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Finite Element Simulation of Textured Tool Surfaces in Sheet Metal Forming

Pichitpong Pongsaranun[1], Sasawat Mahabunphachai[2], Sedthawatt Sucharitpwatskul[2], and Numpon Mahayotsanun[1,*]

[1] Department of Mechanical Engineering, Faculty of Engineering, Khon Kaen University, Khon Kaen 40002
[2] National Metal and Materials Technology Center (MTEC), Thailand Science Park, Pathum Thani 12120
*Corresponding Author: numpon@kku.ac.th, +66-87-554-2879, Fax. +66-43-202-849

Abstract

This study investigated the friction behaviors and load carrying capacity of different die surface textures in sheet metal forming by using finite element simulation. Three types of texture shapes (circular, triangle, and square) and one smooth with no texture (flat) were considered. The flat-on-flat simulations were carried out to obtain the tangential forces, normal forces, and average pressures. The tangential and normal forces were used to calculate the friction coefficients at the die-sheet interface. The results showed that surface texturing caused the friction coefficients to fluctuate along the sliding distance but the amount of fluctuation was considered insignificant in dry lubrication. The average pressure values were used to indicate the load carrying capacity of each texture and its effectiveness in hydrodynamic lubrication. The highest to lowest average pressures were obtained from circular, triangle, square, and flat shapes, respectively. This implied that the circular shape texture was considered the most effective in hydrodynamic lubrication. The results from this study provided a fundamental understanding of surface texturing and could be used to design optimized die surface textures in sheet metal forming process.

Keywords: Finite Element; Friction; Load Carrying Capacity; Sheet Metal Forming; Surface Texturing

1. Introduction

Surface texturing has shown potential benefits to improve friction and wear, enabling extended tool life. In sheet metal forming process, tool and sheet surfaces can be textured in order to increase load carrying capacity, which helps improve friction and wear between the tool and the sheet [1-11]. Several important factors that affect the load carrying capacity of textured surfaces are: (1) texture structures (shape, depth, area density, and orientation), (2) materials, and (3) operating conditions [12-13].

Different models and methods have been proposed to predict and optimize surface texturing designs [14-19]. For instance, Ripoll et al. [17] investigated the influence of texture on friction during reciprocating sliding of the cylinder-on-flat test and found that the loading conditions, diameter of the cylinder, and width of the texture affected the coefficient of friction. Etsion [20] proposed a theoretical modeling of surface texturing in hydrodynamic lubrication and suggested that the hydrodynamic pressure

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distribution was the source for load carrying capacity in parallel surface sliding.

This paper aimed to study the influence of texture on friction and load carrying capacity in the flat-on-flat test by using finite element (FE) simulation. Three types of textured die surfaces (circular, triangle, and square) and one smooth surface with no texture (flat) were considered and evaluated. The friction coefficients and average pressures were compared among the surfaces to observe the tribological effects influenced by surface texturing. The results and analysis obtained from this study provided a basic understanding of friction influenced by surface texturing in sheet metal forming process, which could also be used to design and optimize die texture surfaces.

2. Considered Surface Textures

Four die surfaces were investigated as shown in Fig. 1. The selected shapes and dimensions were based on the feasibility of current manufacturing processes to produce these surfaces. The width and height of all textures were controlled to be the same at 200 μm, the spacing length and depth of each texture was 324 μm and 10 μm, respectively (except for the flat surface). As a result, among the textured surfaces, the depth, area density, and orientation are kept constant; therefore, the only difference is the shape.

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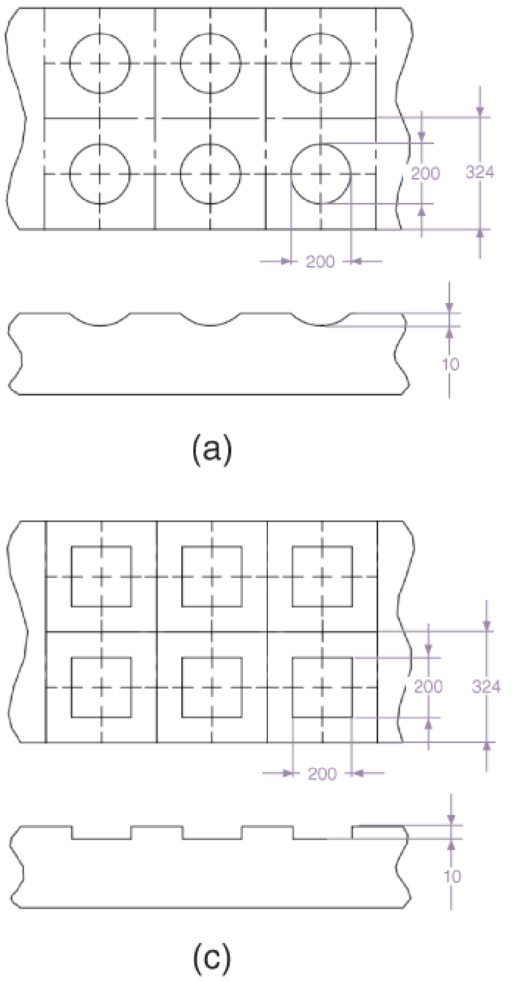

Fig. 1 Considered die surfaces: (a) circular; (b) triangle; (c) square; and (d) flat (Note: all units are in μm)

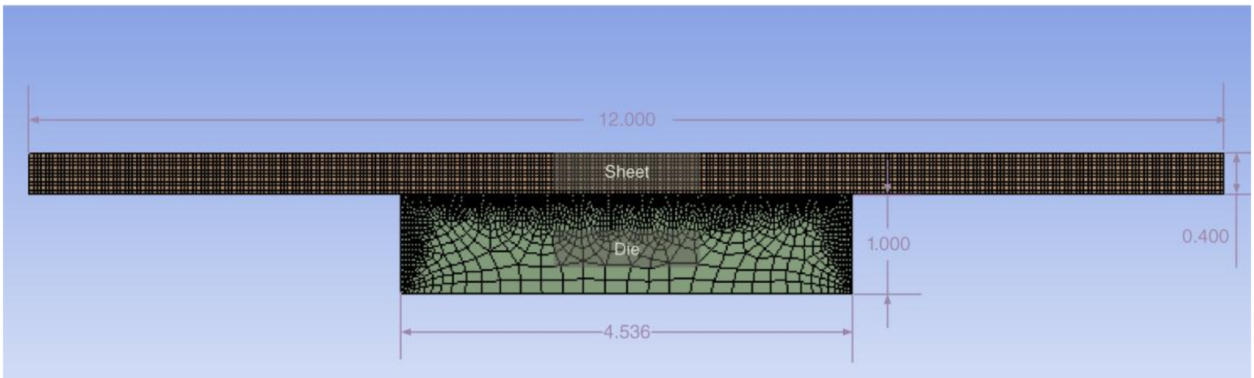

Fig. 2 FE model of the flat-on-flat test (Note: all units are in mm)

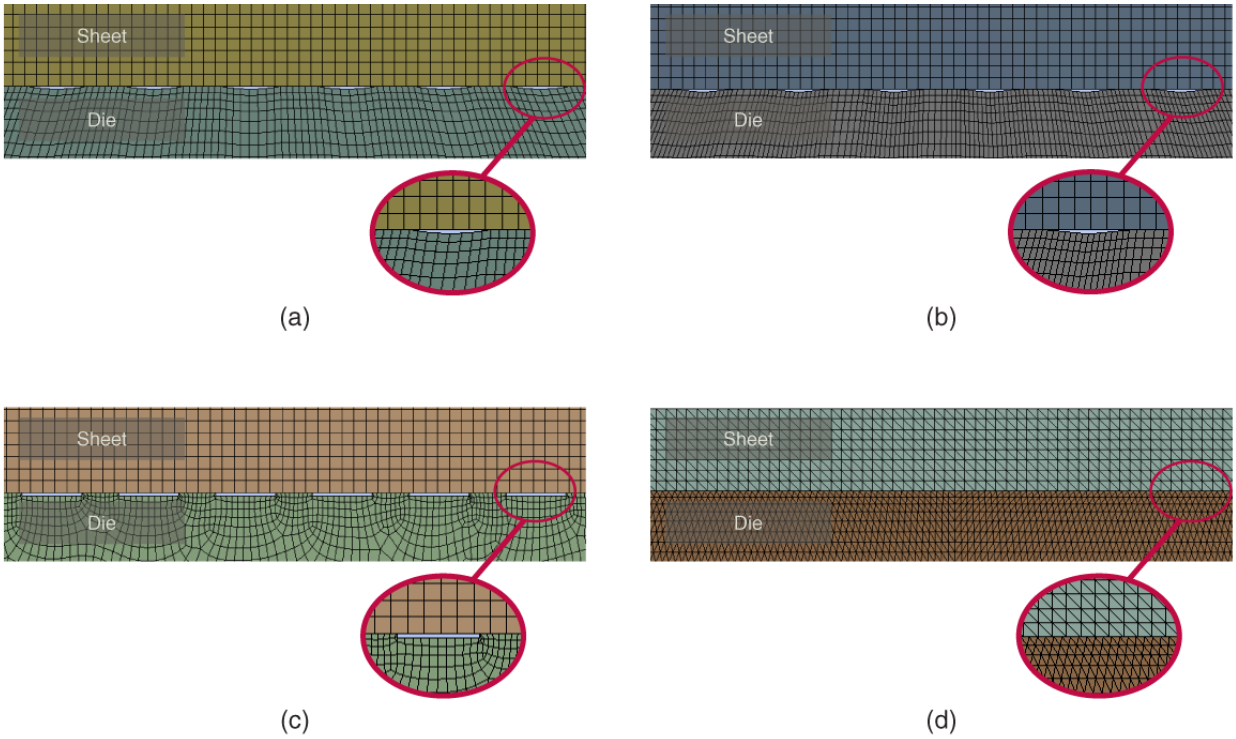

Fig. 3 FE model of different textured surfaces: (a) circular; (b) triangle; (c) square; and (d) flat

3. Finite Element Simulation

The finite element software used in this study is MSC.Marc and the 2D FE model of each surface texture is illustrated in Fig 2. There were 14 textures on the die surface, which was fully covered by the sheet. The detailed models of the FE setup are displayed in Fig. 3. Both the sheet and die were modelled as deformable bodies having isotropic and kinematic hardening property. Four-node quadrilateral elements were used for meshing, and the element sizes were 5 μm and 25 μm for the sheet and die, respectively. The material properties of the sheet and die are presented in Table 1. The contact property at the die-sheet interface was set to follow Coulomb's law with the friction coefficient of 0.1. During the simulation, the die was set to be stationary and two steps were required to simulate the flat-on-flat test. Firstly, the sheet was placed on the top of the die and then moved vertically downward for 1 μm to ensure that the die and sheet were fully in contact. Then, the sheet was moved horizontally to the left for 648 μm (two-texture length).

Table. 1 Material properties of die and sheet used in the FE simulation

Properties/Materials	Sheet (AISI 304)	Die (SKD11)
Density (kg/m^3)	8030	8000
Yield Strength (MPa)	215	1034
Poisson's Ratio	0.29	0.30
Young's Modulus (GPa)	193	209

Although the friction coefficient between the die and sheet was set to be constant, the contact length was different for each texture shape during the sliding, thus, making the lateral and normal forces unequally in each case. In order to take into account the forces due to plastic deformation, the friction coefficient (μ) was calculated using Eq. 1.

$$\mu = F_T/F_N \quad (1)$$

where F_T is the tangential force and F_N is the normal force exerted on the die surface. Another important factor to be considered is the load carrying capacity, which can be obtained by Eq. 2 and Eq. 3 [20].

$$W = (1/A) \int\int P(X_1,X_3)dX_1dX_3 \quad (2)$$

$$P = (1/3)(P_1+P_2+P_3) \quad (3)$$

where W is the dimensionless average pressure, A is the dimensionless area, P is the average pressure, X_1 is the direction in the 1-axis and X_3 is the direction in the 3-axis. P_1, P_2, and P_3 are the pressures in the 1-axis, 2-axis, and 3-axis, respectively. Note that the 1-axis and the 2-axis are on the same plane and perpendicular to the 3-axis. It can be observed that the load carrying capacity highly depends on P. In this study, only P was calculated to indicate the load carrying capacity and compared among the four type of surface textures.

4. Results and Discussions

Fig. 4 shows the von Mises stress results of the FE simulation. Clearly, the stresses are different between textured surfaces and flat surface. The stresses of textured surfaces vary but those of the flat surface are uniform along the die surface. Comparing among the textured surfaces, the stresses are also different depending on the types of texture. Note that the highest stress values normally occur at the edge of each texture, which could be observed in Fig. 5.

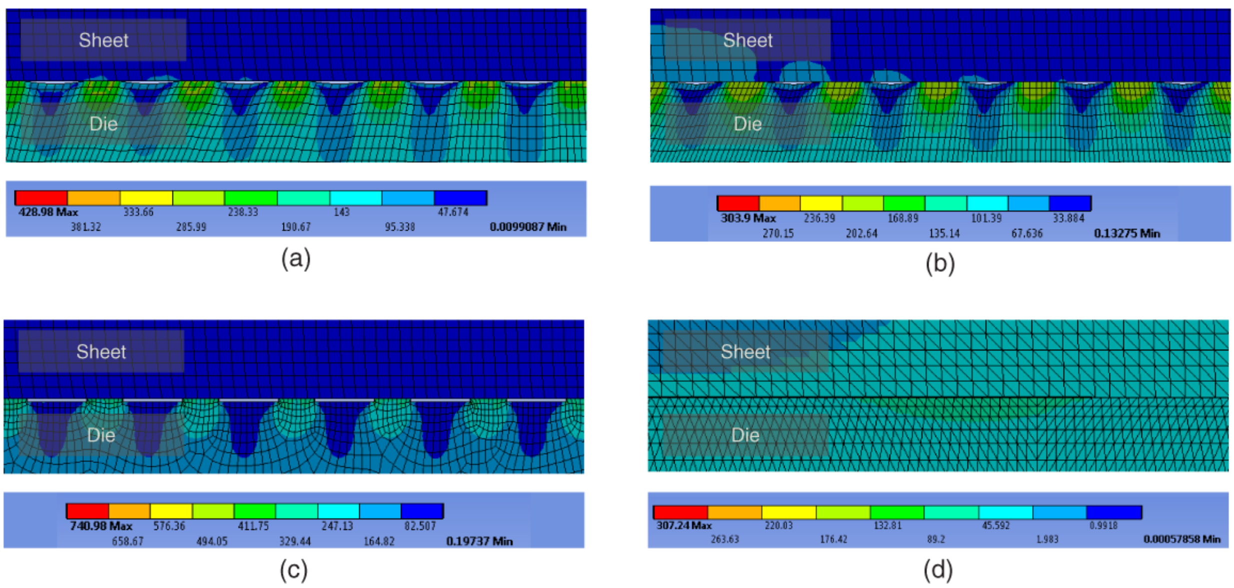

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Fig. 4 FE results: von Mises stress for (a) circular; (b) triangle; (c) square; and (d) flat

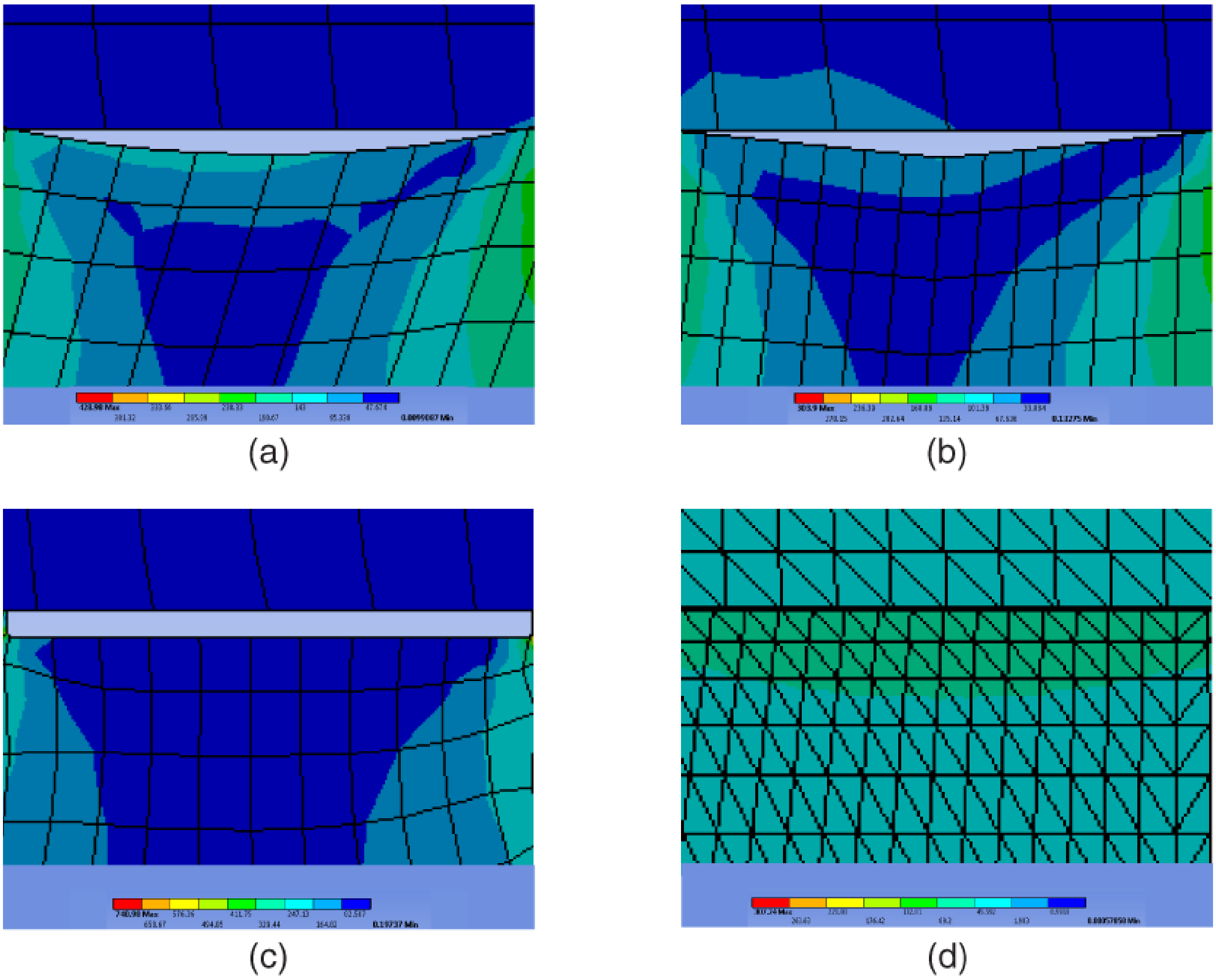

Fig. 5 FE results: stress at the edge of (a) circular; (b) triangle; (c) square; and (d) flat

The obtained tangential and normal forces from the FE simulations for all surfaces are plotted in Fig. 6. These forces are extracted from the middle two textures on each die surface. Note that the results of the other 12 textures are also similar. In order to compare the texture effect, the tangential forces, normal forces, and friction coefficients among these surfaces are plotted in Fig. 7. It can be noticed that the lowest average tangential and normal forces are obtained from the circular, triangle, flat, and square surfaces, respectively. The calculated friction coefficient of the flat surface is 0.1, which matches with the original set value of the friction coefficient in the FE model. The friction coefficients of the textured surfaces fluctuate over the sliding distance and maintain the values at approximately 0.1. The degree of fluctuation ranges from 0.095 to 0.111, which may be considered insignificant in dry lubrication applications.

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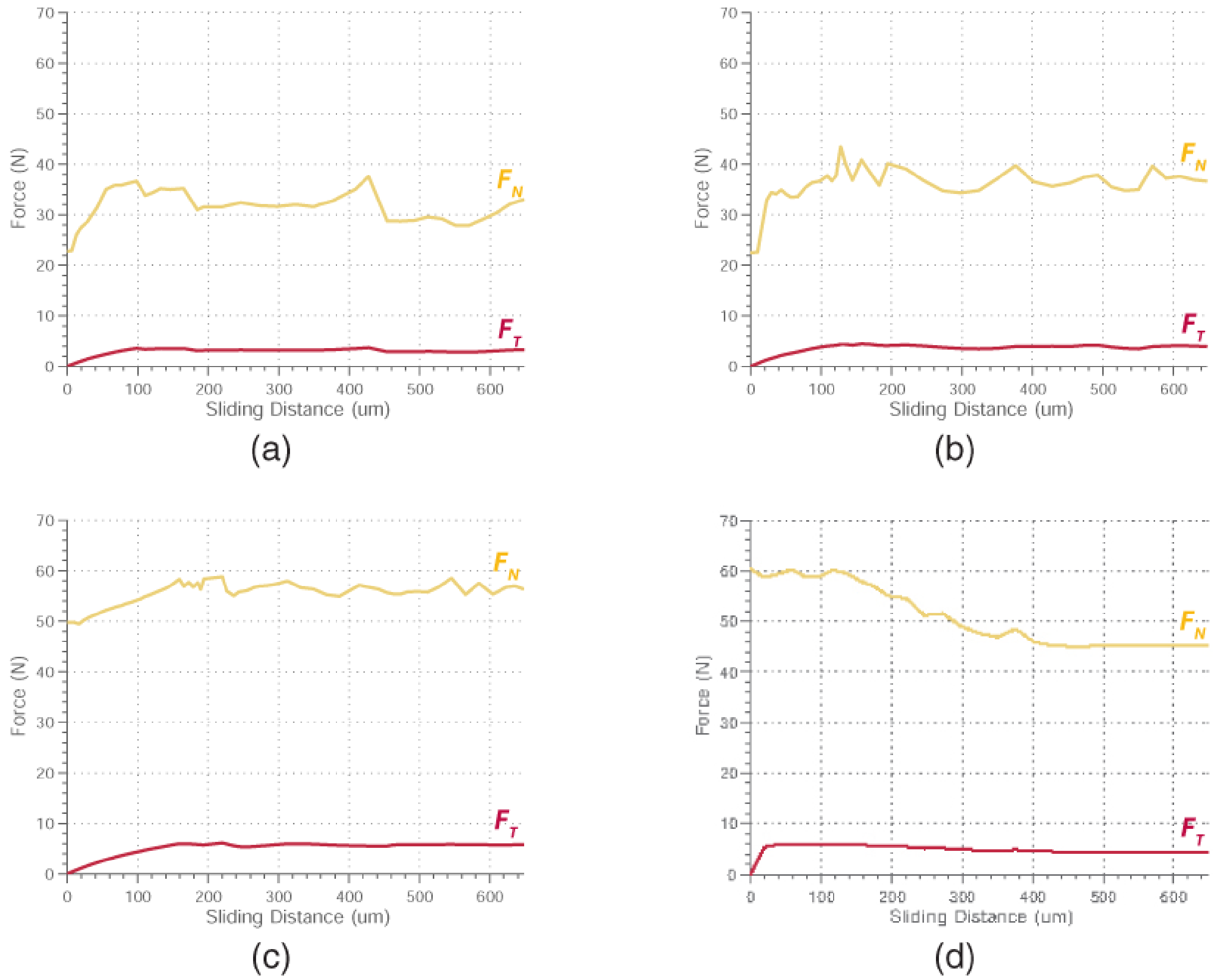

Fig. 6 Tangential and normal forces vs. sliding distance: (a) circular; (b) triangle; (c) square; and (d) flat

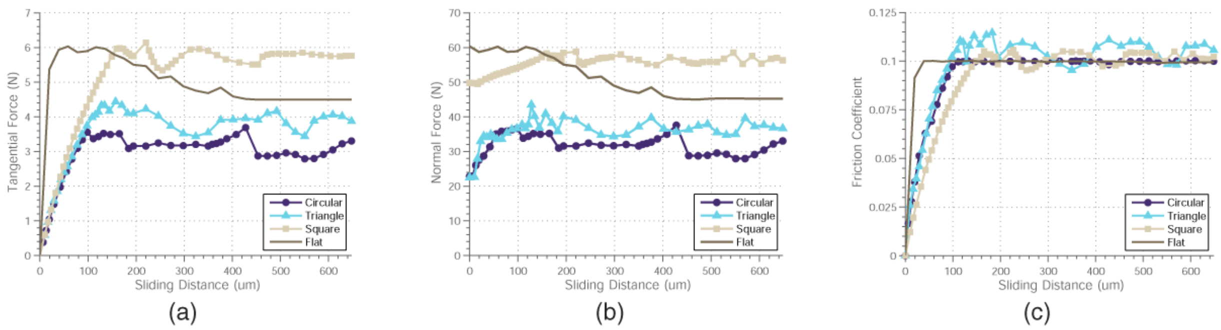

Fig. 7 Comparison among different surfaces: (a) tangential force vs. sliding distance; (b) normal force vs. sliding distance; and (c) friction coefficient vs. sliding distance

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Fig. 8 shows the average pressure over the length of one cavity (200 μm) extracted from the middle texture of the die surface.

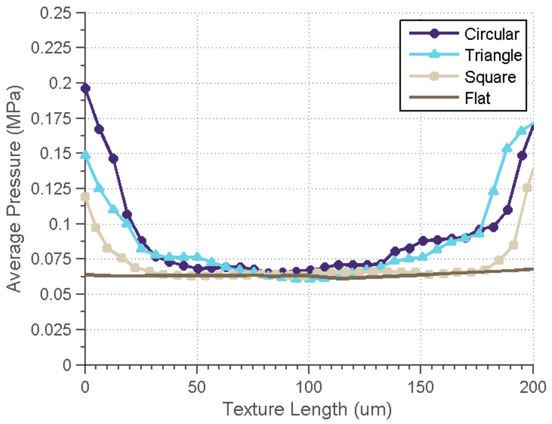

Fig. 8 Average pressure vs. texture length of different surface textures

It can be seen that the flat surface has a constant average pressure because there is no cavity. However, the textured surfaces have increased varying average pressures over the cavities, particularly at the edges. These increased average pressures are considered helpful to support loads in hydrodynamic lubrication [20]. As a result, an effective texturing can be evaluated by measuring the amount of average pressure (load carrying capacity). Thus, the most effective textures range from circular, triangle, square, and flat shapes, respectively.

5. Conclusions

This paper examined the effects of different textured die surfaces on friction coefficient and load carrying capacity using flat-on-flat test through FE simulation. The results showed that surface texturing caused the friction coefficients to fluctuate over the sliding distance but the fluctuation was considered small for dry lubrication. The average pressures of the textured surfaces were higher to that of the flat surface, particularly at the edges of the textures. The increase in average pressures showed the ability of these textures to carry load in hydrodynamic lubrication. The most effective textures observed in this study ranged from circular, triangle, square, and flat shapes, respectively.

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