Wear 376-377 (2017) 643–655

Contents lists available at ScienceDirect

Wear

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

Effect of elevated temperature on fretting wear under electric contact

Xin-long Liu, Zhen-bing Cai*, Ji-fan He, Jin-fang Peng, Min-hao Zhu*

Tribology Research Institute, Key Lab of Advanced Technologies of Materials, Southwest Jiaotong University, Chengdu 610031, China

ARTICLE INFO

Article history:
Received 2 September 2016
Received in revised form
2 February 2017
Accepted 12 February 2017

Keywords:
Fretting
Contact resistance
A-spot
Temperature
Electric contact

ABSTRACT

The elevated temperature can cause serious failure of electrical contact. The fretting wear behavior of two typical materials (aluminum and silver) and contacts at elevated temperatures (from RT to 300 °C) and normal loads (10 N) is addressed in this paper. The morphology and wear surface was analyses by 3D profile and SEM. The results show that elevated temperature significantly affected the contact resistance. Easily oxidized metal usually have higher ECR value under elevated temperature. Elevated temperature accelerated the formation of oxide film and lead to debris which oxidizes, forming an insulating layer. Metal with good ductility and resistant to oxidation shows lower ECR.

1. Introduction

Electrical connectors are currently used in a great number of domains such as automobile [1], electric locomotive, or high-speed rail. One of the most important characteristics of electric contact is the electrical contact resistance (ECR) of connectors [2]. The ECR should be lower and remain constant during its whole lifetime. This is especially important for power distribution or transformer substation. The ECR mainly depends on the following four parameters: (a) The electrical conductivity of the contact pair [3], (b) The normal force [4,5], (c) The state of the contact zone (smoothing, rough, clean or dirty) [5], (d) The working voltage [6].

Different materials have different conductivity [7]. It is reported that the contact point became more and contact area became larger with the increase of the contact force while the contact point transform from elastic deformation to plastic deformation, this position showed low ECR due to the increase of the contact area [8]. In the other hands, different state of the contact area such as dust, colophony, oil contamination or any other impurity adhered on the surface, all of above mentioned as a result that reduced contact area and increase the ECR, under this condition the ECR became extremely unstable [9].

With the inclusion of every new system, additional connectors are provided. Modern upmarket cars have about 400 connectors with 3000 individual terminals that translate into 3000 potential trouble spots. It has been estimated that more than 60% of the electric problems in cars are related to fretting contact problems [10]. For instance, the critical parts of the contactor which showed in Fig. 1 was the contact that play the role of turn on/off the electro circuit. The reason that cause several accidents mainly caused by fretting (Fig. 1(d)).

The main causes of fretting are vibrations and temperature variations inducing different expansion [11]. Subject to vibration, fretting wear damage (cyclic micro-displacements) can occur and, by promoting the formation of insulating oxide debris within the contact. The increase of temperature could dramatically increase the electrical contact resistance [1].

Fig. 2 shown the definition of contact spot (a-spot), due to two conductors with rough surfaces, a-spot always existed between electrical connectors and then rising ECR. In practice performance the contact area of electrical connectors (such as ball/plane contact pair) seems a tiny circular contact surface but actually more or less so called “a-spot”. This a-spot undertake a task of conductive that actual connect the two conductors. When current through the contact area from conductor 1 to conductor 2 (Fig. 2), there existed only “passable path” that is a-spot. Current must be constriction beyond a-spot and cause additional resistance so called “constriction resistance”, If the material of the conductor is not pure metal but metalloid, as a result of making other additional resistance so called “surface films resistance”.

The ECR of a-spot is represented as the summation of constriction resistance and film resistance by using the following Eq. (1) reported by Holm [12]:

$$R_k = \frac{\rho}{2a} + \frac{\rho_f d}{\pi a^2} \quad (1)$$

Where “ρ” indicates the resistivity of a contact metal, “a” indicates a contact radius, “ρ_f” indicates the electrical resistivity of a film, and “d” indicates the thickness of the film. In order to take

* Corresponding authors.
E-mail addresses: caizb@swjtu.cn (Z.-b. Cai), zhuminhao@swjtu.cn (M.-h. Zhu).

http://dx.doi.org/10.1016/j.wear.2017.02.036
0043-1648/

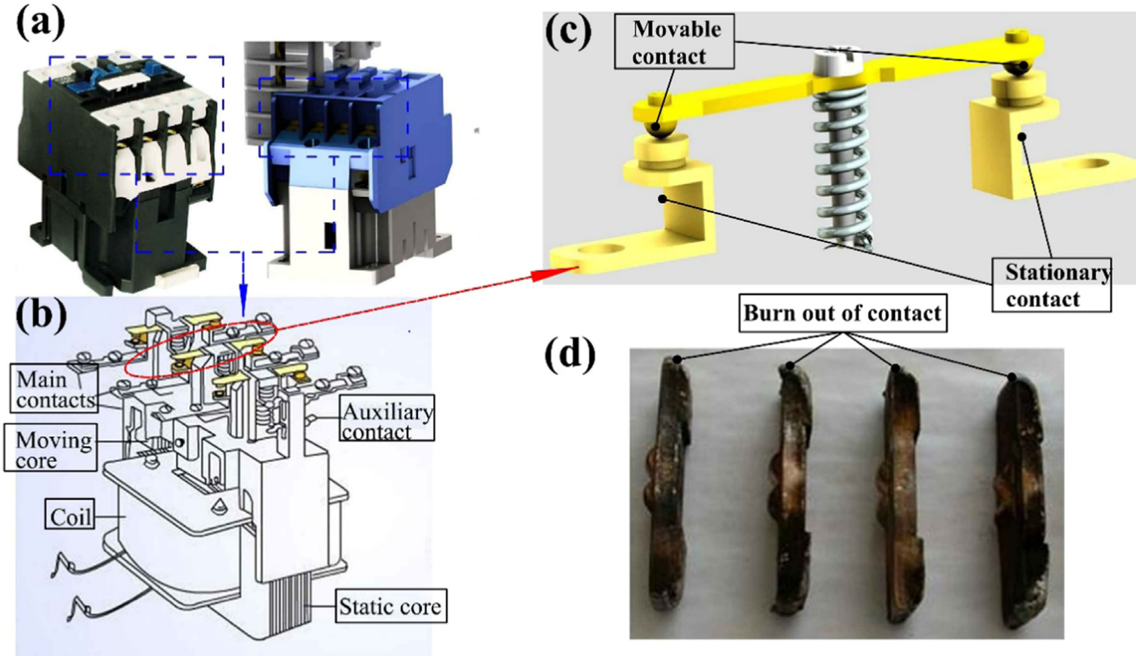

Fig. 1. Typical electrical connector – currently AC contactor.

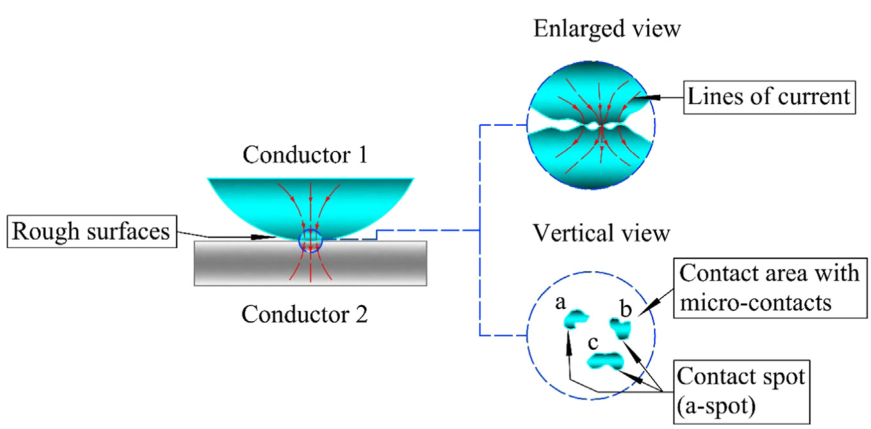

Fig. 2. Definition of electrical contact.

constriction resistance into account, Holm proposed the following approximation Eq. (2) for constriction resistance [13]:

$$R_k = \frac{\rho}{2r} + \frac{\rho}{2na} \tag{2}$$

Where "*r*" indicates the radius of an apparent contact area, "*n*" indicates the number of a-spot, and "*a*" indicates the radius of a-spot. Greenwood released the following contact-resistance approximation Eq. (3) for multiple distinct contacts by considering the interface between a-spot [14].

$$R_k = \frac{\rho}{2\sum a_i} + \frac{\rho}{\pi}\left(\sum\sum_{i\neq j}\frac{a_i a_j}{S_{ij}}\right)\frac{1}{\left(\sum a_i\right)^2} \tag{3}$$

Where "S_{ij}" indicates the distance between a-spot, and "a_i,a_j" indicates the different radius of a-spot.

Current literature discussed tribology issues in electrical contacts and included electrical concepts, constriction resistance, and contact impedance and so on. But current research have not avoid the effect brought from different initiative roughness to experimental result, in this paper, two typical materials (aluminum and silver) have been selected to study the variation tendency of ECR under room temperature (RT) and elevated temperature, all samples have been polished for avoid the effect of initiative roughness and take measurement by white light interferometer. The roughness of regional topography "*Sa*" has been introduced to testify the effectiveness of polish. The measured *Sa* are as follows. (Fig. 3).

All of above work what have been mention was in order to further the study of electrical contact material (ECM) and make it effective used in the industrial field.

2. Experimental details

2.1. Samples and details of materials

The schematic sketch of the fretting apparatus used in this study is shown in Fig. 4(a). The normal load (10 N) applied by weight and hang on the balance arm by wire rope. One of the typical fretting contact mode was set up by flat sample and copper ball (Fig. 4(d)) with the radius being 9.52 mm. The upper sample was made of brass (Cu, 60.5–63.5%; Fe, 0.01%; Pb, 0.08%; P, 0.15%; So, 0.005%; Bi, 0.002% and balance zinc). The copper ball/aluminum alloy (Si, 0.4–0.8%; Fe, 0.7%; Cu, 0.15–0.4%; Mn, 0.15%; Mg, 0.8–1.20%; Cr,0.04–0.35%; Zn,