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Impact of the nickel interlayer on the electrical resistance of tin–tin interface submitted to fretting loading

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ABSTRACT

The behaviour of the tin/tin interface for electrical contact application is addressed in this paper. Two coating systems were studied: a bronze–tin coating system and a bronze–nickel–tin coating system. The transition amplitude δ_t from partial slip (P.S) to gross slip (G.S), defining the domains of infinite and finite lifetime of the contact, was found using the variable–displacement–amplitude methodology (VDA). Constant–displacement–amplitude (CDA) tests were performed in order to determine the influence of the nickel interlayer on the performance of the electrical contact. The conducted analysis concluded that there is no influence of the nickel interlayer on the electrical endurance during G.S. However, the nickel interlayer, which serves as a diffusion barrier, eliminates the diffusion of copper through the tin coating; thus preventing the formation of copper oxides on the top surface. It concludes that the application of the nickel underlayer by maintaining high tin–tin friction coefficient extends the P.S domain and therefore increases the reliability of the electrical contact.

1. Introduction

The use of tin as a coating material in electrical contacts is prevalent. The low-cost application of tin is an alternative to the more expensive solutions using noble materials such as gold [1] or silver. Although tin is a cheap solution, it is also very susceptible to the fretting conditions, which is its major disadvantage.

Small oscillatory movements induced by vibration and thermal expansion can severely degrade the electrical properties of the contact. Indeed those movements, referred to fretting, cause wear of the interface and induce debris formation which can dramatically decay the electrical resistance.

An extensive effort has been made to define the mechanisms of damage of electrical contacts. Antler was one of the first researchers to give a review on this problem [2,3]. Several studies have been devoted to each of the materials used in connectors. Gold finishes were studied by Rabinowicz et al. [4,5], Antler and Drozdowicz [6], Togasaki [7]. Silver coatings were subject to thorough investigation by Kassman-Rudolphi and Jacobson [8–11].

The various aging mechanisms and the range of oxide films formed on the surface of the tin interface were characterised by Malucci [12,13]. The formation of intermetallic phases, another phenomenon very relevant to the performance of the tinned contacts, was investigated by Braunovic [14], Noel [15], and Haimovich [16]. Park et al. performed extensive research on the influence of mechanical and environmental loadings on the electrical resistance. Their thorough studies showed the influence of temperature [17,18] and fretting corrosion [19,20] on the contact resistance.

The work of Hannel et al. [21,22], Kassman-Rudolphi and Jacobson [9,10] provides information on the influence of the sliding regime on the performance of electric connectors.

The aim of this work is to investigate the influence of the nickel interlayer, used as a barrier against the copper diffusion, on the transition from P.S to G.S condition as well as its influence on the performance of the contact under G.S condition. To study this aspect the VDA methodology [23] was applied. The second goal was to confirm the conformity of this methodology with the traditional CDA test methodology, especially the possible effect of imposed mechanical loadings history on the obtained results. The last aspect of the research work was to confirm the hypothesis of the low and stable electrical resistance under P.S and immediate degradation of this parameter when contact turns to G.S condition.

2. Experimental details

2.1. Experimental setup

An original setup was designed and built for this study. This machine made it possible to simulate environmental conditions similar to those due to a car engine. Fig. 1(a) illustrates the schematic diagram of the machine.

The oscillatory motion of the upper holder, fixed via flexible strips, was produced by the electromagnetic shaker. An upper sample was fixed

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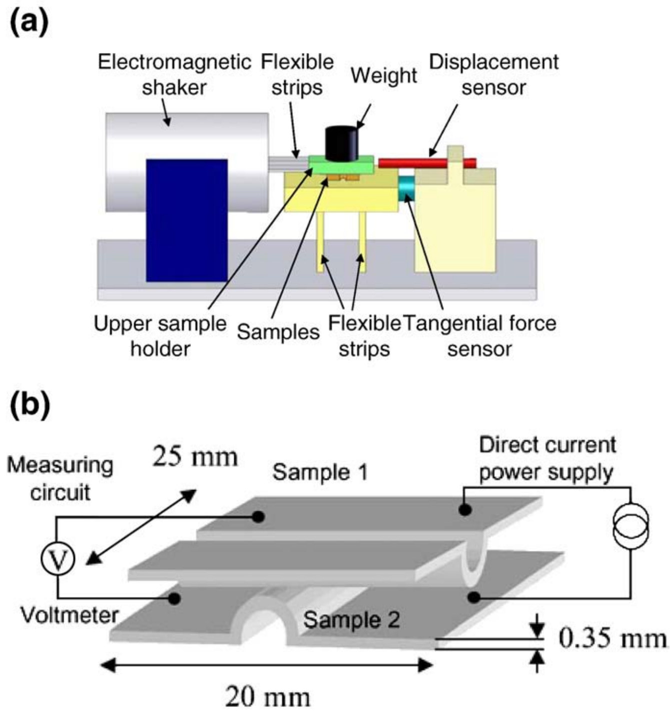

Fig. 1. (a) Schematic presentation of the experimental setup and (b) crossed-cylinders configuration used in the study (illustration of the 4 points electrical measurement method).

to the upper holder while the second sample was fixed to the lower table, whose slight horizontal displacement allowed the tangential force to be measured during the test using a piezoelectric load sensor. The upper specimen movement was controlled using a laser displacement sensor to an accuracy of about 0.1 µm. A dead mass placed on the upper holder was applied to assure the normal force loading. The dedicated software, based on the Labview platform, was used to provide all necessary recording and monitoring. The parameters which can be recorded and controlled during each test are as follows: the relative displacement δ^* [from ±0.5 to ±40 µm], the frequency f [from 1 to 500 Hz], the normal force P [from 0.2 to 5 N], the relative humidity RH [from 1 to 99%], and the temperature T [from 20 to 160 °C].

3. Contact configuration and electrical resistance measurement system

The sample system used in this study consisted of two 90° crossed semi-cylinders (Fig. 1(b)) each with a radius of 2.3 mm. To measure the electrical resistance of the contact during the test a four wire method was applied. Two wires, one for each sample, supplied a stabilised current I=0.005 A±0.2%. Another two wires were used to measure the contact voltage. This system enabled the electrical resistance from 10^{-6} to 10^{3} Ω to be measured. The number of sliding cycles N_C to reach the threshold value of the electrical resistance of R_C=0.004 Ω was assumed as a lifetime of the contact.

Table 1
Surface roughness parameters

	Ra [nm]	Standard deviation [nm]
Cu–Sn system	851.4	38.8
Cu–Ni–Sn system	848.8	26.2

3.1. Materials studied, roughness and test conditions

3.1.1. Materials

Two different tribocouples were investigated. The first system consisted of bronze substrate covered with the 2 µm thick pure-tin coating. The second system was similar, but a 2 µm thick nickel interlayer was deposited between bronze substrate and tin coating.

3.1.2. Surface roughness

The surface roughness of the studied materials was measured before the fretting tests. For each studied material ten measurements along the cylinder's peak (contact areas) were conducted. The obtained results concerning the Ra parameter are listed in Table 1. As it can be clearly seen the surface roughness parameters are almost the same so it can be initially concluded that the roughness of the samples has no influence on obtained results.

3.1.3. Test conditions

Identical experimental conditions were applied to both tested couples: Temperature 23 °C, relative humidity 10%, frequency 30 Hz, normal force 3 N.

3.2. Test methodology

Two different tests were performed on each of the studied coating systems. The first type of test was a VDA test. The second type was a conventional CDA test.

The VDA tests allow the determination of the boundary between P.S and G.S in one single test. The principles of the VDA methodology are shown in the Fig. 2. For a contact with given geometry and normal load, first a small displacement amplitude (δ^*=2 µm) is applied to ensure that the initial sliding condition is P.S. The displacement amplitude is being then progressively increased in small increments ($\Delta\delta^*$=1 µm). Each displacement amplitude is maintained for a sufficient length of time (ΔN_C=15,000 cycles), so that dynamic conditions in the contact have stabilised. In this way the transition amplitude δ_t is determined in a single test. The CDA test methodology consists of the tests carried out in the constant–displacement amplitudes. The imposed amplitude is maintained constant during all period of the test; the electrical resistance is being measured as well. When the value of the electrical resistance becomes higher than the threshold value (R>R_C), the lifetime of the electrical contact (N_C) can be estimated. The lifetime of the electrical contact for different amplitudes can be distinguished allowing the creation of endurance chart, so called Wohler-like curve. This curve represents the lifetime (N_C) of the contact as a function of applied displacement amplitude δ^*.

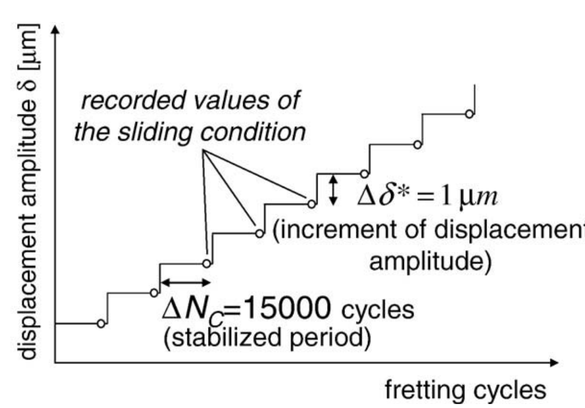

Fig. 2. Illustration of the principles of the Variable Displacement Amplitude (VDA) methodology.