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The effect of brush spring pressure on the wear behaviour of copper–graphite brushes with electrical current

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Abstract

Electrical brushes are used to conduct current between stationary part and moving part of a motor or a generator. To ensure proper current transfer and continuous contact, brushes must be loaded against the sliding contact surface with a sufficient force. High loads increase frictional losses and wear of the brushes and/or sliding surface. While relatively low contact pressure causes arcing and higher voltage drop.

In this study, a novel pin-on-slip ring-type friction and wear test machine was designed and manufactured for the purpose of brush testing. Copper–graphite-based electrical brush containing 90 wt% copper and 10 wt% graphite was manufactured by powder metallurgy and the tribological behaviour and voltage drop were investigated at different brush spring pressures at 10–200 kPa with current.

It was found that the specific wear curve showed three distinct wear rate regimes, such as low, mild, and severe. Severe wear was observed below 30 kPa and above 120 kPa brush spring pressures (BSP) (3 and 12 N loads, respectively). Arc erosion was the main wear mechanism below 30 kPa brush spring pressure while abrasion was dominant above 120 kPa BSP. Low and mild regimes were observed between 30–50 and 50–120 kPa BSP, respectively. SEM observations showed that a continuous surface layer was formed at the sliding surfaces of the wear samples in low and mild wear regimes. The wear debris was examined by SEM and X-ray diffractometer.

Keywords: Brush spring pressure; Copper–graphite brushes; Friction and wear

1. Introduction

The critical components in motors and generators are the sliding electrical contacts. Both the sliding electrical contacts and slip rings experience wear, but, since the brush material is usually softer than that of the slip ring, the brush wears out first [1]. Brushes are exposed to mechanical and electrical loading together. Because, brushes are always loaded against the sliding contact surface with sufficient force by a spring to ensure continuous contact. While mechanical wear takes place due to the brush–rotor friction, electrical wear takes place due to the current passing across brushes which causes arcing. From the viewpoints of electrical and frictional heating and abrasive wear, there could be an optimised load for a certain application. During the service of the brushes, mechanical and electrical power losses appear due to the normal load and the current, respectively.

The wear rate of the brushes is affected by many factors, such as contact force, sliding speed, contact temperature, properties (electrical, mechanical and thermal) of the brush material, surface roughness and rubbing conditions [1]. Mechanical and electrical contact wear involves a number of damage processes such as abrasive and adhesive wear, erosive wear, oxidation wear, transfer film and structure modification [2]. Some workers [3] concluded that in steady state for carbon materials, microcutting and grinding of their surfaces by the abrasive wear products and by the counterbody microasperities primarily contribute to wear.

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Myshkin and Konchits [4] commented that for self-lubricating contact materials wear in the absence of an electrical current is the sum of the fatigue and abrasive forms of wear. With the increasing current, some investigations indicated that wear is associated with the increase in the roughness and intensification of the abrasive properties of the metal counterbody surface [5,6]. Early study [7] demonstrated that wear rate is closely related to temperature. Williamson and Allen [8] showed that in high-speed sliding with large current oxidation of carbon material affects directly the wear due to high temperature. In some cases, the oxide film is beneficial because it prevents high friction and wear caused by metal-to-metal contact, but in other cases, the oxide is detrimental because it promotes abrasive wear [1].

Thermal mounding is widely applied to explain the wear process in high-speed sliding with current [9–14]. Marshall [11] experimentally demonstrated that at sufficiently high current densities, the electrical contact material could thermally expand at a rate greater than the local wear rate and thus produces thermal mounding or thermoelastic instability. Thermal mounds or hot contact spots transmit frictional and electrical heating until they are worn flat or detached from the surface [9,11]. As a thermal mound detaches from the interface, the load supported by the mound is transferred to a nearby spot that becomes a new thermal mound [14]. Burton [10] studied the thermal mounding and measured and correlated wear coefficients and temperatures of sliding carbon graphite blocks on a mild steel rotor. Bryant [12] put forward a particle ejection mechanism for brush wear on the basis of a thermoelastic instability theory and suggested that wear is associated greatly with the stress which is related to the high temperature.

Brush interface power loss is an important factor which influences brush life as well as the efficiency of rotating electrical machines. For a given brush system, selection of proper brush contact pressure is necessary to assure satisfactory operation and to minimise brush power loss. The optimum value may be determined experimentally [15].

In previous researches, less effort [7,16,17] has been put forth on the basic friction and wear performance of electrical contact materials and the metallurgical evidence for the wear process such as the appearance of wear debris is inadequate. The main objective of this study was to investigate the effects of the brush spring pressure on the brush wear, power loss and wear mechanisms of the copper–graphite brushes with electrical current by changing the brush spring pressure between 10 and 200 kPa.

2. Experimental

The brush specimens were fabricated by means of powder metallurgy technique and process included mixing powder, compacting and sintering in an argon atmosphere. The composition of brush specimens contained approximately 90 wt% electrolytic copper and 10 wt% natural flake graphite. The electrolytic copper powder (99.7% purity, −45 μm grain size) and natural flake graphite (98% purity, −63 μm grain size) were homogeneously mixed by hand grinding by using a agate pestle and mortar for 25 min and the mixture was compacted in a steel die under a pressure of 250 MPa and then was isothermally sintered for 1 h in pure argon atmosphere at 800 °C to form copper–graphite brushes [16]. The specimens had taken the shape of square prism with the dimensions of 10 mm × 10 mm × 32 mm after sintering. Specific resistance, bending strength and Rockwell hardness were measured as 0.050 μΩ cm, 70 MPa and 107 RHY (3 kg minor load, 15 kg major load and 12.7 mm ball diameter), respectively.

Several investigators constructed wear test machine systems for research on sliding electrical contact [6,10,12,18]. Pin-on-slip ring-type wear testing machine was designed and manufactured for this investigation. The structure of the wear test machine is schematically shown in Fig. 1. Brushes were tested against a normalised AISI 1040 type steel slip ring of hardness 190 HB and with a diameter of 90 mm and a width of 25 mm. The position of brushes and steel slip ring is shown in Fig. 1. The slip ring was driven by a 1 kW electrical motor and the brush current was provided by analog to digital converter (a.d.c.) power supply, which can provide a maximum voltage of 100 V and a maximum current of 250 A. The sliding surface of both brush and slip ring was polished with a 320 grit emery paper in order to obtain constant surface roughness and the slip ring and specimen surfaces were cleaned with acetone impregnated cloth before each experiment. The slip ring surface roughness was measured as $R_a = 1.3$, $R_z = 4.5$ and $R_{max} = 5.5$.

The tests were performed under the ambient conditions at room temperature. The brush temperature was

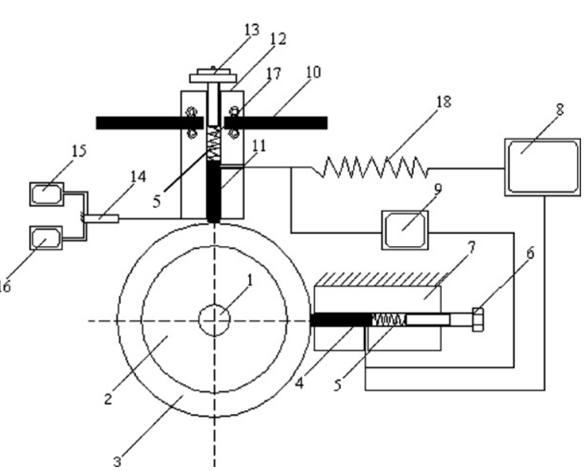

Fig. 1. Schematic representation of pin-on-slip ring-type friction and wear testing machine. 1: Rotating shaft; 2: insulating ring; 3: steel slip ring (AISI 1040); 4: electrical brush; 5: spring; 6: loading screw; 7: brush holder; 8: AC power supply; 9: multimeter; 10: Chamfered frictionless surface; 11: brush; 12: brush holder; 13: dead load; 14: load cell; 15: DC power supply; 16: PC; 17: ball bearing; 18: current adjustable.