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Design Allowables for T300/5208 Graphite/Epoxy Composite Materials

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Material coupon tests were conducted to formulate design allowables for T300/5208 graphite/epoxy unidirectional tape and bidirectional fabric composites. This paper gives a description of the tests conducted, representative ply level and laminate test data, and results of the statistical analysis. The design allowables for tension and compression strength are given and include the effect of notches, impact damage, temperature extremes, and moisture absorption.

Nomenclature

C = confidence
C_V = coefficient of variation
$Cv_{0.95}$ = coefficient of variation for a 95% probability
F = stress allowable for 90% probability and 95% confidence
F_{RTDU} = predicted unnotched room temperature dry strength
i = rank order number
k = number of test groups
K_B = "B" basis multiplying factor
K_{ET} = notched/environment multiplying factor
P = probability
r^2 = coefficient of determination

Introduction

UTILIZATION of advanced composite materials for construction of aircraft structures offers a significant increase in structural efficiency when compared to metallic materials. The weight savings are attributable to two factors: 1) the superior specific strength and stiffness of advanced composites, and 2) the ability to tailor material properties to best meet design requirements. When designing a composite structure, material design must be integrated with structural design to achieve an optimum structure. However, an infinite number of laminate designs can be obtained for a given composite material since the mechanical properties vary with lamina orientation, stacking sequence, and proportion of laminae in each orientation. Therefore, owing to the number of variables associated with laminate design, the traditional approach used to determine design allowables for metals is not applicable to composites.

For the Advanced Composite Vertical Fin and Inboard Aileron Programs,‡ design allowables were determined for Thornel 300/5208 graphite/epoxy unidirectional tape and bidirectional fabric composites. A comprehensive test program was conducted to determine the mechanical and physical properties for these materials. Material characterization tests were conducted to obtain basic lamina stress-strain properties in tension, compression, and shear as well as Poisson's ratios. Also tensile, compressive, and shear tests were conducted on laminate configurations for the fin and aileron components. These tests were conducted on unnotched and impact-damaged specimens exposed to a variety of environmental conditions.

The approach for establishing design allowables is illustrated in Fig. 1. Ply level test data were used to predict the mechanical behavior of cross-plied laminates. A comparison of predicted laminate behavior to measured data was made to modify the ply level property data such that the predicted behavior of unnotched laminates tested at room temperature in the dry condition was equal to or slightly less than measured values. Laminate data for notched coupons, tested at various environmental conditions, were analyzed to determine the notch/environmental factors and statistical factors. These factors were then applied to the predicted unnotched room temperature, dry strength, to establish design allowables.

Since the structure could contain nonvisible damage due to impact during fabrication or in service, the effect of impact damage on laminate properties was also evaluated. Tests were conducted on impact-damaged coupons to determine the applied strain level that could be sustained for the maximum nonvisible size damage. This strain allowable was substantiated by compression tests conducted on vertical fin skin panels with impact damage exceeding these minimum requirements.

Material and Coupon Fabrication

Two forms of graphite/epoxy materials were investigated: 5- and 7.5-mils Thornel 300/5208 unidirectional tape, and 14-mils Thornel 300/5208 bidirectional fabric with a 24×23 eight-harness satin weave.

Laminates were manufactured by hand layup of the prepreg material followed by autoclave cure. Each laminate was nondestructively inspected and process control coupons were removed and tested. The remainder of the laminates were sawed into coupon blanks, the edges of all coupons ground to rms 60 or better, and fiberglass end tabs secondarily bonded in place with a 350°F cure epoxy adhesive.

Two methods of moisture conditioning were utilized for the various test programs. The first approach was to expose the coupons to 95% relative humidity at 150°F in a humidity chamber. The second approach was to immerse the coupons in water at 150°F. Coupons were conditioned for the length of time required to reach a weight gain of approximately 1% as measured on the moisture control coupons. Simultaneously, moisture control coupons were dried for 7 days at 200°F in a desiccant. The average weight loss of these coupons was then added to the weight gain of the conditioned moisture control coupons to determine the total moisture content of the specimens.

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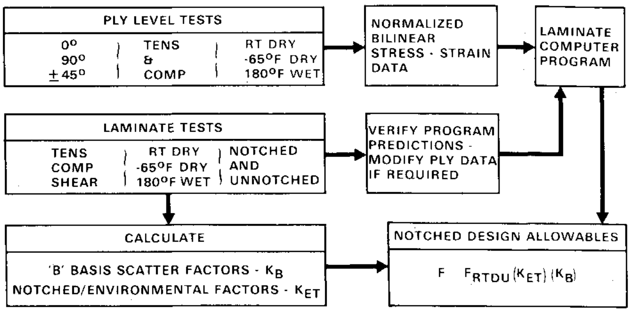

Fig. 1 Design allowables approach.

Test Specimens and Procedures

Tensile tests of 0-deg tape laminates were conducted with coupons measuring 10.5×0.5 in.; for all other laminates the tensile coupons measured 10.5×1.0 in. The Celanese coupon (5.5×0.10×0.24 in.) was used for compression tests of the 0-deg tape laminates. Other notched and unnotched compression specimens were 10.5 in. long by 1.0 in. wide and were tested between support plates to eliminate instability failure.

The notched specimens had a 3/16-in.-diam hole in the center of the specimens. This notch size was selected since most of the fasteners used for assembly of the fin and aileron were 3/16 in. in diameter or smaller.

The 3.0-in. wide compression specimens with impact damage were cut from panels which were impacted with a 1-in.-diam hemispherical steel impactor. Impact energies were varied to produce various levels of impact damage. The coupons were cut so that the damage area was centered in each specimen. Special fully supported sliding platens with a cutout in the damaged area were used to prevent general instability failures.

Evaluation of Test Data

Material Properties

Table 1 summarizes the lamina properties from the 0- and ±45-deg tape and fabric laminate tests. Average tension and compression results obtained for several tape and fabric laminates are summarized in Table 2. These results were

Table 1 T300/5208 graphite/epoxy fabric and tape characterization test data[a]

Property \ Environmental condition	Fabric 70°F, dry unnotched	Fabric −65°F, dry unnotched	Fabric 180°F, wet[b] unnotched	Tape 75°F, dry unnotched	Tape −65°F, dry unnotched	Tape 180°F, wet[b] unnotched
0-deg, tensile						
Strength—10^3 psi	85.8	70.6	80.7	211.1	189.0	223.6
Modulus—10^6 psi	10.3	9.7	10.3	21.4	21.7	21.9
0-deg compressive						
Strength—10^3 psi	84.6	90.0	62.8	233.0	215.9	199.3
Modulus—10^6 psi	9.2	9.4	9.0	18.7	20.0	19.7
±45-deg tensile						
Strength—10^3 psi	29.4	31.5	25.4	26.8	27.5	23.0
Modulus—10^6 psi	2.8	3.0	2.3	3.0	2.9	3.1

[a] Data normalized to a cured ply thickness of 0.014 in. (60% fiber volume) for fabric and 0.005 in. (64% fiber volume) for tape. [b] 1% moisture by weight.

Table 2 Typical T300/5208 graphite/epoxy fabric and tape laminate data[a]

Property \ Environmental Condition		75°F, dry unnotched	75°F, dry notched[c]	−65°F, dry unnotched	−65°F, dry notched[c]	180°F, wet[b] unnotched	180°F, wet[b] notched[c]
Tape	Tension						
$(\pm45°/0°/\pm45°/0°_3)_s$	Strength—10^3 psi	132.2	68.2	117.9	61.4	130.3	76.6
	Modulus—10^6 psi	12.5	11.7	12.9	12.5	12.6	11.9
	Strain—10^{-6} in./in.	10,609	5564	9221	4934	10,478	6413
	Compression						
	Strength—10^3 psi	115.4	81.9	133.3	92.8	103.8	86.0
	Modulus—10^6 psi	11.2	11.5	11.6	11.8	11.0	11.3
	Strain—10^{-6} in./in.	11,748	7551	12,856	8725	10,846	9175
Tape	Tension						
$(\pm45°/0°/\pm45°_2)_s$	Strength—10^3 psi	53.1	34.0	56.1	35.5	47.4	30.3
	Modulus—10^6 psi	5.0	5.3	5.8	5.8	5.1	5.0
	Strain—10^{-6} in./in.	11,390	6490	9970	6070	10,690	6280
	Compression						
	Strength—10^3 psi	62.6	44.2	74.8	47.8	54.4	38.4
	Modulus—10^6 psi	5.2	5.6	5.9	5.9	4.9	5.1
	Strain—10^{-6} in./in.	17,544	9022	17,543	8874	17,562	9207
Fabric	Tensile						
(45°/0°/135°/0°/45°)	Strength—10^3 psi	58.4	34.8	55.6	31.7	59.2	35.3
	Modulus—10^6 psi	6.2	6.0	6.3	6.1	6.2	5.9
	Strain—10^{-6} in./in.	9430	5790	9240	5110	10,070	5880
	Compressive						
	Strength—10^3 psi	72.1	46.1	69.9	52.9	52.8	38.0
	Modulus—10^6 psi	5.8	6.0	6.1	6.3	5.9	5.7
	Strain—10^{-6} in./in.	13,540	7810	12,060	7970	9990	6950

[a] Data normalized to a cured ply thickness of 0.014 in. (61% fiber volume) for fabric and 0.005 in. (64% fiber volume) for tape. [b] 1% moisture by weight. [c] Notch = 3/16-in.-diameter hole.

generally based on the average of five or more specimens for each condition. These data along with data available for other laminates[1,2] were used for determining environmental/notch factors and statistical factors for the calculation of design allowables.

Scatter in Test Data

The composite test data for the family of 0-, ±45-, and 90-deg laminates cover a wide range of static strengths. Examination of the test data for laminates with some percentage of 0-deg plies indicated there was a trend of increasing test scatter (standard deviation or variance) with increasing strength. Therefore the coefficient of variation was used to normalize the scatter characteristics for the various laminates.

The coefficient of variation of the test data was also examined with respect to type of specimen (notched or unnotched) and environmental conditions (−65°F, dry; RT, dry; and 180°F, wet). No significant difference was observed in the scatter characteristics of these various test groups. Therefore the statistical analysis was performed by combining the data for the coefficient of variation for the various conditions for each material (tape and fabric) and material property (tension and compression).

In performing the statistical analysis, it was assumed that each test group provided an independent estimate of the coefficient of variation. The data were arranged sequentially

Table 3 Summary of statistical data for coefficient of variation for notched and unnotched composite strength tests

Material	Property	No. of test groups	Distribution function	Mean C_V, %	C_V 0.95 %[b]
Tape	Tension	35	Normal	5.7	11.9
			Log normal[a]	4.6	14.0
			Weibull	5.1	11.1
	Compression	22	Normal	8.5	16.0
			Log normal	7.2	20.2
			Weibull[a]	7.9	16.7
Fabric	Tension	21	Normal	6.5	10.7
			Log normal[a]	6.1	11.9
			Weibull	6.4	10.4
	Compression	20	Normal[a]	8.7	13.4
			Log normal	8.2	14.8
			Weibull	8.7	13.3

[a]Overall best-fit distribution function based on "F" test and r^2 values from regression analysis. Values of r^2 were between 0.975 and 0.981 for best-fit distribution function. [b]Coefficient of variation for 95% probability.

Table 4 Summary of regression analysis for probability distribution fits to tape and fabric composite static strength test data

Test group	Layup configuration	No. of plies	No. of specimens	Type of test[a]	Type of material	Distribution function[b]	r^2
1	$(\pm45/0_3/\pm45/0)_s$	16	20	UN,T	Tape	Normal	0.962
						Weibull	0.957
2	$(45/90/-45/0_2)_s$	10	20	UN,T	Tape	Weibull	0.983
						Normal	0.931
3	$(\pm45/0/\pm45)_s$	10	20	UN,T	Tape	Normal	0.983
						Log normal	0.980
4	$(\pm45/0_3/\pm45/0)_s$	16	20	UN,C	Tape	Log normal	0.973
						Normal	0.968
5	$(\pm45/0/\pm45)_s$	10	20	UN,C	Tape	Log normal	0.979
						Normal	0.967
6	$(45/90/-45/0_2)_s$	10	20	UN,C	Tape	Normal	0.966
						Weibull	0.958
7	0 deg (warp)	6	100	UN,T	Fabric	Weibull	0.978
						Normal	0.978
8	0 deg (warp)	6	52	UN,C	Fabric	Log normal	0.980
						Normal	0.971
9	90 deg (fill)	6	30	UN,C	Fabric	Weibull	0.961
						Normal	0.950
10	$(45/0/-45/0/90)_s$	10	30	N,T	Tape	Log normal	0.975
						Normal	0.973
11	$(45/0_3/45)_s$	5	30	N,T	Fabric	Normal	0.971
						Log normal	0.967

[a]T = Tension, C = Compression, N = Notched, UN = Unnotched. [b]Two best fits to data sets.

in increasing order and the probability was calculated from the following equation:

$$P = (i - 0.5)k \tag{1}$$

The coefficients of variation for each data set were input into a multiple regression subprogram[3] to obtain probability distribution fits to the data. Results of the analysis are summarized in Table 3. Typically, the log normal distribution yielded the lowest values for the mean and the highest values at a probability of 95%. On the average, the coefficients of variation were lower for the tension tests than for the compression tests. The mean and 95% probability values for the coefficient of variation are about the same for the normal and Weibull distributions.

Probability Distribution of Static Strength

The probability distribution of static strength for data sets containing 20 or more specimens were evaluated for fits to normal, log normal, and Weibull distribution functions using a multiple regression subprogram.[3] The results of the analysis are summarized in Table 4 and include the values of the coefficient of determination r^2 for the two best fits for each data set. The best fit, based on the "F" test, was the same as that on the basis of r^2 values. No one distribution function provided the best fit to all data sets; however, the normal distribution was either the best or second best fit for all sets of data.

For determining allowables, the lower tail of the distribution is of more interest than the best overall fit. To compare results at the lower tail of the test data, the minimum test result was compared with the predicted minimum test result using each regression equation. The results are summarized in Table 5. The log normal distribution predicted the highest values, the Weibull distribution the lowest values, and predictions for the normal distribution fell in between. Compared to the minimum test result, the predicted values for the normal distribution were always second closest to the minimum test result, with the log normal distribution being closest in seven cases and the Weibull distribution closest in four cases. When the overall best-fit equation was used for each data set, the predictions varied from 4% conservative to 3% unconservative. Therefore using the best-fit equation also provided good results near the lower tail of the distribution.

Unnotched Laminate Strength Prediction

To design a composite material laminate, four primary variables must be considered: 1) orientation of the plies, 2) stacking sequence of the plies, 3) reinforcement form of each ply (fabric or tape), and 4) the number of plies of each material at a given orientation. Considering these variables, it is obvious that an infinite number of materials may be created, even if the ply orientations are constrained to combinations of 0, ±45, and 90 deg. A totally empirical approach to establish allowables for all the possible laminates at the various environmental and notch conditions is economically prohibitive. Therefore the allowables were derived by relating the test results to the predicted results using a laminate property prediction computer program and ply level property data.

The laminate prediction computer program calculates the strength and failure sequence of composite laminates under uniaxial or combined loading. Inputs to the program include the tension and compression stress-strain behavior of lamina

Table 5 Comparison between observed minimum test point and predicted minimum test point

Test Group[b]	No. of specimens	Observed minimum test result	Predicted minimum test result: Normal distribution	Log normal distribution	Weibull distribution
1	20	100.7	99.4[a]	100.6	95.7
2	20	77.6	81.1	81.4	77.9[a]
3	20	52.5	52.1[a]	52.5	50.7
4	20	68.0	63.9	68.0[a]	62.1
5	20	44.0	40.8	43.7[a]	40.1
6	20	66.9	68.6[a]	70.6	65.6
7	100	59.1	62.6[a]	63.4	57.7[a]
8	52	65.8	61.4	63.1[a]	58.6
9	30	57.5	60.0	60.8	57.1[a]
10	30	47.2	45.5	45.9[a]	44.3
11	30	32.3	31.8[a]	32.1	30.8

[a]Overall best-fit distribution equation based on "F" test or r^2 value. [b]Same test group number as Table 4.

Table 6 Graphite/epoxy tape and fabric lamina properties for room temperature, dry unnotched predictions

Load direction	Property	Material: Tape 0 deg	Tape 90 deg	Fabric 0 deg	Fabric 90 deg
Tension	Strength—10^3 psi	97.4	7.9	38.2	36.7
	Modulus—10^6 psi	20.5	1.67	9.8	9.4
	Strain—10^{-6} in./in.	4750	4750	3900	3900
Compression	Strength—10^3 psi	74.0	6.40	34.8	33.6
	Modulus—10^6 psi	18.5	1.64	8.74	8.4
	Strain—10^{-6} in./in.	4000	4000	4000	4000
In-plane shear	Strength—10^3 psi	7.3		6.0	
	Modulus—10^6 psi	0.87		0.73	
	Strain—10^{-6} in./in.	8000		8200	
Poison's ratio		0.30		0.053	

in the orthotropic axes, in-plane shear stress-strain behavior, coefficients of thermal expansion, and orientation and thickness of each lamina. The program uses lamination theory to predict the in-plane stresses in each ply.

A maximum strain theory of failure is employed to determine yield (slope change of the stress-strain curve) or failure in any ply. After each yield or failure in a lamina, the loading is redistributed within the laminate. This process is continued until laminate failure. The program selects the appropriate tension or compression modulus for each lamina in the orthotropic axes and selects either the elastic modulus or the reduced modulus after yield. Laminate failure is predicted when the strain parallel to the fibers in any ply exceeds the allowable strain. The output from the program can be plotted as a piecewise, linear stress-strain curve for the laminate.

The mechanical properties for tape and fabric graphite/epoxy composites used for predicting strength are summarized in Table 6. These properties are based on the results from uniaxial tension and compression tests.

Design Allowables

Notch and Environmental Reduction Factors

All notched test data were analyzed to determine the reduction factors, K_{ET}, to be applied to predicted unnotched tensile and compressive strength values. Notched test data for the various environmental conditions were analyzed separately for fabric and tape materials. Mean values for each test group were used in the analysis. To relate the factors to the unnotched predictions, the statistical distribution of the ratio for the notched test strength to the unnotched predicted strength was used in the analysis. Using the derived K_{ET} factors, the ratios (test/predicted) were ordered sequentially and assigned a probability value using Eq. (1).

The K_{ET} values were adjusted so that the mean ratio for each environmental condition was approximately equal. Therefore the scatterbands for each environmental condition cover the same range of values and can be combined for statistical analysis. The factors were also adjusted so that a test/predicted ratio of 1.0 was approximately the value for a confidence level of 95%. The reduction factors, K_{ET}, resulting from this analysis are given in Table 7 for each environmental condition.

Statistical Reduction Factors

The "B" allowables can be calculated in several ways. Since it was impractical to conduct tests for all laminate properties and environmental conditions, the allowables were related to the analytical predictions. Sufficient tests were conducted to cover the range of laminates and test conditions for the fin and aileron structures. For the analysis it was assumed that each test group represents a sample from the population for which the allowable was derived. Tests were conducted to cover a range of laminate layups (combinations of 0-, ±45-, and 90-deg lamina), environmental conditions (−65°F, dry; RT, dry; and 180°F, wet), and batches (minimum of three).

For establishing a "B" allowable, the data can be combined by relating the test strength to the predicted strength, as shown on Fig. 2. For a perfect correlation between predicted strength and test strength, the test data will fall on the line with a slope of 1.0. Analysis of the test data indicated that the scatter was proportional to the strength; i.e., the coefficient of variation was approximately the same within each data set. Therefore the data were distributed within a scatterband represented by the slope of lines through the minimum and maximum test results.

For establishing B allowables the individual results must be considered. The B value for the slope, K_B, is the value that is expected to equal or exceed 90% of the population with a 95% confidence. If the probability distribution of values is known or can be determined, then the K_B value can be determined using the appropriate statistical analysis procedure. However, rather than perform an analysis of the probability distribution for individual values of test/predicted ratios, a nonparametric statistical analysis procedure for an unknown distribution was used (see 9.2.8 of Ref. 4).

The nonparametric procedure ranks the values of test/predicted ratios from the lowest to the highest, including all data points. The K_B value is then determined by counting down to the rth value, which is a function of the total number of test data points as given in Table 9.6.4.2 of Ref. 4. A summary of these calculated values are given in Table 8. Therefore the B allowable can be determined from the predicted strength using the following equation:

$$F = F_{\mathrm{RTDU}} K_{ET} K_B \tag{2}$$

To determine the accuracy of the B allowable, the 11 groups of data, analyzed previously, were analyzed using both the nonparametric method (unknown distribution) and the best-fit distribution. A comparison of B values calculated by the two methods is given in Table 9. The first six test groups do

Table 7 Summary of derived K_{ET} factors

Material	Property	Environment	No. of test groups	K_{ET}
Tape	Tension	−65°F, dry	7	0.49
		RT, dry	10	0.52
		180°F, wet	6	0.59
	Compression	−65°F, dry	5	0.84
		RT, dry	3	0.71
		180°F, wet	6	0.68
Fabric	Tension	−65°F, dry	3	0.46
		RT, dry	3	0.52
		180°F, wet	3	0.54
	Compression	−65°F, dry	3	0.77
		RT, dry	2	0.72
		180°F, wet	3	0.53

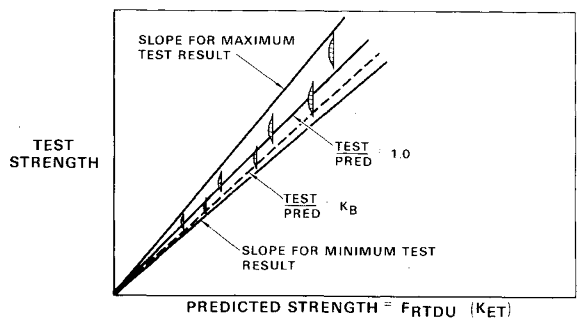

Fig. 2 Schematic showing the relation of the "B" allowable factor, K_B, to test and predicted strength values.

Table 8 K_B factors assuming distribution function is unknown

Material	Type of test	No. of test specimens	rth value for $P=0.90$, $C=0.95$	K_B
Tape	Tension	158	10	0.99
	Compression	76	4	0.95
Fabric	Tension	263	19	1.00
	Compression	65	3	0.90

Table 9 Comparison of "*B*" allowables obtained by nonparametric method and using best-fit distribution function

Test group	No. of specimens	"*B*" allowable, ksi Best-fit distribution	Unknown distribution[b]
1	20	99.3	100.7[a]
2	20	79.8	77.6[a]
3	20	52.2	52.5[a]
4	20	68.0	68.0[a]
5	20	43.7	44.0[a]
6	20	68.5	66.9[a]
7	100	68.0[c]	70.2
8	52	67.5	66.2
9	30	59.8	57.5
10	30	46.8	47.2
11	30	32.7	32.3

[a]Minimum test result. [b]Based on use of Table 9.6.4.2 of Ref. 4. [c]Average for normal and Weibull distribution.

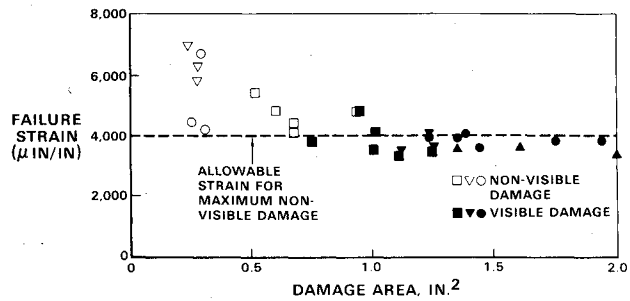

Fig. 3 Results of 3.0-in.-wide compression test specimens with impact damage.

not have the minimum required specimens (29) for the nonparametric approach, so the minimum test result is given. As shown in Table 9, the *B* values obtained for an unknown distribution are very close, within 4%, to the values obtained using the best-fit distribution function.

Impact-Damage Allowable

The compressive strength of composite laminates is reduced significantly by impact damage caused by hailstones or tool drops. Visible impact damage will be detected by in-service inspections and repaired as required. However, the structure must be capable of supporting ultimate loads with nonvisible impact damage that might occur during assembly of the structure or in service. Therefore tests were conducted on laminates to determine the maximum extent of nonvisible impact damage that could occur to laminates.

To establish an allowable compressive strain level for nonvisible impact damage, compression tests were conducted on 3-in.-wide specimens with various amounts of impact damage at the center of the specimens. The results of the tests are plotted in Fig. 3, showing the relation between compressive failure strain and damage area. All the data for nonvisible impact damage fall above an allowable strain level of 4000 μin./in. All damage areas in excess of 1 in.^{2} were visible on the backside for both the 10- and 16-ply laminates. The failure strains level off at approximately 3500 μin./in. for damage areas above 1 in.^{2}.

To verify the strain allowable for impact damage, compression tests were conducted on two hat-stiffened skin panels containing visible impact damage. These panels were impacted with 1-in.-diam hailstones at an impact velocity of 890 ft/sec and at an angle of 16 deg to the skin surface while under a compression limit flight load. After the initial impact damage, the panels were subjected to two lifetimes of fatigue loading and then residual-strength tested to failure. The first panel (with nine impact-damage areas) failed at a compressive strain level of 4123 μin./in. and the second panel (with six impact-damage areas) failed at a compressive strain level of 4375 μin./in. An undamaged panel failed at a compressive strain level of 8615 μin./in. These results demonstrate that the skin structure can support in excess of 4000 μin./in. compressive strain with damage levels exceeding maximum nonvisible damage level and including any growth during two lifetimes of fatigue loading.

Table 10 Graphite/epoxy tape and fabric lamina design allowables[a]

Load direction	0 deg property	Material Tape	Fabric
Tension	Strength—10^3 psi	97.4	38.2
	Modulus—10^6 psi	20.5	9.8
	Strain—10^{-6} in./in.	4750	3900
Compression	Strength—10^3 psi	74.0	34.8
	Modulus—10^6 psi	18.5	8.7
	Strain—10^{-6} in./in.	4000	4000

[a]Worst environmental condition, 3/16-in.-diam. notch or impact damage.

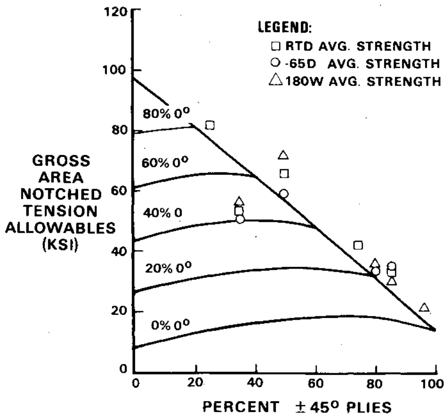

Fig. 4 Comparison of test data to design allowables for tape laminates.

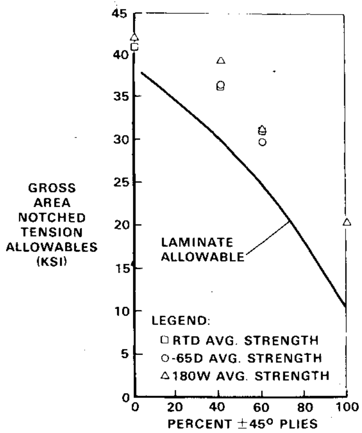

Fig. 5 Comparison of test data to design allowables for fabric laminates.

Design Allowables and Correlation With Test Data

The allowable lamina level design properties in the fiber direction for tape and the warp direction for fabric are presented in Table 10. These allowables reflect the worst environmental condition in combination with a 3/16-in.-diam hole for the tension allowable and nonvisible impact damage for the compression allowables. Comparisons of design allowables with average test data for various tape and fabric laminates are presented in Figs. 4 and 5. For the tape design allowables the predicted strength allowable is generally about 10% less than the average measured strength. For fabric laminates the predicted strength allowable is considerably less than the average measured strength.

Summary

Data from over 2000 tests on coupons constructed of Thornel 300/5208 graphite/epoxy unidirectional tape and bidirectional fabric have been statistically analyzed to formulate design allowables for these materials. Since the basic tape and fabric materials can be used to configure an infinite number of laminates, a statistical approach different than that used for metals has been derived for establishing design allowables. Comparisons of the design allowables to measured test data have verified this approach for a wide variety of tape and fabric laminates.

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