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Ti–Ni–C nanocomposite coatings evaluated in a sliding electrical contact application

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ABSTRACT

Nanocomposite Ti–Ni–C coatings, with nanosized carbide grains in an amorphous carbon (a-C) matrix have been suggested to have low friction and low contact resistance making them suitable for sliding electrical contacts. In this study we investigate further the previously observed influence of the amount of amorphous carbon, in a test set-up simulating instrumentation and control applications. The tribological and electrical performance is evaluated at high speed and continuous sliding against silver-graphite, where the mechanical load and current are fairly low. It is shown that under these circumstances there is no significant influence from the amount of a-C on neither the contact resistance nor the amount of wear of the silver-graphite. The reason for this is suggested to be that similar tribofilms are formed on the surface of the coatings, regardless of the amount of a-C phase. Degradation of the nanocomposite coatings is observed under electrical load, even though they are both much harder than the silver-graphite counter surface.

1. Introduction

For continuously sliding electrical contacts, the performance has to be evaluated based on electrical properties as well as on tribological properties. A sufficiently low contact resistance is the most important characteristic, while the tribological aspects of friction and wear are important for reliability and improved component lifetime. From a tribological point of view, hard materials are often beneficial, resulting in low wear rates and low friction due to small real contact areas [1]. The opposite is true for the contact resistance, which is inversely proportional to the conducting area [2], meaning that large real contact areas are desirable from an electrical point of view. For this reason, and because they do not tarnish to form insulating films, soft noble metals are common electrical contact materials. The conducting area between two surfaces is composed of many smaller conducting areas, called a-spots. In total, the a-spots constitute only a fraction of the real contact area, or load bearing area, see Fig. 1a. This is due to the presence of insulating films, such as oxides, that need to be ruptured in order to create metallic bridges capable of conducting current. This gives rise to a constriction resistance, illustrated in Fig. 1b. If additional insulating films are still present at the conducting area, this will give rise to further resistance, called the film resistance [3]. The term *contact resistance* includes both of these contributions; the film resistance in addition to the constriction resistance. In sliding electrical contacts, as in any sliding contacts, the two surfaces will affect each other and possibly react with each other and the surrounding atmosphere. In applications where it is not possible to control the atmosphere, the contacting materials should either be inert to oxygen or form an electrically conducting tribofilm. In sliding electrical contacts, tribofilms will be decisive not only for the friction and wear but also for the contact resistance.

Recent work by the authors on nanocomposite transition metal carbide coatings deposited by magnetron sputtering has shown an interesting combination of mechanical, tribological and electrical properties suggesting a potential use as materials for electrical contacts (see e.g. [4–6]). The fundamental nanocomposite system nc-TiC/a-C (hydrogenated or hydrogen-free) has been thoroughly studied (see e.g. [4, 7–14]). Martínez-Martínez et al. showed that 60–65% a-C phase was the optimum for the tribological performance [14]. Lewin et al. investigated the possibilities of nc-TiC/a-C coatings for electrical contact applications showing that large grains and a thin matrix are favourable for the static contact resistance [4]. Obviously the design possibilities are large for this type of coating; the grain size and matrix thickness can be tailored to achieve desired properties and the design possibilities increase even more by addition of a second metal [15]. During magnetron sputtering at low or moderate temperatures, weak carbide forming metals such as Fe, Al or Ni form metastable solid solutions with

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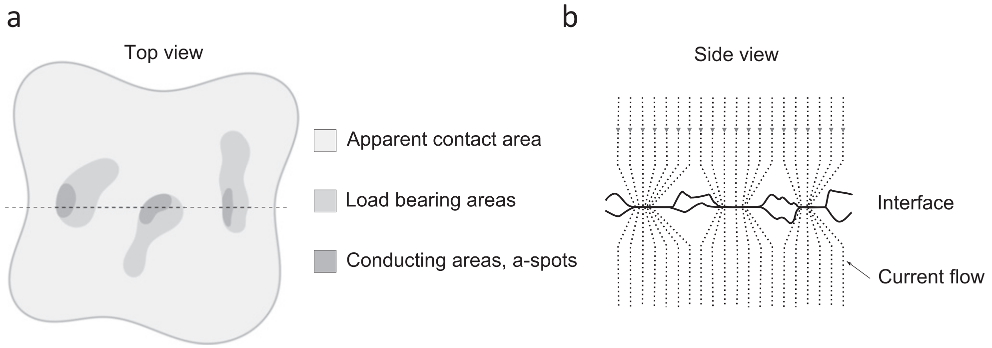

Fig. 1. a) The conducting area is a part of the load bearing area, which itself is a part of the apparent contact area. b) The current is restricted to pass only at the a-spots resulting in a constriction resistance.

(Ti,Me)C grains in an a-C matrix (see e.g. [15–18]). The effect of this is two-fold: firstly it leads to an increase in the amount of a-C matrix in the as-deposited coatings [15]. Secondly, with mild heating or in a tribological contact, carbon atoms will diffuse out of the metastable carbide to form additional a-C on the surface, which has been shown to be favourable in certain tribological applications [5,15,19]. For electrical applications Ni is a proper choice of transition metal as it is not expected to cause problems with hard oxides or corrosion. It has been shown theoretically that Ni destabilise TiC in the same manner as Al [20]. Ni may also catalyse graphitization [21] which is favourable for both conduction in the a-C matrix and for low friction. Ti–Ni–C nanocomposites for electrical contact applications have been investigated by André et al. [5] and Lewin et al. [18]. These studies have shown that the amount of a-C phase in the coating has an affect on the tribo-electrical properties under certain circumstances. From a whole series of Ti–Ni–C coatings, a sample with approximately 70% a-C matrix phase and a grain size of 2–3 nm showed the best tribo-electrical properties [18] and Ti–Ni–C in reciprocating sliding against silver resulted in contact resistances of around 200 μΩ [5].

In the mentioned studies in Ref. [5] and Ref. [18] the Ti–Ni–C coatings were tested with connector applications in mind, simulated by reciprocating sliding against silver at fairly high load and current during a low number of cycles. We suggest that the advantages of a wear resistant coating will be more prominent in applications with continuous motion and long lifetimes. In this study, the test set-up is constructed with instrumentation and control applications in mind. For such applications, the sliding is generally continuous and both the mechanical load and the current are low. The demands on low noise levels and long life times are high. A slip-ring assembly with stationary spring wires contacting a rotating v-grooved ring has been used. The ring is made out of composite silver-graphite which is a common brush material in slip-ring systems for signal applications. It is a proper choice of material for high rotational speed and/or high current density. With this set-up the wire cannot be allowed to be worn at all, which motivates the use of a wear resistant coating. It should also give a sufficiently low contact resistance and preferably contribute to a low coefficient of friction and a low wear rate of silver-graphite. More details about this test set-up can be found in Ref. [22], where it is shown that a difference in the measured contact resistance can be distinguished for different amounts of metal in the graphite composite, different spring-wire loads and different currents. In conclusion, this study focus on an application like set-up and two different industrially produced coatings. The choice of coating composition is based on previous work on Ti–Ni–C coatings and their tribo-electrical performance [23,24]. The high a-C coating has an optimal composition based on previous tests and the low a-C coating has less a-C phase. The aim is to study how the two coatings perform tribologically and whether a coating with higher amount of a-C phase will provide a lower contact resistance than a coating with lower amount of a-C phase also in this set-up.

2. Experimental

2.1. Materials

The Ti–Ni–C coatings were deposited in an industrial high vacuum chamber (base pressure of 10^{-5} Pa) using dc magnetron sputtering from compound targets (210×100 mm^2) of two compositions. The targets were sintered from powder with a nominal composition of 40 at.% Ti/10 at.% Ni/50 at.% C and 28 at.% Ti/7 at.% Ni/65 at.% C respectively. The substrates were spring steel wires with a diameter of 0.45 mm and a principal alloying composition of 0.90 wt.% C, 0.67 wt.% Mn and 0.25 wt.% Si. They were polished manually before coating deposition to an R_a value below 100 nm and an R_z value of about 2 μm. In the deposition chamber the wires were fixed midway between two sputtering sources that were facing each other. The distance between substrate and target was 10 cm in both directions and the substrates were stationary during deposition, rotation is not possible. An Ar-plasma was generated at a constant pressure of 0.7 Pa. Prior to deposition, the substrates were plasma etched for 30 s. This was followed by deposition of a thin Ti bonding layer, estimated to a few tens of nanometers, in order to improve the adhesion between the coating and the substrate. A bias voltage of −50 V was applied to the substrates during deposition. A constant current of 4 A was applied to the targets resulting in a power density of about 5 W/cm^2. There was no external heating of the substrates during deposition. The coating time was 17 min for the 40/10/50 target and 20 min for the 28/7/65 target. The silver-graphite used is a commercial silver-graphite[1] with a silver content of 14 vol.% and small additions of MoS_2 (Molykotes microsize). After pressing and heat treatment, it has an average silver particle size of about 36 μm. It is specified to have a resistivity of 11 μΩm and a hardness of 100 $HR_{10/60}$. Nanoindentation performed in the silver and graphite phases separately shows a hardness of 0.6 GPa in the silver and 0.2 GPa in the graphite.

2.2. Slip-ring assembly

The test set-up, shown in Fig. 2, consists of two rotating silver-graphite rings. The rings are electrically insulated from each other which allows for simultaneous testing of the pure mechanical case on one ring and the case where current is transferred between the surfaces on the other. Each ring has five v-grooved tracks. One wire is placed in a track on the front (positive) side of the ring and another one is placed in a different track on the back (negative) side (not visible in Fig. 2). This allows wear mechanisms on the positive and negative sides to be studied separately. The circular cross-section of the wire and the v-groove shape of the track stabilize the contact in two points, one on each side of the wire, as can be seen in Fig. 2b. A constant direct current is applied

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