THE ASSESSMENT OF METAL FIBER REINFORCED POLYMERIC COMPOSITES

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ABSTRACT

Because of their low cost, excellent electrical conductivity, high specific strength (strength/density), and high specific modulus (modulus/density) short metal fiber reinforced composites have enjoyed a widespread use in many critical applications such as automotive industry, aircraft manufacturing, national defense, and space technology. However, little data has been found in the study of short metal fibrous composites. Optimum fiber concentration in a resin matrix and fiber aspect ratio (length-to-diameter ratio) are often not available to a user. Stress concentration at short fiber ends is the other concern when the composite is applying to a load-bearing application. Fracture in such composites where the damage will be initiated or accumulated is usually difficult to be determined. An experimental investigation is therefore carefully designed and undertaken to systematically evaluate the mechanical properties as well as electrical properties. In this study, Inconel 601 (nickel based) metal fiber with a diameter of eight microns will be used to reinforce commercially available thermoset polyester resin. Mechanical testing such as tensile, impact, and flexure tests along with electrical conductivity measurements will be conducted to study the feasibility of using such composites. The advantages and limitations of applying chopped metal fiber reinforced polymeric composites will also be discussed.

INTRODUCTION

Over the years, polymers have been well known for their electrical insulating properties and great strides have been made in electrical and electronic applications, mainly related to electrical insulation. Consequently, research has been directed to improve the dielectric strength of polymers so that they can be used for better insulators. In the past ten years, with the advent of electrically conductive polymers, their potential to perform as active roles in conducting electricity has been discovered and realized (ref. 1). Recent polymer researches have revealed that polymers can indeed conduct electricity as well as metals. Now the electrically conductive polymers can be used as antistatic coatings, fuel cell catalysts, solar electrical cells, photoelectrodes in a photogalvanic cell, protective coatings on electrodes in photoelectro-chemical cells, and as lightweight, inexpensive batteries.

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Add to this developing need for electrophotographic industry, due to the increasing need of lightweight, low cost, moldable, and high specific strength for defense and high tech applications, it is expected that the development of electrically conductive polymeric materials will grow strongly and significantly. On the other hand, conductive plastic housings and molded parts can also be beneficial to the controls of electromagnetic interference shielding (EMI) and electrostatic charge discharge (ESD). Advanced research studies have shown that there are three possible methods to make polymers conductive. The first approach is to apply a thin conductive coating onto the molded part. This approach, however, is costly and not efficient because of involving a two-step operation which increases the difficulties in obtaining a good adhesion as well as a uniform coating. The second approach is often held by synthesis or by doping (ref. 2-5). Synthesis is done by side reactions. One of the major side reactions involves the benzene ring. Other reactions lead to branched and cross-linked polymers. Doping involves oxidation and reduction reactions. This method, usually produces polymeric compounds such as polyacetylene and polyphenylene, although it has been proven to be effective and has been widely used, problems rise from conductive polymers themselves such as their processability, stability, mechanical and physical properties, etc. The last approach, proposed in this study, is to incorporate electrically conductive fillers in the polymeric resin matrix. Many conductive materials such as carbon, metals, metal-coated fillers in the form of particles, particulates, and fibers can be randomly dispersed into a resin matrix and form a so-called "conductive composite." This approach so far appears to be a viable solution to the development of conductive polymers. Due to the lack of systematic research study in this area, limited data can be found to help research scientists, engineers in industries in the application of these materials. More importantly, much research is urgently needed to fully understand the interrelationships among structure, property and processing prior to their commercial utilizations (ref. 1-6).

The conductive polymeric composite was first presented in 1966 by Garland (ref. 7). He used silver particles, approximately 50 to 200 microns in diameter, to reinforce a thermoset phenol-formaldehyde (Bakelite) resin matrix. His experimental data indicated that metal-filled polymers undergo a sharp transition from an insulator to a conductor at a critical volume concentration of metal fillers. In his study the electrical resistivity remained almost constant until the silver volume concentration of 38% is reached - then it droped drastically and the whole composite became an electrical conductor. Since Gurland's work, many other researchers have reported different sharp transition from insulators to conductors at different volume concentrations (ref. 8-15).

Among their studies, Dearaujo and his co-investigator (ref. 10) had found that normally at least 40% volume fraction of metal fillers was needed in order to make a composite conductive. In the curing process of a resin matrix, they also suggested that a slow curing rate at lower temperatures would greatly enhance the conductivity of the composite.

Recently, because short fiber reinforced composites can offer design flexibility, weight reduction, energy savings and high-volume production for structural applications, they are widely used in automotive, recreation, business machinery, electrical appliance, and military applications. Metal fiber reinforced composites become highly desirable to meet the aforementioned requirements not only for load-bearing capability but electrical conductivity as well, which normally metal particle reinforcement cannot achieve. However, not much work has been done in this area. Experimental data were found only limited to individual cases. Davenport (ref. 16) mentioned in his study that the metal fiber length (L) to diameter (D) ratio (known as aspect ratio) in a composite must have 100 or more in order to induce electrical conductivity. He demonstrated the electrical conductivity should be a function of L/D. In addition, the fiber packing density is a significant factor which is closely associated with the ratio of L/D (ref. 17). Bigg and Stutz investigated a stainless steel fiber (8 microns in diameter, aspect ratio: 750) reinforced ABS system, and found that the composite had an electrical resistivity of 0.70 ohm-cm at the fiber volume concentration of 1% (ref. 18). They also claimed in their research that a highly conductive composite can be achieved with a low concentration of metal fibers by simply using high aspect ratio fibers. Their work seems very promising, yet needs to be proved. Most of the metal fiber reinforced composites emphasized the electrical properties rather than the mechanical properties.

Nickel has long been considered as a preferred metal because of its low electrical resistivity. In this study, Inconel 601 nickel based fiber with a dimeter of 8 microns and an aspect ratio of 125 was heavily used to reinforce a commercially available thermoset polyester resin. Composite samples were made in coupon shapes depending on the test requirements. Both mechanical and electrical measurements were further conducted to help understand the micromechanical behavior as well as electrical conductivity.

SPECIMEN PREPARATION AND TESTING

Chopped Inconel 601 metal fibers were donated by Bekaert Fiber Technologies. To prevent the sizing effect from the interfacial bonding between fiber and resin matrix, a thin water-soluble PVA (polyvinyl alcohol) coating originally attached to fibers was removed from Inconel fibers prior to the process. Fiber volume concentration, varied from 0% to 50%, was carefully controlled as a material parameter to conduct this study. Metal fibers were completely mixed with an appropriate amount of polyester resin and MEKP (Methyl Ehtyl Ketone Peroxide) curing agent in a chemical beaker based on a predetermined volume ratio. The mixure was then poured into an aluminum mold for cure. Traditional compression molding practice was employed in the curing process; pressure was around 17 psi (1.17×10^5 Pa) and temperature was set at 356° F (180° C). Specimen dimensions were carefully prepared according to ASTM standard test methods; they were 6 x 3/4 x 1/8 in. (152.4 x 19.05 x 3.18 mm) size for tensile test, 5 x 1/2 x 1/4 in. (127 x 12.7 x 6.35 mm) size for Izod impact test, and 4 x 1/8 x 1/2 in. (101.6 x 3.18 x 12.7 mm) for flexure bars. The tensile and flexure tests were performed in a screw-driven computer-asisted Satec testing machine. A testing speed of 0.1 in./min. (2.54 mm/min.) was used for tensile and flexure tests. The ASTM method D257 was also followed to measure the volume resistance of each sample. The test data were collected and discussed in the following sections.

RESULTS AND DISCUSSION

Tensile test data, as shown in Table 1, have demonstrated that fiber concentration can indeed increase the tensile strength of the composite. Young's modulus is also improved as well. It is interesting to note that the small fiber concentration at the ratio lower than 10 volume percent will not contribute to the increase of entire tensile strength. According to the study, fiber concentration at 25 % has the maximum UTS. It is found that fiber orientation along the pulling direction will have significant effect to tensile properties. Since the specimens are prepared through a casting process, the fiber orientation in all directions is assumed the equal. Impact test data (in Table 2) reveal that impact strength increases with the addition of metal fibers. However, there is a limitation set at 35%. Low fiber concentration impairs the impact strength of the composite. Optical microscopy indicates that because of the existing of metal fibers, small air bubbles are attached to fiber ends, which is believed to be responsible for the degraded impact strength. Three point (flexture) test data show that fiber fillers can improve the flexural strength and tangent modulus of the composite, as shown in Table 3. It is also noticed that metal fibers can dissipate some energy in a crack propagation.

In other words, with the addition of metal fibers the crack pattern of a given composite shifted from a pure tension failure mode toward a more shear failure mode, which increases the flextural properties. Fiber pull-outs and fiber breakage are some evidence. In the electrical measurements, a critical fiber concentration is recorded. Electrical resistivity of 1.0 ohm-cm is measured at the fiber volume ratio of 45%, which is unexpectedly high. Figure 1 shows fiber concentration below 30%; the electrical resistance remains almost constant, that is the composite is still an electrical insulator. In this study, metal fiber reinforced composites did undergo a sharp transition which is in concert with Garland's work (ref. 7).

CONCLUSION

Because of excellent electrical conductors, metal fibers are suitable additives for inducing electrical conductivity in traditionally known insulators, polymer materials. Inconel metal fibers, although proved to be effective reinforcing elements, are considerably more dense than expected. It is found, during this study, that the explanation of mechanical properties is often difficult to make because it involves many unseen factors such as stress concentration, orientation effect, viscoelastic behavior etc. While significant progress has been made, much work still needs to be done. A systematic approach including experimental and theoretical techniques should be developed to help understand the micromechanisms and to clarify the interrelationships among structure, property and processing. Several factors such as fiber concentration, fiber aspect ratio, compatibility between fiber and marix can then be studied under this guidance. The aforementioned suggestions, if applicable, may lead to a complete data bank setup which may eventually benefit all the designers, engineers, and scientists who are using conductive composites in their work.

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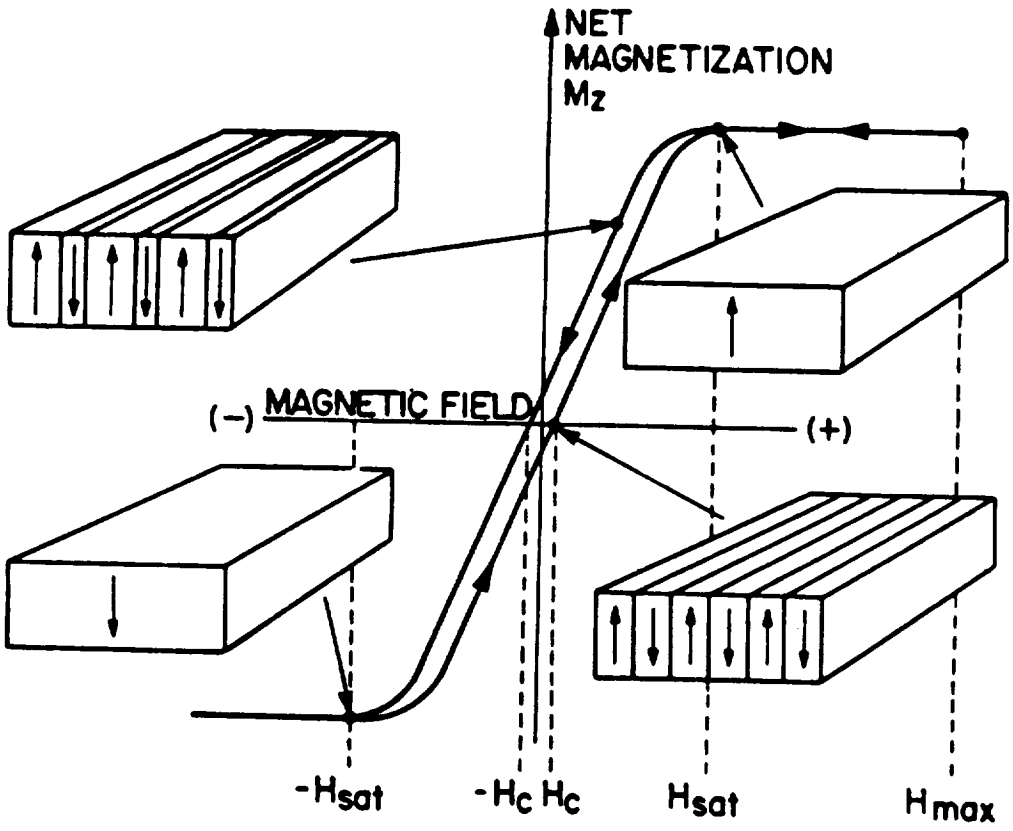
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