Effect of Surface Roughness on Contact Pressure

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Abstract-In engineering problems surface roughness is often neglected for the sake of simplicity of model and to reduce time, but surface roughness plays an important role in many engineering applications like MEMS, Thermal Contact Conductance, and Insulation etc. In this paper, modeling of surface roughness is done in Ansys 13 and effect of surface roughness on contact pressure is shown. The rough surface model created as array of asperities with the same radius of asperities and same asperity height, which is assumed to be following Gaussian distribution. The modeling is done for surface roughness 1, 5, 10, 15 and 20 µm. The effect of surface roughness on contact pressure is shown by comparison of contact pressure of 1 and 5 µm roughness. Physical dimension of the two body contacting each other is 1 X 1 X 6 mm. The pressure applied on the body is 1.8MPa with consideration of other body with fix support.

Appendix
Contact pressure, Surface roughness, Models, Asperity

Nomenclature

GW	Greenwood and Williamson model
N	Number of asperities per unit area
R	Radius of curvature of asperity
RMS	Root mean square
m	Average slope of asperities

Greek

η	Asperity density
σ	Surface roughness (µm)
σ_s	Standard deviation of asperity height
Φ	Probability density function.

I. INTRODUCTION

Although the most engineering surfaces are rough, the surface roughness is neglected to reduce the complexity of model. The nature of contact phenomenon is important to gaining insight into interfacial behavior such as thermal resistance, electrical resistance and wear.

Surfaces can be modeled analytically using different theories. Asperities can be modeled in variety of geometric shapes. Surface asperity heights and contact pattern is treated as probability distributions. The solid surface can be classified in several groups as shown in Fig. 1

About 90% of engineering surfaces are treated as Gaussian surfaces because the probability density of asperity heights of nearly 90% of engineering surfaces tends to be Gaussian. Therefore in this work, Gaussian distribution is adapted for asperity density.

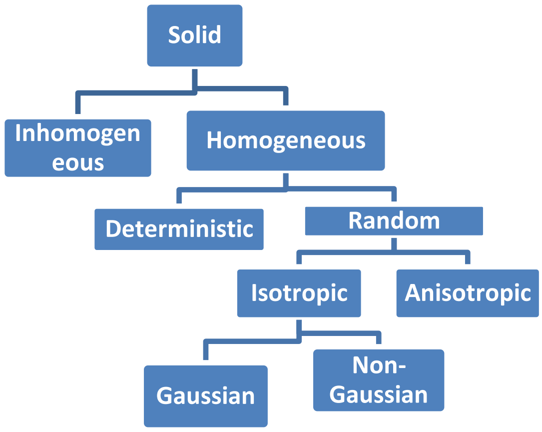

Fig. 1 Types of Surfaces

Due to complex nature of real surfaces it is difficult to predict the real contact area of rough surface under contact load. So, the rough surface is modeled analytically considering the surface as a Gaussian surface. The main advantage of selecting Gaussian distribution is that this distribution is reproductive under addition, i.e. sum of Gaussian random variables is also Gaussian. Hence by using this distribution the contact of two rough surfaces can easily be represented by the contact of an equivalent rough surface having asperities with Gaussian height distribution and a smooth plane.

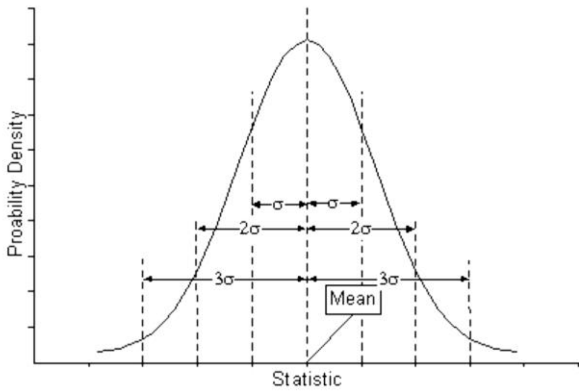

Fig. 2 Gaussian Probability density function

There are various contact mechanics approaches available as follows. [1]

A. *Statistical:*

In this method, one contact surface is considered flat, while the other is covered in spherically shaped asperities. The primary assumptions of this model are that all the asperities must have the same radius of curvature, each asperity behaves independently of its neighbors, and the substrate material is not allowed to deform, only the asperities. With these assumptions, the contact area is determined through statistical contact.

B. Fractle:

The fractal methods assume that a true rough surface appears and behaves like a mathematical fractal equation. The fractal equation assumes self-affinity but not self-similarity. Each scale of the surface is related by the fractal equations but the relation is different in the normal and lateral directions.

C. Multiscale:

A multiscale modeling technique recognizes surface geometry at every scale available for contact. At some scale, the surface is viewed so closely that the only remaining topography is the individual molecules. In this model, it is assumed that, each set of spheres with their own unique radius is a “scale” and, as load in increases the small scales are pressed into complete contact where the next layer begins to compress. Experimentally found that the rougher surfaces require greater loads to flatten the asperities and that the relationship between area and load approaches linearity.

McCool [2] numerically compared the basic Greenwood and Williamsons [3] model of elastic microcontact with isotropic and anisotropic model and suggested after series of detailed numerical examples that GW model, in addition to its simplistic form, estimates good order of magnitude of number of contacts, real contact area and nominal pressure.

As statistical approach is simple to evaluate the details of asperities, the Greenwood and Williamson [3] statistical approach for asperity contact is used.

II. SURFACE ROUGHNESS MODELLING

The Greenwood and Williamson[3] type statistical method is used to obtain statistical parameters that describe the surface. For the GW model, certain assumptions made are as follows [3]:

i) Each asperity is assumed to behave independently of neighboring asperities
ii) All asperities have same radius of curvature
iii) The asperities height follows a Gaussian height distribution
iv) Only actual asperities may deform, all substrate is rigid as well as contacting surface

The radius of curvature, R, and the areal asperity density, η, are calculated using the spectral moments of the surfaces given by McCool [2] are:

$$M_2 = \frac{1}{N}\sum_{n=1}^{N}\left(\frac{dz}{dx}\right)_n^2 \qquad (2.1)$$

$$M_4 = \frac{1}{N}\sum_{n=1}^{N}\left(\frac{d^2z}{dx}\right)_n^2 \qquad (2.2)$$

Where N is the total number of asperities on the surface and z is the distance from mean height of the surface to asperity peak. Then R and η are found from:

$$\eta = \left(\frac{M_4}{M_2}\right).\left(\frac{1}{6\pi\sqrt{3}}\right) \qquad (2.3)$$

$$R = 0.375\left(\frac{\pi}{M_4}\right)^{0.5} \qquad (2.4)$$

The Gaussian distribution for asperity height is given as follows:

$$\Phi = \frac{\left(4\frac{\pi}{2}\right)^{\frac{-1}{2}}}{\sigma_s} exp\left[-0.5\left(\frac{Z}{\sigma_s}\right)^2\right] \qquad (2.5)$$

Where σ_s is standard deviation of asperity height.

This is calculated from the standard deviation of entire surface (RMS roughness):

$$\sigma^2 = \sigma_s{}^2 + \frac{3.717X10^{-4}}{\eta^2R^2} \qquad (2.6)$$

A. Parameters of asperity

To model geometry of rough surface, dimension of asperities are to be needed. Height of asperity and number of asperities per unit area is enough dimensions to model geometry of surface.
The average asperity slope m, is given by Antonetti et al.[4]

$$m = 0.124\sigma^{0.743} where, \sigma \leq 1.6(\mu m) \qquad (2.7)$$

Another correlation of slope m, is given by Tanner and Fahoum[5]

$$m = 0.152\ \sigma^{0.4} \qquad (2.8)$$

One more correlation is given by Lambert and Fletcher[6]

$$m = 0.076\ \sigma^{0.52} \qquad (2.9)$$

From calculations, following value of m is found:

Slope m and asperities per meter square for surface roughness $\sigma = 1.3\mu m$

Antonetti et al.[4]	$m = 0.124\sigma^{0.743}$	$m = 0.1507$	2.5158x 10^8
Tanner et al.[5]	$m = 0.152\ \sigma^{0.4}$	$m = 0.1688$	3.157xx10^8
Lambert et al.[6]	$m = 0.076\ \sigma^{0.52}$	$m = 0.0871$	8.4071x10^7

Table.1. comparison of different correlation

The value of mean absolute slope m, obtained by method given by McCool[2]'s equations is 0.1268 and number of asperities per meter is 2.3049 X 10^8. This value is in good match with correlation of mean absolute slope given by (2.7). So reliable to use Antonetti et al[4] correlation. Even if it have limitation to use the correlation up to 1.6µm, the values found from correlation are much more satisfactory at higher roughness also as compare to other correlations shown in Table 1.

The surface roughness is described by a standard deviation of combined heights distribution and average absolute slope (m) for the asperities. S.SunilKumar et al[7] had simplified the equation for number of asperities per unit area which is given by

$$N = \left(\frac{m}{7.308\sigma}\right)^2 \qquad (2.10)$$

The maximum and mean summit height is derived by S.SunilKumar et al[7]

$$x_{max} = 8\sigma \text{ and } R_a = 4\sigma \qquad (2.11)$$

By using above correlations, the values of mean absolute slope and number of asperities per mm for surface roughness 1, 5, 10, 15 and 20 µm are calculated using MATLAB 7.10.0. The values are shown below.

	Surface roughness in µm				
	1	5	10	15	20
Mean Slope	0.124	0.41	0.686	0.927	1.148
No.of asperities per mm^2	287.9	125.88	88.15	71.57	61.73

Table. 2. Parameters of asperities

B. Rough surface generation in ANSYS

Many finite element programs like ANSYS, MATLAB have ability to create models using plain text commands. These commands can then be read in to the program as a input file. In this work, Surface geometry is created by importing the data obtained from MATLAB 7.10.0 in to ANSYS 13.0.

C. Random number in ANSYS

In ANSYS, random numbers are generated using recursive relation. Recursive relation involves a seed number. This relation depends on the current and previous value of the seed. In ANSYS, the start value for the seed is reset each time the program is closed and restarted for verification purpose.

D. Creation of rough surface geometry in ANSYS

The element type solid 185with 8 node is selected for the geometry. The procedure to create array of asperity in ANSYS 13.0 using APDL is shown below.

i) Create a two dimensional array which hold the surface values. This is done by using *DIM command.

ii) Fill the array with probabilistic surface values using the *DO and *VFILL command.

iii) Use the array values to generate nodes and elements, to create solid model geometry.

The rough surface is generated by using moving all nodes method which given by M.K.Thomson [8]. In this procedure, x and y asperity size should be corresponding to x and y mesh size and asperity density should be corresponding to mesh density. All vertical deviations between the asperity height and nominal surfaces are contained within a single element. As the asperity size is clearly relating to the mesh size, the hexagonal sweep meshing is done among available mapped, sweep and free type of meshes.

The generated rough surface of 1 and 5 µm is shown in Fig.2 and in Fig. 3 respectively.

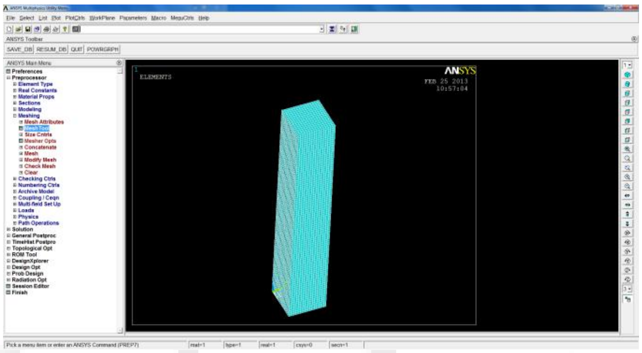

Fig. 2(a) surface roughness of 1 µm

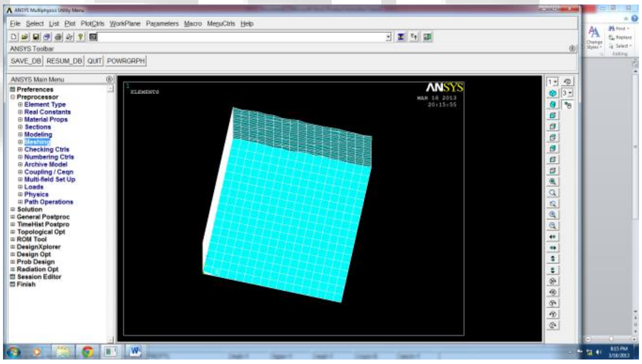

Fig. 2(b) surface roughness of 1 µm

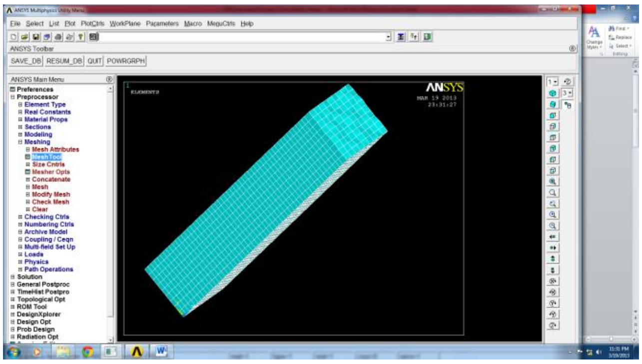

Fig. 3 surface roughness of 5 µm

The surface roughness is created in a face of 1 x 1 x 6 mm block. As, the surface roughness of 1 µm is not clearly viewed in Fig. 2(a), roughness of 1 µm is created in a 17mm cube. Roughness profile of 5 µm is clearly visible.

III. SIMULATION OF CONTACT PRESSURE

For the current study, FFT Modeler of Ansys 13.0 is used with material assignment as structural steel with density 7850kg/m^3, tensile yield strength 250MPa and tensile ultimate stress 460MPa. The two 1 x 1 x 6 mm objects are placed over each other and pressure of 1.8 MPa is applied. The simulation is done for pair of 1 µm to 1 µm and for the pair of 5 µm to 5 µm surface roughness. The contacts of bodies are considered to be rough. The lower part of the pair is considered to be fix support. The contact pressure of 1 µm is shown in Fig. 4.

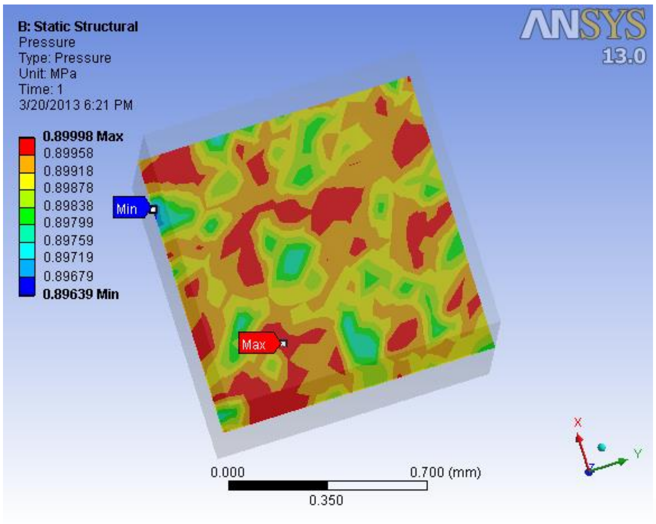

Fig. 4 contact pressure of bodies 1 µm roughness

The contact pressure of 5 µm roughness is shown in Fig. 5.

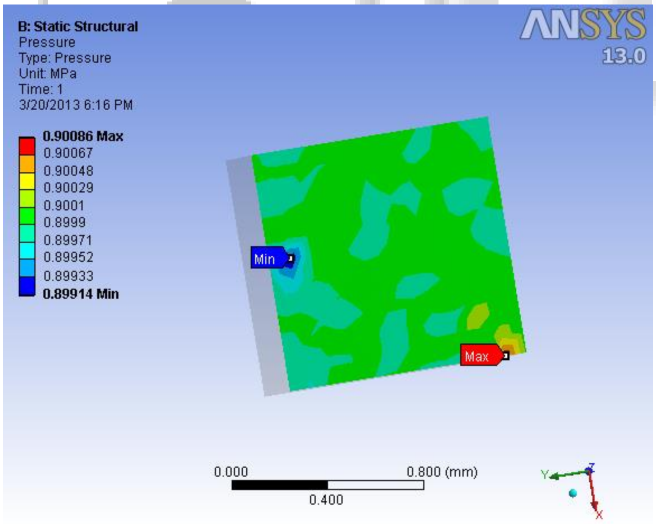

Fig. 5 contact pressure of bodies of 5 µm roughness

It is very clear from the plot that, the maximum contact pressure of 1 µm rough surface is 0.899980MPa while maximum contact pressure of 5 µm rough surface is 090086MPa.The maximum contact pressure is in more area in case of 1 µm rough surface than in 5 µm rough surface. The maximum pressure in 5 µm surface roughness is only at fraction of total area. Mostly, the contact is having 0.9001MPa contact pressure which is higher than maximum contact pressure of 1 µm surface roughness contact.

IV. RESULTS

From simulation, it is clear that with increasing the surface roughness, contact pressure is increasing. Also there is increase in thermal and electrical resistance. The increase in contact pressure is due to lessen number of asperities are in contact. As the surface roughness increases, number of asperities on surface decreases and the size of asperities increase. Due to this fact, the gap between the asperities increases and contact pressure increases. Here, only simulation for only 1 and 5 µm surface roughness is done. Same can be done by increasing surface roughness value and hence increasing contact pressure even higher than what is obtained in case of 5 µm surface roughness. The contact pressure is increased by 0.097779% by increasing surface roughness from 1 µm to 5 µm.

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