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Numerical Investigation of the Plastic Contact Deformation between Hemispheres: Variation of Radii Ratio and Normal Loads

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Abstract. Investigation of local plastic deformation between rough surfaces in mechanical components such as gears, camshaft and bearings is very important. Contact between real surfaces occurs at the summits of the highest asperities which vary in height and radius. The plastic deformation of the contact between two asperities was studied in this paper. Asperity contact was modelled as a contact between hemispheres. The commercial finite element software, ABAQUS, was employed to perform the numerical contact analysis of the elastic perfectly-plastic deforming hemispheres with the ratios of radii (R_2/R_1) from 1 to 7. Normal loads of 5000 N, 8000 N and 11000 N were applied to the frictionless contact of the hemispheres. It was shown that the plastic deformation ratio (ω_{p1}/ω_{p2}) decreases as the radii ratio increases. The higher normal load showed a lower plastic deformation ratio for high radii ratio. The results indicate that the radii ratio contributes to the severity of the plastic deformation and the total displacement of the contacting asperities.

Introduction

Mechanical engineers have to perform a comprehensive study on plastic deformation during their effort in designing the surface characteristics of mechanical parts. For components which are in contact in mechanical systems, such as bearings and gears, local plastic deformation occurs during the early phase of the contact, called as the running-in phase. Running-in is known as a tribological process that occurs during the initial phase between contacting fresh and unworn solid surfaces. A successful running-in phase leads to improve the degree of conformity so that the performance of the contacting components enhances.

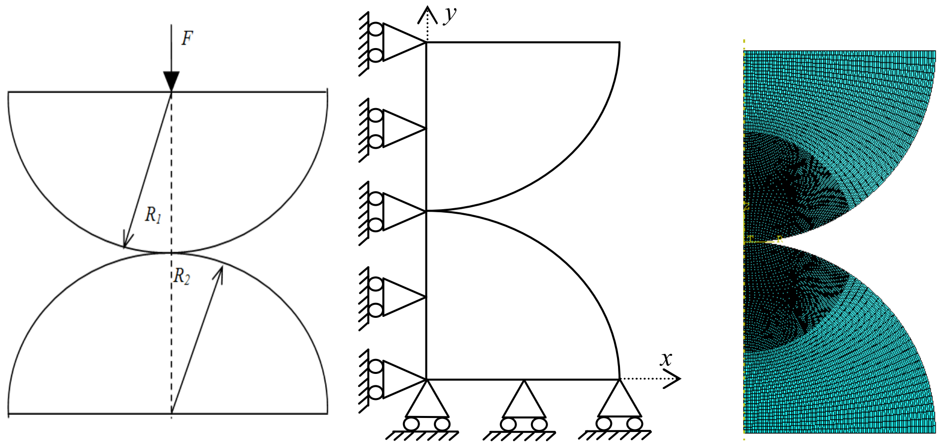
Running-in phase observation incorporates the contact and interaction of the summits of the higher asperities of the opposite rough surfaces. Many researchers have conducted analytical and numerical studies of the contact between asperities which are modelled as spheres, ellipsoids or paraboloids. Greenwood and Williamson [1] introduced the contact on micro scale and assumed all asperities are spherical with the same radius near their summits. The interference, ω, was introduced as an important variable to measure the asperity deformation. They used an elastic regime description where ω is sufficiently small, low load is applied and the deformation is reversible. Several researchers, such as Chang, Etsion and Bogy (CEB model) [2], Zhao, Maietta, and Chang (ZMC model) [3], Kogut and Etsion (KE model) [4] and Jamari and Schipper (JS model) [5] continued the work of [1] by proposing their new model, incorporating the elastic-plastic regime.

However, most of the models were developed without considering the effect of the radii ratio of the contacting spheres. The radii ratio becomes very important when studying the plastic deformation of rough surfaces in contact. Jamari [6] argued that the plastic deformation for two contacting hemispheres with different ratio of radius does not follow the hypothesis of Johnson and Shercliff [7] that when two contacting asperities have the same hardness, the depth of plastic deformation is expected to be the same for each body, independent of the geometries used.

Jamari [6] reported that the contact between two hardened steel balls (H = 8.3 GPa, E = 210 GPa and v = 0.3) with the same hardness, the degree of plastic deformation of the balls in contact differs significantly as a function of the radii ratio of the contacting hemispheres. The ratio of the plastic deformation decreases as the ratio of the radii of the balls increases. The ball with a higher contact radius deforms plastically less than the body with a lower contact radius. When considering the rough surface, the topographical change of the surface will be determined by the plastic deformation of the asperities [8]. The aim of this research is to study numerically the plastic deformation between two contacting hemispheres with respect to the radii ratio and normal load using the finite element method.

Finite Element Model

The three-dimensional numerical simulation employed is the commercial finite element analysis software ABAQUS. The contact model between hemispheres, the boundary conditions of the contact model and the refined mesh of the model are shown in Fig. 1 (a-c). The upper hemisphere, with R_1 = 17.5 mm, presses the lower hemispehere with ratios of the upper hemisphere and the lower hemisphere (R_1/R_2) of 1 to 7. The radius of the upper hemisphere was designed to be constant and the lower hemisphere was varied as follows: 17.5, 8.75, 5.84, 4.38, 3.5, 2.92 and 2.5 mm.



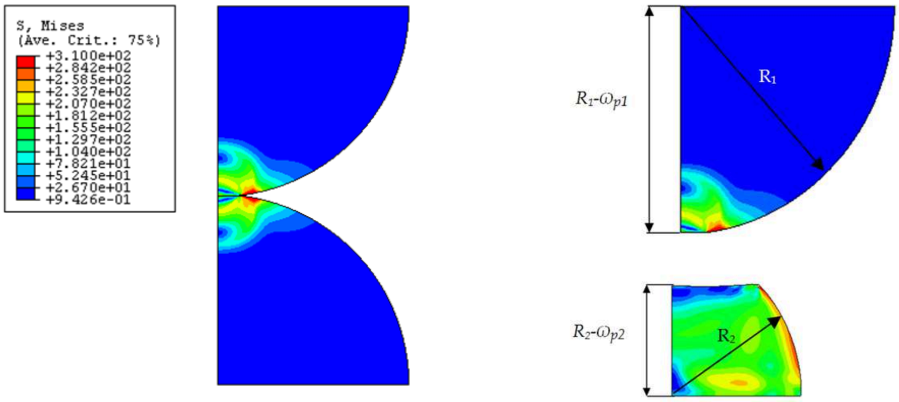
(a) (b) (c)

Fig. 1. (a) Contact between two hemispheres, (b) the boundary conditions of the contact, and (c) the refined mesh.

Both hemispheres were modelled as brass material with elastic-perfectly plastic material behaviour. The contact is frictionless (μ = 0). The mechanical properties of this material i.e. the elastic modulus (E), yield stress (σ_Y), and Poisson's ratio (υ) are 96 GPa, 310 MPa and 0.34, respectively. The contact load applied in the simulation are 5000 N, 8000 N and 11000 N. The contact load is positioned on the upper hemisphere at the center (axis) as is shown in Fig. 1(a). For determining the plastic deformation the hemispheres contact system is then unloaded.

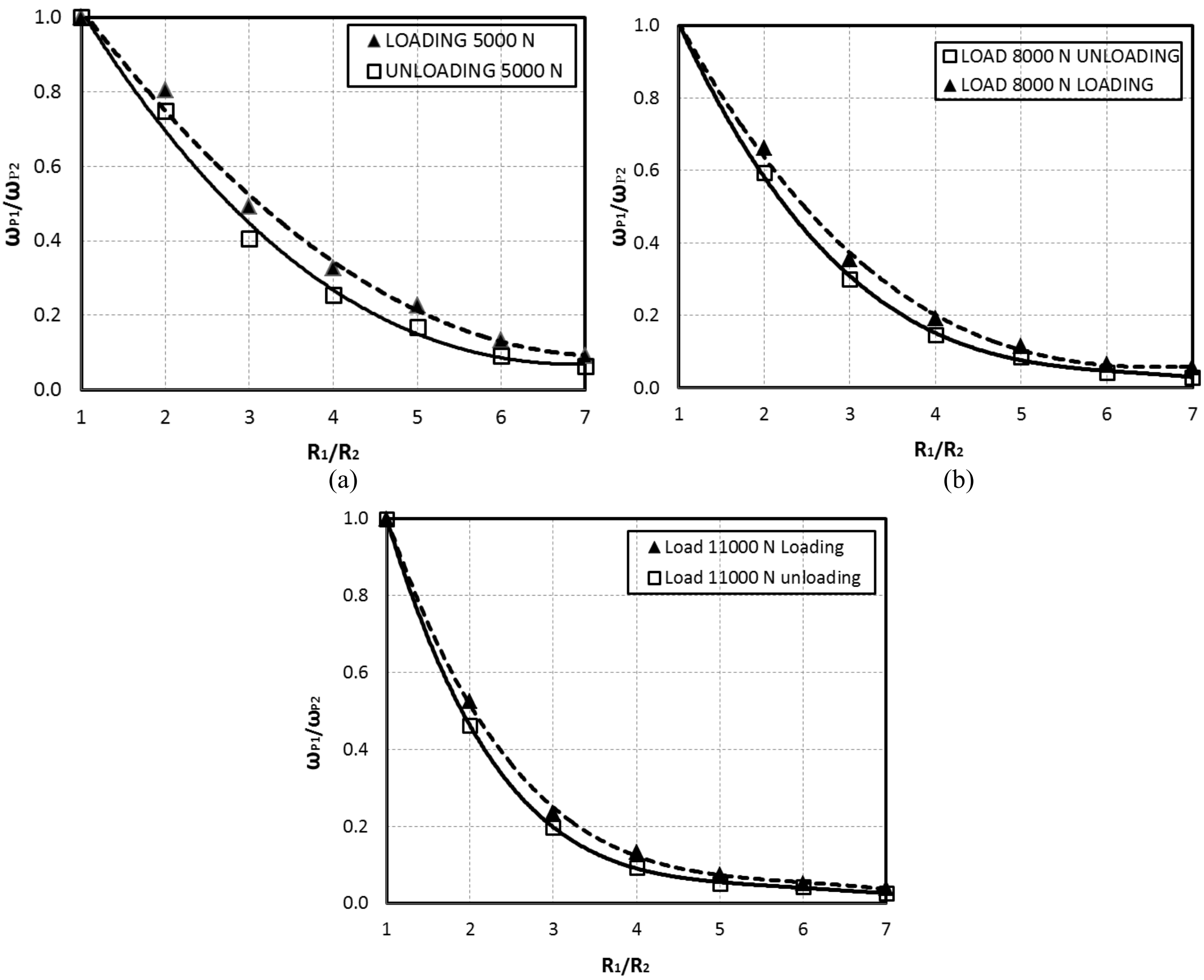
Results and Discussions

The result of von Mises stress distribution for the ratio of R_1/R_2 = 1 and the applied load of 5000 N is depicted in Fig. 2(a). Fig. 2(b) shows the method for calculating the plastic deformation for both hemispheres after unloading. For R_1/R_2 = 1 it can be seen that the von Mises stress distribution for both hemispheres are the same but this condition does not apply when the $R_1/R_2 \neq 1$ (see Fig. 2(b)). This result does not confirm the hypothesis of [7]. Fig. 3 (a-c) show the plastic deformation ratio of the loading and unloading condition of the contact as a function of the ratio of radii for the load of 5000 N, 8000 N and 11000 N. The loading condition was captured when both hemispheres were still in contact whereas the unloading condition was captured when the upper hemispheres was moved upwards. Here, the phenomenon of elastical recovery was observed on both hemispheres. The elastic recovery decreases when a higher contact load was applied and lower radius due to severe plastic deformation.



(a) (b)

Fig. 2. (a) The von Mises stress distribution for the ratio of $R_1/R_2 = 1$ and F = 5000 N. (b) The measured plastic deformation after unloading.



(a) (b)

(c)

Fig. 3. The plastic deformation ratio of the loading and unloading condition of the hemisperes contact as a function of the ratio of radii for a load of (a) 5000 N, (b) 8000 N and (c) 11000 N.

Fig. 4 shows the comparison of the plastic deformation ratio as a function of the radii ratio for different contact loads after unloading. It was found that the ratio of the plastic deformation ω_{p1}/ω_{p2}

decreases as the ratio of the radii R_1/R_2 increases. This phenomenon was observed for the three different contact loads. The body with a higher radius show less plastic deformation than the body with a lower radius. These results confirm the experimental work of Jamari [6]. Jamari pointed out that this phenomenon is caused by material flow. The body that has more ability for transferring material (to lateral direction in this case) will show more plastic deformation.

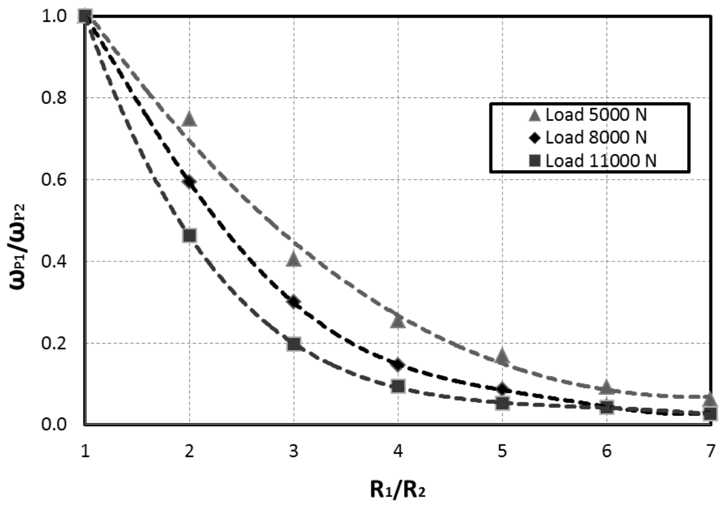


Fig. 4. Comparison of the plastic deformation ratio as a function of the radii ratio for different contact loads after unloading.

Conclusion

The present research investigates the plastic deformation of the contacted hemispheres using the commercial finite element software ABAQUS for different sphere radii and loading conditions. The elastic perfectly-plastic material behaviour was used and the ratio of radii of hemispheres (R_2/R_1) was varied from 1 to 7. Three normal loads of 5000 N, 8000 N and 11000 N were applied to the frictionless contact of the hemispheres. It was found that the plastic deformation ratio (ω_{p1}/ω_{p2}) decreases as the radii ratio increases for all three different contact loads. The result confirms the experimental work of Jamari [6] and rejects the hypothesis of Johnson and Shercliff [7].

References

[1] J.A. Greenwood, J.B.P. Williamson, Contact of nominally flat surfaces, Proc. R. Soc. Lond. 295 (1966) 300-319.

[2] W.R. Chang, I. Etsion, D.B. Bogy, An elastic-plastic model for the contact of rough surfaces, ASME J. Tribol. 109 (1987) 257-263.

[3] Y. Zhao, D.M. Maietta, L. Chang, An asperity micro contact model incorporating the transition from elastic deformation to fully plastic flow, ASME J. Tribol. 122 (2000) 86-93.

[4] L. Kogut, I. Etsion, Elastic-plastic contact analysis of a sphere and a rigid flat, ASME J. Appl. Mech. 69 (2002) 657-662.

[5] J. Jamari, D.J. Schipper, An elastic-plastic contact model of ellipsoid bodies, Tribol. Lett. 21 (2006) 343-354.

[6] J. Jamari, Running-in of Rolling Contact, PhD Thesis, University of Twente, The Netherlands, 2006.

[7] K.L. Johnson, H.R. Shercliff, Shakedown of 2-dimensional asperities in sliding contact, Int. J. Mech. Sci. 34 (1992) 375-394.

[8] R. Ismail, E. Saputra, M. Tauviqirrahman, J. Jamari, D.J. Schipper, Modeling of repeated rolling contact on rough surface: surface topographical change. Advanced Materials Research 896 (2014) 642-645.