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SOME IMPORTANT ASPECTS IN TESTING HIGH-MODULUS FIBER COMPOSITE TUBES DESIGNED FOR MULTIAXIAL LOADING

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SOME IMPORTANT ASPECTS IN TESTING HIGH-MODULUS FIBER COMPOSITE TUBES DESIGNED FOR MULTIAXIAL LOADING

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ABSTRACT

Tubular specimens were potted in metal grips to determine the feasibility of this gripping method in applying multiaxial loads. Strain gage rosettes were used to assess grip transitional strains, through thickness strain variation, and strain variations along the tube length and circumference. The investigation was limited to loading 0°, 45°, ±45°, and 90° graphite/epoxy and glass/epoxy tubes in axial tension. Results include modifications made to the grips to reduce transitional strains, illustrations of the tube failure modes, and some material properties. The gripping concept shows promise as a satisfactory technique for applying multiaxial loads to high-strength, high-modulus fiber composite tubes.

Key Words: fiber composite, tubular specimens, gripping, graphite/epoxy, glass/epoxy, transition strains, mechanical properties, through-thickness strain variations.

INTRODUCTION

For experimentally characterizing the mechanical behavior of fiber/matrix composite materials, a tubular specimen offers a distinct advantage. All the loads required to fully characterize a composite system can be applied to this single specimen type. However, transferring load into a tube and keeping transitional stresses sufficiently low to avoid end failures can be a problem. Tube ends can be reinforced with tabs but this significantly increases the cost of a tube. The load transfer technique investigated at the Lewis Research Center consisted of potting the tube ends into grips designed to reduce transitional stress to an acceptable level.

In order to test the grips under a variety of conditions, two fiber/matrix systems and four ply-lay-up configurations were used. High-modulus graphite/epoxy and high strength glass/epoxy circular cylindrical tubes were tested with the fibers oriented at 0°, 45°, $\pm 45^{\circ}$, and 90° with respect to the tube longitudinal axis. The tubes were 8-plies (0.060-in.) thick, 2 inches in diameter, and 12 inches long. They were instrumented with single strain gages and strain gage rosettes to measure strain variation in the grip transition region, along the tube length, around the tube circumference at the midlength, and through the tube thickness.

This paper describes the development of the grips and presents strain gage results and composite properties obtained from testing tubes in uniaxial tension.

EXPERIMENTAL APPARATUS AND PROCEDURE

Grip Design

It was our desire to grip composite tubes in a relatively simple manner without going to the added expense of reinforcing the ends. The concept we chose was to hold the tube ends in metal grips with an epoxy potting material. The metal grips were bolted together so that following a test they could be readily disassembled and used over again. Two sets of grips were designed, one for a potting depth of one inch and the second for two inches.

Initial concern was with the strength of the bond between the potting material and the tube. Therefore, a high strength epoxy (Epon 815 with curing agent Z) was chosen for the potting material. To add additional gripping strength the grips were tapered (fig. 1(a)) so that a radial compressive force was exerted on the ends when the tube was loaded in tension. In initial tests of 0^{o} tubes longitudinal cracking occurred, so curing agent Z was replaced with T-1. This allowed curing to take place at room temperature. The adverse effect of differential expansion coefficients was eliminated at a sacrifice in epoxy strength. Except where otherwise noted, all results reported herein were obtained from tests using grip configuration I (see fig. 1(a)). This configuration produced satisfactory results except for the 0^{o} graphite/epoxy tubes which failed at the grips. Therefore, an effort to further reduce grip transitional stresses was made by simply supporting the tube on the inside and potting on the outside only (fig. 1(b)). It would be possible to further reduce transitional stresses by slightly tapering the inside support to allow unrestricted Poisson's contraction to take place.

Specimens, Instrumentation, and Testing

In order to test the grips with composite systems covering a wide range of strength and stiffness properties, two systems were selected. The systems were graphite (Modmore I)/epoxy (ERLA 4617) and S-glass/epoxy (ERLA 4617). The tubes were made by a lay up procedure using broad goods. Fiber volume content was 50 percent in both cases. The tube dimensions were 12 inches long by 2 inches in diameter. They were 8 plies thick. Ply layups were 0^{o}, 45^{o}, $\pm 45^{o}$, and 90^{o}. In the latter stages of the program several 0^{o} E-glass/epoxy (Scotch ply) tubes were tested to study grip transitional strains. The tubes contained only the constituent materials mentioned above except the 0^{o}, 45^{o}, and 90^{o} graphite/epoxy tubes which had glass scrim cloth on the inner and outer surfaces. The glass scrim was used to prevent cracking during the fabrication process.

The primary form of instrumentation used was the 60° delta rosette strain gage. Gage resistance was 120 ohms. Gage length was either 1/8 or 1/4 inch. Gages were placed along the length of the tube, around the circumference of the tube at its midlength and inside the tube. The smaller rosettes were used near the grip. Figure 2 shows a typically instrumented tube mounted in the grips. This tube had gages mounted on the inside and their alinement with respect to the gages on the outside can be seen in figure 3. Alinement was so close that the X-ray gives the appearance of a single rosette at each location. Strip strain gages, which were partially embedded by the potting epoxy, were used to measure both longitudinal and transverse (hoop) grip transitional strains.

The strain gages were read out using a multichannel digital strain recorder. The gage excitation voltage used was 1.4 volts, a voltage low enough to prevent gage drift due to heat buildup. Strain gage and load data were reduced to stress, structural axis strains, moduli, and Poisson's ratios using the computer program described in reference 1. All the tubes were tested in tension to failure using a 120 000 pound capacity universal testing machine. Loading was held constant at convenient intervals for taking strain gage data.

RESULTS AND DISCUSSION

Grip Transitional Strain

Tube tests using grip configuration I were generally successful, i.e., failures occurred away from the grips. This was true for all except the 0° graphite/epoxy tubes which failed at the grips. Some typical failed specimens are shown in figure 4.

Strain gage data showed that undesirable loads were being induced in the tube ends by grip configuration I. Therefore, it was modified as shown in figure 1(b) and described in the previous section. The improvement obtained by this modification is illustrated in figure 5. An E-glass/epoxy tube with 0^{o} fiber orientation was tested where one end was gripped using configuration I and the other end by configuration II. With configuration II the transverse strain in the transition region was much closer to that at the tube midlength. Gage C' shows that configuration I induced sufficient transverse strain to cause the tube to crack and relax the transverse strain. The transverse failure strain was about 2000 μin./in.

Strain Along Tube Length

In order to determine the effect of gripping away from the grips, rosettes were placed on tubes 3/8, 7/8, and 2 inches from the grip (potting boundary) and at the tube midlength. The results obtained from testing these tubes are shown in figure 6. Strain values were normalized by dividing by the strain values obtained at the tube midlength. Strains at two stress levels are plotted: stress equal to about half the failure stress and the stress at which the last strain gage readings were taken prior to failure.

In general, longitudinal strain varied slightly along the tube length as one would expect from the restraint caused by the grips. Transverse strain variation was more significant. The greatest variation in transverse strain occurred in the 0^{o} graphite/epoxy tube (fig. 6(a)). The strain in the gage closest to the grip was tensile rather than the compressive strain expected from Poisson's effect. The transverse strain obtained from the 90^{o} graphite/epoxy tube (fig. 6(d)) is not plotted because these strain readings were too small (less than 50 μin./in.) to be considered meaningful. Transverse strain variation can be attributed primarily to the radial force induced in the tubes by the grips.

With one exception stress level had little or no effect on the results. This exception was the $\pm 45^{\circ}$ S-glass/epoxy tube (fig. 6(g)) where the grips had a significantly greater restraining effect at the higher stress than at the lower stress. Grip restraining effects would be expected to show up prominently with this type of tube because of the very high strain levels induced by interply relative rotation (scissoring effect).

Only one stress level is plotted for the 45° S-glass/epoxy tube (fig. 6(f)). This tube failed at an unexpected low stress and only a single set of strain gage data were obtained.

For the 45° graphite/epoxy and 90° S-glass/epoxy tubes (figs. 6(b) and (h), respectively), longitudinal strain for only the higher stress level is plotted. In these two cases, normalized longitudinal strain was the same for both stress levels.

Strain Around Tube Circumference

Strain rosettes were placed around the tube at its midlength at -90°, 0°, and 90° to detect strain variation around the circumference. The angle was measured from the meridian on which the rosettes along the tube length were mounted. The 0° meridian was chosen arbitrarily. Results from these rosettes are shown in figure 7 where normalized strain is plotted against angle. Strain was normalized by dividing by the strain values obtained from the 0° rosette. Results from two $\pm 45^{\circ}$ graphite/epoxy tubes are plotted in figure 7. No 45° graphite/epoxy tube was instrumented around the circumference.

Longitudinal strain results showed that a significant amount of bending was introduced into all but the 0° tubes. Both the 0° graphite and S-glass tubes had an inside diameter about 0.010-inch smaller than the other tubes. This allowed a more precise centering of the 0° tubes in the grips before they were potted and therefore eliminated any bending due to eccentric loading. Closer tolerances on the inside diameter of tubes tested in the future should eliminate this cause of bending.

Variation in transverse strain around the circumference even when no bending was present (fig. 7(a)), was probably due to slight gage and/or fiber misalinement with respect to the longitudinal axis. The rosettes were mounted so that longitudinal strain was measured directly while a transformation was necessary to obtain transverse strain. The calculated transverse strain was more sensitive to the effect of gage and/or fiber misalinement.

Through-Thickness Strain Variation

An analysis by Pagano and Whitney[2] showed that a stress variation through the thickness would occur in the gage section of nonsymmetrical composite tubes loaded in axial tension. Of the tubes tested in this program, the greatest through-thickness stress variation would be expected to occur in the 45° graphite/epoxy tubes. To determine strain variation through the thickness, one of these tubes was instrumented with back to back rosettes at 3/8, 7/8, and 5 inches from the grip and loaded to failure. Stress-strain curves for these locations are plotted in figure 8.

At the tube midlength (fig. 8(a)) there was no difference in longitudinal strain through the thickness. As can be seen in figure 3, the inside and outside elements measuring longitudinal strain were precisely alined. The variation in shear and transverse strain through the thickness is the only indication of a possible through-thickness stress variation.

Near the grip (fig. 8(b) and (c)) there was a difference in the longitudinal strain. However, this could be due to local bending. The variation in shear and transverse strain could be due to a combination of bending and through-thickness stress variation.

Composite Material Properties

The properties obtained from the tube tests are shown in figure 9 for graphite/epoxy and figure 10 for S-glass/epoxy. The data points represent an average of results from either 2 or 3 rosettes mounted around the circumference of the tube at its midlength. Two or three tubes were tested for each type of fiber orientation. In general the results show the extreme anisotropy of unidirectional composites and the effect on strength and stiffness obtained by cross plying.

Graphite/epoxy tube test results (fig. 9) were affected by the gripping method and by the glass scrim on the 0°, 45°, and 90° tubes. Strength and failure strain values of 0° tubes were reduced by having grip failures. The presence of the glass scrim no doubt affected all the results, some negligibly (0° strength and modulus) and others more significantly (45° and 90° strcngth). The 0° Poisson's ratio was higher than what was expected for a 50 percent fiber volume graphite composite. The glass scrim and/or excess resin on the tube outer surface could account for this discrepancy. The dashed line in figures 9(d) and 10(d) gives the curve shape predicted in reference 3.

S-glass/epoxy tube test results (fig. 10) were affected by the gripping method; however, no glass scrim was present to confuse the results. The 0° tubes failed by longitudinal separations forming at a point on the circumference. Under continued loading the separations proceeded around the circumference until the specimen looked more like a broom than a tube. These separations probably formed as a result of transverse and shear loads introduced into the tube by the grips. The stress-strain curve for the $\pm 45^{\circ}$ tubes was nonlinear and modulus and Poisson's ratio values plotted are for initial conditions. The failure strain of the $\pm 45^{\circ}$ tubes exceeded the measurement capability of the strain rosettes.

SUMMARY OF RESULTS

A method for gripping fiber composite tubes was devised that does not require specimen end reinforcement. Initial strain gage data showed high transverse strain near the grip. However, failure occurred away from the grips in all but the 0° tubes. Modification of the grip design reduced the transverse strain to a level much closer to that at the middle of the tube.

Strain gages around the circumference of the tubes showed that bending was introduced into some of the tubes by the gripping technique. Holding a closer tolerance on the tube inside diameter to allow more precise centering in the grips should eliminate most bending.

Analysis of the data from back to back gages showed that a stress variation through the tube wall thickness was possible in the 45° graphite/epoxy tubes.

The material properties obtained from these tests were, for the most part, what would be expected for the materials and fiber volumes tested. The high degree of anisotropy of these materials is shown as well as the effect of cross plying. The major Poisson's ratio obtained from the 0° graphite/epoxy tubes was higher than expected. This may result from having a layer of glass scrim cloth on the surface of the tube.

REFERENCES

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2. Pagano, N. J. and Whitney, J. M., "Geometric Design of Composite Cylindrical Characterization Specimens." Technical Report AFML-TR-70-130, Air Force Materials Laboratory, Wright-Patterson Air Force Base, Ohio, 1970.
3. Chamis, C. C., "Important Factors in Fiber Composite Design," Society of the Plastics Industry 24th Annual Technical Conference, Washington, D.C., 4-7, Feb. 1969, Section 18-E, pp. 1-13.

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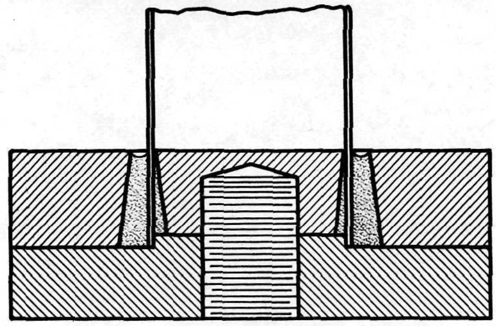
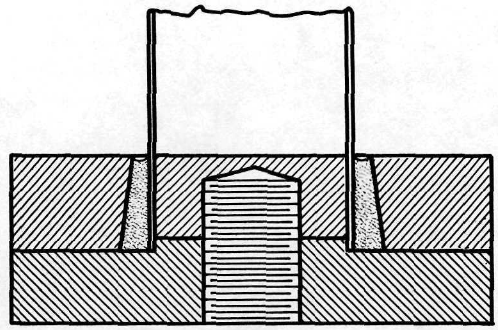


(a) CONFIGURATION I.



(b) CONFIGURATION II.

Figure 1. - Tubular specimen grip configurations.

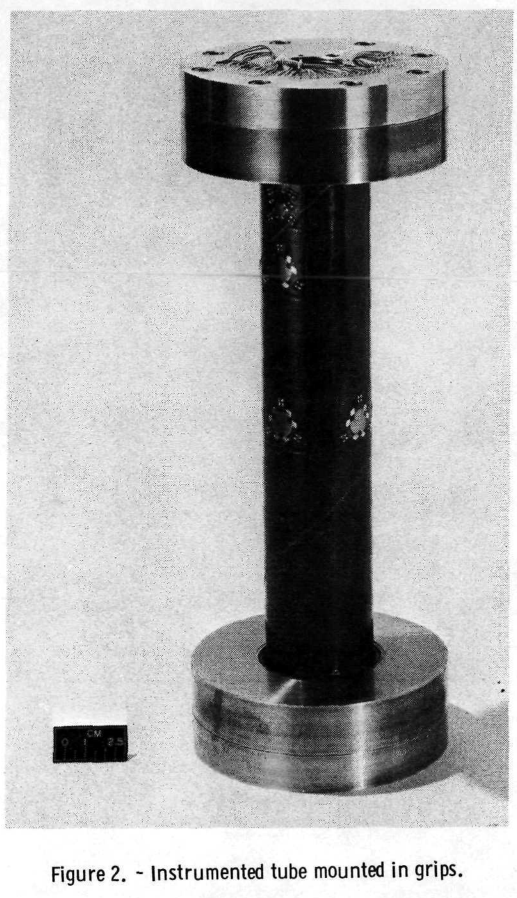


Figure 2. - Instrumented tube mounted in grips.

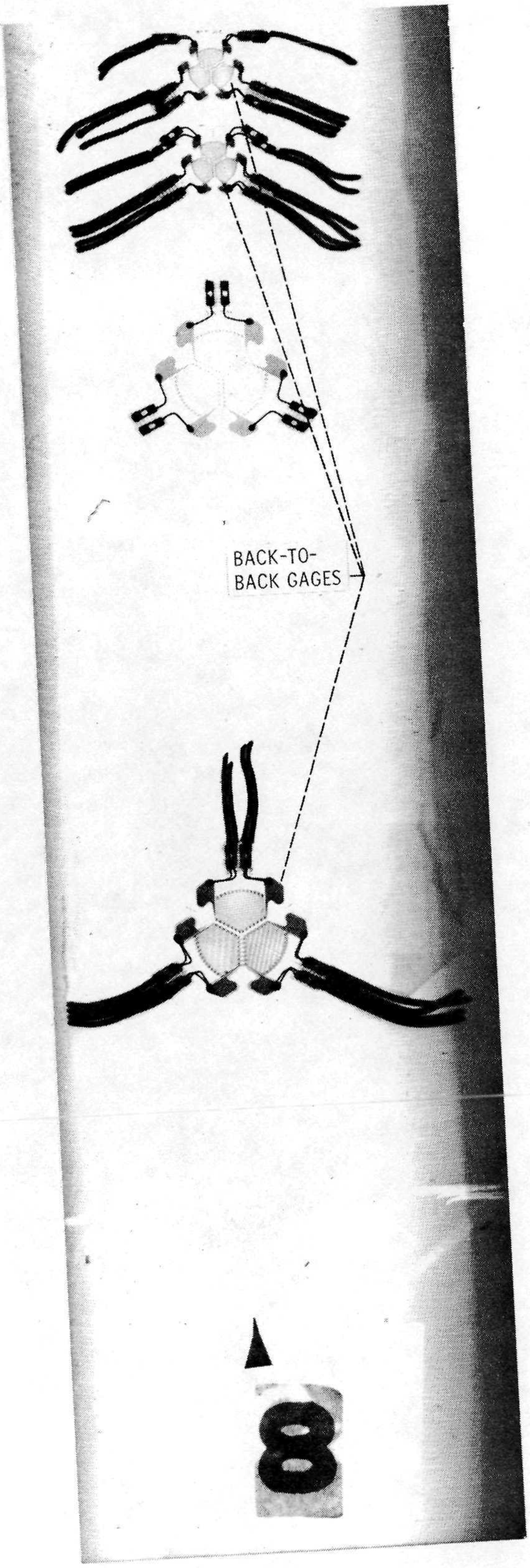
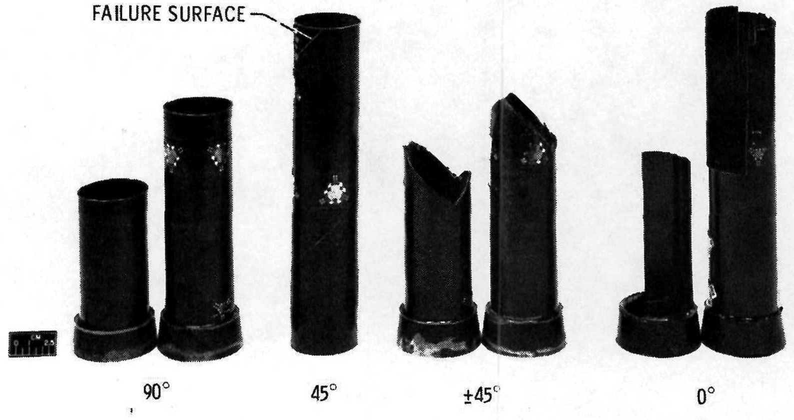
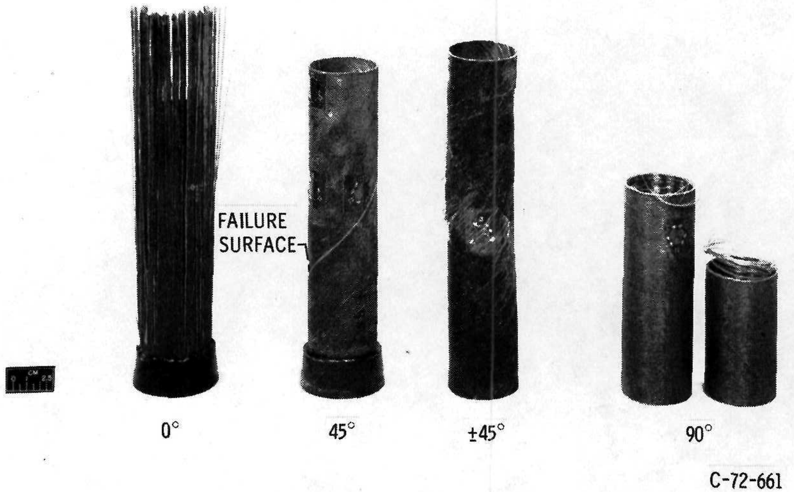


Figure 3. - X-ray showing alignment of inside and outside gages.



(a) GRAPHITE/EPOXY TUBES.



(b) S-GLASS/EPOXY TUBES.

Figure 4. - Failed specimens.

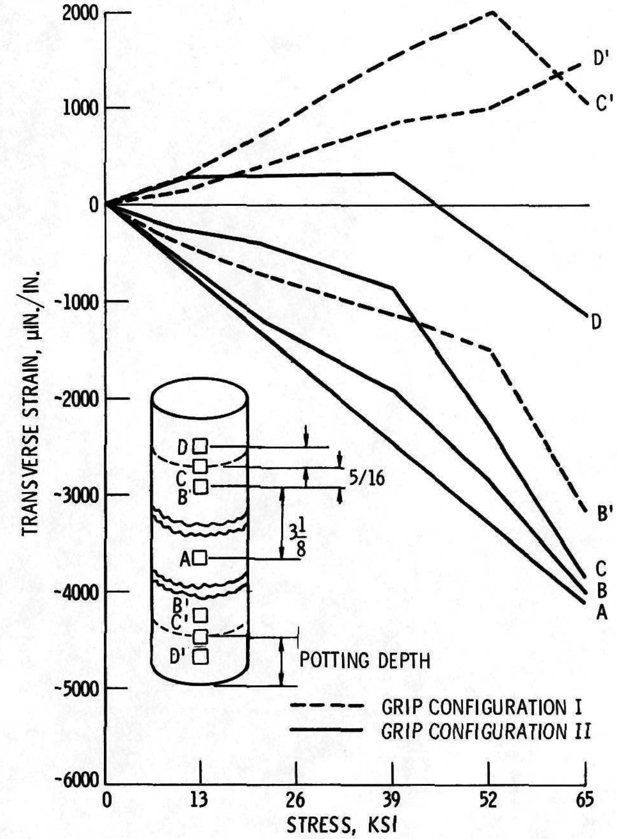


Figure 5. - Variation of transverse strain in grip area; 0^0 E-glass/epoxy tube.

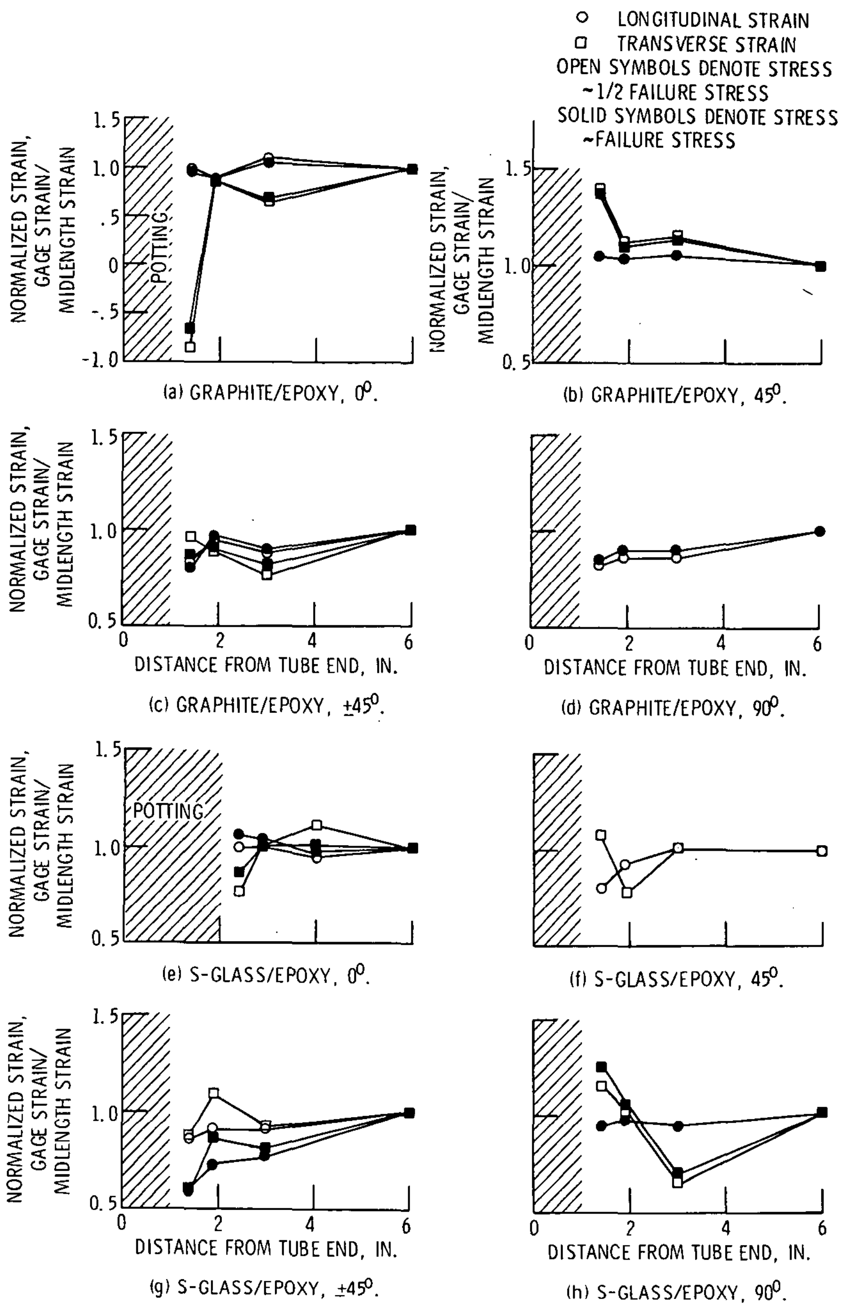


Figure 6. - Variation of strain along tube length.

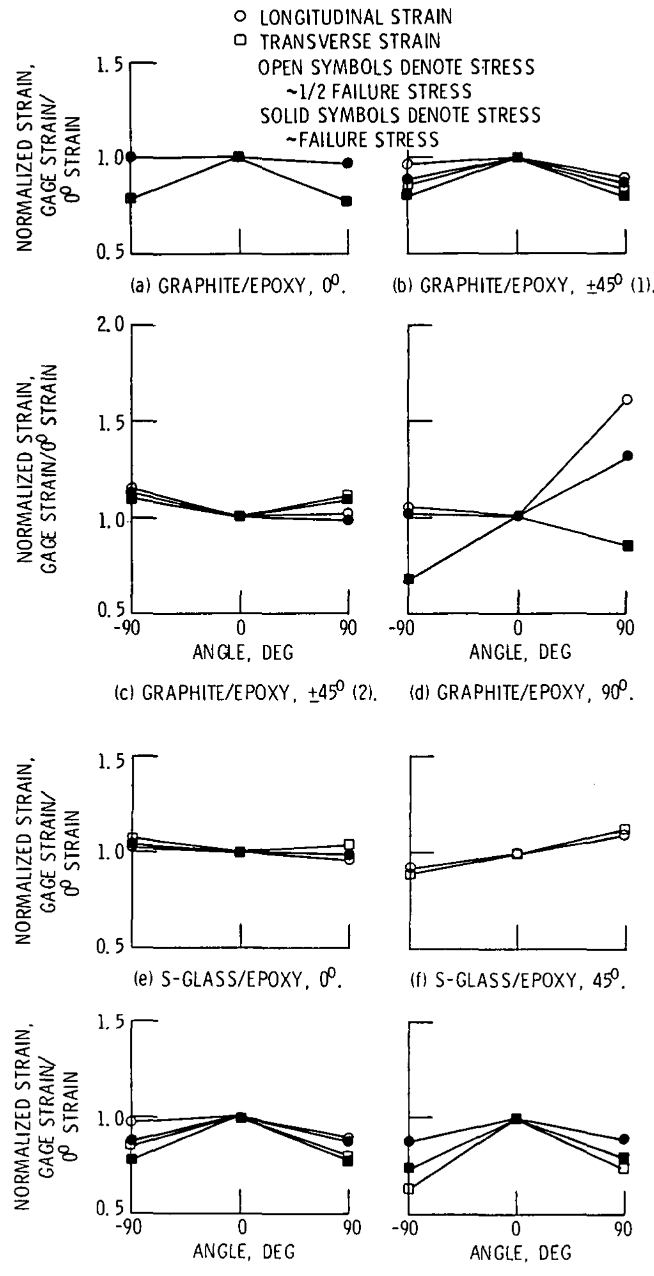


Figure 7. - Variation of strain around circumference of tube at its midlength.

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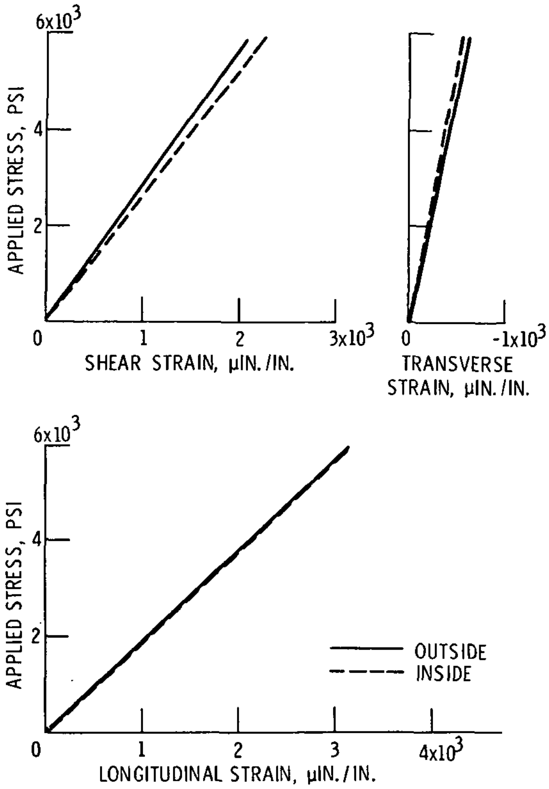
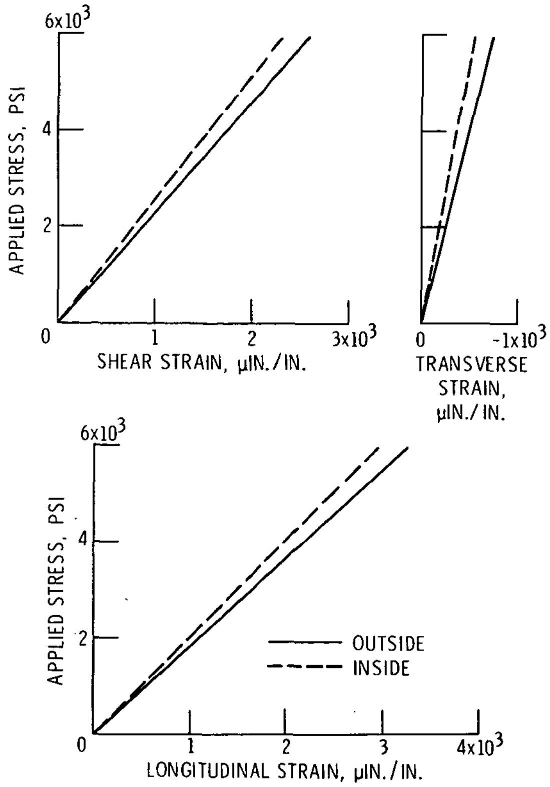


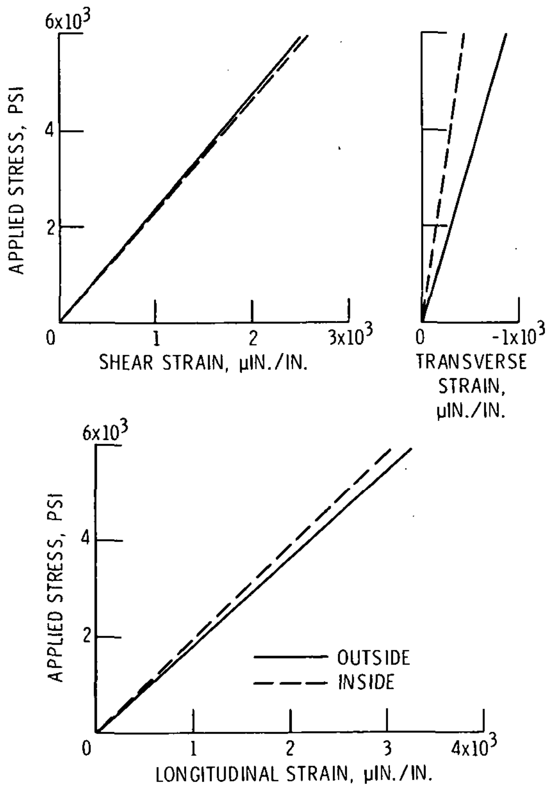
(a) 5 INCHES FROM GRIP (MIDLENGTH).

Figure 8. - Stress versus strain, 45° graphite/epoxy.



(b) 7/8 INCH FROM GRIP.

Figure 8. - Continued.



(c) 3/8 INCH FROM GRIP.

Figure 8. - Concluded.

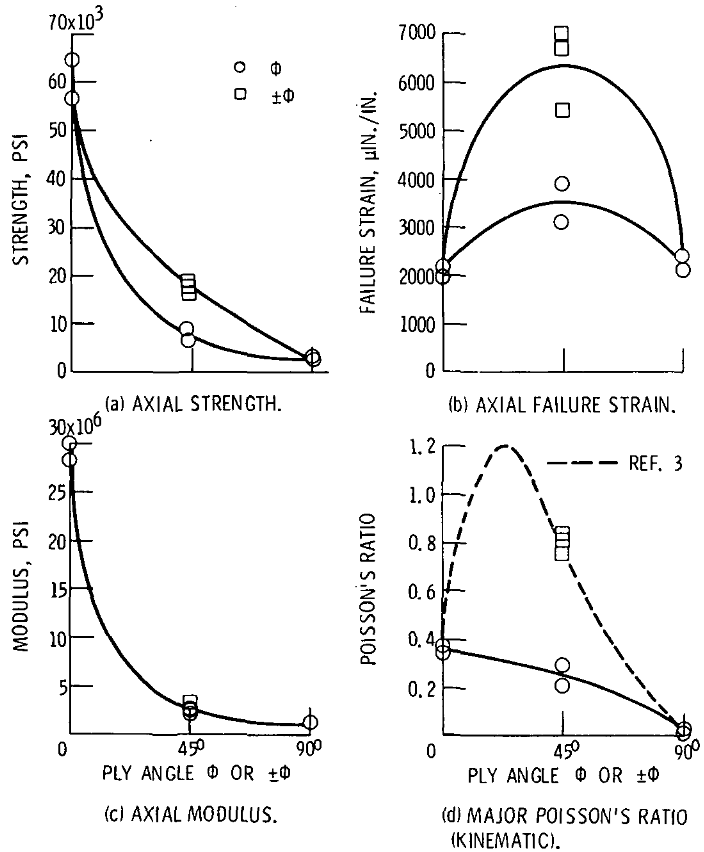


Figure 9. - Properties of graphite/epoxy composite tubes in uniaxial tension.

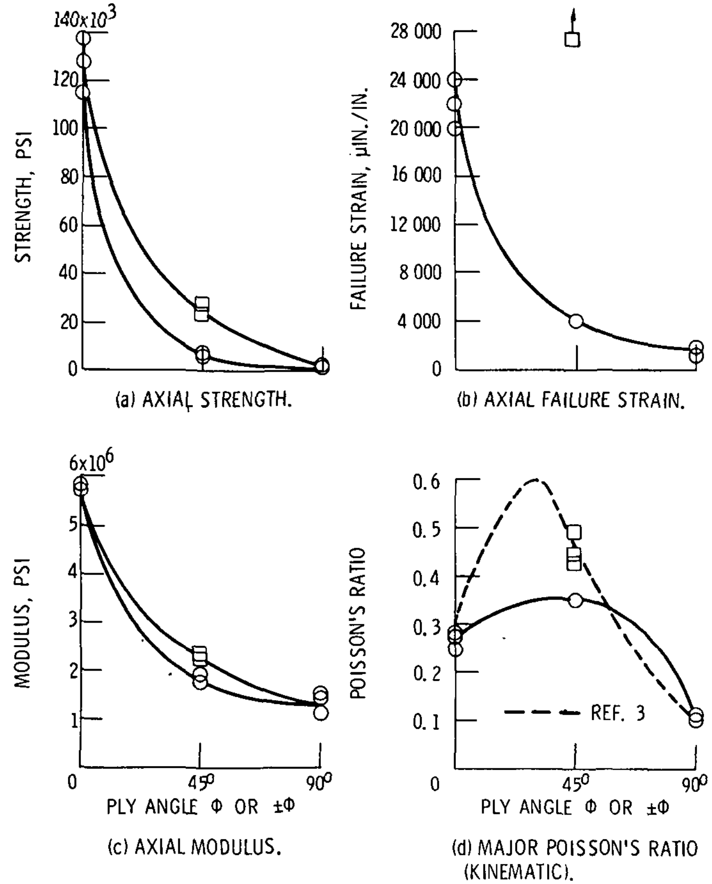


Figure 10. - Properties of E-glass/epoxy composite tubes in uniaxial tension.