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THICKNESS PROPERTIES OF LAMINATED FIBER COMPOSITES.(U)

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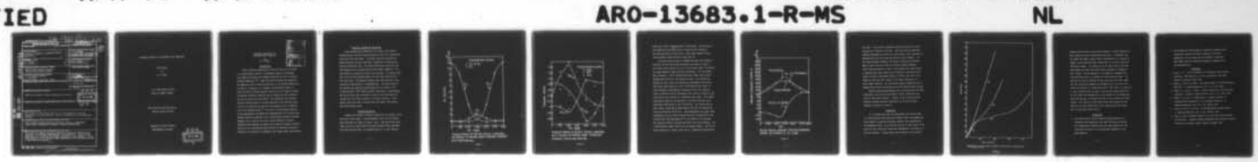

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SECURITY CLASSIFICATION OF THIS PAGE (When Data Entered)

REPORT DOCUMENTATION PAGE		READ INSTRUCTIONS BEFORE COMPLETING FORM
1. REPORT NUMBER	2. GOVT ACCESSION NO.	3. RECIPIENT'S CATALOG NUMBER
4. TITLE (and Subtitle) 6 Thickness Properties of Laminated Fiber Composites.		5. TYPE OF REPORT & PERIOD COVERED 9 Final Report, 17 NOV 75 - 31 DEC 77
		6. PERFORMING ORG. REPORT NUMBER
7. AUTHOR(s) 10 A. A. Fahmy		8. CONTRACT OR GRANT NUMBER(s) 15 DAAG29-76G0106 new
9. PERFORMING ORGANIZATION NAME AND ADDRESS North Carolina State University Raleigh, North Carolina 27650		10. PROGRAM ELEMENT, PROJECT, TASK AREA & WORK UNIT NUMBERS
11. CONTROLLING OFFICE NAME AND ADDRESS U. S. Army Research Office P. O. Box 12211 Research Triangle Park, NC 27709		12. REPORT DATE 11 24 Apr[redacted]978
		13. NUMBER OF PAGES 10 12 12p.
14. MONITORING AGENCY NAME & ADDRESS (if different from Controlling Office)		15. SECURITY CLASS. (of this report) unclassified
		15a. DECLASSIFICATION/DOWNGRADING SCHEDULE

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16. DISTRIBUTION STATEMENT (of this Report)

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DDC RECEIVED JUN 14 1978 B

17. DISTRIBUTION STATEMENT (of the abstract entered in Block 20, if different from Report)

18. SUPPLEMENTARY NOTES

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Elastic Moduli, Thermal Expansion Coefficient, Angle ply composites, Stress-strain relationship, Thickness direction, Kevlar-epoxy

20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

The elastic and thermal expansion properties of angle-ply laminated fiber composites are evaluated experimentally and analytically. These include properties in or involving the thickness direction of the laminates. Stress-strain behavior of the laminates under compression in the thickness direction is described and discussed.

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Thickness Properties of Laminated Fiber Composites

Final Report

by

A. A. Fahmy

U. S. Army Research Office

Grant No. DAAG29 76G0106

North Carolina State University

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Introduction

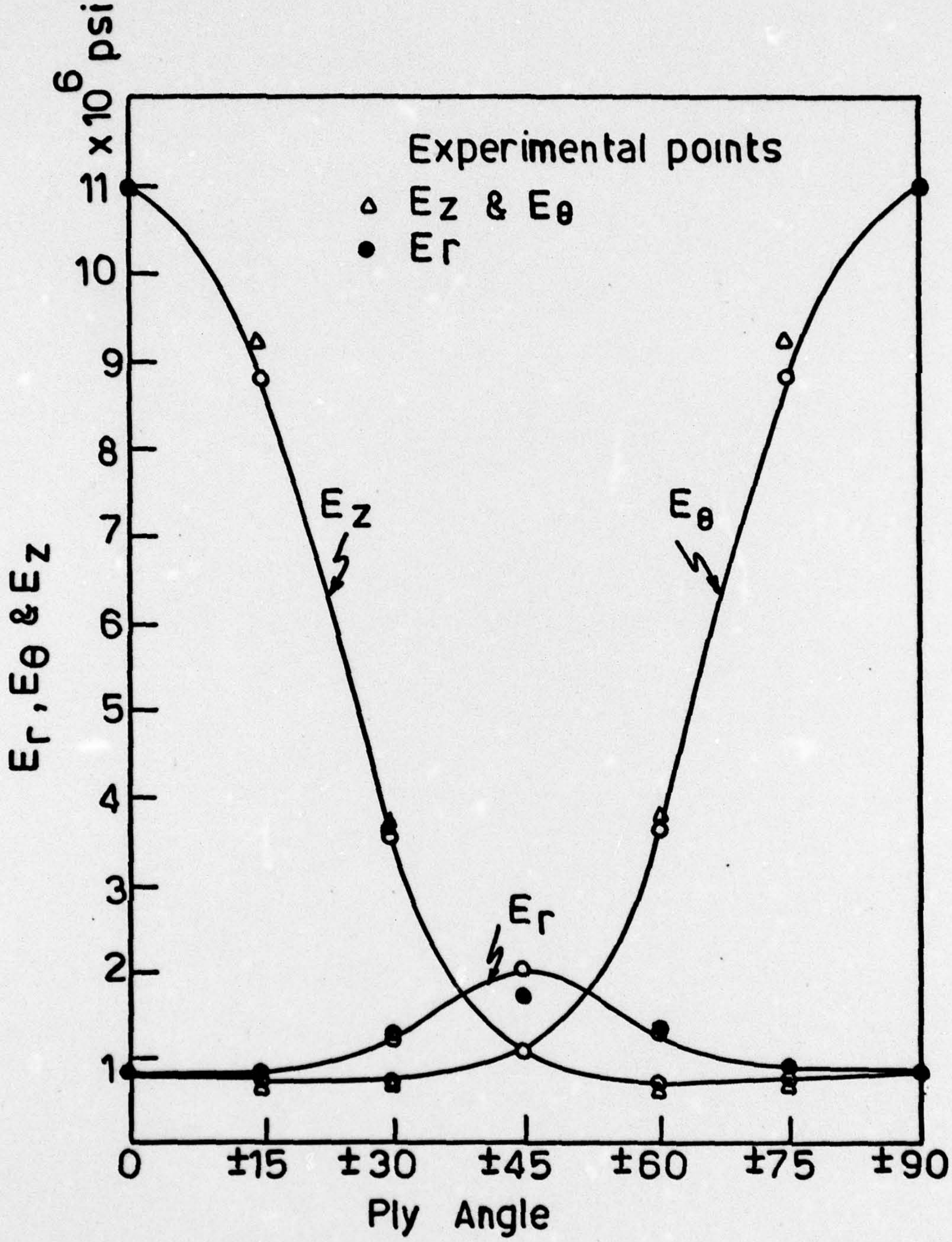
Fiber reinforced composites in which the fibers are aligned i.e. undirectional, exhibit a considerable degree of anisotropy with regards to elastic and strength properties as well as thermal expansion behavior.[1,2,3] Along the fiber direction the composites are generally stiff, strong and typically of low thermal expansivity. By properly laminating plies together unidirectional layers in which the fiber direction changes from ply to ply a range of elastic and thermal expansion properties may be conferred on the laminates to suit the particular application. The properties that received the most attention have so far been measured in the laminate plane. Little or no attention was given to any property which is measured out of the laminate plane.[4,5] This work is thus devoted primarily to the experimental and theoretical determination of the elastic and thermal expansion properties in or involving the thickness direction together with a study of the stress strain behavior of certain laminates when subjected to compression along the thickness direction. Results of the investigation make possible an evaluation and understanding of the behavior of laminates and filament wound constructions.

Materials: Design and Processing

Three systems were selected for this study, Kevlar-Epoxy, Graphite-Epoxy, and Glass-Epoxy although the first was studied more extensively than the others. The Kevlar-Epoxy was supplied by Narmco Materials Division, Whittaker Corporation as prepreg tape Rigidite 5208-Kevlar 49A. The Graphite-Epoxy was supplied by the same company also as prepreg tape Rigidite 5208- Graphite R. The Glass-Epoxy was supplied as Scottish ply prepreg. The prepreg tapes were cut up at the required angles with the fiber direction and laid up by hand. The prepreg laminates were then autocalve cured according to manufacturer's recommendations. The construction of the laminate was angle-ply construction with ply angles of 0^o (unidirectional), $\pm 15^o$, $\pm 30^o$, and $\pm 45^o$ (cross-ply). Unidirectional thin walled tubes were also made for each of the three materials systems, with the fibers running in the axial direction. These samples which were used in torsion were also made of the prepreg tape and autoclave cured.

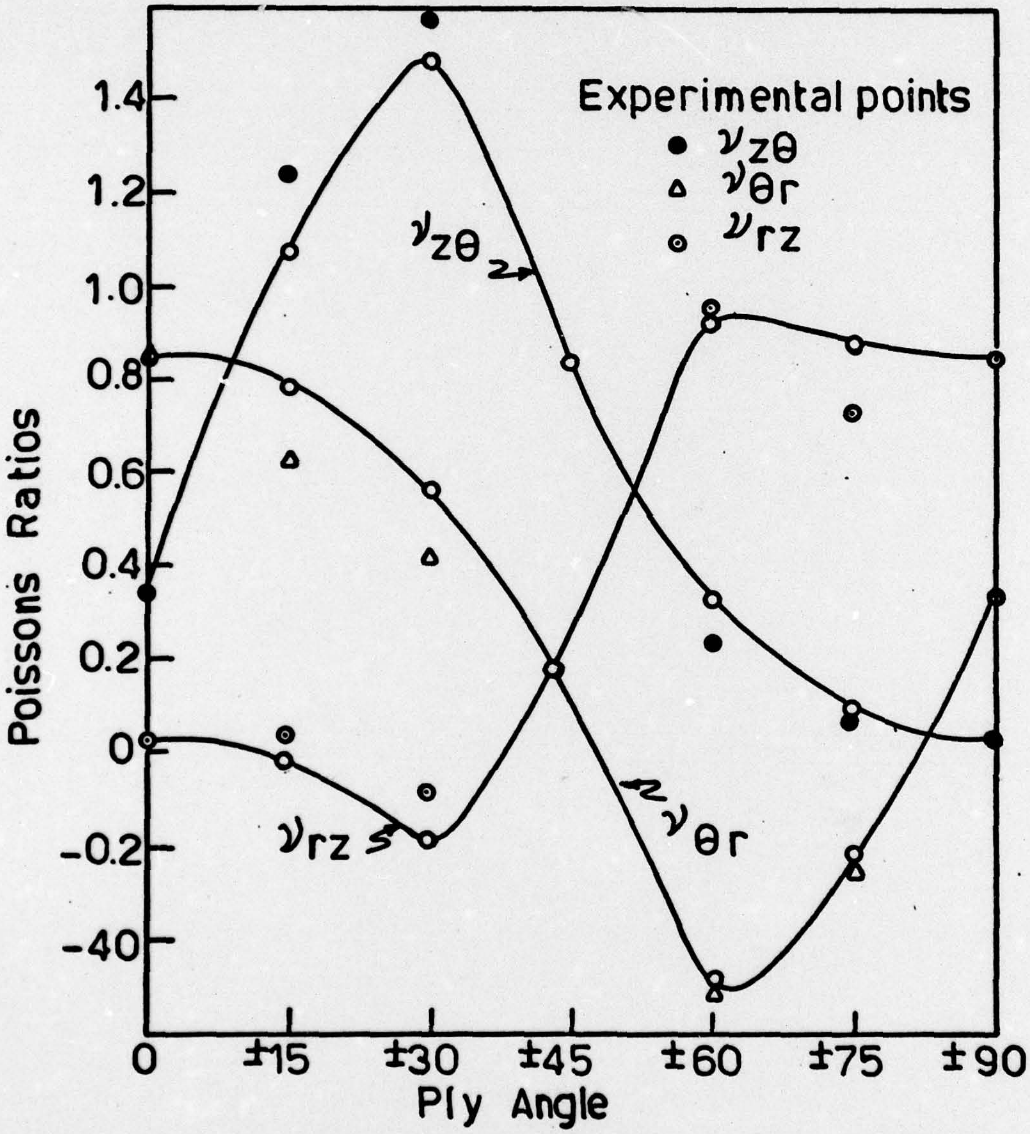
Testing and Results

Samples were tested in tension, compression and flexure, using electrical strain gages. The experimental results on the Kevlar-Epoxy laminates are shown on Figure 1 and 2. Here the three orthotropic axis are z which bisects the angle between fibers and makes less than 45^o with them, θ is perpendicular to z in the laminate



Young's Moduli of Kevlar-Epoxy Laminates as function of winding angle "computer analysis" and experimental.

Figure 1

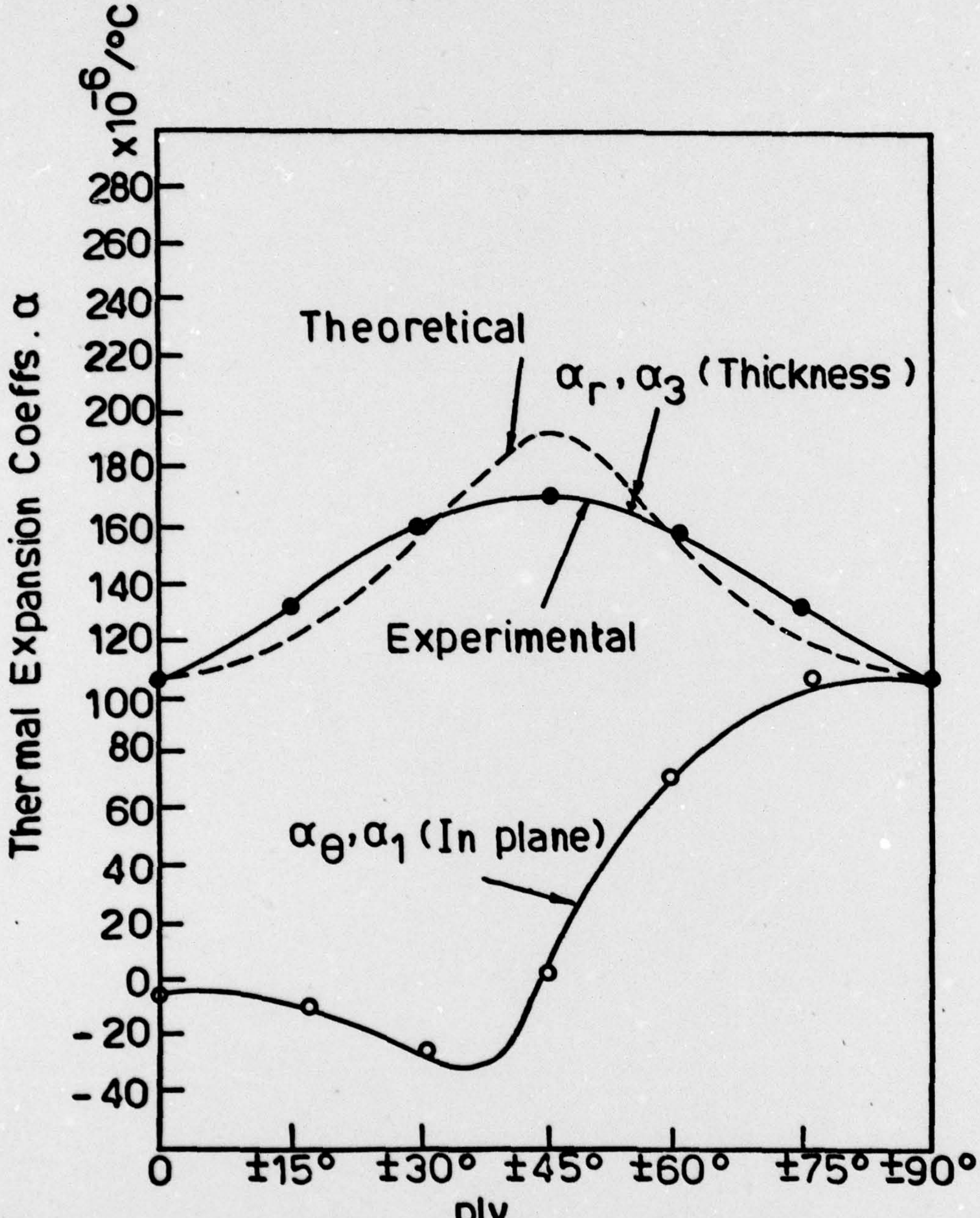


Poissons Ration of Kevlar-Epoxy Laminates as a function of Winding Angle "Computer Analysis." And Experimental.

Figure 2

plane and r which is perpendicular to that plane. On the graph is also shown the calculated values of these elastic constants. The calculation was carried out by a high speed computer using a finite element linear elasticity code ELAS 75.[6]

The stress-strain curves in compression along the thickness direction for the Kevlar-Epoxy laminates are shown in Figure 3. The stress-strain behavior as well as the failure modes of different ply angle laminates showed striking differences. For the Kevlar-Epoxy laminates: The 0^{o} laminate exhibited linear stress-strain response and failed at a low fracture stress. The fracture was through the resin matrix as revealed by micrographic observation. The stress-strain beahvior of the +/-15^{o} material was linear at first followed by considerable flattening of the curve during a stage of extensive plastic deformation and finally an upturn of the curve ending with fracture at a moderate stress value. This sample experienced expansion and barrelling in the 90^{o} direction, with contraction and necking in the 0^{o} direction. The fracture was by shear along a plane making approximately 30^{o} with the compression axis and containing the 0^{o} axis. Some delamination also took place. Furthermore, the ply angle increased from 15^{o} to around 26^{o} on the surface layers and approached 45^{o} in the middle of the midplane. The fracture obviously involved both matrix and fiber breakage. The +/-30^{o} laminate showed similar but less marked effects. The failure which occurred at a higher stress was by a combination delamination



Kevlar-Epoxy Laminate Thermal Expansion Coeffs. as function of ply Angle.

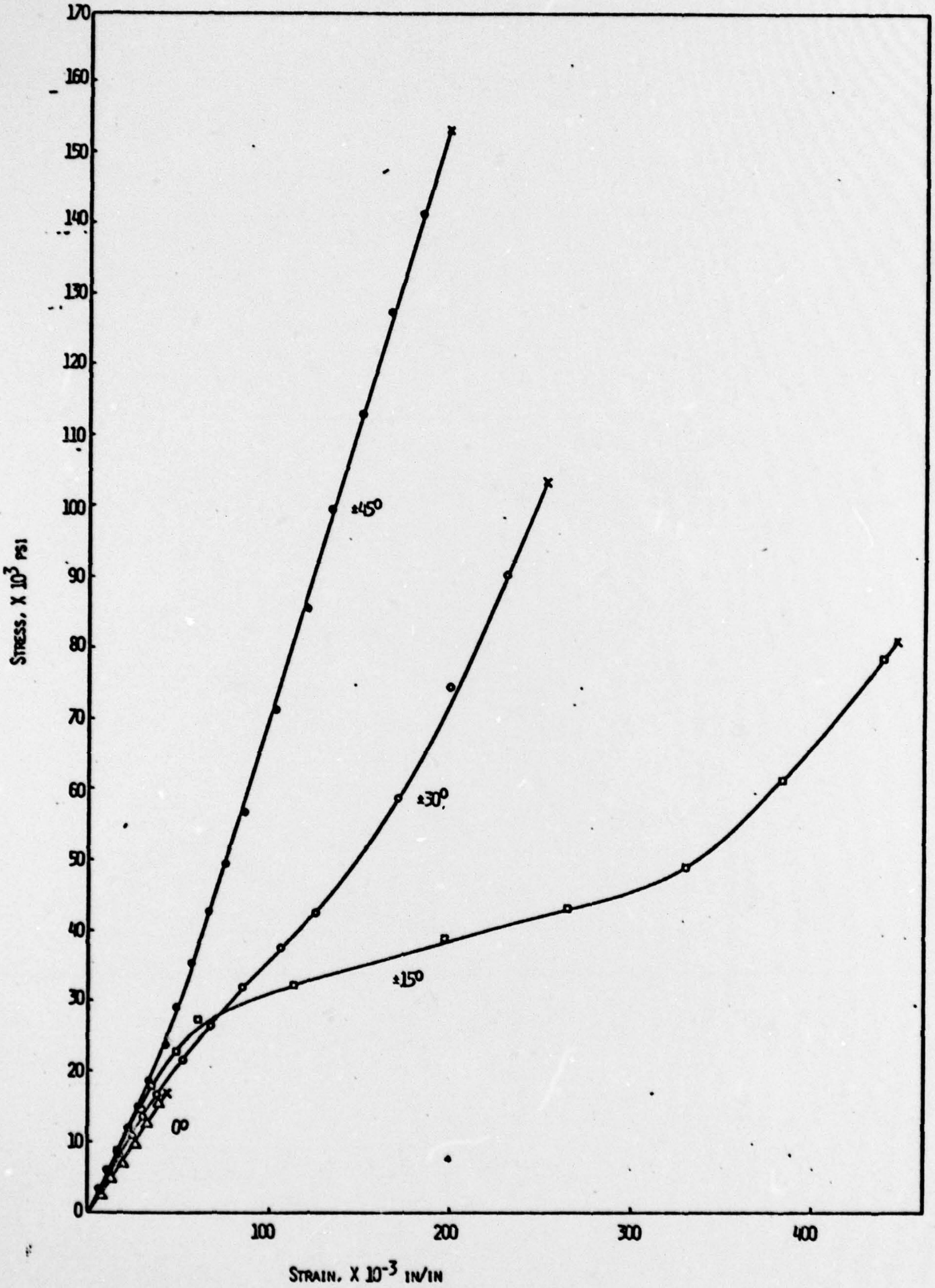
Figure 3

and shear. The cross-ply laminates exhibited practically linear stress-strain response to failure. The cross-section dimensions remained unchanged and failure at a much higher stress occurred by delamination with plies being ejected out of the laminate. For the Graphite-Epoxy laminates, the trend of behavior and failure mode is quite similar to that of the Kevlar-Epoxy laminates, except that the behavior of the +/-15^{o} laminate was linear within a comparatively higher range then followed by a relatively small amount of plastic deformation before it failed; the shift in ply angle did occur but not as much as the former counterpart of Kevlar-Epoxy laminate. The Glass-Epoxy samples showed behavior in between that of the Kevlar-Epoxy and of the Graphite-Epoxy systems.

Thermal expansion measurements were also made along the three orthrotropic axes and the experimental results showed the same trend as predicted by theory. Results of the in-plane and the thickness thermal expansion experiments on the Kevlar-Epoxy lamaintes are shown in Figure 4.

Discussion

It is evident that prior to delamination and failure there is a considerable scissoring effect whereby fibers in neighbouring plies rotate in opposite directions around an axis perpendicular to thelaminate plane. This involves not only in plane shear of the plies but also relatively large shear deformation in the matrix at the ply interface. The nonlinear shear response of the material



COMPRESSION TEST TO FAILURE OF ANGLE PLY KEVLAR-EPOXY LAMINATES WITH AXIS OF COMPRESSION ALONG THE THICKNESS DIRECTIONS.

Figure 4

explains the nonlinear stress-strain behavior of these laminates in which extensive plastic deformation took place. Furthermore, one can reason the rather unusual effects encountered, e.g. necking of samples in one direction under compression, in a fairly simple and qualitative manner. The fibers are by far the stiffer of the two constituents and would thus offer great resistance to changes in their length. Yet the composite in a attempt to accomodate the increasing load tends to increase its cross-sectional area. The only way this can be achieved without increasing the fiber length and with satisfying compatability between plies is for the cross-section to increase its length along axis θ and reduce it along axis z, thus increasing the ply angle. Once the ply angle reaches 45° and the fibers are perpendicular to one another in the neighboring plies the only way to increase the area is by increasing the fiber length. This requires a high fiber stress and accounts for the sharp rise in the stress-strain curve slope and once the fibers fail the laminates finally fails.

Conclusions

1. The elastic moduli and the thermal expansion behavior of laminated fiber composites along their thickness directions are substantially different from the same properties in the transverse direction of a unidirectional composite of the same materials.

2. The strength and failure modes of angle-ply laminates under compression along the thickness direction is strongly dependant on the ply angle and the strength is generally much higher than the transverse strength of composites of the same materials.

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