Optical Evaluation of Surface Deffects Influence upon the Contact Area between a Metallic Spherical Punch and a Flat Surface

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The present paper aims to investigate the effect of surface defects upon contact area shape and dimensions in the case of metallic spherical punches pressed against a flat, optically transparent surface. Experimental investigations were conducted using a previously advanced, optical method, based on surface reflectivity. Various surface defects were artificially generated on the surface of steel ball bearing balls with 12.775 mm in diameter. The considered defects were grooves and holes. The employed experimental method is based on the accurate evaluation of contact interface reflectivity of loaded contacts, by aid of laser profilometry, as described in previous works [1-9].

Keywords: surface defects, mechanical contacts, contact area, laser profilometry, reflectivity

Surface defects in contacting bodies represent weak points. In the case of cyclic loading, as is the case of most practical situations, very strong stress and pressure concentrations occur in the immediate vicinity of the defects. These concentrators may lead to the initiation of new cracks or they can accelerate the propagation of pre-existing ones. Various studies can be found in literature [10- 14] that deal with evaluating the effects of surface imperfections upon stress states generated in contact bodies, and implicitly upon contact durability. In all these cases, artificial grooves or imprints were introduced on contacting bodies surfaces to simulate defects, and numerical simulations were conducted regarding their influence upon contact conditions. It was concluded that the presence of these surface defects changes the conditions in which contacts take place and significantly reduces their durability.

As shown in, [11], it can be appreciated that in the presence of a groove on the contact surface, the two groove shoulders take part in supporting the load, either equally or differently, depending on groove position. Numerical simulations were previously conducted, [11,15], to investigate the influence of groove position on contact surface upon stress states and pressure distributions generated in contact bodies. In order to evaluate stress states and pressure distributions, the above mentioned simulations used as input data the equations describing the limiting surfaces for both spherical punch with surface defect and elastic half-space, along with the elastic parameters of employed materials and applied loads. In order to simplify the calculations, most numerical simulations resort to transferring the groove on the flat surface, [10]. Using the mathematical model advanced in [11], similar simulations were conducted in the present work to highlight the influence of various groove eccentric positions upon contact behaviour. Figure 1, illustrates numerical results obtained for the contact between a spherical rigid punch pressed against an elastic half-space. A surface groove was placed on punch surface, in several eccentric positions by report to contact symmetry plane. Typical results regarding pressure distributions were plotted in figure 1. Pressure distributions generated in contact were evaluated by aid of a CG-DCFFT (Conjugated Gradient Discrete Convolute Fast Fourier Transform) algorithm previously described in [15], which uses punch surface equations as input data. For the simulation results shown in figure 1, the groove position is expressed in terms of comparing its eccentricity to the groove half-width, c.

Experimental part

The work presented herein aims to investigate the effect of surface defects upon contact area shape and dimensions in the case of metallic spherical punches pressed against a flat, optically transparent surface. Experimental investigations were conducted using a previously advanced, [1-9] optical method, based on surface reflectivity.

The experimental optical method of investigation for mechanical contacts mainly consists of using laser profilometry in order to map contact surfaces generated by applying load to a contact model between an equivalent punch and an elastic half-space. This model simulates real contacts by means of an equivalent punch (the punch surface incorporates characteristics from both real bodies in contact) pressed against an elastic half-space (modeled by a thick, optically transparent, plate), with elastic properties similar to those of investigated bodies. The present research was conducted to investigate steel-on-steel contacts in the presence of surface defects. To that end, steel bearing balls with generated surface defects were pressed against a thick sapphire plate. Sapphire was chosen to simulate the elastic half-space as it meets the above mentioned requirements (optical transparence and elastic properties similar to those of steel: longitudinal elasticity modulus is 3454 Gpa for sapphire and 210 Gpa for steel; Poisson's ratio -0.29 for sapphire similar to the $\nu = 0.3$ corresponding to steel; maximum contact stresses for bearing steel and sapphire share the same order of magnitude $\sigma_{c\ sapphire} = 2$ GPa and $\sigma_{c\ bearing\ steel} = 2.5$ GPa).

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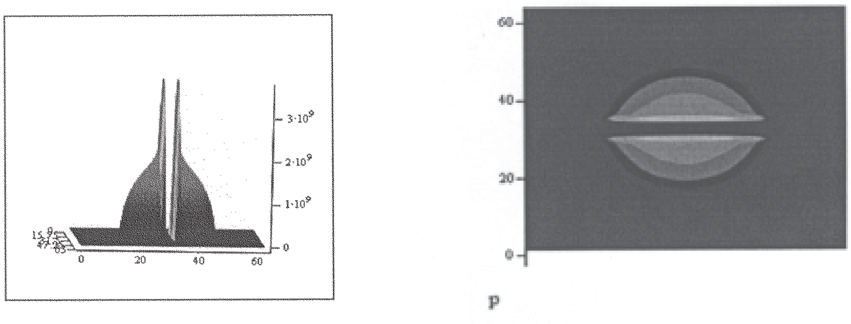
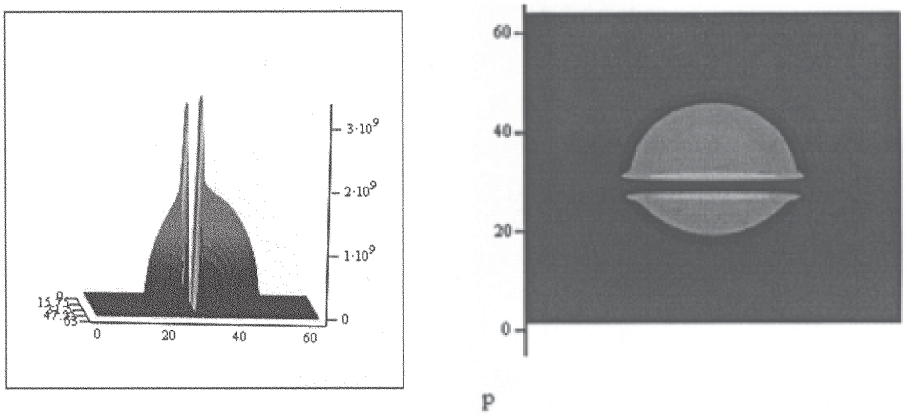


a) eccentricity 0 c



e) eccentricity 1.8 c

Fig. 1. Pressure distribution for the contact between a spherical punch with a surface groove and an elastic half-space

It is well known that light is partially reflected and partially transferred when it meets the interface of two optically different media. Based on this phenomenon the principle of the employed optical method is schematically illustrated by figure 2.

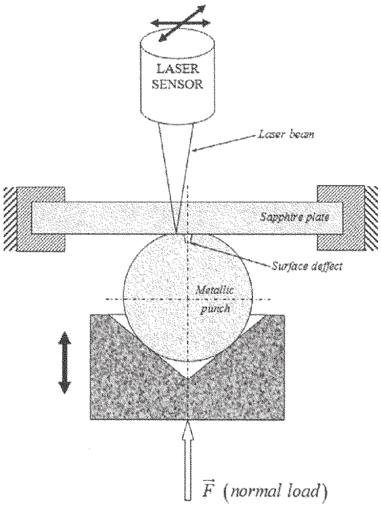


Fig. 2. Reflection–refraction of light when the punch-sapphire window contact model is investigated by aid of laser profilometry

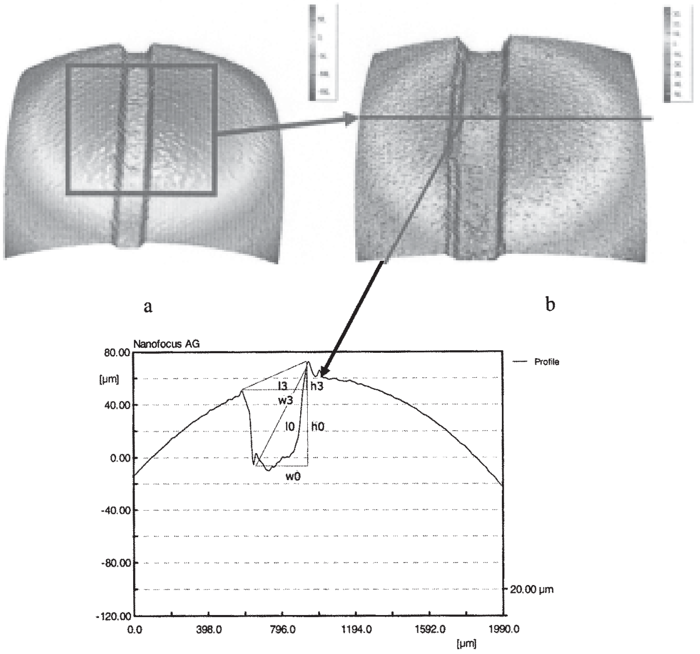
Besides surface microtopography most modern optical profilometers have the ability to evaluate the reflectivity given by the ratio between incident and reflected light energies. In the case of the studied contact model, it was previously demonstrated, [1-8] that light is reflected differently by surface points placed inside contact area (corresponding to a metal-sapphire interface) and by one from outside contact area (corresponding to sapphire-air interface). As was shown in [3], because refractive index is higher for sapphire than air and lower than metal, the measured surface reflectivity will be lower inside contact area and higher outside it. This property allows accurate evaluation of the contact area, if the variation of surface reflectivity is known.

In order to experimentally investigate the effect of surface defects upon contact parameters and characteristics, various surface defects were artificially generated on the surface of steel ball bearing balls with 12.775 mm in diameter. New bearing balls and the one subject to various stages of functioning (after 18, 19 and 50 million cycles) were both considered in present research. Before making contact, the surface microtopography of the used balls was mapped by laser profilometry. This allowed for accurate evaluation of the shape and dimensions of considered surface defects. Typical results obtained for surface microtopography are illustrated three-dimensionally in figures 3a and 3b. Figure 3c shows a transversal profile of the same surface defect which allows to accurately measure the groove dimensions. For the considered surface defect it was determined that the practiced groove is 350.4 μm wide (measured near contact surface) and 75.6 μm deep (measured between highest and lowest regions).

Results and discussions

The considered bearing balls with surface defects were placed in contact with a flat, thick sapphire window and various load levels were applied. The loaded contacts were placed on the X-Y stage of a μ Scan® laser profilometer manufactured by NanoFocus, equipped with a CLA 10 chromatic optical sensor. After the light beam from the sensor was focused on the metal-sapphire interface (in the central region of the contact area), the whole contact region was scanned and surface microtopography as well as its reflectivity were determined. Obtained results were then plotted both three-dimensionally, as illustrated in figures 4 and 5, and by aid of 2D surface plots using different shades of gray, as shown in figures 6 and 7.

The experimental results illustrated in figures 4-7 clearly show the effect of a surface groove upon contact area shape and dimensions. It can be easily seen that the size and position of the groove by report to the contact symmetry plane has a very strong influence on resulting contact area. Implicitly, this will affect the generated contact pressure and therefore contact ability to ensure



a

b

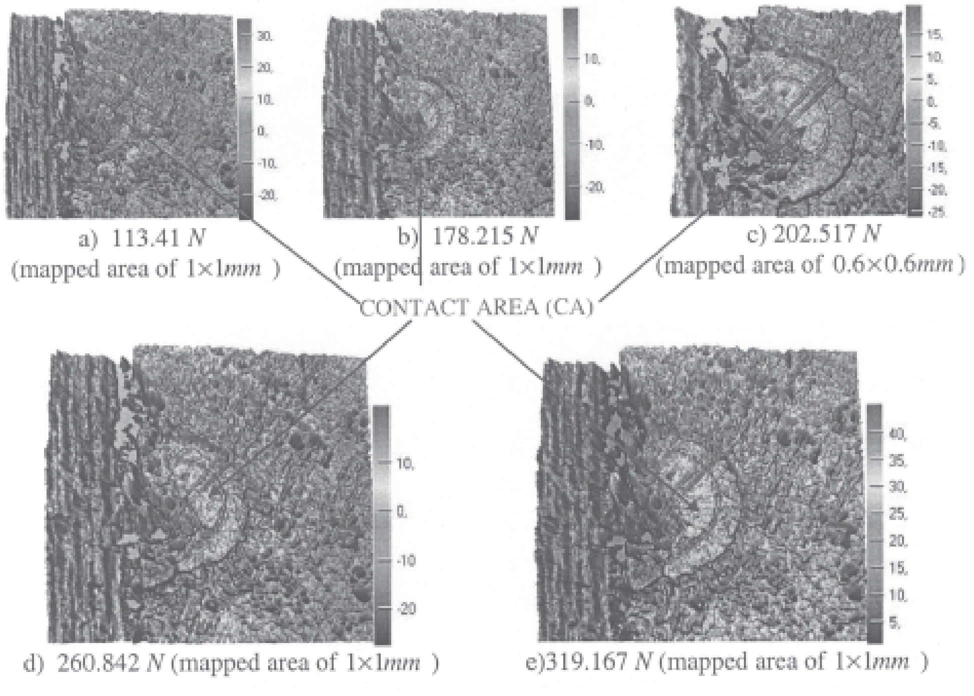
c

Fig. 3. Surface microtopography (a) and transversal profile and dimensions (b) for a 12.7 mm steel ball bearing ball with a surface groove obtained by laser profilometry

Profile values

Shape 0
Width w0 = 279.8 µm
Height h0 = 75.627 µm
Length l0 = 289.8 µm
Angle = 15.13 µm

Shape 3
Width w3 = 349.7 µm
Height h3 = 21.505 µm
Length l3 = 350.4 µm
Angle = 3.52 µm



a) 113.41 *N* (mapped area of 1×1*mm*)

b) 178.215 *N* (mapped area of 1×1*mm*)

c) 202.517 *N* (mapped area of 0.6×0.6*mm*)

d) 260.842 *N* (mapped area of 1×1*mm*)

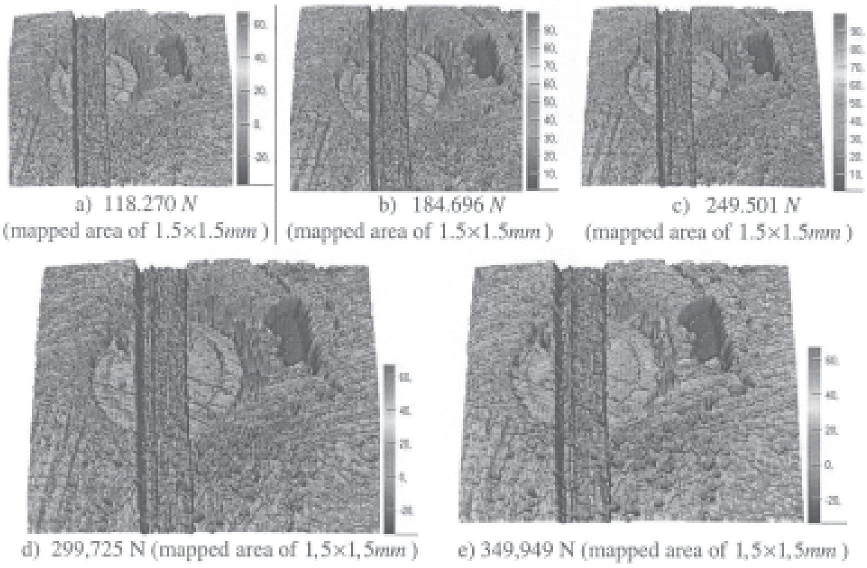
e)319.167 *N* (mapped area of 1×1*mm*)

Fig. 4. 3D plots surface reflectivity in the contact region between a 12.7 mm bearing ball with a groove type surface defect and a thick sapphire plate under various normal loads

good working conditions and resistance to wear. In all presented cases the contact area is no longer circular, as it would be in absence of the surface defect.

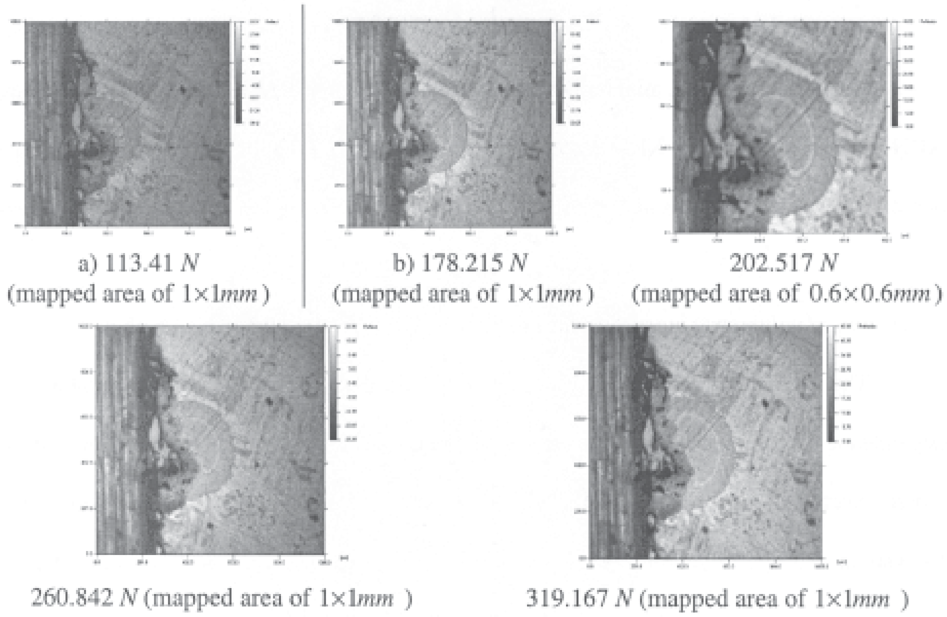
In the case illustrated by figures 4 and 6 the position of the groove was strongly eccentric, by report to contact symmetry plane, and only one of the groove shoulders takes part in bearing the applied load. The contact perimeter has a circular portion on the far side from the groove, and becomes irregular near it. As expected, the resulting contact area increases with load, as the body suffers elastic strains.

In the case illustrated by figures 5 and 7, the groove eccentricity was reduced, resulting in both groove shoulders taking part in the contact. The two contact regions obtained have similar shapes to the ones obtained by numerical simulations.



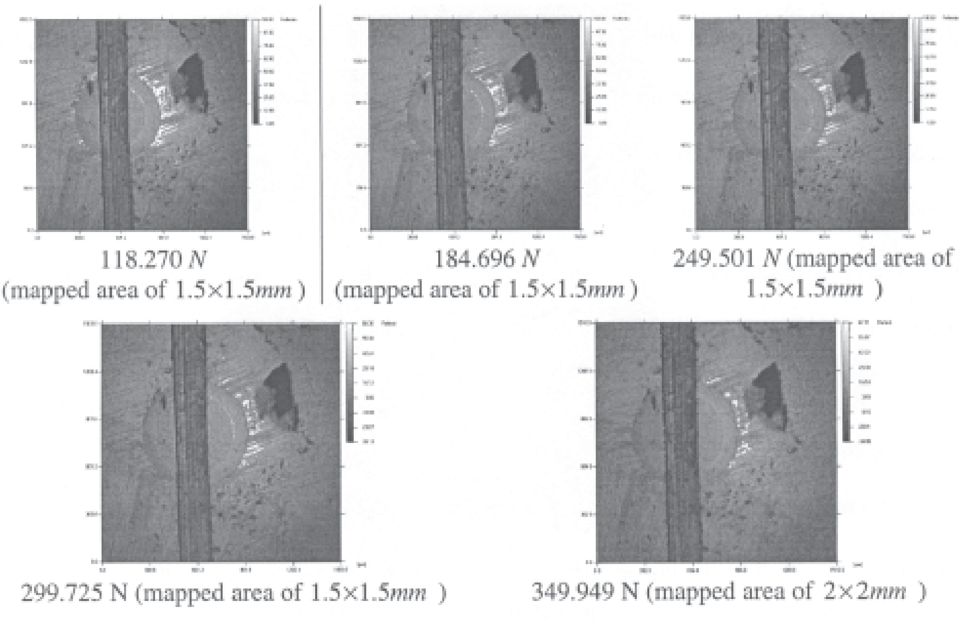
a) 118.270 *N* (mapped area of 1.5×1.5*mm*)
b) 184.696 *N* (mapped area of 1.5×1.5*mm*)
c) 249.501 *N* (mapped area of 1.5×1.5*mm*)
d) 299,725 N (mapped area of 1,5×1,5*mm*)
e) 349,949 N (mapped area of 1,5×1,5*mm*)

Fig. 5. 3D plots surface reflectivity in the contact region between a 12.7 mm bearing ball with a groove type surface defect and a thick sapphire plate under various normal loads



a) 113.41 *N* (mapped area of 1×1*mm*)
b) 178.215 *N* (mapped area of 1×1*mm*)
202.517 *N* (mapped area of 0.6×0.6*mm*)
260.842 *N* (mapped area of 1×1*mm*)
319.167 *N* (mapped area of 1×1*mm*)

Fig. 6. Plane representation, by shades of grey, of surface reflectivity in the contact region between a 12.7 mm bearing ball with a groove type surface defect and a thick sapphire plate under various normal loads



118.270 *N* (mapped area of 1.5×1.5*mm*)
184.696 *N* (mapped area of 1.5×1.5*mm*)
249.501 *N* (mapped area of 1.5×1.5*mm*)
299.725 N (mapped area of 1.5×1.5*mm*)
349.949 N (mapped area of 2×2*mm*)

Fig. 7. Plane representation, by shades of grey, of surface reflectivity in the contact region between a 12.7 mm bearing ball with a groove type surface defect and a thick sapphire plate under various normal loads

Conclusions

Experimental studies were conducted in order to verify the effect of surface defects upon the contact area between a spherical punch and a flat surface. The experimental evaluation of contact areas was done using a previously advanced optical method based on the variation of surface reflectivity inside and outside the contact area in the case of a steel equivalent punch pressed against a flat sapphire window. The used materials allow for accurate modeling of steel-on-steel contacts behaviour. The experimental results obtained in the present research are in agreement with theoretical predictions found in literature and the one obtained by numerical simulations. It was confirmed that, as expected, the presence of a surface groove leads to splitting the circular contact area in two separate contact regions. Depending on the position of the groove by report to the central symmetry plane of the contact, and the applied loads, the two contact regions vary in size, shape and dimensions.

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