Wear 376-377 (2017) 634–642

Contents lists available at ScienceDirect

Wear

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

Grease lubricated fretting of silver coated copper electrical contacts

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ARTICLE INFO

Article history:
Received 2 September 2016
Received in revised form
7 February 2017
Accepted 8 February 2017

Keywords:
Fretting
Grease lubrication
Electrical contacts
Lithium complex (LiX) grease
Polypropylene (PP) grease

ABSTRACT

Fretting of silver coated electrical contacts has been studied in a crossed cylinder contact model setup at varying displacement amplitude. The contacts have been tested dry (unlubricated) and lubricated with lithium complex (LiX) and polypropylene (PP) thickened greases. The same polyalphaolefin (PAO) base oil blend was used, hence the thickener is the only difference between the greases. At low displacement amplitude no large difference between dry and lubricated conditions was found. Contact welding occurs for all contacts, also the lubricated. The grease is ejected from the contact area after only a few fretting cycles and the contact welds. A positive effect of grease lubrication on friction and wear is primarily seen at high vibration amplitude, where gross slip is the prevailing fretting regime. For the LiX grease lubricated contacts, fretting at intermediate displacement amplitudes show to be the most critical and the wear marks show much surface damage. Here, the PP grease showed better lubricating effect than the LiX grease.

1. Introduction

Electrical contacts for power applications need to have low and stable contact resistance. Materials are primarily chosen for their electrical conductivity and their ability to resist formation of insulating films such as oxides. One common material combination is silver coated copper, where silver is used to make the contact surface relative inert. The real contact area needs to be large to accomplish a low contact resistance, hence high contacts forces are applied, typically 10–100 N. The high loads together with the soft contact materials, as silver and copper, combine to give an unsatisfactory tribological system with massive plastic deformation, high friction and high risk of wear.

Electrical contacts are subjected to for instance sliding wear, corrosion, resistive heating and fretting. Fretting is a special process occurring between materials under load and subject to minor relative motion by vibration or some other force. The fretting process causes enhanced corrosion, fatigue, wear, material transfer, etc., that can lead to unacceptable increases in contact resistance.

Several fretting contact conditions or fretting regimes prevail [1–3]. Under elastic conditions, the pressure distribution follows the Hertzian equations. A sphere on flat or crossed cylinders geometry gives a circular contact area. Due to the pressure drop at the rim of the contact area, it is divided into a sticking central area surrounded by a slipping annulus. This means that the outer part of the contact will slip even for moderate tangential forces. When increasing the tangential force, the slip annulus increases and the sticking zone decreases. The whole contact area will slip at a critical tangential force. Partial slip corresponds to very low displacement amplitudes whereas larger amplitudes provide slip conditions. Depending on parameters as normal force and displacement amplitude different regimes may arise: partial slip, mixed slip and gross slip. In the mixed fretting regime, also called the temporary weld regime, the regime changes from partial slip to gross slip after some time. This regime has been identified to be the most critical regarding crack nucleation and service failure [3]. The normal force, the amplitude and material properties strongly influence the mixed fretting regime.

In reality, the electrical contacts are subjected to plastic deformation, but the corresponding fretting regimes are still found. This has been shown in earlier studies of unlubricated silver coated power connectors [4,5], where gross plastic fretting comprising the gross weld, temporary weld and gross slip regime were found. The prevailing regime was determined primarily by a combination of the applied normal force and displacement amplitude. These studies also showed an extensive contact area growth during fretting in the gross weld regime.

To reduce friction and wear, electrical contacts are often lubricated with oil or grease. Lubrication generally reduces the friction coefficient, wear and the oxygen content at the surfaces. Lubrication of electrical contacts must take into account that some metal-to-metal contact is required in order to get a low contact

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http://dx.doi.org/10.1016/j.wear.2017.02.022
0043-1648/

resistance, i.e. the lubricant must not completely separate the surfaces. The lubricant must also remain in the contact for very long service periods including for example periods at elevated temperatures. Therefore, grease lubrication is often a solution.

The lubricant viscosity is of importance when it comes to fretting. Low viscosity oil has been shown to be more effective in preventing fretting damage compared to high viscosity oil due to its possibility to easier reach the fretting area [2]. However, oil that penetrates into the interface can penetrate into micro-cracks and cause particle detachment which has been reported to be more severe in the mixed fretting regime than in the gross slip regime [6,7]. High viscosity oils have been reported to be more effective because of a better restriction of oxygen in the contact [2]. With these aspects in mind it is difficult to conclude that lubrication, regardless fretting regime, decreases the fretting wear.

In this study, silver coated copper electrical contacts have been studied dry (unlubricated) and lubricated with lithium complex (LiX) and polypropylene (PP) thickened greases at varying displacement amplitudes. LiX grease was chosen since it is commonly used worldwide and PP since it is a relatively new grease on the market with many interesting features. The PP grease has shown to have a better low-temperature performance, long life and oxidation behavior, lower friction and better additive response compared to the lithium complex based grease [8,9]. The effect of the displacement amplitude on the friction behavior of grease lubricated fretting has been investigated before [10–13]. Kassman et al. [10] studied grease lubricated silver contacts and observed the contact weld formation and break-up also found in the present study. Haviez et al. [11] studied two types of greases, one with a lithium thickener and one with a Microgel® non-melting inorganic thickener. The greases differed in base oil type and base oil viscosity. A transition from grease starvation to full lubrication was reached at lower displacement amplitudes for the lower oil viscosity grease.

The aim of this study was to examine if there is a difference in lubricating performance for LiX and PP greases also in fretting. Good lubrication combined with low contact resistance is a challenge for electrical connectors for power applications and a grease that offers these aspects over a wide range of vibration amplitudes is of interest. The novelty of this study is that the two compared greases consist of the same base oil and have been blended to the same consistency. Thus the effect of the two different thickeners on the fretting behavior and electrical contact performance can be separated from other effects, such as different base oil viscosity as in [11]. In addition, the mechanisms behind the contact development of LiX and PP lubricated contacts at intermediate displacement amplitudes, where the contact conditions are most critical, have been studied in more detail than in previous studies such as [10].

2. Materials and methods

2.1. Test setup

The fretting test setup consists of two crossed silver coated copper cylinders (10 mm in diameter and 20 mm long) simulating an electrical contact. The equipment has been used for several studies and [4,5,10] are examples. The equipment is illustrated in Fig. 1a. An electromagnetic vibrator is used to provide a sinusoidal vibration of the table holding the sample holder for the lower cylinder, while the upper cylinder, mounted on an arm, is intentionally fixed. The normal force is applied by a spring force. Current is mated through the cylinder contact and the contact resistance is determined by measuring the voltage drop over the contact area using a four-point probe set-up, see Fig. 1b. During the tests the tangential force (using a strain gauge), the actual vibration of the table (using an accelerometer) and the contact resistance are continuously recorded. (Note: In the Results section i) the term friction force is used as a synonym to tangential force, also for welded contacts that do not slide, and ii) the friction coefficient is calculated from the RMS value of the tangential force divided by the normal force).

2.2. Materials

Silver coated copper cylinders were used. The silver coating was about 20 μm thick and the surface roughness R_a about 0.9 μm. The contacts were tested dry (unlubricated) and lubricated with LiX and PP thickened greases. Both greases are based on a polyalphaolefin oil blend with 93.7wt% PAO (with kinematic viscosity of 10 cSt at 100 °C) and 6.3wt% adipate ester as in [8,9]. The addition of ester facilitates the saponification in the case of lithium complex. The thickener content for both greases was used to adjust the grease consistency and it was measured in terms of cone penetration. Hence, both greases had the same consistency. The greases were made to keep them as comparable as possible, even though the PP grease differs from its commercial formulation. The greases were provided by Axel Christiernsson AB. All cylinders were cleaned with acetone and ethanol in an ultrasonic bath and cleaned with ethanol between tests using the same cylinders (by rotating the cylinders several test can be run on the same cylinder pair). The grease was applied in excess in the contact area prior to testing.

2.3. Test parameters

Testing was performed at three levels of vibration. A pre-set vibration displacement amplitude was applied. This is the amplitude of the table holding the sample holder of the lower cylinder before the cylinders were put into contact. The tests were

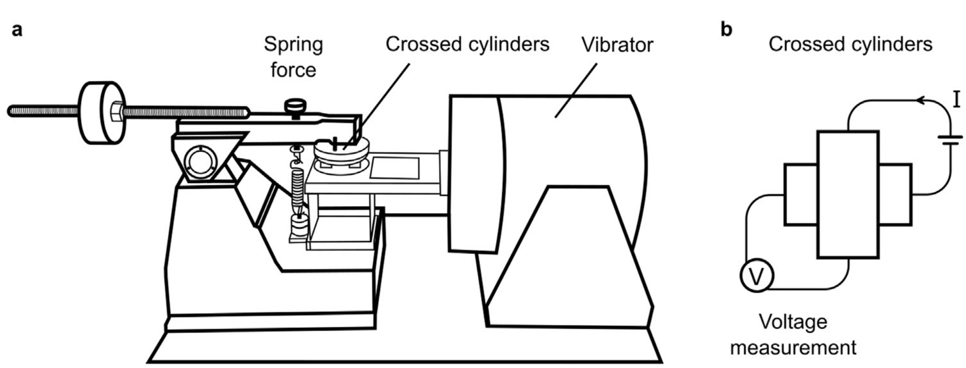

Fig. 1. a) Fretting test equipment using a crossed-cylinders contact geometry where the lower cylinder is vibrating and the upper is intentionally fixed. b) Four-point probe set-up for contact resistance measurement.