Wear 330-331 (2015) 400–405

Contents lists available at ScienceDirect

Wear

journal homepage: www.elsevier.com/locate/wear

Correlation between friction and wear properties and electrical performance of silver coated electrical connectors

Jian Song*, Vitali Schinow

Precision Engineering Laboratory, Ostwestfalen-Lippe University of Applied Sciences, Liebigstrasse 87, 32657 Lemgo, Germany

ARTICLE INFO

Article history:
Received 20 August 2014
Received in revised form
3 February 2015
Accepted 10 February 2015

Keywords:
Friction
Wear
Electrical resistance
Contacts
Silver
Thickness

ABSTRACT

The wear resistance of coatings is a very important factor which not only influences the reliability but also the lifetime of electrical connectors. The coefficient of friction of the coating, along with the normal force of the contacts, determines the insertion and extraction force of connectors and in addition represents an important indicator for the state of the contact surfaces.

The main finding of this study is the disproportionate increase in lifetime with increasing thickness of silver coating. The difference between wear and friction curves of thin and thick silver coatings and the correlation between the different phases of friction curves and different stages of wear curves are analyzed, with the adhesive friction being the dominating type of friction in all four phases of friction, which peaks to its maximum in the phase II.

1. Introduction

With an increasing number of electrical connectors in electronics, machines and vehicles, the requirements regarding reliability and lifetime of connectors is also rising. Electrical contacts of connectors are usually coated in order to prevent corrosion of the base copper alloy. One of the important coating materials of electrical connectors is silver which is not only highly resistant to oxidation and corrosion but also much less expensive than gold. Coatings of electrical connectors experience wear because of the motion between contacts due to vibration, different thermal expansion coefficients on both sides of connectors or mating and unmating of connectors. Once the protective coatings have been worn through, electrical contacts will fail rapidly due to corrosion or fretting corrosion. Therefore the wear resistance of the coatings is a vital factor which influences the reliability and lifetime of electrical connectors. The coefficient of friction of the coating, together with the normal force of the contacts, determines the insertion and extraction force of connectors, which is one of the important handling characteristics of connectors. The coefficient of friction of the coating varies immensely due to the wear of the coating and is therefore also an important indicator for the state of the contact surfaces [2,5,6,13–16].

Many aspects of the tribology of electrical contacts have been investigated in recent years, including the influence of lubrication films, modifications of coatings and influence of vibrations. Most studies focus on the conventional thickness of coatings of up to 5 μm [13–18]. Even within this very small range of coating thickness, the nonlinearity of the correlation between the lifetime of electrical contacts and the coating thickness was observed. The authors of previous studies defined a threshold thickness and identified the linear correlation between the lifetime and the coating thickness [15,18]. The requirements for many new applications have however been increased, for instance in the case of extremely high wear resistance of the coatings used for charging devices for electrical vehicles. We have therefore investigated a larger range of coating thickness up to more than 10 μm. Due to this large range of the coating thickness the nonlinearity of the correlation between the lifetime and the coating thickness can be clearly identified. The online measurement of wear also shows a continuous decreasing wear rate with the increasing sliding distance which reveals the disproportionate increase of the wear resistance and accordingly the lifetime with the increasing coating thickness.

Our study deals with the following issues:

- The friction and wear characteristics of silver coatings of different thicknesses as function of sliding distance.
- The wear rate in the wear-in stage and in the steady-state wear stage.
- The correlation between the friction and wear characteristics and the state of silver coatings on the contact surfaces, which are analyzed using microscopical methods in order to identify

* Corresponding author. Tel.: +49 177 2131820; fax: +49 5261 70285028.
E-mail address: jian.song@hs-owl.de (J. Song).

http://dx.doi.org/10.1016/j.wear.2015.02.026
0043-1648/

the mechanisms responsible for changes in friction and wear properties.
- The correlation between friction, wear characteristics and electrical performance of contacts, these being measured with self-developed test rigs.

The findings obtained in this study provide important reference points for the improvement of connector performance. In the case of the application in electrical contacts, the disproportionate increase in lifetime with the increasing thickness of the coating creates new possibilities for silver coated electrical contacts e.g. in charging connectors for electrical vehicles, in addition to providing new models for the calculation of lifetime.

2. Materials and methods

2.1. Contacts and materials

The contacts used for the investigation were stamped and the base material is $CuSn_4$. The size of the contacts is shown in Fig. 1. The contacts are coated with pure silver of varied thickness ranging from 3 to11 μm.

2.2. Test rig and analysis of contact areas

A test rig is used for the tribological and fretting tests, which enables a defined displacement of fretting motion at the contact interface, Fig. 2. A piezo actuator is programmed to move forwards and backwards with an amplitude of 50–300 μm and cycle duration of 1 s. The contact normal force is provided with a dead load and various normal forces can be applied. The average pressure can be estimated with the Hertz's equation for a ball-on-plate setup, Table 1. The true value of the average pressure is somewhat lower due to the plastic deformation in the middle. The contacts are wired for a four-wire resistance measurement, with a computer- controlled data acquisition system.

The wear measurement is conducted with a laser distance sensor, which measures the relative movement of the sample holder. The online measurement has the advantage that it differentiates the run-in stage of wear at the beginning of the test from the normal stage of wear after the run-in stage, which consequently enables a precise forecast of the development of the wearing process. An optical microscope is also used for the surface analysis.

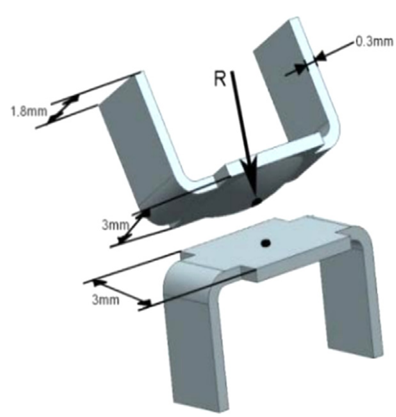

Fig. 1. Size of contacts.

3. Theory

3.1. Contact resistance, surface protection, motion and wear

According to Holm the contact resistance R_C is proportional to the specific electrical resistance ρ and inversely proportional to the contact area [1]:

$$R_C = \frac{\rho}{2a} \quad (1)$$

where a is the radius of the contact area. Copper or copper alloys are commonly used as base metals for electrical contacts due to their high conductivity. However copper and copper alloys have low standard electrode potentials and therefore corrode and oxidize easily. Corrosion and oxidation products lead to a marked increase of the specific electrical resistance. Different materials are used for the coatings of electrical contacts in order to protect copper or copper alloys against corrosion and oxidation with silver being one of the important coating materials used for electrical contacts. In many cases the motion of contacts is unavoidable as a result of vibration or thermal expansion and in these cases the wear properties of the coating determine the duration of the surface protection and effect the lifetime of contacts [2].

3.2. Wear

The volumetric wear is the quantity of worn material [mm^3]. It is more convenient to use the linear wear for coatings of electrical contacts, which is the volumetric wear divided by the apparent contact area, and this is therefore used to quantify wear in this paper. The linear wear rate is the linear wear per unit sliding distance [m].

Table 1
Normal force and estimated average pressure.

Normal force [N]	1	2	5
Average pressure [MPa]	240	300	400

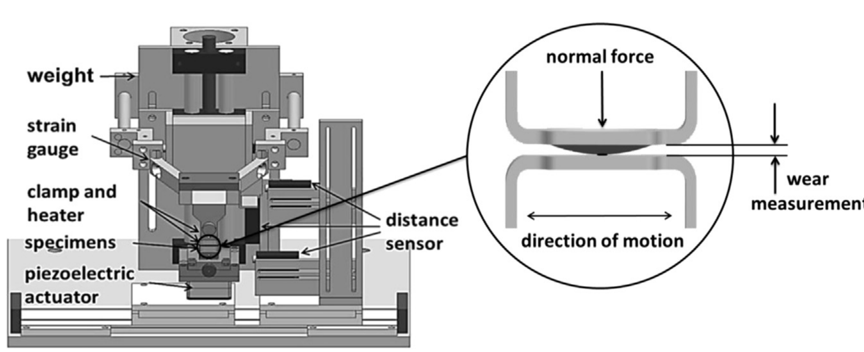

Fig. 2. Test rig for wear and fretting corrosion tests.