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(NASA-TM-84638) ENERGY ABSORPTION OF COMPOSITE MATERIALS (NASA) 9 p HC A02/MF A01 CSCL 11D N83-19816

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ENERGY ABSORPTION OF COMPOSITE MATERIALS

Gary L. Farley

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16. Abstract

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Abstract

This paper presents results of a study on the energy absorption characteristics of selected composite material systems and compares the results with aluminum. Composite compression tube specimens were fabricated with both tape and woven fabric prepreg using graphite/epoxy (Gr/E), Kevlar®[1] epoxy (K/E) and glass/epoxy (Gl/E). Chamfering and notching one end of the composite tube specimen reduced the peak load at initial failure without altering the sustained crushing load, and prevented catastrophic failure. Static compression and vertical impact tests were performed on 128 tubes. The results varied significantly as a function of material type and ply orientation. In general, the Gr/E tubes absorbed more energy than the Gl/E or K/E tubes for the same ply orientation. The [0/±15] Gr/E tubes absorbed more energy than the aluminum tubes. Gr/E and Gl/E tubes failed in a brittle mode and had negligible post crushing integrity, whereas the K/E tubes failed in an accordian buckling mode similar to the aluminum tubes. The energy absorption and post crushing integrity of hybrid composite tubes were not significantly better than that of the single material tubes.

Introduction

All new U.S. Army helicopters, designed after 1974 must meet the Army's crashworthiness requirements as defined by Military Standard 1290 [1]. These crashworthiness requirements specify various crash conditions, including impact velocity, vehicle attitude, minimization of change in occupancy volume, and aircraft bounce, which must be survivable for the occupant. Aircraft bounce, a result of energy release from the deformed structure, can induce unanticipated secondary crash attitudes and conditions. Energy absorption in a helicopter crash is accomplished primarily through three mechanisms; stroking of the seats, stroking of the landing gear, and crushing of the fuselage subfloor structure. Other systems that contribute to the total crashworthiness of the helicopter include occupant restraints, fuel system, and the protective shell of the fuselage structure.

Only two helicopters, the UH-60 and AH-64, have been designed to MIL-STD-1290, thus a limited data base exists for designing energy absorbing metal structure. Much of the existing technology was developed by the automobile industry through crash testing components and full-scale cars. An extensive bibliography of reports on energy absorption can be found in reference 2. Use of composite materials in aircraft structures is increasing. As composites replace more metal components and the role of aircraft crashworthiness and survivability becomes more clearly defined, the need to establish the energy absorption characteristics of composites becomes paramount.

Efficient design of a structural component to meet MIL-STD-1290 requires knowledge of the loads and energy absorption mechanisms. Also, the specific energy absorption, post crushing integrity and energy release of the candidate materials must be known. The specific energy absorption is a function of the constituent materials (fiber and matrix) and ply orientation whereas the specific energy absorption for metals is primarily a function of their plastic behavior.

Thornton [3] measured the energy absorption of small diameter graphite/epoxy, Kevlar/epoxy, and glass/epoxy tubes. Fabric prepreg with a [0/90] layup was used almost exclusively. Specific energy absorption of graphite/epoxy composites having a [0/90] layup were found to exceed 6061-T6 aluminum and mild steel for certain values of tube wall thickness/diameter ratio. Loading rate sensitivity was found to be negligible for loading rates below 27 ft/sec. Graphite/epoxy and glass/epoxy tubes exhibited brittle failure modes characteristics of interlaminar shear failure followed by fiber fracture.

Foye, et al. [4 and 5] examined the energy absorption characteristics of skin stiffened and honeycomb core sandwich cylinders fabricated from both composite materials and aluminum. All cylinders were designed to the same stiffness and strength

[1]Kevlar® is a registered trademark of Du Pont.

values. Each cylinder was tested under static compression or torsional load. The energy absorption characteristics were examined but the specific energy absorption of the base material was not evaluated. Foye determined that the aluminum cylinders were more efficient energy absorbers than the composite cylinders. Of the composite cylinders tested, the Gr/E specimens absorbed the most energy but failed in a brittle mode with no post crushing integrity.

Cronkhite, et al. [2], determined the energy absorption of [±45] K/E, Gr/E and Gl/E tubes. Conically shaped or flat loading heads were placed on composite tubes and an axial compressive load was applied. Cone angle varied from 0 (flat) to 45 degrees. Generally, highest sustained crushing loads were developed in tests with flat loading heads and the Gr/E tubes absorbed more energy than the K/E or Gl/E tubes.

The objective of the study reported herein was to investigate the specific energy absorption, post crushing integrity and post crushing energy release of composites. The matrix material was either Narmco 5208 or Fiberite FM934, and the fibers were Thornel[2] 300 Graphite, Kevlar 49 or E-glass. Tubes were fabricated with unidirectional and woven fabric prepreg. Thirty (30) combinations of materials and ply orientations were tested and the data were compared with results for aluminum tubes. Both static and dynamic loading tests were conducted. The failure modes and energy absorption mechanisms for all tubes were examined.

Identification of commercial products and companies in this report is used to describe adequately the test materials. The identification of these commercial products does not constitute endorsement, expressed or implied, of such products by the National Aeronautics and Space Administration or the publishers of this paper.

Specimens and Procedures

Test Specimens

Tubes nominally 10.16 cm (4.00 in.) in length by 3.81 cm (1.50 in.) inside diameter, were used for composite test specimens, figure 1. The tube was selected on the basis of stability and ease of fabrication.

One end of each tube fabricated with composite material was chamfered and notched so that crushing could be initiated without causing catastrophic failure, figure 1. Preliminary tests and reports in the literature [2, 3, and 6] indicated that modifying the end greatly reduced peak loads without affecting the sustained crushing load, figure 2. Henceforth, the end modification is referred to as a load limiting concept (LLC).

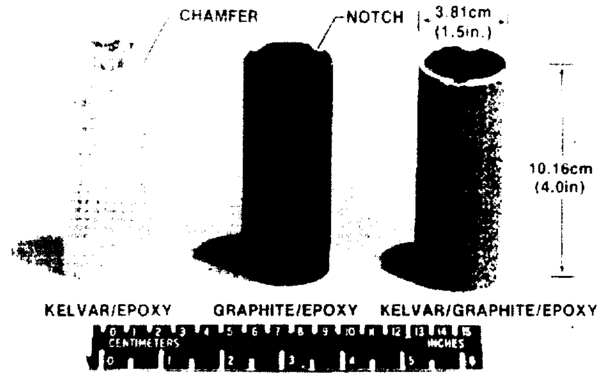


Figure 1. Composite tube specimens with chamfered and notched ends.

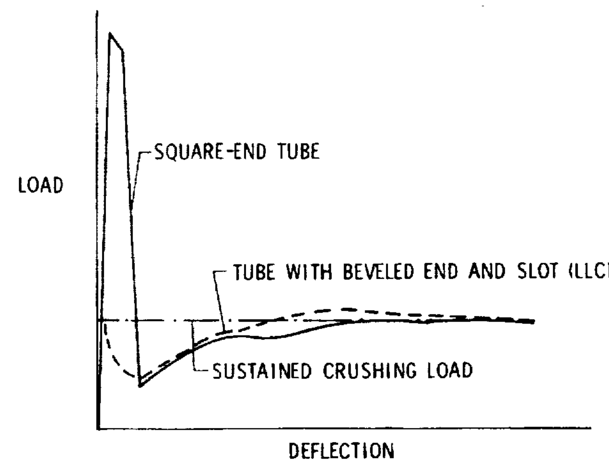


Figure 2. Effects of load limiting concept (LLC) on load-deflection response of composite tube.

Prepreg materials used to fabricate specimens were: T300/5208 fabric and unidirectional tape, Kevlar 49/5208 fabric and unidirectional tape, E-glass/5208 fabric and E-glass/934 unidirectional tape. Nominal ply thicknesses and fabric style are listed in table 1. E-glass/epoxy tape was not available with the 5208 matrix therefore tape with the 934 matrix was used. Both 5208 and 934 contain the same epoxide base MY720, and are compatible resins. A belt wrapper was used to lay prepreg materials on a metal mandrel to fabricate 30.5 cm (24.0 in.) long tubes. After curing at 176°C (350°F), 10.16 cm

[2] Thornel is a registered trademark of Union Carbide.

(4.00 in.) long specimens were cut and the ends were machined. [0/±θ] and [±45] ply orientations were selected to develop trends to assess the effects of ply orientation on energy absorption. All composite tubes were fabricated in a similar manner. For example, a nine ply [0/±θ] tube has a stacking sequence of [0/±θ/0/±θ/0/±θ]. Detailed information on ply orientations and tube wall thickness are presented in tables 2 and 3.

Table 1.- Composite Prepreg Materials

FIBER/MATRIX	NOMINAL CURED PLY THICKNESS, cm (in.)	TYPE
T300/5208	.0330 (.0130)	24× 24 PLAIN WEAVE FABRIC
T300/5208	.0139 (.0055)	TAPE
KEVLAR 49/5208	.0254 (.0100)	285 STYLE FABRIC
KEVLAR 49/5208	.0139 (.0055)	TAPE
E-GLASS/5208	.0254 (.0100)	1581 STYLE FABRIC
E-GLASS/934	.0254 (.0100)	TAPE

Table 2.- Composite Tube Data

PLY ORIENTATION	GRAPHITE/EPOXY TUBES		KEVLAR/EPOXY TUBES		GLASS/EPOXY TUBES	
	NUMBER OF PLIES	WALL THICKNESS, • cm (in.)	NUMBER OF PLIES	WALL THICKNESS, • cm (in.)	NUMBER OF PLIES	WALL THICKNESS, cm (in.)
[±45]	8	.1127 (.0444)	8	.1173 (.0462)	6	.2768 (.1090)
[±45^F]	4	.1341 (.0528)	6	.1567 (.0617)	6	.1480 (.0583)
[0/±15]	9	.1336 (.0526)	9	.1457 (.0574)	6	.2590 (.1020)
[0/±30]	9	.1361 (.0536)	9	.1605 (.0632)	6	.2717 (.1070)
[0/±45]	9	.1287 (.0507)	9	.1341 (.0528)	6	.2565 (.1010)
[0/±60]	9	.1305 (.0514)	9	.1569 (.0618)	6	.2667 (.1050)
[0/±75]	9	.1381 (.0544)	9	.1363 (.0537)	6	.3073 (.1210)
[0/±90]	9	.1285 (.0506)	9	.1363 (.0562)	6	.3073 (.1210)
[0/±45^F]	6	.1938 (.0763)	6	.1348 (.0531)	6	.2717 (.1070)

[θ^F] DENOTES FABRIC
• AVERAGE OF FOUR SPECIMENS

Hybrid material combinations and ply orientations investigated are listed in table 3. In all cases, fabric was used for the ±45 plies. Aluminum tubes were also tested to establish a base for comparison with the composite tubes. The wall thickness of each aluminum tube, refer to table 3, was sized to prevent a column instability failure mode.

Static and Dynamic Crushing Tests

Static crushing tests were performed in a 1.35 MN (300 kip) capacity hydraulic loading machine. Load platens were set parallel to each other prior to initiation of the tests. All tubes were compressed at a rate of approximately .018 cm/min (.007 in./min) until crushing was initiated and then the test machine head speed was increased to .076 cm/min (0.3 in./min). Load and deflection were recorded by an automatic data acquisition system. Three replica tests were performed.

Table 3.- Hybrid Composite Tube and Aluminum Tube Data

PLY ORIENTATION	NUMBER OF PLIES	WALL THICKNESS, • cm (in.)	AVERAGE SPECIFIEC SUSTAINED CRUSHING STRESS, $\frac{N\text{-}m}{kg}$ $\left(\frac{lb_f\text{-}in}{lbm}\right)$
$[0_{Gr}/\pm 45^F_{Gl}]$	6	.1414 (.0557)	44344 (177377)
$[0_{Gr}/\pm 45^F_{K}]$	6	.1084 (.0427)	50725 (202903)
$[0_{K}/\pm 45^F_{Gr}]$	6	.1757 (.0692)	34745 (138982)
6061 Al. DIA. 2.54 cm (1.00 in.)		.1473 (.0580)	77485 (309941)
6061 Al. DIA. 3.81 cm (1.50 in.)		.2438 (.0960)	88533 (354133)

F DENOTES FABRIC Gr = GRAPHITE
K = KEVLAR Gl = GLASS
EPOXY MATRIX MATERIAL USED IN ALL COMPOSITE TUBES
• AVERAGE OF FOUR SPECIMENS

Impact tests were performed in the drop tower to determine the dynamic sustained crushing load, failure mode, energy absorption mechanism, and post crushing structural integrity for comparison with the static test results. Tubes were impacted with a 45 Kg (100 lb) mass having an approximate velocity of 7.6 m/sec (25 ft/sec). Deceleration of the mass was measured by an accelerometer and recorded on a strip chart. The sustained crushing force was determined from the mass and deceleration measurements. High speed motion pictures, approximately 4000 frames/sec, recorded selected tests to document the dynamic energy absorption mechanism. Only one specimen of each configuration was tested. A limited number of dynamic tests are reported due to invalid test results.

Results and Discussion

A typical load-deflection curve for a composite tube is shown in figure 3. After static crushing was initiated, the load required to sustain crushing remained relatively constant. Energy absorbed in crushing a tube can be depicted as the area under the load-deflection curve. The specific energy absorbed per unit of deformation equals the specific sustained crushing stress, obtained by dividing the sustained crushing stress, σ, by the tube density, ρ. Comparision of energy absorbed, for the materials and ply orientations investigated, will be made on the basis of specific sustained crushing stress, σ/ρ.

A typical load-deflection curve for an aluminum tube is shown in figure 4

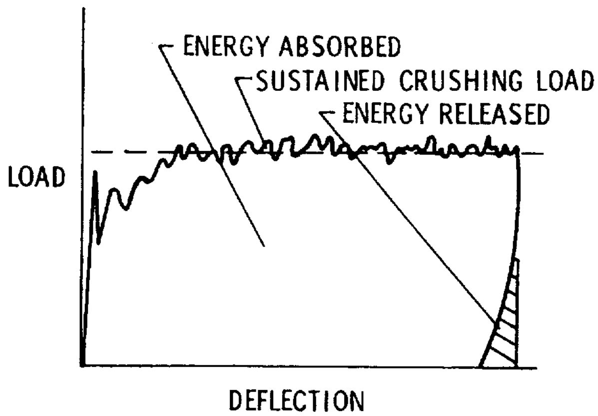


Figure 3. - Typical load-deflection curve of composite tube.

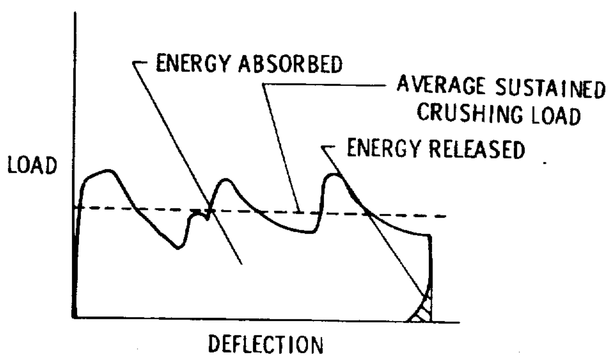


Figure 4. - Typical load-deflection curve of aluminum tube.

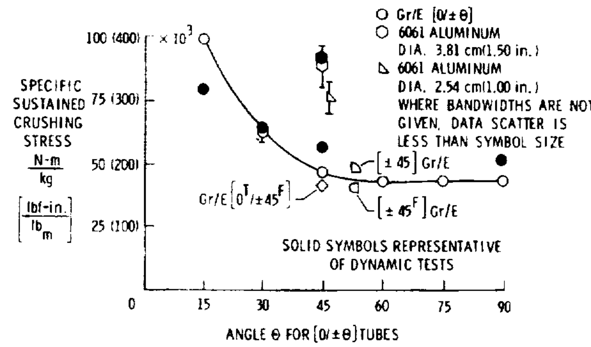
and large deviations from the average sustained crushing load are evident. The deviation was cyclic and is attributed to the successive formation of local buckles. The inclusion of aluminum test data is for comparison with the composite tube data. More extensive energy absorption data for aluminum tubes can be found in reference 6.

Values of σ/ρ for each composite and metal tube tested are plotted in figure 5. Statically crushed tubes are shown in figures 6 and 7 and photographs taken during dynamic crushing of tubes are shown in figure 8. Detailed discussion of test results follows.

Static Crushing Tests

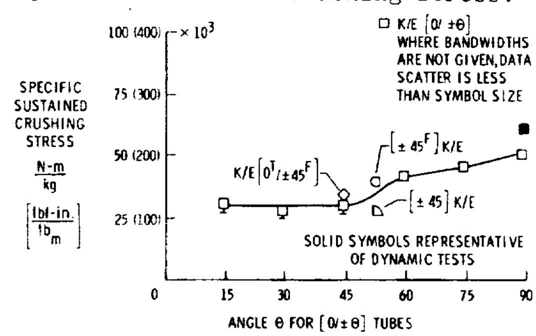
Graphite/Epoxy Tubes

Values of σ/ρ for Gr/E tubes are plotted in figure 5 (a). For the [0/±θ] ply orientation tubes, σ/ρ decreased as θ increased from 15 to 45 degrees but remained relatively constant for values of θ between 45 and 90 degrees. The data



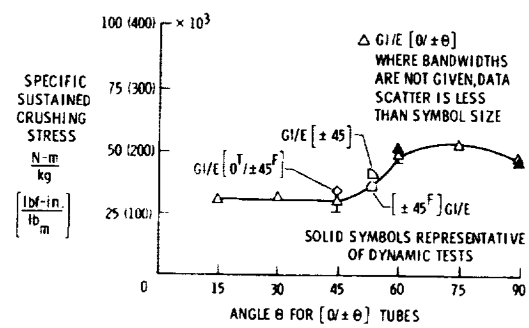
(a) Graphite/epoxy tubes.

Figure 5. - Effect of ply orientation on specific sustained crushing stress.



(b) Kevlar/epoxy tubes.

Figure 5. (cont.)



(c) Glass/epoxy tubes.

Figure 5. (concluded)

trend suggests a relationship between the energy absorbed and alignment of the fibers with respect to the longitudinal axis of the tube. However, caution should be used in employing this interpretation since [±45] and [0/±45] tubes absorbed an equivalent amount of energy. Tubes containing fabric, [$\pm 45^F$] and [$0/\pm 45^F$] exhibited 16 and 8 percent, respectively, lower specific sustained crushing stress than tubes fabricated from unidirecitonal tape. Lower specific sustained crushing stress was expected on the basis of comparing mechanical properties for tubes fabricated with fabric and tape prepreg. All Gr/E tubes failed in a brittle mode, figure 6. These findings agree with those of Thornton [3] and Foye, et al. [4]. No significant energy release was observed upon unloading the Gr/E tubes.

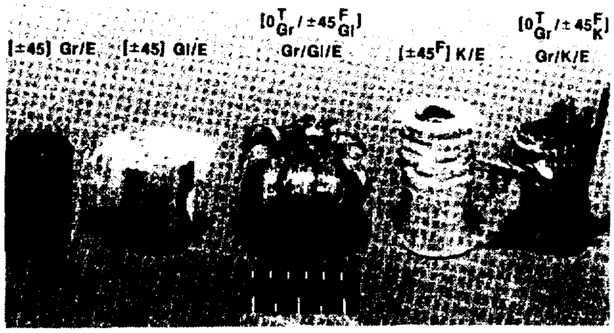


Figure 6. - Statically crushed composite tubes.

Kevlar/Epoxy Tubes

The σ/ρ data for [0/±θ] K/E tubes are plotted in figure 5 (b). The value of σ/ρ remained constant for θ between 15 and 45 degrees and increased as θ increased between 45 and 90 degrees. The trend is opposite that obtained for Gr/E tubes and suggests that longitudinal orientation of the fibers had little effect on σ/ρ for K/E. The average σ/ρ for [±45] tubes is 8 percent less than σ/ρ for [0/±45] tubes. Tubes containing fabric, [±45^F] and [0/±45^F] exhibited 14 and 17 percent, respectively, higher values of σ/ρ than tubes fabricated from unidirectional tape. An accordian buckling failure mode was exhibited by all K/E tubes, (figure 6), and is attributed to plasticity of the fiber. No significant post crushing energy release was observed for the K/E tubes.

Glass/Epoxy Tubes

The σ/ρ values obtained for Gl/E tubes are plotted in figure 5 (c). Data for the [0/±θ] tubes are grouped at two levels. For 15° <θ< 45°, σ/ρ averages approximately 31 N-m/kg whereas for 60° <θ< 90°, (σ/ρ) averages approximately 47 N-m/kg. The results suggest that orientation of the fibers with respect to the longitudinal axis of the tube had little effect on the specific sustained crushing stress. Tubes containing fabric, [±45^F] and [0/±45^F], exhibited 11 percent lower and 16 percent higher, respectively, sustained crushing strengths than tubes fabricated from unidirectional tape. All Gl/E tubes failed in a brittle mode, figure 6, as noted by Thornton [3]. Virtually no post crushing energy release occurred.

Energy Absorption Trends

The energy absorption trends for all [0/±θ] tubes are depicted in figure 5. For θ< ∓45 degrees the Gr/E tubes absorbed more energy than either K/E or Gl/E tubes. For θ> 60 degrees, σ/ρ for each material is comparable. The results suggest that longitudinally oriented graphite fibers absorb more energy than longitudinally oriented Kevlar or glass fibers. The energy absorption of K/E and Gl/E was similar for all ply orientations. The [±45] Gr/E tubes absorbed more energy than [±45] K/E or Gl/E tubes. This agrees with the findings of Cronkhite, et al. [2].

Energy Absorption Failure Mode Correlation

As previously mentioned, Gr/E and Gl/E tubes failed in a brittle mode and K/E tubes failed in an accordian mode. Since a common matrix material was used in all tubes, the differences in failure modes may be related to the failure characteristics of the fibers. The graphite and glass fibers exhibit brittle failures whereas Kevlar fiber has an elastic-plastic response with some splitting [7].

The σ/ρ trends for [0/±θ] tubes could be attributed to differences in ultimate strain of the fibers and matrix material. Inasmuch as the ultimate strain of the graphite fiber is less than that of the epoxy matrix, the matrix could provide some stabilization to the fibers during crushing. As θ increases from 15 to 45 degrees, the decrease in σ/ρ could be due to a reduction in stiffness of the composite. For 60 <θ< 90 degrees, σ/ρ would remain relatively constant since the stiffness of the composite would not appreciably change.

The ultimate strain of glass fiber is greater than that of the matrix. Thus, the matrix would be expected to fail first and would provide little or no stabilization to the glass fibers during crushing. The higher value of σ/ρ for [0/±θ] Gl/E tubes with 60 <θ< 90 degrees compared to 15 <θ< 45 degrees is attributed to the stabilization of the axial fibers by the circumferential fibers.

The ultimate strain of Kevlar fibers is also greater than that of the matrix. Thus failure trends similar to that of Gl/E tubes would be expected, except the K/E tubes fail in an accordian mode due to fiber plasticity and splitting.

Results of the energy absorption tests suggest higher strain to failure graphite fiber could improve energy absorption. Higher strain to failure matrix materials may provide stability to fibers at higher stress levels than achievable with the matrix materials used in this investigation and thereby also offer the potential for improved energy absorption. Although this discussion is by no means conclusive the available data appear to support the hypothesis. Further testing and analysis are needed to determine validity.

Hybrid Composite Material and Aluminum Tubes

Hybrid specimens were also fabricated in attempt to exploit the best energy absorption characteristics of each composite material. Preliminary studies had shown that K/E composites exhibit better post crushing integrity than Gr/E and Gl/E whereas Gr/E generally absorbs more energy than K/E or Gl/E. The layups investigated were, $[0_{Gr}/\pm45^F_{Gl}]$, $[0_{Gr}/\pm45^F_K]$ and $[0_K/\pm45^F_{Gr}]$. Results are presented in table 3. Values of σ/ρ for $[0_{Gr}/\pm45^F_{Gl}]$ and $[0_{Gr}/\pm45^F_K]$ tubes were within 7 percent of the value for $[0/\pm45]$ Gr/E tubes and were approximately 1.5 times the value for $[0/\pm45]$ K/E or Gl/E tubes. The $[0_K/\pm45^F_{Gr}]$ tube absorbed 16 percent more energy than the $[0/\pm45]$ K/E tube and 20 percent less energy than the $[0/\pm45^F]$ Gr/E tube. Energy absorption characteristics of the hybrid tubes were consistent with behavior of tubes containing a single type of reinforcing fibers. Graphite fibers oriented in the direction of applied load absorbed more energy than either Kevlar or glass fibers in the same application. No significant post crush energy release was exhibited by any hybrid tube.

Nominally 2.54 cm (1.00 in.) and 3.81 cm (1.50 in.) diameter aluminum tubes were tested to establish a baseline for comparison. The aluminum tubes crushed in either of two modes, figure 7. For either mode, the values of σ/ρ were equal. The average specific sustained crushing stresses for both size aluminum tubes differed by less than 7 percent. The cyclic load-deflection response of the aluminum tube, figure 4, is attributed to successive local collapse of the tube.

Post Crushing Integrity.

As mentioned previosuly, energy absorption is only one requirement for a crashworthy structure. Post crushing structural integrity is also important because the structure must remain intact to provide protection for the occupants. Based on energy absorption tests, the K/E tubes were the only composite tubes that exhibited post crushing integrity, figure 6. This characteristic of the K/E tubes may be attributed to fiber splitting and fiber plasticity effects as described in reference 7. Neither Gr/E nor Gl/E tubes exhibited post crushing integrity. The post crushing integrity of the hybrid tubes was representative of the constituent materials. The Gr/E and Gl/E within the hybrid tube failed in a brittle mode with no post crushing integrity. The K/E within the Gr-K/E tube failed in an accordian mode, however, the post crushing integrity was reduced by the graphite fibers cutting into the Kevlar. The aluminum tubes exhibited excellent post crushing integrity, as shown in figure 7.

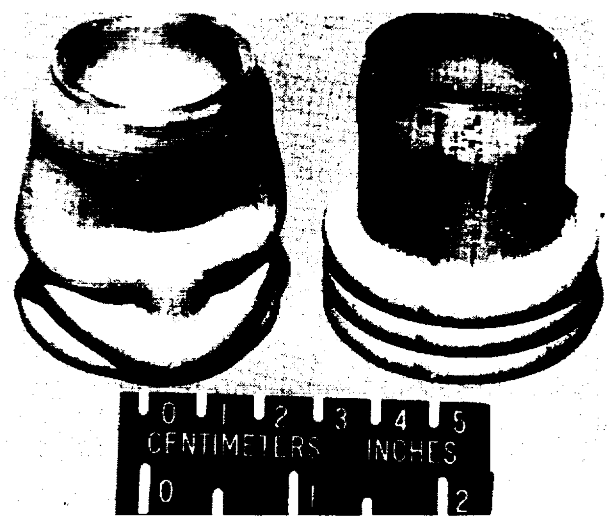


Figure 7. - Statically crushed aluminum tubes.

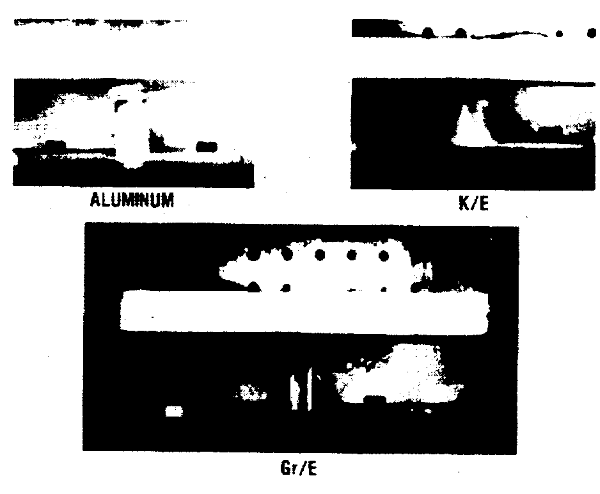


Figure 8. - Dynamically crushed aluminum, Kevlar/epoxy and graphite/epoxy tubes.

Dynamic Crushing Tests

Impact tests were performed and the results were compared with static test results. The sustained impact crushing load was determined for selected tubes and agreed within 20 percent with the static crushing load. High speed motion pictures of tests on aluminum, Gr/E, K/E, Gl/E, and Gr-K/E hybrid tubes showed that failure modes, energy absorption mechanism and post crushing integrity observed in the dynamic tests and the static tests were similar, figure 8.

Conclusions

The energy absorption characteristics of selected composite materials were determined using a modified tube specimen and the results were compared with the energy absorption of aluminum. Both static and dynamic test results were obtained for Gr/E, K/E, Gl/E, hybrid composite tubes and aluminum tubes. The following statements are based on results of the study.

The chamfered and notched load limiting concept reduced initial peak loads without affecting the sustained crushing loads. The static and dynamic test produced essentially the same energy absorption, failure modes and post crushing integrity.

The composite materials evaluated in this study were shown to absorb energy without "catastrophic" failure of the specimen. Ply orientations and constitutive material properties determine the energy absorption characteristics of the specimen. [0/±15] graphite/epoxy tube specimens absorb more energy than aluminum. The energy absorption of hybrid composite materials was only slightly better than that of the single type fiber composites with the same ply orientation.

Gr/E and Gl/E tubes exhibited negligible post crushing integrity whereas the K/E tubes exhibited failure characteristics similar to the aluminum tubes. Gr-K/E hybrid tubes had better post crushing integrity than the Gr/E tubes though less than the K/E tubes. Post crushing energy release was insignificant for all tubes.

The results of this study indicate that, further investigations are needed to develop a more comprehensive understanding of the effects of tube diameter, wall thickness, ply orientation, and alternate fibers and matrix materials on energy absorption characteristics.

References

1. "Light Fixed and Rotary Wing Aircraft Crashworthiness," MIL-STD-1290, January 1974.

2. J. D. Cronkhite, T. J. Haas, V. L. Berry and R. Winter, "Investigation of the Crash Impact Characteristics of Advanced Airframe Structure," USARTL-TR-79-11, September 1979.

3. P. H. Thornton, "Energy Absorption in Composite Structures," Journal of Composite Materials, Vol. 13 July 1979.

4. R. L. Foye, C. W. Swindlehurst, W. T. Hodges, "A Crashworthiness Test for Composite Fuselage Structure," Fibrous Composites in Structural Design, ed. by E. M. Lenoe, D. W. Oplinger and J. J. Burke, Plenum Press, New York, 241-258, (1980).

5. R. L. Foye, and W. T. Hodges, "Some Results from a Crash Energy Absorption Test for Evaluating Composite Fuselage Construction," 37th Annual Forum of the American Helicopter Society, May 1981.

6. C. L. Magee and P. H. Thornton, "Design Considerations in Energy Absorption by Structural Collapse," SAE 780434, February 1978.

7. S. V. Kulkarni, J. S. Rice and B. W. Rosen, "An Investigation of the Compressive Strength of PRD-49-111/Epoxy Composites," NASA CR-112334, June 1973.