ALLOWABLES FOR STRUCTURAL COMPOSITES

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Introduction

In order to obtain the most benefit from building a structure with composite laminates, the strength of the laminate must be known. Based on the "weakest link" theory, the lower strength numbers obtained from testing are the ones to be used for design and analysis. The strength value to be used is determined by a statistical analysis of the test data, and is known as an allowable. MIL-HDBK-17 outlines procedures to follow for determining these allowables. There are two types of statistically determined allowables, A-Basis and B-Basis. A-Basis is defined as a strength value at which only 1 in 100 specimens will fail with a 95% confidence level. B-Basis is a strength value at which only 10 in 100 specimens will fail with a 95% confidence level. As more specimens are tested a higher value of strength can be used as a valid allowable. Composites are highly process dependent and show much strength variation with environment, so it is critical to test materials and environments that are representative of hardware. Either using data obtained from a previous test series, or extrapolation to a certain temperature is highly discouraged.

Statistical Approach

Before any statistics can be applied to the strength data, the distribution of the data needs to be known. The distribution is represented by a histogram as shown in Fig. 1.

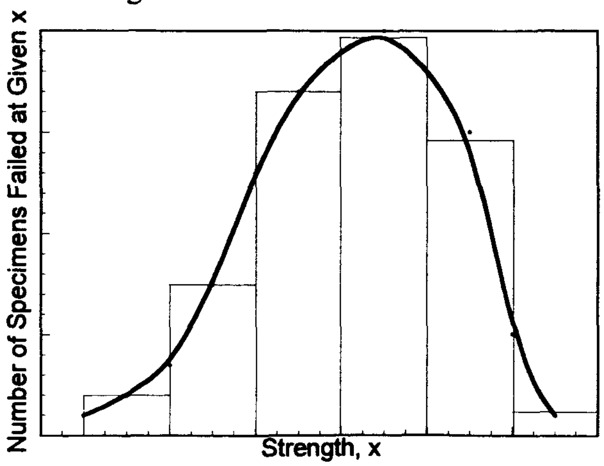

Fig. 1. Example of a strength histogram

It is obvious that a fair number of specimens (more than 10) need to be tested in order to construct a histogram. There are three types of histograms that can occur: Normal (Bell Curve), Log-Normal (Skewed) and Weibull (More heavily skewed.). Once a histogram is constructed, a test for each of these three types of distributions is performed. The best fitting one is used for the analysis. If none of the three types of distribution fit, then a nonparametric basis calculation must be made. If batch-to-batch variability can be identified, then an Analysis of Variance (ANOVA) approach should be used. If not then the Hanson-Koopmans method can be used if the population size is 28 or smaller. The following formulas are used to determine a B-Basis value for each of the three distributions:

Normal distribution: $B = \overline{X} - k_B(s);$ (1)

Where $\overline{X}$ is the arithmetical Mean, k_B is a constant (called the tolerance factor) depending on the number od specimens, n and s is the standard deviation

Lognormal Distribution: Convert each data point to its natural logarithm and use the normal distribution with the converted data.

Weibull distribution:

$$B = \alpha(0.1054)^{\frac{1}{\beta}}\left(\exp\left(\frac{-V}{\beta\sqrt{n}}\right)\right); \quad (2)$$

Where α and β are the Maximum Likelihood Estimators and V is the one-sided tolerance factor which depends on n.

Criticality of Number of Specimens

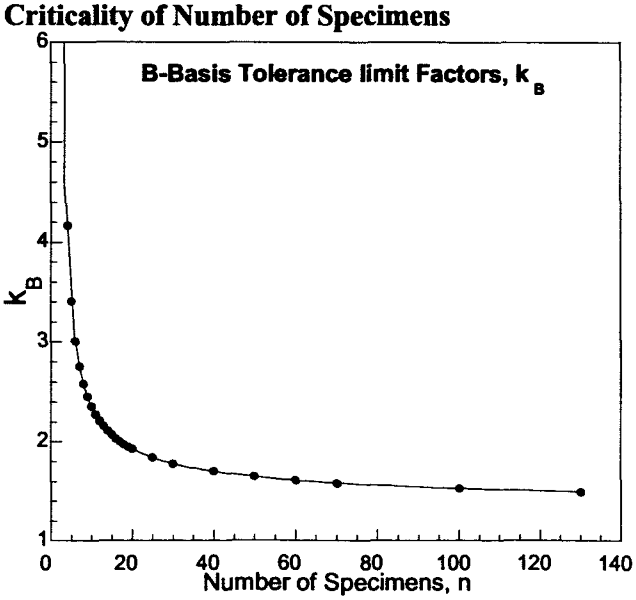

Fig. 2. Tolerance limit factor versus specimens tested

Fig. 2 shows the B-Basis tolerance factor as a function of number of specimens tested. From the definition of a normal distribution B-Basis allowable, it can be seen that if only five specimens are tested, the allowable will be the mean minus over three standard deviations. This will result in a very low number and lead to over design of a structure. Testing ten specimens will result in a tolerance factor of a little over two, a vast improvement over using only five specimens.

For a Weibull analysis, the one-sided tolerance factor V is not defined for $n<10$. Figure 3 shows plots of the exponential term in Eqn. 2 for $\beta = 10, 20$ and 30. This is shown to demonstrate that at least 10 specimens must be tested to even attempt a Weibull analysis and that the criticality of the number of specimens used to get a higher allowable is heavily dependent upon the Weibull modulus β.

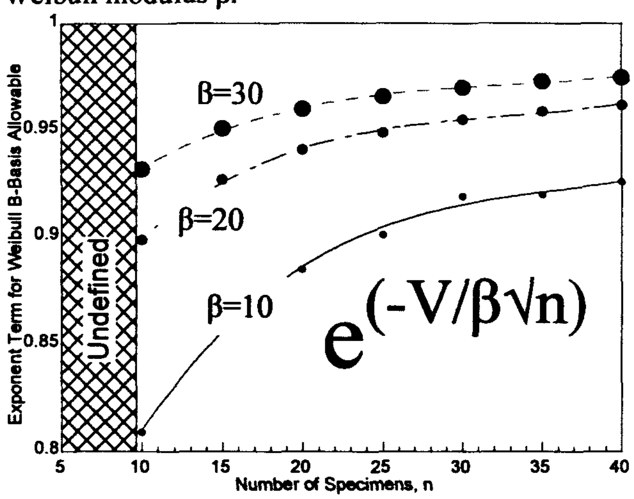

Fig. 3. Exponential term for Weibull B-Basis allowable with $\beta = 10$, 20 and 30.

Comments on "85% of the Mean"

A disturbing trend has arisen regarding the use of 85% of the average values (even when as few as 5 specimens are tested) for a "quasi" B-Basis allowable (100% of B-Basis). This erroneous application appears to be due to a misapplication of a 1987 Military Specification (MIL-A-8860B). Paragraph 3.2.1 of this specification states: "Eighty-Five percent of the average values or of the "B" values, *whichever is less*, shall be used in the design of the composite structural components". Three key points are being missed when only 85% of the average is used as a "quasi" B-Basis allowable:

1. A B-Basis database is needed before the statement can even be applied because a comparison is required.
2. The lower value must be used.
3. The numbers to compare are 85% of the average and 85% of the B-Basis value, not 100% of the B-Basis allowable.

Examples

Table 1 shows actual data from various test programs on composites. The data include material and test type, the number of specimens used, 100% of the B-Basis value as calculated per MIL-HDBK-17, and the difference between the B-Basis value, (100% not 85%) and 85% of the mean.

Table 1. B-Basis allowables versus 85% of mean.

Material * Code	Specimens	85% of Avg.	B-Basis	% difference
1	23	49.0 ksi	36.5 ksi	-34
2	150	92.0 ksi	97.0 ksi	+5
3	150	56.0 ksi	52.0 ksi	-8
4	16	13.9 ksi	12.0ksi	-16
5	19	56.9 ksi	50.1 ksi	-14
6	16	42.4 ksi	33.7 ksi	-25.7

* Material Codes:
1. AS4/3501-6 Simple Weave (Tensile, 550F)
2. AS4/3502 5-H Weave (Tensile, 250F)
3. AS4/3502 5-H Weave (Compression, 180F)
4. IM7/977-2 (Short Beam Shear, RT)
5. IM6/3501-6 Unidirectional (Compression, RT)
6. IM7/Epoxy 5-H Weave (Compression, RT)

As can be seen, sometimes the B-Basis is close to 85% of the average, but for the most part it grossly overestimates the proper allowable. This difference becomes greater if 85% of the B-Basis value is taken as it should be when performing this comparison. While testing only 5 specimens and taking 85% of the average value is attractive from a cost and schedule standpoint, it can prove (and has proven) disastrous in the long run.

Conclusions

Material allowables need to be very carefully developed with a sufficient number of specimens tested to generate these values. Any mention of a "quasi" B-Basis allowable by taking 85% of the mean should cause immediate concern and be rectified if possible, otherwise these "quasi" values are meaningless.

The practice of using properly generated material allowables from another program that used a "similar" material should also be avoided. Unless the existing data set can be shown to be a statistically equivalent population to the current material, the existing database cannot be used to develop an allowable. This will rarely be the case with composite laminates as they are very process dependent.