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Effect of the Friction Characteristics of Sliding Contacts on Electrical Signal Transmission

Ho Jang[†] **and Hyung Kyu Park**

Division of Materials Science and Engineering, Korea University

Abstract : A resin bonded copper-graphite brush was investigated to evaluate the characteristics of electrical signal transmission through a sliding contact as a function of the relative amount of graphite and copper in the brush. Particular attention was given to the correlation between electrical signal fluctuation and tribological properties in an electrical sliding contact system. A ring-on-block type tribotester was used for this experiment and the ring was made from pure copper. Results showed that a copper-graphite brush at a particular composition range exhibited the most stable frictional behavior with a minimum voltage drop. The amount of voltage drop at the friction interface was affected by the surface roughness, transfer film formation at the friction interface, and the real area of contact. Microscopic observations and the surface analysis showed a good agreement with the results from this experiment. The results also indicated that the electrical signal flunctuation was directly associated with the oscillation of the coefficient of friction during sliding by nanoscale variation of contacts at the friction interface.

Key words : Electrical signal, slipring-brush, real contact area, copper, graphite, friction characteristics

Introduction

An electrical brush used in a slipring assembly is a component that transmits an electrical signal that is generated from sensors or power sources in a rotating body to a stationary module through sliding electrical contacts. The sliding electrical contact is omnipresent in the machines and electronic devices that involve a rotating body that generates electrical signals. Electric motors, CT scanners, navigators, radars, commutators, satellites and are a few examples of numerous applications. The transmission of the electrical signal is carried out through the real area of contacts between surface asperities at the sliding interface on a molecular scale [1]. In general, the real contact area is only a small fraction of an apparent area of contact and continuously changes during sliding. The real area of contact is strongly associated with the material properties of the ring and brushes [2]. Therefore when an electrical signal passes through a sliding interface, constriction of the contact area occurs at the junction, resulting in the increase of the resistance. The constriction resistance is, therefore, influenced by the physical condition of rubbing surfaces such as surface roughness. The increase of the resistance by the current constriction is defined as a constriction resistance. Fig. 1 show a schematic diagram of the constriction resistance formation at the contacts [3,4]. On the other hand, the resistance at the sliding interface is also affected by the transfer film at the friction interface. Therefore, the contact voltage drop and signal fluctuation at the sliding interface are mainly attributed to the increase of contact resistance at the sliding contacts and transfer film formation [5].

Generally accepted prerequisites for brush materials considering accurate signal transmission through the sliding interface are: 1. Thermal and electrical conductivity of a brush material must be excellent. 2. Small fluctuation of an electrical signal with changes of sliding velocity, signal intensity, contact pressure, and etc. 3. Excellent wear resistance. In order to satisfy the above requirements, various materials have been developed for brushes for electrical sliding contacts. They are electrographite, carbon-graphite, resin-bonded materials, metal-graphite materials, and etc [4,5]. Among them the metal-graphite brushes are most frequently used for sliding contacts due to their low contact voltage drop. The metal-graphite brush contains high electrical conductivity metals such as silver, copper, and gold with graphite as a solid lubricant.

The performance of the electrical brush is associated with the mechanical, chemical, thermal, and material factors, which

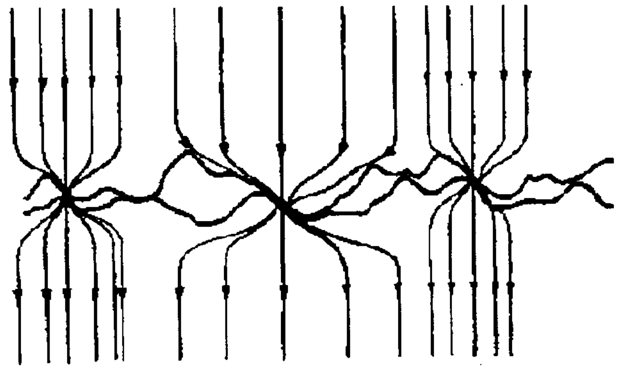


Fig. 1. A Schematic diagram of bulk electrical interface showing constriction of currents [4].

[†] Corresponding author; Tel: 82-2-3290-3276; Fax: 82-2-3290-3714
E-mail: hojang@korea.ac.kr

Table 1. The composition and physical properties of electrical brush materials used in this work [vol. %]

Ingredients	CG95	CG80	CG60	CG40	CG20
Copper	95	80	60	40	20
Graphite	0	15	35	55	75
Resin	5	5	5	5	5
Hardness (HV)	31	22	19	12	7
Resistivity (μΩcm)	6	11	23	42	73

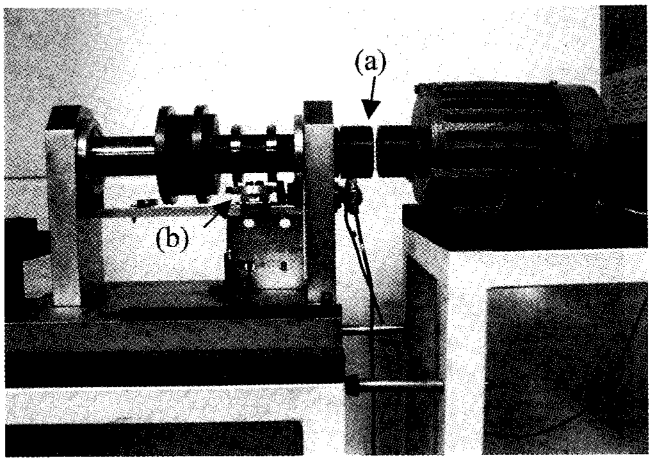


Fig. 2. Slipring-brush assembly used in this study: (a) Magnetic coupling, (b)Brush holder assembly.

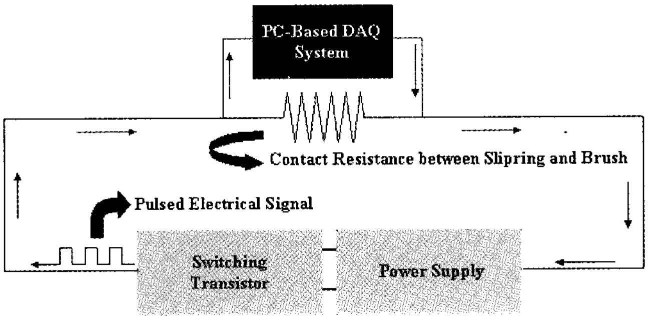


Fig. 3. A schematic diagram of the electrical circuit of the slipring brush assembly for voltage drop measurements.

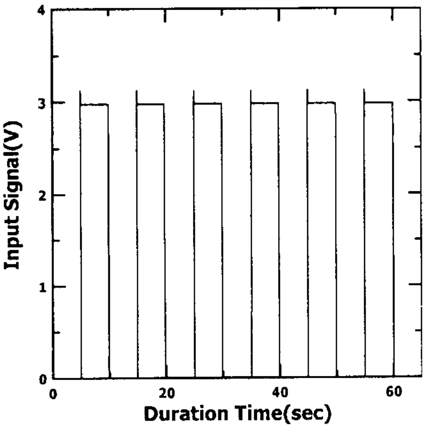


Fig. 4. A pulse type input signal used in this experiment.

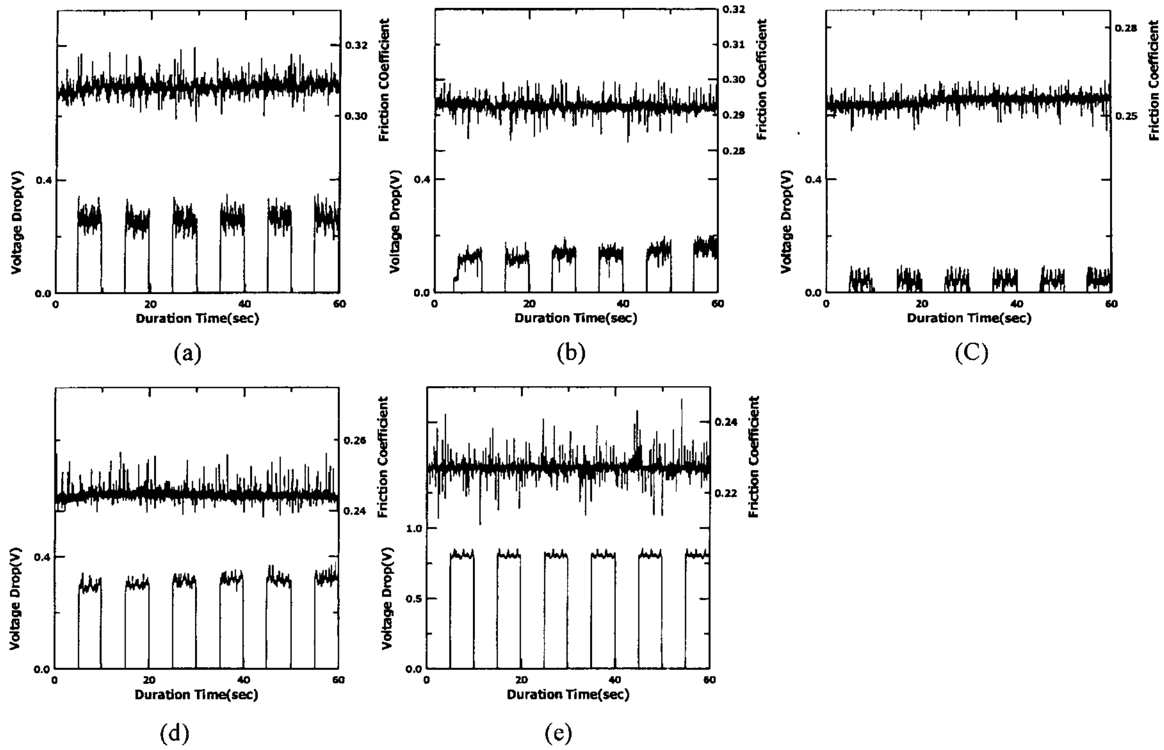
should work together for successful applications. Mechanical factors are related with the radius of contact, friction excited vibration, and heat flow at the friction interface. Chemical factors involve the oxidation of conductor surfaces, effects from the environmental condition, and the formation of friction film at the sliding interface. Thermal factors changes the electron behavior of the contact materials by changing the material properties at elevated temperatures. Among them the friction excited vibration and the effect from the surface films are known as major sources of voltage drops and signal fluctuation in the sliding electrical contacts [6-8].

In this study, a copper-graphite brush with a resin binder was investigated using a ring-on-block type tribotester. Main focus was given to the relation among voltage drops, the coefficient of friction, and the intensity of friction oscillation. Those friction characteristics during sliding were examined as a function of the relative amount of graphite and copper in the brush.

Experimental Details

Brush materials used in this work were made from copper powder (200 μm), phenolic resin (Xylok™, Mitsuitoatsu Chemical Co.), and graphite (400 μm). Five different brush specimens were manufactured. The detailed composition and physical properties of the brush specimens were given in Table 1. The brush specimen was manufactured using a conventional method for a composite comprising mixing, hot pressing, and curing. Table 2 showed the detailed manufacturing condition used in this study for brush specimens. The size of the brush specimen was 10×10×5 mm. The ring was made from a pure copper and it was 70 mm in diameter, 10 mm in width, and 10 mm in thickness. Hardness of the brush specimen was measured using a Vickers hardness tester (HMV-2000, Shimadzu) and electrical conductivity was measured using a four-point probe (CMT-series, CM Co.).

A slipring-brush assembly was designed for this research, which was similar to a block-on-disk type tribotester. Fig. 2 shows a photograph of the slipring-brush assembly designed for this work. The normal force that the brush applies to the slipring was controlled by a dead weight. To prevent the vibration generated from an electric motor, the driving part and the measuring part were separated using a magnetic coupling. Fig. 3 shows a schematic diagram of the electrical circuit. A power supply (Hewlett Packard 6642A system DC power supply) with a switching transistor was used for an input signal that generated a pulse-type voltage. Fig. 4 shows a pulse type input signal used



(a) (b) (C)

(d) (e)

Fig. 5. The coefficient of friction and contact voltage drop of brush specimens: (a) CG95 (95 vol. % Cu), (b) CG80 (80 vol. % Cu), (c) CG60 (60 vol. % Cu), (d) CG40 (40vol. % Cu), (e) CG20 (20vol. % Cu).

in this work. A signal fluctuation occured at the friction interface was measured from a contact voltage drop at the sliding interface. Friction force, sliding velocity, and contact voltage drop were measured at a 100 Hz data acquisition rate using a PC-based DAQ system (Lab-PC 1200, National Instrument Co.). A run-in process was carried out on 400 Pa at 1000 rpm for 3 hrs. An electrical signal transmission test was carried at 1A during sliding at 30 rpm under 220, 280, 340, 400 Pa of load. The frictional and electrical behaviors at each sliding condition were observed and analyzed. Surface morphology of brush specimen after sliding tests was examined using an optical microscope (LEICA MZ6), and the surface roughness of each specimen was measured using a surface profilometer (Tenor Co. Alpha-step 500 surface profiler).

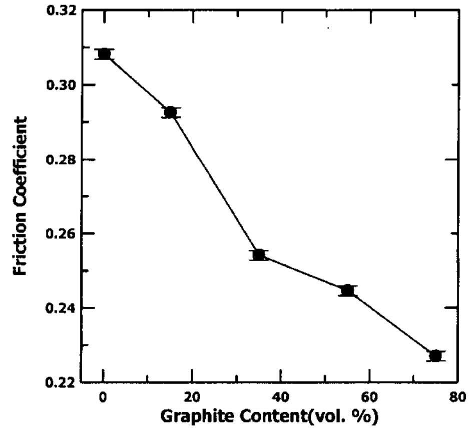


Fig. 6. Friction coefficient as a function of graphite content.

Results and Discussion

The Change of the Friction Coefficient and Voltage Drop According to the Relative Amounts of Graphite and Copper in the Brush

To investigate the effect of the graphite content on friction characteristics, the coefficient of friction (COF) and voltage drop were measured during sliding of the brushes on a copper ring. The friction tests were carried out at 1A (current), 220 Pa (pressure), 30 rpm (rotating speed) for 60 sec. The COF and voltage drop according to the graphite content in the brush were shown in Fig. 5. The figures indicated that the amount of copper (or graphite) in the brush specimen strongly affects the COF and voltage drop. Fig. 6 summarized the COF as a function of graphite contents in the brush. The figure shows that the COF is linearly proportional to the graphite content in the brush. However, the voltage drop exhibited a minimum value near 35 vol.% of graphite, suggesting that factors other than the COF play a role in determining the voltage drop as shown in Fig. 7. In the Fig. 7, energy loss (V· I· t (J): V (voltage), I (current), t (time)), instead of voltage drop, was plotted. This is because some voltage drops during sliding were deviated from original pulse shape. In order to investigate the change of the voltage drop as a function of graphite content, surface roughness of the rubbing surface of brush specimens were also measured (Fig. 8). The figure showed that the surface roughness increased as the graphite content in the brush specimen decreased, implying that the smaller area of real contacts exists at the rubbing surface. The high COF and

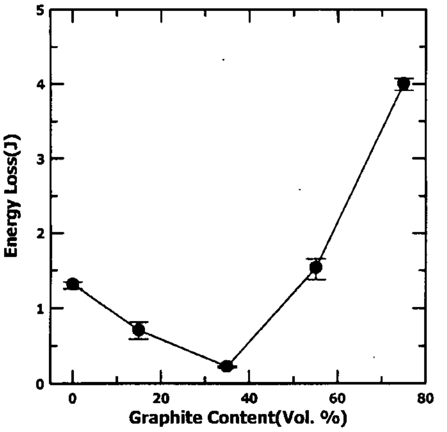


Fig. 7. Energy Loss as a function of graphite content in the brush specimens.

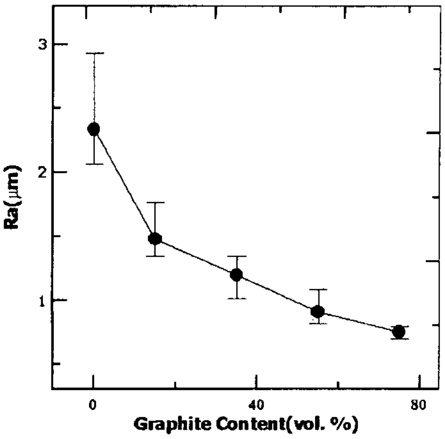
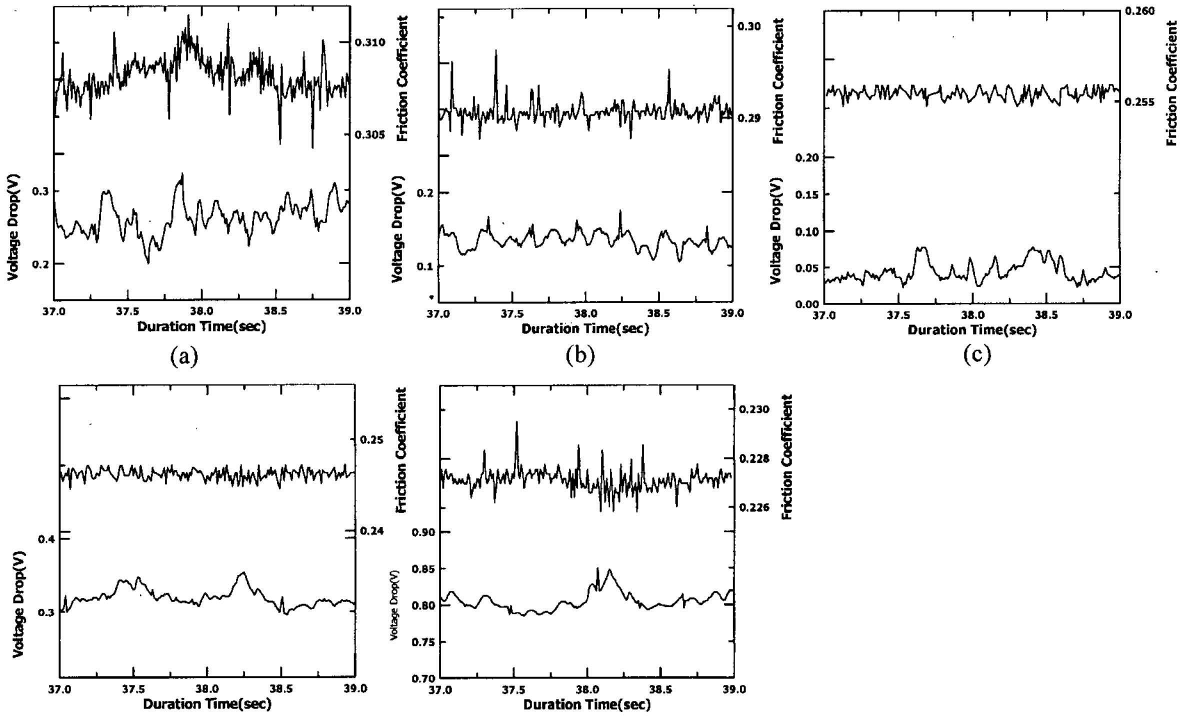


Fig. 8. Surface roughness (Ra) of brush specimens as a function of graphitecontent.

the high surface roughness of brush specimens in the case of high copper contents appeared to provide high resistance at the friction interface during sliding due to friction-induced vibration and small area of metallic contacts. The energy loss from the brush specimen appeared to be caused by the electrical resistivity of the brush itself and the real area of contact that is associated with surface roughness of the rubbing surface. Therefore, the energy loss during sliding decreased as a function of the graphite content in the case of using brush specimens containing small amount of graphite due to high surface roughness and friction-induced vibration of high copper content brush specimens. On the other hand, the increase of energy loss with high graphite contents suggested that the resistivity of brush dominated the effects from surface roughness and the high COF.

Oscillations of Friction Coefficient and Fluctuation of the Transmitted Electrical Signal During Sliding

Oscillation of the COF and fluctuation of electrical signals during sliding were carefully examined to correlate them with the relative amount of ingredients in the brush specimen. The oscillations of the COF and electrical signal are attributed partly to the mechanical vibration of the experimental apparatus and also due to the different friction characteristics at the sliding interface. It is believed that the friction characteristics and voltage oscillation are not independent each other since non-uniform sliding contacts results in fluctuation



(a) (b) (c)

(d) (e)

Fig. 9. Fiction coefficient and contact voltage drop of brush specimens: (a) CG95, (b) CG80, (c)CG60, (d) CG40, (e) CG20.

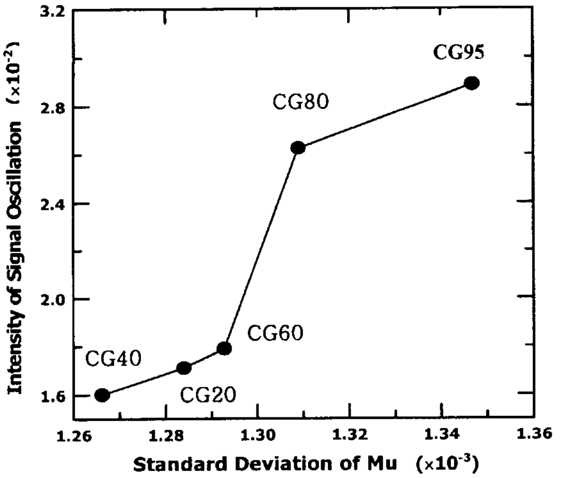


Fig. 10. Intensity of signal oscillation as a function of standard deviation of friction coefficient.

of an electrical signal. Fig. 9 shows the fluctuation of voltage drop and oscillation of the COF according to the 5 different brush specimens. As we expected, an approximate linear relationship between the fluctuation from voltage signal and the oscillation of the COF was found (Fig. 10). However, the signal oscillation and the oscillation of the COF were not proportional to the amount of copper (or graphite) content in the brush specimen. Fig. 11 shows the amounts of signal fluctuation and the oscillation of the COF as a function of graphite content in the brush. The figure suggested that the amounts of the oscillations were approximately proportional to the graphite content except the brush specimen containing 80 vol.% of graphite. The monotonous decrease of the signal oscillations suggested that the graphite played a role to form a lubricating film on the ring surface as shown in Fig. 12. However, Fig. 12 (e) showed that the rubbing surfaces of the brush and ring retain too much graphite and result in delamination of extra graphite on the friction films. The unstable friction film on the rubbing surfaces seemed attributed to the slight increases of the signal oscillation and the fluctuation of the COF in the Fig. 11.

The Effect of Applied Load on the Coefficient of Friction and the Amount of Voltage Drop

Drag tests were carried out to examine the effect of applied load on the COF and the voltage drop at the sliding electrical contact. The tests were carried out at 4 different applied loads (220, 280, 340, 400 Pa) at 30 rpm and the current was set at 1 A. Fig. 13 showed the change of the COF as a function of the applied load for 5 different brush specimens. The COF was increased with applied load suggesting that a large friction force was exerted at the friction interface due to the increase of copper to copper contacts at high loads. The level of the COF showed a similar trend as in the Fig. 6, exhibiting the lower values of the COF for brushes with high contents of graphite. Fig. 14 shows the change of the energy loss at the sliding interface as a function of the applied load. The figure showed that energy loss (or voltage drop) was decreased as the applied load was increased. This result appeared due to the fact that the thickness of the friction film decreased as the applied load increased and squeezed the friction film. This result also showed the similar trend as in the Fig. 8, suggesting that the contribution from inherent resistivity of the brushes and surface roughness of the rubbing surface play important role in determining the voltage drop at the slipring-brush assembly.

Conclusions

Tribological and electrical behaviors were investigated using a ring-on-block tribotester according to five different brush materials containing different relative amount of copper and graphite. The experimental results showed following conclusions:

1. The coefficient of friction was directly related to the amount of graphite (or copper) in the brush specimen.
2. Surface roughness of the rubbing interface after tests increased as the copper content in the brush increased.
3. The voltage drop from the rubbing interfaces of a slipring-brush system was dependent on the resistivity of the brush and surface roughness of the rubbing surfaces. Optimum composition of the brush showing lowest voltage drop was approximately at 35 vol. % graphite+60

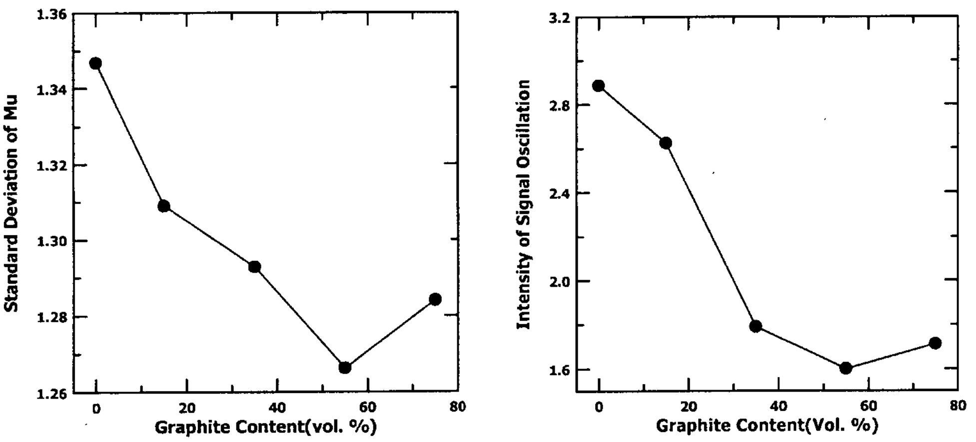


Fig. 11. Standard deviation as a function of graphite content: (a) STD of friction coefficient, (b) Intensity of signal oscillation.

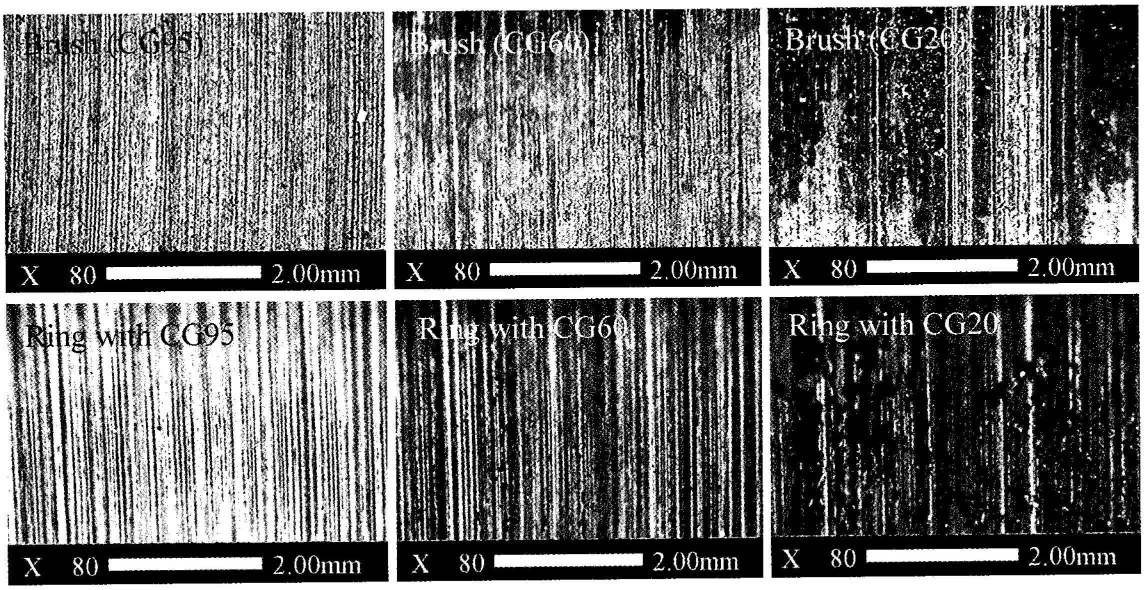


Fig. 12. Surface morphlogy of brushes and a slipring: (a) CG95(Cu 95vol.%) brush, (b) CG60(Cu 60vol.%) brush, (c) CG20(Cu 20Vol.%) brush, (d) slipring rubbed with CG95 brush, (e) slipring rubbed with CG60 brush, (f) slipring rubbed with CG20 brush.

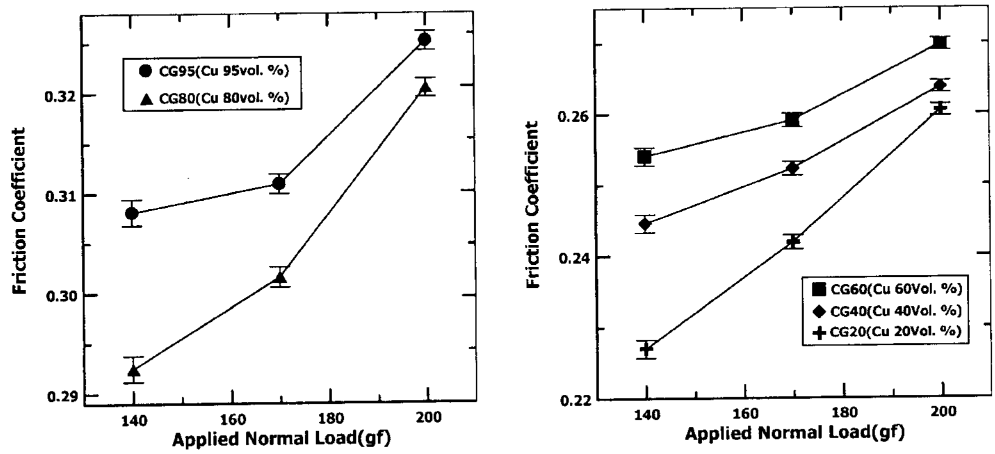


Fig. 13. Friction coefficient as a function of the applied load.

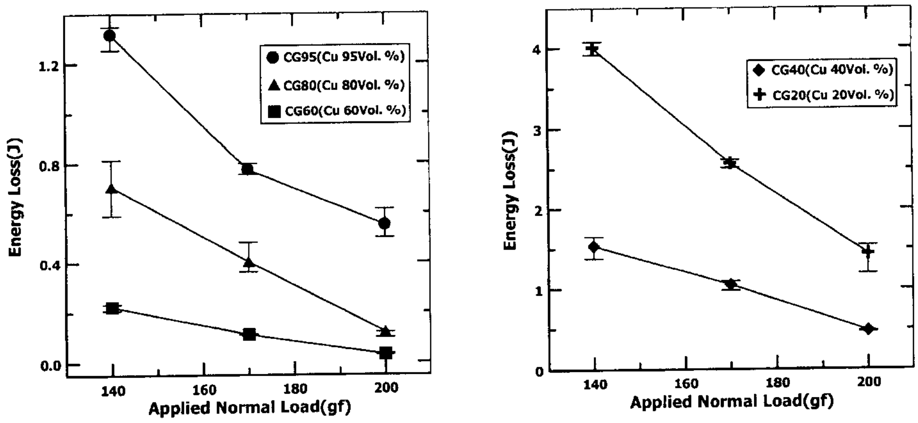


Fig. 14. Energy loss as a function of the applied normal load.

vol. % copper+5 vol. % phenolic resin.

4. The fluctuation of voltage signal during sliding contact was proportional to the oscillation of the coefficient of friction during sliding.
5. Increase of the applied load on the friction couple increased the coefficient of friction and decreased the

voltage drop at the friction interface.

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