Effects of Prestressing Boron/Epoxy Prepreg on Composite Strength Properties

George J. Mills*
Northrop Research & Technology Center, Hawthorne, Calif.

AND

Richard J. Dauksys†
Air Force Materials Laboratory, Wright-Patterson Air Force Base, Ohio

Theme

PRODUCTION boron fibers have wide variations in tensile strength due to a statistical distribution of defects along the fiber. The "tail" of the fiber strength distribution controls the composite strength level and property dispersion. A process is described for selectively prebreaking the fibers at these defects while in the prepreg condition. This "prestressing"‡ method increases the average fiber strength concurrent with a reduced standard deviation. Fiber improvements translate into laminates as significant increases in engineering design allowables, converting substandard prepreg to usable values. Laminate tension test results are compared for two levels of prepreg fiber quality. At a 180 ksi "B" design allowable acceptance criteria, prestressing effects increases in low strength prepreg to acceptable levels and produces a comparable improvement in high quality material to 220 ksi.

Contents

Boron/epoxy composites show a large spread in tensile strengths. The weak sections along the fiber length control the composite strength. Elimination of these weaker sites could result in improved strengths, achieving a more effective utilization of the full strength potential inherent to the fiber. The "prestressing" concept removes the weak spots from the fiber strength statistics by purposely prebreaking these fibers during processing of a prepreg tape material. This is accomplished by bending the tape over a sharp radius, thus applying a tensile load greater than the strength of the local weak sections. Tape samples of 6 in. length were removed from production batch rolls of 4.0-mil-diam boron/epoxy prepreg procured from the various suppliers. Individual boron fibers, extracted from commercial production prepreg, exhibit strengths ranging from 100 to 650 ksi, when tested in 3 in. gage lengths. Twenty-five individual rolls of prepreg material were characterized. Figure 1 shows the narrow band within which the average fiber strength and dispersion clearly correlate. The dotted line divides material above which composite, unidirectional tensile strength should meet a 180 ksi "B" allowable level. A method for applying a controlled stress level utilizes a bend stress to continuously induce breakage at the weakest sites along the fiber length. Figure 2 shows a fiber, which in practice is contained in a resin impregnated tape, of radius R_f, bent over a radius R_D with a tensile stress increasing from zero at the neutral 0-0 axis to a

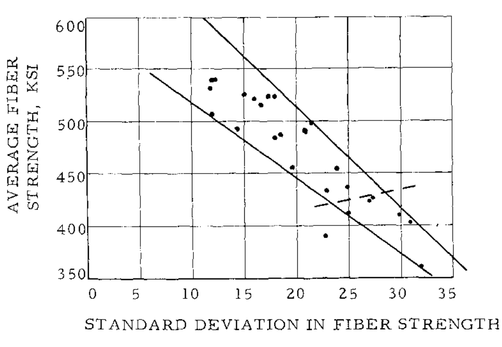

Fig. 1 Dispersion in boron fiber properties from unstressed commercial epoxy prepreg.

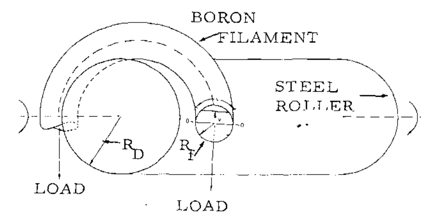

Fig. 2 (Not to scale) model of fiber in tape undergoing prestressing by bending.

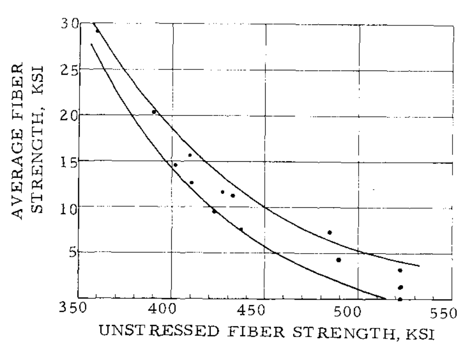

Fig. 3 Prestressed fiber strength increase.

Presented as Paper 73-382 at the AIAA/ASME/SAE 14th Structures, Structural Dynamics, and Materials Conference, Williamsburg, Va., March 20–22, 1973; submitted April 2, 1973; synoptic received June 18, 1973. Full paper available from AIAA Library, 750 Third Avenue, New York, N.Y. 10017. Price: Microfiche, $1.00; hard copy, $5.00. **Order must be accompanied by remittance.** This research was supported under Contract F33615-71-C-1567 by the Air Force Materials Laboratory, Nonmetallic Materials Division, Plastics & Composites Branch.

Index categories: Structural Composite Materials (Including Coatings); Materials, Properties of; Aircraft Structural Materials.

* Director, Device Technology Laboratory. Member AIAA.

† Adhesives Group Leader.

‡ Patent 195,590 pending.

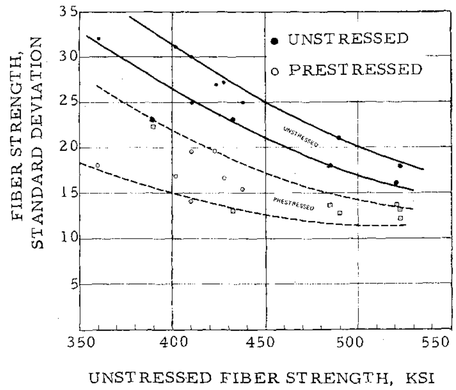

Fig. 4 Decrease in fiber strength dispersion with prestressing.

maximum of Ey/R_D as $y \to R_f$ at the outer surface of the fiber. Various levels of prepreg fiber quality, ranging in average strengths from 360 ksi to 539 ksi, were prestressed under several roller conditions. Since fiber property improvements are accompanied by the breaking of filaments, optimization of processing conditions for maximum strength and minimum dispersion is accomplished at minimum fiber breakage to limit their effect on composite behavior. The data presented in Fig. 3 plots the effect of prestressing on fiber strength increase for the different incoming prepreg fiber levels. Conditions of stressing for optimum increases in lower strength material can be accomplished and even the best quality fiber is raised to values approaching the "defect" free state of ~560 ksi. Figure 4 shows the prestressing effect on the fiber strength dispersion where data for unstressed and prestressed material are correlated within a band, with the latter at a substantially lower dispersion level. The bendstressing method has, therefore, provided significant improvements to prepreg fiber of all quality where low strength material has been prestressed to fiber properties approaching that of unstressed, high strength prepreg. The over-all effect is best seen in Fig. 5 where the limits for unstressed prepreg are over-layed (from Fig. 1) to indicate the extent of improvement achieved. The process has been developed to the point where predictable strengths and dispersions are achievable. Processing and testing of a statistically significant sample to ascertain its utility in practical application were accomplished. Two levels of prepreg material were studied; material A at 427.4 ksi av. fiber strength and 27.3% dispersion would not meet the selection criteria for a 180 ksi minimum "B" allowable. It has a large defect content, representing 70% of the fiber distribution. The B prepreg, at 484.5 ksi strength and 18% dispersion, would exceed the same criteria with its 20% defect mode. These prepregs

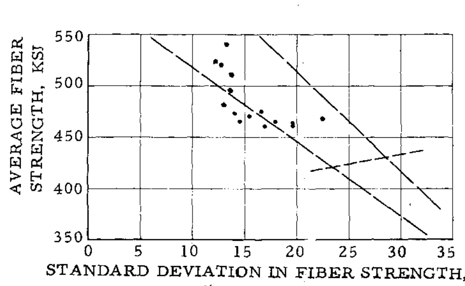

Fig. 5 Dispersion in boron fiber properties for prestressed commercial prepreg.

Table 1 Fiber and composite strength comparison

Fiber prepreg material	Fiber strength, ksi (coef. var. %)	50 V% Composite strength, ksi (coef. var. %)	Calculated "B" allowable, ksi
Type A low strength			
Unstressed	427.4 (27.3)	198.5 (6.8)	175.4
Prestressed	477.5 (16.7)	209.4 (3.4)	197.1
Type B high strength			
Unstressed	484.5 (18.0)	223.0 (5.3)	202.0
Prestressed	495.0 (13.7)	232.0 (3.2)	219.0

were prestressed in the bend machine with appropriate rolls. Unidirectional composites were prepared from both unstressed and prestressed prepreg material and tensile testing performed on 30+ coupons for each material and condition. Table 1 shows an increase in composite strength and a substantial reduction in data dispersion corresponding to the improvements imparted to the fiber. Prestressing serves two useful purposes, a reduction in laminate test data variation with increases in strength level. Both factors are necessary to a basic design allowable formulation policy. Calculated "B" design allowables for the unidirectional laminate tensile test data are shown, and based upon a 180 ksi design level, the unstressed A material would be unacceptable. However, through prestressing, it exceeds this acceptance criterion. Type B material, while meeting such specification, is increased to a level where consideration could be given to increasing the "B" allowable to perhaps 200 ksi. The feasibility of prestressing commercial boron/epoxy prepreg tape material to higher strengths and lower standard deviations has been demonstrated and its practical application as an on-line process for improving quality levels of the most recent production material is possible. The mechanics of the bendstressing technique effects a controlled alteration in the fiber defect content which suggests similar effects in other filamentary reinforced composites such as graphite, glass and metal matrix systems. The level of improvements experienced indicates that composites can be improved to the extent that the inherent fiber quality will allow and that dispersion in composite properties in the 1% to 2% range can be realized. The results suggest the following conclusions. 1) The commercially available boron/epoxy prepreg materials exhibit appreciable variations in filament mechanical properties, both within long length rolls (in excess of 100 ft) and between rolls and batches. 2) Variations in this material result in excessive design value penalties, requiring extensive specimen testing and quality control procedures, as a significant factor in processing costs. 3) All fibers exhibit a low strength tail in their distributions, indicating a defect failure mode as an inherent characteristic. 4) Prestressing reduces this tail in proportion to its contribution to the initial distribution. 5) The prestressing process can accomplish selective filament breaking, producing an altered distribution approaching the full strength potential of the fiber. 6) Prestressing reduces batch-to-batch prepreg material variations by raising lower strength material distributions and simultaneously lowering the standard deviation. 7) Fiber property improvements are carried into the composite, as a reduction in standard deviation, and, with minimal fiber breakage, as an increase in strength. 8) The prestressing process can be varied and modified to optimize the altered fiber strength distributions for maximum composite property improvement. 9) Interpolated data suggest that an immediate minimum increase of 20% in boron/epoxy "B" level design allowables can be obtained by implementation of a stressing operation on a prepreg tape line. 10) A prestressing process could be a useful quality control method for reducing the variability in production material.