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STANDARD TEST EVALUATION
OF GRAPHITE FIBER/RESIN MATRIX
COMPOSITE MATERIALS
FOR IMPROVED TOUGHNESS

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INTRODUCTION

Composite structures technology for large transport aircraft has been under development for several years through contracts sponsored by the NASA Aircraft Energy Efficiency (ACEE) Project Office. Secondary and empennage composite components, developed to replace metal structures on existing transport aircraft, have demonstrated weight reduction of 20 to 28 percent. The success of the NASA sponsored programs has encouraged manufacturers to apply composite structures in numerous components of their new generation transport aircraft. To translate the weight saving potential of composites into significant increases in aircraft operating efficiency, NASA is currently sponsoring programs with the commercial transport manufacturers to develop the technology data base required to design and build composite wing and fuselage structures. However, realizing the full potential of composites in strength critical designs of transport wing and fuselage structures may depend upon improvements in current material systems to achieve higher design strains (see refs. 1 and 2). A significant effort is underway by both NASA and the material suppliers to improve ductility and interlaminar toughness, yet retain other desirable features such as mechanical properties, processability, and environmental stability.

To promote systematic evaluation of the evolving new materials, NASA and the commercial transport manufacturers have selected and standardized a set of five common tests for characterizing the toughness of resin matrix/graphite fiber composites. Procedures and specifications for these tests are described in reference 3. Notch sensitivity is evaluated through open hole tension and open hole compression tests. Impact damage tolerance is evaluated through compression tests following impact at a selected energy level. Resistance to delamination is evaluated through tension edge-delamination tests and double cantilever beam tests.

This report summarizes standard test results from ten toughened resin/graphite fiber materials. The tests were performed by the transport manufacturers on their initial selection of newer, toughened resin composites. Selection of these materials does not represent an endorsement of, or commitment to use any particular material.

TESTS AND MATERIALS

Specifications for the standard tests are described in detail in reference 3. Each specification includes specimen dimensions, laminate orientation, test apparatus, test procedure, and requirements for reporting data. The standard tests are listed with a description of the specimens in table 1. Specimen configurations are shown in figure 1.

The composite materials are listed in table 2 which identifies the resin matrix, the reinforcing graphite fiber, and the company performing the test. Each company, in general, evaluated their choice of one or two materials. However, in some cases it was not possible to subject every material to the complete array of tests.

RESULTS

Results of the five standard tests are presented in tables 3 through 7. Performance of materials in each test is compared in figures 2 through 7. The materials evaluated for improved toughness are compared with a widely used composite material, AS4/3502, which represents a baseline for indicating improvements in performance.

Open Hole Tension (ST-3)

Results of open hole tension tests are presented in table 3, and average values of strain-to-failure are compared in figure 2. The highest open-hole-tension failure strains were obtained for CHS/5245 and AS6/5245. Each of these materials combined a high strain fiber with the 5245 bismaleimide resin system. Tension failure strains for these materials were 8300 to 8360 microstrain, which represents a 37 percent improvement over the baseline AS4/3502.

Four materials failed at tension strains between 7300 and 7800 microstrain which represent 21 to 30 percent improvement over the baseline. Three of these materials, CHS/1504, AS6/2220-3, and AS4/2220-3, were modified epoxies with higher strain CHS or AS6 fibers, or intermediate strain AS4 fibers. The fourth material in this group combined AS4 fibers with 5245 bismaleimide resin. The remaining three materials failed at strains between 6100 and 6700 microstrain which represent no more than an 11 percent improvement over the baseline.

Open Hole Compression (ST-4)

Results of open-hole compression tests are presented in table 4 and average values of strain-to-failure are compared in figure 3. The highest open-hole compression strain was obtained for AS4/5245 which combined the intermediate strain, larger diameter AS4 fiber with 5245 resin. Compression failure strain for this material averaged slightly higher than 7000 microstrain which represents a 53 percent improvement over the baseline AS4/3502.

Compression tests of two other materials, AS4/2220-3 and CHS/2566, resulted in strains-to-failure between 5700 and 6000 microstrain which represent 25 to 29 percent improvement over the baseline. Although AS6/5245 exhibited the highest tension strain level of the materials tested, compression strain to failure of this material represented only an 8-percent improvement over the baseline.

The highest notched tension and compression properties were obtained with materials containing 5245 bismaleimide resin system. The highest notched tension properties were obtained with high strain-to-failure, small diameter CHS and AS6 fibers, while the highest notched compression properties were obtained with larger diameter intermediate strain AS4 fibers. These materials exhibited 37 percent improvement over the baseline in tension tests and 53 percent improvement in compression. One material which performed well in both tension and compression, AS4/2220-3, combined intermediate strain AS4 fibers with a modified epoxy system. This material exhibited a 30 percent improvement over the baseline in tension and a 25 percent improvement in compression.

Compression After Impact (ST-1)

Compression after impact test results are presented in table 5. The standard test impact energy specified in reference 3 is 20 ft-lb, however, several materials were subjected to impact energies from 20 to 42 ft-lb before compression tests. Compression failure strain after impact at 20 ft-lb is compared in figure 4. The highest strain-to-failure was exhibited by AS4/2220-3 which failed at 6370 microstrain, a 58 percent improvement over the baseline AS4/3502. Four other materials, AS6/5245, AS4/5245, CHS/2566, and C/982, failed at strain levels between 5257 and 5350 microstrain which represent 31 to 33 percent improvement over the baseline.

The comparatively high compression after impact performance of several materials, including AS4/2220-3, AS4/5245, and CHS/2566, is consistent with good performance in notched tension and compression tests. However, several other materials which performed well in compression after impact tests, such as AS6/5245 and C/982, did not perform well in both notched tension and notched compression tests. In general, it would appear that, while compression after impact performance of several materials was consistent with results from notched laminate tests, the notched laminate test results alone did not clearly indicate which materials would have superior compression after impact performance.

Impact damage area resulting from 20 ft-lb impact energy is compared in figure 5. Damage area was measured by ultrasonic through transmission (C-skan). The materials sustaining the smallest damage area, AS4/2220-3, AS4/5245, CHS/2566, and AS6/5245, also exhibited high compression after impact performance as shown in figure 4. Two materials, CHS/1504 and CHS/5245, sustained greater damage than the baseline AS4/3502 although compression after impact performance of both materials was higher than the baseline.

Detailed studies of damage tolerance of composites are reported in references 4 through 6.

Edge Delamination Tension (ST-2)

The edge delamination tension test (ST-2) measures the total strain-energy-release rate for delamination onset, G, which includes components due to interlaminar or peel stress, G_I, and interlaminar shear stress, G_{II}. An analysis for determining strain-energy-release rate from edge delamination tension tests is described in reference 7. Further investigations using this test are described in references 8 and 9. Results of the edge delamination tension tests are presented in table 6. Two different laminate orientations were tested: an eleven-ply $[(\pm30)_2/90/\overline{90}]_s$ laminate, and an eight-ply ($\pm$35/0/90) laminate. The relative interlaminar tension component, G_I, and in-plane shear component, G_{II}, are dependent on laminate orientation and have been determined for these two laminates using finite element analysis (ref. 8). For the $[(\pm30)_2/90/\overline{90}]_s$ laminate, G_I is approximately 57 percent of G, and for the $[\pm35/0/90]_s$ laminate, G_I is approximately 90 percent of G.

The total critical strain-energy-release rate, G, is directly proportional to the strain at delamination onset which is compared for the materials tested in figure 6. Four materials exhibited superior resistance to delamination; these were CHS/1504, CHS/5245, AS4/2220-1, and 5 mil lamina T300/914. The use of 5 mil thickness prepreg tape instead of 10 mil thickness dramatically improved delamination resistance of T300/914. The relative performance of materials was the same for the two laminate orientations.

The interlaminar fracture toughness energy, G_c, is the critical value of the strain-energy-release rate required to initiate delamination (ref. 7) at the delamination onset strain shown in figure 6. Values of G_c, calculated according to the procedures described in references 3 and 7, are compard in figure 7. The relative ranking of G_c in figure 7 correspond to those in figure 6 for delamination onset strain. The component of interlaminar-fracture-toughness due to peel stress, G_{Ic}, is also shown in figure 7. The G_{Ic} components for the two laminates compare closely for all materials, except CHS/5245, which exhibited the highest G_c values.

Double Cantilever Beam (ST-5)

The double cantilever beam test provides a direct measure of the strain-energy-release rate component due to interlaminar tension or peel stress, G_I. This test is described in reference 3 as ST-5. A development of the underlying analysis for this test together with experimental results is presented in reference 10. Results for double cantilever beam tests, which have been completed for only three materials, are presented in table 7. Interlaminar fracture toughness values due to peel stress, G_I, determined from the double cantilever beam test data, are compared in figure 7 with G_I values calculated from the edge delamination tension tests. For CHS/5245, the G_I values from double cantilever beam tests and edge delamination tests agree closely. Discrepancies between double cantilever beam and edge delamination test results, such as shown by the AS4/2220-3 data, are discussed in references 8 and 11. Complete data are, at present, not available to compare results of these two test methods for all materials represented in this report.

Interlaminar Fracture Toughness

A comparison of compression failure strain after impact (fig. 4) with interlaminar fracture toughness (fig. 7) shows lower impact performance for materials having higher interlaminar fracture toughness. Poor correlation between the two tests may be due to the difference in the properties interrogated. Impact damage and resulting reduction in compression properties are controlled by fiber as well as matrix properties. Results of the notched laminate tests and tests after impact show a strong dependence on the type of fiber used in a given resin system. Conversely, the edge delamination tension tests, and especially the double cantilever beam tests, are primarily evaluations of resin properties.

CONCLUDING REMARKS

Ten resin matrix/graphite fiber composite materials have been evaluated for improved toughness using a series of five standard tests selected by NASA and the commercial aircraft manufacturers. These tests evaluated open hole tension and compression performance, compression performance after impact at energy levels of 20 ft-lb, and resistance to delamination. Performance was evaluated by comparison with a widely used composite system, AS4/3502. Results of these tests may be summarized as follows:

1. Materials containing 5245 bismaleimide resin matrix exhibited superior performance in notched tension and compression tests. These materials exhibited superior notched tension performance when combined with high strain AS6 or Celion fibers, and were superior in compresssion when combined with intermediate strain AS4 fibers. Notched tension performance of AS6/5245 and CHS/5245 was 37 percent higher than the baseline material, AS4/3502. Notched compression performance of AS4/5245 was 53 percent higher than the baseline.

2. A material consisting of 2220-3 epoxy matrix in combination with AS4 fibers exhibited superior performance in compression tests after 20 ft-lb impact and performed well in both notched tension and notched compression tests. Compression strain-to-failure of AS4/2220-3 after 20 ft-lb impact was 58 percent greater than the baseline AS4/3502.

3. Resistance to delamination, as measured by edge delamination tests, did not correlate with resistance to impact damage. Materials exhibiting the highest resistance to delamination (interlaminar fracture toughness energy) actually exhibited comparatively low compression failure strain after impact.

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TABLE 1 - STANDARD TEST SPECIMEN DESCRIPTION

TEST DESIG-NATOR	TEST TYPE	PLY ORIENTATION	NO. OF PLIES	THICKNESS (NOMINAL) IN.	WIDTH, IN.	LENGTH, IN.
ST-1	COMPRESSION AFTER IMPACT	$(+45/0/-45/90)_{ns}$		0.25	BEFORE 7.00 AFTER IMPACT 5.00	12.5 12.5
ST-2	EDGE DELAMINATION TENSION	A $(\pm30/\pm30/90/\overline{90})_s$ B $(\pm35/0/90)_s$	11 8	— —	1.50	10.00
ST-3	OPEN HOLE TENSION	$(+45/0/-45/90)_{ns}$	—	0.25	2.00	12.00
ST-4	OPEN HOLE COMPRESSION	$(+45/0/-45/90)_{ns}$	—	0.25	5.00	12.50
ST-5	DOUBLE CANTILEVER BEAM	$(0)_n$	—	0.12	1.50	9.00

TABLE 2—MATERIALS EVALUATED IN STANDARD TESTS

RESIN & PREPREG SUPPLIER / FIBER SUPPLIER	AMERICAN CYANAMID	CIBA-GEIGY		HEXCEL	NARMCO	HERCULES		
	982	914	2566	1504	5245	2220-1	2220-3	3502
HERCULES AS-4					BCAC	LCC	BCAC	LCC
HERCULES AS-6					BCAC		BCAC	
CELANESE CELION	LCC							
CELANESE CELION HIGH STRAIN			DAC	LCC	LCC			
UNION CARBIDE T-300		DAC						

COMPANIES FABRICATING LAMINATES AND PERFORMING TESTS

BCAC – BOEING COMMERCIAL AIRPLANE COMPANY
DAC – DOUGLAS AIRCRAFT COMPANY
LCC – LOCKHEED CALIFORNIA COMPANY

TABLE 3.- STANDARD TEST-3: OPEN HOLE TENSION

(a) CHS/1504 tension test results

Resin content: 35.9%							
Specimen identification	Thickness, in.	Width, in.	Hole diameter, in.	Failure load, kips	Failure stress, ksi	Failure strain, μin./in.	Modulus, msi
211-10	0.271	1.955	0.250	24.14	45.63	6768	6.74
-12	.268	2.003	.250	31.95	59.50	8398	7.19
Average					52.57	7583	6.965

(b) CHS/5245 tension test results

Resin content: 31.3%							
Specimen identification	Thickness, in.	Width, in.	Hole diameter, in.	Failure load, kips	Failure stress, ksi	Failure strain, μin./in.	Modulus, msi
248-4	0.258	2.006	0.250	31.71	61.26	8200	7.42
-5	.260	2.009	.250	31.56	61.42	8600	6.92
-6	.255	2.004	.250	30.89	60.47	8000	7.50
Average					61.05	8300	7.28

TABLE 3.- Continued

(c) AS6/5245C tension test results

Resin content: 34%							
Specimen identification	Thickness, in.	Width, in.	Hole diameter, in.	Failure load, kips	Failure stress, ksi	Failure strain, μin./in.	Modulus, msi
ST3-2D-1	0.284	1.998	0.250	37.97	66.92	8550	
-2	.282	1.994	.250	35.07	62.37	8230	
-3	.285	1.995	.250	38.24	67.26	8300	
Average					65.52	8360	

(d) AS6/2220-3 tension test results

Resin content: 34%							
Specimen identification	Thickness, in.	Width, in.	Hole diameter, in.	Failure load, kips	Failure stress, ksi	Failure strain, μin./in.	Modulus, msi
ST3-1D-1	0.297	1.996	0.250	32.26	54.42	7340	
-2	.295	1.998	.250	30.97	52.54	7140	
-3	.299	1.998	.250	32.25	53.98	7400	
Average					53.65	7293	

TABLE 3.- Continued

(e) AS4/5245 tension test results

Resin content: 34%							
Specimen identification	Thickness, in.	Width, in.	Hole diameter, in.	Failure load, kips	Failure stress, ksi	Failure strain, µin./in.	Modulus, msi
ST3-3D-1	0.268	2.001	0.2494	31.51	58.76	7400	
-2	.266	2.002	.2492	32.04	60.16	7540	
-3	.268	2.002	.2490	31.34	58.41	7350	
-4	.266	2.001	.2499	31.73	59.61	7700	
Average					59.24	7500	

(f) AS4/2220-3 tension test results

Resin content: 34%							
Specimen identification	Thickness, in.	Width, in.	Hole diameter, in.	Failure load, kips	Failure stress, ksi	Failure strain, µin./in.	Modulus, msi
P1-20	0.295	2.00	0.251	31.0	52.4	7820	6.7
-21	.292	2.00	.251	31.3	52.9	7900	6.7
-22	.295	2.00	.251	30.7	51.9	7750	6.7
Average					52.4	7820	

TABLE 3.- Continued

(g) AS4/2220-1 tension test results

Resin content: 34.3%							
Specimen identification	Thickness, in.	Width, in.	Hole diameter, in.	Failure load, kips	Failure stress, ksi	Failure strain, μin./in.	Modulus, msi
12-1	0.2592	1.996	0.250	25.81	49.59	6778	7.36
-1	.2570	1.997	.250	24.93	48.57	6474	7.50
-3	.2564	1.999	.250	25.28	49.34	6918	7.13
Average					49.27	6723	7.33

(h) CHS/2566 tension test results

Resin content: 30.0%							
Specimen identification	Thickness, in.	Width, in.	Hole diameter, in.	Failure load, kips	Failure stress, ksi	Failure strain, μin./in.	Modulus, msi
ST 3-1	0.132	1.900	0.250	15.05	60.01		
-2	.135	1.950	.250	16.20	61.53		
-3	.131	2.009	.250	15.26	57.76		
Average					59.77		

TABLE 3.- Continued

(i) C/982 tension test results

Resin content: 36.33%							
Specimen identification	Thickness, in.	Width, in.	Hole diameter, in.	Failure load, kips	Failure stress, ksi	Failure strain, μin./in.	Modulus, msi
13-1	0.2978	2.000	0.250	28.84	48.42	6647	7.28
-2	.3065	2.000	.250	28.74	46.89	6530	7.18
-3	.3065	2.000	.250	29.39	47.94	6313	7.59
Average					47.75	6496	7.35

(j) T300/914 tension test results

Resin content: 29.5%							
Specimen identification	Thickness, in.	Width, in.	Hole diameter, in.	Failure load, kips	Failure stress, ksi	Failure strain, μin./in.	Modulus, msi
ST 3-1	0.238	2.000	0.250	19.75	41.492	5730	7.6
-2	.248	2.003	.250	24.00	48.290	6750	7.5
-3	.248	2.000	.250	21.50	43.347	5910	7.3
Average					44.376	6130	7.47

TABLE 3.- Concluded

(k) AS4/3502 tension test results

Resin content: 35%							
Specimen identification	Thickness, in.	Width, in.	Hole diameter, in.	Failure load, kips	Failure stress, ksi	Failure strain, μin./in.	Modulus, msi
15-7	0.265	2.007	0.277	31.43	59.20	6220	9.72
15-8	.258	2.005	.254	32.28	62.44	6028	10.33
16-5	.262	2.005	.253	32.79	62.41	5866	10.28
Average					61.35	6038	

TABLE 4.- STANDARD TEST-4: OPEN HOLE COMPRESSION

(a) CHS/1504 compression test results

Resin content: 33.7%							
Specimen identification	Thickness, in.	Width, in.	Hole diameter, in.	Failure load, kips	Failure stress, ksi	Failure strain, μin./in.	Compression modulus, msi
210-3	0.271	5.000	1.00	-47.56	-36.0	-5609	6.46
-4	.271	5.002	1.00	-44.61	-32.9	-5227	6.69
-5	.269	5.001	1.00	-44.34	-33.0	-5190	6.32
Average					-33.97	-5342	6.49

(b) CHS/5245 compression test results

Resin content: 33.0%							
Specimen identification	Thickness, in.	Width, in.	Hole diameter, in.	Failure load, kips	Failure stress, ksi	Failure strain, μin./in.	Compression modulus, msi
243-3	0.263	5.000	1.00	-45.89	-34.85	-5292	6.64
-4	.265	4.999	1.00	-51.86	-39.13	-5800	6.58
-5	.266	5.000	1.00	-44.17	-33.16	-5154	6.55
Average					-35.71	-5415	6.59

TABLE 4.- Continued

(c) AS6/5245C compression test results

Resin content: 34%							
Specimen identification	Thickness, in.	Width, in.	Hole diameter, in.	Failure load, kips	Failure stress, ksi	Failure strain, μin./in.	Compression modulus, msi
ST4-2D-1	0.286	4.995	0.998	-47.0	-32.9	-5050	
-2	.280	4.994	1.000	-45.0	-32.2	-4808	
-3	.282	4.994	.996	-46.6	-33.1	-4963	
Average					-32.7	-4940	

(d) AS6/2220-3 compression test results

Resin content: 34%							
Specimen identification	Thickness, in.	Width, in.	Hole diameter, in.	Failure load, kips	Failure stress, ksi	Failure strain, μin./in.	Compression modulus, msi
ST4-1D-1	0.298	4.995	1.001	-48.4	-32.5	-5038	
-2	.294	4.996	1.008	-50.7	-34.5	-5326	
-3	.300	4.993	1.002	-47.9	-32.0	-4988	
Average					-33.0	-5117	

TABLE 4.- Continued

(e) AS4/5245 compression test results

Resin content: 34.0%							
Specimen identification	Thickness, in.	Width, in.	Hole diameter, in.	Failure load, kips	Failure stress, ksi	Failure strain, μin./in.	Compression modulus, msi
ST4-3D-1	0.266	5.000	1.017	-52.4	-39.4	-6780	
-2	.267	5.000	1.007	-56.2	-42.1	-7300	
-3	.265	5.000	1.000	-51.1	-38.6		
Average					-40.0	-7040	

(f) AS4/2220-3 compression test results

Resin content: 34%							
Specimen identification	Thickness, in.	Width, in.	Hole diameter, in.	Failure load, kips	Failure stress, ksi	Failure strain, μin./in.	Compression modulus, msi
P1-1	0.294	4.999	1.000	-53.1	-35.9	-5880	6.7
-2	.289	4.995	1.001	-56.5	-38.2	-6150	6.4
-3	.294	4.994	1.000	-48.8	-33.0	-5250	6.7
Average					-35.7	-5760	6.6

TABLE 4.- Continued

(g) AS4/2220-1 compression test results

Resin content: 34.32%							
Specimen identification	Thickness, in.	Width, in.	Hole diameter, in.	Failure load, kips	Failure stress, ksi	Failure strain, μin./in.	Compression modulus, msi
2-2-12B	0.256	5.000	1.000	-39.94	-31.20	-4720	6.56
2-3-12A	.255	5.000	.998	-40.78	-31.98	-4800	6.75
2-3-12B	.257	5.000	.997	-38.65	-30.08	-4620	6.61
Average					-31.09	-4713	6.64

(h) CHS/2566 compression test results

Resin content: 30.0%							
Specimen identification	Thickness, in.	Width, in.	Hole diameter, in.	Failure load, kips	Failure stress, ksi	Failure strain, μin./in.	Compression modulus, msi
ST4-B1	0.281	5.031	1.000	-55.00	-38.91	-6100	
-B2	.278	5.039	1.000	-54.20	-38.69	-5837	
-B3	.281	5.042	1.000	-55.00	-38.91	-5852	
Average					-38.84	-5930	

TABLE 4.- Continued

(i) C/982 compression test results

Resin content: 36.33%							
Specimen identification	Thickness, in.	Width, in.	Hole diameter, in.	Failure load, kips	Failure stress, ksi	Failure strain, μin./in.	Compression modulus, msi
2-2-13B	0.303	5.001	1.000	-44.13	-29.12	-4750	6.34
2-3-13A	.307	5.000	.998	-46.09	-30.03	-4950	6.43
2-3-13B	.306	5.000	.999	-49.16	-32.13	-5180	6.21
Average					-30.42	-4960	6.33

(j) T300/914 compression test results

Resin content: 29.5%							
Specimen identification	Thickness, in.	Width, in.	Hole diameter, in.	Failure load, kips	Failure stress, ksi	Failure strain, μin./in.	Compression modulus, msi
ST-4A	0.2432	5.000	1.000	-42.50	-34.95	-5100	6.85
-4B	.2499	5.000	1.000	-46.70	-37.37	-5900	6.33
-4C	.2473	5.000	1.000	-43.50	-35.18	-5200	6.77
Average					-35.83	-5401	6.65

TABLE 4.- Concluded

(k) AS4/3502 compression test results

Resin content: 35.1%							
Specimen identification	Thickness, in.	Width, in.	Hole diameter, in.	Failure load, kips	Failure stress, ksi	Failure strain, μin./in.	Compression modulus, msi
15-4B	0.263	5.003	0.999	-51.44	-39.07	-4594	8.35
16-1A	.274	5.002	.993	-48.80	-35.56	-4304	8.16
16-1B	.274	5.001	.998	-52.69	-38.44	-4899	7.66
Average					-37.69	-4599	

TABLE 5.- STANDARD TEST-1: COMPRESSION AFTER IMPACT

(a) CHS/1504 compression test results

Resin content: 33.7%									
Specimen identification	Thickness, in.	Width, in.	Impact energy, ft-lb	Impact width, in.	Impact area, $in.^2$	Failure load, kips	Failure stress, ksi	Failure strain, μin./in.	Modulus, msi
211-1A	0.266	5.000	20	2.12	3.55	-42.88	-32.24	-4806	7.33
-1B	.268	4.999	20	2.14	3.45	-40.69	-30.37	-4658	6.53
-2A	.269	5.000	20	2.18	3.55	-44.21	-32.87	-5218	5.84
Average				2.15	3.52		-31.83	-4894	6.57
211-2B	0.270	5.000	30	2.48	4.55	-36.10	-26.74	-4181	6.18
-3A	.268	5.000	30	2.58	5.10	-34.66	-25.87	-3871	6.72
-3B	.269	5.000	30	2.66	5.45	-34.71	-25.81	-3964	6.54
Average				2.57	5.03		-26.14	-4005	6.48

TABLE 5.- Continued

(b) CHS/5245 compression test results

Resin content: 31.3%									
Specimen identification	Thickness, in.	Width, in.	Impact energy, ft-lb	Impact width, in.	Impact area, in.^{2}	Failure load, kips	Failure stress, ksi	Failure strain, μin/in.	Modulus, msi
248-1A	0.258	5.019	20	2.00	2.95	-39.36	-30.4	-4400	6.85
-1B	.258	5.021	20	2.00	2.95	-40.06	-30.9	-4400	6.94
-2A	.259	5.021	20	1.95	3.00	-39.70	-30.6	-4400	6.91
Average				1.98	2.97		-30.6	-4400	6.90
248-9B	0.259	5.022	30	2.55	4.90	-32.81	-25.2	-3700	6.84
-3A	.258	5.022	30	2.45	4.35	-32.40	-25.0	-3600	6.83
-3B	.258	5.021	30	2.30	4.10	-33.09	-25.6	-3700	6.78
Average				2.43	4.45		-25.3	-3700	6.82

TABLE 5.- Continued

(c) AS6/5245C compression test results

Resin content: 34%									
Specimen identification	Thickness, in.	Width, in.	Impact energy, ft-lb	Impact width, in.	Impact area, in.^{2}	Failure load, kips	Failure stress, ksi	Failure strain, μin/in.	Modulus, msi
ST1-2D-1	0.281	4.990	34	2.0	3.25	-42.2	-30.1	-4600	
-2	.286	4.991	34	2.0	3.46	-42.7	-29.9	-4675	
Average					3.36		-30.0	-4638	
ST1-2D-3	0.285	4.992	42	2.2	4.30	-38.1	-26.8	-4213	
	.284	4.991	42	2.6	4.27	-39.6	-27.9	-4258	
Average					4.28		-27.4	-4235	
ST1-2D-4	0.290	4.992	23	1.6	2.20	-51.7	-35.7	-5345	
-5	.282	4.992	23	1.3	1.55	-52.3	-37.2	-5425	
-6	.290	4.994	23	1.5	1.88	-51.0	-35.2	-5285	
Average					1.88		-36.0	-5352	

TABLE 5.- Continued

(d) AS6/2220-3 compression test results

Resin content: 34.0%									
Specimen identification	Thickness, in.	Width, in.	Impact energy, ft-lb	Impact width, in.	Impact area, $in.^2$	Failure load, kips	Failure stress, ksi	Failure strain, μin/in.	Modulus, msi
ST1-1D-1	0.296	4.991	34	2.0	3.60	-37.4	-25.3	-3883	
-2	.297	4.992	34	2.0	3.65	-39.2	-26.4	-4175	
Average				2.0	3.62		-25.9	-4029	
ST1-1D-3	0.297	4.994	42	2.6	4.86	-36.1	-24.3	-3958	
	.296	4.994	42	2.4	4.39	-38.0	-25.7	-4175	
Average				2.5	4.62		-25.0	-4067	
ST1-1D-4	0.299	4.995	23	1.6	1.20	-53.6	-35.9	-5552	
-5	.295	4.996	23	1.3	2.30	-47.3	-32.1	-4883	
-6	.298	4.995	23	1.5	2.10	-41.3	-27.7	-4163	
Average				1.5	1.87		-31.9	-4866	

TABLE 5.- Continued

(e) AS4/5245C compression test results

Resin content: 34%									
Specimen identification	Thickness, in.	Width, in.	Impact energy, ft-lb	Impact width, in.	Impact area, in.^{2}	Failure load, kips	Failure stress, ksi	Failure strain, μin/in.	Modulus, msi
ST1-3D-4	0.267	4.999	21	1.30	1.42	-44.6	-33.4	-5200	
-9	.266	4.998	21	1.45	1.77	-44.9	-33.8	-5340	
-2	.266	5.001	21	1.40	1.57	-44.4	-33.4	-5450	
Average					1.59		-33.5	-5330	
ST1-3D-1	0.265	4.999	31	1.80	2.65	-38.6	-29.1	-4500	
-7	.268	4.999	31	2.10	3.04	-39.8	-29.7	-4620	
-5	.267	5.001	31	1.60	1.95	-42.4	-31.8	-5190	
Average					2.55		-30.2	-4770	
ST1-3D-6	0.266	4.995	38	1.85	2.77	-35.2	-26.5	-4160	
-3	.263	4.995	38	2.10	3.30	-32.7	-24.9	-3880	
-8	.268	5.001	38	2.20	3.65	-40.0	-29.8	-4960	
Average					3.24		-27.1	-4330	

TABLE 5.- Continued

(f) AS4/2220-3 compression test results

Resin content: 34%									
Specimen identification	Thickness, in.	Width, in.	Impact energy, ft-lb	Impact width, in.	Impact area, in.^{2}	Failure load, kips	Failure stress, ksi	Failure strain, μin/in.	Modulus, msi
P1-4	0.294	4.973	0		0	-93.9	-63.4	-11 450	6.7
-5	.290	4.970	20		1.23	-59.0	-39.9	-6 530	6.9
-6	.292	4.972	20		1.05	-58.2	-39.3	-6 500	6.7
-7	.293	4.971	20		1.19	-56.3	-38.0	-6 080	6.9
Average					1.16		-39.1	-6 370	6.8
P1-8	0.292	4.981	30		2.05	-41.4	-28.0	-4 350	6.7
-9	.292	4.973	30		2.37	-46.1	-31.1	-4 930	6.7
Average					2.44		-29.5	-4 640	6.7

TABLE 5.- Continued

(g) AS4/2220-1 compression test results

Resin content: 34.32%									
Specimen identification	Thickness, in.	Width, in.	Impact energy, ft-lb	Impact width, in.	Impact area, in.^{2}	Failure load, kips	Failure stress, ksi	Failure strain, μin/in.	Modulus, msi
2-4-12A	0.255	5.001	20	1.40	1.81	-35.71	-28.00	-4160	6.90
2-4-12B	.259	5.000	20	1.50	2.02	-32.70	-25.25	-3930	6.64
2-5-12A	.255	4.963	20	1.47	1.99	-32.96	-26.04	-4060	6.80
Average					1.94		-26.43	-4050	6.78

(h) CHS/2566 compression test results

Resin content: 30.0%									
Specimen identification	Thickness, in.	Width, in.	Impact energy, ft-lb	Impact width, in.	Impact area, in.^{2}	Failure load, kips	Failure stress, ksi	Failure strain, μin/in.	Modulus, msi
ST1-B1	0.276	5.024	20	2.68	1.387	-49.00	-35.34	-5251	
-B2	.276	5.052	20	2.14	1.394	-47.90	-34.35		
-B3	.276	5.000	20	1.76	1.365	-47.80	-35.02	-5283	
Average					1.38		-34.90	-5267	

TABLE 5.- Continued

(i) C/982 compression test results

Resin content: 36.33%									
Specimen identification	Thickness, in.	Width, in.	Impact energy, ft-lb	Impact width, in.	Impact area, $in.^2$	Failure load, kips	Failure stress, ksi	Failure strain, µin/in.	Modulus, msi
2-4-13A	0.309	5.000	20	1.78	2.61	-50.74	-32.84	-5480	6.04
2-4-13B	.308	4.995	20	1.90	2.94	-49.78	-32.36	-5410	6.01
2-5-13A	.304	5.000	20	1.50	1.82	-45.37	-29.85	-4880	6.18
Average					2.46		-31.68	-5257	6.08

(j) T300/914 compression test results

Resin content: 29.5%									
Specimen identification	Thickness, in.	Width, in.	Impact energy, ft-lb	Impact width, in.	Impact area, $in.^2$	Failure load, kips	Failure stress, ksi	Failure strain, µin/in.	Modulus, msi
ST-1A	0.247	5.031	30		3.0	-23.00	-18.51	-2620	7.06
ST-1B	.243	5.031	30		3.0	-23.20	-18.97	-2610	7.27
Average					3.0		-18.74	-2615	7.17

TABLE 5.- Concluded

(k) AS4/3502 compression test results

Resin content: 35.1%									
Specimen identification	Thickness, in.	Width, in.	Impact energy, ft-lb	Impact width, in.	Impact area, in.^{2}	Failure load, kips	Failure stress, ksi	Failure strain, μin/in.	Modulus, msi
15-1A	0.268	5.013	20		2.30	-45.79	-34.07	-3937	8.56
-2A	.259	5.015	↓		2.35	-44.80	-34.51	-3868	8.96
-4A	.275	5.003	↓		2.85	-46.17	-33.56	-4141	8.14
22-1A	.269	4.999	↓		3.20	-43.67	-32.49	-4082	8.20
-1B	.269	4.999	↓		2.85	-46.09	-34.32	-4024	8.94
Average					2.71		-33.79	-4010	8.55
15-2B	0.273	5.014	30		3.15	-42.91	-31.81	-3741	9.16
-3A	.269	5.012	↓		4.90	-41.09	-30.02	-3392	8.52
-3B	.275	5.013	↓		4.20	-39.29	-28.49	-3392	8.32
Average					4.08		-30.11	-3508	8.67

TABLE 6.- STANDARD TEST-2: EDGE DELAMINATION TENSION

(a) CHS/1504 edge delamination test results

Laminate orientation $(\pm35/0/90)_s$ Resin content: 31.7%							
Specimen identification	Thickness, in.	Width, in.	Delamination onset strain, μin./in.	Failure strain, μin./in.	Tensile modulus, msi	Secant modulus, msi	Interlaminar fracture toughness, G_c, $\frac{\text{in.-lb}}{\text{in.}^2}$
216-1	0.046	1.505	6075		8.70		1.071
-2	.046	1.505	5600		8.85		1.020
-3	.046	1.504	5775		8.81		1.054
-5	.046	1.505	6450	13 388	8.18	7.75	.701
-11	.046	1.506	5900	14 207	8.65	7.63	.969
Average			5960	13 798	8.64	7.69	0.963

Laminate orientation $(\pm30/\pm30/90/\overline{90})_s$ Resin content: 30.6%							
Specimen identification	Thickness, in.	Width, in.	Delamination onset strain, μin./in.	Failure strain, μin./in.	Tensile modulus, msi	Secant modulus, msi	Interlaminar fracture toughness, G_c, $\frac{\text{in.-lb}}{\text{in.}^2}$
215-1	0.061	1.505	4438		7.38	7.06	1.425
-2	.063	1.505	4850		7.40	7.40	1.716
-3	.063	1.505	4662		7.32	7.32	1.532
-4	.062	1.506	4725		7.28	7.44	1.546
-5	.062	1.506	4588		7.56	7.83	1.641
Average			4653		7.39	7.41	1.572

TABLE 6.- Continued

(b) CHS/5245 edge delamination test results

Laminate orientation $(\pm 35/0/90)_s$ Resin content: 28.3%							
Specimen identification	Thickness, in.	Width, in.	Delamination onset strain, μin./in.	Failure strain, μin./in.	Tensile modulus, msi	Secant modulus, msi	Interlaminar fracture toughness, G_c, $\frac{\text{in.-lb}}{\text{in.}^2}$
247-1	0.0436	1.503	6200		9.42	8.85	1.25
-4	.0431	1.507	6000		9.34	8.72	1.23
-5	.0434	1.507	6400		9.37	8.79	1.24
-2	.0432	1.500	6200	13 800	9.17	8.95	1.24
-3	.0431	1.505	6200	13 700	9.19	8.74	1.23
Average			6200	13 800	9.30	8.81	1.24

Laminate orientation $(\pm 30/\pm 30/90/\overline{90})_s$ Resin content: 29.1%							
Specimen identification	Thickness, in.	Width, in.	Delamination onset strain, μin./in.	Failure strain, μin./in.	Tensile modulus, msi	Secant modulus, msi	Interlaminar fracture toughness, G_c, $\frac{\text{in.-lb}}{\text{in.}^2}$
246-3	0.060	1.508	6200		7.45	7.18	2.84
-4	.060	1.507	5900		7.60	7.28	2.57
-5	.060	1.506	6400		7.33	7.47	3.02
-1	.060	1.508	6000	17 800	7.63	7.63	2.66
-2	.060	1.508	6000	20 700	7.63	7.63	2.66
Average			6100	19 200	7.53	7.44	2.75

TABLE 6.- Continued

(c) AS6/5245C edge delamination test results

Laminate orientation $(\pm 35/0/90)_s$ Resin content: 34%							
Specimen identification	Thickness, in.	Width, in.	Delamination onset strain, μin./in.		Failure strain, μin./in.	Tensile modulus, msi	Interlaminar fracture toughness, G_c, $\frac{\text{in.-lb}}{\text{in.}^2}$
			(a)	(b)			
ST2-2F-1	0.061	1.500	4100	4000	14 400	9.29	0.75
-2	.061	1.500	4240	4100	15 750	8.35	.79
-3	.059	1.497	4300	4200		8.43	.80
-4	.061	1.499	4540	4540		8.11	.97
-5	.061	1.497	4150	4000		9.06	.75
Average			4270	4170		8.65	0.81

Laminate orientation $(\pm 30/\pm 30/90/\overline{90})_s$ Resin content: 34%							
Specimen identification	Thickness, in.	Width, in.	Delamination onset strain, μin./in.		Tensile modulus, msi	Secant modulus, msi	Interlaminar fracture toughness, G_c, $\frac{\text{in.-lb}}{\text{in.}^2}$
			(a)	(b)			
ST2-2E-1	0.079	1.494	3650	3550	7.72		1.27
-2	.078	1.493	3760	3600	7.36		1.29
-3	.079	1.497	2900	2900	7.68		.85
-4	.080	1.493	3000	3000	7.46		.92
-5	.079	1.495	____	3200	7.85		1.03
Average			3330	3250	7.61		1.07

[a]Strain at first deviation from linear stress-strain curve.
[b]Strain at first visible delamination.

TABLE 6.- Continued

(d) AS6/2220-3 edge delamination test results

Laminate orientation $(\pm 35/0/90)_s$ Resin content: 35%							
Specimen identification	Thickness, in.	Width, in.	Delamination onset strain, µin./in.		Failure strain, µin./in.	Tensile modulus, msi	Interlaminar fracture toughness, G_c, $\frac{\text{in.-lb}}{\text{in.}^2}$
			(a)	(b)			
ST2-1F-1	0.062	1.499	3500	3400	12 500	9.68	0.64
-2	.063	1.499	4400	4100	13 300	8.66	.94
-3	.062	1.499	5400	4250		8.18	1.00
-4	.062	1.498	3970	3970		8.61	.87
Average			4320	3930		8.78	0.86

Laminate orientation $(\pm 30/\pm 30/90/\overline{90})_s$ Resin content: 35%							
Specimen identification	Thickness, in.	Width, in.	Delamination onset strain, µin./in.		Tensile modulus, msi	Secant modulus, msi	Interlaminar fracture toughness, G_c, $\frac{\text{in.-lb}}{\text{in.}^2}$
			(a)	(b)			
ST2-1E-1	0.083	1.495	3050	2750	7.25		0.92
-2	.084	1.495	3250	3100	6.83		1.19
-3	.083	1.496	3050	3050	7.03		1.13
-4	.084	1.496	3650	3650	6.94		1.64
-5	.084	1.495	3250	3100	6.12		1.19
Average			3250	3130	6.83		1.21

[a]Strain at first deviation from linear stress-strain curve.
[b]Strain at first visible delamination.

TABLE 6.- Continued

(e) AS4/2220-3 edge delamination test results

Laminate orientation $(\pm 35/0/90)_s$ Resin content: 34%							
Specimen identification	Thickness, in.	Width, in.	Delamination onset strain, μin./in.		Failure strain, μin./in.	Tensile modulus, msi	Interlaminar fracture toughness, G_c, $\frac{\text{in.-lb}}{\text{in.}^2}$
			(a)	(b)			
1-1	0.0609	1.519	3600			8.96	0.45
1-2	.0605	1.522	4400			8.56	.67
1-3	.0608	1.520	3700			8.89	.47
1-4	.0608	1.522	4700			8.72	.77
1-5	.0606	1.521	4000			8.71	.55
Average			4080				0.58

Laminate orientation $(\pm 30/\pm 30/90/\overline{90})_s$ Resin content: 34%							
Specimen identification	Thickness, in.	Width, in.	Delamination onset strain, μin./in.		Tensile modulus, msi	Secant modulus, msi	Interlaminar fracture toughness, G_c, $\frac{\text{in.-lb}}{\text{in.}^2}$
			(a)	(b)			
2-1	0.0815	1.509	3800		6.69		1.09
2-2	.0819	1.507	3800		5.89		1.09
2-3	.0822	1.507	3000		7.23		.68
2-4	.0820	1.506	3600		6.71		.98
2-5	.0819	1.505	2200		7.69		.36
Average			3280				0.84

[a]Strain at first deviation from linear stress-strain curve.
[b]Strain at first visible delamination.

TABLE 6.- Continued

(f) AS4/2220-1 edge delamination test results

Laminate orientation $(\pm 35/0/90)_s$ Resin content: 29.6%							
Specimen identification	Thickness, in.	Width, in.	Delamination onset strain, µin./in.		Failure strain, µin./in.	Tensile modulus, msi	Interlaminar fracture toughness, G_c, $\frac{\text{in.-lb}}{\text{in.}^2}$
			(a)	(b)			
40-1	0.043	1.498	6060			8.94	1.308
-2	.044	1.497	6080			8.76	1.348
-3	.044	1.497	5508			8.70	1.106
-4	.045	1.497	6000		13 040	8.53	1.342
-5	.044	1.496	5370		12 225	8.99	1.051
Average			5804				1.231

Laminate orientation $(\pm 30/\pm 30/90/\overline{90})_s$ Resin content: 28.6%							
Specimen identification	Thickness, in.	Width, in.	Delamination onset strain, µin./in.		Tensile modulus, msi	Secant modulus, msi	Interlaminar fracture toughness, G_c, $\frac{\text{in.-lb}}{\text{in.}^2}$
			(a)	(b)			
39-1	0.058	1.504	4675		7.28	7.11	1.732
-2	.058	1.504	5140		7.46	7.07	2.094
-3	.059	1.502	5075		7.36	7.24	2.077
-4	.058	1.504	4526		7.48	7.16	1.624
-5	.059	1.503	5170		7.41	7.18	2.155
Average			4917				1.935

[a]Strain at first deviation from linear stress-strain curve.
[b]Strain at first visible delamination.

TABLE 6.- Continued

(g) T300/914 edge delamination test results, ply thickness = 0.010 in.

Laminate orientation $(\pm35/0/90)_s$ Resin content: 29.5%							
Specimen identification	Thickness, in.	Width, in.	Delamination onset strain, μin./in. (a)	Delamination onset strain, μin./in. (b)	Failure strain, μin./in.	Tensile modulus, msi	Interlaminar fracture toughness, G_c, $\frac{\text{in.-lb}}{\text{in.}^2}$
ST-2F	0.0700	1.5374	3060		8250	8.80	0.496
-2G	.0712	1.5331	3130		6000	9.03	.527
-2H	.0708	1.5337	3060		6750	9.37	.501
-2I	.0699	1.5365	3060		7000	8.87	.495
-2J	.0706	1.5340	3000		7000	8.62	.480
Average			3062				0.500

Laminate orientation $(\pm30/\pm30/90/\overline{90})_s$ Resin content: 29.5%							
Specimen identification	Thickness, in.	Width, in.	Delamination onset strain, μin./in. (a)	Delamination onset strain, μin./in. (b)	Tensile modulus, msi	Secant modulus, msi	Interlaminar fracture toughness, G_c, $\frac{\text{in.-lb}}{\text{in.}^2}$
ST-2A	0.1082	1.5043	2630		7.45		0.949
-2B	.1133	1.5042	2500		7.25		.898
-2C	.1042	1.4917	3000		7.51		1.190
-2D	.1140	1.4956	2750		7.44		1.090
-2E	.1103	1.5012	2840		7.64		1.130
Average			2744				1.050

[a]Strain at first deviation from linear stress-strain curve.
[b]Strain at first visible delamination.

TABLE 6.- Continued

(h) T300/914 edge delamination test results, ply thickness = 0.005 in

Laminate orientation $(\pm35/0/90)_s$ Resin content: 30%							
Specimen identification	Thickness, in.	Width, in.	Delamination onset strain, µin./in.		Failure strain, µin./in.	Tensile modulus, msi	Interlaminar fracture toughness, G_c, $\frac{\text{in.-lb}}{\text{in.}^2}$
			(a)	(b)			
ST25-6	0.0424	1.512	6500		9 125	9.14	1.35
-7	.0449	1.509	6200		7 500	8.86	1.30
-8	.0450	1.514	6825		11 250	8.92	1.58
-9	.0451	1.509	6300		9 750	8.82	1.35
-10	.0443	1.503	7000		9 750	8.88	1.64
Average			6565		9 475	8.92	1.44

Laminate orientation $(\pm30/\pm30/90/\overline{90})_s$ Resin content: 30%							
Specimen identification	Thickness, in.	Width, in.	Delamination onset strain, µin./in.		Tensile modulus, msi	Secant modulus, msi	Interlaminar fracture toughness, G_c, $\frac{\text{in.-lb}}{\text{in.}^2}$
			(a)	(b)			
ST25-1	0.0633	1.509	5875		6.98	6.42	2.77
-2	.0633	1.507	5000		6.71	6.76	2.01
-3	.0580	1.510	5375		7.25	7.27	2.12
-4	.0623	1.512	5000		7.17	7.00	1.97
-5	.0613	1.511	5125		7.37	7.24	2.04
Average			5275		7.10	6.94	2.18

[a]Strain at first deviation from linear stress-strain curve.
[b]Strain at first visible delamination.

TABLE 6.- Concluded

(i) AS4/3502 edge delamination test results

Laminate orientation $(\pm 35/0/90)_s$
Resin content: 27.1%

Specimen identification	Thickness, in.	Width, in.	Delamination onset strain, μin./in.		Failure strain, μin./in.	Tensile modulus, msi	Interlaminar fracture toughness, G_c, $\frac{\text{in.-lb}}{\text{in.}^2}$
			(a)	(b)			
20-1	0.040	1.506	4550	5539		9.94	0.55
-2	.039	1.503	4980	5542		10.30	.81
-3	.039	1.506	5000	5304		10.22	.78
-4	.039	1.506	4810	4810	11 690	10.10	.67
-11	.040	1.506	4900	5000	11 010	9.97	.65
Average			4848	5239	11 350	10.11	0.69

Laminate orientation $(\pm 30/\pm 30/90/\overline{90})_s$
Resin content: 27.8%

Specimen identification	Thickness, in.	Width, in.	Delamination onset strain, μin./in.		Tensile modulus, msi	Secant modulus, msi	Interlaminar fracture toughness, G_c, $\frac{\text{in.-lb}}{\text{in.}^2}$
			(a)	(b)			
19-1	0.054	1.511	2940	3400	8.40		0.58
-2	.054	1.511	2970	3250	8.30		.57
-3	.054	1.511	3140	3240	8.19		.61
-4	.055	1.510	2730	3168	8.54		.54
-5	.054	1.510	3095	3095	8.40		.64
Average			2975	3231	8.37		0.59

[a]Strain at first deviation from linear stress-strain curve.
[b]Strain at first visible delamination.

TABLE 7.- STANDARD TEST-5: DOUBLE CANTILEVER BEAM

(a) CHS/5245 double cantilever beam test data

Laminate orientation: $(0)_{24}$																		
Specimen identification	Thickness, in.	Width, in.	A_1, in.	δ_1, in.	P_1, lb	A_2, in.	δ_2, in.	P_2, lb	A_3, in.	δ_3, in.	P_3, lb	A_4, in.	δ_4, in.	P_4, lb	A_5, in.	δ_5, in.	P_5, lb	G_{Ic}, $\frac{\text{in-lb}}{\text{in}^2}$
249-1	0.1356	1.505	2.19	0.21	15	3.13	0.40	12	4.10	0.70	9	5.06	1.04	8	6.04	1.46	6	1.42
-2	.1246	1.504	2.10	.18	13	3.07	.38	10	4.10	.69	8	5.07	1.03	6	6.06	1.48	5	1.18
-3	.1225	1.505	2.10	.18	13	3.07	.39	10	4.08	.68	7	5.07	1.08	6	6.05	1.72	5	1.25
-5	.1280	1.504	2.05	.18	14	3.08	.40	10	4.04	.66	8	5.05	1.01	7	6.11	1.49	5	1.21
Average																		1.26

TABLE 7.- Continued

(b) AS4/2220-3 double cantilever beam test data

Laminate orientation: $(0)_n$													
Specimen identification	Thickness, in.	Width, in.	A_1, in.	$P_1\ \delta_1$, in-lb	A_2, in.	$P_2\ \delta_2$, in-lb	A_3, in.	$P_3\ \delta_3$, in-lb	A_4, in.	$P_4\ \delta_4$, in-lb	A_5, in.	$P_5\ \delta_5$, in-lb	G_{Ic},* $\frac{\text{in-lb}}{\text{in}^2}$
1		0.5	2.60		3.30	0.3049	4.10	0.3705	4.80	0.2882	5.65	0.3920	0.89
2		.5	2.95		3.50	.253	4.30	.3795	4.90	.281			.94
3		.5	2.75		3.35	.186	3.90	.253	4.40	.294			.89
Average													0.90

*G_{Ic} calculated by energy-area integration method.

TABLE 7.- Concluded

(c) CHS/2566 double cantilever beam test data

Laminate orientation: $(0)_n$																		
Specimen identification	Thickness, in.	Width, in.	A_1, in.	δ_1, in.	P_1, lb	A_2, in.	δ_2, in.	P_2, lb	A_3, in.	δ_3, in.	P_3, lb	A_4, in.	δ_4, in.	P_4, lb	A_5, in.	δ_5, in.	P_5, lb	G_{Ic}, $\frac{\text{in-lb}}{\text{in}^2}$
ST5-B1	0.130	1.512	2.71	0.432	14.40	3.74	0.78	11.3	5.07	1.45	9.10	6.09	2.03	7.60				2.19
-B2	.131	1.508	2.70	.424	15.20	3.87	.808	10.80	5.18	1.40	8.30	6.38	2.08	6.95				2.10
-B3	.136	1.508	2.72	.400	15.70	3.80	.780	12.40	4.98	1.324	10.30	6.06	1.86	8.10				2.29
Average																		2.19

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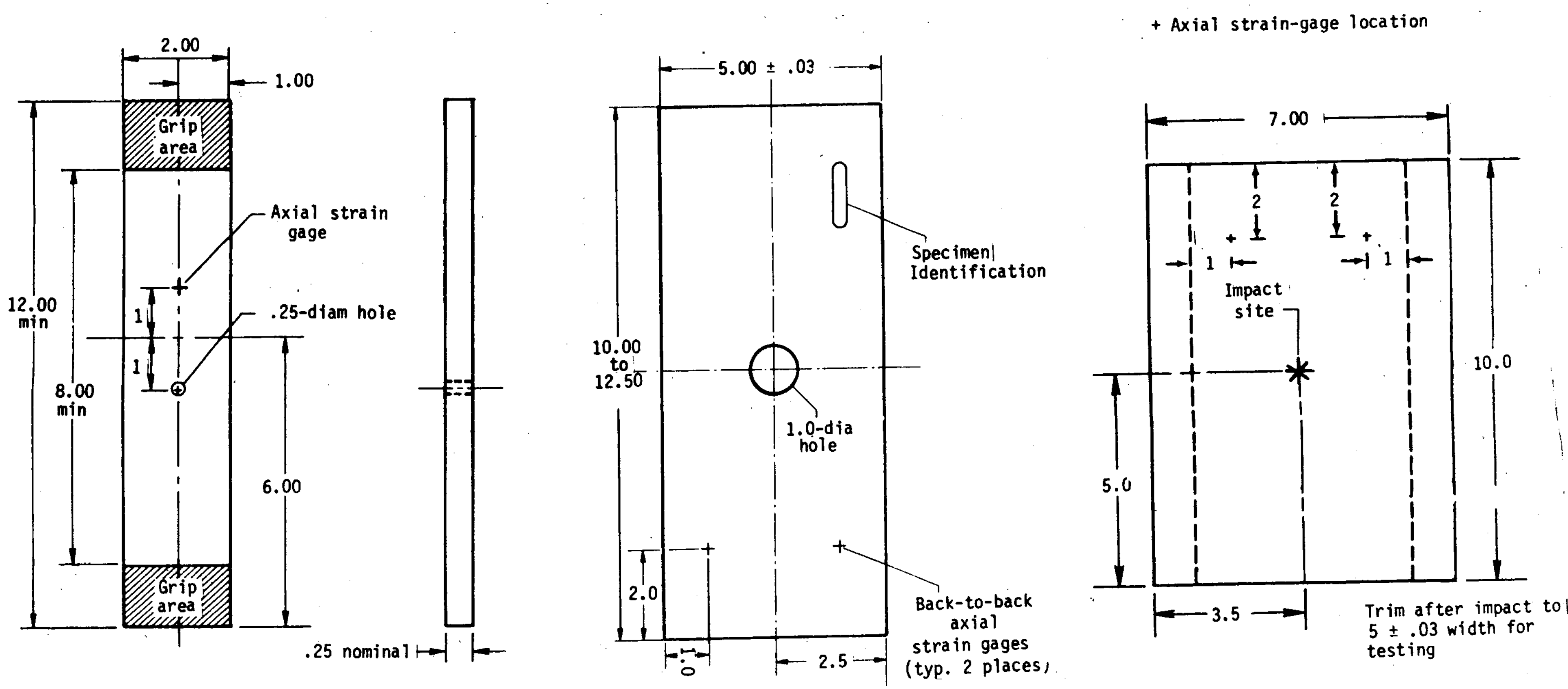
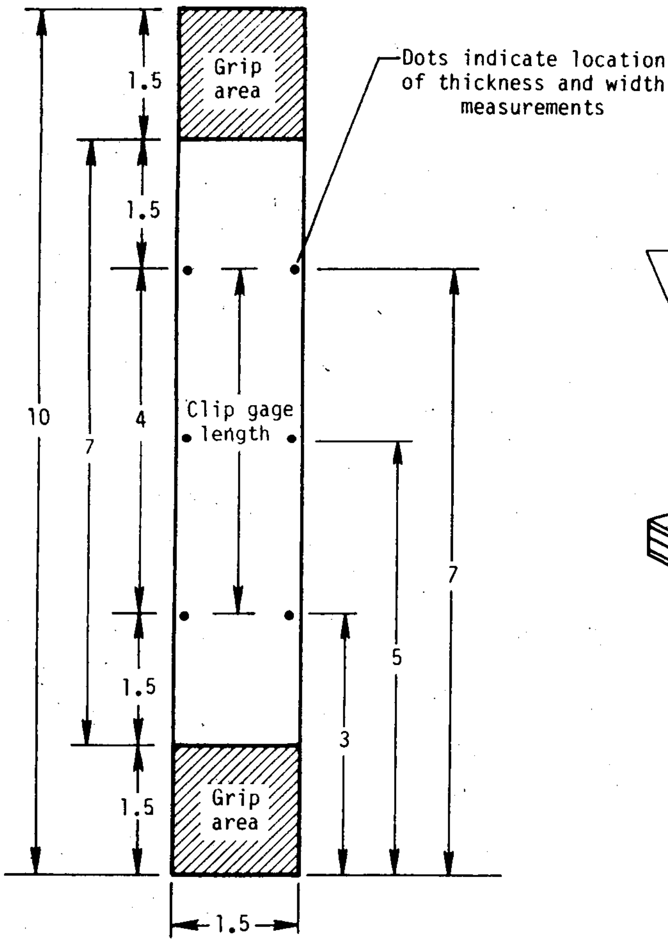


(a) Standard Test–3, open hole tension specimen

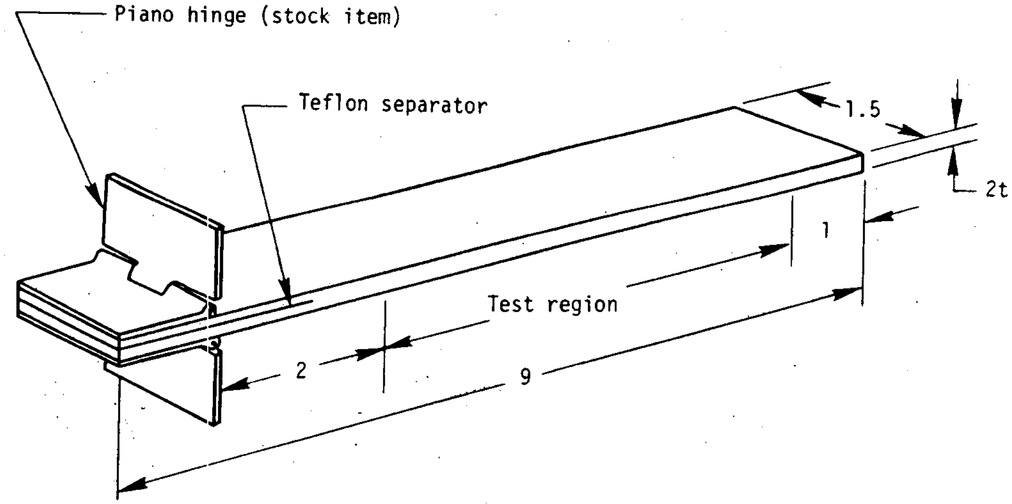
(b) Standard Test–4, open hole compression specimen

(c) Standard Test–1, compression after impact specimen

Figure 1 – Standard Test Specimen Configurations (Dimensions are in inches)



(d) Standard Test–2, edge delamination tension specimen



(e) Standard Test–5, double cantilever beam specimen

Figure 1 – Concluded

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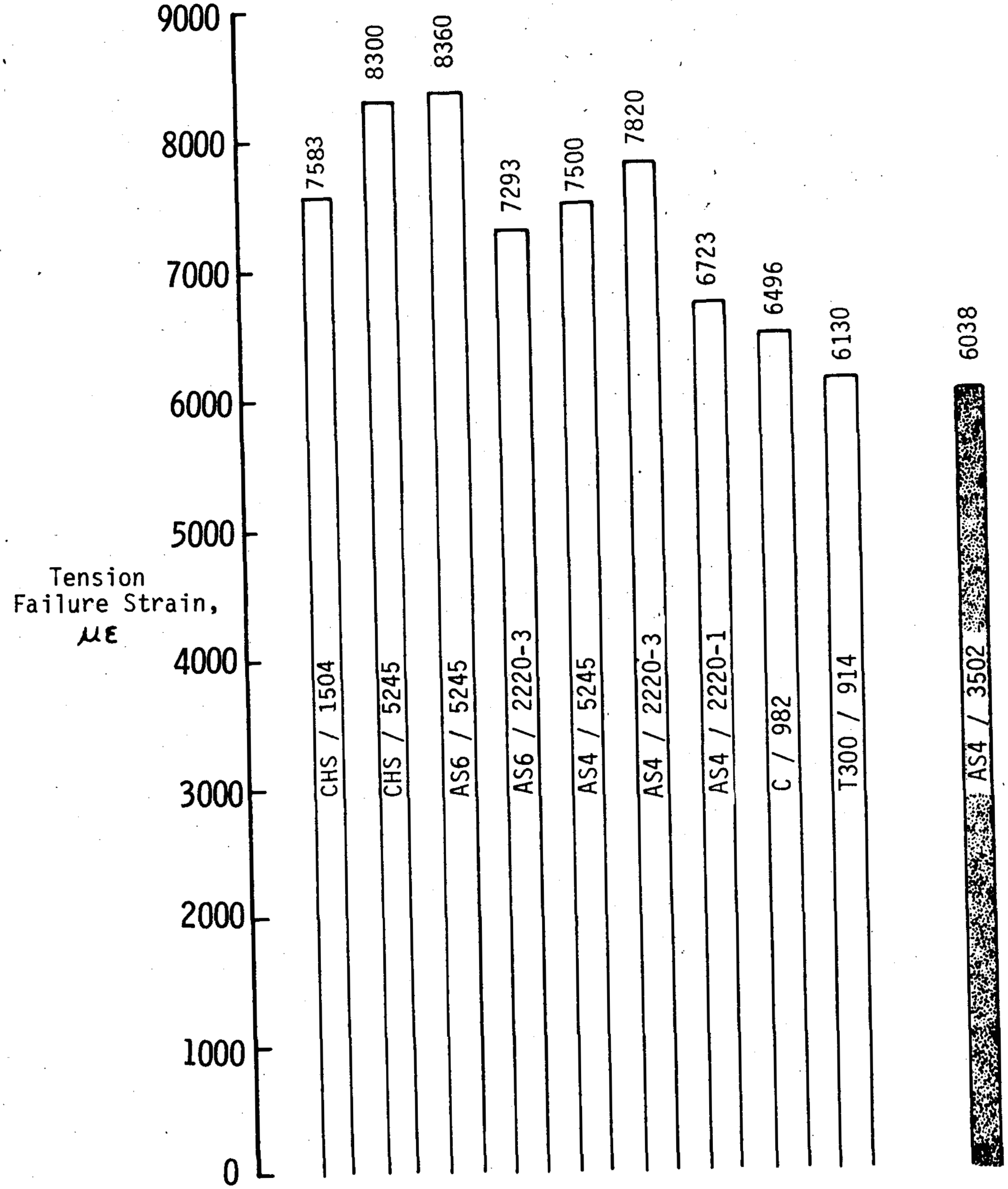

Figure 2 - Open Hole Tension Failure Strain

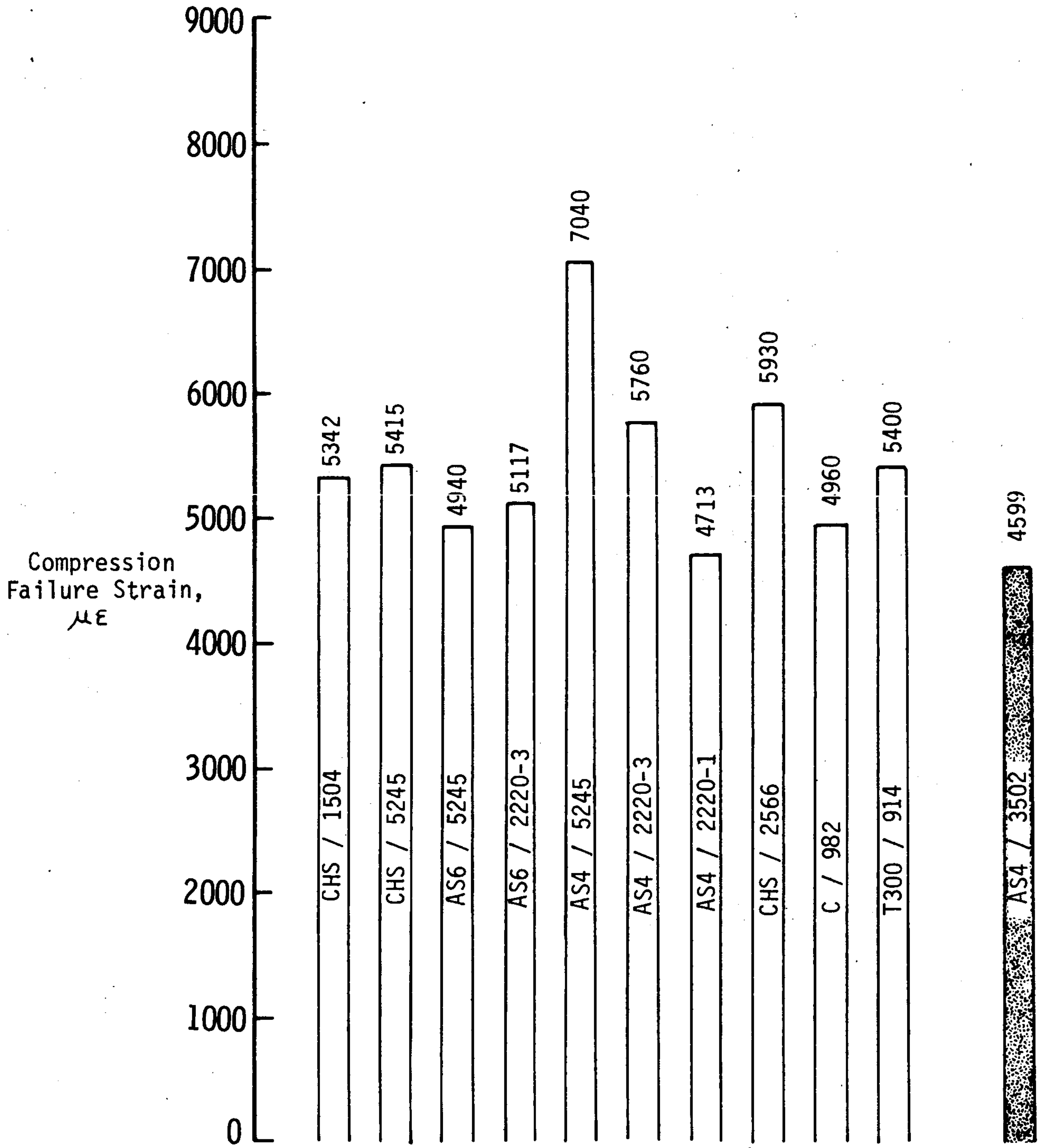

Figure 3 - Open Hole Compression Failure Strain

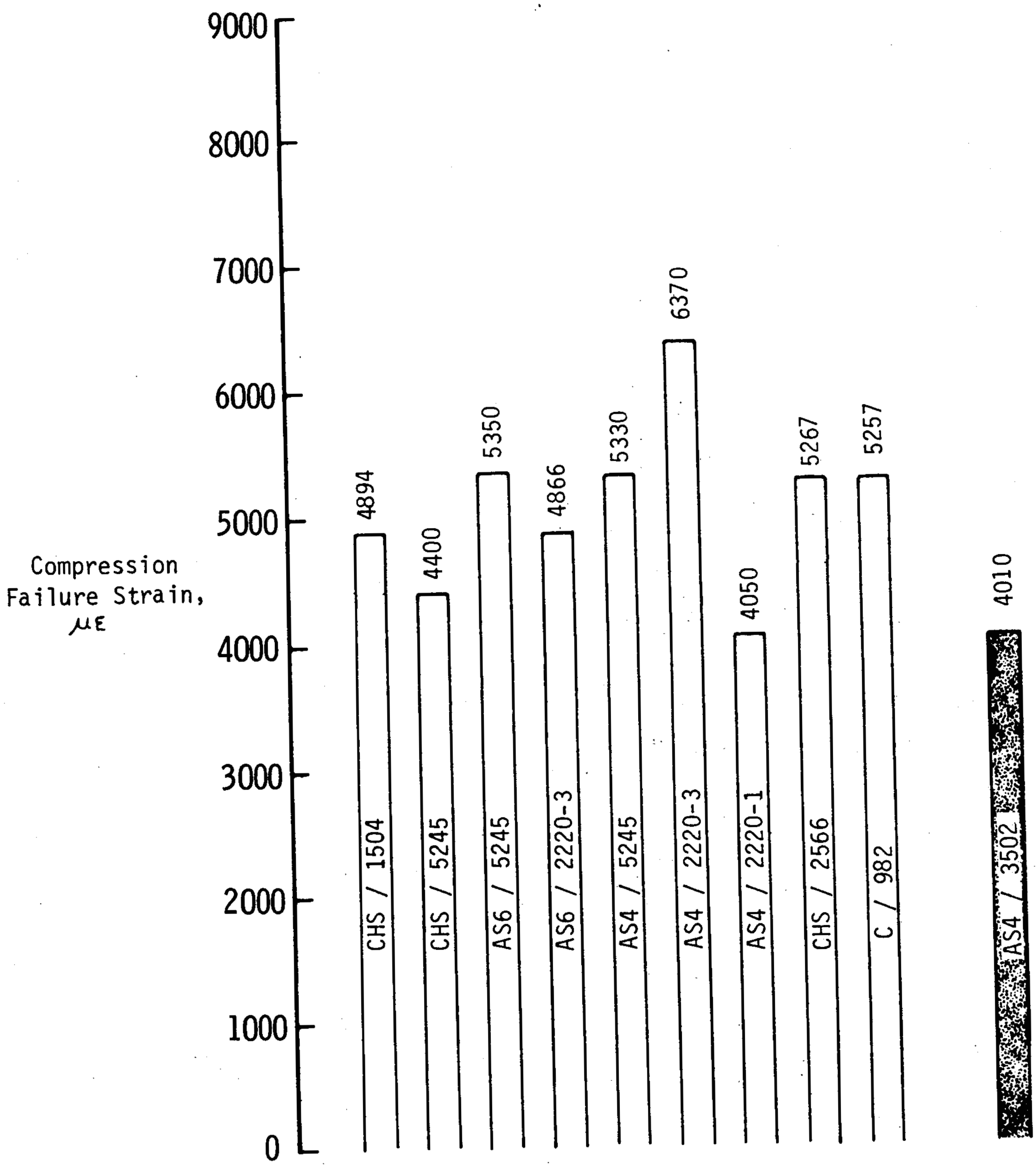

Figure 4 - Compression Failure Strain after 20 Ft-Lb Impact

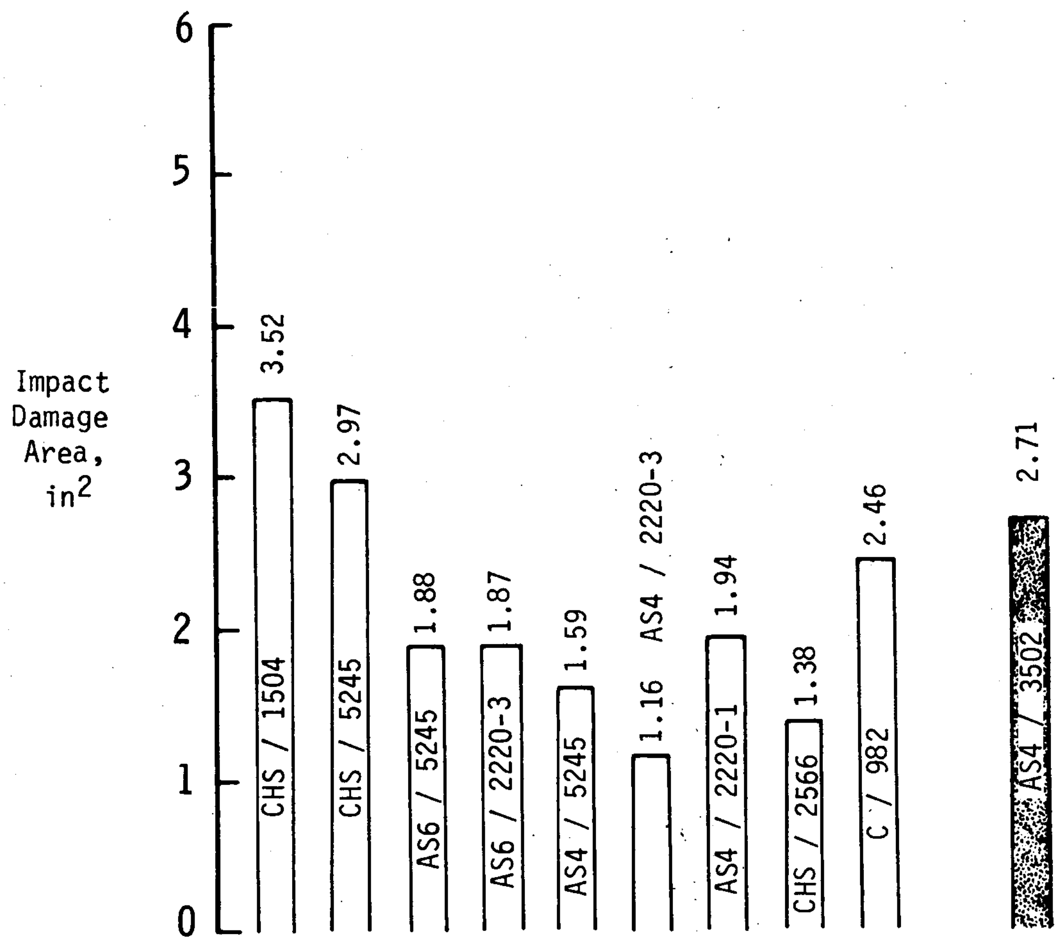

Figure 5 - Impact Damage Area after 20 Ft-Lb Impact

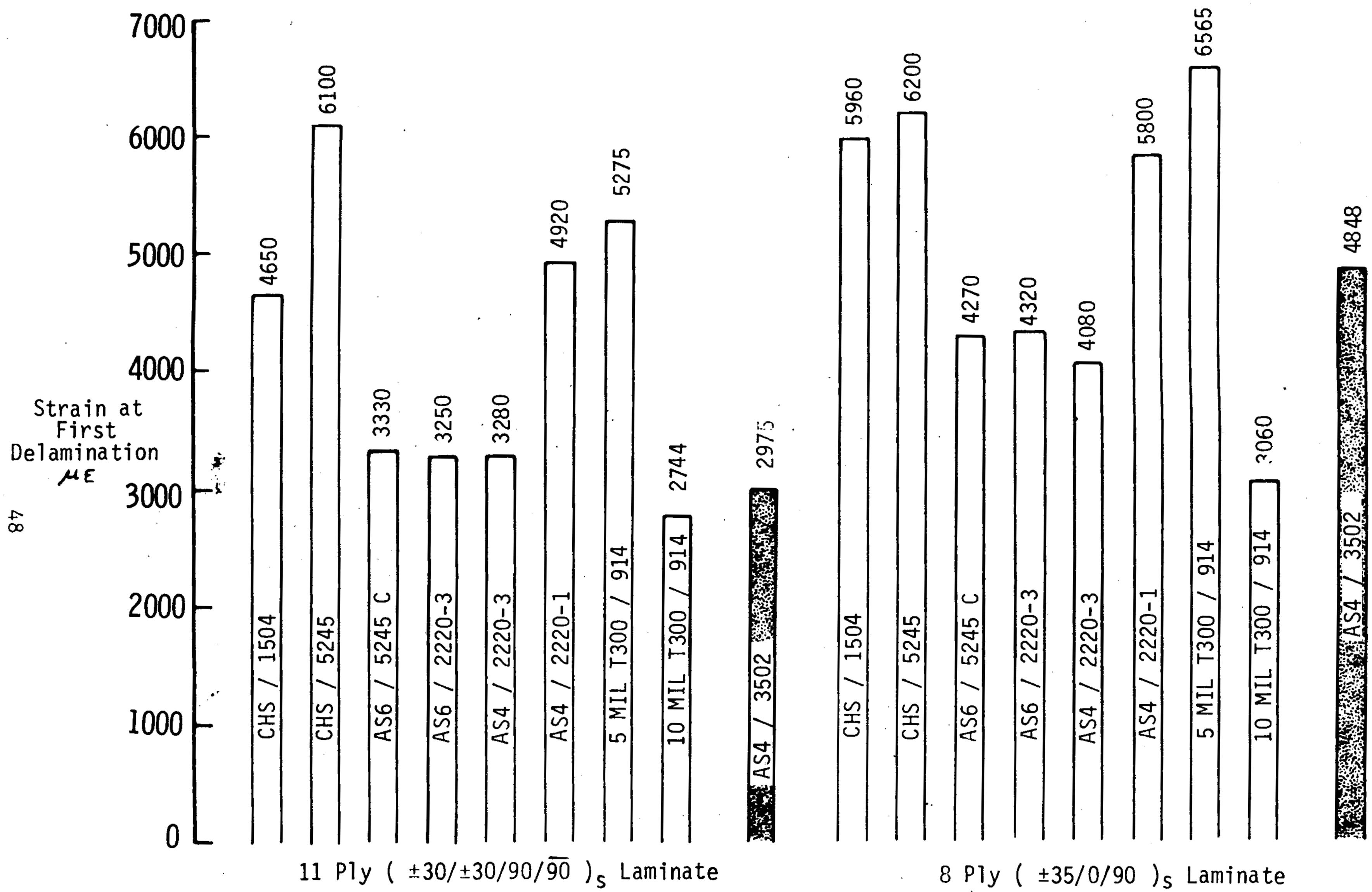

Figure 6 - Strain at Delamination Onset from Tension Edge Delamination Tests

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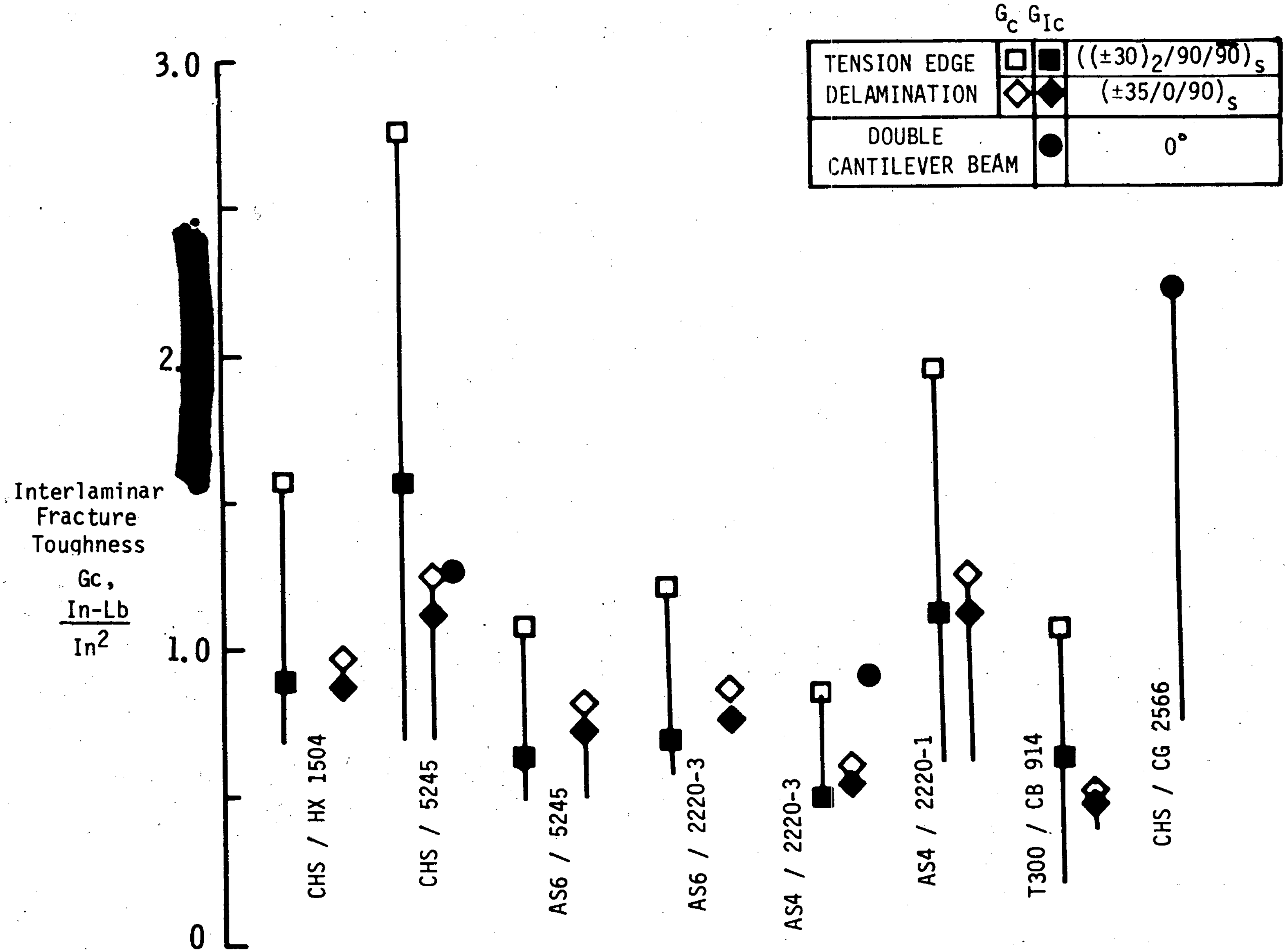

Figure 7 - Interlaminar Fracture Toughness Energy

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15. Supplementary Notes

16. Abstract

NASA is sponsoring programs with the commercial transport manufacturers to develop a technology data base required to design and build composite wing and fuselage structures. To realize the full potential of composite structures in these strength critical designs, material systems having improved ductility and interlaminar toughness are being sought. To promote systematic evaluation of new materials, NASA and the commercial transport manufacturers have selected and standardized a set of five common tests. These tests evaluate open hole tension and compression performance, compression performance after impact at an energy level of 20 ft-lb, and resistance to delamination. Ten toughened resin matrix/graphite fiber composites have been evaluated using this series of tests, and their performance is compared with a widely used composite system.

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