



The Influence of Engineered Tool Surfaces in Ironing

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Abstract. The present paper focuses on the application of engineered tool surfaces in sheet metal forming. A strip-reduction test was used to investigate the textured tool topographies with small-to-large distances between the pockets in ironing process. An optimum contact area ratio α exists at larger speeds, which ensures the effectiveness of the table-mountain structure of the tool topography. The tool texture with a too large amount of pocket area, i.e. with low α -value, can reduce the friction and enhance lubrication performance in comparison to that of a finely polished tool surface.

Keywords: Engineered tool surface · Textured surface · Sheet metal forming

1 Introduction

While texturing of sheet metal surfaces to promote lubrication in metal forming has been applied for several decades, tool surface texturing is rather new. A few experiments of engineered surfaces in deep drawing tools [1] and in microelectronics mechanical systems [2] have shown promising results, indicating that the textured tool surfaces may provide mechanical lubrication systems, which can function instead of chemical ones. This is beneficial to replace environmentally hazardous lubricants with environmentally benign ones [3]. The study focuses on a sheet metal workpiece sliding on a textured table mountain-like tool surface topography in ironing process. Adopting a severe tribological condition that may lead to galling occurrence in sheet-metal forming, a Strip-Reduction-Test (SRT) emulating the ironing process has been selected to study the influence of the contact area on the textured tool surface topographies.

2 Methodology and Materials

The SRT is a simulative testing of ironing as detailed in ref. [4] (see Fig. 1). The tool material was made of AISI D2 cold work tool steel. The workpiece material was a commercially pure Al 99.5, H111 with dimensions $480 \times 20 \times 4$ mm. The as-received workpiece surface roughness was $Ra = 0.21 \mu\text{m}$. The stress-strain curve of the workpiece material A199.5 H111 was determined by plane strain compression test, in accordance to Voce’s model: $\sigma_o = \sigma_i + (\sigma - \sigma_i)[1 - \exp(-n\varepsilon)] = 55 + (149 - 55)[(1 - \exp(-1.52\varepsilon))]$ MPa. A high viscous mineral oil contained additives with boundary lubrication properties, Rhenus oil with viscosity of 800 cSt, was used in the study.

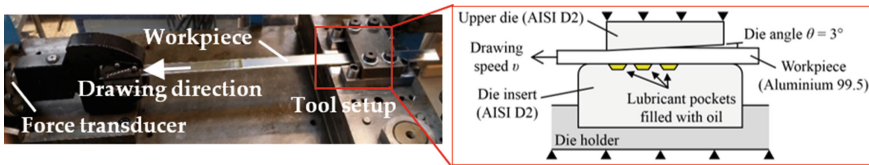


Fig. 1. Schematic of strip reduction test (left), and die insert with textured features (right).

Figure 2 shows the die insert consisting of a deformation region, $X \times Y = 11.5 \times 20$ mm, and a transverse pocket length $y = 16$ mm. Varying textured features between the pockets were manufactured in both transversal and longitudinal to the sliding direction. Table 1 lists surface texture parameters in form of contact area ratio α along the tool/workpiece interface. The smooth tool surface with no textures on the tool surface has a contact area ratio $\alpha = 1$. For the textured tools with $y = 0$ mm, the plateau distances $x = 0.23$ -, 0.46 -, and 0.92 -mm results in $\alpha = 0.60$, 0.74 and 0.84 , respectively. Meanwhile, for the textured tools with $y = 0.8$ mm and $y = 2$ mm, the plateau distances $x = 0.23$ -, 0.46 -, and 0.92 -mm results in $\alpha = 0.75$, 0.84 and 0.90 , respectively.

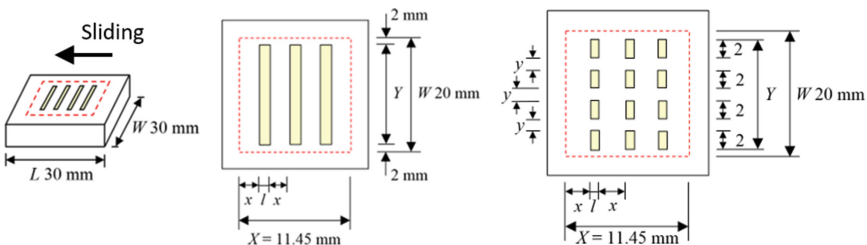


Fig. 2. Different textured features with varying distance between pockets in transversal (*Tool A*) (middle) and longitudinal (*Tool B* and *Tool C*) (right) to the sliding direction.

Table 1. Contact area ratio α demonstrates different textured features.

Tool type	Distance between pockets	$x = 0.23$ mm		$x = 0.46$ mm		$x = 0.92$ mm	
		Notation	α	Notation	α	Notation	α
<i>Tool A</i>	$y = 0$ mm	A1	0.60	A2	0.74	A3	0.84
<i>Tool B</i>	$y = 0.8$ mm	B1	0.75	B2	0.84	B3	0.90
<i>Tool C</i>	$y = 2$ mm	C1	0.75	C2	0.84	C3	0.90

3 Results and Discussion

Figure 3 shows the measurements of average drawing loads as a function of contact area ratio at drawing speeds $v = 65$ mm/s and 240 mm/s. All evaluations are shown in Fig. 3 describes all oblong pockets with (*Tool B* and *Tool C*) and without (*Tool A*) different longitudinal gap y in regards to contact area ratio α , see the difference of the contact area on the textured tool surfaces in Fig. 2 above. It is seen that no improvement was noted on the drawing load, when testing tool textures at the lower speed 65 mm/s (Fig. 3a). Therefore, the rest of the discussion is focused on the tool texture at a larger speed 240 mm/s (Fig. 3b). The positive influence of high drawing speed is explained by micro-plasto-hydrodynamic lubrication, which is promoted by high sliding speed and high viscosity of the lubricant [5]. Tool texture with a too large amount of pocket area, i.e. with low α -value, was found to increase the drawing load, Fig. 3b. A smaller amount of pocket area, on the other hand, may also lead to increased drawing load since the lubricant escape by micro-plasto-hydrodynamic lubrication may not be sufficient to cover the entire flat plateau. This implies an increase in drawing load.

It is furthermore noticed that increasing speed leads to the reduction of the drawing forces. This may be explained by improved micro-plasto-hydrodynamic lubrication at higher viscosity leading to effective separation between tool and workpiece on the plateaus of the tool table mountain [6]. Application of the Rhenus oil generates a thin,

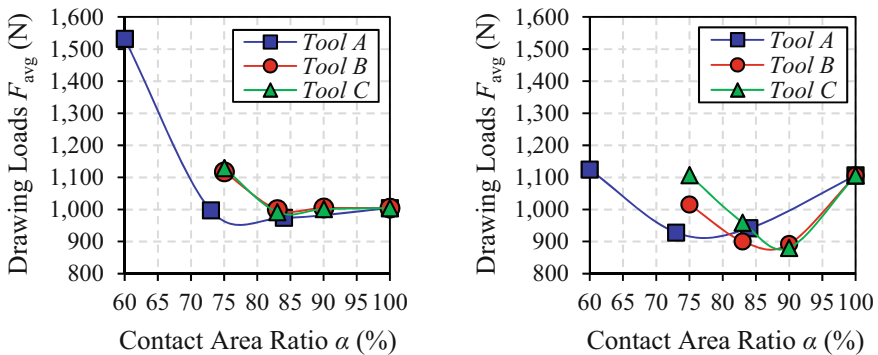


Fig. 3. Average drawing load F_{avg} as a function of contact area ratio α : Low speed $v = 65$ mm/s (Left) and High speed $v = 240$ mm/s (Right).

protective film to separate the tool/workpiece interface. This further reduce the friction resisting the sheet-metal flow sliding onto the textured tool surfaces, while experiencing increasing contact pressure with the reduction r in each test was 10–15% (see Fig. 1). The 10–15% reduction emulates an ironing operation in aluminium can production.

4 Conclusion

A method to enhance lubrication and reduce friction by utilizing engineered tool surfaces was investigated. Textured tool topographies with small-to-high contact area ratio were investigated. The strip reduction test, which emulates the tribological conditions in an ironing process, was used for experimental measurements of friction and determination of possible pick-up and galling. The experiments confirmed that the tool texture, with a larger amount of pocket area, i.e. with low α -value, can lower friction and improve lubrication performance in comparison to that of a finely polished tool surface, which ensures a table-mountain structure of the tool topography. The tool textures were advantageous at larger sliding speeds when using higher viscosity oils, which facilitates the escape of trapped lubricant by micro-plasto-hydrodynamic lubrication.

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References

1. Wiklund, D., Liljebgren, M., Berglund, J., Bay, N., Kjellsson, K., Rosén, B.-G.: Friction in sheet metal forming – a comparison between machined and manually polished die surfaces. In: Tribology of Manufacturing Processes, Proc. Int. Conf. on Tribology in Manufacturing Processes, pp. 613–622. ICTMP (2010)
2. Kamis, S.L., Lah, M.A.C., Rahama, N.S., Rahim, N.A.A.: Fabrication and tribological characterization of aluminium alloy by using photochemical machining. *J. Tribol.* **28**, 82–95 (2021)
3. Ahmad, N.A., Samion, S., Rahim, E.A., Jamir, M.R.M.: Environmentally approach for enhancing tribological characteristics in metal forming: a review. *J. Tribol.* **26**, 37–59 (2020)
4. Sulaiman, M.H., Farahana, R.N., Bienk, K., Nielsen, C.V., Bay, N.: Effects of DLC/TiAlN-coated die on friction and wear in sheet-metal forming under dry and oil-lubricated conditions: Experimental and numerical studies. *Wear.* 438–439 (2019). <https://doi.org/10.1016/j.wear.2019.203040>
5. Sulaiman, M.H., Christiansen, P., Bay, N.: The influence of tool texture on friction and lubrication in strip reduction testing. *Lubricants.* **5** (2017). <https://doi.org/10.3390/lubricants5010003>
6. Sulaiman, M.H., Christiansen, P., Bay, N.: Influence of tool texture on friction and lubrication in strip reduction. *Procedia Eng.* **207**, 2263–2268 (2017). <https://doi.org/10.1016/j.proeng.2017.10.992>