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A KEVLAR 49-EPOXY INSULATOR

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R. H. Ericksen

Prepared by Sandia Laboratories, Albuquerque, New Mexico 87115
and Livermore, California 94550 for the United States Energy Research
and Development Administration under Contract AT (29-1)-789

January, 1978

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SF 1004-DF (3-75)

Printed in the United States of America
Available from
National Technical Information Service
U. S. Department of Commerce
5285 Port Royal Road
Springfield, VA 22151
Price: Printed Copy ~~\$4.50~~; Microfiche \$2.25

4.00

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A KEVLAR 49-EPOXY INSULATOR*

R. H. Ericksen
Composite Materials Development Division 5844

ABSTRACT

Kevlar 49-Epoxy composite structural insulators were fabricated from two and three dimensionally reinforced material. The insulator configuration was that of a cylindrical cup having both external and internal threads. Electrical and mechanical property data was obtained for test samples of both materials. Relatively little difference in electrical properties was obtained for the two materials; however, the mechanical properties varied markedly. The transverse strength of the two dimensionally reinforced material was 2000 psi in tension as compared with 110,000 psi in compression. In the three dimensionally reinforced composite the difference was less, 57,400 psi in tension and 71,000 psi in compression. These properties are described along with the techniques used to fabricate prototype parts of the two composites.

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INTRODUCTION

Kevlar-49 reinforced-epoxy composites have become widely used as structural members because of their high specific strength and modulus. In addition, being electrically non-conductive these materials are potentially useful as structural insulators. Such an application motivated the work described in this report. The composite was used to isolate the radar antenna portion of a test system from the remainder of the structure. The insulator configuration was that of a cylindrical cup with internal and external threads. The material was required to have a low dielectric constant and loss tangent, and must provide resistance to complex loading, including axial compression and shear forces acting on the cup wall. The exact strength requirements could not be defined until tests were performed on a mockup of this part of the system. Discussions with design engineers indicated that Kevlar-epoxy resin composites would have suitable electrical insulating properties. Available mechanical property data for unidirectionally, and two dimensionally ($0\pm 90^\circ$) reinforced Kevlar-epoxy resin composites suggested that the complex loadings could most likely be carried by a two dimensionally reinforced composite, although no transverse compression data for such a composite could be found. As a backup for the two dimensional part it was decided that prototype parts would also be fabricated from a three dimensionally reinforced composite in the event that system loads might exceed the transverse strength of the two dimensionally reinforced composite.

The purpose of this report is to summarize the fabrication procedures and mechanical and electrical properties of the material used to fabricate prototype parts.

MATERIALS AND FABRICATION

The insulator is a cylindrical cup having internal and external threads. A cross-section of the part is shown in Figure 1. The Mogul thread was chosen to minimize stress concentrations and sharp discontinuities in the composite.

Two dimensional composite

In order to shorten the labor involved in fabricating such a thick composite section it was decided to make a large composite block. This would provide material for several test parts. Kevlar cloth (181 style) prepreg was cut into 11.5 in. squares and stacked in an aluminum support fixture. The resin system was USP*781, an anhydride cured epoxy. The support fixture was designed so that a top cover plate applied uniform pressure to the layup and the side plates restrained the layers of prepreg from shifting in position. The assembly was put in a hot press with insulation around the edges of the support fixture to reduce heat loss. A pressure of 50 psi was applied, the platens of the hot press heated to 325°F at 1°F per minute, then held at this temperature for 1 hour. Thermocouples were inserted into the corners of the composite near the mid-thickness. The temperatures recorded at these points verified that temperature uniformity was obtained during the preliminary cure. The composite was removed from the hot press and post cured 16 hours at 325°F. The fiber volume fraction was estimated to be 45 percent.

*

United States Polymeric Co.

The weak transverse tensile direction of the two dimensional composite was parallel to the axis of the cylindrical insulator. As a result there was a tendency for the part to separate during machining. This problem was overcome by starting with a blank of composite somewhat larger in diameter than the final part. The center threaded section was first machined using the general guidelines provided by DuPont (1) for machining Kevlar. Particular care was taken to use light passes as the interior threads were formed. A matching aluminum blank was then screwed into the inside of the part before the outer surface was machined. This insert, being threaded, provided some restraint in the weak transverse direction and was sufficient to keep the part from cracking during machining of the outside threads. In addition the insert resulted in a part having a more uniform circular cross section than earlier parts machined without the restraint. The final machined part is shown in Fig. 2.

Three dimensional composite

The three dimensionally reinforced composite was obtained from Fiber Materials, Inc. Biddeford, ME as a cylindrical tube 3.5 in. outside diameter with a 2.25 in. diameter central hole. The fiber volume fraction was $50 \pm 5\%$ with one third of this in each reinforcing direction: axial, radial, and circumferential. The resin was EPON 828-Z* and the part was cured as follows:

4 hours at room temperature under vacuum

4 hours at 130°F

4 hours at 200°F

*

Shell Chemical Company

The threaded sections were machined from this cylinder. In this case a support liner was not required to control splitting because of the axial reinforcement. A bottom section of two dimensionally reinforced material was match machined to fit a tapered surface at the bottom of the three dimensionally reinforced section. The two pieces were bonded together using the same 828-Z epoxy resin. This part is shown in Figure 3.

MATERIAL PROPERTIES

Mechanical

1. Two Dimensionally Reinforced Composite

Transverse tensile and compressive strength and moduli for test samples from the two dimensionally reinforced composite are presented in Table I. The composite transverse strength is considerably lower than the tensile strength of the unreinforced matrix, as is clearly evident from their stress-strain curves shown in Figure 4. No attempt was made to optimize the strength of this composite by varying processing conditions, however the transverse tensile strength for this material was in agreement with the values reported by Allred and Gerstle (2) for other Kevlar-epoxy composites prepared by filament winding. As expected, the composite tensile modulus is slightly higher than that of the unreinforced matrix as evidenced from Figure 4.

No data could be found in the literature for the compressive strength of Kevlar-epoxy composites reinforced in two directions normal to the direction of loading. The values obtained experimentally are shown in Table I. Cylindrical specimens 0.625 in. in diameter by 0.75 in. long were used. This sample geometry was

picked for convenience and because of this the strengths obtained may be peculiar to this particular configuration. It is well documented (3) that compression tests performed on any given composite can show substantial differences depending upon the test geometry used. The compressive stress-strain curve obtained for the composite was linear for strains up to 5 percent, the point on the loading curve where strain gage failure was observed. Failure occurred at a high stress (110,000 psi) and in an explosive manner. This is noticeably different from the compressive behavior of the unreinforced matrix which exhibited a compressive yield point at 12,000 psi and failure at 21,000 psi. The role of the reinforcing fibers transverse to the loading direction of a two dimensionally reinforced composite must be to restrain lateral expansion of the composite. This is further indicated by the lack of barreling observed during composite deformation, as contrasted to the severe barreling observed during compression of the unreinforced matrix.

2. Three dimensionally Reinforced Composite

No information could be found in the literature concerning the mechanical behavior of three dimensionally reinforced Kevlar-epoxy composites. The data obtained in this study are summarized in Table II. The tensile strength and modulus in the axial direction are in the range expected for a unidirectional composite of equivalent volume fraction to that in the direction of testing for the three dimensionally reinforced material. Likewise, the stress-strain curves in both cases are linear to failure.

In compressive loading the shape of the stress-strain curve in the low stress region showed two distinct stages of deformation.

The initial linear region, Figure 5, had a modulus of 3.5×10^6 psi similar to that obtained on this composite in tensile loading. In the second region, the compressive modulus is only slightly higher than that of the unreinforced matrix (0.67 vs. 0.50×10^6 psi).

Similar two-stage compressive stress-strain curves have been reported by DuPont (1) for a two dimensionally reinforced composite (181 cloth reinforcement) when the applied load was parallel to the warp direction. The slope of the compressive stress-strain curve changes at a stress of 11 ksi (see Figure 5) and the modulus data indicate that this reflects the loss of any contribution by the fibers loaded in axial compression to the load bearing capability of the composite. The compressive strength of unidirectional composites of Kevlar 49-epoxy is usually only about 20% of the tensile strength. In the case of the three dimensionally reinforced composite the high compressive strength is provided by the two dimensional array of fibers normal to the direction of loading.

Preliminary system tests under complex loading conditions indicated the composites had suitable mechanical properties for this application.

Electrical

The dielectric constant and loss tangent data for the two composites are summarized in Table III along with data for the unreinforced resins. The electrical measurements were made by Sandia's Primary Standards Laboratory using a cavity method. The specimens were 0.25 in. x 0.25 in. x 2.0 in. long bars with the electric field applied parallel to the long direction of the specimens.

The different electrical properties between the two dimensional and three dimensional composites mainly reflect the different resin properties. In the case of the two dimensional composite the properties differ depending on the direction of the fiber orientation relative to that of the applied field. Similar results have been reported by DuPont (1). Several samples of the unreinforced 781 resin (2-D composite matrix) were aged at 300°F for 117 and 2090 hours. The dielectric constant and loss tangent data are also presented in Table III. Relatively little change was obtained in the dielectric constant. A significant decrease in loss tangent was recorded after 117 hours at 300°F. This was apparently due to additional curing, which stabilized the material, since the same value was obtained after 2090 hours.

Electrical tests of the antenna part of the system mockup showed less antenna gain than desired for this application. This indicated the dielectric constant and loss tangent of the insulator were too high. No attempt had been made to optimize these properties for the prototype part development, although it would have been possible to improve the system performance by changing the matrix material. Instead, the system design was changed, eliminating the requirement for this particular insulator configuration.

CONCLUDING REMARKS

The present study has shown that Kevlar 49-epoxy composites can be fabricated into complex configurations suitable for use as structural insulators. Although not used in this particular application, the materials information obtained can provide an improved basis for future designs.

Relatively little difference in electrical properties was obtained for the two composites in this case, mainly because the fibers have properties similar to those of both epoxy resin systems. It should be possible to vary dielectric properties with different fiber and matrix components, or to select, for instance, a suitable epoxy resin system for a Kevlar reinforced composite with essentially isotropic electrical properties.

The mechanical properties of two and three dimensionally reinforced Kevlar 49 composites vary markedly. The data obtained in this study shows that Kevlar 49 reinforced composites can provide a high resistance to compressive deformation if a two dimensional fiber grid can be oriented perpendicular to the direction of loading. In order to obtain a high tensile strength in all directions, it is necessary to utilize three dimensional reinforcement. Use of 3-D reinforcement would be restricted to specialized applications where material requirements preclude the use of other, less expensive materials.

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ACKNOWLEDGEMENT

Initial work in setting up this program was carried out by W. R. Hoover and his advice during the entire study is gratefully acknowledged.

Table I

Mechanical Properties of a Two Dimensional
Kevlar Epoxy Composite

	psi
Tensile Strength	2000
Compressive Strength	110,000
Tensile Modulus	0.95×10^6
Compressive Modulus	1.0×10^6

Load applied perpendicular to layers of reinforced (transverse direction)

Table II

Three Dimensional Kevlar Epoxy Composite

	psi
Tensile Strength	57,400
Compressive Strength	71,000
Tensile Modulus	4.0×10^6
Compressive Modulus	3.5×10^6 0.67×10^6

Table III

Electrical Properties (at 2.25 GHz) of Composite Insulators and Unreinforced Resins

	Dielectric Constant	Loss Tangent
2-D		
Electric field in plane of cloth	3.49	0.0157
perpendicular to cloth direction	2.99	0.020
781 Resin	3.22	.036
781 Resin 117 hrs at 300°F	3.17	.015
781 Resin 2090 hrs at 300°F	3.19	.015
3-D	4.00	.049
828-7*	3.60	.040

*

Hardbook values

FIGURE 1. CROSS SECTION OF INSULATOR

FIGURE 2. TWO DIMENSIONALLY REINFORCED
COMPOSITE INSULATOR

FIGURE 3. THREE DIMENSIONALLY REINFORCED
COMPOSITE INSULATOR

FIGURE 4. STRESS-STRAIN CURVES FOR TWO DIMENSIONALLY REINFORCED COMPOSITE AND UNREINFORCED RESIN MATRIX

FIGURE 5. INITIAL PART OF THE COMPRESSIVE STRESS-STRAIN CURVE FOR THE THREE DIMENSIONALLY REINFORCED COMPOSITE

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