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ANALYSIS OF THE CONTACT AREA OF SMOOTH AND ROUGH SURFACES IN CONTACT WITH SPHERE INDENTER USING FINITE ELEMENT METHOD

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ABSTRACT

This paper analyzes the contact area of the contact between a deformable rough surface (smooth and rough) and a hard smooth sphere indenter using finite element method. A method was introduced to generate a three dimensional rough surfaces using Computer Aided Design (CAD) software. The rough surface model was developed based on the surface measurement data, while the smooth surface model was generated from the CAD software. Contact area and contact deformation were analyzed. Results showed that the contact area between rough surface versus sphere and smooth surface versus sphere is different.

Keywords: rough surface; finite element simulation; contact area; contact pressure.

INTRODUCTION

In micro scale, the real surface topography of mechanical component that has smooth appearing is rough surface. It is the component of surface texture due to the production process, excluding waviness and deviation of form (van Beek, 2012). Machining process in component manufacturing will affect the surface quality, because the final process of machining is determined by surface roughness. Therefore, a variety of machining process will generate different surface roughness.

The rough surface can be described as the collection of hill and valley, or called as "asperity" (Jamari, 2006). Therefore, the real contact interaction in engineering surfaces is the contact interaction between rough and rough surfaces. In other words, the real contact interaction in the engineering surface is asperity against asperity. In this case, topographical changes that occurred was actually at the level of asperity. Based on this condition, the behavior of interaction of two contact surfaces can be analyzed at the asperity level.

To simplify this, a lot of research on the interaction between the asperity contacts was made with simple model. It is contact interaction of sphere against sphere or sphere against flat, where the sphere is assumed as one asperity. Hertz (1882) proposed a theory of static contact model in elastic condition, where the asperity was modeled as sphere and cylinder geometries. Chang et al. (2008) generated static contact model in elastic-plastic condition analytically where asperity was modeled in sphere geometry. Zhao et al. (2005) also created static contact model in elastic-plastic condition where asperity was modeled in sphere geometry. Kogut and Etsion (2002) and Jackson and Green (2005) also analyze it in elastic-plastic condition. Later, Jamari and Schipper (2006) modeled the asperity in ellipsoid geometry.

Analysis of the real rough surface is negligible because of the difficulty to build a model of real rough surface and also to simplify it in order to save the time calculation (Peyrou et al., 2007). Indeed, the surface roughness plays an important role in influencing the friction, wear, and lubrication (Lee and Ren, 1996). Therefore, the rough surface model to approach the real surface and in order to get results closer to the actual topography changes is needed where the real condition of contact interaction on rough surfaces can be seen from the contact area.

The purpose of this research is to study the contact area on smooth and rough deformable surfaces in contact with a hard smooth sphere indenter using finite element analysis.

MODELING OF STATIC CONTACT

Commonly, the first step was to create rough surface based on mathematical calculations in the form of point clouds with extension (*.xyz) randomly. These point clouds were then sent to the CAD software to be converted into three-dimensional (3D) model. By using CAD software, it was changed to IGES extension (*.iges) or other extensions which were compatible with FE software. The static contact simulation on rough surface was performed using ABAQUS commercial software. These processes will be explained in more detail.

Rough surface model

The rough surface model could be directly created in finite element (FE) software as had been done by Thompson. The rough surface by utilizing the nodal or elements had been formed first, then the height of the nodal needed to be changed randomly (Thompson, 2007). That method had disadvantage of being very sharp peak asperity, whereas the surface with a sharp peak asperity should be avoided since it would bring extreme stress. In this research, the rough surface that was created would decrease these weaknesses by using alternative method. The method was a combination of mathematical, CAD and FE software.

The rough surface in this study was based on a mathematical equation and constructed using mathematical software. Gaussian equations were used to create a surface with random roughness. Figure 1 shows the code used in mathematical software to generate rough surface randomly by Gaussian height distribution (GHD) equation. The rough surface can also be obtained from

VEECO 3D images data which are then exported to the mathematical software for conversion into a form of point clouds with extension (*.xyz). The GHD equation will produce the rough surface with vary asperity heights randomly. The GHD equation that applied into a mathematical software consists of several variables. *N* is the number of points in one surface, *rL* is the length of the surface area, *h* is height of the root means square (rms) and *clx* is the correlation between points in a surface distance (pixel).

```
N=200;
rL=1;
h=0.05;
clx=0.05;
x = linspace(-rL,rL,N);
y = linspace(-rL,rL,N);
[X,Y] = meshgrid(x,y);
Z = h.*randn(N,N);
F = exp(-((X.^2+Y.^2)/(clx^2/2)));
f                                              =
2/sqrt(pi)*rL/N/clx*ifft2(fft2(Z).*fft2(F));
surf(X,Y,f,'FaceColor','interp',...
'EdgeColor','none',...
'FaceLighting','phong')
axis equaloff
```

Figure-1. The code of Gaussian height distribution (GHD) for rough surface.

The implementation of *N*, *rL*, *h* and *clx* with different values would resulting a different rough surface. And also, the same value of *N*, *rL*, *h* and *clx* would generate different rough surface every time, for the same rms value. As an illustration, the variation of *h* is presented in Table 1 and and its generating surfaces as are shown in Fig. 2 to Fig. 5.

Table-1. Variation of *N*, *rL*, *h* and *clx*.

Variation	N	rL [mm]	h [mm]	clx [mm]
Var1	200	1	0.0025	0.05
Var2	200	1	0.01	0.05
Var3	200	1	0.05	0.05
Var4	200	1	0.5	0.05

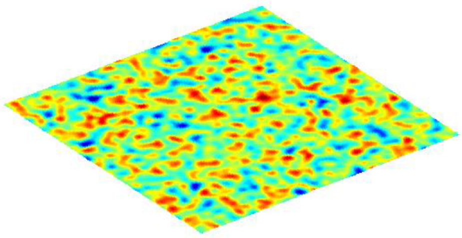


Figure-2. The rough surface with Var1 (*N*=200; *rL*=1; *h*=0.0025; and *clx*=0.05).

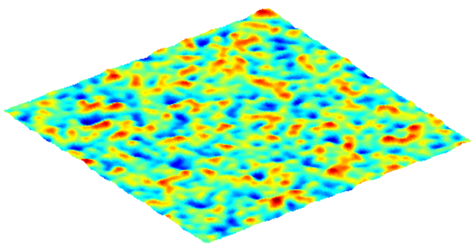


Figure-3. The rough surface with Var2 (*N*=200; *rL*=1; *h*=0.01; and *clx*=0.05).

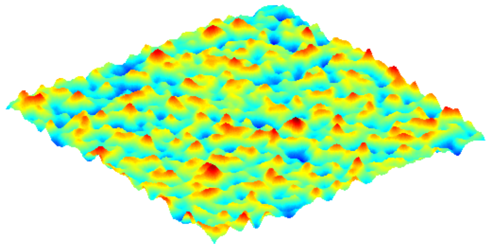


Figure-4. The rough surface with Var3 (*N*=200; *rL*=1; *h*=0.05; and *clx*=0.05).

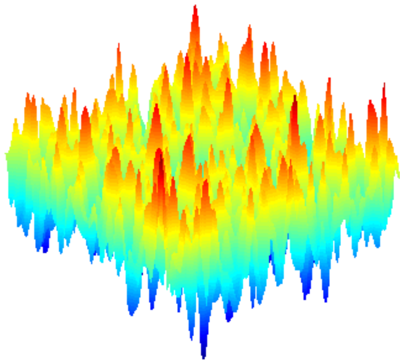


Figure-5. The rough surface with Var4 (*N*=200; *rL*=1; *h*=0.5; and *clx*=0.05).

Figure 2 to Figure 5 show that value of *N*, *rL*, *h* and *clx* give different rough surfaces. As can be seen, the *h* variable plays an important role in this equation. The *h* variable represents *Rt* in the surface roughness standard parameter. *Rt* is the distance between the highest asperity and the lowest valley measured over the entire assessment length or usually called as peak-to-valley height (van Beek, 2012).

```
N=200;
rL=2;
h=0.5;
clx=0.05;
x = linspace(-rL,rL,N);
y = linspace(-rL,rL,N);
[X,Y] = meshgrid(x,y);
f = h.*cos(5.*X).*cos(5.*Y)
surf(X,Y,f,'FaceColor','interp',...
'EdgeColor','none',...
'FaceLighting','phong')
axis equal off
```

Figure-6. The code of Gaussian height distribution (GHD) for sinusoidal surface.

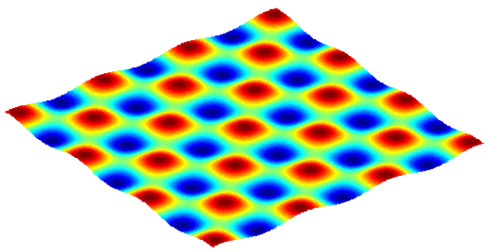


Figure-7. The sinusoidal surface with (*N*=200; *rL*=2; *h*=0.05; and *clx*=0.05).

Another example, the GHD surfaces are presented in sinusoidal surfaces. Figure 6 shows the code for generating the GHD sinusoidal surface. With the variation of *h*, different surfaces can be obtained, see Fig.

7 and Fig. 8. It can be seen from these figures that the topography of these surfaces are well-regulated. Therefore, this surface will not be used in the present study due to its simplicity.

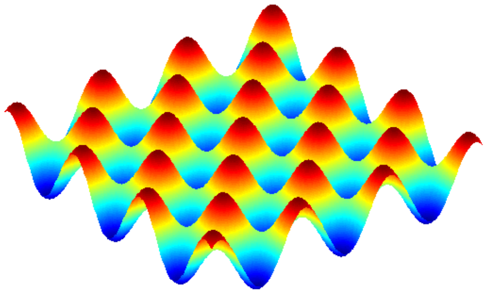


Figure-8. The sinusoidal surface with (*N*=200; *rL*=2; *h*=0.05; and *clx*=0.05)

3D rough surface model

After generating the roughness (2D), next is developing 3D rough surface model. The rough surface point clouds (Fig. 9) was then analyzed to form a 3D surface using CAD software and then converted to form solid 3D (Fig. 10). The 3D surface model was then converted into (*.iges or *.sat) extension. The IGES (initial graphics exchange specification) is a common form of the extension that can be used in any CAD or FEA software. Then, the 3D model was exported to the FEM software.

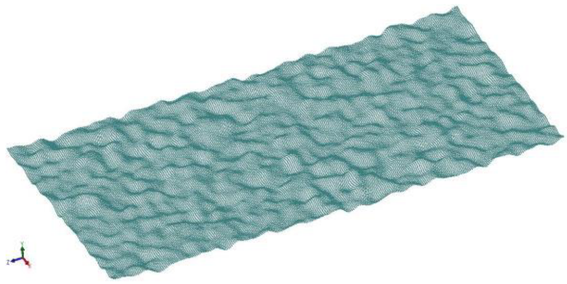


Figure-9. Point clouds of rough surface.

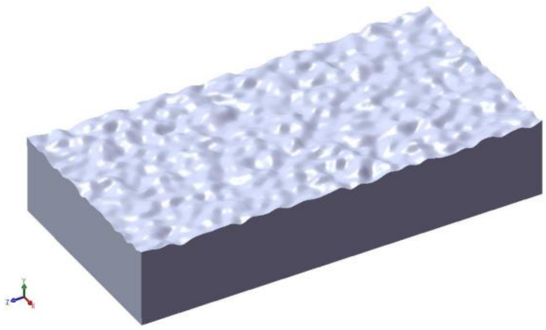


Figure-10. The three dimensional model (3D) of rough surface.

Modeling the contact

Analysis performed in this study was a static contact. A commercial finite element analysis software ABAQUS was employed. The steps for finite element analysis were creating of parts (create geometry), property (define the material properties), assembly, step (specify the type of analysis and simulation stages), interaction (define a contact interaction), load (specify loads and boundary conditions), mesh (discretize geometry into several elements), job (ordered the software to perform iterations) and visualization (see the results of the simulation). The 3D finite element model with the generated mesh of the rough surface is presented in Fig. 11.

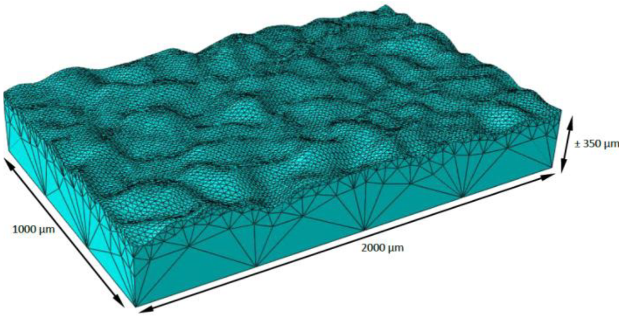


Figure-11. The 3D model with mesh for static contact simulation

Figure 12 shows the finite element contact model of the contact between a rough surface and a smooth sphere. For the case of the contact between the smooth surface and the smooth sphere, the rough surface is replaced by the smooth surface. The rigid sphere indenter was loaded with a normal force *F* of 5N toward to the deformable rough surface in *-z* direction. All nodal at the bottom of the deformable rough surfaces were fixed. The elastic-plastic contact analysis was performed for the elastic-perfectly plastic material property.

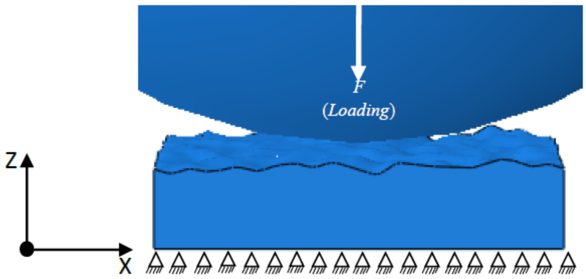


Figure-12. FEM model of the contact between a rough surface and a smooth sphere.

RESULTS AND DISCUSSION

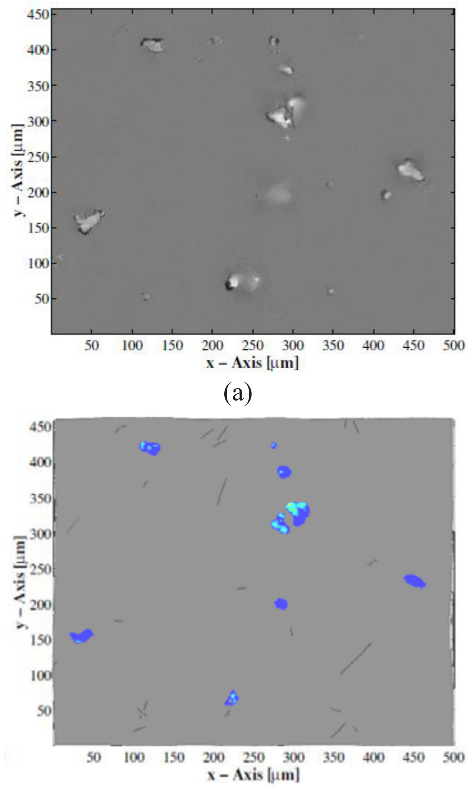
Validation

Results of the developed finite element contact model was validated with the experimental result of Jamari et al., 2006. In the experiment of Jamari et al., 2006, a static contact between a steel ball and an aluminum rough surface was performed. Diameter of the steel sphere indenter is 10 mm with the rms roughness value of about 0.05 µm. This roughness is relatively smooth compare to the rms roughness of the aluminum of about 4 µm. The applied normal load was 1 Newton. The same contact conditions were simulated in the present study. The material properties of the contact pair is presented in Table 2.

Table-2. Material properties of steel and aluminum, Jamari et al., 2006.

Components	E [GPa]	σy [GPa]	*ν* [-]
Steel sphere indenter	210	2.67	0.3
Aluminum flat	75.2	0.086	0.34

Figures 13(a) and (b) show the results of the experiment of Jamari et al., 2006 and the present finite element analysis, respectively. Here, the data of the surface roughness was taken from the measured data of Jamari et al., 2006. On the qualitative comparison, the present model shows a good agreement with the experiment.



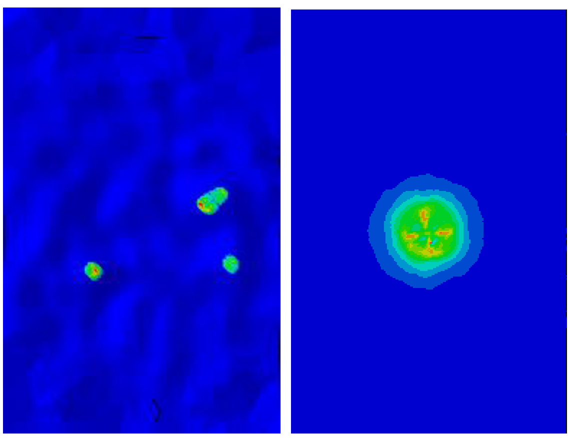
(a)

(b)

Figure-13. Contact are of a) the experimental result of Jamari et al., 2006, and b) the finite element analysis of present study.

Smooth surface and rough surface contacts

Figure 14 shows the results of the contact area for the contact of the hard smooth sphere against the deformable rough surface (a) and for the hard smooth sphere against the deformable smooth surface (b) for the same load.



(a) (b)

Figure-14. Contact area of a) rough surface, b) smooth surface.

The total contact area for the rough surface is smaller than the total contact area for the smooth surface. The difference of the contact area is caused by the difference deformation mode. In the rough surface there are many asperities deform plastically while in the smooth surface the asperity deform elastically.

CONCLUSION

Analysis of the contact area of the contact between a deformable rough surface (smooth and rough) and a hard smooth sphere indenter using finite element method have been performed. The 3D rough surface model was developed based on the surface measurement data and the CAD software. Results showed that the developed rough surface finite element contact model agree well with the experimental result. For the contact area simulation it was found that the contact of rough surface versus sphere is smaller than the contact of smooth surface versus sphere.

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