PAPER • OPEN ACCESS

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To cite this article: Zahrul Fuadi *et al* 2018 *IOP Conf. Ser.: Mater. Sci. Eng.* **352** 012009

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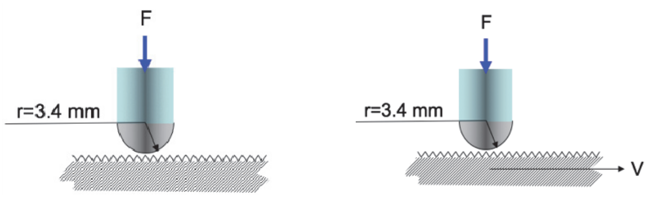
Abstract. In this paper, the viscoelastic material was used to investigate the effect of roughness on stiction. The material is chosen because it is highly deformable so that contact during friction can be fully elastic. The soft surfaces were prepared by casting the silicon material on metal surfaces having smooth and unidirectional grooved texture. Two tests were conducted, indentation and friction, to find out the effect of roughness on parameters of normal contact stiffness, friction force and the difference between static and kinetic friction coefficient, μs-μk. As the results, it is found that all parameters are related to the surface roughness. Smoother surface tends to have a higher value of normal contact stiffness and higher value of friction force thus resulting in a larger difference between the static and kinetic coefficient of friction. Since the value of μs-μk is commonly related to the stick-slip motion, the smoother surface tends to have a larger propensity of stiction. It is shown by the result that the texture can reduce the stiction because it reduces the value of normal contact stiffness, resulting in a lower value of μs-μk.

1. Introduction

Dry friction controls two different phenomena in nature, i.e. the resistance against the beginning of a motion from the state of rest and the resistance against an existing motion [1,2]. The first phenomenon is known as stick and the latter is known as slip. Coulomb describes this as static friction and kinetic friction.



(a) (b)

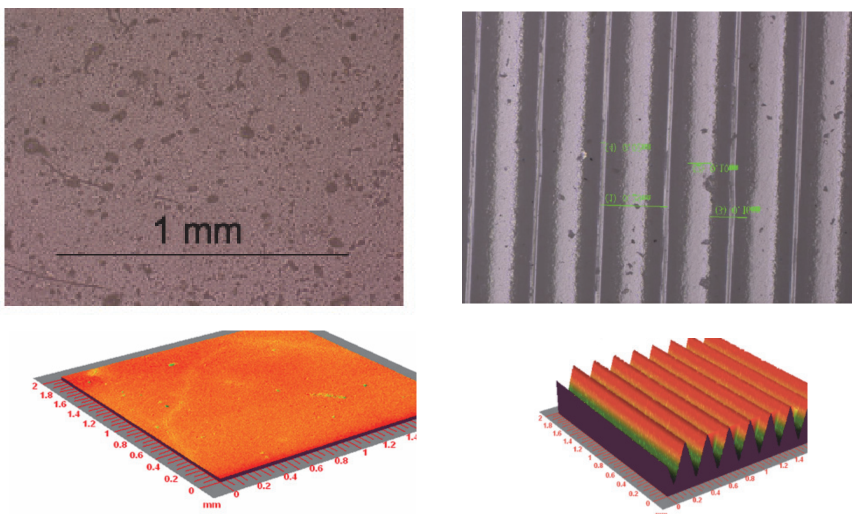
Figure 1. Schematic diagram of the tests; indentation (a) and friction (b)

In a continuous motion, both phenomenon could take place successively, resulting in stick-slip motion, or also known as stiction. This motion is undesirable in the mechanical system because it has negative effects on the system's performances such as positioning errors, fatigue failure, severe wear, and sound emission. Stiction is caused by various factors such as material properties, forces, and surface irregularities. In literature, the stiction is commonly related to various parameters such as difference of static and kinetic coefficient of friction [3], negative slope of friction-velocity relationship [4], and the parameter of contact stiffness [5]. Various experimental models have also be employed in the investigation of stiction phenomena such as a caliper-slider model [6].

One of the most important factors in stiction is the surface roughness. In this paper, soft materials were used to demonstrate the effect of surface roughness on stiction. Soft material is chosen because it is highly elastic so that plastic deformation effect during surface interaction can be omitted. The roughness on the soft surface was prepared by casting the soft material on a metal surface having a smooth and unidirectional grooved texture. Thus, there are two different surfaces; smooth and textured.The static (indentation) and friction tests were conducted to find out the parameters of normal contact stiffness, friction force, and the difference between static and kinetic friction coefficient, μs-μk. The objective of this study is to find out the effect of surface roughness on stiction propensity and to relate it to the parameters of normal contact stiffness and the difference between the static and kinetic coefficient of friction, μs-μk.

2. Methodology

Static (indentation) tests and friction tests were conducted in this analysis. The schematic diagram of the tests is given in figure 1. In the indentation test (figure 1 (a)) the force applied (normal) was 100 μN. The indenter had a diameter of 3.4 mm and made of stainless steel. The similar test setup was used in the friction test. In the friction test, after the normal force of 100 μN is applied, the indenter moves translationally for a traveling length of 2000 μm. Thus, sliding takes place and the friction force can be measured as well as the difference between static and kinetic friction coefficient, μs-μk.



(a) (b)

Figure 2. Surface roughness; Smooth (Ra = 0.03μm) (a) and Textured (b) surfaces

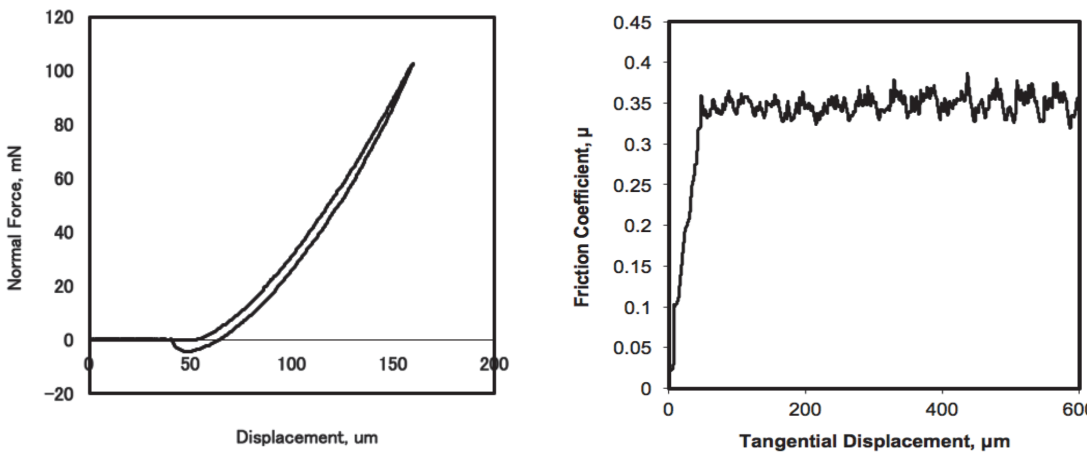
Two different roughness were prepared for the surface specimens. The specimens were marked as "smooth" and "textured". The detail of the specimens was given in figure 2. Figure 2(a), smooth specimen, was achieved by casting the silicon on the metal surface having a surface roughness Ra of

0.03 μm. The textured specimen was achieved by casting the silicon on a metal surface having unidirectional grooves.

Figure 1 shows the schematic diagram of the tests. The indentation test (figure 1(a)) has two steps; 1) force application and 2) relaxation. As a result, the relationship between normal displacement and normal force can be achieved (figure 3(a)). Using the result, two quantitative parameters can be calculated i.e. normal contact stiffness, Kn, and the adhesion force between indenter and surface, N.
In the friction test (figure 1(b)), there are also two steps; 1) force application and 2) translational displacement (figure 3(b)). As a result, the parameter of friction force, N, and the difference between the static and kinetic coefficient of friction (μs-μk) can be achieved.

3. Results and discussions

The results of indentation tests were given in figure 4. Figure 4(a) indicates the hysteresis loop of the normal force as it is applied and relieved for the smooth and textured surfaces. The vertical axis indicates the normal force of 100 mN applied for both conditions. The horizontal axis indicates the displacement, i.e. the elastic deformation of the surface occurred as the effect of normal force application. As indicated by the figure, in the case of a smooth surface (the one on the left) the displacement started from 100 μm and reached the peak at 222 μm. Thus the overall displacement for the smooth surface is 122 μm. In the case of textured surface, the displacement started from 212 μm and reached a maximum at 329 μm. Thus, the overall displacement of the textured surface was 117 μm. This indicated that in both conditions, the material properties are similar. For the relatively similar normal force, the displacement is also relatively similar (differ by only 5 μm).



(a) (b)

Figure 3. Relationship between normal displacement and normal force; smooth (a), and grooved (b)

Referring to the method given in figure 3(a), the normal contact stiffness value, Kn, for both conditions can be calculated. For the case of a smooth surface, the value of Kn is 650 N/m. For the case of textured surface, the value of Kn is 738 N/m. Thus, the normal contact stiffness of the textured surface is lower than that of smooth surface. This results indicated that there is a quantitative relationship between the surface parameter and the normal contact stiffness. Therefore, in the future, it is interesting to find out the relationship between surface parameters and the normal contact stiffness.

Figure 4(b) shows the detail image of the adhesion force between the ball and the surface after the normal force is relieved. In the case of smooth surface (the left one), the adhesion force is 9 mN and for that of the textured surface, it is 2 mN. This figure indicates that the textured surface has a lower value of adhesion force. This could be caused by the reduction of the surface contact area. In smooth surface, the contact occurs at almost entire ball's surface. This area is reduced by the presence of grooves on the surface. The reduce of contact area caused by the presence of groves, the texture, resulting in the reduction of the normal contact stiffness. According to Hertzian contact theory, one of the parameters affecting the contact stiffness is real contact area. Thus, the smoother the surface, the larger the contact area.

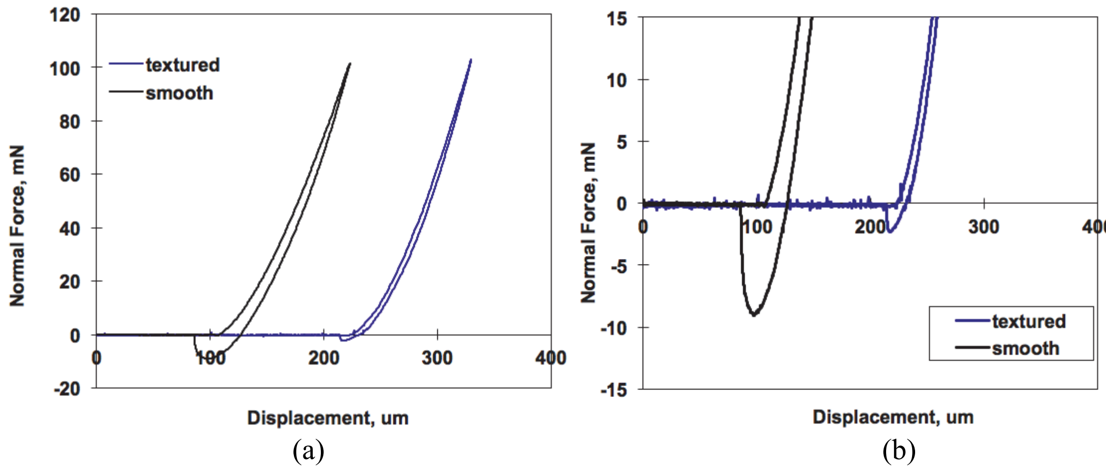


Figure 4. Indentation test result (a), and adhesion force (b)

So far, the presence of grooves on the surface has resulted in the reduction of normal contact stiffness in which this reduction can be attributed to the reduction of real contact area according to available contact theory. Furthermore, it is interesting to find out the effect of grooves on the value of the difference between the static and kinetic coefficient of friction, μs-μk. This value has been related to the occurrence of a stick-slip motion in the mechanical system [3].

The result of friction test is given in figure 5. It can be seen that the coefficient of friction of smooth surface is larger than that of the textured surface. In both cases, the normal force applied is 100 mN. In the case of smooth surface, the coefficient of friction is 0.35, but in the case of the textured surface, it is 0.15. The value of μs-μk for the smooth surface is 0.04 and that for the textured surface is 0.02, averagely.

From the results it is clear that smoother surface tends to have a larger value of μs-μk. Since the value of normal contact stiffness for the smoother surface is also larger than that of the textured one, the larger value of μs-μk can also be related to the contact stiffness. Thus, a higher value of contact stiffness tends to have higher value of μs-μk. Since the value of μs-μk is related to the stick-slip motion, the smoother surface tends to have a larger propensity of stiction.

It is shown by the result that rougher surface could reduce the stiction because rougher surface tends to have a lower value of μs-μk. Here, it is important to notice that a low value of μs-μk is caused by the reduction of normal contact stiffness which is caused by the reduction of the real contact area. Therefore, stiction can be directly related to the parameter of contact stiffness. The relation between the contact stiffness value and stick-slip motion has also been highlighted in ref [6].

Therefore, since the stiction is undesirable in mechanical systems, it is possible to minimize the stiction by decreasing the value of normal contact stiffness. This study has clearly shown that introducing the texture to a surface is an effective method to minimise the stiction. Unlike roughness that is highly random, texture can be designed according to the purpose. In this case, the texture has not only decreased the value of μs-μk but also the friction force drastically. In another case, it is also possible to design a textured surface that will only decrease the value of μs-μk but will have a relatively similar friction force.

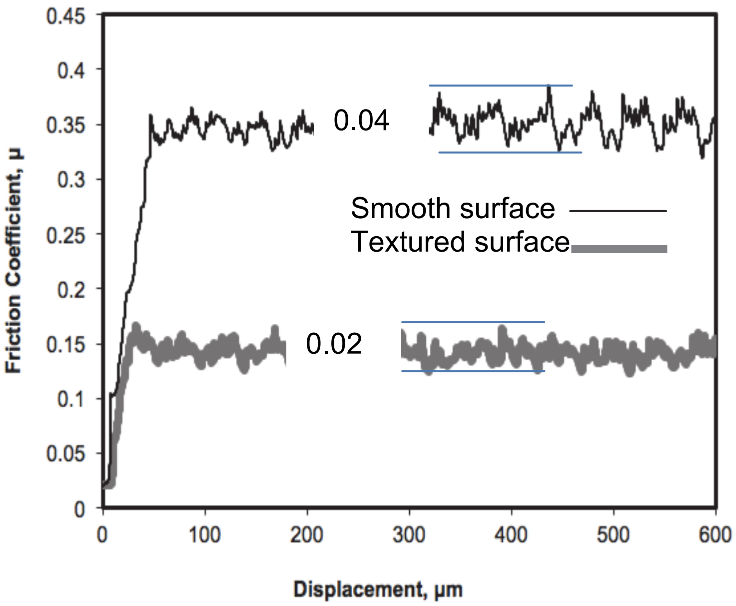


Figure 5. Friction test result

4. Conclusion

The effect of the surface parameter to the stiction propensity has been investigated by using the viscoelastic material. The result can be summarized as follows:

1. The normal contact stiffness of the textured surface is lower than that of the smooth surface. This effect is caused by the reduction of real contact area due to the presence of the texture.
2. The value of the difference between the static and kinetic coefficient of friction, µs-µk, for the textured surface is lower than that of the smooth surface. Thus, introducing texture to a contact interface could reduce the stiction propensity.

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