Available online at www.sciencedirect.com
ScienceDirect
ELSEVIER
Tribology International 41 (2008) 87–102
TRIBOLOGY INTERNATIONAL
www.elsevier.com/locate/triboint

Fretting corrosion of lubricated tin plated copper alloy contacts: Effect of temperature

T.S.N. Sankara Narayanan[1], Young Woo Park, Kang Yong Lee*

Stress Analysis and Failure Design Laboratory, School of Mechanical Engineering, Yonsei University 134, Sinchon-dong, Seodaemum-gu, Seoul 120-749, Korea

Received 12 September 2005; received in revised form 14 May 2007; accepted 22 May 2007
Available online 5 July 2007

Abstract

The fretting corrosion behaviour of lubricated tin plated copper alloy contacts at ambient and elevated temperatures is addressed in this paper. At 27 °C, lubrication is very effective and the contact resistance remains stable for several thousand fretting cycles whereas at elevated temperatures (155 °C) the performance of lubricated contact is not appreciable. Surface profile and surface roughness confirm that the lubricated contacts have a smoother profile and experience a lesser damage at the contact zone at ambient as well as at elevated temperatures. The mechanism of fretting corrosion of tin plated contacts appears to be similar with and without lubrication at all the temperatures studied. The difference in performance of the lubricated contacts at ambient and elevated temperatures is due to the faster wear rate of tin coating at elevated temperatures. Oxidation of the contact zone of the lubricated contacts is prevented at all temperatures studied. The study concludes that lubrication is effective in improving the life of the tin plated copper alloy contacts under fretting conditions at ambient temperatures whereas at elevated temperatures lubrication provides only a marginal improvement in performance. The decrease in performance of lubricated tin plated contacts at elevated temperatures is due to the higher wear rate of tin coating and not due to evaporation of the lubricant.

Keywords: Fretting corrosion; Lubrication; Tin plated contacts; Contact resistance; Intermetallic compounds; Surface analysis

1. Introduction

Fretting, an accelerated surface damage that occurs at the interface of contacting materials subjected to small oscillatory movement, is a common problem encountered in many engineering applications. The deleterious effect of fretting in electrical connections is considered to be of significant practical importance as it influences the reliability and system performance. A comprehensive review of fretting in electrical contacts has been given by Antler [1]. Tin plated contacts have gained acceptance as a low-cost alternative to gold. Besides cost, tin plating has two main technical advantages; the thin oxide film (10–30 nm) forms on the surface could act as a shield, inhibiting further oxidation and being a relatively soft metal, tin provides a low constriction resistance [2,3]. However, the susceptibility of tin plated contacts for fretting corrosion is considered to be a major limitation for its use in connectors. Fretting corrosion of tin plated connectors has been the subject of many papers [4–8]. It has been established that during fretting motion, the hard tin oxide layer (hardness: 1650 kg/mm^2) is easily broken and its fragments are pressed into the underlying matrix of soft and ductile tin (hardness: 5 kg/mm^2). With time, the fragments accumulate and cause an increase in the electrical resistance.

The use of lubricants is considered as one of the possible solutions for preventing the fretting corrosion of electrical contacts. Lubricants enable a reduction in coefficient of friction between the mating surfaces, and, a decrease in the insertion and withdrawal forces. Lubricants reduce the mechanical wear by placing an oil film between the surfaces, slow down the oxidation process, and with added

*Corresponding author. Tel./Fax: +82 2 2123 2813.
E-mail address: KYL2813@yonsei.ac.kr (K.Y. Lee).
[1]#On leave from National Metallurgical Laboratory, Madras Centre, CSIR Complex, Taramani, Chennai- 600 113, India.

0301-679X/$ - see front matter © 2007 Published by Elsevier Ltd.
doi:10.1016/j.triboint.2007.05.004

additives minimize corrosion. The effect of lubricants on electrical contacts evaluated using either an existing connector or a rider-to-flat configuration clearly reveals that there is a strong improvement in wear and corrosion resistance of the electrical contacts with the application of lubricants [9–14]. Lubrication has also been shown to reduce or eliminate fretting corrosion [15–18] and is considered as a possible solution for preventing fretting corrosion [19]. A large number of lubricants, namely, polyphenyl ethers, natural and synthetic hydrocarbons, several types of esters, polyglycols, some fluorinated materials, silicone and some proprietary formulations were evaluated for their suitability for connector applications [20–22]. Antler [21] suggests that large differences exist in the volatility of lubricants and it is one of the important factors in deciding the performance of the lubricant. Lubrication of electrical contacts proves to be a viable option when the contacts are used at ambient temperatures. However, their performance is always a debatable issue when the temperature is relatively higher.

Since tin plated contacts are continued to be used in engine compartments and sometimes they are closer to the engine, such as sensor connectors or in environments where there is reduced air flow, the tin plated connectors are required to withstand a temperature of 150 °C [23]. Swingler et al. [24] have also reported that automobile connectors have to encounter several high temperature regimes namely, 85, 105, 125 and 155 °C. At higher temperatures, all contact degradation mechanisms may become more severe. This includes higher wear because of softening of tin at higher temperature, faster oxide formation, more intermetallic diffusion and other chemical reactions. Increase in temperature could cause significant thermal expansion and influence the contact interface movements. Variation in temperature could also influence the contact resistance of tin plated contacts since the rate of oxidation of tin varies with temperature. Lee et al. [5] have reported that at elevated temperatures, the rate of oxidation of tin is increased and the tin coating hardness is decreased, both of which would influence the fretting corrosion of tin plated contacts. At elevated temperatures, diffusion of copper will be higher and this will enable the formation of Cu–Sn based intermetallic compounds (IMC) at a much higher rate. The formation of IMC will also cause an increase in the contact resistance. As the tin plated contact fails at higher temperatures due to the higher rate of oxidation of tin and formation of IMC, the volatility of the lubricant assumes significance when it has be used with tin plated contacts in environments where the temperature is higher than the ambient. The present paper aims to study the fretting corrosion behaviour of lubricated tin plated copper alloy contacts at various temperatures ranging from 27 to 155 °C.

2. Experimental details

The fretting corrosion behaviour of tin plated copper alloy contacts under unlubricated and lubricated conditions was studied using a fretting apparatus in which the relative motion between the contacts was provided by a variable speed motor/precision stage assembly. The normal contact force was supplied by the weights placed on the balance arm. The contacts were flat verses 1.5 mm radius hemispherical rider, both of them were made of copper alloy (Ni—1.82%, Si—0.75%; Zn—0.01%; Sn—0.37% and Cu–Balance) and tin plated to a thickness of 3 microns, supplied by Korea Electric Terminal Company Ltd., Korea. The rider and flat specimens were degreased using acetone in an ultrasonic cleaner, dried and carefully mounted in the fretting test assembly. The temperature of the rider and flat samples was kept constant using an electrically heated copper block, which is placed over the flat sample and controlled by a constant temperature device. The temperature of the tin plated copper alloy flat and rider was varied from 27 to 155 °C. Fretting motion was started after soaking the contacts at the desired temperatures for 30 min so that the contacts will be in thermal equilibrium.

It is well established that at gross slip conditions, the wear process will induce formation of debris which in turn gets oxidized and forms an insulating third body layer [25]. Such a condition prevents the metal–metal interactions and results in high and unstable contact resistance. Since the present study intends to evaluate the ability of the lubricant to perform a variety of functions such as, decreasing the extent of mechanical wear, decreasing the rate of oxidation and dispersing the wear debris, the tests were conducted under gross slip conditions. A periodic relative displacement with amplitude of $\pm$ 90 μm and a frequency of 10 Hz were applied between the rider and flat contacts loaded by a constant normal force of 0.5 N. The contact area is defined to be a point contact by "sphere plane" geometry. An electric current of 100 mA was applied between the contacts and the contact resistance was continuously measured throughout the fretting cycle. All tests were performed at 60 $\pm$ 2% RH.

The lubricant used in this study is a commercial lubricant. The important properties of the lubricant are given in Table 1. A variety of methods were followed in the application of lubricants on the contacts, which include immersion/dip, spray, brushing, etc. The dose of the lubricants also varies depending on whether it is applied as neat or it is diluted with solvents. Since the use of solvents is not preferred due to environmental concerns, it was decided to use the lubricant without the addition of any solvents. In the present study, a drop (~0.01 ml) of the neat lubricant was applied with the help of a syringe (5 ml) only on the flat contact which was held vertically and the lubricant was allowed to flow under gravitational force to form a thin film. The slight excess which creeps at the bottom was absorbed using thin absorbent paper wipes. The lubricant was not applied on the rider samples. The surface coverage of the film on the flat contact was measured based on the gain in weight after the application of the lubricant film and the surface area covered by the