions at the tool-workpiece interface in real industrial production. The findings and conclusions can be drawn as follows:

- Lubricant performance was significantly improved when the lubricant was applied onto the hot workpiece blank, compared to the cold tooling surface; a better lubricity was observed where the average COF reduced from 0.32 to 0.21 when the temperature decreased from 300°C to 250°C.
- A general increase of lubricity was observed when the lubricant quantity at the tool-workpiece interface increased. The average COF decreased from 0.82 to 0.25 at the temperature of 350°C when the quantity increased from 37.6 g/m^2 to 81.6 g/m^2.
- A gradual increase of friction values during an individual sliding cycle was due to the aluminium transfer layer formation at the tooling surface. Increased temperature would accelerate the formation of material transfer layers and reduce the efficiency of lubrication.

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