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Friction, wear and tribofilm formation on electrical contact materials in reciprocating sliding against silver-graphite

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ABSTRACT

In this study nanocomposite coatings mating silver-graphite were investigated for sliding electrical contact applications with the aim to optimize tribological and electrical properties. Apart from two different Ti–Ni–C nanocomposite coatings, brass, steel and TiN were also tested against a commercial silver-graphite at varying load and current. Friction, wear and contact resistance were measured in reciprocating sliding in ambient air. It was concluded that the wear of the silver-graphite was increased by current, for TiN and steel as much as four times, at a 5 N load. A tribofilm, with properties differing from the silver-graphite, formed on the coating/metal surface in all cases. This resulted in a very similar coefficient of friction, 0.3, for all mating materials. However, different load and current gave rise to slightly different thickness and morphology. A too low load was detrimental, as the coating became damaged, while a too high load was not favorable for tribofilm formation. In tests with varying current, a specific current could be identified that best governed the build-up of a well conducting and stable tribofilm. The largest differences were observed in the initial stages of testing, since once the tribofilm was built up, the contact resistance approached that of self mated silver-graphite, 40 mΩ. Experiments showed that the load and the current can be optimized to minimize wear of the silver-graphite which in turn would allow for lower maintenance costs.

1. Introduction

Continuously sliding electrical contacts are necessary whenever current or signal need to be transferred between one stationary and one rotating part. For example, such a sliding contact transfers the current in generators and motors, the power and signals for pitching the blades in wind turbines and the signals in medical computer tomography scanners. Most important for a satisfactory performance is that the current is transferred within acceptable levels of electrical power loss and that signals are transferred with sufficiently low noise. Low wear is important especially in applications where maintenance is complicated and expensive, e.g. in sea based wind turbine generators, or in applications where wear particles may cause problems. Low friction is seldom a priority even though it would be beneficial as less heat is generated and less mechanical energy is lost.

The term electrical brush arose in the mid nineteenth century when the current collectors were made of bundles of copper wire. Associated with these types of brushes were high temperatures, high friction and wear. In the late nineteenth century graphite was introduced as brushes. Although they were blocks of natural graphite or electro graphite, they still kept the name brush. Later, a metal was added to improve conductivity [1]. Different metals and compositions are utilized depending on application and copper is perhaps the most widely used. For transferring signals it is common to add silver rather than copper to improve the signal quality. Likewise, in applications where the current density or rotational speed is high, silver is also the preferred metal.

The rotating part of the contact pair, against which the carbon brush slides, is generally called a collector or slip-ring. Copper or copper alloys such as brass are common materials in slip-rings [1], sometimes replaced by steel to lower the cost. In applications where space is limited, brushes as small as parts of a millimeter are necessary. Such small brushes are difficult to manufacture and they only allow a small amount of wear before their function is affected. Hence, a surface that does not wear the carbon brush, but still transfers current or signals just as well, would be desirable. A low friction coefficient is also of interest, especially in such small designs, as the heat generated is not easily conducted away from the contact zone.

Very little research evaluating different kinds of slip-ring materials in combination with silver-graphite brushes can be found in the literature. Focus seems to have been on the brush part of the contact, describing the influence of the silver content [2,3], and how the environment affects the performance [4,5]. Some research also deals with the formation of thick and thin

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films in the interface [6–8]. In one of the chapters of his book Carbon Brushes, Shobert [9] describes slip-rings for low and intermediate power. For low power applications that use silver- or gold-graphite brushes, slip-rings are commonly made of gold, silver, indium or alloys of noble metals. For intermediate power, silver and silver-alloy slip-rings are most common. In 1978 Johnson [10] evaluated 19 different slip-ring materials and concluded that the best overall performance, minimizing mechanical and electrical loss, was achieved for slip-rings of Cu, Cu alloys and silver against copper graphite brushes. Following this, Rabinowicz [11] evaluated different noble metals against silver-graphite during high speed and high current in 1980. He concluded that metallurgical incompatibility of the slip-ring metal with graphite gave the lowest amount of wear. Rhodium, palladium and platinum would hence be good candidates but the cost of these metals hinders them all from being commonly used today.

When deciding on the content of copper or silver in brushes, there has traditionally been a compromise between good electrical properties, good tribological properties and the cost. Carbon is generally considered to help creating a low friction graphite layer in the interface, whereas increased metal content in the brush results in better conductivity. Deposition of a carbon containing coating on a mating surface, as a contributing carbon source, rather than relying solely on the carbon composite, offers a possibility to increase the amount of metal in the composite without compromising the tribological properties. This could hopefully improve the performance of the entire system and allow increased applicability.

In this study, a type of metastable nanocomposite PVD coating is investigated as alternative surfaces sliding against a silver-graphite composite with low current or signal transfer applications in mind. The nanocomposite Ti–Ni–C coatings are of special interest because they have been shown to have good conducting properties [12], and, as they are deposited as metastable compounds, they are capable of releasing small amounts of carbon. Upon use, the carbon released from the structure diffuses to the surface and helps lower the friction in the sliding interface. The mechanism for release of free carbon is the same in Ti–Ni–C as in the more thoroughly investigated system Ti–Al–C [13].

2. Tribological aspects of sliding electrical contacts

Contact resistance is a common parameter for characterizing an electrical contact. It shows how difficult it is for the current to pass from one part of an electrical contact pair to the other. The contact resistance is a combination of a constriction resistance and a film resistance. The constriction resistance arise from the fact that the current can only pass through spots that are truly in contact and the film resistance is due to any less conducting film present in the interface [14]. The true contact area or load bearing area, which is only a fraction of the apparent contact area, is the area that has to support the mechanical load. The material therein, and its shear strength will dictate the friction coefficient of the contact. In turn, only a small part of this load bearing area might be conducting due to the presence of insulating films, such as thin oxides, or adhering layers of poorly conducting material or wear debris, see Fig. 1. The nature of this minute resulting area is thus highly decisive for the contact resistance and any means to control its properties are highly interesting.

In every sliding contact the two surfaces will affect each other and possibly react with each other and the surrounding atmosphere. The situation is no different in sliding electrical contacts where, in addition, the surfaces also risk forming less conductive compounds or even insulating materials. Unless the atmosphere can be controlled and oxygen free, it is thus important that the elements present in the surface either are inert to oxygen or govern the formation of an electrically conducting cover. Such a cover, a tribofilm, will have properties differing from both the original mating materials and the tribofilms are decisive not only for the contact resistance but also for the wear resistance and friction coefficient [15]. In the sliding contact between silver-graphite and the slip-ring, the very soft silver-graphite will most often adhere to the mating surface and ideally form a conductive and easily sheared tribofilm. Mating surfaces with different chemical composition or topography have, however, different capability to support the buildup of suitable tribofilms. It is likely that the composition, morphology and thickness of the film will be influenced by the load and current which in turn will influence both the coefficient of friction and the contact resistance.

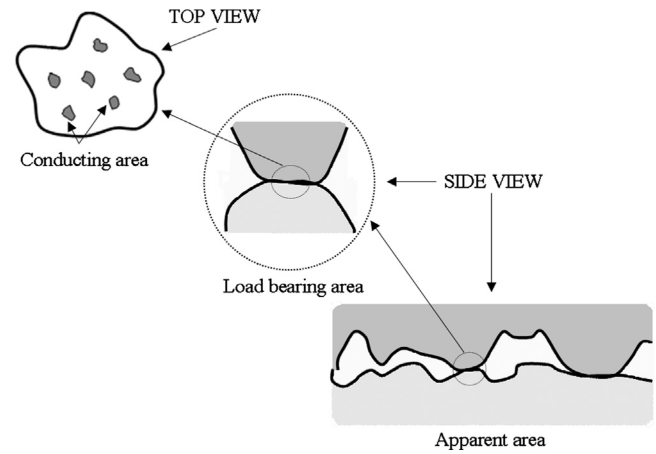

Fig. 1. The conducting area (upper left) in an interface is only a fraction of the load bearing area (middle), which in turn is only a fraction of the apparent contact area (lower right).

Initially, there will be plastic deformation and mechanical wear until the load bearing area is large enough to support the load, and after this the contact area should no longer increase for that reason. However, as soon as we apply current there will be heating caused by the current, joule heating, on top of the frictional heating in the contact. According to Joule's first law, higher current or higher resistance will generate more heat. Even if this does not pose a problem in the bulk of the material, where the resistance is low enough to keep the temperature at safe levels, the situation in the interface is different. In the interface, where the current is restricted to pass through tiny contact spots, the resistance is much higher which might in fact generate enough heat to reach the melting temperature of the material. The melting voltage is a materials property stating the threshold voltage over a contact interface causing melting in the contact spot [5] and the melting voltage of silver is 370 mV. There is also a corresponding softening voltage where the material will begin softening, which for silver is 90 mV [3]. Already at the softening voltage the contact area will increase which will act to lower the resistance and the temperature.

3. Experimental

3.1. Materials

The metal-graphite used in this work is a commercial silver-graphite[1] with a silver content of 50 wt% and small additions of MoS_2 (Molykote® microsize). It is a sintered material where the

[1] Available from Carbex AB, Vadstena, Sweden. www.carbex.se.