Some Effects of Lubricants and Corrosion Inhibitors on Electrical Contacts

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ABSTRACT

Reported are the results of a study on the effect of lubricants and corrosion inhibitors on initial contact resistance monitored while normal force increases and while a wiping motion is made.

Contact materials were brass and phosphor bronze, electroplated gold and bright tin-lead. Petroleum jelly and a 6-ring PPE were used for lubrication. The contact configurations were flat against flat for brass and gold, and a hemisphere with a radius of 3.2 mm against flat for all materials.

The effect of lubricant on the contact resistance during static loading was strong for flat against flat, and weak for flat against hemisphere. The effect on the appearance of the wipe track was very strong, The effect of the lubricant during the wiping motion was an increase of about 0.5 m Ω for all materials except for brass, which showed more of an increase.

The inhibitors affected the contact resistance of brass and phosphor bronze significantly only while the load was applied. Additional lubrication on inhibited materials gave a lower resistance during the loading part of the measurement; however, resistance increased during the wiping motion.

INTRODUCTION

The design of electrical connectors involves creating a combination of materials, geometries, force and motion that reproducibly leads to a set of desired properties: contact properties, wear resistance and corrosion resistance. However, these properties are contradictory in the sense that good electrical contact implies intimate and abundant contact between mating faces, while good wear resistance is achieved by limiting the interaction between surfaces, and good corrosion resistance by limiting the access and effect of the atmosphere.

To achieve good initial contact, a high force and a sharp geometry, combined with a proper wiping motion, are desirable. This explains the results, found in field investigations, showing sharp geometries to be more reliable (high Hertz stress[1,2] or appstress[3]). However, these same parameters have a negative effect on wear properties, which necessitates a compromise. Especially in such high-density connectors as found in telecommunication applications where high insertion forces are a major problem, it is attractive to consider the use of low normal forces combined with sharp geometries and lubrication.

The effects of lubricants and inhibitors on electrical contacts have been investigated and reported by several authors. Using either an existing connector contact or a rider-to-flat configuration, they studied the effect of applying lubricant on wear and corrosion properties as well as the effect of dust. Strong improvements of wear and corrosion properties are mostly reported.[4-9]

Major problems associated with the application of lubricants and inhibitors are process control, cost and product responsibility: it is difficult to guarantee long-term product performance relying on the presence of basically removable lubricants.

Other problems are increased dust collection and loss of mechanical stability. The latter problem occurred in an application with a tin-plated edge connector. The lubricated interface showed relative motion and wear, whereas at equal rotational movement of the printed circuit board the unlubricated contacts did not move and wear.

This paper reports some measurements of the effect of lubricants and inhibitors on the initial contact resistance and the wiping effect on brass and phosphor bronze bare base metals and electroplated gold and tin-lead surface layers.

EXPERIMENTAL PROCEDURE

The instrument used is the DISC (Dutch Instrument for Support in Contact Physics), designed and built at the AMP European Development Centre. The basic setup is shown in Figure 1. The instrument has three moving slides, with the movement in X-direction manually driven and in Y- and Z-direction controlled by DC motor. Force is built up by moving the Z-slide downwards with one contact fixed to it while the other contact is mounted on top of a fourth slide, which is suspended from two compliant springs. The force is increased until a preset level is reached, then the vertical motion stops and the Y-drive makes a wiping motion of 1 mm. The speed was lower than 1 mm/s. The force was measured with a strain-gauge transducer. Contact resistance was measured using a four-wire arrangement, with a current of 20 mA and a maximum open circuit voltage of 50 mV. For the voltage measurement a Keithley 182 digital voltmeter was used. All functions were controlled with an HP data acquisition and computer system.

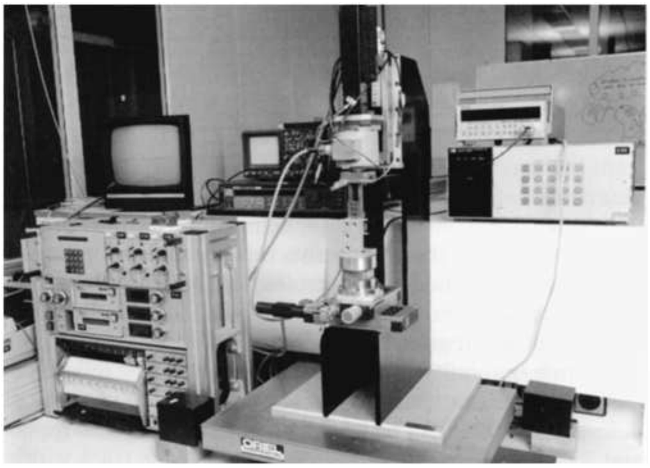


Figure 1. Measurement setup.

Two different shapes of contacts were used (see Figure 2): two cylinders with 10-mm diameter for the flat-to-flat configuration, of which the surfaces were ground and polished (Ra < 0.25 μm) and, for the hemisphere-to-flat configuration, a spherical contact with a radius of 3.2 mm and a flat coupon, both made of 0.4-mm-thick, rolled stock with a smooth surface finish (Ra = 0.1 μm).

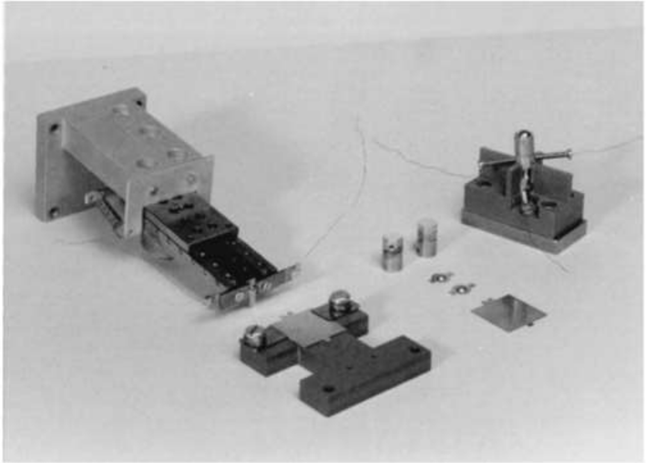


Figure 2. Electrodes and auxiliary fixtures. Cylinders were used for the flat-flat configuration, and the flat-plate and spherical contacts for the hemisphere-flat configuration.

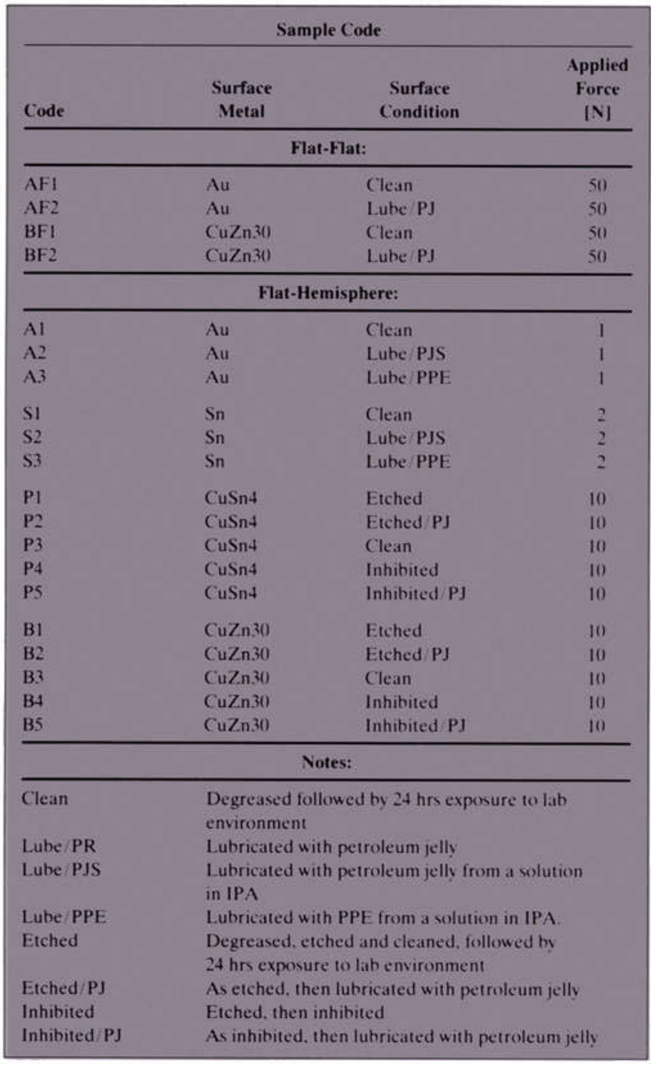
The gold-plated samples had a layer thickness of 1-μm gold over 1.25-μm nickel, the tin-lead (93-7) plated samples 3.5-μm tin-lead over phosphor bronze. Table 1 gives the sample identification.

Figure 3 shows the surface profile of hemisphere and flat as recorded with a Perthometer and a graph of the theoretical distance between ideally smooth circular and flat surfaces as a function of the distance to the point of contact. Comparing this with the surface roughness range of 0.3 μm (estimated average top-to-top value) shows that at low force the width of contact spot and wipe track area function of roughness range and contact radius rather than normal force. For gold, the contact radius of 3.2 mm and the force increasing up to 1 N, the size of individual, deformed spots increases rather than the global-spot size. At spot widths of 100 μm and larger, plastic yield in the top layer together with elastic stresses underneath govern the size of the contact region. Then the global spot size increases rather than the size of individual spots.

RESULTS AND DISCUSSION

As expected on gold-over-nickel-plated flat surfaces, very low resistances were measured at low forces (Figure 4). When lubricated with petroleum jelly 10 N normal force was built up before electrical contact was established. The resistance in the lubricated state stays higher by about 0.5 m Ω over the remainder of the curve.

Table 1. Sample identification.



Sample Code

Code	Surface Metal	Surface Condition	Applied Force [N]
Flat-Flat:			
AF1	Au	Clean	50
AF2	Au	Lube/PJ	50
BF1	CuZn30	Clean	50
BF2	CuZn30	Lube/PJ	50
Flat-Hemisphere:			
A1	Au	Clean	1
A2	Au	Lube/PJS	1
A3	Au	Lube/PPE	1
S1	Sn	Clean	2
S2	Sn	Lube/PJS	2
S3	Sn	Lube/PPE	2
P1	CuSn4	Etched	10
P2	CuSn4	Etched/PJ	10
P3	CuSn4	Clean	10
P4	CuSn4	Inhibited	10
P5	CuSn4	Inhibited/PJ	10
B1	CuZn30	Etched	10
B2	CuZn30	Etched/PJ	10
B3	CuZn30	Clean	10
B4	CuZn30	Inhibited	10
B5	CuZn30	Inhibited/PJ	10

Notes:

Clean	Degreased followed by 24 hrs exposure to lab environment
Lube/PR	Lubricated with petroleum jelly
Lube/PJS	Lubricated with petroleum jelly from a solution in IPA
Lube/PPE	Lubricated with PPE from a solution in IPA.
Etched	Degreased, etched and cleaned, followed by 24 hrs exposure to lab environment
Etched/PJ	As etched, then lubricated with petroleum jelly
Inhibited	Etched, then inhibited
Inhibited/PJ	As inhibited, then lubricated with petroleum jelly

Figure 5 shows similar curves for unplated brass surfaces. The resistance is quite high as could be expected with material taken from the warehouse and degreased only.

The force required to compress the lubricant to a film thin enough to enable conduction at 50 mV is again about 10 N. Reproducibility of this value of 10 N over a number of measurements was not very good: values anywhere between 5 and 30 N were measured. The difference in resistance of the lubricated contacts compared to clean contacts was much larger for brass than for gold. A possible explanation is that in the unlubricated state the crack patterns of the oxide-layers on opposing surfaces match, whereas in the lubricated state they may be formed independently, so that the conducting surface area is much smaller.

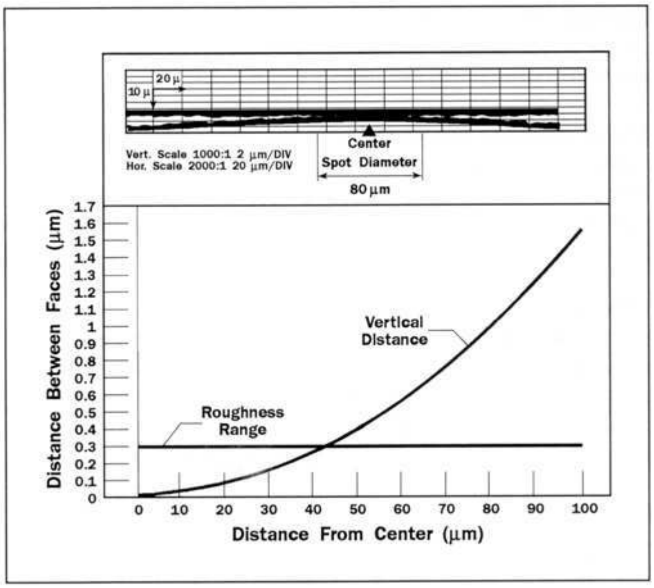


Figure 3. Plot of the distance between a circle with a radius of 3.2 mm and its tangent versus the distance along the tangent. The inset shows the recorded surface profiles of hemisphere and flat.

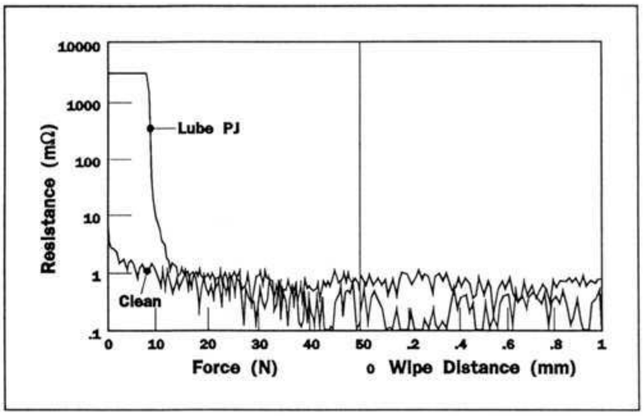


Figure 4. Load-wipe curves for gold with the flat-flat configuration, clean and lubricated with petroleum jelly.

For the gold-over-nickel-plated, hemisphere-to-flat configuration (figure 6), there is again a very small flat portion for the version lubricated with petroleum jelly. Overall, lubrication increased the resistance by about 0.5 m Ω in the flat portion of the curve as well as during the wiping motion. This can be explained by assuming that lubricant reduces the friction forces, shear stresses and the degree of surface deformation. This can be seen by comparing Figures 7a, 7b and 7c. There is only a slight difference in wipe track width, but a clear difference in the degree of surface deformation. The lubricated samples show less deformation and a slightly smaller wipe track.

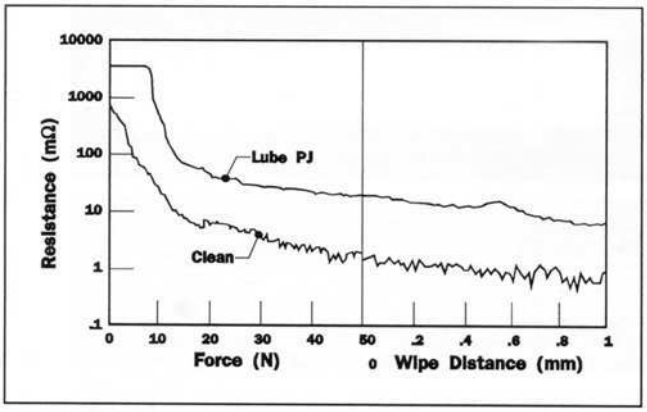


Figure 5. Load-wipe curves for brass with the flat-flat configuration, clean and lubricated with petroleum jelly.

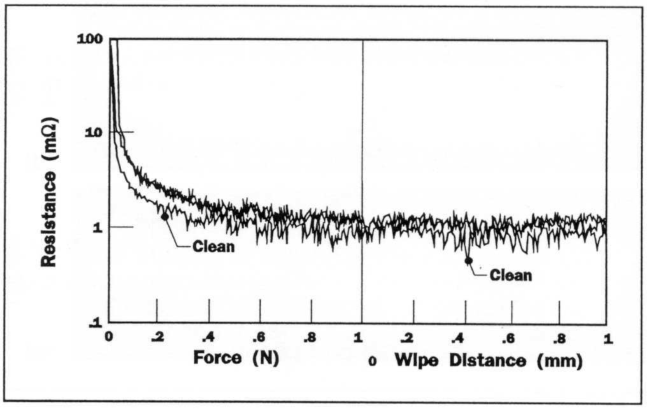


Figure 6. Load-wipe curve for gold with the hemisphere-flat configuration.

For tin-lead-plated, phosphor bronze samples (see Figure 8) the resistance in the flat part of the curve of the one lubricated with petroleum jelly was again about 0.5 m Ω higher than that of the clean as well as the PPE-lubricated sample. Also, the wipe track of the sample lubricated with petroleum jelly (Figure 9b) differs from the two others (Figures 9a and 9c). Actually, it appears to be hardly deformed at all. Thin oxide and/or lubricant layers affect the contact resistance only slightly. The width of the wipe track of the sample with petroleum jelly is about 120 **m** m and constant, the width of the other two tracks starts at about the same width but increases during the wiping motion to about 250 μ m. It is a nice example of prow formation and strong transfer of material, already during the first wipe. Seeing the difference in surface deformation, it is surprising that the difference in contact resistance during the wiping motion is so small.

For the unplated phosphor bronze contacts the width of the wipe track is large enough to be approximated by the Hertz theory for elastic deformation. Using a force of 10 N, a Young's modulus of 120 GPa, a radius of 3.2 mm and a Poisson ratio of 0.3 results in a calculated spot diameter of 140 μ m and a maximum stress of 940 MPa.

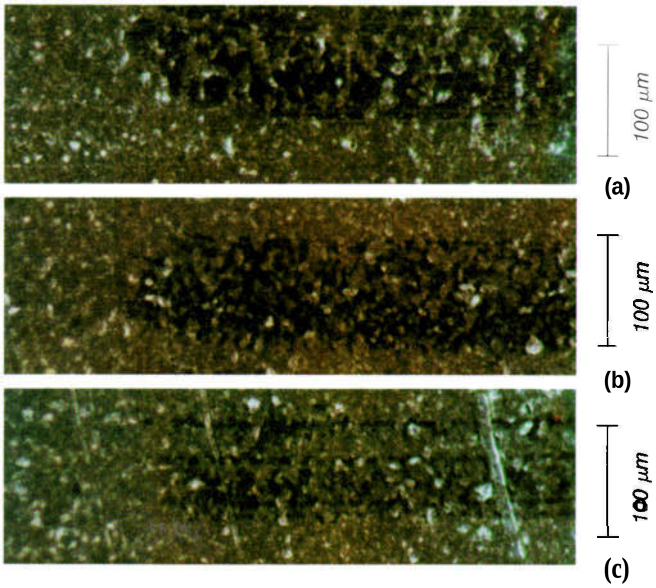


Figure 7. Wipe tracks for gold **a)** clean, **b)** lubricated with petroleum jelly, and c) lubricated with PPE.

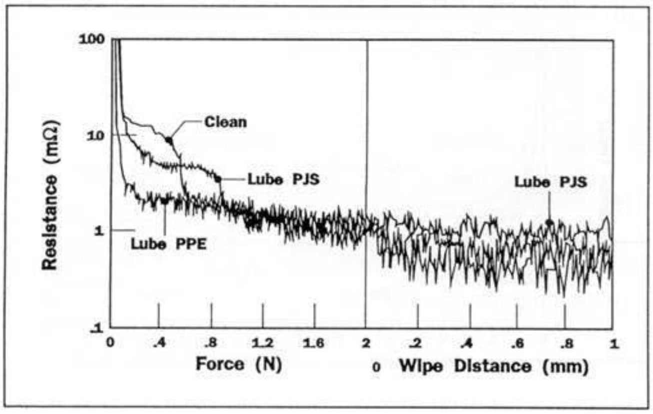


Figure 8, Load-wipe curves for tin-lead with the hemisphere-flat configuration.

As can be seen in Figure 10 the etched condition gave the lowest resistance in the load part of the curve, which was to be expected because of the removal of oxide. When lubricated with petroleum jelly the resistance was slightly higher and the wipe track less deformed (Figures lla and 1lb), to be attributed to lower friction forces. The clean sample was taken from the warehouse and degreased. Figure 1lC shows a smaller wipe track and signs of strong adhesion. Figure 14 shows a resistance similar to the etched/ lubricated condition in the load part of the curve; the wipe part, however, shows the lowest resistance of all versions. In Figure lld it can be seen that the wipe track after

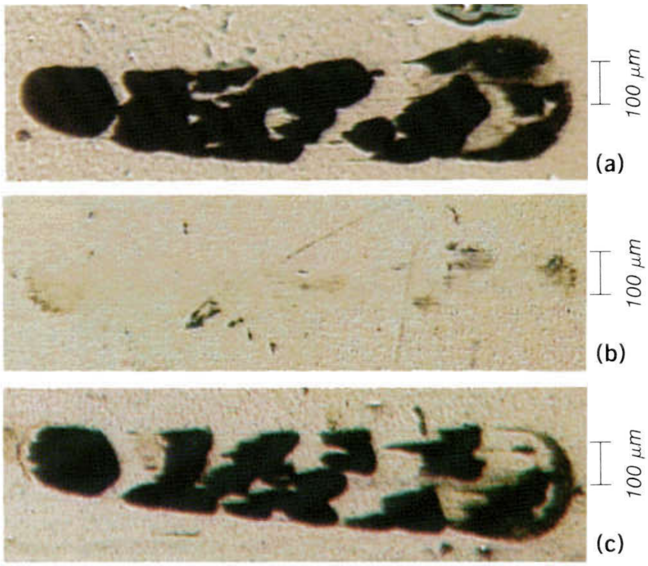


Figure 9. Wipe tracks for tin **a)** clean, **b)** lubricated with petroleum jelly, and c) lubricated with PPE.

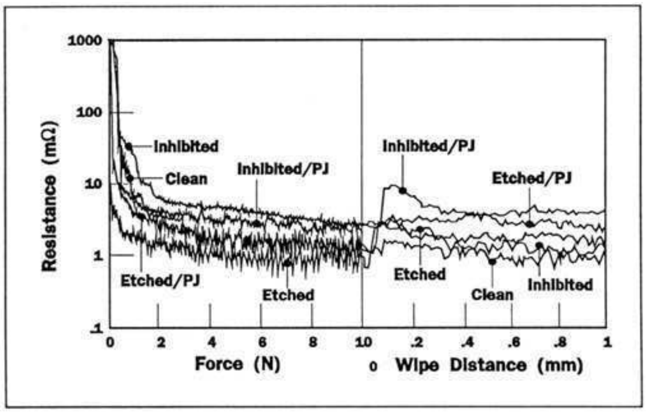


Figure 10. Load-wipe curves for phosphor bronze with the hemisphere-flat configuration.

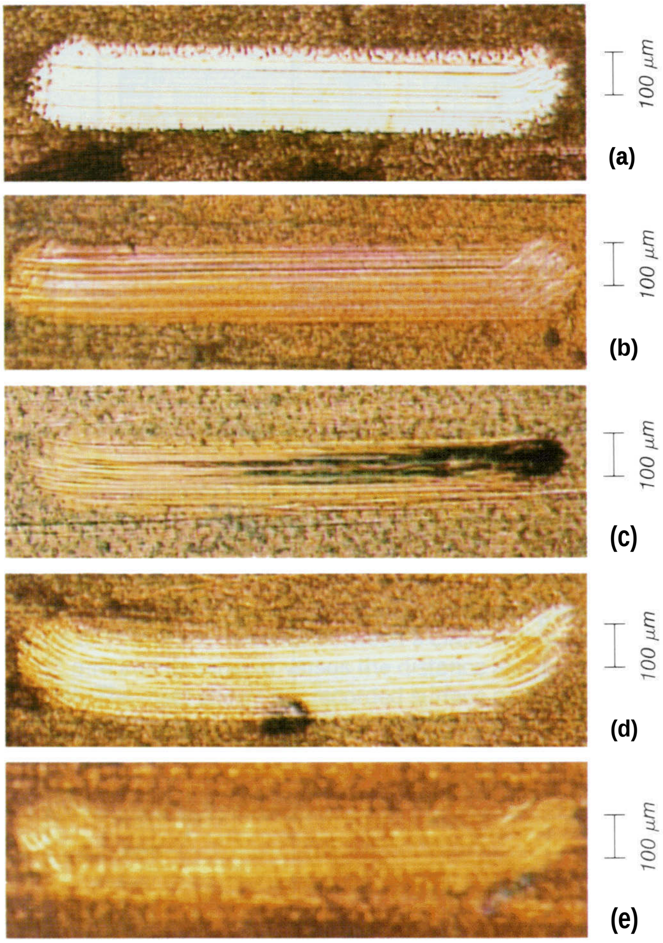


Figure 11. Wipe track for phosphor bronze **a)** etched, **b)** etched and lubricated with petroleum jelly, **c)** clean, **d)** inhibited, **e)** inhibited and lubricated with petroleum jelly.

inhibition is much less deformed. The resistance in the load part is about 1.5 m Ω higher. This difference is reduced to 0.5 μΩ after wipe. Figure lle shows what lubrication does to an inhibited surface: the wipe track is only vaguely visible and the resistance in the load part of the curve is, strangely enough, lower than that of the inhibited surface. Also the resistance shows some sharp increases, suggesting that the cracked oxide patterns sometimes move relative to each other. During the wiping motion the inhibited/lubricated sample has the highest resistance, about 3.5 m Ω higher than the clean sample. Figure 12 shows that for brass the etched condition had the lowest resistance curve, both during loading and wiping. The results on the etched/lubricated samples deviate from the etched condition only at very low force and during the wipe. The clean sample, as received from the warehouse and degreased, only shows a high resistance in the load part of the curve, 50 m Ω at 10 N. During the wipe resistance is reduced to 2 m Ω; in Figure 13 strong adhesive wear can be observed at the end of the track. The inhibited curve shows very high resistance at low force and a clear overall increase compared to the etched condition. Resistance at the end of the wipe is 3 m Ω. As for phosphor bronze, the inhibited/lubricated samples have a lower resistance and some sharp peaks in the loading zone of the curve. In the wipe zone this sample has the highest resistance of all, 6 m Ω. For brass the wipe track width is about the same as for phosphor bronze (Figure 13a). The wipe tracks of both inhibited samples are dim (Figures 13d and 13e), and the increase of resistance is again small considering the difference in appearance.

The following calculation illustrates that this effect is partly due to the hyperbolic nature of resistance-to-spot-diameter relation, and partly due to the fact that a large number of very small spots, even when covered by a film, conduct current very effectively.

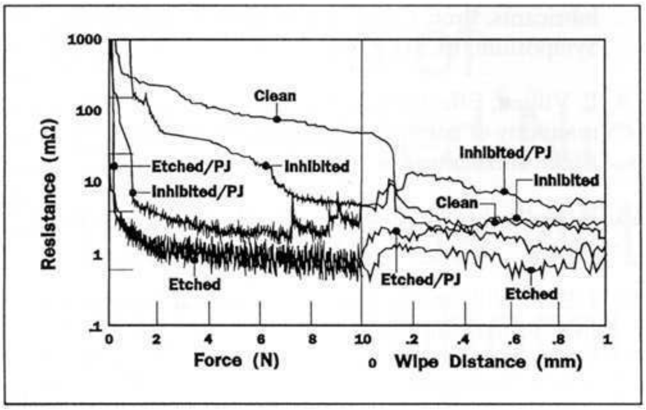


Figure 12. Load-wipe curves for brass with the hemisphere-flat configuration.

Ragnar Helm derived formulas[10-12] for the constriction resistance of one circular spot:

$$R = \frac{\rho}{2a} \tag{1}$$

as well as for n microspots with radius a spread out over a macrospot with radius α:

$$R = \rho\left(\frac{1}{2na} + \frac{1}{2\alpha}\right) \tag{2}$$

wherein:

R = constriction resistance [m Ω]
ρ = resistivity [m Ω • µ,m]
n = number of single spots
a = radius of a single spot [µm]
α = radius of cluster of spots [µ m]

Let us take the case of brass as an example and first idealize the constriction to one solid spot. For brass p is about 70 m Ω µ m, and the spot size is 160 µ m (Figure 13b). The resistance calculated with formula (1) is then 0.44 m Ω. The lowest readings in Figure 13a are pretty well in agreement with this result. Now consider the reading of 6 m Ω from the inhibited/lubricated sample. Calculated as if it were one spot, the spot diameter is 12 µ m. The reduction in surface area is a factor 180. Looking at the wipe track of Figure 13e, it is more realistic to suppose that we have many spots distributed over a cluster with a radius of 80 µ m. With R=6 m Ω formula (2) yields 2na = 12.6 m Ω As a model we can think of 10 spots with a diameter 1.26µ m each, or even 100 spots with diameter 0.126 µ m. Of course we should not forget that these spots are covered by a non-conducting film. The effect of such film on the calculation is that for R=6, M Ω , the product 2na will be larger than previous calculations indicate.

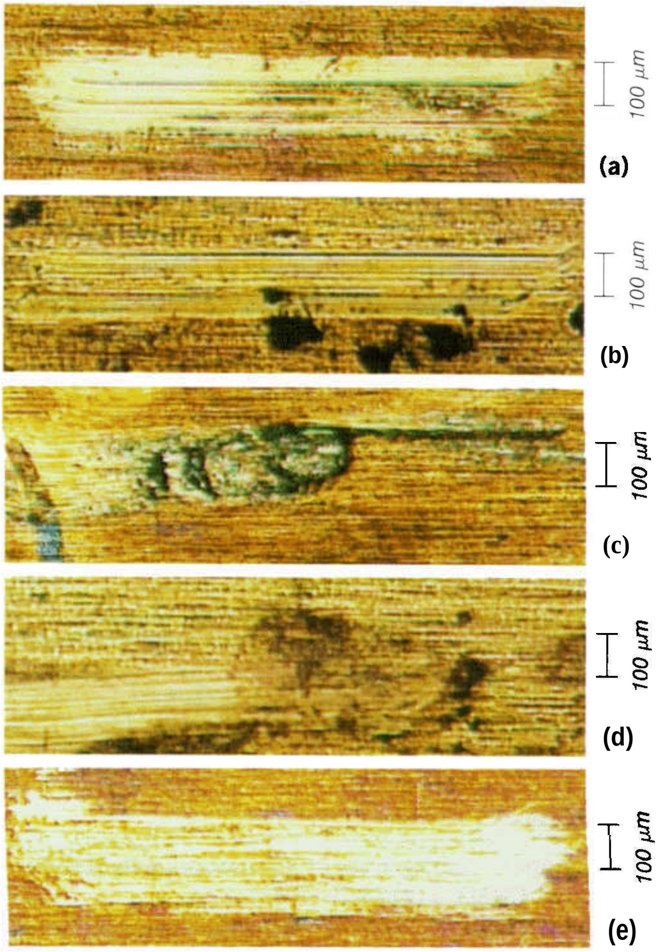


Figure 13. Wipe track for brass a) etched, b) etched and lubricated with petroleum jelly, c) clean, d) inhibited, e) inhibited and lubricated with petroleum jelly.

CONCLUSIONS

For gold and tin plated surfaces, lubrication causes large changes in the morphology of the wipe track, but only a small increase in contact resistance.

For brass and phosphor bronze, inhibition as well as lubrication cause big changes in the morphology of the wipe track and increases of the contact resistance of up to 6m Ω

Lubrication reduces the effect of a wiping motion, particularly after inhibition or in the presence of other non-conducting layers.

The contact pressure for the lubricated hemisphere-to-flat contact is high enough to realize a low contact resistance at very low force.

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