INVITED PAPER Special Section on Recent Development of Electro-Mechanical Devices (IS-EMD2008)

Fretting in Electrical/Electronic Connections: A Review

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SUMMARY Basic features of fretting and factors affecting its deleterious effects on the performance of electrical/electronic connection were reviewed. It was shown that although the fretting cannot be eliminated completely, its deleterious effects can be substantially reduced by lubrication and also connection design.
key words: *fretting, contact load, frequency, temperature, slip amplitude*

1. Introduction

In recent years, there has been considerable interest in investigating the effects of fretting, a common problem of significant practical importance that can affect a wide range of electrical equipment incurring costly component replacement and expensive equipment downtime.

Fretting is defined as accelerated surface damage occurring at the interface of contacting materials subjected to small oscillatory movements. Two basic conditions for fretting to occur are relative movement or slip and amplitude of motion sufficient to cause the damage. Experimental evidence shows that amplitudes of the order of 10^{-8} cm (<100 nm) are sufficient to produce fretting [1]. Thus, from a practical standpoint, there appears to be no minimum surface slip amplitude below which fretting will not occur.

Although there may be argument as to the upper limit which may still qualify the process as fretting, there is no doubt that in situations where micro-slip prevails, i.e. where slip occurs over only part of the contacting surface, the movement is entirely characteristic of fretting. This problem has been studied by Mindlin [2] who has shown that the minimum slip amplitude for fretting to occur is given by

$$\delta = \frac{[3(2-\upsilon)(1+\upsilon)]}{8Ea}\mu P\left[1-\left(1-\frac{T}{\mu P}\right)^{2/3}\right] \qquad (1)$$

where a is the diameter of the contact outer radius, E is the Young modulus, ν is Poisson's ratio, P is the normal force, μ is the static coefficient of friction between the contact surfaces and T is the tangential force ($T < \mu P$).

Figure 1 illustrates a classical example of micro-slip occurring between a steel ball and flat, where the ball experiences an oscillating tangential force. It is generally agreed that fretting damage increases with increasing amplitude and that the mechanical properties of the contacting materials significantly affect the threshold value for fretting to occur [2].

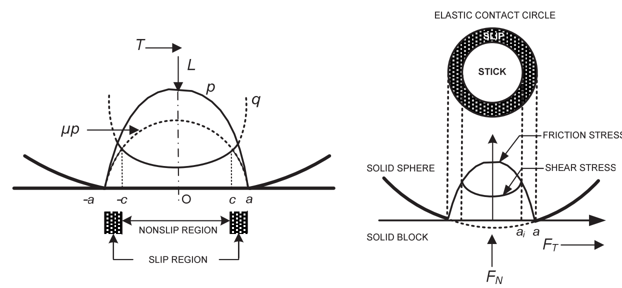

Fig. 1 Micro-slip occurring between a steel ball and flat, where the ball experiences oscillating tangential force.

2. Mechanisms of Fretting

A study of the literature reveals that complex physico-mechanical processes occur during fretting in the contact zone and that a single mechanism is unlikely to be responsible for the observed surface damage. It is therefore of interest to briefly review the principal theories regarding the mechanisms of fretting.

Although the adverse effects of fretting were observed as early as 1911 [3], at the contact surfaces closely fitting machine elements subjected to vibration and correctly diagnosed as mechanical in origin, the phenomenon was given little attention until 1927 when Tomlinson [4] coined the term "fretting corrosion" to cover this form of surface damage. This definition includes fretting wear, fretting fatigue, and fretting corrosion. Tomlinson suggested that fretting corrosion is caused by molecular attrition is not influenced by the normal load because, according to him, molecular attrition is independent of external forces.

Since then, numerous theories, mechanisms and models have been put forward to describe the mechanisms of fretting specifically with regard to the relative importance of the processes involved. However, despite the significant progress that has been made in our understanding of the fretting phenomena in general, and electrical contacts in particular, there is still no complete unanimity on the mechanisms of fretting. A comprehensive review of the theories, mechanisms and models is given elsewhere [5].

Manuscript received December 10, 2008.
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DOI: 10.1587/transele.E92.C.982

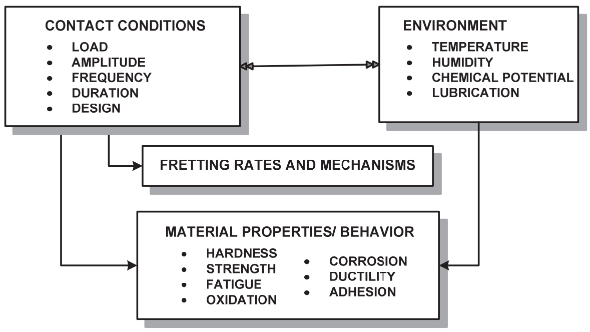

Fig. 2 Schematic representation of the factors affecting fretting.

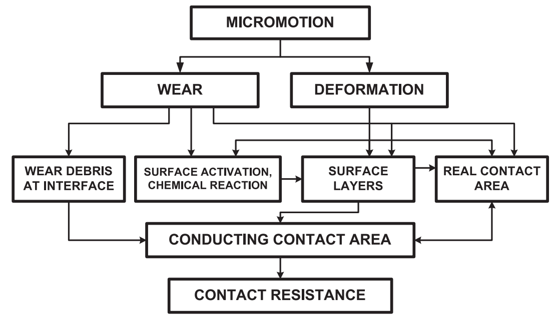

Fig. 3 Influence of micromotion on nominally stationary electrical contact reliability.

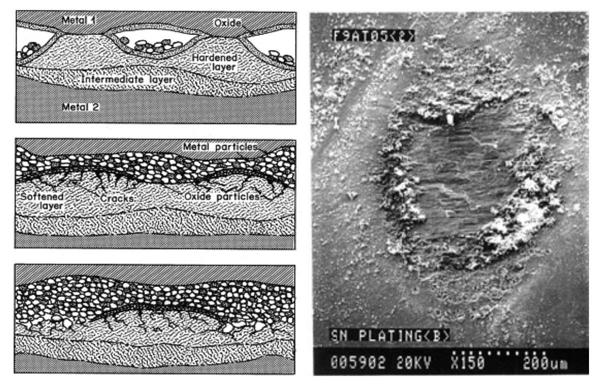

Fig. 4 Schematic of evolution of fretting damage in electrical contacts and a SEM image of a typical fretting wear damage of the contact zone.

3. Factors Affecting Fretting

The nature of fretting depends on a large number of variables. Many theories have been proposed to account for the effects observed but no unified model for the process has yet emerged and no one theory has yet been established as correct to the exclusion of any other. Detailed accounts of fretting and fretting corrosion have been given by Waterhouse [6] and Hurricks [7].

Factors known to affect fretting are indicated in Fig. 2. These factors may interact with one another and influence both the nature and the extent of fretting damage. For example, under certain conditions, the effects of environment may be excluded from the contact area and, hence, will have no strong influence on fretting. On the other hand, under different contact conditions the same environment may have ready access to the contact zone and have a strong influence.

4. Fretting in Electrical/Electronic Contacts

A significant issue for electrical/electronic contacts is their normal and tangential microdisplacements under fretting conditions causing a number of tribological problems. The microdisplacements induce the deformation and wear of the contact surfaces leading to surface activation, corrosion, formation of wear particles and contaminations on contact spots, and, finally, current passage breakdown (Fig. 3).

An important feature of the moving electrical contacts is inevitable interrelation of frictional and electrical processes in their operation, which changes the contact quality. This specific feature is taken into account in requirements to contact materials, coatings, lubricants, and contact design. The contact areas in moving electrical contacts, through which the current passes, coincide, at least, partially with deformation spots. Therefore, the interrelation of the friction and electrical processes is governed by the state of the interface and by behavior of boundary films.

Although contact resistance was used to monitor the development of fretting damage in steel specimens as long ago as 1956 [8], it was only eight years later that Fairweather et al. [9] revealed how fretting can cause considerable instability and serious degradation of telephone relays and switches. Its effect, however, was not widely recognized as a serious factor in the degradation of electrical connections until 1974, when Bock and Whitley [10] clearly demonstrated its importance. Since then, systematic studies of electronic and automotive connector systems and reports on in-service failures have established that fretting is one of the major contact deterioration mechanisms in dry connections. A number of models were proposed the effects of fretting on contact resistance. A detailed account of these efforts is given in [5].

The sequence of events depicting the initiation and spreading of fretting damage is electrical contacts and the SEM image of the fretting damage in contact zone of tin-plated contact are shown in Fig. 4. The effect of fretting on the contact resistance of different contact materials is shown in Fig. 5 [5].

The required oscillatory movement of the contacting members can be produced by mechanical vibrations, differential thermal expansion of the contacting metals, load relaxation, and also, by junction heating as the power is switched on and off. It is generally accepted that fretting is concerned with slip amplitudes not greater than 125 μm. Since this movement is of limited amplitude, it is ineffective in cleaning away the wear debris and accumulating oxides, and a highly localized, thick insulating layer is formed in the contact zone, leading to a dramatic increase in contact resistance and, subsequently, to virtual open circuits.

The characteristic features of the fretting damage observed in contact zones are melting/arcing, abrasion, adhesion and delamination wear. Examples of these types of damage are shown in Fig. 6.

In the case of power connectors, however, very little published information of failures due to fretting is available, for two main reasons. First, there is general lack of awareness of fretting as it affects power connections. This is not surprising; since fretting is time-related processes causing an appreciable effect only after a long period of time as a result of the accumulation of wear debris and oxides in the contact zone. Second, the effects of fretting, particularly in the early stages, are not readily recognizable because failure of a power connection is usually associated with destruction of the contact zone by arcing and melting. This makes identification of the fretting products, namely wear debris and oxides accumulated at the interface between contacting members, quite difficult.

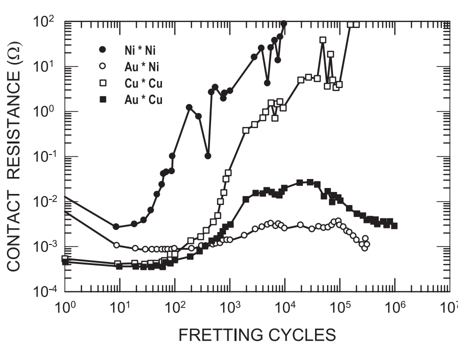

Fig. 5 Effect of fretting on the contact resistance of different contact plating materials [11].

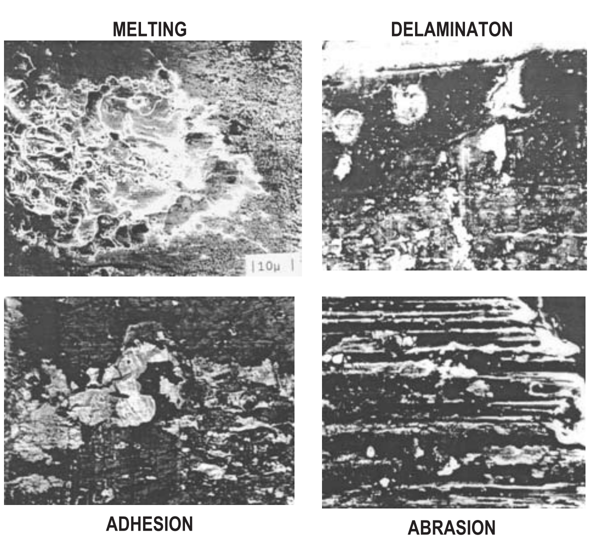

Fig. 6 SEM micrographs of the contact zones illustrating the various types of damage caused by the fretting action.

5. Factors Affecting Fretting

5.1 Contact Load

Contact load exert significant influence on the contact resistance under fretting conditions. The effect is manifested by significant suppression of the deleterious effect of fretting with increasing load [12], [13]. This is illustrated in Fig. 7 showing the contact resistance of aluminum wire fretting against tin-plated copper at 1 N and 10 N contact loads [5].

As it can be seen, over the entire range of fretting time (cycling) the contact resistance at 10 N is practically unaffected by the fretting action whereas the contact resistance at 1 N is characterized by large fluctuations and eventually an open circuit.

At low contact loads (1 N) when a contact is made, surface asperities of a harder material penetrate the natural oxide films, thereby establishing localized metallic contacts and, thus, conducting paths. Displacement of the contact interface during fretting shear these metallic bridges, resulting in the formation of the first wear products, a fraction of which will oxidize with the greater portion remaining as metallic particles (burnishing effect), thus, a good metallic contact between contacting surfaces is established as manifested by decreasing contact resistance.

Prolonged exposure to the fatigue-oxidation process, metallic layers in the contact zones soften and progressively separate. The contact zone now consists of a thick insulating layer containing oxides and wear debris, and any remaining metallic contact is lost, causing a sharp increase in the contact resistance.

The cyclic nature of the latter is due to the temporary rupture of the insulating layer and the appearance of localized metallic contacts and conducting paths. Subsequent wiping and accelerated oxidation due to the high current density will rapidly eliminate these conducting spots and the contact resistance will rise sharply. The sequence of events depicting the development of fretting damage in the contact zone at 1 N contact load is illustrated in Fig. 8(A).

At higher contact loads, contact resistance remains relatively stable and fluctuation-free and gradually increases as the fretting action proceeds. This is because when a contact is made, the asperities rupture the oxide and be-

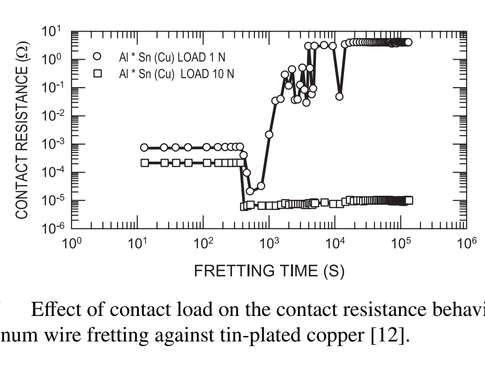

Fig. 7 Effect of contact load on the contact resistance behaviour of aluminum wire fretting against tin-plated copper [12].

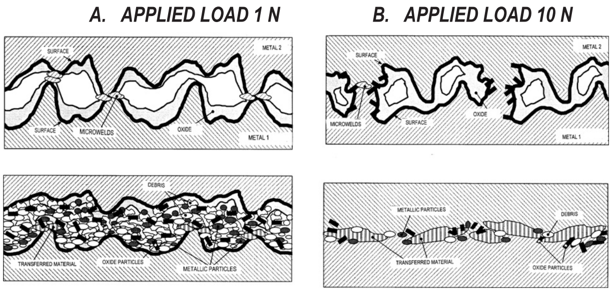

Fig. 8 The sequence of events depicting development of fretting damage in the contact zone of a connection between two different conductor and/or contact materials at 1 N and 10 N load.

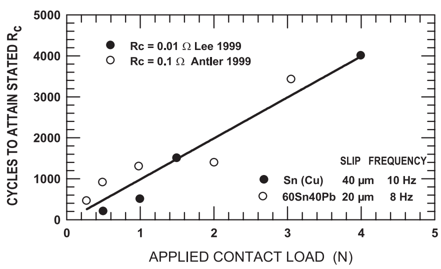

Fig. 9 Number of fretting cycles in tin-plated and 60Sn40Pb vs 60Sn40Pb contacts required to attain 0.01 and 1 Ω respectively as a function of contact load.

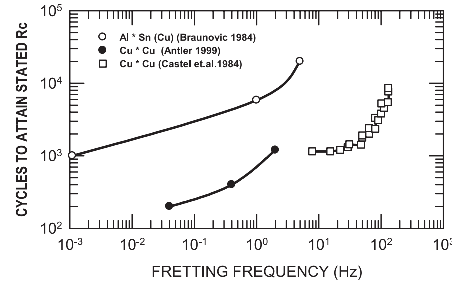

Fig. 10 Number of fretting cycles in Cu-Cu [15], [16] and Al-Sn plated copper [17] contacts required to attain a predetermined level of contact resistance as a function of fretting frequency.

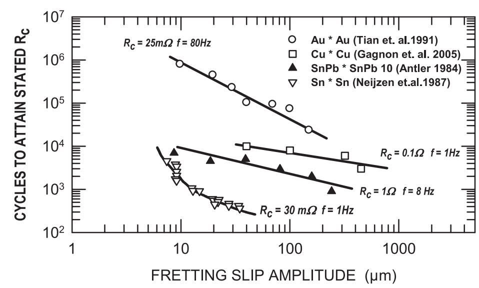

Fig. 11 Number of fretting cycles required to attain predetermined contact resistance level as a function of fretting slip amplitude [14], [17]–[19].

come practically embedded in the contacting surfaces under high contact pressure, thus forming a large number of strong adhesive bonds (micro-welds). The ruptured oxide film is trapped in the surface pits and virtually seal off the contact zone. When fretting motion is initiated these bonds are broken and primary wear products, composed almost entirely of metallic particles, will be formed. Since the contact zones are practically sealed-off from the environment, oxidation of these wear products is minimal. The sequence of events depicting the development of fretting damage in the contact zones of aluminum-to-copper connections at 10 N contact load is shown in Fig. 8(B).

Higher loads only delay the onset of fretting damage, since the prolonged fretting action causes eventually fretting fatigue and fracture of the surface layers. Subsequent formation of thick insulating layer that higher contact loads would not be able to break through results in a sharp increase of the contact resistance as shown in Fig. 7. The observed linear relationship between the numbers of fretting cycles required to attain the stated contact resistance values as seen in Fig. 9 is fortuitous and in no way implies that for different loads and different contact configuration this relationship would hold.

5.2 Frequency of Motion

Since fretting is rate-dependent phenomenon, the contact resistance will be affected by the frequency of oscillations. The results in Fig. 10 show the variation of the number of fretting cycles required to attain a predetermined contact resistance value as a function of the oscillating frequency.

The observed linear relationship between the numbers of fretting cycles required to attain the stated contact resistance values is fortuitous and in no way implies that for different loads and different contact configuration this relationship would hold.

The observed effect of frequency can be explained in terms of oxidation factor of fretting. Since oxidation is time dependent, at lower frequencies for a longer time the contact zone will be exposed by fretting to oxidation as a result of which an increasing number of conducting spots in the contact zone will be closed, thus increasing the contact resistance.

5.3 Slip Amplitude

The effects of fretting slip amplitude at different frequencies and for different combinations of contact materials is shown in Fig. 11. These depict the number of fretting cycles required to attain a predetermined contact resistance levels as a function of fretting slip amplitude. It is clear that for all contact material combinations the longer the slip amplitude the shorter is the time to attain a given increase in the contact resistance.

The observed effect can be rationalized in terms of kinetics of debris removal and also the formation and closure of the conducting spots in the contact area. In other words, the shorter slip amplitude the lower is the number of contact spots exposed to oxidation which, in turn, delays the onset of contact resistance degradation. On the other hand, longer slip amplitudes facilitates the exposure of the contact zone to oxidation thus reducing the number of conducting con-

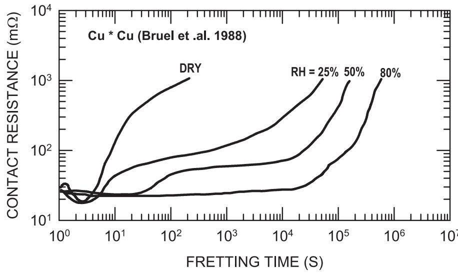

Fig. 12 Effect of relative humidity on the evolution of contact resistance under fretting condition [20].

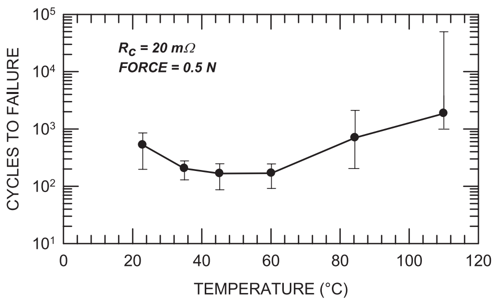

Fig. 13 Cycle to failure as a function of temperature as derived from the fretting corrosion data for contact force 0.5 N. Failure is defined by the contact resistance attaining 20 mΩ for the first time [21].

tact spots thus shortening the time to onset of the increases of contact resistance.

5.4 Relative Humidity

Relatively humidity (RH) has a significant and complex effect on the fretting behaviour of electrical contacts since it involves interaction between chemical reaction rates, the effect of moisture on the physical characteristics of the debris, and possibly effects of moisture on the surface.

Introduction of an aqueous solution into a fretting zone may influence the fretting process in one or both of two distinct ways. Firstly, the liquid can serve as a lubricant, thus separating the metal surfaces and reducing adhesion, friction and wear rates. Secondly, a liquid may induce an anodic corrosion reaction within the fretting scar, causing the corrosion products to be trapped in the scars and thus increasing the rate of wear (Fig. 12).

5.5 Temperature

The effect of temperature on the fretting process is manifested in two ways: changing the rate of oxidation or corrosion with temperature and affecting the mechanical properties of the materials. The effect of temperature on the contact resistance of tin-plated copper alloy under fretting conditions at elevated temperatures is shown Fig. 13 [21].

The results shown indicate that up 60°C, the number of cycles to failure decreased whereas at higher temperature the trend was reversed. Oxidation of tin at temperatures bellow 60°C was the main cause for the increased sus-

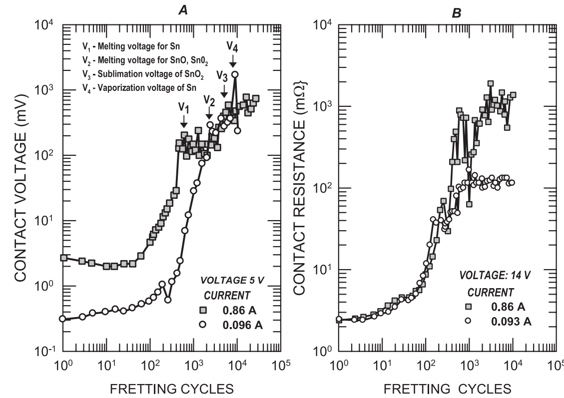

Fig. 14 Contact resistance (A) and contact voltage (B) as a function of fretting cycles at two different current levels 0.86 A and 0.096 A [13].

ceptibility of tin-plated samples to failure. At temperatures above 60°C, softening of tin plating occurs thus enlarging the contact area thus reducing of the effective track length and lowering the rate of degradation. It should be pointed out that although the elevated temperatures can bring some improvement to the performance of tin plated samples, other base metals with higher softening temperature may not have the same tendency.

5.6 Effect of Current

The passage of current across the contact interface may affect surface film formation, interface topography and provokes interface heating, structural changes in near-surface regions and microarcing. As a result, the profound changes in the contact resistance would occur.

Bowden and Williamson [22] have shown that for any given current there is a certain critical degree of constriction through which it will just pass without causing a permanent change in the contact region. That is, if the current flows through a contact area which presents a constriction resistance greater than this critical value, then the heat generated will be sufficient to decrease the yield pressure of the metal near the interface and thus increasing the area of contact.

The effect of current on the contact resistance of tin-plated copper contacts under fretting corrosion conditions was shown in Fig. 14. The contact voltage (A) and contact resistance (B) are shown as a function fretting cycles and electrical current.

The contact resistance behavior was characterized by the presence of fluctuating resistance plateaus delaying further resistance rise. Lower and longer resistance plateaus were the result of higher currents and applied voltages. These resistance plateaus are consistent with the physical picture that the current through the contact constriction causes the contact spots to thermally run-away until melting of tin occurs (the first plateau). Further fretting increases resistance and more heating whereby the temperature can rise up to the melting, sublimation, and decomposition of the oxides, and even up to the vaporization of tin collectively

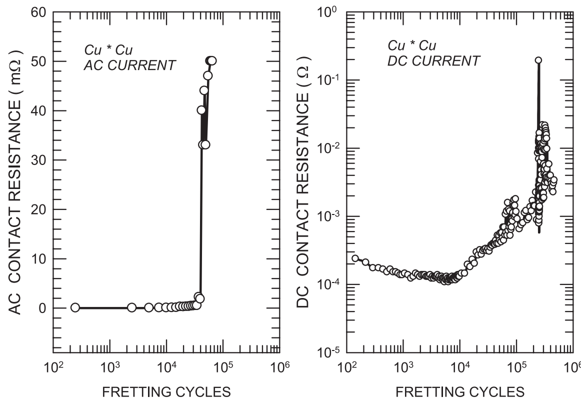

Fig. 15 Effect of fretting on the AC and DC contact resistance of copper-to-copper wire-plate contacts. Fretting conditions: contact load 400 grf, fretting frequency 1 Hz, slip amplitude 100 μm current 50 mA [25].

forming the second contact resistance or voltage plateau.

The effect of electrical current on the contact resistance behavior under fretting conditions was investigated in of aluminum wire in combination with different plating materials [23] and in hot-dipped tin contacts [24]. It was shown that the applied current determines the presence of plateaus in the contact voltage dependence on the fretting cycles: the higher the applied current, the lower is the number of cycles at which this plateau is reached. The effect of electrical load was attributed to fritting that is, breakdown of the insulating layer by high electrical fields.

More recently, Gagnon and Braunovic [25] have investigated the effect of fretting in copper-to-copper contacts under AC (60 Hz) and DC current conditions. It was shown that the overall contact resistance behaviour of copper-to-copper wire-plate couples under AC and DC current was practically the same as seen in Fig. 15. The characteristic feature of the samples under AC current conditions is a pronounced distortion of the contact voltage and the presence of large amounts of flake-like fretting debris widely scattered around the contact zone. However, fretting debris in the samples fretted under DC conditions are compacted and without the flake-like debris (Fig. 16).

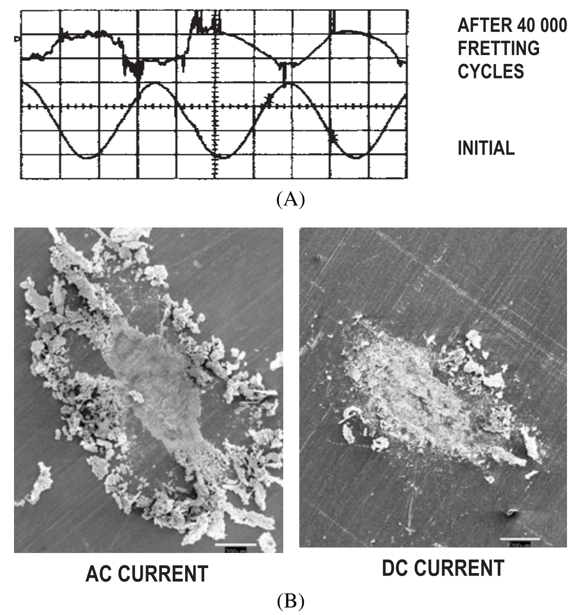

Fig. 16 (A) Contact voltage wave forms initial and after 40 000 fretting cycles; (B) SEM images of the contact zones after 40 000 fretting cycles under AC and DC current conditions [25].

5.7 Surface Finish

It is a general observation that the higher is the degree of surface finish, the more serious is the fretting damage. Rough surfaces have a higher plasticity index than smooth surfaces so that some plastic deformation will occur at the tips of the asperities but work hardening is likely to prevent them being completely flattened, allowing the sharper asperities on a rough surface there is more possibility of debris being able to escape from areas of contact and settling in adjacent hollows in the surface.

5.8 Hardness

Hardness can influence fretting behaviour in two possible ways. Higher hardness implies higher ultimate tensile strength and higher fatigue strength. Since fretting involves breakdown of the surface by local high-stress fatigue processes, a decrease in damage is to be expected with an increase in surface hardness. Secondly, the abrasive action of oxide debris is a factor in fretting corrosion, and therefore the harder the surface, the higher the abrasion resistance, and the less the damage. In particular, the relative hardness of the debris and the surface would seem to be an important factor.

Combinations of similar metals with different hardnesses and surface finishes will have the best resistance to fretting. It is likely that combinations of metals showing poor alloying tendencies will be more resistant to fretting that those which alloy readily. Surface treatments which increase the surface hardness would be expected to reduce fretting wear and delay the onset of contact resistance degradation.

5.9 Metal Oxide

The properties of the metal oxide formed during fretting significantly affect the extent and the kinetics of fretting damage. The oxide debris produced by fretting action will increase the coefficient of friction and act as an abrasive to increase the surface damage. Bowden and Tabor [22] have shown that the relative hardness of the underlying metal plays the primary role in determining the wear rate. A hard metal producing a soft oxide will resist fretting wear, whereas a soft metal producing a hard oxide may result in a severe wear. The effect of metal oxide is further complicated by the variation in the strength of the metal-oxide bond.

Since oxides are much less plastic than their underlying parent metals, when mated materials differ in hardness, the harder material partially supports the softer materials and inhibits cracking of the oxide.

Oxide fracture is a necessary requirement for metal contact and low contact resistance, but when the metals have similar hardnesses there is more extensive fracture of the oxide film. Furthermore, there is a higher degree of superposition of the cracks which facilitates establishment of the bridges that extrude through them [22].

5.10 Coefficient of Friction

If the length of the slip amplitude is short, it may be possible to prevent slip by raising the coefficient of friction since, for slip to occur, the product of the normal force and the coefficient of friction must be exceeded by the tangential force. However, high friction will cause severe plastic deformation and fatigue failure of the contacts. Wear particles, generated by the accumulation of plastic strain and the interface failure, will result in plowing, thus, increasing the friction and accelerating damage to the contacting surfaces.

On the other hand, if slip is unavoidable, a low coefficient of friction is desirable, since a low friction causes no plastic deformation of the contact surface and may result in elastic sliding. Nevertheless, the plastic deformation of the contacting surfaces is inevitable even for very low friction because a contact is in the elastic-plastic regime whenever a friction force exists, but the magnitude of plastic strain and the extent of plastically deformed region may be reduced by decreasing friction.

5.11 Frictional Polymerization

The phenomenon of frictional polymer formation refers to the build-up of organic polymer deposits in and around the contact area due to exposure to relatively low levels of simple organic vapors under operating conditions. In the presence of even minute amounts of organic vapors Pd, Pt, Ru, Rh, Au, and their alloys become susceptible to the formation of complex solid, insulating polymeric compounds at the sliding interfaces. The compounds are of high molecular weight and adhere to the surface and thus increase the contact resistance leading ultimately to contact failure [27].

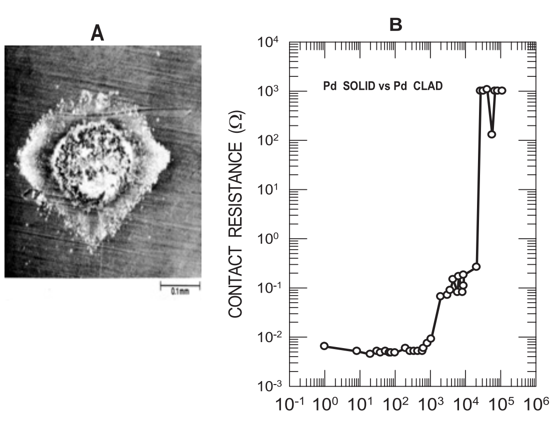

Fig. 17 (A) SEM image of the fretted contact zone showing palladium wear particles and friction polymer debris (B) Effect of the formation of a frictional polymer on the contact resistance of Pd-Pd contact [28].

An example of the contact zones following the friction polymerization effect on palladium-palladium contacts subjected to fretting motions is shown in Fig. 17A. The debris consists of mixture of palladium wear particles and frictional polymers. Figure 17B depict the contact resistance changes with fretting cycles of palladium-palladium contact as a result of the formation of a frictional polymer in the contact zone.

The experimental evidence indicates that deleterious effect of frictional polymerization can be mitigated, but not eliminated, by alloying and lubrication. Additions of 36% and more of silver was found to significantly reduce the effects of frictional polymerization since silver is not a catalytically active transition metal and does not form friction polymer [28].

Antler [29] has shown that lubricants are able to stabilize the contact resistance of metals susceptible to degradation by frictional polymerization. The stabilization of contact resistance was attributed to dispersal of friction polymer by excess unreacted lubricant. Hence, lubricants with frictional polymer-causing metals should have low volatility and migration tendencies to assure that they are always present on the contact surfaces. Common lubricants, polyphenylethers, produce coatings that are highly effective, particularly when they are thick.

In view of deleterious effect of frictional polymerization on the reliability of palladium-based contact materials, it is rather surprising that the mechanisms of frictional polymerization remained unknown and structural characterizations extremely limited.

6. Palliative Measures

The effect of fretting motion at the interface is generally considered as the most important factor determining the contact performance. There are three basic directions for improving the contact performance: a) development of new contact materials, coatings, and lubricants; b) special techniques affecting structure and state of the interface; c) improvement in contact design (Fig. 18).

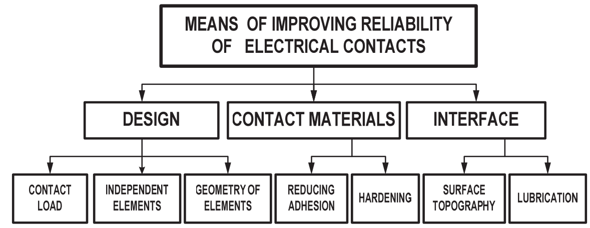

Fig. 18 Main means of improving reliability of sliding contacts.

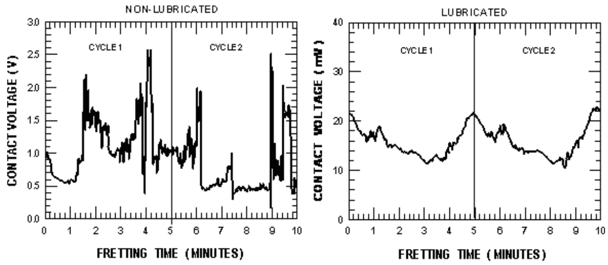

Fig. 19 Contact voltages of non-lubricated and lubricated Al-Cu couples along the wear track as a function of fretting time [26].

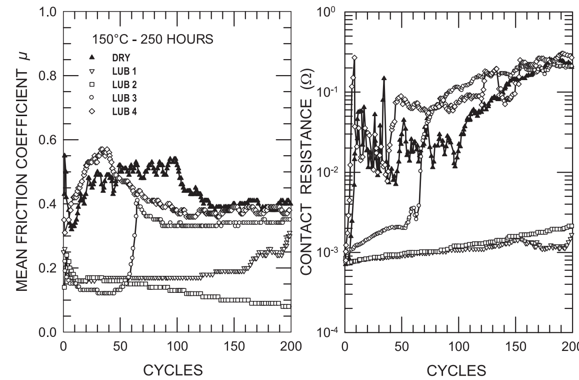

Fig. 20 Effect of lubrication on the coefficient of friction and contact resistance of hot-dipped tin plated separable contacts.

6.1 Lubrication

Lubrication is one of the most effective means of improving and maintaining the reliable performance of electrical/electronic connections. When the contact is made, the lubricant is squeezed away from the points of highest pressure and hence the metallic conduction through the contact is not disturbed. Thus, the oxidation of clean metal surfaces is virtually prevented and a high area of metallic contact, low contact resistance, and protection of the contact zone from adverse environmental effects are maintained.

Lubrication reduces coefficient of friction, thus wear, and fretting between mating surfaces and provide protection against corrosion by inhibiting the ingress of the corrosive environments into the contact zone. It protects against substrate corrosion by sealing the pores in the thin precious metal (usually gold) plating thus preventing the oxidation of substrate which can eventually exude through the pores, build up on the noble metal surface, and lead to high contact resistance.

An example of the beneficial effect of lubrication is shown in Fig. 19 [26]. The contact voltage of non-lubricated and lubricated aluminum-copper contact under fretting conditions was shown as function of two complete fretting cycles. These results were obtained after 10^6 s of fretting at 2 N contact load and 25 μm slip amplitude. The data were obtained by continuously recording the contact voltage variations with time.

The effect of lubrication on the friction, wear, and electrical contacts of hot-dipped tin coatings on bronze-base separable contacts can be improved using the fluorinated lubricants It was shown that different lubricant exert different effect on the contacts resistance, friction and wear characteristics of tin-plated contacts. The results shown in Fig. 20 illustrate the effect of lubrication on the friction coefficient and contact resistance as a number of friction and fretting cycles before and after heat treatment at 150°C [30].

These results indicate that both coefficient of friction and contact resistance are greatly affected by the type of lubricant used and temperature. Viscosity of the lubricant appears to exert considerable influence on the friction and contact resistance behaviors either prior to and after heat treatment. Noel et al., have shown [30] that if the viscosity is too high, severe degradation is observed which leads to the accumulation of the tin and tin oxides particles in the contact zone thus raising the contact resistance values. The effect of a low viscosity and low tension energy fluid is to postpone wear and lead to very thin powder like particles. An additional advantage of lubrication is the possibility of using thinner plating without compromising the reliability of a connection.

Clearly, lubricants can stabilize contact resistance by retarding the rate of wear of thin noble metals on film-forming substrates, by dispersing frictional polymers and with base metals by protecting the surfaces and wear debris from the environment and reducing the oxidation rate.

It should be pointed out that, although lubrication improves significantly the stability and performance of electrical and electronic connections brought about by lubrication, there are also some shortcomings when lubricants are used.

6.2 Coating (Plating)

Presently, electronic and electrical industries are experiencing a relentless increase in the use of protective and wear-resistant coatings for electrical contact applications. Such trend is driven not only by the cost benefit demands but also useful functions offered by the coatings such as: corrosion and wear protection, diffusion barriers, conductive circuit elements, fabrication of passive devices on dielectric surfaces and others.

The performance of an electronic/electrical connection is basically controlled by the surface phenomena such as contamination, oxidation, re-oxidation, sulfide-formation, corrosion, etc. The presence of these contaminants on the surface increases the contact resistance and is detrimental to the connection reliability.

Examples of the effect of coating materials on the contact resistance and coefficient of friction on the fretting behavior of different plating materials are shown in Fig. 21.

To a large extent, the contact quality of different devices and systems is controlled by the electrical and mechanical properties of the surface layers. Depending on the coating material characteristics, contact operating conditions and intended functions, the thickness of deposited

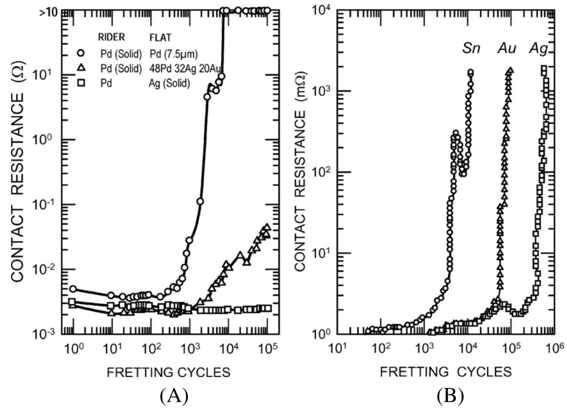

Fig. 21 Contact resistance of (A) solid palladium fretting against palladium- and PdAgAu-plating and solid silver [14] and (B) tin plated spherical pin (rider) fretting against tin-, gold- and silver-plated flats [31].

material onto the contacting surfaces vary from 0.1–0.3 to 20–30 μm and sometimes to 100 μm.

The characteristics of contacts that otherwise could not be realized by common metallurgical methods, can be modified and engineered within a wide range of appropriate arrangements of the layers in the coating, the layer thickness and composition, the substrate material and deposition conditions.. The use of noble metals as coating materials in low-current contact applications decreases substantially their consumption in a variety of applications without any change in the design and dimensional requirements of a coated product. An exhaustive review of the coating materials used in electrical/electronic connections is given in [5].

It should be noted, however, that despite the obvious advantages of the coatings, there is still a number of factors such as surface imperfections (porosity), hardness (softness), adherence to the substrate and resistance to oxidation and the effects of a corrosive environment are probably the most important affecting the characteristics of practically all types of coated electrical connections.

7. Conclusions

A review of the fundamental aspects of fretting and its deleterious effect on the performance of electrical and electronic connections was presented. It was shown that the minute fretting motion at the contact interface results in the formation of a dense insulating layer between the contacting members that adversely affects the integrity of these connections. Factors such as contact, environmental conditions and materials properties affecting fretting and palliative measure sued to suppress the effects of fretting are also discussed.

Acknowledgments

The author wishes to acknowledge the kind invitation of Prof. T. Tamai of Mie University, Japan, to write this review paper on fretting.

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