ENERGY LOSSES OF SOFT METAL FILMS ON STEEL IN ROLLING FRICTION

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ABSTRACT

For a sphere rolling freely on a flat elastic surface, energy loss is usually refered to the elastic hysteresis losses. The value of the elastic hysteresis loss coefficient is constant and function of the elastic properties of the contacting materials.

In the present work, the experimental results showed that soft lead films behave elastically under the application of high values of normal force. It is also shown that the elastic hysteresis loss coefficient is, not only a function of the elastic properties of the contacting material, but also function of the normal load. The relationship between the value of the elastic hysteresis loss coefficient, for lead and silver films on steel substrate, and the normal force is presented together with the measured value for the uncoated steel surface which took a constant value.

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INTRODUCTION

Any rolling situation can be analysed from three standpoints where any combination of the following effects may be contributory to the rolling friction torque :

1- Pure rolling or free rolling, where the resultant force between the contacting surfaces is perpendicular to the plane of contact, it is most nearly approached in the case of a cylinder or ball rolling without constraint in a straight line along a plane.

2- Rolling with combined applied surface tractions which takes place when the transmitted force contains a tangential component.

3- Rolling with regions of slip in the contact zone necessitated by the geometry of the system or by the constraint on the rolling motion.

It has been shown by Tabor (1) that the energy dissipated in free rolling of elastic cylinder or sphere lies in the influence of the elastic hysteresis of the material of the two surfaces.

As almost all engineering surfaces are covered by films of some sort, and due to the wide application of soft-metal-film lubricated elements, the study of the rolling process should be extended to include systems where one surface is covered by a layer of material having elastic properties different from those of the substrate.

A substantial program of work has, therefore, undertaken to investigate the behvior of soft-metal-film coated surfaces in static and rolling contact with different rolling conditions. The results of the static contact showed that,soft metal films behave elastically under the application of high values of normal force(2,3).

It is the aim of this paper to describe the initial investigation of the free rolling of three steel balls on flat ball-bearing steel covered by thin layers of lead and silver.

EXPERIMENTAL DETAILS

Specimen Preparation

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

Experimental Procedure

In the static contact test,the diameter of the contact area was measured for several ball diameters and normal loads.The measuring system of a Leitz microhardness tester were used for measuring the contact area radius.

In rolling of a ball between flat surfaces,the apparatus, illustrated schematically in fig.1,was designed to measure the rolling friction force for three balls rolling between two similer surfaces were the three balls are equally spaced around the circumference of a circle. The lower specimen is fixed on a table mounted on four leaf springs through which rolling friction force was applied and measured by a linear displacement transducer.The normal force is applied to the upper specimen by means of dead weights.The lower specimen was driven with a crouzet motor through a micrometer drum to move with a linear speed of 1.5 mm/min. The measuring system was calibrated by means of dead weights,fig.2 represents the calibration chart for the transducer used.

RESULTS AND DISCUSSION

When an elastic sphere is loaded against an elastic half space the radius of the circle of contact is given by :

$$a = \left[\frac{3Nr}{4E'}\right]^{1/3}$$

whereas if the sphere is loaded against an elastic/plastic half space the radius of the circle of contact is given by :

$$a = \left[\frac{N}{\pi H}\right]^{1/2}$$

a plot of log a against log N should,therefore,give a linear relationship,having a slope of 1/3 for elastic deformation or 1/2 for elastic/plastic deformation.

Graphs of log a V log N are shown in fig.3 for various film thicknesses.It can be seen that at higher loads, all surfaces gave slopes of 1/3, indicating elastic deformation.At lower loads,this relationship was maintained for thin films only. It has been shown in previous paper by the auther(3) that the rigidity of the system does not change with film thickness.

In the case of rolling of balls on a flat surface, if we consider λ to be the ratio between the tangential force F and the normal force N, then it is given :

$$\lambda = \frac{F}{N} = \frac{3}{16}\,\varepsilon\,\frac{a}{r} \qquad (1)$$

where ε is the elastic hysteresis loss coefficient which is constant and function of the elastic properties of the contacting materials(1).

The result of test for rolling of steel balls of different radii on flat steel surface is shown in fig.4.
The result shows that the value of ε for steel is constant and equals to 0.0064 .

The results of similer tests on steel surfaces covered by thin films of lead are shown in fig.5 where it shows that the value of $\frac{\lambda r}{a}$ does not change with film thickness .
When changing the normal load, results shown in fig.6, fig.7 indicate that $\frac{\lambda r}{a}$ decreases with increasing the normal load.
Assuming that equation(1) is applicable for surfaces covered by soft films using elastic hysteresis loss coefficient ε where

$$\varepsilon = A_f . N^{B_f} . \varepsilon_s \qquad (2)$$

where

ε_s is the elastic hysteresis loss coefficient of substrate material.
N is the normal load.
A_f, B_f are respectively, constant and exponent of the relationship, corresponding to film material.

Plotting log $\frac{\lambda r}{a}$ V log N for lead films is shown in fig.8 giving a linear relationship, from which we can get the values of the constant and exponent A and B to be as follows:

$A_1 = 4.5$ and $B_1 = -0.64$

Similer tests were made for silver films on steel,from which the values of constant and exponent were found to be :

$$A_{sil.} = 2.67 \quad \text{and} \quad B_{sil.} = -0.64$$

CONCLUSION

In the case of contact between a sphere and flat elastic surface covered by soft metallic film,the film behave elastically under the application of high values of normal force.

In case of free rolling of the ball,the film thickness has no effect on the rigidity of the system,and the energy loss coefficient,in this case,is found to be function of the elastic properties of the film and the substrate materials and the normal load applied.

NOMENCLATURE

r = Ball radius mm.

a = Contact radius um.

N = Normal Force.

H = Hardness.

E' = Constant where

$$\frac{1}{E'} = \frac{1-\nu_1^2}{E_1} + \frac{1-\nu_2^2}{E_2}$$

λ = Dimensionless value of the Rolling Friction Coefficient

$$= \frac{F}{N}$$

F = Frictional force.

ε = Elastic hysteresic loss coefficient.

REFERANCES

(1) Tabor, D., Proc. of the Royal Society, Series A, vol-229, 1955

(2) El-Sherbiny, M.G.D., and Halling, J. Wear, 40, p325(1976)

(3) El-Shafei, T.E.S., Arnell, R.D. and Halling, J. ASLE Trans. 1983,26 (4), 481-487.

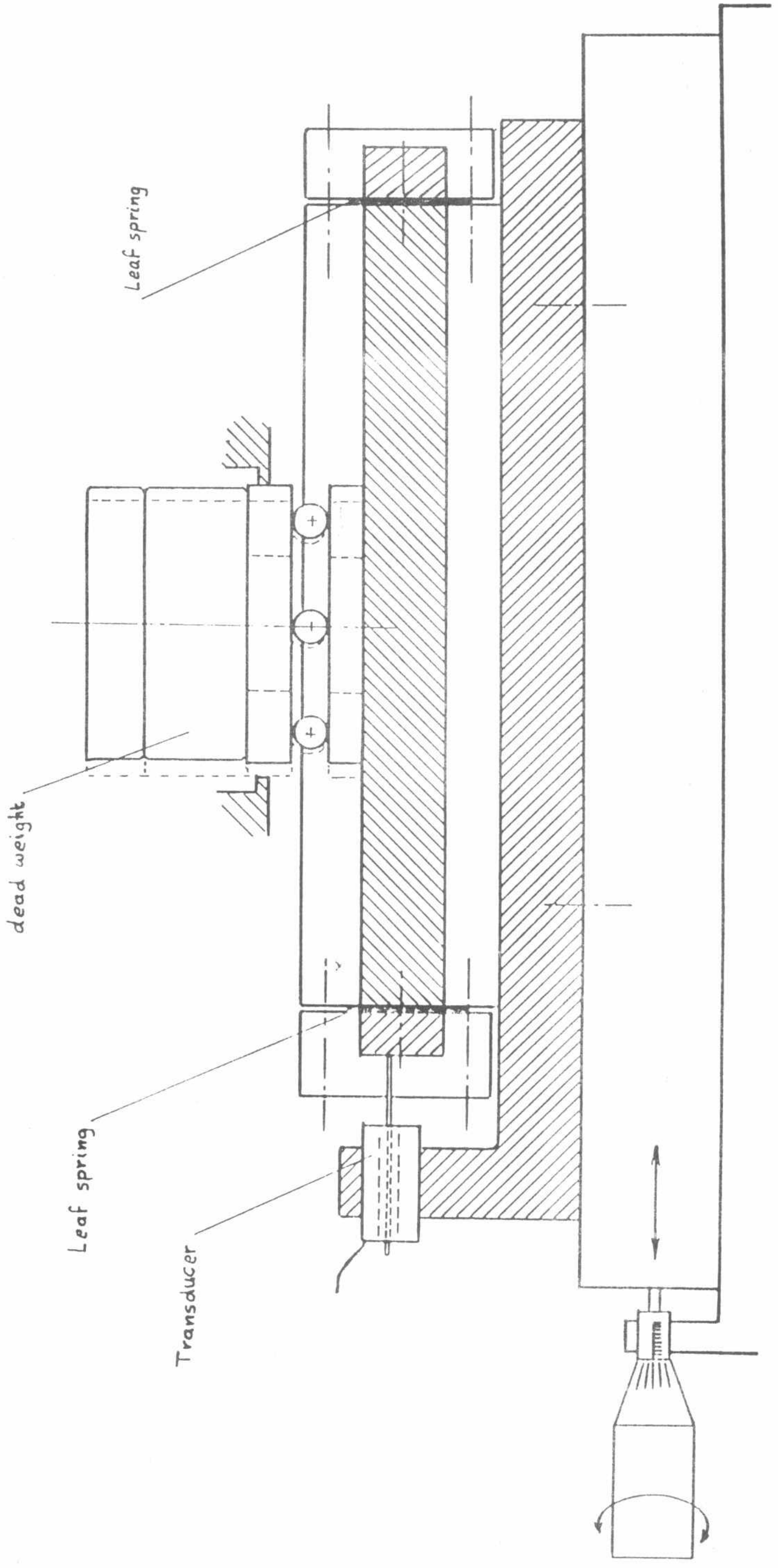

Figure (1) Measuring apparatus for rolling friction force in rectilinear motion

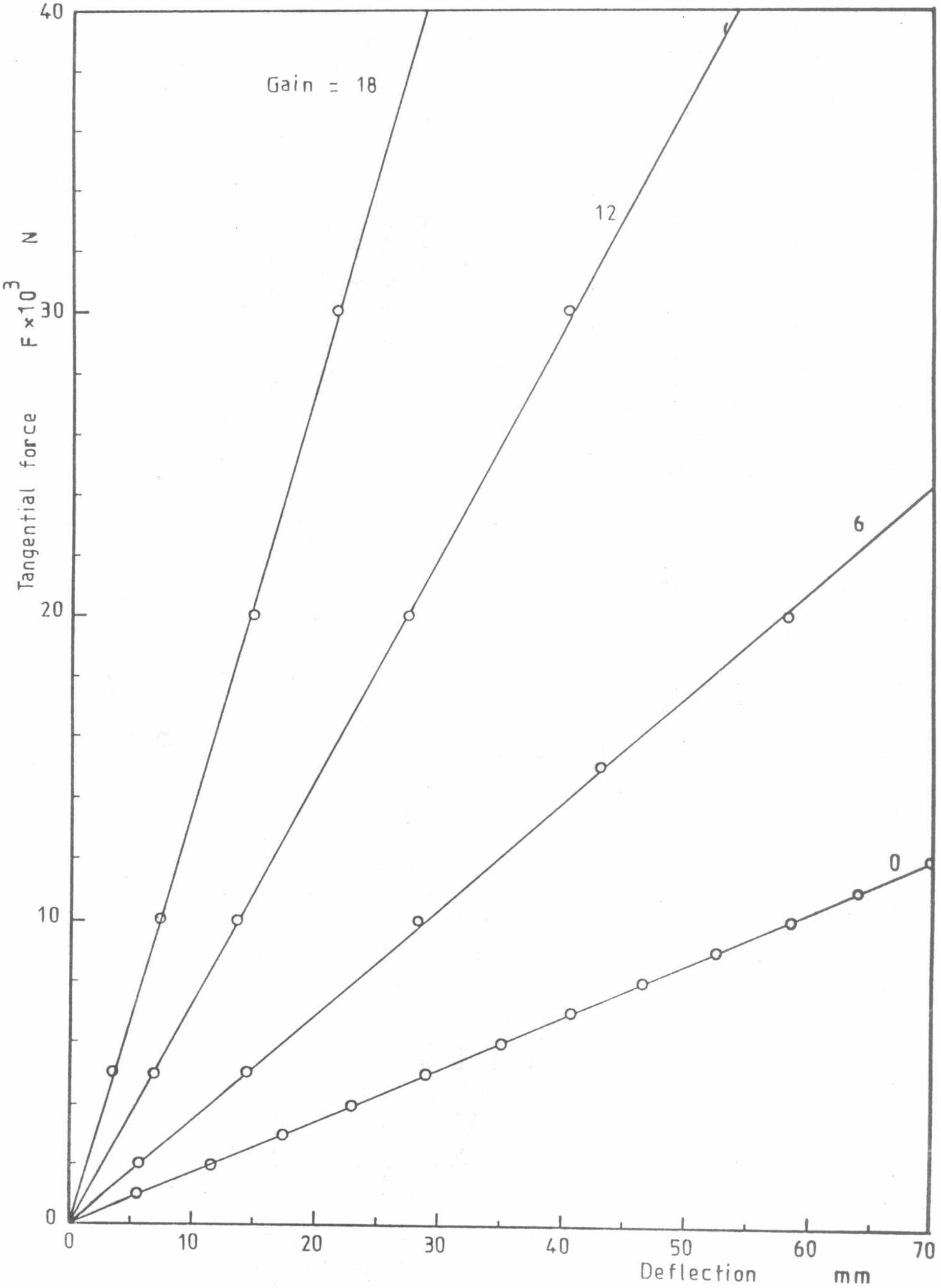

Figure (2) Calibration chart for rig at different amplifier gains

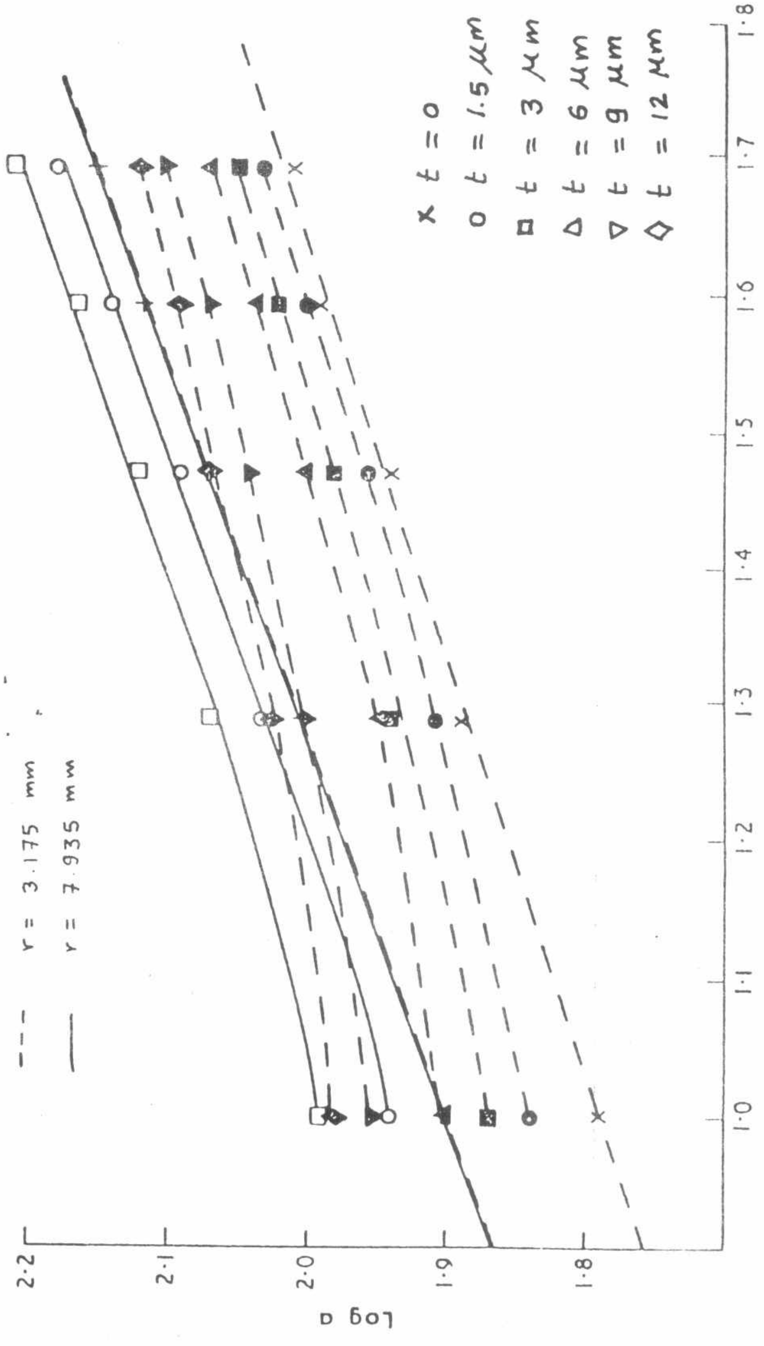
Log q
2·2
2·1
2·0
1·9
1·8
Log N
1·0
1·1
1·2
1·3
1·4
1·5
1·6
1·7
1·8
--- r = 3.175 mm
— r = 7.935 mm
× t = 0
○ t = 1.5 μm
□ t = 3 μm
△ t = 6 μm
▽ t = 9 μm
◇ t = 12 μm

Figure (3)

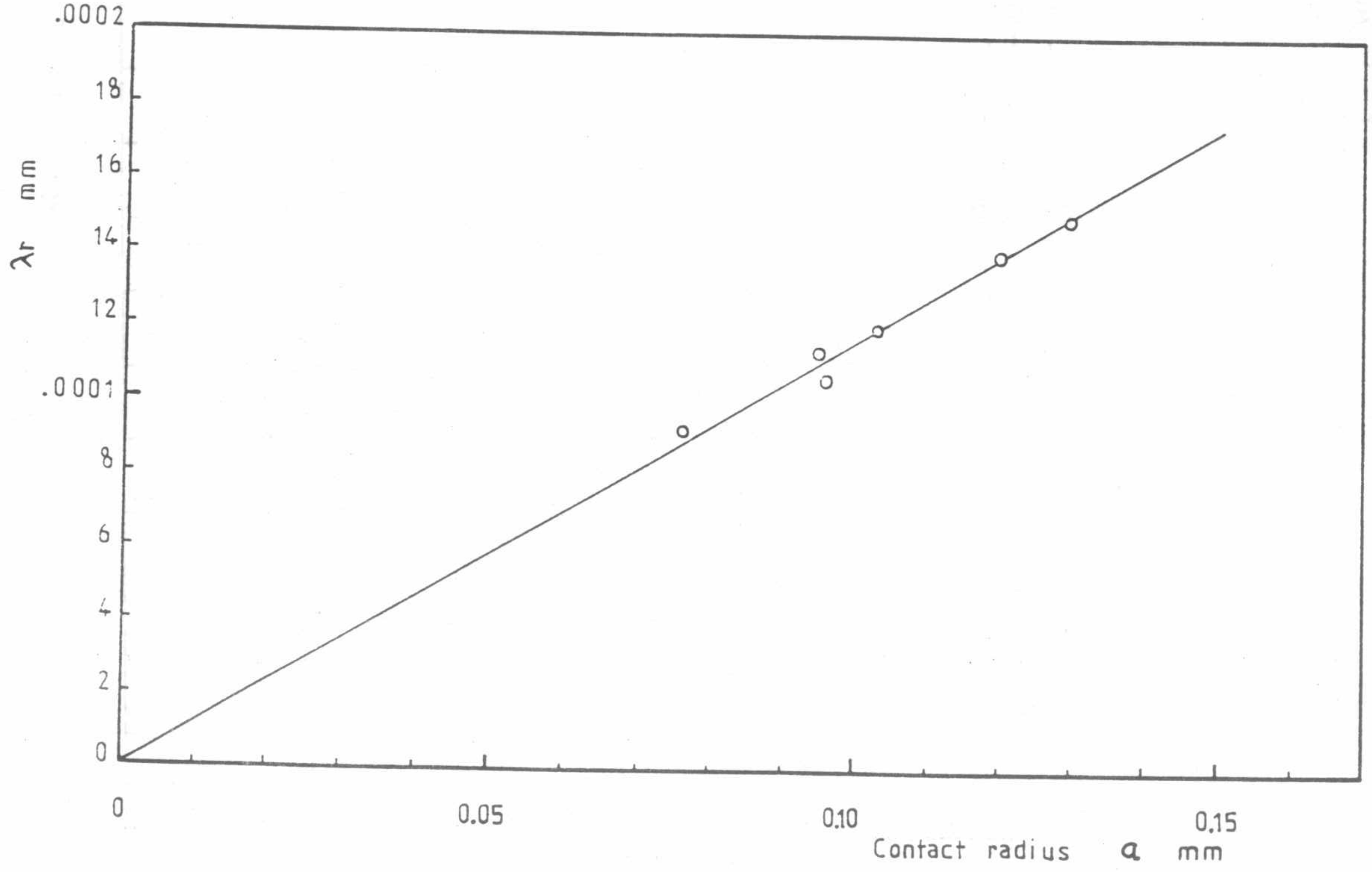

Figure (4) Relationship between λr and a for uncoated flat steel

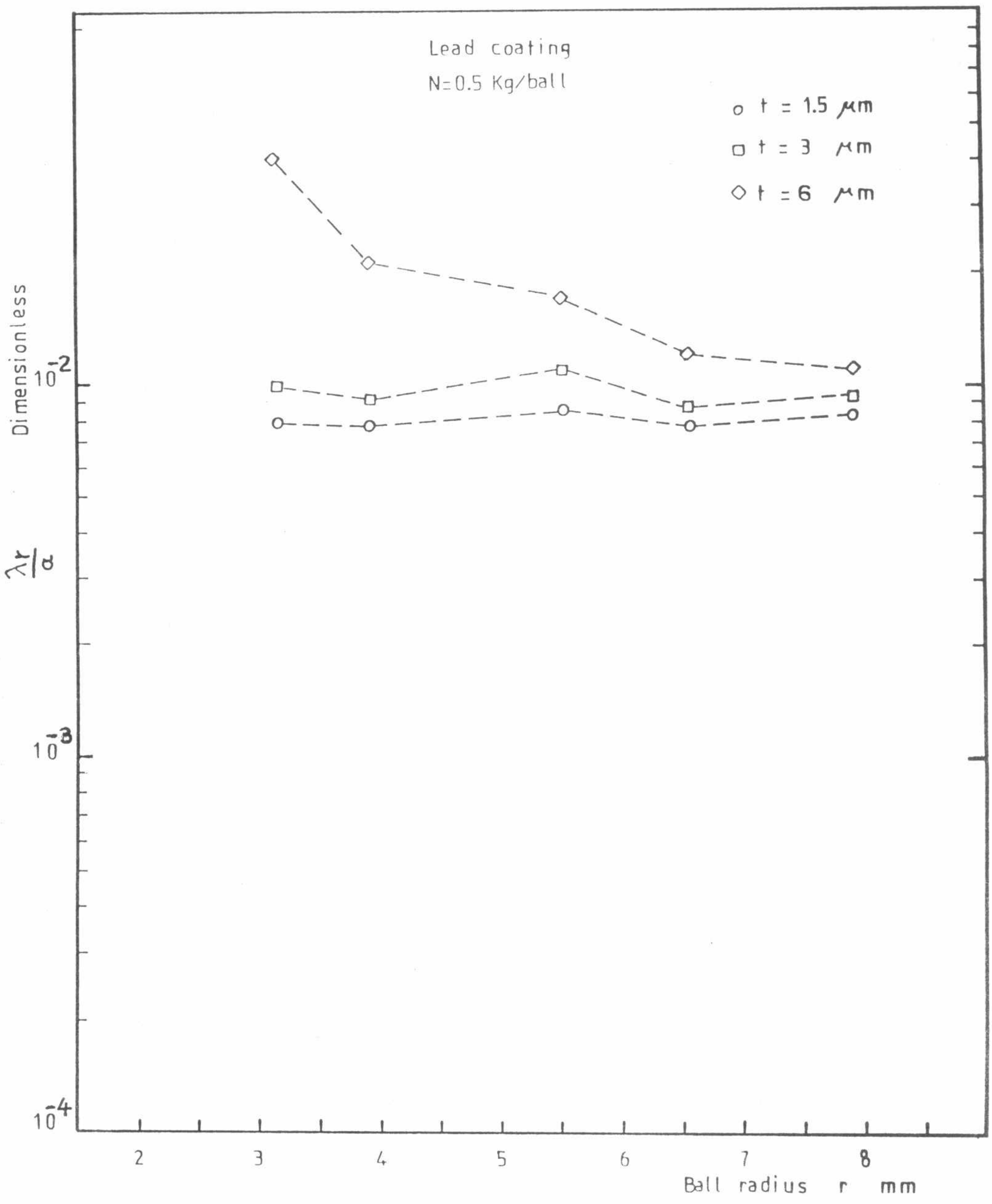

Figure (5) Ion plated lead on flat steel, N = 0.5 Kg/ball

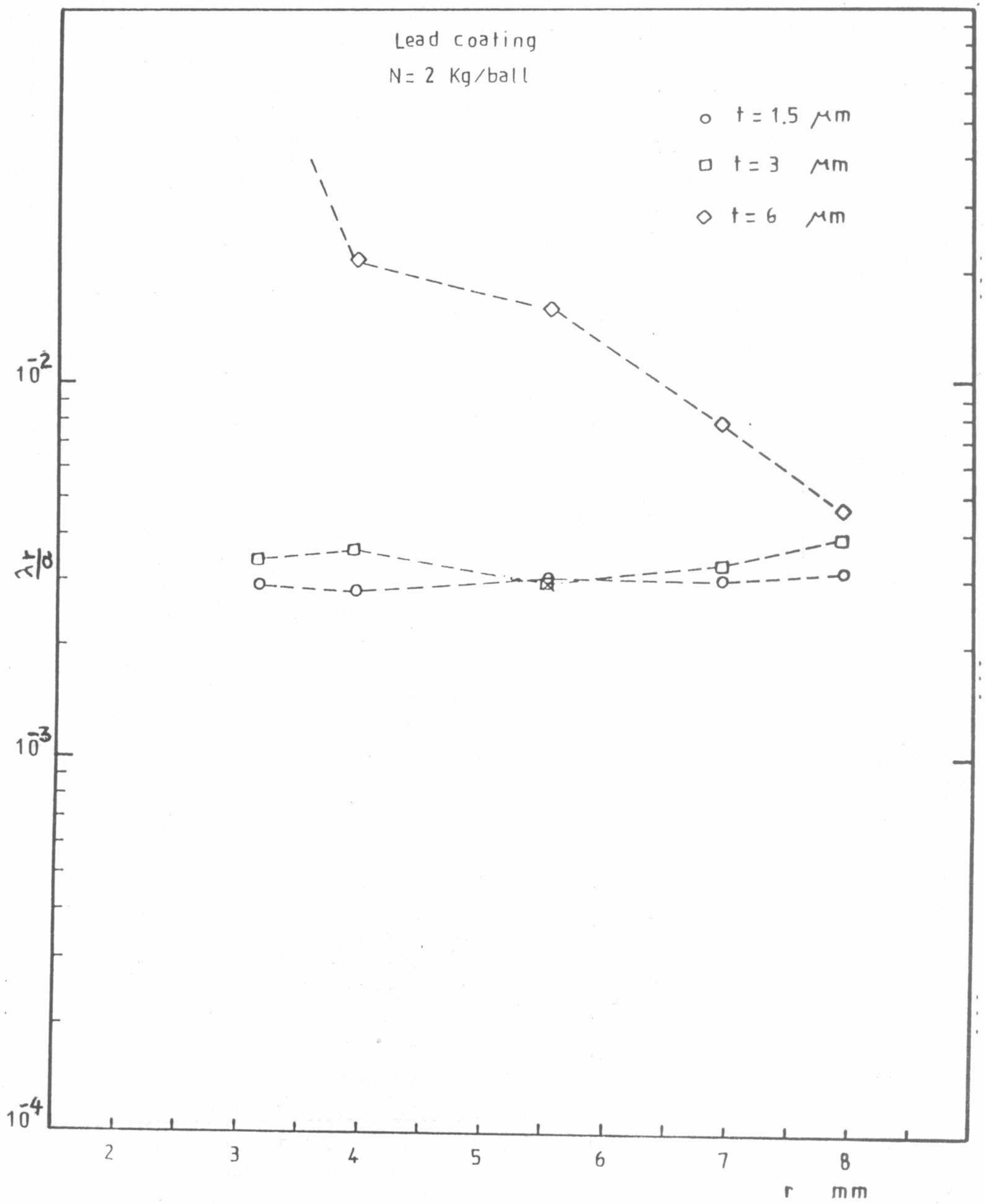

Figure (6) Ion plated lead on flat steel, N = 2 Kg/ball

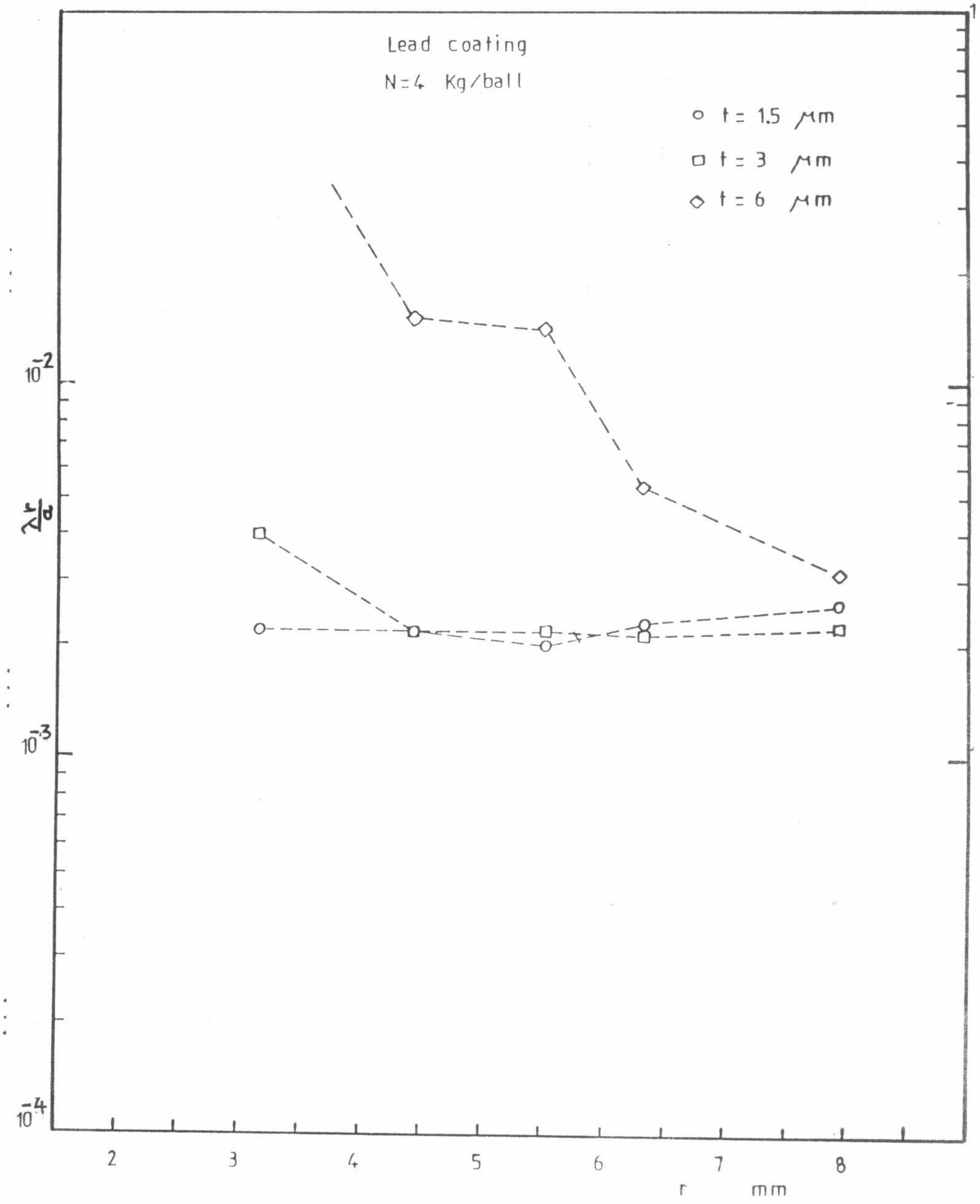

Figure (7) Ion plated lead on flat steel, N = 4 Kg/ball

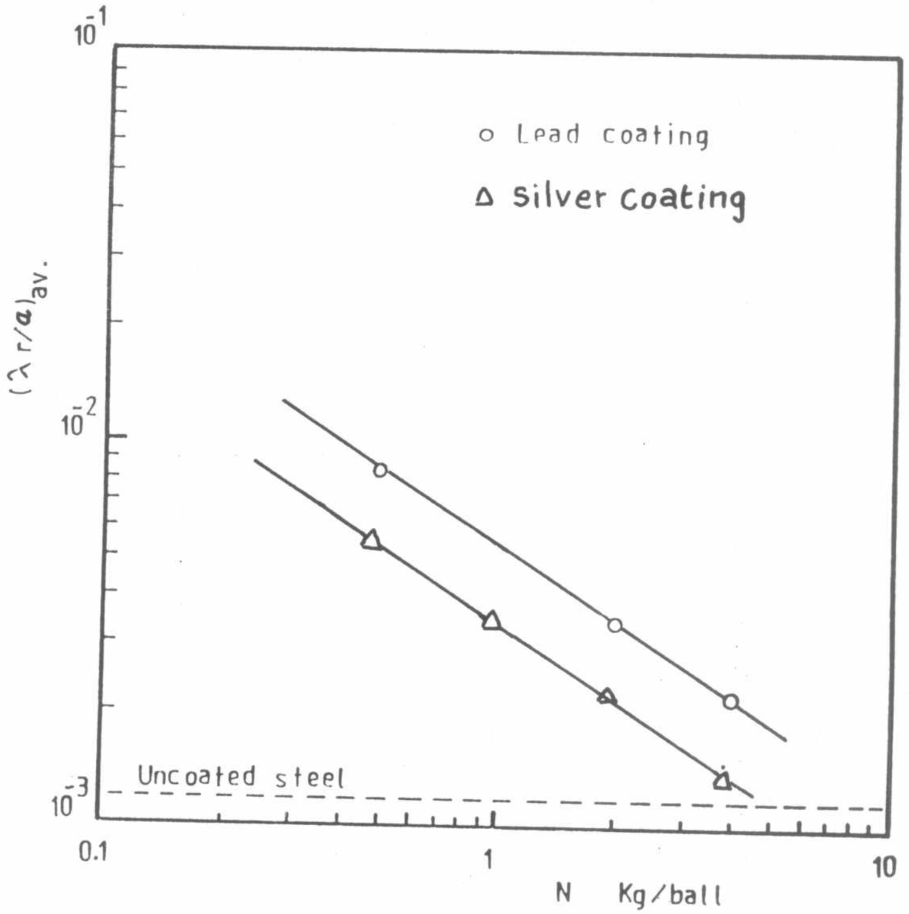

Figure (8) Elastic hysteresis loss coefficient for ion plated lead films on steel