Wear Resistance and Electrical Properties of Functionally Graded Epoxy-Resin/Silica Composites

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Abstract

In this paper graded Silica/Epoxy composites fabricated by controlled mold filling to obtain a stepwise graded structure. The generated graded structure was controlled by the wt% content of silica particulates of size ranges from (45 μm–250 μm). Microstructural characterization was conducted using Scanning Electron Microscope (SEM). Electrical properties were conducted in High Voltage–Lab using Sphere-Plate Electrode System and Insulating Resistance Equipments. Wear characteristics were studied using Block-on-Ring wear testing machine for the different layers of the graded Silica/Epoxy composites. The prepared materials are used as coating materials for the floors of chemical laboratories.

1. Introduction:

Functionally graded materials (FGMs) are well known generation of engineering materials wherein the material composition varies gradually in some directions to achieve unique mechanical and electrical performances different from those of homogeneous or joined dissimilar materials. Composites constituted of FGMs are of attracting wide attention especially in radiation protection [1]. Criteria for graded material classification include the geometry of the gradation, distinguishing whether the gradation goes throughout the bulk or only affects the coating, and also the function of the gradation. The main feature of a graded material is that it is used to produce components having deliberately introduced transitions in microstructure and/or composition, which ultimately cater the need of functional requirements that vary with location within the part. Numerous techniques for synthesizing functionally graded materials are available however synthesis of such a material is possible only if there is a precise control on chemical composition and fabricability exists for such a material.

There is a great need for composites because the combination of two or more materials can lead to enhance performance and outstanding properties compared to their constituents. Especially, the polymer-based composites reinforced with small percentages of strong fillers can significantly improve the mechanical, thermal and barrier properties of the pure polymer. The combination of several materials in one component offers, in many cases, significant improvements to its functional performance. Optimally, material properties throughout a component should be tailored to its specific application, often requiring combinations of properties that are unattainable with a single homogeneous material. Functionally graded materials (FGMs) offer an advantageous means of combining materials, providing a spatial variation in composition and properties, as an alternative to homogeneous materials and bimaterial interface structures [1].

The initial emphasis for FGMs focused on the synthesis of thermal barrier coatings for aerospace applications, however, subsequent investigations have addressed a wide variety of applications [2,3]. Many of these applications involve dynamic events such as blast protection for critical structures and armors for ballistic protection. Other applications of FGMs include bone and dental implants, piezoelectric and thermoelectric devices, and optical materials with graded refractive indices [4]. Parallel to advancements in FGM manufacturing and experimentation, methodologies to evaluate and predict FGM properties and behaviors have been developed. For example, homogenization technique and higher-order theory have been adopted to evaluate effective material properties and responses [5-8].

When silica particles added into a polymer matrix to form a composite, they play an important role in improving electrical, mechanical, and thermal properties of the composites [9, 10].

The aim of the present work was to fabricate graded Silica/Epoxy composites using mold-filling technique to obtain a stepwise FGM structure. Studying the correlation between electrical conductivity, breakdown voltage and wear resistance with the variation of silica wt% content in graded Silica/Epoxy composites. During this work we attempted to use simple mechanical stirring technique and slowly poured in glass tubes to create graded distribution of silica particulates in epoxy structure. Microstructural characterization was conducted using Scanning Electron Microscope SEM. Electrical properties were conducted in High Voltage-Lab using Sphere-Plate Electrode System and Insulating Resistance Equipments. Wear characteristics was studied using Block-on-Ring wear testing machine for the different layers of the graded Silica/Epoxy composites.

2. Experimental Procedure:

The material of specimen used in this study was epoxy Novo Floor SI2 composites reinforced by silica particles with median diameters of (45-250) µm. The filler material mixed with epoxy resin in different percentages (0 wt.%, 10 wt.%, 15 wt.% and 20 wt.%) by simple mechanical stirring technique and slowly poured in glass tubes so as to get cylindrical specimens. The low temperature curing epoxy resin and corresponding hardener are mixed in a ratio of 10:1 by weight as recommended. The mix is stirred manually to disperse the filler particles in the matrix. The functionally graded material was produced by successive pouring of resin with several filler volume contents. In a gravity molding process, the mold was partially filled with the first layer of epoxy mixed with a specific volume content of silica, and in a further step, the second layer of epoxy mixed with different volume content of silica was poured on the partially solidified first layer. Processing sequence shown in Figure 1. Thereafter moulds are kept for post-curing at room temperature as recommended and then the hardened composite samples are extracted from the container. Finally, a gradient in the filler content is obtained. An unfilled sample is also fabricated for comparison purpose.

The reinforced epoxy composite plates with silica particles were cut into specimens with proper dimensions and shapes for each test of wear resistance.

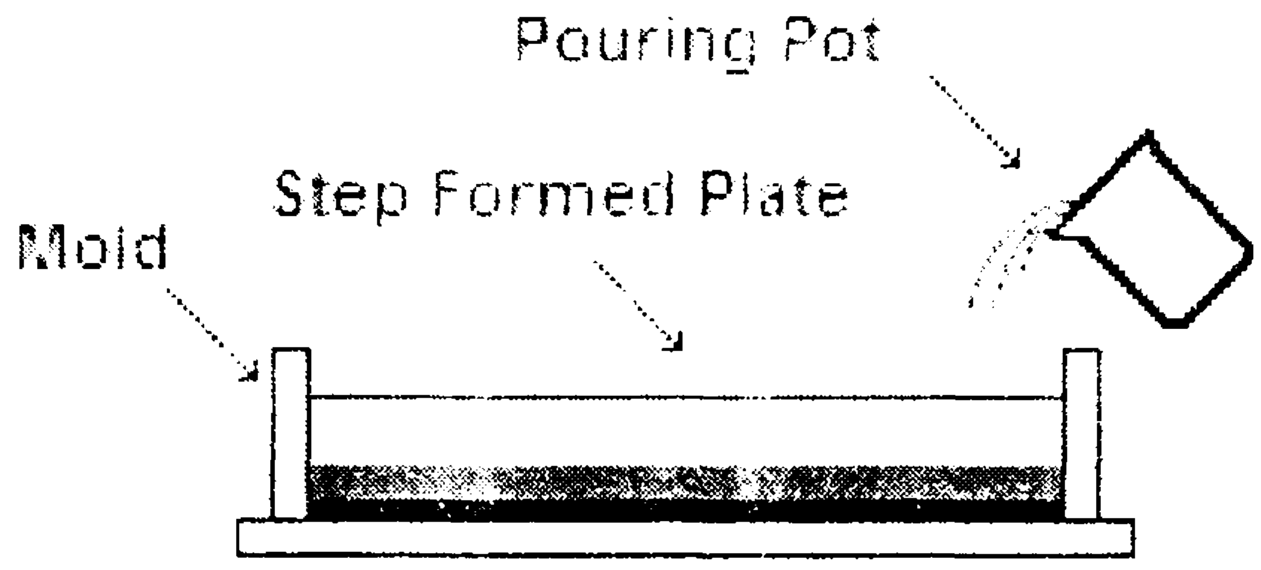

Figure 1: Controlled Mold Filling Processing Sequence.

Wear tests were carried out as per ASTM G 99 using a pin-on-disc type friction and wear monitoring test rig supplied by DUCOM Ltd to estimate the performance of the specimen under dry sliding conditions [11]. The counter body is a disc made of hardened ground steel. The specimen is held stationary and the disc is rotated while a normal force is applied through a lever mechanism. Three sliding velocities of 10, 20 and 30 cm/s under three different normal loading of 20 N, 30 N and 40 N are used for conducting wear tests.

The specific wear rate (mm^3/Nm) can be expressed on 'volume loss' basis as [9]:

$$W_s = \Delta m / \rho t V_s F_N \quad (1)$$

where Δm is the mass loss in the test duration (g), ρ is the density of the composite (g/mm^3), t is the test duration (s), V_s is the sliding velocity (m/s), F_N is the average normal load (N). The specific wear rate is defined as the volume loss of the specimen per unit sliding distance per unit applied normal load.

Measurements of the electrical conductivity were carried out using a surface resistivity-testing device. The surface resistivity is the ability of a material to leak away localized charges across the surface, and it is related to the ability of a sample to control the electrostatic discharge. The electrical conductivity was measured between the two electrodes by applying a voltage across the surface of the sample, measuring the resultant current, and then performing the following calculation:

$$\sigma = \frac{IL}{UA} \quad (2)$$

where I is the resultant current; U, the voltage potential; A, the surface of the electrode; L is the distance between electrodes [11].

A sphere-plate electrode system was designed and used for the measure the breakdown voltage of silica/epoxy graded and homogenous plates. The plate electrode, which is above the ground plane, is grounded where as the sphere electrode is connected with HV connector. The used sphere electrode has a diameter of 25 cm and the electrode is made of aluminum material with nickel coating and silica/epoxy plates is acting as an insulating medium between sphere electrodes shown in Figure 2. Before conducting the test the sphere electrode is cleaned with carbon tetra chloride (CCl4) so that it is free from floating dust particles, fibers. With the application of the high voltage between the electrodes, a non-uniform electric field is generated, as the surfaces of electrodes are not uniform. The HV electrode is energized from the 50 HZ transformer with a power rating of 50 kV. The test voltage applied gradually till the current crossing between the two electrodes. The break down voltage recorded from the control panel.

The maximum electric field in gap between the electrodes is:

$$E_{max} = 0.9\frac{V}{x}\left(\frac{a+x}{a}\right) \qquad (3)$$

where: V is the voltage applied (kV); x, is the distance between the sphere and the plane plate (mm); a is the radius of the sphere (mm).

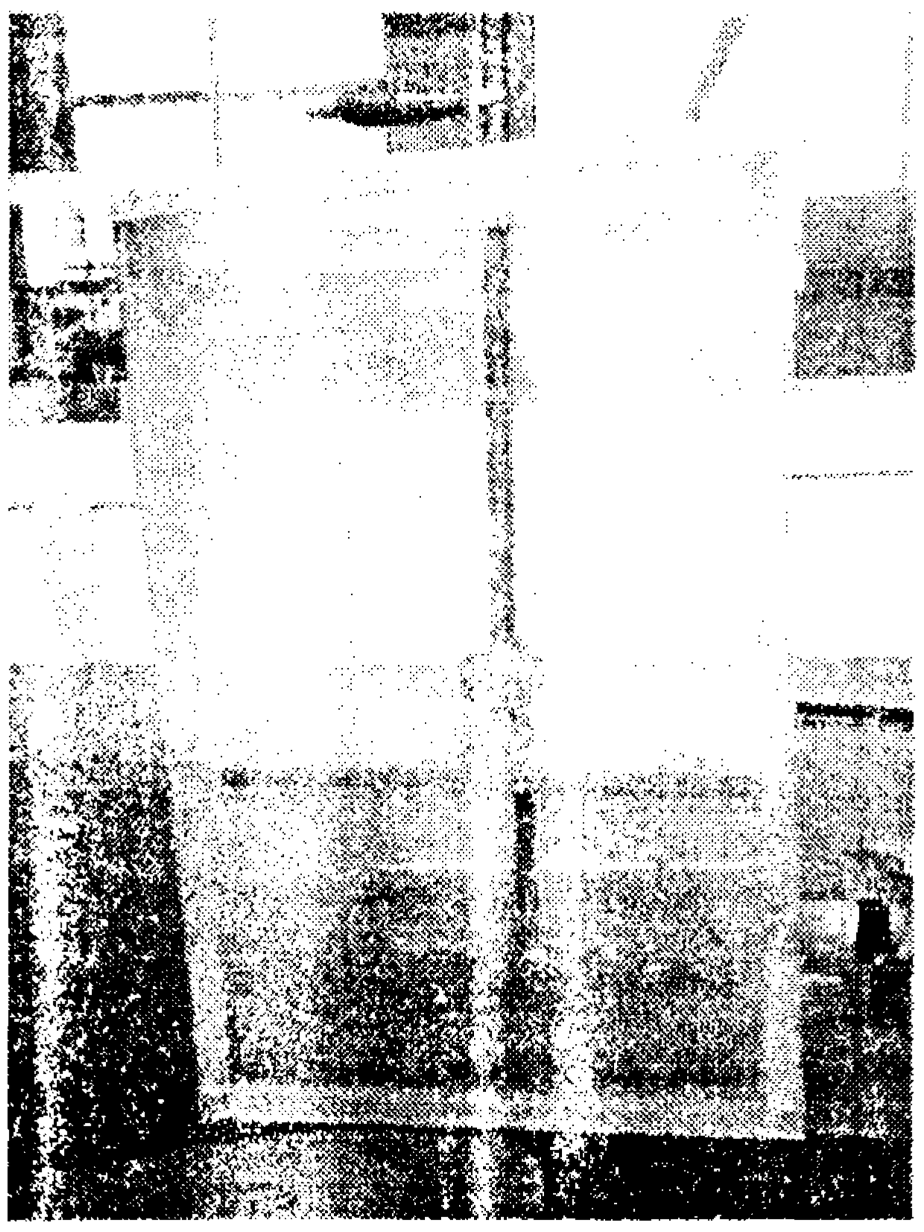

Figure 2: Break down voltage of Silica/Epoxy Plates Introduced Between The Two Electrodes.

3. Results and Discussion:

Figure 3 shows the graded distribution for stepwise graded Silica/Epoxy composites, as observed by scanning electron microscope under magnification of 150X. It's clearly shows that the content of Silica increased in every layer with respect to the preceding layer.

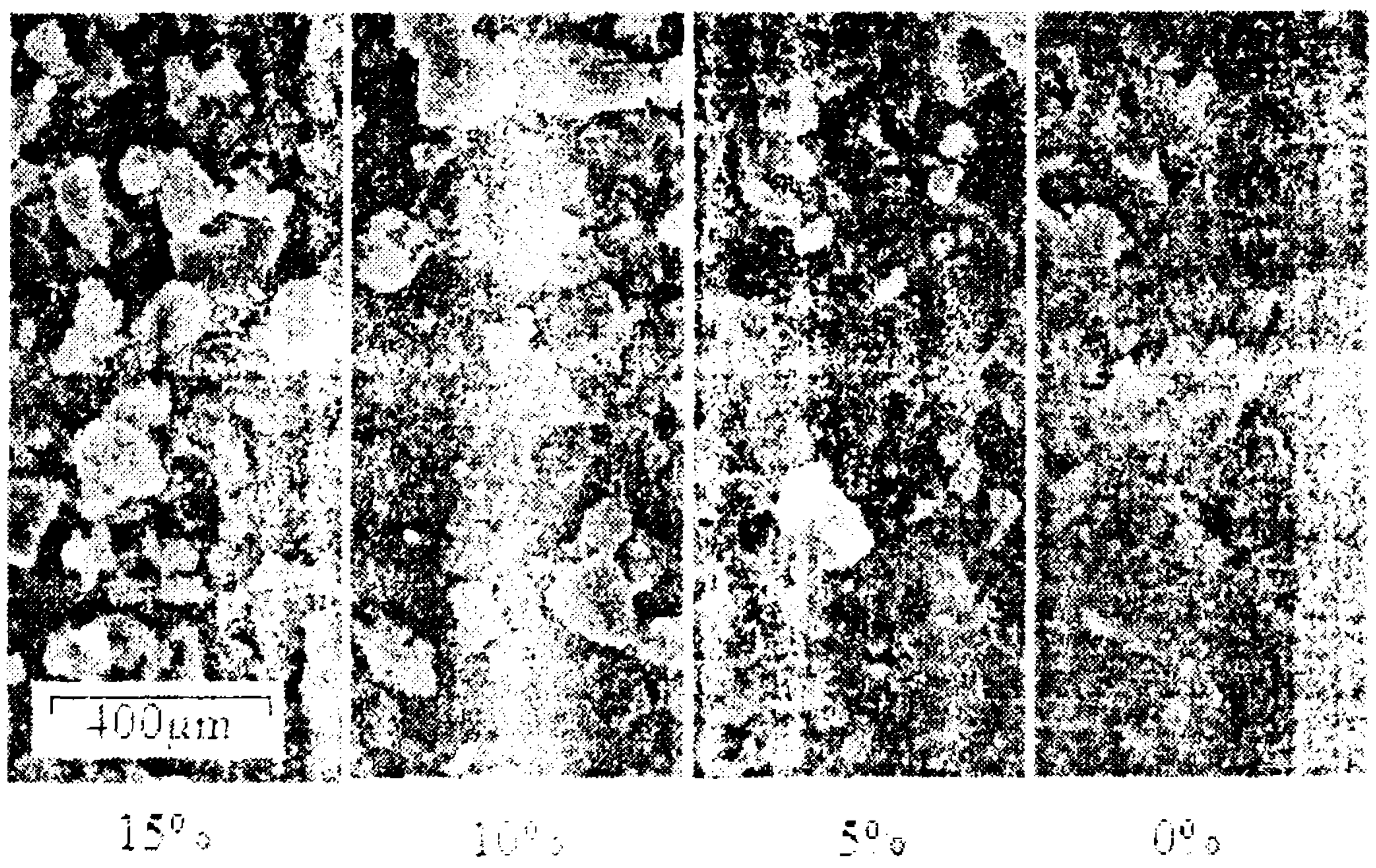

Figure 3: Microstructure of Stepwise graded Silica/Epoxy Composites.

Figure 4 shows the electrical conductivity due to the silica filled epoxy polymer composites and the pure epoxy resin as a function of silica wt% content at constant voltage (20 KV). The electrical conductivity didn't affect till about 15 wt% silica content. Above 15 wt% content silica till 20 wt% silica content the electrical conductivity increased by a large amount at a high rate of increment. Above 20 wt% silica content the electrical conductivity increased slowly by increasing the silica content.

The breakdown voltage at different silica wt% content at constant applied frequency (50 Hz) and room temperature (34°C) for positive and negative polarities are shown in Figure 5. The breakdown voltage didn't affect till about 15 wt% silica content. Above 15 wt% content silica till 20 wt% silica content the breakdown voltage decreased by a large amount at a high rate of decrement. Above 20 wt% silica content the breakdown voltage decreased slowly by increasing the silica content. The changes in the breakdown voltages due to the change in polarity indicate that the negative polarity exhibits a lower breakdown voltages compared with positive polarity.

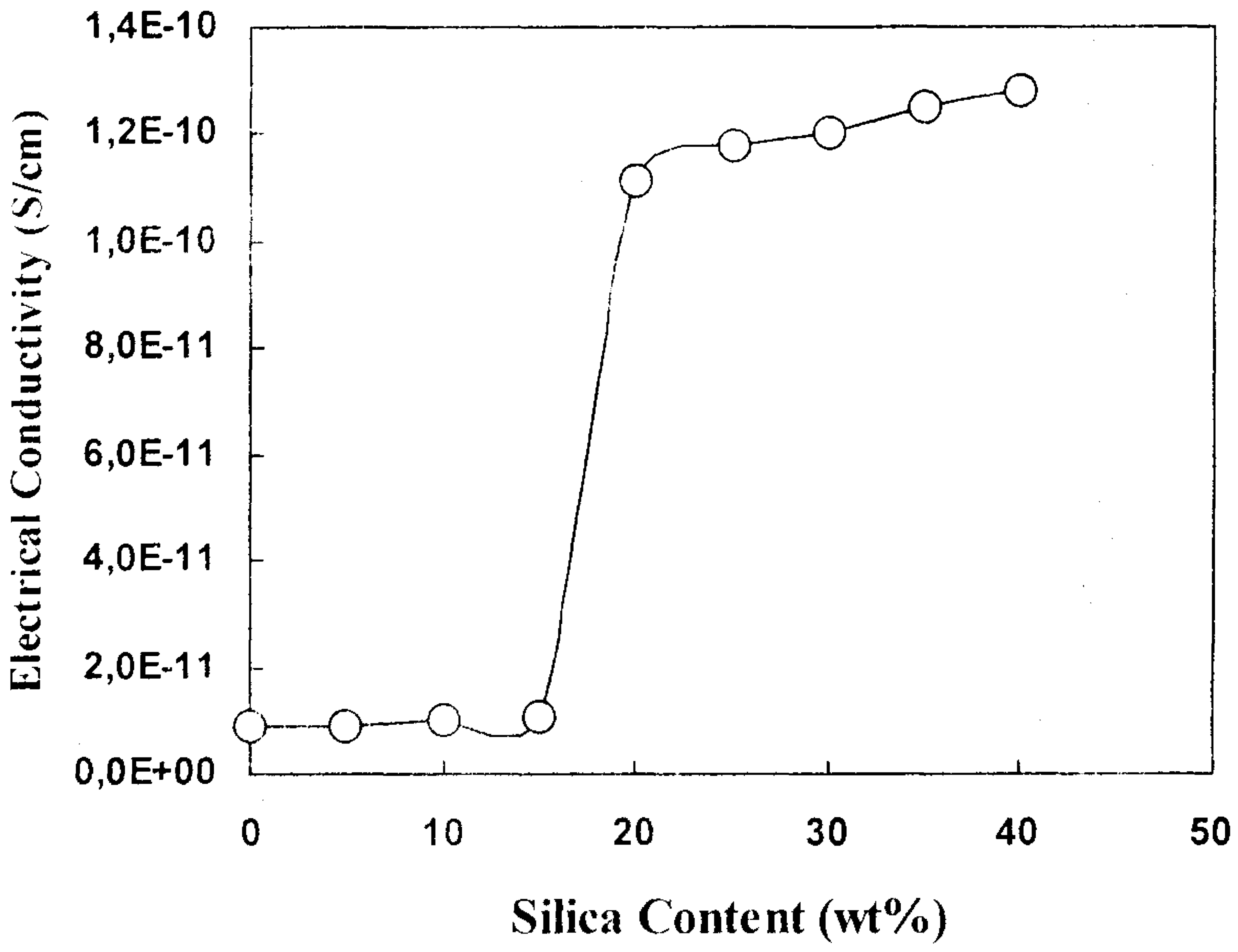

Figure 4: Electrical Conductivity vs. Silica Content (wt%).

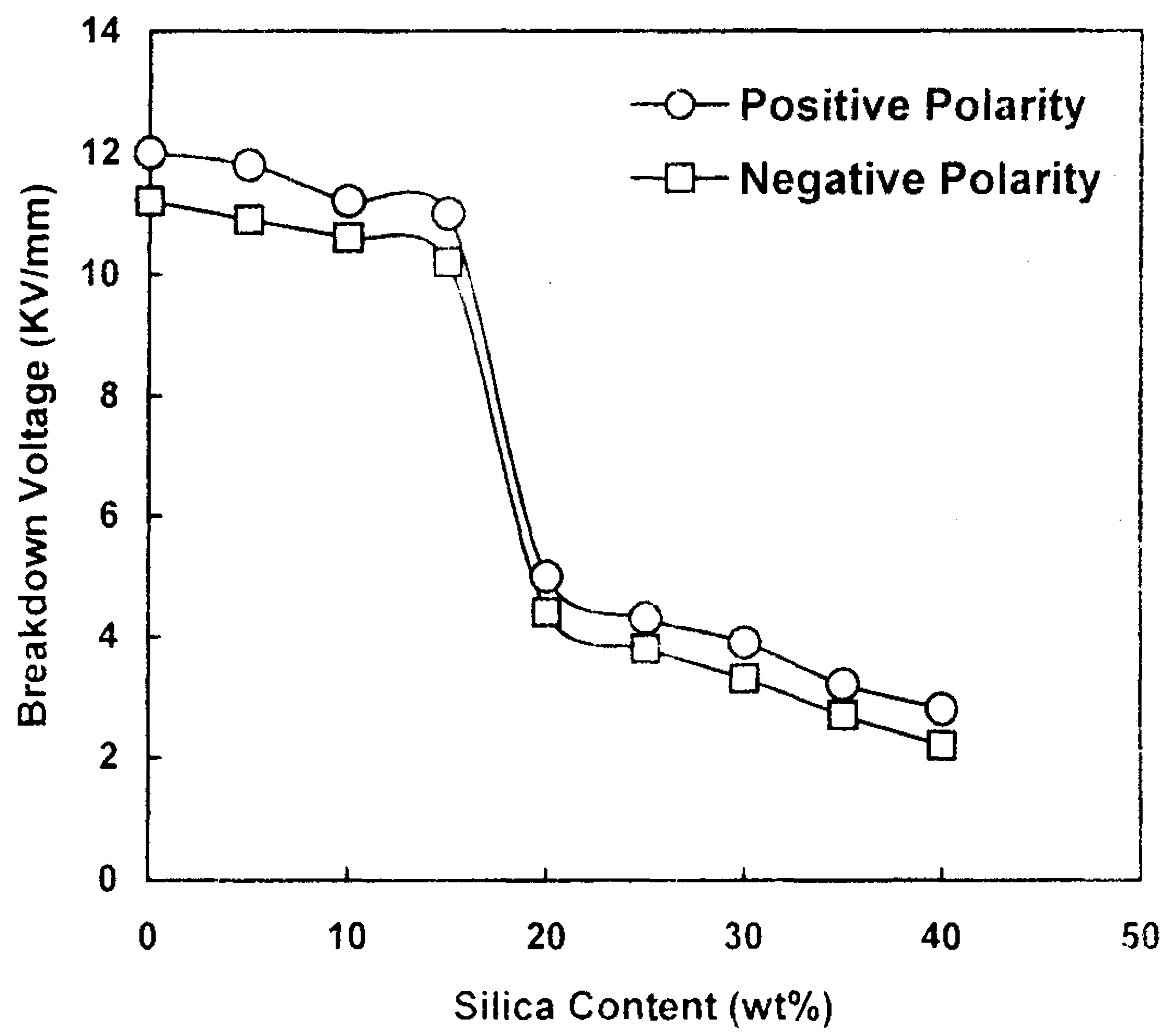

Figure 5: Breakdown Voltage vs. Silica Content (wt%).

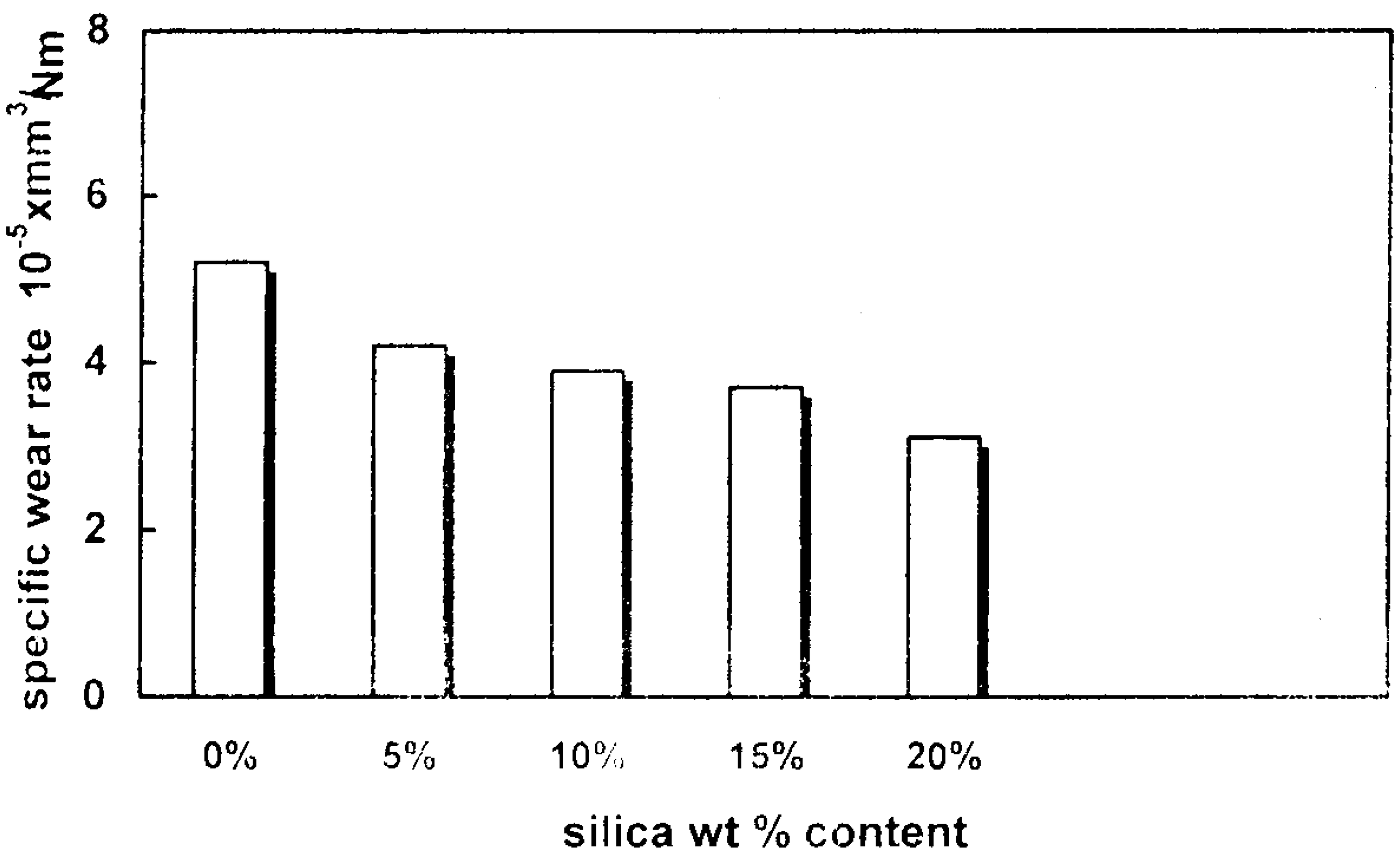

Figure 6: Specific Wear Rate vs. Silica wt% Content.

Figure 6 shows the specific wear rate due to wear of the silica filled epoxy polymer composites of different silica wt% content and the pure epoxy resin at constant sliding speed of 10 cm/s and normal load 20 N. The composite exhibits a lower wear loss than the epoxy resin compare with neat epoxy as shown.

Figure 7 shows the specific wear rate due to wear of the silica filled epoxy polymer composites and the pure epoxy resin as a function of sliding speed at normal load 20 N and sliding distance 9.97 m. The composite exhibits a lower wear loss than the epoxy resin as shown. The lower weight loss in the reinforced samples indicates that the particulates effectively prevent wear of the matrix epoxy resin.

The wear rates at different loads versus sliding distances at constant sliding velocity (20 cm/s) and 15%wt silica for the composites are shown in Figure 8. The specific wear rate increased as the load increased and by increasing the sliding distance.

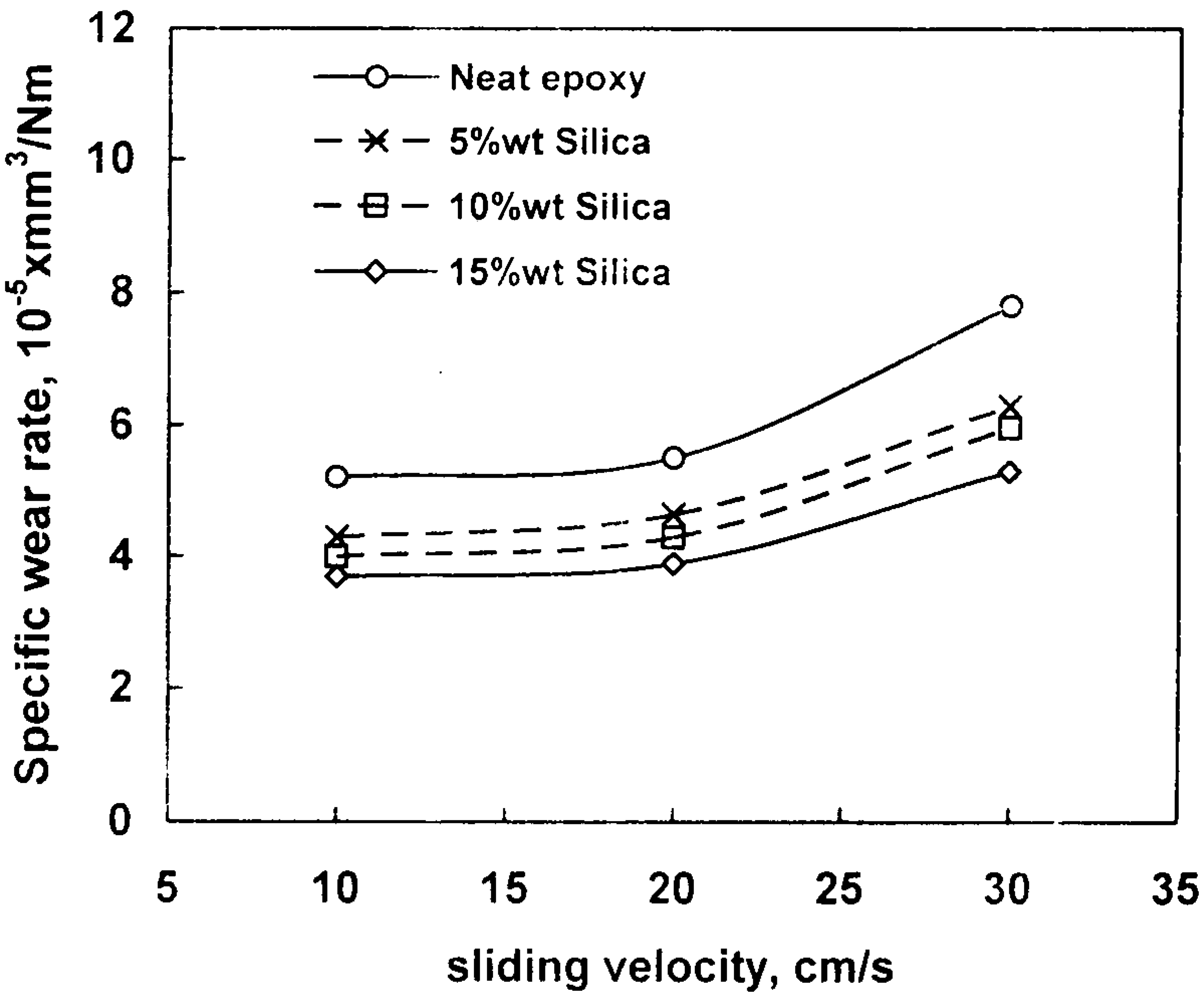

Figure 7: Specific Wear Rate vs. Sliding Velocity.

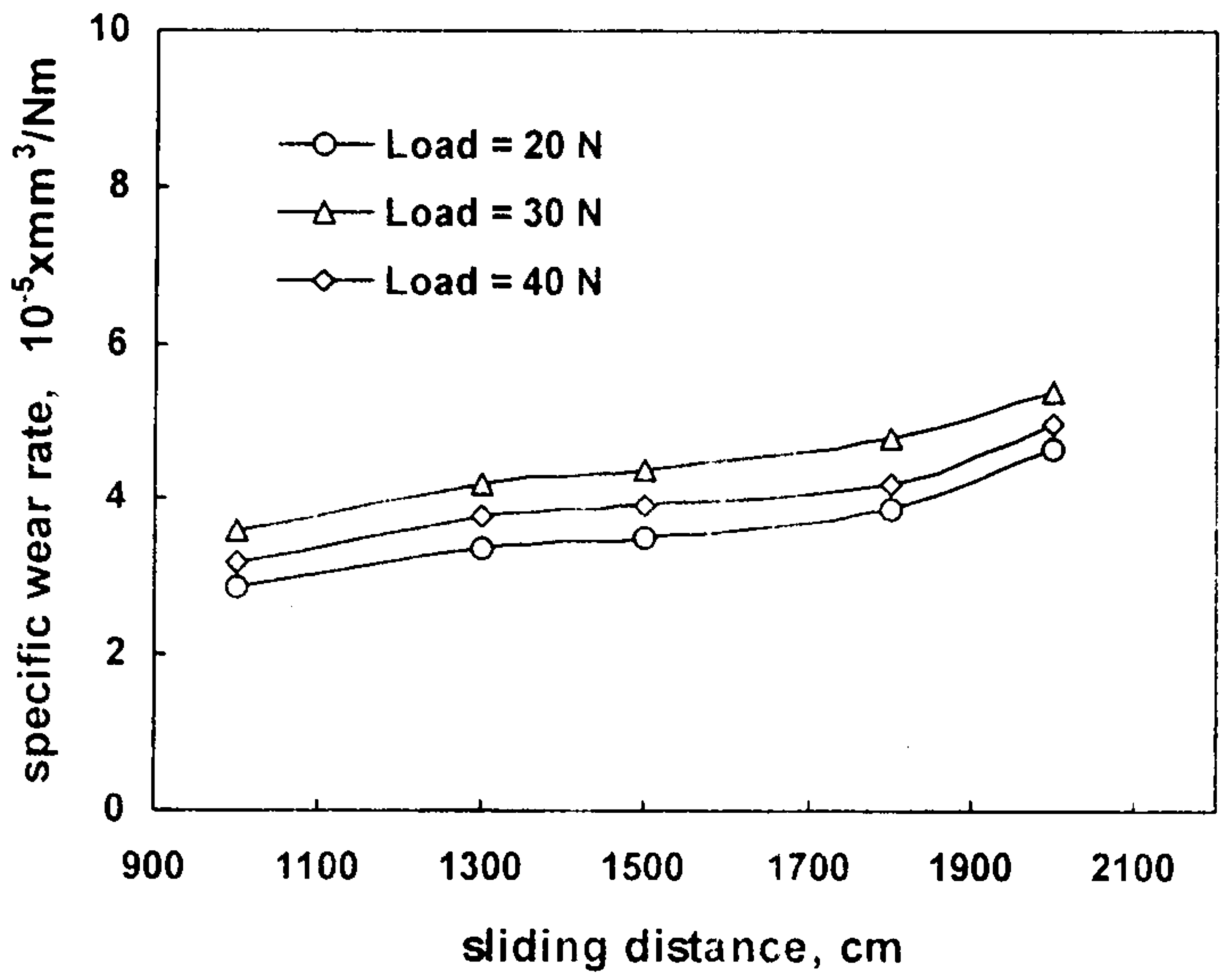

Figure 8: Specific Wear Rate vs. Sliding Distance at Different Loads.

4. Conclusion:

An experimental study has been carried out for graded silica/epoxy composites and homogenous composites to investigate the effect of silica content on the electrical properties and wear characteristics.

1. Controlled mold filling is found to be an efficient technique to create the studied graded silica/epoxy composites of stepwise type as shown in the morphological study.
2. Electrical conductivity remains constant till about 15% wt content of silica but. it increases at high rate for wt content of (15% - 20%) and above 20% wt content it increases slowly with increasing silica content, so it's recommended to use composites containing less than 15% wt content of silica for insulating applications.
3. Breakdown voltage remains constant till about 15% wt content of silica but. it decreases at high rate for wt content of (15% - 20%) and above 20% wt content it decreases slowly with increasing silica content. so it's recommended to use composites containing less than 15% wt content of silica for insulating applications.
4. The wear resistance increased by increasing the wt% content of silica compared with the neat epoxy: so it's recommended to use graded silica/epoxy composites for applications, which require surfaces of high wear resistance.

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