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Friction Behavior of Micro-scale Groove Surface Patterns Under Lubricated Sliding Contact

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Abstract: Surface texturing of tribological applications is an attractive technology of engineered surface. Therefore, reduction of friction is considered to be necessary for improved efficiency of machines. The current study investigated the potential of textured micro-scale grooves on bearing steel flat mated with pin-on-disk. We discuss reducing friction due to the influence of sliding direction at surface pattern. We can indicate lubrication mechanism as a Stribeck curve, which has a relationship between the friction coefficient and a dimensionless parameter for the lubrication condition. It was found that the friction coefficient was changed by the surface pattern and sliding direction, even when surface pattern was the same. It was thus verified that micro-scale grooves could affect the friction reduction considerably under mixed and hydrodynamic lubrication conditions. The lubrication regime influences the friction coefficient induced by the sliding direction of groove pattern. The friction coefficient depends on a combination of resistance force and hydrodynamic.

Key words: tribology, friction, surface texture, groove, stribeck curve, friction map

1. Introduction

Surface texturing of tribological applications is an attractive technology of engineered surfaces. Especially, tribological contact situations have been improved by texturing with lubricated mechanical elements (e.g. honed cylinder surfaces). In order to improved efficiency of machine part, we need to do more research of surface texturing.

Most of the applications of surface texturing have been developed with relatively large frictional interfaces, for example mechanical seals. Micro-dimples contribute to function mainly in hydrodynamic lubrication conditions. In the case of flat parallel sliding surfaces, a texture can improve reducing friction. Wang et al. have also investigated the influence of the texture density and size for SiC with water lubrication condition. Surface texturing has recently focused on potential benefits.

Surface texturing for tribological situation provides reservoirs of lubrication and wear particle trapping, preventing seizures due to insufficient lubrication. Recent research has investigated specially-shaped contact surface and the effect of reducing friction in abruptly vertical pressure generation. However, we cannot design for surface texturing in tribological conditions because we do not fully understand the mechanism of surface texturing.

This study investigates the potential of textured micro-scale groove on bearing steel flat mated with pin-on-disk. We discuss mechanism of reducing friction due to the influence of the sliding direction at surface pattern.

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2. Experimental procedure

2.1. Micromechanical fabrication of surface pattern

Specimens in this research listed Table 1, the pin of bearing steel using bearing ball. The pin of contact area was 5 mm in

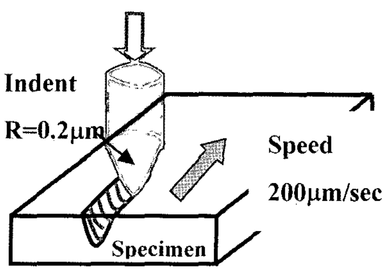


Fig. 1. Schematic for fabricated micro-groove.

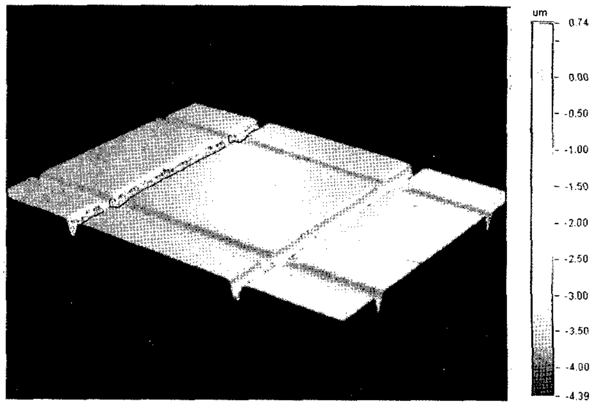
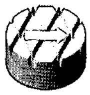
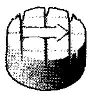


Fig. 2. Surface topography for micro-groove.

Table 1. Notation for specimens and the geometric parameters of pattern

Notation	Pattern & Sliding dir.	Dimension (μm)	Depth (μm)	Pitch (μm)	Area of density (%)
g135-d45		40	4	600	11
g90-d45		40	4	600	11
g135-d135		40	4	600	11
g90-d90		40	4	600	11

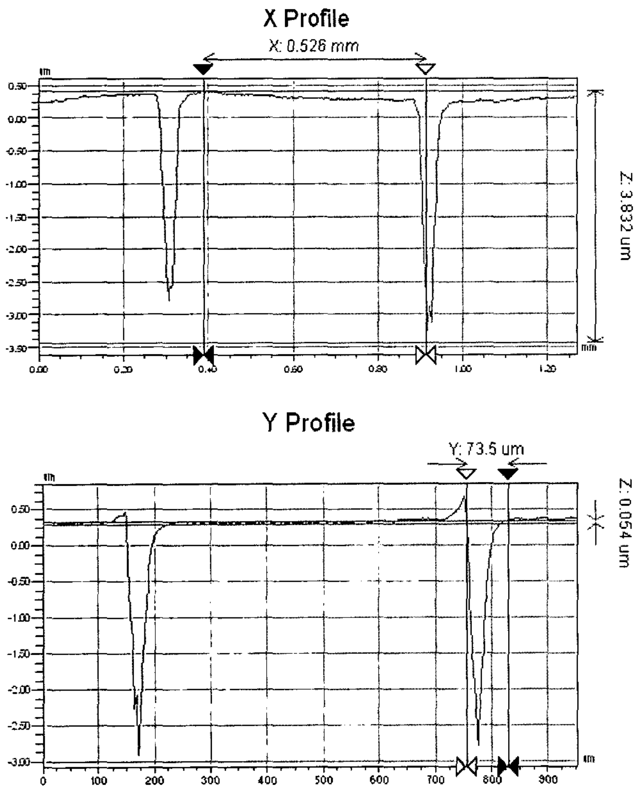


Fig. 3. Surface profile for micro-groove.

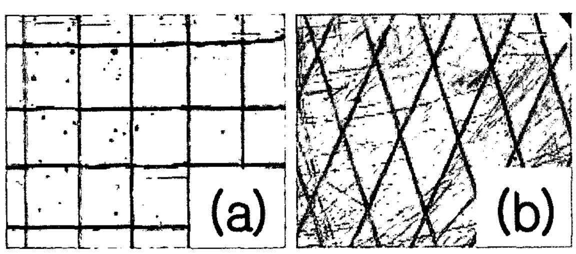


Fig. 4. Surface pattern for 2 kinds of micro-grooves.

diameter. In order to fabricate the surface pattern on the surface of the contact area, we used indentation device to make the micro-groove, as shown in Fig. 1. It has xy-stage with a linear motor that can control the sliding velocity and displacement. Moreover, it is controlled so as to indent by deadweight.

Figure 2 shows the surface patterns for the micro-grooves and topography. It has 4 μm of depth, 40 μm of width, and 600 μm of pitch from the surface profile, as shown in Fig. 3.

The pattern for the micro-groove is shown in Fig. 4. We fabricated two kinds of surface patterns, the square (Fig. 4[a]) and cross-hatch (Fig. 4[b]) of the groove.

Table 2. Experimental condition for test

Parameters	Condition
Contact type	Flat-on-Flat
Disk material	Carbon steel
Pin material	Bearing ball
Surface roughness	
Pin [μm]	0.008Ra, 0.016Rq
Disk [μm]	0.039Ra, 0.052Rq
Diameter of small disk [mm]	5
Diameter of sliding track [mm]	40
Normal load range [N]	1-20
Pressure range [MPa]	0.08-1.59
Speed range [m/s]	0.12-0.32
Lubricant	Paraffin oil (Saybolt No. 125/135)
Temperature	Room temperature

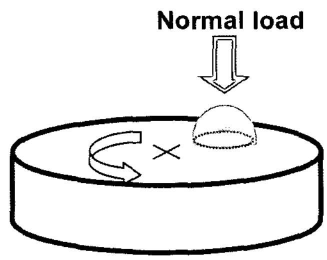


Fig. 5. Schematic illustration of the pin-on-disk.

2.2. Testing method and test condition

Friction test was carried out pin-on-disc type. The details of the friction tester and specimen configurations are described elsewhere. The test machine used in this experiment (CSEM Tribometer) was designed to reciprocate a sliding friction and

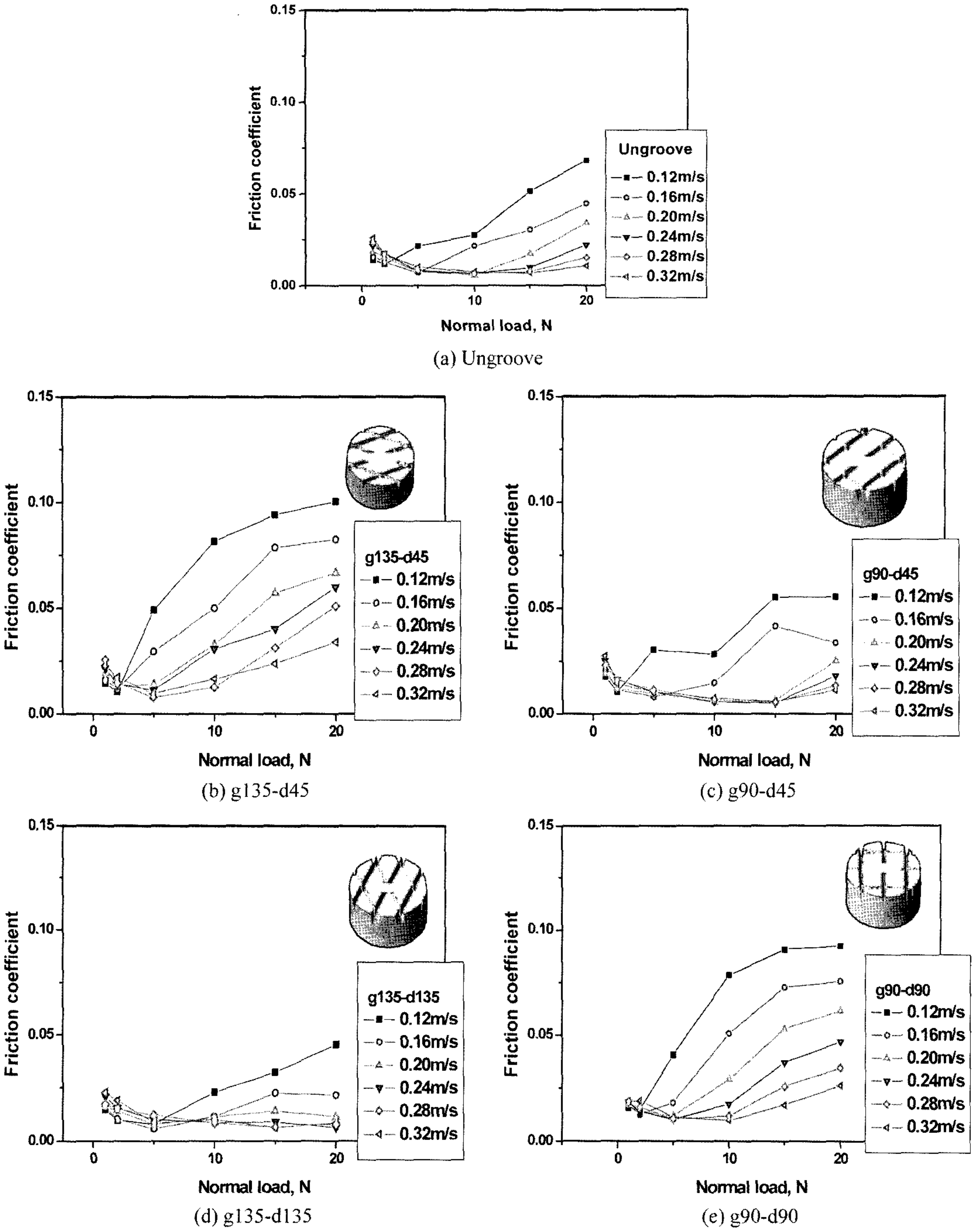


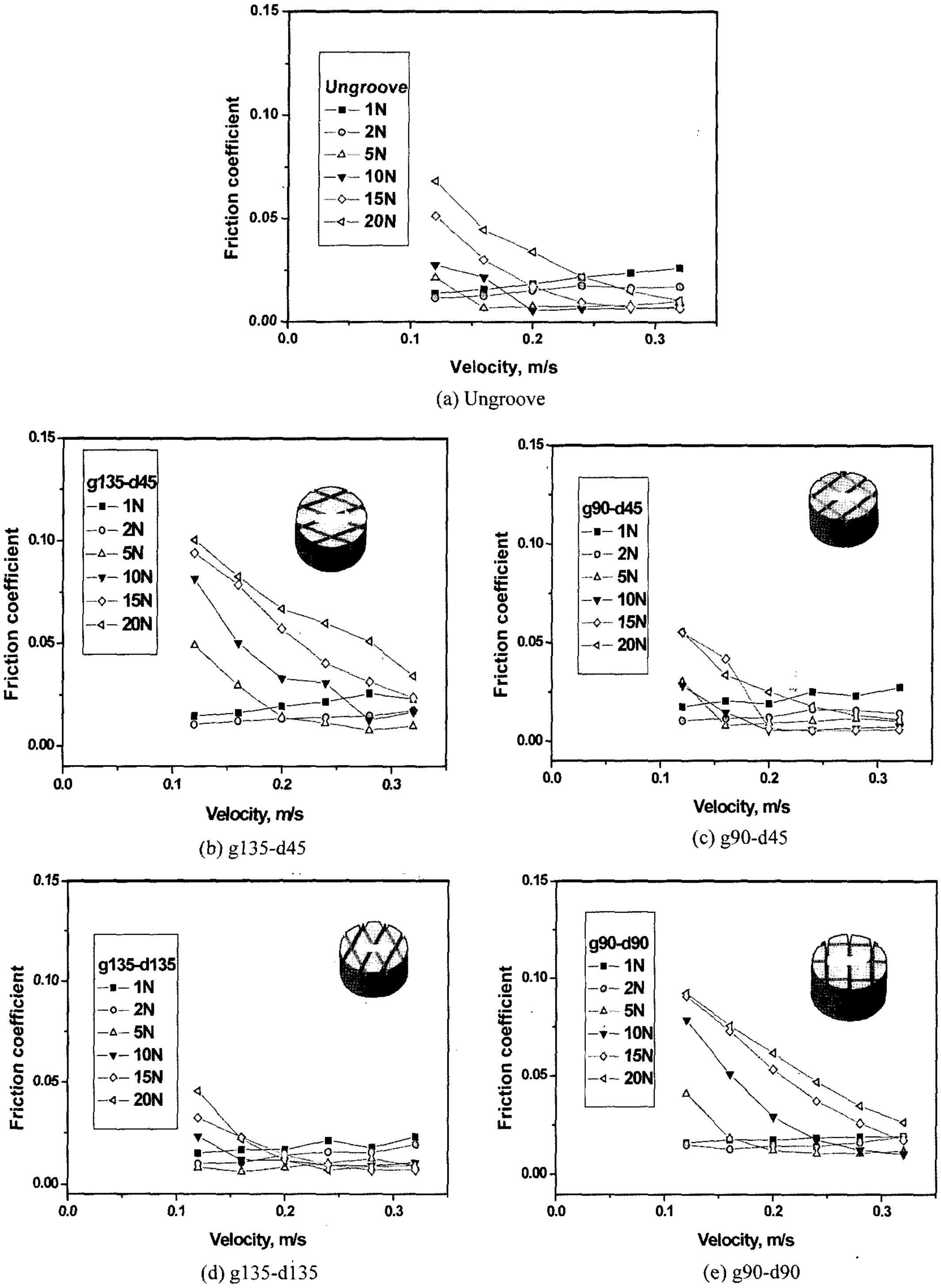
Fig. 6. The friction coefficient as a function of normal load for various micro-grooves.

can be controlled at variable speeds within a 0.12-0.32 m/s range. A normal load is applied deadweight. The friction test condition is shown in Table 2. The friction coefficient was saved through an A/D converter using a compatible IBM PC. The contact point was designed at an eccentricity of 20 mm from the center of the rotary motion, which then created a round slid track 40 mm in diameter on the surface of the disk, as shown in Fig. 5. In order to avoid initial unstable conditions, each friction test was carried out following a running-in operation with duration of 5 min.

3. Results of Friction

3.1. The effect of normal load

The variations of the friction coefficient with a normal load are shown in Fig. 6. These figures indicate that the friction coefficient depends on the normal load, groove pattern, and sliding direction. The friction coefficient for micro-groove patterns at the low sliding velocity is exhibited similar curves to those of ungroove. However, where the normal load was over 10 N, the friction coefficient was distinguished by the



(a) Ungroove

(b) g135-d45

(c) g90-d45

(d) g135-d135

(e) g90-d90

Fig. 7. The friction coefficient as a function of function of velocity for various micro-grooves.

effect of the micro-groove patterns and sliding direction. Therefore, the normal load influences the friction coefficient, which is caused by lubrication condition between contact surfaces.

3.2. The effect of velocity

The friction coefficients for different velocities are shown in Fig. 7. The important point to notice form this figure is that the curve of the g135-d135 specimen improved the friction coefficient more than other specimen upper normal load of 20 N. Therefore, the friction coefficient for 1 N and 2 N of normal load is independent of sliding velocity. Under lower normal loads, it does not reduce friction due to the effect of surface pattern. However, the normal load shows decreasing friction coefficient due to the effect of surface pattern and sliding direction.

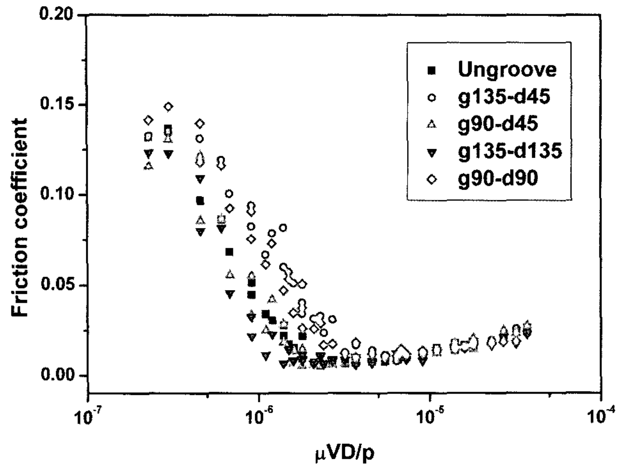


Fig. 8. Stribeck curve for various micro-groove pattern and sliding direction.

4. Discussion

4.1. The effect of lubrication condition

To analyze the results of micro-scale grooves under a lubricated surface texture, we describe the lubrication mechanism for a Stribeck curve. This is a relationship between the friction coefficient and a dimensionless parameter for lubrication condition, which can be expressed as;

$$S = \frac{\mu VD}{L}$$

Where S is the dimensionless parameter, μ is the dynamic viscosity in Pa-s, V is the sliding velocity in ms-1, D is the diameter of contact in m, and L is the normal load in N.

The generalize Stribeck curve depends on the geometry, materials, sliding conditions, and thickness of the lubrication oil film between the sliding surfaces. The dimensionless number S was calculated for this experiment and plotted against the friction coefficient in order to derive generalized Stribeck curve shown in Fig. 8. This figure shows the occurrence from the mixed lubrication to the hydrodynamic lubrication condition. Additionally, the Stribeck curves for specimens of g90-d45 and g135-d135 shift to left in comparison with specimen of ungroove. Figure 8 describes friction reduction for micro-scale groove patterns in a lubrication condition.

4.2. Friction map for micro-scale groove patterns

Figure 9 shows the friction map of micro-grooves as a function of velocity and load. In such a map, one can observe simultaneously the functional dependence of the friction coefficient with respect to velocity and/or load.

Given the nature of contour maps, the occurrence of a friction coefficient can be easily identified on the contour maps where the lines of constant friction coefficient bunch together to represent a steep ascent. In addition, the functional dependence of the friction coefficient line on velocity and load can be easily ascertained.

The effect of surface pattern and sliding direction on the location of the friction coefficient can be clearly seen. Figure 9 compares the friction coefficient of ungroove specimen, 2 surface pattern and 2 sliding direction. The micro-groove of the square, it shows that the friction coefficient depends on the sliding direction. It is known that boundary lubrication condition region is high load and low velocity. As you can see a graph, this regime of boundary lubrication is the right under corner. If we have effect of surface texturing, a contour of fiction coefficient change or move toward improved friction property. In the g135-d135 (Fig. 9 [d]) case, the contour line of low friction coefficient shifts from hydrodynamic lubrication to the boundary lubrication regime. The effect of surface pattern on micro-scale groove is quite dramatic. The results shown above demonstrate the need to construct a friction map to better describe the friction coefficient of surface patterns in a lubricated condition. Additionally, it reveals that significant differences are present in friction characteristics under different surface patterns and sliding directions.

4.3. The mechanism of micro-scale groove

Based on the Stribeck curve and friction map for various surface patterns, we can describe the hydrodynamic lubrication mechanism. From the results of this experiment, the lubrication condition regime has an influence on the friction coefficient induced sliding direction of the groove pattern (Fig. 9). The lubrication flow statue in the interface between contact surfaces depends on velocity and normal load. Therefore, the hydrodynamic lubrication induced sliding direction and angle of the pattern is related to generation pressure at micro-groove patterns and vertical overflow to contact surface. When a contact surface passes through lubrication film, the resistance force for the shape and the angle of the surface micro-scale groove due to separated flow could be generated at the contact surface groove. Therefore, the friction coefficient is the relation of the combination of resistance force induced separated flow and vertical pressure induced hydrodynamic.

3. Conclusion

This study investigated the potential of textured micro-scale grooves on bearing steel flat-mated with pin-on-disk. We discuss reducing friction due to the influence of sliding direction at the surface pattern.

It was thus verified that micro-scale grooves can affect the friction reduction considerably under mixed and hydrodynamic lubrication conditions. The lubrication condition regime influences the friction coefficient induced sliding direction of groove pattern. The friction coefficient is the relation of the combination of resistance force and hydrodynamic lubrication conditions.

Acknowledgment

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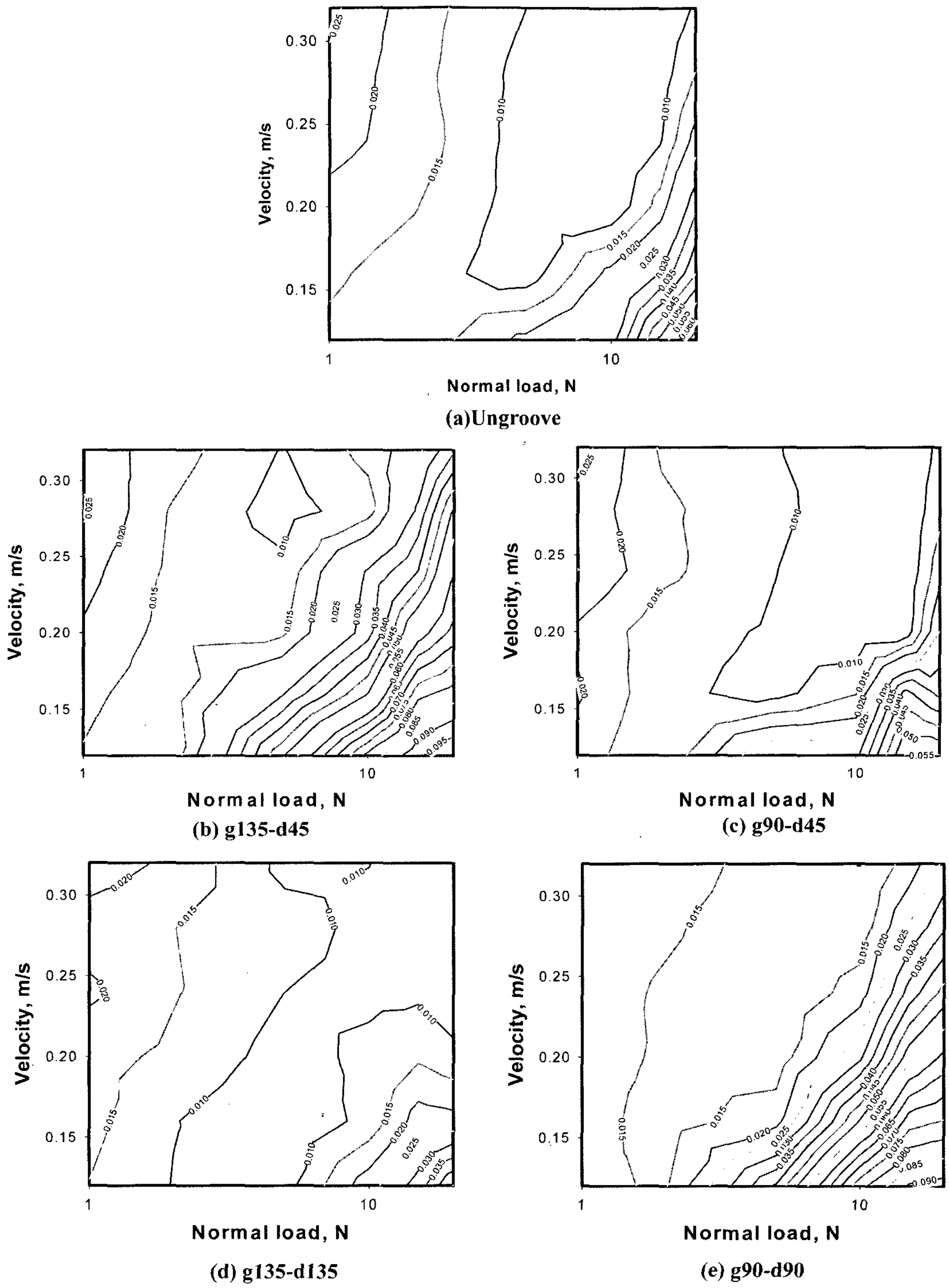

Fig. 9. Friction map for micro-scale grooves.

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