MILITARY TECHNICAL COLLEGE

CAIRO - EGYPT

APPLICATION OF HERTZ ANALYSIS TO THE CONTACT OF SURFACES COVERED BY SOFT METAL FILMS

T.E.S. El-Shafei*

ABSTRACT

Understanding of the behaviour of Hertzian contact is basic to the design of the tribological contacts such as rolling bearings, gears and cams. This paper describes an investigation of the static contact between a steel ball on a lead plated steel flat. Both the normal approach of thes surfaces and their area of contact have been measured as functions of normal loads and the the thickness of the lead film. It is shown that at high loads all the coated surfaces behaved elastically. It is also shown that the Hertz solution can be applied to calculate both normal approach and contact area when using the suitable value of the elastic modulus. An imperical equation has been given to calculate the equivelent elastic modulus which is shown to be function of both, elastic properties of the contacting surfaces together with the film thickness.

* Lecturer.Military Technical College, Cairo, Egypt.

. . .

INTRODUCTION

For many years, Hertzian analysis has been applied to studies of asperity contact between engineering surfaces in static contact (1) and in sliding contact (2).

Morerecently, Hertzian analysis has been extended to model the contact of systems where one surface is covered by a layer of material having elastic properties different from those of the substrate (3). These models are also relevant to any tribological systems where solid/solid contact can occure, due to the presence of some sort of film on almost all engineering materials.

The experimental program has been made to investigate the contact behaviour of soft metal-film coated surfaces in case of static contact, with the aim of providing the designer with the contact data by application of the simple Hertz solution on the static contact of two surfaces one of which is covered by a thin soft-metal film.

EXPERIMENTAL DETAILS

SPECIMEN PREPARATION

Flat annular discs of SAE 52100 steel, 90 mm O.D, 40 mm I.D and 10 mm thick were ground and polished to a surface finish 0.17 μm R_A. The test specimens were coated with thin films of lead using the ion-plating process, which gives excellent adhesion between the film and the substrate. Specimens were prepared with film- Thicknesses of 1.5,3,6,9 and 12 μm.

EXPERIMENTAL PROCEDURE

The apparatus illustrated schematically in Fig.1, was designed to measure the normal approach of the surfaces when three spheres equally spaced around a circle are compressed between two similar flat surfaces.

Measurement were made using loading masses of 1,2,3,4, and 5 Kg, and ball diameters of 7.935 mm and 3.175 mm .

The capacitance probes used for measurement of the normal approach consisted of a 25.4 mm diameter steel ball, and the end face of a 25.4 mm disk steel cylinder. Both probes were located in insulating material contained in earthed steel cups. The capacitance was measured using a standerd capacitance bridge, and was found to obey the empirical relationship shown in Fig.3. In the present work, the diameter of the contact area was also measured. This contact area could be seen quite clearly as it was more lustrous than the surrounding surface, due to plastic deformation of some

6

asperities within the contact areas.

The contact diameters were measured using the measuring system of a Leitz microhardness tester.

RESULTS AND DISCUSSION

When an elastic sphere is loaded against an elastic half space the radius of the contact circle and the normal approach, according to Hertz solution, are calculated as follows :

$$a = \left(\frac{3Nr}{4E'} \right)^{1/3} \quad (1)$$

$$\delta = \left(\frac{9N^2}{16E'^2 r} \right)^{1/3} \quad (2)$$

$$k = \frac{1}{E'} = \frac{1-\nu_1^2}{E_1} + \frac{1-\nu_2^2}{E_2} = K_1 + K_2 \quad (3)$$

where a= radius of contact circle

δ = normal approach

N = normal load

r = ball radius

E'= equivelent elastic modulus defined by the relation (3)

E_i, ν_i, K_i= Youngs modulus, Poissons ratio and modulus of rigidity of material i.

A plot of log a Vs log N should, therefore, give a linear relationship having a slope of 1/3 for elastic deformation.

Simelerly, a plot of log δ VS log N should give a linear relationship having slope 2/3.

Graphs for log a VS log N are shown, for both ball diameters and various film thicknesses, in Fig.4 . It can be seen that at higher loads, all surfaces give slopes of 1/3 indicating elastic deformation. At lower loads this relationship was maintained for the thinnest films only.

Graphs for log δ VS log N are also shown in Fig.5 giving similer results with slope 2/3.

It can also be seen that the graphs for different film thickness do not coincide,where the contact radius and the normal approach at any load increesing with film thickness.

This observation suggests, at first sight, that the modulus of a coated surface decreases with increasing film thickness. Although this conclusion has not yet been proven to be correct, the experimental results have been used, backwards, to calculate the equivelent modulus of rigidity K of the coated surfaces behaved elastically assuming that Hertz solution is applicable. Assuming that the film/substrate system can be treated as new composite material, having modulus of rigidity K_c, knowing the values of the contact radius at different loading conditions, we would be able, be a appling Hertz equations, to calculate the corresponding values of K_c (equations 1 and 2).

From equation 3 we get

$$K_c = K_2 = K - K_1$$

where

$$K = \frac{1-\nu_1^2}{3Nr} = \left(\frac{16\,\delta^3 r}{9N^2}\right)^{1/2}$$

$$K_1 = \frac{1-\nu_1^2}{E_1} \quad \text{for the steel ball.}$$

Fig.6 shows the graphs of K_c VS t/a_o where t is the film thickness and a_o is the contact radius of the ball with a flat substrate material as calculated from Hertz solution.

The experimental results show that the value of K_c approaches the value of that of the substrate material K_s when t/a_o tends to zero, and approaches the value of that of the film material when the value of t/a_o tends to infinity.

The following imperical equation has been established to full-fill these requirements

$$K_c = K_s \cdot \frac{1+A.K_f.\ t/a_o}{1+A.K_s.\ t/a_o} \qquad (4)$$

Equation (4) is shown as dashed line in Fig.6 to fit the experimental results and it showed a good correlation when the value of $A=7.6 \cdot 10^5$.

Where in equation (4), K_s and K_f are the modulus of rigidity of substrate and film materials respectively.

El Sherbiny and Halling (3), introduced a theoretical solution for the problem of deformation of thin elastic film on a rigid substrate. A computer program was established to calculate the values of K_c by applying-Hertz solution on their calculated values of the contact radius a, for different values of film thickness. The results are also plotted in Fig-.6 and shown as full line. It is shown that the theoretical solution gave lower values of K_c than the experimental results. This differance should be due to ignoring the elasticity of the substrate by assuming it to be rigid.

CONCLUSION

Thin soft films on hard substrate behave mainly elastically under the application of high values of normal loads.

The contact parameters, needed by the designer could be approximatly calculated using Hertz solution in which a modified modulus of rigidity is used. This modulus of rigidity is calculated from the given imperical equation and is shown to be function of s elastic properties of both film and substrate materials, and the film thickness.

REFERENCES

(1) Greenwood, J.A. and William Son, J.B.P., "Contact of nominally flat surfaces" Proc. Roy,Soc. (London), 295(A), P. 300 (1966).

(2) Halling, J., Wear," A Contribution to the theory of mechanical wear", 34, PP 239-249 (1975).

(3) El-Sherbiny, M.G.D. and Halling, J., " The Hertzian Contact of Surface covered with metallic films", wear, 40, P. 325 (1976).

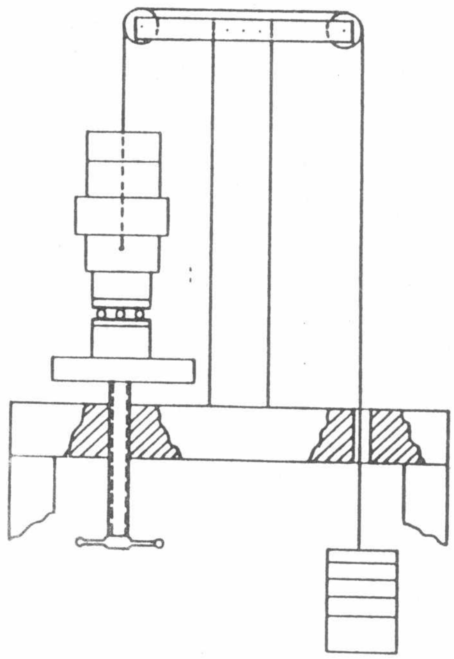

Figure (1) Normal approach test rig

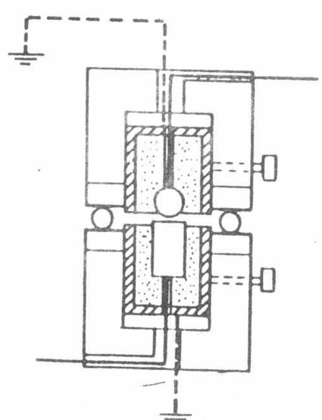

Figure (2) Capacitance probes

6

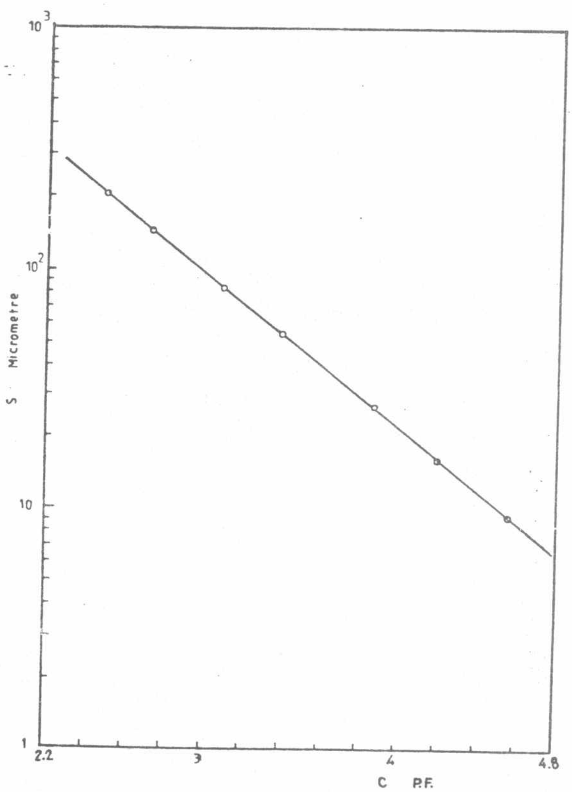

Figure (3) Calibration chart for the capacitance probes

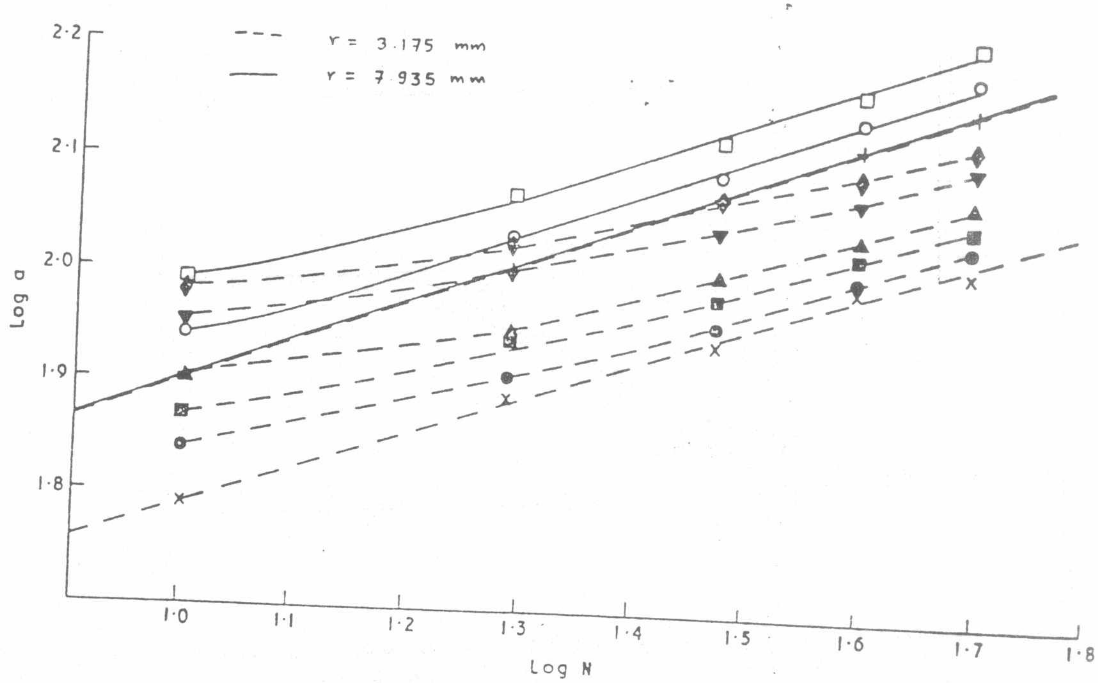

Figure (4)

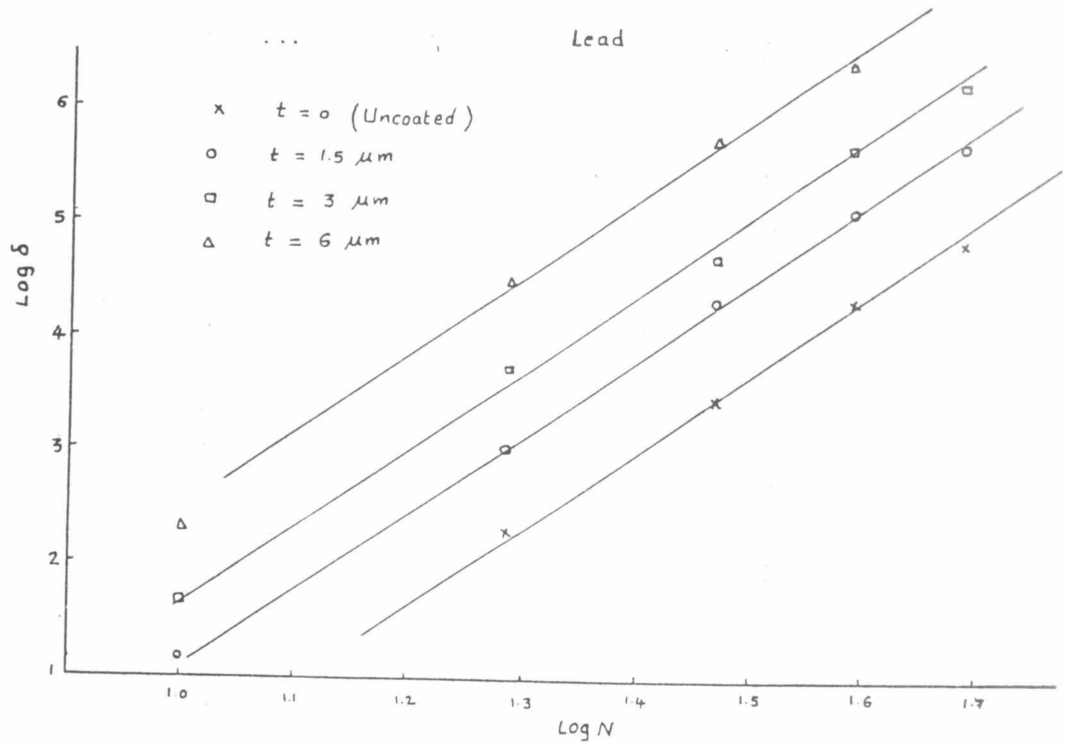

Figure (5)

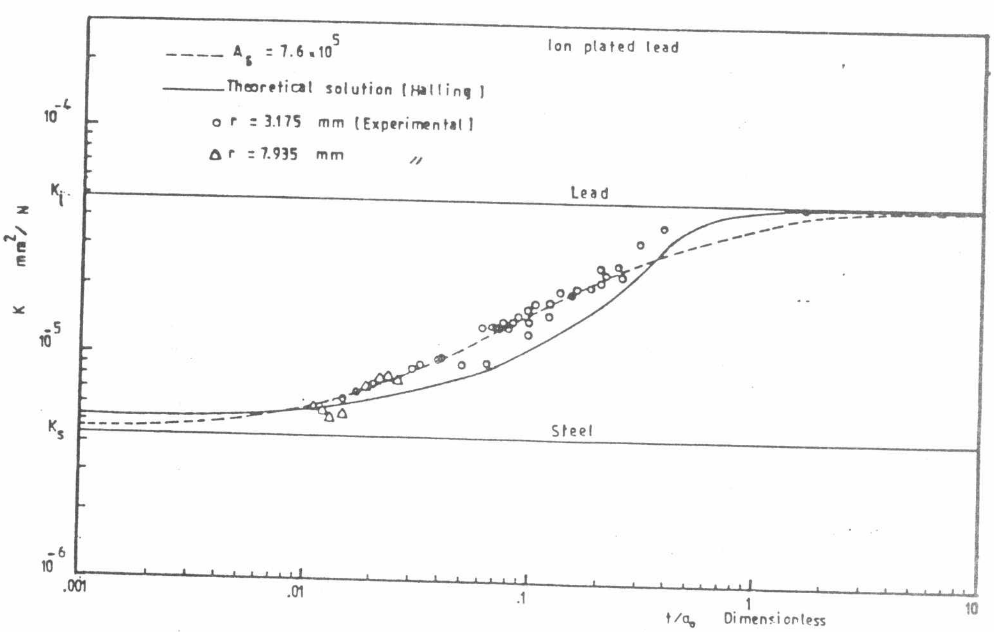

Figure (6) Relationship between K and t/a_o for ion plated lead films on steel substrate. Equation (4) is shown by dashed line for A = 7.6x10⁵ for lead