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DOE/MSU Composite Material Fatigue Database: Test Methods, Materials, and Analysis

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Prepared by Sandia National Laboratories Albuquerque, New Mexico 87185 and Livermore, California 94550 for the United States Department of Energy under Contract DE-AC04-94AL85000

Printed December 1997

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ABSTRACT

This report presents a detailed analysis of the results from fatigue studies of wind turbine blade composite materials carried out at Montana State University (MSU) over the last seven years. It is intended to be used in conjunction with the DOE/MSU Composite Materials Fatigue Database. The fatigue testing of composite materials requires the adaptation of standard test methods to the particular composite structure of concern. The stranded fabric E-glass reinforcement used by many blade manufacturers has required the development of several test modifications to obtain valid test data for materials with particular reinforcement details, over the required range of tensile and compressive loadings. Additionally, a novel testing approach to high frequency (100Hz) testing for high cycle fatigue using minicoupons has been developed and validated. The database for standard coupon tests now includes over 4100 data points for over 110 materials systems. The report analyzes the database for trends and transitions in static and fatigue behavior with various materials parameters. Parameters explored are reinforcement fabric architecture, fiber content, content of fibers oriented in the load direction, matrix material, and loading parameters (tension, compression, and reversed loading). Significant transitions from "good" fatigue resistance to "poor" fatigue resistance are evident in the range of materials currently used in many blades. A preliminary evaluation of knockdowns for selected structural details is also presented. The high frequency database provides a significant set of data for various loading conditions in the longitudinal and transverse directions of unidirectional composites out to 10^8 cycles. The results are expressed in stress and strain based Goodman Diagrams suitable for design. A discussion is provided to guide the user of the database in its application to blade design.

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INTRODUCTION

The fatigue program at Montana State University (MSU)* has generated over 4100 static and fatigue data points for E-glass fabric reinforced composites typical of those used by many U.S. wind turbine blade manufacturers. While most of the data points represent materials which have been fabricated at MSU using resin transfer molding (RTM) to obtain a broad range of materials parameters, a section of the database represents materials supplied by several U.S. blade manufacturers. The complete DOE/MSU fatigue database may be obtained through SNL Project Monitor Dr. Herbert J. Sutherland (tel.# (505) 844-2037). Some of the data generated under this program have been reported in a previous SNL report [1], and in several published papers [2-8] and student theses [9-16].

The DOE/MSU database has several main features. First, it contains tensile fatigue data from over 110 materials, compressive fatigue from over 45 materials, and reversed load data from 10 materials. The reason for the great number of materials studied is that significant and unexpected variations were found in fatigue resistance as the materials parameters were systematically varied, using the fabrics and resins being supplied to the turbine blade industry. A second feature of the database is ply property fatigue data for various fabrics in the 0° and ±45° directions, which can be used as ply properties in composites analysis. A third feature is a section reporting the development of specialized, high frequency test methods and resulting data, where tests have been carried out to 10^8 cycles under a variety of loading conditions and represented in Goodman Diagrams for longitudinal and transverse directions. The final feature is a section including 22 materials supplied by U.S. blade manufacturers.

A fatigue database for blade materials has also been developed in Europe [17]. The main feature of DATABASE FACT as compared with the DOE/MSU database is a more detailed statistical representation of results based on an apparently narrower range of materials variables.

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* This program has received support from Sandia National Laboratories (SNL), the National Renewable Energy Laboratory (NREL), and the Department of Energy (DOE) through the Experimental Program to Stimulate Competitive Research (EPSCoR), which has equal matching funds from the State of Montana. Materials have been supplied by many U.S. blade manufacturers, including Kennetech, Northern Power Systems, Phoenix Industries, and P.S. Enterprises. Reinforcing fabrics have been supplied in some cases by Knytex.

Data in the two databases are in general agreement for many materials, with some differences which will be pointed out in later sections. This report is intended to serve as a guideline for using the DOE/MSU database, as an aide in selecting materials to obtain optimal blade performance and lifetime, and to provide background information on test methods and conditions.

MATERIALS AND TEST METHODS

REINFORCEMENT ARCHITECTURE

Stranded fabrics are available in a variety of architectures, as noted earlier. Strand size and tightness within a fabric varies. The nesting of strands from adjacent layers in the laminate varies (particularly for multiple adjacent unidirectional layers), and the degree to which strands from one layer are held (by stitching) against strands of another orientation in adjacent layers in multi-layer fabrics varies greatly. The internal arrangement of strands is also sensitive to the overall fiber content. These factors have been found to have a strong influence on fatigue performance in tension, as described later. Table 1 lists fabrics included in the Database.

Examples of fabric architecture variations are shown for Knytex fabrics in Figure 1. Figure 1(a) shows typical laminate layer stacking. For unidirectional fabrics, the architecture may be either stitched, as in D155 weft unidirectional in Figure 1(b), or woven over and under a thermoplastic coated fiberglass strand, as in the warp unidirectional A130 fabric, Figure 1(c). Figure 1(d) shows fabric obtained as bias stitched ±45°. Figure 1(e) shows variations in nesting of weft unidirectional D155 fabric strands with several adjacent unidirectional layers. Triaxial stitched fabrics combining (b) and (c) vary greatly in how tightly the 0° and ±45° layers are held together by stitching. A typical polished section taken after a period of fatigue testing (Fig. 1(f)) shows pores, matrix cracks, and broken 0° strands along stitching lines which debond from the matrix. These are very heterogeneous structures whose details will be shown to influence the fatigue behavior strongly under certain loading conditions. There is also remarkably little sensitivity of some properties to the variations in internal structure, including the fatigue sensitivity under some loading conditions such as compression.

RESINS AND CURING

Three different resins were used in RTM (resin transfer molded) materials in this study: CoRezyn 63-AX-051, an unsaturated orthophthalic polyester resin, obtained from Interplastic Corporation, Derakane 411-C-50, a vinyl ester produced by Dow Chemical Company, and Epon epoxy resin 9410 with 9450 Epon curing agent obtained from Shell. The epoxy is a modified bisphenol "A" resin system and the curing agent is a liquid MDA (methylenediamine) based aromatic amine system. Details of the resins for Industrial Materials are not available in all cases. The mixing and cure schedules are shown in Table 2, as recommended by each respective manufacturer. Methyl Ethyl Ketone Peroxide (MEKP) was the catalyst used with both the CoRezyn and the Derakane. The Derakane was promoted with cobalt naphthenate (CoNap) and dimethylaniline (DMA) prior to mixing with the MEKP catalyst.

Most of the RTM composites in this study involved the CoRezyn polyester resin, which is a common wind turbine blade manufacturing resin. The other two resin systems were chosen due to their commercially wide acceptance and general use in industry. The resin systems were initially stored at approximately -15°C until needed. The resin was allowed to warm up to room temperature (20°) for 24 hours before mixing with MEKP or mixing the two component Epon system. For the CoRezyn, if the room temperature was greater than 25°C, the percentage of MEKP was reduced to 1.5% to ensure a minimum 30 minutes before it gelled. The catalyzed resin was then pumped into the two center injection holes in the aluminum baseplate using a peristaltic pump (Cole-Parmer Instruments Co. Model 7553) and silicone tubing. The resin was transferred to the mold over a 5 to 15 minute period with pressures less than 150 kPa depending upon fiber reinforcement layup, angle, fiber volume content and injection pressure. Approximately 50 ml of resin was allowed to flow out of the two ports at each end of the mold to ensure that all the layers had been wet out. The pumping was then stopped and the center injection ports were plugged. The resin exit ports at the ends were left open to equalize the pressure throughout the mold. This prevented pressure induced deflection of the mold faces, which would vary the thickness of the composite plate. The CoRezyn and Derakane plates were removed from the mold after a minimum of 4 hours from the time of the MEKP addition and placed in a post cure oven at 60°C for 2 hours. The Epon epoxy plates were injected and directly placed in a 80°C oven for 10 hours and then allowed to cool down slowly to room temperature overnight inside the oven.

FABRICATION

Almost all of the materials manufactured at MSU for this study involved resin transfer molding (RTM). This process produces a composite with uniform thickness, excellent fiber wet-out, low porosity, and negligible fiber wash. The process also allows easy manipulation of ply lay-up and fiber volume content, and produces consistent material characteristics as compared to hand layup.

Fabric reinforcement was obtained on 127 cm wide rolls. The fabrics were unrolled onto a table where 22.5 cm by 85 cm rectangular patterns were cut using a standard rotary cutter, with the 0° fibers in the long dimension to aid in fiber wet out. Fabrics in this study were limited to 0°, ±45° and 0°/±45° degree stitched fabrics, which are summarized in Table 1. These rectangular cut fabric patterns were then placed in the RTM mold and stacked as per the specific ply arrangement desired.

The flat rectangular plate resin transfer mold consisted of a lower 13 mm thick aluminum baseplate with a gasket channel milled around its perimeter, as shown in Figure 2. This channel allowed the placement of a 13 mm by 13 mm extruded Buna N (nitrile rubber) gasket. The relative height of the top of this gasket to the top of the baseplate could be changed by the addition of sheet metal spacers under the gasket, allowing the thickness of the composite plate to be changed. A 13 mm thick tempered glass plate acted as the top of the mold, allowing visual examination of the mold filling process as the resin was injected into the mold. A positive seal between the glass, gasket and the aluminum plate was accomplished with ten C-clamps. Steel blocks were placed in between the C-clamp heads and the glass plate to provide a bearing surface and to prevent fracturing of the glass. The clamps were torqued to 340 N-cm. This torque was set at the beginning of the project and provided reproducible composite plate thicknesses throughout the study. Both the inside surfaces of the mold were coated with external mold release F-57NC from Axel Plastics Research Laboratories Incorporated or Frekote 700 - NC mold release by the Dexter Corporation. The aluminum plate was initially polished with 600 grit emery paper which produced an excellent carrier surface for the mold release. The mold release was applied over both the aluminum and the glass surfaces using a small cloth and approximately 10 to 15 ml of mold release, then air dried for 15 minutes. This produced a viable film which permitted 30 to 40 plates to be manufactured before it was depleted. When this film was exhausted, the mold surfaces were cleaned with acetone and a new film layer were applied.

For composite plates with a fiber volume greater than 50 percent or plates with poor resin transfer channels, a special method of resin injection was developed. A special process was necessary to insure fiber wet-out, prevent fiber wash in the mold, and insure that injection pressures below than 200 kPa were adequate (the capacity of the pumping system). A layer of double sided mounting tape (Scotch 110) was placed between the glass and the rubber gasket and initially very lightly clamped. The mold was then completely injected with resin and the C - clamps were torqued up to 35 cm kg. This caused the foam tape to compress from 1.6 mm to approximately 0.4 mm, causing excess resin to flow out the vent ports of the mold. The maximum fiber volume produced by this process was 67 percent with excellent fiber wet-out and negligible porosity.

TEST SPECIMEN PREPARATION

The edges of the resin transfer molded plates were trimmed off to eliminate any edge composition variability, ensuring representative, uniform material properties. The trimmed plates were then cut to produce flat rectangular coupons for testing. The plates were cut into 25 mm or 38 mm wide strips depending upon the required coupon width. From these strips, at least two tensile and two compressive coupons were cut. This stratified random sampling scheme, with replication, was necessary to produce the required number of testing specimens with an unbiased variance estimator (statistical degree of freedom >1) in the experimental design. The plates were cut with a 20 cm diameter diamond coated blade rotating at 3,450 rpm (36 m/s), which was water cooled and lubricated. The feed rate of the composite plates during cutting was less than 5mm/second to ensure a clean, perpendicular cut edge. Coupons which were thickness or width tapered were machined with a 3 flute carbide router bit rotating at 23,000 rpm.

Determining accurate and representative material fatigue properties involves a number of tradeoffs. The material tests should involve a representative volume, require low forces (which prevents load transfer problems and grip failures), have a short gage length to allow higher fatigue frequency, and have an area of uniform axial strain where the material modulus can be determined. Table 3 and Figure 3 summarize the nominal geometry of the test coupons. These geometries worked well in the static and fatigue tests performed on the MSU suite of servohydraulic machines used in this study (Table 5). The coupons used in the Instron 8511, due to the 10 kN capacity, had a smaller cross section which is described later.

Additional tab material was added to some materials in the coupon gripping regions to reduce the stress concentration generated by clamping the coupon and to provide a wear surface between the composite and the metal wedge grips. Additional tab material was bonded to the coupons, when necessary, as the last step in the manufacturing process. The tab material utilized in this study included electronic protoboard, fiberglass (0°/90° and ±45° layups) and aluminum as summarized in Table 4 and shown in Fig. 3. A range of tab materials and adhesives were investigated in order to achieve gage section failure modes and limit the number of tab failures.

The areas of the coupon and the tab material to be bonded were lightly sanded with 180 grit emery cloth, cleaned with a sponge and water, and air dried. Each surface was then smeared with a thin layer of Hysol EA 9309.2NA or Dexter epoxi-patch adhesive and assembled. Paper binder clips, 50 mm wide, were used to apply pressure to the assembly and provide alignment. The assembly was then cured in a convection oven at 60°C for 2 hours. After curing, the clamps were removed and the tab faces were lightly sanded to remove any excess adhesive and to provide flat and parallel clamping surfaces. The coupons were provided with a material label and a specimen number. The coupon was then dimensionally measured for its cross-sectional area using a Mitutoyo Digimatic digital caliper, or equivalent, with a minimum resolution of 0.01 mm.

The percentage of glass reinforcement by volume in a sample was determined by the matrix burn off method described under ASTM D 2584. This process involves placing a known volume of composite material in a muffle furnace at a temperature of 550°C for 1 hour or until all of the carbon on the glass fibers has been removed. The glass reinforcement is then weighed on a digital balance and the fiber volume content is calculated using a measured glass density of 2.56 g/cm^3. The only deviation from the ASTM standard was the amount of material to be used in the burn off test, 5 grams. It was felt that the ASTM standard would not generate a representative average fiber volume fraction due to the coarse architecture of the stitched fabrics, so a greater amount of material, 15 to 25 grams, was used.

MECHANICAL TESTING EQUIPMENT

The static and fatigue and tests were performed on five different testing machines listed in Table 5. Approximately 85 percent of the tests were performed on the Instron 8501, 10 percent on the MTS 880 with the remainder of the tests on the other machines. All these machines had their respective transducers, load cell, extensometer, and actuator LVDT, calibrated to their respective, applicable ASTM standards.

The load cells in each of the mechanical testing machines, along with their associated readout electronics, were calibrated as a complete system and conformed to the standard practices of ASTM E 4 and E 74. This procedure was also used for additional piggy-back load cells used with lower force tests. These ASTM standards allow a maximum of ±1 percent error. The Instron 8501, 8562, 8511 and MTS 880 had maximum errors less than ±0.4 percent. The load cells were calibrated or checked every 4 to 6 months using standard calibration cells calibrated through Morehouse Instrument Company and by class 3 dead weights, calibrated directly against secondary national standards. The dead weights were necessary to calibrate over the 0 to 2 kN range, where extensometers were used to measure the initial elastic modulus of the test coupons.

Extensometers and their associated electronics were calibrated and verified to ASTM E 83 and classified as class B2 extensometers with a maximum error of ± 0.5 percent. The five extensometers used during this study are summarized below in Table 6. The extensometers were calibrated using a Boeckeler Instruments mechanical micrometer model 4 - MBR which had a resolution and accuracy of 0.005 mm and a maximum error of 0.33 microns. A Mitutoyo IDC - 112E digital gage with a resolution of 0.001 mm was also used. The gage lengths of the extensometer were also checked with this digital gage and an optical microscope as described in ASTM E 83. During tensile strain measurements the extensometer was attached to the edge of the test coupon, or when possible, on the face of the coupon, using rubber bands. When placed on the face of the coupon, it was necessary to attach two pieces of self adhering 240 grit polishing paper (extensometer mounts) to prevent the extensometer knife blades from slipping and to prevent the blades of the extensometer from damaging the composite surface. The extensometer was not used during compression tests due to the short gage length of the compression coupon and the possibility of extensometer damage; strain gages were used instead.

The actuator position was calibrated with a CDI J4 - C100 - 5000 mechanical dial gage with a resolution of 0.0254 mm (0.001 inches). Gage blocks were also used to check displacements and set compression gage lengths (12.70 mm). In all cases the gage blocks were of grade A+ or better. Although no ASTM standard was referenced for this procedure, the maximum amount of error was less than ±1 percent.

A Measurements Group Incorporated 2100 system strain gage conditioner and amplifier system with 8 strain channels was used to measure strains. The strain gages were calibrated using the internal shunt calibration of the 2100 system. This active gage method of calibration and operation used a three lead wire circuit and conformed to ASTM E 251. A minimum wire gage of 26 was used for connecting the gages to the instrumentation and the total length of connection wire was minimized to reduce lead wire resistance effects. In all cases the excitation voltage was 2.00 VDC with 350 ohm strain gages. Electronic gains of approximately 500 were used for strains up to 13.6 percent and gains of 5000 allowed measurement of strains up to 1.36 percent. Generally one quarter wheatstone bridges were used for strain measurements. The strain gages used in this study are summarized in Table 7. In all cases the life of the strain gage was limited to a few hundred cycles as matrix cracks on the surface of the composite opened up and damaged the strain gage, shown in Figure 4.

Using extensometers on the fatigue coupon for extended periods caused damage and subsequent failure of the coupon, as the knife edges of the extensometer dug into the coupon. These strain measurement problems were addressed with the development of strain clips which are shown in Figure 5. These devices reduce the running strain that the strain gage undergoes, which prevents fatigue failure of the gage and eliminates strain gage failure by matrix cracking. Of the many methods tried to measure the fatigue running strain of the composites studied, this method yielded the best results. The clip is manufactured from 0.15 mm brass (C26000) shim stock, using a one half wheatstone strain gage bridge with temperature compensation which minimizes any material thermal mismatch problems and produces a durable gage. An additional aspect associated with this gage is that it initially has to be calibrated with an extensometer or another strain gage on the composite surface.

Adhesives used to bond the strain gages to the composite surface included Loctite 496 cyanoacrylate ester and Micro Measurements Incorporated M - Bond AE 15 epoxy resin. The AE 15 was used when the expected strains were greater than 2 percent.

Testing Machine Load Train Alignment

Alignment of the load train in the mechanical testing machines was critical to ensure a uniform stress distribution across the test coupon, especially during compression tests. The grip and actuator travel centerline was adjusted to conform to ASTM E 3039 even though the main standard concerning alignment is detailed in ASTM E 1012. ASTM E 1012 does not address the acceptable amount of bending in a testing setup, whereas ASTM D 3039 addresses it as an additional aspect to composite testing. Table 8 summarizes the available standards and their recommended allowable bending strains. The amount of bending during an axial test must be minimized, but it cannot be totally eliminated, so every effort was made to limit the amount of bending strain to less than 5 percent of the axial strain. The load train alignment was checked every time the grips were removed from the machine or just prior to compression testing.

To measure the amount of bending, four strain gages were placed on a thin rectangular, 4130 steel coupon as per ASTM D 3039. The 3 mm thick by 50 mm wide steel calibration coupon was chosen as it was similar in dimensions to the fiberglass coupons. The coupon was loaded up to a calibration load of 53 kN and the maximum amount of bending was calculated using the equation in Section 10 of ASTM D 3039. This maximum load, 53 kN, was used to prevent yielding of the calibration coupon. If the amount of bending strain was greater than 5 percent of the axial strain, the load train of the testing machine was adjusted. This alignment procedure was performed with the actuator in the position it was to be used during the material test to ensure test alignment.

TEST DEVELOPMENT

Coupon Test Methodology

The machined test coupons were selected using a simple random sampling without replacement scheme for static and fatigue tests at the different required R values. When additional test coupons were needed from two or more material plates, every effort was made to randomly select coupons from all the different material plates prior to initial testing to ensure a random selection from all the possible material.

For all the tensile tests, static and fatigue, an initial material elastic modulus, E, was calculated by taking the least squares fit of a straight line through at least five evenly spaced axial stress - strain data points, at total strains of less than approximately 0.12 percent (points were selected to avoid any initial curvature in the stress-strain curve). This procedure allowed for multiple modulus calculations with little, if any, matrix cracking and to ensure no extensometer slippage. The extensometer was also used to obtain the initial fatigue running strain of the coupon and then removed to prevent damage to the test coupon. Compression tests utilized strain gages for the static tests and the fatigue tests used the average material modulus to calculate the fatigue running strains.

A minimum of three static tensile tests were initially performed to obtain an accurate ultimate tensile strength of the composite test material. These static tensile tests were performed with the testing machine under displacement control, using a linear displacement - time ramp rate of 13 mm per second. This ramp rate provided similar strain rates to the fatigue tests. Most of the tests were performed without computer data acquisition and relied upon the testing machine instrumentation to accurately record the maximum load applied to the test coupon. This method was periodically checked with a digital oscilloscope with no noticeable problems. With the ultimate tensile strength calculated, the first fatigue test (usually $R = 0.1$, where R is the ratio of minimum to maximum cycle stress) was then run at approximately 60 percent of the static strength. This fatigue data point then was used to approximate the fatigue coefficient b in Eq.5 (discussed in detail later), and determine the other stress levels of the fatigue tests. Stresses were picked to obtain fatigue failures in each log decade (2, 3, 4, 5 and 6) of the fatigue semi-log graph to accurately determine the fatigue trend. Test coupons were then randomly assigned to these stress levels, with a minimum of three coupons per stress level. These coupons were then tested in their assigned order. Most tests were run to less than a million cycles, but some materials were tested to the 10 to 40 million cycle range.

Fatigue tests used a sine-wave cyclic waveform with the testing machine under load control. This active amplitude control increased the internal gain as the coupon compliance changed during the testing. The frequency of the waveform was varied approximately inversely with the maximum stress level. This was done to limit the hysteretic heating within the coupon and prevent thermal failures. The frequency was varied between 1 and 20 Hz. All the test coupons were ambient air cooled with an air flow velocity of approximately 2 meters per second measured 1 cm away from the coupon surface. This limited the maximum coupon surface temperatures to less than 5°C above ambient room temperature. Generally the test coupons were not removed from the hydraulic grips once the fatigue test was started. Occasionally, tests were stopped and the test coupon removed for examination and then placed back in the grips and continued. Fatigue tests were performed until coupon failure, which was defined as the inability of the coupon to sustain the applied fatigue loading. Some of the coupons did not fail, but had sustained a large number of fatigue cycles and were stopped due to testing and time constraints. These coupons were labeled as "run outs". With the completed fatigue diagram, the fatigue coefficient b was then calculated using a least squares fit of the data points. The goodness of fit coefficient of the least squares fit was generally greater than 0.98. This procedure was then repeated for different fatigue R values (R = 10, -1).

Tensile Test Development

Most of the test development involving the tensile coupons was done in defining a suitable geometry which minimized mechanical grip induced failures and produced "good" fatigue failures in the gage length. Geometries different than the flat rectangular coupons with tapered tabs in the gripping areas, as described in ASTM D 3039, were studied. This was necessary as the initial number of grip induced failures was quite high, which is a common testing problem with composite materials. It is unlikely that a universal test coupon shape could be developed which would work for all composite layups. It is therefore necessary to design specific test geometries for different layups. The highest percentage of grip failures involved the unidirectional, 100% 0° fabric, materials. The best testing geometry found for these materials involved tapering the thickness of the coupon by at least 40 percent. When tested, this tapered coupon did delaminate, creating a rectangular cross section, but the delaminations stopped at the point where the coupon was clamped by the hydraulic grips. The method of thickness tapering is similar to placing tabs on the rectangular ASTM D 3039 coupon but, during initial experiments with tabs, tab failures occurred as the adhesives used to bond the tabs onto the coupons failed. This did not occur with the thickness tapered coupons. It is assumed that waviness in the glass fabrics (z direction) creates some additional through-the-thickness reinforcement and thus more shear resistance as compared with bonded tabs.

Thickness tapering only worked for unidirectional materials. For materials with additional ply orientations, a width taper, resulting in a cross-sectional area reduction of approximately 40 percent or more, proved better at minimizing the number of grip failures. This geometry still had grip failures, especially with high percentages of zero fibers in the load direction. Most of the coupons with grip failures did have other damage nucleation sites all over the gage length before final failure. Width tapered coupons did split at the shoulders, which created a rectangular coupon. The shoulder cracks stopped in the compressive zone created by the gripping force, just as for the thickness tapered coupon (Figure 6).

Coupons with the width tapered geometry were tried with and without additional tabs. There was no noticeable difference in the number of grip failures or the number of fatigue cycles to failure. In fact, the presence of a tab produced no beneficial effect on the grip induced damage in the composites with fatigue lifetimes less than approximately a million cycles. The tab material, however, did provide abrasive protection to the test coupon on higher cycle (> 1 million) fatigue tests. Composite coupons with 50 or less percent 0° material did not generally need any special machining or tabs. These coupons had very few grip failures and the flat rectangular geometry proved acceptable.

Hydraulically operated wedge grips were used to clamp the test coupons into the axial load train of the testing machine. These grips apply a clamping force to the coupon by externally generated hydraulic pressure. The clamping force on the coupon is directly proportional to the applied hydraulic pressure. The hydraulic pressure causes the grip body to move down, causing the wedge grips to close and clamp onto the test coupon. The hydraulic pressure in the grips is also dependant upon the applied tensile load being transferred through the test coupon. Due to the hydraulic grip design, the hydraulic fluid pressure causes any axial load transmitted through the test coupon to be transmitted through the hydraulically prestressed grip body. When the load transferred through the test coupon is greater than the load induced by the hydraulic grip prestress, the hydraulic pressure in the grip body will increase as the fluid starts to transfer more load. An extensive study of grip behavior and damage in the grip area has been carried out, and will be reported in the forthcoming thesis by Samborsky.

Compressive Test Development

Compressive testing of materials is always a difficult and controversial process as premature failure or buckling of the coupon will undermine the test. Presently, ASTM specifies only 3 different methods of compression testing (under ASTM D 3410), while approximately 17 other methods are also used [18]. All these methods represent an attempt to obtain representative compression properties of the material being tested while limiting the amount of buckling. Buckling can be prevented by continuously supporting the edges of the coupon and keeping the gage length as short as possible [18]. Exploratory tests at the beginning of this study led to the choice of an unsupported gage length of 12.7 mm, which has given results consistent with compression failures in composite beam flanges [4]. With this gage length, and a rectangular cross section, the column slenderness ratio, SR, is calculated by: SR =3.46 x (gage length / thickness). A study by Adams and Lewis [19] indicates that a slenderness ratio less than 30 was not prone to buckling failure. With a 12.7 mm gage length, this guideline limits compressive testing to composites with a thickness that is greater than 1.5 mm.

The initial compression tests performed on the Instron 8501 provided very low ultimate compressive strength values, as the actuator moved sideways under the side loads produced by the coupon during testing, causing premature failure due to eccentric loading. This side movement of the actuator was due to the Instron 8501 actuator top hydrostatic bearing, whereas previous compression tests were performed on the MTS 880 which had both upper and lower labyrinth bearings which prevented this translation. The translation of the Instron 8501 grip was corrected by placing two needle bearings connected to the machine frame on either side of the grip head. This acts as a linear bearing guide for the grip and prevents the sideways translation of the grip head during compression testing. This apparatus is shown in Figure 7, which also shows the grip anti-rotation device which prevented the lower grip, and actuator, from rotating and causing premature coupon failure due to additional torsion loads.

High Frequency Tests

A major objective of this study was to develop specialized test methods for high frequency testing. Specimen geometrics were kept as small as possible to represent the failure modes of standard coupons while allowing rapid heat dissipation. The minimum thickness was limited by the need to use standard fabric reinforcements representative of the application. A second thickness limitation was imposed in tests including compressive stress, to avoid elastic buckling while maintaining sufficient gage length for practical grip separation. Details of the development of the tension and compression tests used here can be found in Refs. 10, 13, and 15. All modulus measurements used untapered specimens at a lower strain rate of about 10^{-2}%/sec. The specimens and materials used in the initial study [10] were slightly different, and the data from that study are not presented here.

Figure 8 shows the final test specimen designs used for the various R-values. All of these specimens allowed 100 Hz testing, except for the reversed loading longitudinal case which was limited to 50 Hz due to increased hysteretic heating under the fully reversed condition. Temperature rises in all cases were less than 10°C above the initial ambient value, as determined by heat sensitive liquid crystal paint (Omega Templaq). It should be noted that the requirements on specimen details such as thickness tapering to obtain the required gage section failure modes increase significantly as the material strength, failure strain, or lifetime is increased. Specimens were generally simple in geometry except for thickness tapering in the case of longitudinal specimens which failed in a tensile mode. The longitudinal specimen contained only two plies of fabric through the thickness. Thickness tapering was accomplished with a Dremmel tool to the radius shown; the tapering prevented failure in the grips, but did partially remove strands from each of the two plies, complicating the geometry (for details see Ref. 15).

Materials were prepared by resin transfer molding using stitched unidirectional E-glass fabric (Two plies of Knytex D155 for longitudinal specimens and four plies of D100 for transverse specimens) and the standard unsaturated polyester resin. Molded plates were cured at ambient conditions followed by a 60°C postcure overnight. The reinforcing fabric consists of discrete strands of fibers stitched together with an organic fiber yarn. The thinner fabric was used with transverse specimens to allow the use of four plies for symmetric angle-plied laminates. The average fiber volume fraction was 0.50, with some variations discussed later; the porosity content was about 2% as measured by quantitative microscopy. With two plies of stranded reinforcement, the strands varied in relative position, so that strands from one layer were usually nested between strands of the second layer, but sometimes the strands stacked over each other. Details of the effects of local packing variations are discussed in Ref. 11.

DATABASE ANALYSIS

OVERVIEW

The database contains over 4100 data points for over 110 materials, including different loading conditions using high frequency as well as conventional coupon tests. This section of the report breaks out the database into groups of materials with similar characteristics, so that the behavior to be expected for a particular type of laminate and process can be estimated. Trends of the data with parameters such as fabric type, matrix, fiber content, and percent 0° material are established. A brief discussion presents recent results on knock-down factors for common structural details. The final section suggests an approach for using the database in blade lifetime prediction.

DATA TRENDS FOR STANDARD COUPON TESTS

Most of the database contains results of tests using standard 25 or 51 mm wide coupons run at frequencies around 5-20 Hz. These results cover a broad range of fatigue behavior from poor to good resistance, where good fatigue resistance refers to the best which is observed for glass fiber composites under the particular type of loading conditions being discussed. Carbon fiber composites, for example, would have much better tensile fatigue resistance than the "best" fiberglass [20]. This section breaks the database down into material characteristics which produce various types of behavior. Trends are established from materials manufactured by RTM at MSU, and industry supplied materials are then compared to these trends.

Static Properties

Static modulus and strength are determined at the testing conditions, including loading rate, used for the fatigue tests. Strength values are typically obtained at loading rates which produce failure in about 0.1 seconds. If strength values are desired for slower or constant loading conditions, the strength value should be reduced by about 4% for each factor of 10 in increased time to failure to account for what is termed “static fatigue” in glass fiber composites [20]. The modulus values would show considerably less rapid decrease with increasing loading time. Figure 9 shows the effects of loading rate on a variety of materials from this study. The DD5 material trend is considerably steeper than the 4% slope, apparently due to a complex sequence of tensile failure related to the strand structure.

The measured properties of unidirectional fabrics, and ±45° (double bias) fabrics, which were disassembled into separate layers for testing, are given in Table 9. These properties are useful as the "ply" properties for predicting the behavior of more complex, multilayered laminates. Predictions can be made using any "laminate theory" analysis such as that in Ref. [21]. The properties in Table 9(a) are for materials with a fiber volume content of about 45%. Tables 9(b) and (c) give full three-dimensional properties for D155 unidirectional material (molded into a thick laminate for testing). These properties are useful when three-dimensional data are needed for FEA property input. The elastic constants can be adjusted to other fiber contents using an approximate micromechanics theory such as Halpin and Tsai [22]. The longitudinal modulus, E_L, and Poisson's Ratio, ν_{LT}, would adjust approximately linearly with fiber volume fraction, V_f, over the range of 20 to 60% fiber. Thus,

$$\frac{E_L}{E_L^*} = \left(\frac{1}{32.71}\right)(3.1 + 65.8V_F) \qquad \textbf{(1)}$$

Where * indicates the property at the 0.45 fiber volume fraction from Table 3. The transverse modulus, E_T, and shear modulus, G_{LT}, would change less rapidly with fiber content. The following adjustments should provide approximate values at different fiber contents, assuming that the fiber modulus and Poisson's ratio are 68.9 GPa and 0.20 respectively, and the matrix modulus and Poisson's ratio are 3.1 GPa and 0.35 respectively.

$$\frac{E_T}{E_T^*} = \frac{1}{2.206}\,\frac{(1 + 0.836\ V_F)}{(1 - 0.836\ V_F)} \qquad \textbf{(2)}$$

$$\frac{G_{LT}}{G_{LT}^*} = \frac{1}{2.809} \frac{(1 + 1.672\ V_F)}{(1 - 0.836\ V_F)} \tag{3}$$

$$\frac{\nu_{LT}}{\nu_{LT}^*} = \frac{1}{0.318} (0.385 - 0.15\ V_F) \tag{4}$$

These ratios are also plotted in Figure 10 for convenience. The elastic properties of laminates in this study approximately follow the values predicted from the elastic constants given above, when used with laminate theory predictions. Elastic modulus and strength values are given for all materials in the database at the loading rates used in the fatigue tests. Figure 11 gives the modulus and strength values as a function of fiber content for the DD series of materials, which are typical main structural laminates with 72% of the fibers in the 0° direction.

The modulus, E_X, in the 0° direction, and the ultimate tensile strength vary approximately linearly with V_F, with little sensitivity to fabric type. The modulus trend agrees well with the prediction based on Eqs. 1-4 and laminate theory. Compressive strength is less easily predicted [18], and is less sensitive to fiber content. The laminates with the stitched weft unidirectional D155 fabric are about twice as strong in compression as those using the woven warp unidirectional A130 fabric. (The elastic modulus in compression is not significantly different than that in tension.)

FATIGUE DATA TRENDS

Typical S-N Dataset

A typical S-N dataset is obtained for a material by conducting a series of fatigue tests at varying maximum stress, S, which produces a range of specimen cycles to failure, N. The S-N dataset is conducted at a constant value of load or stress ratio, R, where

$$R = (\text{Minimum Stress})/(\text{Maximum Stress}) \tag{5}$$

Figure 12 shows typical fatigue waveforms at different R values. The values commonly used in the database are tension-tension, R=0.1; compression-compression, R=10; and reversed loading, R=-1.0.

Figure 13a is a plot of a typical S-N curve. The load ratio, R, is 0.1, so that the entire series of data points are run in tensile fatigue with a minimum stress on each cycle equal to 10% of the maximum stress. The loading waveform is a sine wave at a constant stress amplitude; the resulting strain may increase slightly as the test progresses. Eventually, the test specimen breaks into two pieces at a particular number of cycles, and the result is recorded as a particular point. A point for each such test is recorded on the S-N graph at the respective maximum stress and cycles to failure. The data at one cycle is from a "ramp" test at the same load rate as for the fatigue data, but run at a constant loading rate to failure. The material shown, DD5, is a well behaved material with relatively good fatigue resistance and relatively little strength scatter or lifetime scatter at a particular maximum stress. (In fact, this roll of D155 fabric produced lower ultimate strength and less scatter than was observed for other fabric rolls.)

Figure 13b shows the same dataset as in Fig. 13a, but with the maximum stress, S, normalized by the one-cycle strength, S_o. This plot allows a determination of the fatigue performance, independent of the static strength. The fatigue resistance can be represented by a linear curve fit forced through $S/S_o = 1$, giving

$$S/S_o = 1 - b \operatorname{Log} N \tag{6}$$

where N is the cycles to failure and b is the fatigue coefficient, close to 0.10 in this case. The data could also be represented on a Log-Log plot, as discussed later for the high frequency database. The fatigue coefficient, b, is a good measure of the fatigue resistance, with a steeper, more fatigue sensitive S-N curve yielding a higher value of b. While some datasets clearly deviate from the log-linear relationship in Eq. (6) at some lower stress, where the data may become less steep, the data for material DD5 appear to fit well to this trend over the entire stress range tested. The value of b in Fig. 13, 0.10, is about the best which is obtained for fiberglass materials in tensile fatigue at R=0.1 [20]. By way of comparison, aluminum would have a roughly similar slope, while carbon fiber composites would be much less fatigue sensitive, with a value of b close to 0.03 to 0.04 [20] at R = 0.1. Material DD5 is a typical structural fiberglass material with a ply configuration $[0/\pm45/0]_s$, 70% of the fibers in the 0° direction and an overall fiber content of 38% fiber by volume. The test specimens were width tapered (Fig. 3) and loaded uniaxially in the 0° direction. Shoulder damage was evident during the tests as in Fig. 6. Failure modes are discussed in a later section.

The fatigue data for material DD5 can also be represented in terms of maximum initial strain in the fatigue test vs. cycles to failure, where the strain is measured with an extensometer on the first cycle. While the strain may gradually increase during the test as noted later, the changes in strain are usually not recorded. Figure 14 gives the initial strain vs. cycles to failure, or strain S-N dataset. The strain is usually of greater interest in judging structural performance, since the stress actually varies layer by layer depending on the modulus of each layer, even under uniform tensile or compressive loading. The maximum initial strain which can be withstood for one million (10^6 or 1E6) cycles is taken as a representative measure of the fatigue resistance, like the parameter "b" used for stress. Here, an initial strain of about 1.15% can be withstood for one million constant load amplitude cycles.

Compressive fatigue data have also been generated for many of the materials under the R value of 10, which corresponds to R = 0.1, but with negative stresses in fatigue (the minimum stress is the most negative, see Figure 12). Several materials have also been tested under reversed tension-compression loading, R = -1.0. Figure 15 shows strain S-N data for R values of 0.1, 10, and -1.0 for material DD5P (the same as DD5 but with 36% fiber by volume).

In Fig. 15, the stresses are plotted as maximum absolute stress value for convenience. The compressive one-cycle strength is typically lower than the tensile strength, but the fatigue coefficient, b, is also lower (less fatigue sensitive), so the R = 0.1 and 10 datasets usually cross at some point as the stress decreases. The reversed loading case, R = -1, tends to follow below the stresses for the lowest of the other curves, being dominated by compression at higher stresses (shorter lifetimes) and tension at lower stresses (longer lifetimes). The corresponding one million cycle maximum initial strain values for R = 0.1, 10, and -1.0 are 1.15%, 1.30%, and 0.62%, respectively. The strain value is usually the lowest for R = -1.0, while the fatigue coefficient, b, for this case is poorly defined because the failure mode shifts from compression to tension dominated. Thus these data are markedly nonlinear. The data in Figure 15 are for a material with tensile and compressive ultimate strengths which are closer together than is often the case, as shown later.

Overall Database Fatigue Trends

Figures 16 and 17 give tensile fatigue stress and strain based S-N data for a broad sampling of the database, including both MSU and industry fabricated materials. The results show a very broad range of performance, varying from the best observed fiberglass response (b = 0.10, 10^6 cycle ε = 1.2%), evident for many materials, to much poorer performance. The one million cycle strain varies down to about 0.4% for the poorest materials, and b increases to about 0.14 for these same materials. The consequences of the poorer materials relative to the best materials are lifetimes of over 100 times shorter and stresses and strains reduced to as low as one-third of the values for typical material DD5 in the mid-stress range. This materials difference could represent a factor of three in wind turbine blade weight if the entire blade length were tensile fatigue dominated in design (which is unlikely).

Figure 18 gives a simplified representation of the data in Figure 16, in terms of "best" and "worst" normalized S-N performance under tensile loading. While fatigue limits have not been rigorously established, failures have not been observed at maximum stresses below $S/S_0 = 0.15$ in the database, which extends to between 10^7 and 10^8 cycles for several materials. This figure should not be interpreted to indicate that $S/S_0 = 0.15$ represents a fatigue limit out to any cycle range. Rather, it indicates that even the poorest performing materials (containing some 0° fibers) do not fail at stresses below this value over the cycle range tested. Continuing research is exploring whether this also would apply to blade structural areas where there are flaws such as matrix-rich areas, fiber misalignment, or ply termination. Materials with few or no fibers in the 0° direction often fail at much lower strains than those of the "worst" materials in Figure 17, as discussed later.

Figures 19, 20, and 21 give corresponding results for the overall database at R = 10 and -1.0., with the -1 data normalized by the compressive strength in Figure 20 and the tensile strength in Figure 21. There is considerably less variation in fatigue performance between different materials under compressive loading (R = 10), as compared to tensile fatigue (R=0.1). The compressive fatigue response is actually slightly better than the best tensile fatigue performance, with b values generally in the 0.07 to 0.10 range. The reversed loading performance, as noted earlier, is slightly worse than the lowest (lowest stresses on the S-N curve) of the tensile and compressive fatigue datasets. At worst, the strains under reversed loading are around 0.40% at one million cycles, with the best performance around 0.70%. Table 10 compares these values for several materials.

Origin of Poor Tensile Fatigue Behavior

The poor fatigue resistance exhibited by many materials under tensile fatigue loading was surprising, although many woven roving-type glass fabrics are also known to behave poorly [23]. The reason for poor fatigue performance in woven roving fabric reinforced materials was postulated as delamination between the rovings at the roving cross-over points. These local delaminations, which are matrix and interface failures, were observed just prior to failure of the load-bearing 0° strands in this class of fabric reinforcement [23].

The stitched fabrics used in this study were expected to behave more like uniform layer composites common in materials such as prepreg laminates, which show a fatigue coefficient, b, of about 0.10 at R=0.1 [20]. However, early results in this study with the Triax fabrics showed trends following the "worst" behavior in Figure 18 [1]. The Triax fabrics vary in detail, but have ±45° strands stitched against the 0° strands. Detailed experimental study of these materials showed that the 0° strands failed at these stitch points, as shown in Figure 1(f) [1]. A very detailed finite element model for the individual strands with cracked matrix found the apparent cause of this problem: if there is no layer of resin matrix between the strands, matrix cracks along the 45° strands will produce significant stress concentrations in the 0° load-bearing strands. Results reported in Refs. 1, 3, and 11 showed that the Triax reinforced materials failed under tensile fatigue loading shortly after the ±45° layers failed, giving it the worst behavior. Figure 22 shows the differences in stress concentration calculated for the 0° strands under various conditions. Similar calculations with elastic constants representing carbon fiber composites show much reduced effects of this type. In general, it is expected that a composite will be designed to fail in a "fiber dominated" mode, where the trend, b, is the same as for the 0° material alone. Here, the combination of glass fiber properties and tightly stitched fabrics resulted in composite failure soon after matrix failure, a behavior which is "matrix dominated". Since matrix failure in 45° layers occurred at lower strains than for fiber failure, this produced poor composite performance in tensile fatigue.

Unfortunately, this matrix dominated response is not limited to Triax reinforcements. Additional tests [6] have shown similar behavior under some conditions with separate 0° and ±45° layers, and even with 0° unidirectional stitched fabric composites without any ±45° material. Figure 23 shows the database trends for several materials at R=0.1, but broken into several groups. The top group (denoted with the solid triangles in the figure) behaves like the "best" materials, with b close to 0.1. The middle group (denoted by an open triangle) behaves like the "worst" materials, with b close to 0.14. The lower group of materials (denoted by a solid square) are ±45 laminates containing no 0° layers. Just as determined for Triax laminates earlier, Figure 23 indicates that the poorly performing laminates with 0° layers fail close to the "worst" line in Figure 18, because they fail shortly after the ±45° layers reach their failure condition. Thus, the "worst" line in Figure 18 appears to originate from matrix failure in the ±45° layers, where present. Unidirectional laminates with only 0° layers which show "worst" behavior (at high V_f) appear to fail shortly after the fabric stitching debonds. The conditions which produce matrix-dominated "worst" behavior are described in the next sections.

EFFECTS OF FIBER CONTENT AND LAMINATE CONSTRUCTION

Tensile Fatigue Coefficient

Tensile S-N data for the DD series of structural materials (72% 0°, 28% ±45°) at various overall fiber contents are given in Figure 24. The trends are clear: at fiber contents below 42% the data follow the "best" line in Figure 18, b = 0.10; at higher fiber contents the data approach the "worst" condition, b = 0.14. Thus, there is a transition with increasing fiber content from "best" to "worst" fiberglass behavior in tensile fatigue. The strains at 10^6 cycles shown in the insert on Figure 24, and later, in Figure 30, follow a similar trend, from around 1.0 to 1.2% at lower fiber content to 0.6 to 0.7% at higher fiber content. (Strains can be determined approximately by dividing by the modulus (E) given in the database.) Even though the increasing fiber content raises the static modulus and ultimate tensile strength (Figure 11), the fatigue performance deteriorates significantly on either a normalized (b) or absolute (strain at 10^6 cycles) basis. Similar trends for unidirectional composites with fabrics D155, D092, and A130 are shown in Figures 25, 26, and 27, respectively.

Figure 28 shows the trend in tensile fatigue coefficient b for several groups of laminates. The Triax material, based on CDB200 fabric with 0° and ±45° layers stitched together, shows poor performance even at low overall fiber contents; similar data for several other Triax materials are given in Refs. 2 and 3, and in the database. The DD materials, with separate 0° and ±45° layers, show the transition from good to poor resistance as the fiber content increases, with the transition centered around 42% fiber by volume. Unidirectional laminates (with DO92, D155, A130 fabrics) tested in the 0° direction show a similar trend to the DD materials (with the same 0° fabric), but the absence of ±45° layers shifts the transition to about 2% higher fiber content. When the stitching is manually removed from the D155, 0° fabric, the trend to increasing b with fiber content is shifted to still higher fiber contents, so that good fatigue resistance is now observed above 50% fiber by volume. The D155 materials with stitching removed are difficult to handle, and show fiber wash problems during matrix infiltration. Literature values [20, 23] for E-glass/epoxy prepreg laminates with a very uniform distribution of fibers in each layer show a b-value close to 0.10 at 50 to 60% fiber by volume, demonstrating that much of the fatigue problem in tension is related to the stranded fabrics.

These results indicate a similar trend for all stranded E-glass fabric reinforced laminates toward a steeper S-N curve (higher b) as the fiber content increases, with the presence of off-axis (± 45°) layers shifting this transition to lower fiber contents. Fabrics with an effectively high fiber content inherent in the fabric construction, Triax materials with 0° and ±45° strands stitched tightly together, show poor fatigue resistance over the entire fiber content range studied. Earlier work has also shown that those Triax fabrics with the tightest stitching have the highest b value [3]; for example, material U, with tighter stitching, and W, with looser stitching, have b values of 0.138 and 0.116, respectively (even though W had a higher overall fiber content). The Triax material (AA) in Figure 28 uses the same CDB-200 fabric as in material U.

Figure 29 shows the variation in the coefficient b with fiber content for two series of laminates designated CH and DD, having varying amounts of 0°, D155 fabric layers, with the remainder being ±45° layers. The CH series materials (typical of webs and skins), with 16 to 39% 0° layers, fall close together, while the more structural DD materials, at 72% 0° fabric and unidirectional D155 (all 0°) materials shift to the right, to higher fiber contents. However, each of these materials, with the exception of pure ± 45° laminates, show an increase in the coefficient b from close to 0.10 at lower fiber content to close to 0.14 at higher fiber content. This approximately spans the range from best to worst materials in the database, Figure 16. Thus, the trend of tensile S-N curve steepness with fiber content is found for almost all unidirectional and multidirectional laminates containing some 0° layers, included in the database. The exception is tightly stitched Triax materials and laminates with only ± 45° layers, which show a high value of b at all fiber contents studied.

Tensile Fatigue Million-Cycle Strain

The data are also interesting when plotted as the million-cycle initial maximum strain which can be withstood in tensile fatigue. Figure 30 gives the million-cycle strain plotted against the percent 0° layers for low and high fiber volume fraction ranges. At high fiber contents, where b approaches the "worst" value close to 0.14, the million-cycle strain is about 0.5% for the ±45° laminates alone, and for all laminates containing 0° and ±45° layers, rising slightly for the pure unidirectional (0°) laminates. This is consistent with the view that the "worst" behavior corresponds to laminate failure when the ±45° layers or matrix regions fail (all layers are at the same strain). This is matrix-dominated behavior, since the laminate fails shortly after matrix cracks form in the ±45° layers.

The behavior is different at lower fiber contents, close to the "best" behavior line in Figure 18. At high percentages of 0° layers, the million-cycle strain now reaches the range of 1.0 to 1.2%, the same as the unidirectional 0° material; this is now clearly fiber dominated, the desired composite behavior. At lower contents of 0° material, 16 to 56% in Figure 30, the low fiber volume fraction behavior shows million-cycle strain values which are in the 0.7 to 0.8% range, somewhat below that for the 0° material alone, but well above the ±45° material alone. The origin of this effect is clear from Figure 31, where the million-cycle strain is normalized by the static ultimate tensile strain for materials with fiber volumes less than 37%. Now the normalized strain values are similar over the entire range of 0° material content, and are the same as the unidirectional 0° material values of about 0.40. Thus, all of these low fiber content laminates fail in a fiber-dominated mode, but the difference is in the static ultimate strain values. The laminates with high 0° content fail around 2.8 to 3.0% static ultimate strain, while the laminates with lower 0° material content fail around 1.8 to 2.2% static strain. This difference is preserved in fatigue, with similar fiber dominated b coefficients resulting in a lower million-cycle strain at lower per cent 0° material.

The reason for the tensile strain falling below the 0° unidirectional values at low 0° material contents is not entirely clear. Typical test specimens for each 0° content range in Figure 32 show more localized failures at lower 0° content (Figures 32 (f)-(g)), with more widespread brooming failure at higher 0° content (Figures 32 (h)-(i)). Thus, the failure process may be more localized in the low 0° content materials, with the local strains in the area of severe ±45° damage exceeding the values measured at the extensometer, so that the recorded extensometer strains represented in the data are significantly lower than the actual strains at the failure site for low 0° content laminates. The failure progression appears to be similar for fatigue and static tests.

Compression and Reversed Loading Trends

Figures 19 and 33 give the results corresponding to Figures 16 and 17, but now for compression fatigue, R = 10. The S-N curves are less steep in compression than in tension, with b coefficients ranging from about 0.07 to 0.10 (Figure 34a). The million-cycle strains (Figure 34b) are slightly higher than the "best" in tensile fatigue, even though the static ultimate strains are slightly lower. In general, the compression data show less variation with materials parameters than the tension data, with no sharp transitions with fiber volume fraction. The b values and million-cycle strains are around 0.10 to 0.12 and 0.5 to 0.7%, respectively, for the pure ±45° laminates, improving to 0.06 to 0.08 and 1.0 to 1.1% for the pure 0° laminates. Laminates with differing percentages of 0° material gradually improve from the ±45° properties to the 0° properties as the per cent 0° material increases. The Triax material AA, with a b value of 0.081 at 35% fiber volume now shows very similar behavior to laminates with separate 0° and ±45° layers. It should be noted that some uncertainty often exists in whether bending was present in the static compression tests, which then influences the normalized fatigue results. The fatigue tests, run at lower stress than static tests, are less subject to problems. (Materials DD5V and DD5E were not included in Figures 19 and 33 until their static strengths are reconfirmed, as they may include a high bending content).

As noted earlier, reversed loading (equal tension and compression on each cycle R = -1), produces behavior which falls below both the tension and compression S-N curves, often shifting from the compression dominated to tension dominated failure modes as the stress range decreases, consistent with the higher static strength in tension, but steeper S-N curve as compared to compression. Figures 15, 35, 36 compare R = 0.1, 10, and -1 results for three materials. Most notable in reversed loading is that it produces the lowest absolute values of million-cycle strain of the three loading cases. Table 10 compares the million-cycle strains for several cases. The Triax material again shows the poorest fatigue resistance, but the penalty relative to a more optimized laminate such as DD5P at low fiber volume fraction is less than in tensile fatigue. Figures 20 and 21 gave the normalized S-N curves for all materials tested at R=-1, where in Figure 20 the normalization is by the compressive strength and in Figure 21 the normalization is by the tensile strength. It is unclear what representation of the R=-1 data is preferred. Figure 37 gives the data in terms of absolute strain, which has no normalization. The effects of different loading conditions are considered in more detail in the next section.

Failure Modes

Figure 32 (a) - (l) shows photographs of typical failed specimens for a variety of materials and loading conditions. Failure modes for all tests in the database were compared, and, for the most part, few strong trends were evident. This section describes the main differences seen in failure modes.

Testing of unidirectional materials of fiberglass in tensile fatigue is difficult, as noted earlier. Figure 32 (a) compares failures of unidirectional Material A tested in the standard tabbed configuration and the tapered thickness configuration (Figure 3). The failure is much improved for the tapered specimen, with the brooming-type of separation as compared with failure under the tabs for the standard specimen. However, differences in the tensile fatigue results for the two cases were not significant. Figures 32 (b)-(d) show typical failures for unidirectional RTM materials with two fabrics and low vs high fiber content. The A130 fabric failures show a clear association with the bead over which they are woven, particularly in compression. The D155 fabric based materials show no effect of the stitching in the failure patterns; axial splitting is evident at high fiber content in compression.

Figures 32 (f) through (k) show materials varying from low to high percent 0° layers at different fiber contents. The 0° layers include both woven (A130) and stitched (D155) fabrics. Other weights of these types of fabric show similar failures. The tensile static and fatigue failures become less localized, more specimen-long brooming as the fiber content increases. The bead effects evident in the unidirectional A130 materials are also evident when ±45° layers are added. Cracking and delamination at tapered-width specimen shoulders (described in Fig. 6) is more prominent, even at low cycles, as the percent of 0° layers increases. The typical structural materials such as DD5 (Fig.

32 (i) and (j)) show severe shoulder delamination, but failure zones (failed 0° strands) can be seen in the gage section prior to failure at low stresses. At high fiber contents (Fig. 32 (k)), the failures tend to localize in the gage section, with less shoulder damage. The D155 fabric with stitching removed (Fig. 32 (k)) behaves similarly. Shoulder damage starts as splits parallel to the 0° fibers at the break between cut and uncut 0° material, with interply delamination then developing at higher loads or cycles. Specimens which fail away from the shoulder area are preferred, since there is no possible effect of specimen geometry on the test. However, for many materials, this has been impossible to achieve for all specimens in a series of S-N tests.

Compressive failures are very similar for static and fatigue tests, with a symmetrical splaying-out of the layers from the unconstrained specimen surfaces. Little damage is evident in the compressive specimens prior to sudden failure. The A130 fabric based materials often show independent delamination of strands at failure in compression (Fig. 32 (h)). The thermoplastic-coated bead over which strands are woven is evident in this figure.

The series of angle-plied (±θ) materials with D155 fabric layers, are shown in Figure 32 (l). When the fibers are close to 90° to the load, failure is by a single crack parallel to the fibers. In the orientation range close to 60°, a narrow band of cracking and delamination is evident. At lower angles, like 30° and lower, failure generates from cracks and delaminations at the specimen edges.

Effect of Matrix Material

It has been reported consistently in the course of this study [1, 2, 6] and in the European database [17] that changes in the matrix material have minimal effects on the static and fatigue properties of standard coupons. This has been explored under very well controlled conditions with the RTM process for materials DD5E, DD5P, and DD5V, for epoxy, polyester, and vinyl ester matrices at the same fiber content and with other parameters held constant. These are all relatively brittle thermoset polymer matrices which have various processing and cost differences. Whether matrix toughness affects structural details, where delamination is prominent, will be explored in future work.

Figures 38 and 39 compare these two matrices under tensile and compressive fatigue, respectively. There is no discernable difference in the results for each matrix in fatigue, and with only small differences in static properties. Similar results have been found in recent tests on pultruded material; comparing vinylester and low profile (smooth surface) polyester, as discussed under industrial materials.

Other Laminate Types

Mat Containing Fabrics

The problem of finding a fabric for structural areas with good fatigue properties, good compressive strength, and a high percentage of warp unidirectionals has led in several directions, but has not been solved at this writing. One type of fabric available from Knytex is warp unidirectionals similar to D155, produced by stitching strands to a light mat material. D155 in weft unidirectional provides a good balance of properties at fiber contents below 42%, but is not produced as a warp unidirectional. Fabric CM1701 was tested at 38% fiber volume fraction. The results show disappointing tensile (R=0.1) fatigue results for this low fiber content, with b=0.126 and the million cycle strain at 0.64%. Other glass mat-containing reinforcements are discussed in the Industrial Materials section.

Angle-ply Laminates

It is often more efficient in composite structures to include a ply orientation other than ± 45°, although this is a standard orientation. A series of laminates, materials θD155 in the database, have been tested to explore the effect of fiber orientation angle. Figure 40 gives the elastic modulus in the 0° direction as a function of ply angle for $[(\pm\theta)]_s$ laminates, with θ varying from 0° (load direction) to 90° (normal to the load direction). Figure 41 (a) and (b) gives the tensile and compressive static strength values for this series of laminates; the popular quadrotic failure criteria [21] provides a good fit to the data using the ply properties in Table 9. These results illustrate the extreme sensitivity of strength to any misorientation of fibers when the plies are oriented close to 0°. The prediction in the 10 to 30 degree range is low, as expected due to the contribution of interlaminar resistance.

The relatively linear tensile fatigue S-N curves for this series of laminates are given in Figures 42 (a) and (b). These results are similar to those reported in Ref. [24] for carbon/epoxy, with the exception of the 0° laminates in tension. All angles and loadings except tension close to 0° are matrix/interface dominated, and are not very sensitive to fiber type. Carbon fiber systems have much flatter tensile S-N curves at orientations close to 0°. The slopes of the normalized tensile S-N curves, b, are given in Figure 43a. These are within the usual range of tensile matrix dominated curves, with b ranging from 0.07 to 0.11. The million cycle strain data are given in Figure 43b. The laminates behave slightly differently close to ± 45°, where the plies must delaminate after matrix cracking to provide total separation. This results in a very nonlinear stress-strain curve with high apparent strains prior to total failure (on the order of 50% ultimate strain in some cases). This complicates the S-N behavior slightly, but the materials are not really useful above the strain where the plies are heavily matrix cracked, around 0.4% [1,2] for these materials, since they quickly fail in fatigue after this strain range.

Industry Supplied Laminates

The database includes 22 materials which were manufactured and supplied by the U.S. blade industry, most provided in the form of flat sheets. These were mostly manufactured by hand layup with or without bagging. The EE series were cut from pultruded blades. The fabrics used in the laminates were known in some cases, but in others the %0°, ±45°, and mat were determined at MSU by gravimetric methods; the overall fiber volume fraction was measured in each case. The tensile S-N curves and static data for these materials have been published previously in most cases [1,3].

It is interesting to compare the industry-supplied laminate performance with that of laminates fabricated at MSU by RTM. Comparisons can be found in Table 10 and in the database. The results are generally very consistent in terms of the static properties, the fatigue coefficient b, and the million cycle strain for cases of similar fiber content and content of 0° material. All of the Triax materials showed steep S-N curves in tensile fatigue, including materials T and V, which were specially made with wrapped coupon edges rather than machined edges [3]. The unidirectional 0° materials (A, B, and L) showed similar performance to the D155 and A130 laminates prepared at MSU; A and B had low fiber content (30%), and a relatively low b in tension of 0.11 for A, while L, at 50% fiber, showed a higher b of 0.135. While the early tests on the unidirectional materials gave testing problems with tabbed specimens, recent retesting with thickness tapered specimens yielded similar results (Table 11). The L material also showed a low compressive strength typical of the A-series woven fabrics. The X and Y materials, with separate 0° (80%), ±45°, and mat layers and a low fiber content (35 and 39%) showed properties similar to the "best" RTM laminates, as expected. Interestingly, material P, with separate 0° layers and Triax layers behaved poorly in tension fatigue despite the low fiber content (36%), and was clearly dominated by the Triax layer failing at low strain, leading to failure of the 0° layers (see Ref. 2). The low compressive strength of the 0° woven layers also led to a low laminate compression strength. The S-N curves at R=.1, 10, and -1 in Figure 35 show a distinct shift from compression to tension domination as cycles increase. Several of the industry-supplied laminates contained ply drops for delamination studies. These have been discussed in Refs. 1,2; delamination at ply drops is the subject of a major study at MSU currently [7].

The only materials which were removed directly from manufactured blades are the EE series, which were cut from the positions shown in Figure 44 (EE was from an early run, with the EEA, EEB, EEC materials shown in Fig. 44). These materials, particularly EEA, were among the best tested in terms of fatigue resistance and static properties for a relatively high fiber content, around 48% glass by volume for most of the blade. Figure 45 compares the S-N curves for R=.1, 10, and -1; notable is the R= -1 performance, with the highest R= -1 million cycle strain of any material tested (Table 10). The reason for the better than expected performance of EEA is uncertain, but the 0° strands appeared more smeared out into a uniform layer as compared with the distinct strand structure for the materials in Figure 1.

HIGH FREQUENCY, HIGH CYCLE DATABASE

Background

Wind turbines experience a very high number of total cycles over a 20 to 30 year service life. Many of the smaller amplitude cycles resulting from vibration in the blade may be of little or no consequence, although the limits below which cycles produce no significant damage are not well established at this time. If only the number of rotor rotations is considered, the total cycles is on the order of 10^8 to 10^9 cycles. Thus, it was one of the original goals of this program to develop a database out to at least 10^8 cycles. Conventional test coupons cannot be fatigued above 10 to 20 Hz without significant temperature rise due to internal hysteretic heating from the energy loss (area under the stress-strain hysteresis loop) on each cycle [3, 10]. One test taken to 10^8 cycles at 10 Hz requires 110 days of continuous testing. Thus, a significant database for even one material under different loading conditions would take years.

It should be noted that blade lifetime predictions using this database [5] tend to show most of the damage occurring due to relatively rare, high load parts of the wind load spectra considered, so the broad-based conventional coupon database, with results out to 10^6 to 10^7 cycles, is of great significance. However, a separate database using specialized high frequency testing has been developed to probe the effects of the more frequent, lower load parts of the spectrum in the 10^8 cycle range. Small cycles may be important in spectral loading, i.e. the field loads on the turbine blade.

The goals of this effort were to develop a series of test methods for testing to 100 Hz, and to use these methods to establish a database with a broad range of loading conditions (compression to tension) out to 10^8 cycles. Tests at 100 Hz require 11 days to complete 10^8 cycles, and are, therefore, manageable in terms of the testing time required. Development of these tests has been described earlier, and results are presented in this section. Further details of these tests can be found in MSU theses by Creed [10], for the initial methodology and heat transfer studies, Belinky [13] for compression test development, and Wei [15] for reversed loading and transverse loading test development and much of the final testing, including the preparation of Goodman Diagrams in the longitudinal and transverse directions. These efforts have also been chronicled in the literature [3,5], including the use of the database in blade lifetime prediction. The results are given in the database under "High Cycle Fatigue Database".

As noted in the test development section, there are some aspects to these tests which require consideration when using the data in design. Only one to two layers of the standard D155 fabric are used in the specimens, often with part of the layers machined away to provide a tapered thickness. Gage lengths are very short. While failure modes and data trends generally follow those for larger coupons, the tests are specialized in nature and preclude some failure modes which produce "worst" tensile fatigue performance in earlier discussions. The results should only be applied to materials which are close to the "best" line in Figure 18 at low to moderate cycles. The longitudinal test materials were prepared at high fiber contents of from 49 to 67% by volume, but the actual fiber content in the gage section is difficult to establish. Furthermore, effects such as matrix cracking around fabric stitch yarns, prevalent in standard unidirectional coupons, is not relevant in the small specimens with gage sections which usually don't include such yarns. The transverse test specimens were tested at a lower fiber volume content, 39%, and used thinner plies of fabric D100; these tests show less complications due to local structure.

Longitudinal Test Results

Figure 46 shows the S-N data for R values 0.1, 0.5, 10, 2 and -1 (see Fig. 14). The data are least squares fit to the power law relationship

$$S/S_o = BN^{-1/n} \tag{7}$$

where S_o is the ultimate tensile strength for R=0.1 and 0.5, and the ultimate compressive strength for R= -1, 10, and 2, and B is taken as 1.0 in Figure 46. Arrows on the 10^8 data points indicate run-outs, where the test was terminated without specimen failure. Runout data are conservative when they are included in the curve fit, as was done here.

The choice of which form of equation to use in fitting the S-N data is important. Equation (6) represents the data as linear on a semi-log plot of stress vs. log cycles, while Eq. (7) represents the data as linear on a log-log plot (although the plot itself is semi-log in Fig. 46). The high frequency results fit better to Eq. (7), which is the reason for shifting from the representation in Eq. (6) used in the remainder of the report. Most standard coupon data tend to fit better to Eq. (6), as demonstrated in Figure 13(b). Equation (7) tends to give a less conservative prediction of high cycle data when used to extrapolate S-N results, and tends to fit the high-cycle part of the dataset more accuarately than Eq. (6). The implications of using Eq. (6) vs. Eq. (7) have been discussed in detail in Ref. 20, and a recent discussion relative to the European database is given in Ref. 25.

Relative to the best standard coupon S-N data, such as Figure 12a, these results show more scatter in lifetime, probably reflecting increased variation in the small specimen gage sections. The data conform well to the power law relationship, and so are nonlinear on the semi-log plot shown. There is a continual decrease in S-N curve slope over the entire range of the data, including the highest cycle results. Although the R=0.1 curve falls to the lowest normalized stress on this plot, it should be noted that this is caused by the use of the compressive strength to normalize the R= -1.0 data. As shown in the following, the absolute stress and strain values for the R= -1 tests were the lowest over the entire cycle range, as was the case with standard coupon data.

Improved curve fits at cycle ranges of greatest interest can be obtained by fitting the data in these selected ranges. Figures 47-51 show the curve fits obtained for each R value when Eq (6) was applied to the separate ranges above 10^3 cycles, and above 10^5 cycles. Table 12 gives the values of B and n in Eq (6) for each cycle range and R value, and Table 13 gives static strengths and modulus values.

Validation of the high frequency results is considered by comparing them with the standard coupon data at low to moderate cycles. Figures 52 and 53 compare the tensile (R=.1) and compressive (R=10) S-N high frequency data with the spread of standard coupon data reported in Figures 18 and 19. The high frequency data fall within the range of the standard coupon results, with a slightly conservative trend relative to the "best" tensile behavior and a more conservative trend at moderate cycles in compression. The high frequency tensile fatigue data represent high fiber content, small specimens, which would behave less favorably than the "best" data in Figure 18, as can be seen from standard D155 coupon results in Figure 25. The small high frequency tensile specimens tend to exhibit some matrix splitting parallel to the fiber direction prior to failure [15], much like early test results on tabbed unidirectional standard coupons [1].

The nonlinear semilog S-N trend at R=0.1 for the high frequency specimens probably indicate some matrix splitting influence on the S-N trend. Matrix crack growth usually follows a Paris Law trend for crack length, a, with cycles, N, as

$$da/dN = A(\Delta K)^n \qquad (8)$$

where A and n are constants and K is the stress intensity factor from fracture mechanics [26]. This relationship, integrated over the crack growth history, predicts a matrix dominated S-N trend in Eq. (7) similar to those observed for matrix crack growth [20]. As the failure mode in tensile fatigue tests improves to a more general fiber dominated wear-out of the gage-section area, it is usually found (for fiberglass) that the S-N trend becomes very linear on a semi-log plot, fit well by Eq(6). The well-behaved data for the DD5 material in Figure 12a demonstrates this trend, giving the "best" line in Figure 18. This very linear semi-log trend is observed for small unidirectional strands [27] and for well prepared 0°/90° crossplied glass/epoxy [20].

As can be seen in Figure 52, the high frequency data fall below this "best" tensile fatigue line over much of the lifetime range, approaching it at higher cycles. Comparison with standard coupon results is more conservative for compressive fatigue in Figure 53. The R=-1, reversed loading data show a million cycle strain of 0.55%, similar to materials DD4 and DD5 in Table 10.

The results for the high frequency tests greatly expand the existing database for 10^8 cycles. They show no unexpected trends, and tend to justify extrapolation of other S-N results to beyond the 10^5 to 10^7 cycle range, using Eq. (7).

Strain Representation of Longitudinal Results

The small, tapered high frequency test coupons do not lend themselves to extensometers and strain gages. Instead, modulus values were taken from similar specimens with no thickness taper. The moduli were determined at a lower load rate than for the high frequency tests. Table 13 gives the modulus values measured for both the longitudinal and transverse materials. Initial strains were obtained by dividing the measured stresses by the calculated modulus values.

Strain based fatigue data are of greatest usefulness in design, and so the high frequency stress data have been reduced to strains and refit to regression curves [5]. The data have been fit to the relationship

$$\varepsilon/\varepsilon_o = CN^{-1/m} \tag{9}$$

where ε_o is the ultimate tensile or compressive strain and ε is the highest tensile or compressive strain in the fatigue cycle. Eq(9) is analogous to Eq(7). Again, the data were fit in three ranges, 1 to 10^8 cycles, 10^3 to 10^8 cycles, and 10^5 to 10^8 cycles. The C and m curve fit parameters are given in Table 14. To obtain the best overall S-N trend, the first set of parameters was used to 10^3 cycles, the second set from 10^3 to 10^5, and the third set beyond 10^5, including extrapolation beyond 10^8. An average value was used at the intersections of the curves. The resulting strain based S-N curves are given in Figures 54a (semi-log) and 54b (log-log). As before, the R= -1 data use the compressive ultimate strain for normalization. Figure 55 gives the denormalized strain curves for a typical material like material A in the database.

Goodman Diagrams

The stress and strain based curve fits to the high frequency database have been used to construct Goodman Diagrams. These diagrams are plots of the cyclic stress or alternating strain (half the difference between the maximum and minimum) on each cycle against the average or mean stress or strain. S-N curves at a constant R-value then plot as straight lines on the Goodman Diagram, and lines are drawn to connect constant lifetime points at each R-value. Figure 56 gives the stress based Goodman Diagram above 10^3 cycles. Since the tensile ultimate strength is much higher than the compressive ultimate strength for the high frequency specimens, the Goodman Diagram is unsymmetrical at low cycles. The failure mode for these tests was compressive for R=2, 10, and -1, shifting to tension for R=0.1 and 0.5. Thus, the section between R=0.1 and -1 is uncertain, shown here by simply connecting the points. The static strengths shown on the horizontal axis varied from batch to batch and R value to R value as shown in Table 13. The strength plotted on the average stress axis is the average value of the strength from different batches.

More useful Goodman Diagrams are those represented in terms of strain, which also tends to reduce batch to batch variations in the specimens, since a higher fiber content raises both the modulus and ultimate tensile strength roughly proportionally. Figure 57 shows the strain based Goodman Diagram, where the alternating and mean strains are normalized by the ultimate tensile strain. The ratio of tensile to compressive failure strain assumed here is 2.7/1.5=1.80, typical of unidirectional industrial materials in the database. Since the ultimate compressive strain is considerably lower than the tensile value, this creates the same nonsymmetrical shapes as for the stress diagram. Again, the transition from tensile to compressive failure modes is somewhere in the R=0.1 to R=-1 sector, not yet defined in the database. Figure 58 shows Figure 57 but with an extension of the tensile mode shown by the dashed line. This is clearly nonconservative and has not been established by experimental data, although the tension mode must dominate in at least part of this sector to the left of R=0.1. The actual transition from tensile to compressive failure modes in many laminates is cycle as well as R-value dependent (Figures 15, 35, 36, 45).

It should be noted that Figures 57 and 58 depend strongly on the assumed ratio of tensile to compressive ultimate strains used to normalize the results. Materials in the database show selected representative ratios such as given in Table 15, which range from 0.90 to 2.48; the ratio for an average of the different batches used in the high frequency tests was 1.93, close to the 1.80 used in Figures 57 and 58. Different Goodman Diagrams must be constructed for each material system of interest before the database can be used for blade lifetime prediction. The ratio increases for a given material construction as the fiber content increases.

Transverse Direction

A high cycle database has also been generated for the transverse direction of unidirectional composites; these materials used four layers of a lighter fabric, D100, and had a fiber volume content of 39%. Transverse strength values are sensitive to porosity; the porosity level for these specimens was 2.6%. The transverse strength is very low in tension in most composite systems, and this system was no exception. The transverse ultimate tensile strength averaged 21.5 MPa with a modulus of 8.96 GPa, yielding an ultimate failure strain of 0.24%, an order of magnitude lower than the longitudinal ultimate strain. The transverse properties in compression are much better than in tension, and the values for these specimens were 117 MPa strength and 1.3% strain to failure.

The transverse S-N curves are given in Figures 59-63 for R values of 0.1, 0.5, -1, 10 and 2, respectively. These tests were relatively simple in nature, with failure by a crack or shear zone running across the gage section, parallel to the fibers [15]. Linear regression parameters for two cycle ranges are given in Table 16 for stress; strain values may be obtained by dividing the stresses by the modulus of 8.96 GPa. Figures 64-66 give stress and strain based Goodman Diagrams for the transverse direction. These are very unsymmetrical due to the very low tensile strength relative to the compressive strength.

The transverse database can be used to predict initial damage in composites of similar construction. In typical $0°/\pm 45°$ laminates, the $\pm 45°$ layers fail first in tensile fatigue due to the transverse stress component. These results show that cracking in transverse tension fatigue at 10^6 cycles can be expected at transverse strains below 0.15%, which is within the operating range of many wind turbine blades. Higher porosity contents or larger pores would significantly lower the strain to produce damage.

DAMAGE DEVELOPMENT AND MODULUS CHANGES

The very low strain to failure in the transverse direction of this class of materials insures that extensive matrix cracking in off-axis plies like ± 45's will be present long before failure of the material. Standard laminated plate theory allows calculation of the transverse strains in off-axis plies, as well as decreases in laminate stiffness as a result of matrix cracking. The transverse ply ultimate strain to failure of around 0.24% strain is calculated to produce first cracking under static loading at around 0.39% strain for loading in the 0° direction of a $[0/\pm 45]_s$ laminate; this would reduce to 0.24% strain in the ± 45's for one million tensile fatigue cycles. The much higher transverse compressive strain raises the ± 45° failure strain in compression to the same range as that of the 0° layers, so that less progressive damage development is observed prior to failure of the 0° layers.

The more conservative approach to modulus change is to delete or severely decrease matrix dominated off-axis ply properties if the composite is predicted to develop matrix cracking, and to run stiffness predictions for the laminate assuming that the off-axis plies are thoroughly cracked. Figure 67 shows typical modulus change with cycles for a Triax laminate (Material N) from Ref. 1, as a function of fractional specimen lifetime, n/N, for several specimens. The maximum observed stiffness decrease is about 20%. As discussed earlier, it is generally very difficult to retain strain gages or extensometers during fatigue, and so data of this type is not usually recorded. The new hat-type gages described earlier show promise, and coupon data from them is given in Figure 68. This shows a more severe modulus drop very close to failure, where 0° damage also occurs.

Table 17 gives the expected drop in laminate stiffness for several laminates used in this study. These calculations are carried out by assuming that the matrix dominated moduli, E_T and G_{LT}, decrease to 25% of their original value when matrix cracking in the ± 45° layers occurs. The 25% figure is an empirical observation over the years at MSU, and reflects the fact that the cracked layers still retain some load carrying capability in the transverse and shear directions between matrix cracks, as these layers remain well bonded to the 0° layers. The prediction applies to the first few fatigue cycles only, and good agreement with experiments is found in this range. The increasing stiffness loss over the lifetime for DD5 in Figure 66 is not expected from ± 45 ply cracking alone.

Experience with composite structures has shown that major stiffness changes occur primarily due to delamination or adhesive failure between parts of the structure [17]. Material stiffness changes in laminates with significant 0° material are not great, as shown in Table 17.

APPLICATION TO STRUCTURES

References 3, 4, 7, 8, and the recent report in Ref. 28 have discussed the application of the database to simple composite structures such as I-beams. Findings to date with beams which are fabricated by secondary bonding of the flanges show that the beams fail at similar strains and cycles to those found in coupon tests, as reported in the database. This was observed for both good fatigue materials, like DD5, and poor fatigue materials, like triax. The beams were constructed from relatively uniform materials with well controlled thicknesses. They did not generally include large matrix rich areas or locally high fiber content regions; ply drops were included on the flange surfaces in some cases.

The question currently being considered in on-going research is whether laminates which behave well in coupon fatigue tests, such as the "best" materials in tensile fatigue in Figure 18, might fail at much lower strains in the presence of certain structural details. It is clear that the same general material which follows the "best" trend in Figure 18, can fail on the "worst" line if the fiber content increases above a certain range. Local fiber content variations or other details might conceivably have a similar effect, lowering the failure strain by a factor of two to three and the lifetime by a factor of ten to a hundred.

The beam studies confirm that adjoining structure such as stiffeners do not necessarily have a detrimental effect. A knockdown for the stiffener intersections of about 1.2 is the most that has been observed. Recent tests of coupons of "good" tensile fatigue material (DD5) containing special features simulating potential structural variations are summarized in Figure 69. (These are preliminary results.) The worst effect was found from a locally high fiber content zone formed by "pinching" the laminate to a locally higher V_f in the mold. This zone delaminated in fatigue, and failed at a condition close to "worst" in Figure 18. The inverse of this geometry, a bump of 90° oriented material which cracks at low strain, had no negative effect. The dropping of interior plies produced delamination and also reduced the strain at failure moderately. Figure 69 gives preliminary knock-downs for these details. The local fiber content increase is expected to be a problem around corners and other geometry changes in materials with molded-in features as are possible in RTM and inflated bladder processes.

USE OF THE DATABASE IN BLADE DESIGN

The DOE/MSU fatigue database contains a wealth of materials information on fatigue and static properties. A first cut at using this database for the prediction of blade lifetime has been made in Ref. 5, using the high frequency test Goodman Diagrams, coupled with two typical wind load spectra, and assuming a Miner's Rule linear cumulative damage law for variable amplitude cycling, as well as a nominal stress concentration factor, following Sandia's LIFE2 Code.

Research is ongoing in the area of validation of these procedures for the prediction of lifetime under actual wind loading. The extension of fatigue results from uniform coupon specimens to the many structural details of a real blade is planned to continue at MSU. Aspects of the problem such as ply drops, adhesive bonds, and root connections are currently being considered at both the substructure (I-beam) and small blade (8m long) levels. Consideration of delamination problems has been explored to the point of reaching recommended practices for ply drops in Ref. 7. Composite blade structures are very complex in geometry, with many possible modes of fatigue failure possible in addition to concerns with buckling, blade stiffness, static overloads, and system dynamics.

The following are a number of relatively simple recommendations for using the database in materials selection and design at the present level of understanding.

1. The static elastic constants available in the database should be adequate for finite element analysis of blades. Areas of blades expected to experience tensile strains greater than 0.2% should use reduced elastic constants to account for matrix cracking, as described in the section on Damage.
2. In areas of the blade where the design is to be limited by tensile fatigue, select materials which perform close to the "best" line in Figure 18. This is recommended in all critical structural parts

of the blade which will experience significant tensile loads.

3. Prepare a strain-based Goodman Diagram like Figures 54 and 55. If the ratio of tensile to compressive ultimate strain is close to 1.8, then these figures can be used directly, by including the particular ultimate tensile strain value for the selected material to denormalize the Goodman Diagrams. For other ultimate strain ratios, a new Goodman Diagram should be constructed. The R=-1 part of the Diagram is critical, this should also be adjusted to fit experimental standard coupon results where possible, using extrapolations to the available S-N data.
4. Use the Goodman Diagram with a code such as Sandia's LIFE2 [5] to predict blade lifetime for appropriate wind spectra.
5. If there is uncertainty about whether the material will follow the "best" line in Figure 18, a conservative approach would be to assume a b-value of 0.14 in tension, with a lower limiting S/So for damage of 0.15. This is particularly recommended near areas of complex internal structure, with significant matrix-rich regions which could crack adjacent to the structural laminate. A second problem can be locally high fiber contents, which can rapidly shift the behavior to a "worst" tensile fatigue condition, as noted earlier.
6. It is good practice to limit the 0° layer content to something in the range of 75% to avoid large matrix cracks propagating along the 0° direction, which can lead to delamination failures and other problems. The 0° layers should be as thin and interspersed with ± 45's or other directions as is possible.
7. This database does not include statistical or environmental treatment at the present time. Appropriate factors of safety or other reliability treatment must be applied to any lifetime prediction. Hot, wet environments have proven to be most severe for polymer matrix composites. Ref. 29 gives results for the effects of wet environments on wind turbine materials; these results show the greatest effects of moisture on compressive and shear strengths. (Tests are currently in progress to explore moisture and temperature effects on the DOE/MSU database materials.)

REFERENCES

1. Mandell, J.F., Reed, R.M. Jr. and Samborsky, D.D., Fatigue of Fiberglass Wind Turbine Blade Materials, SAND92-7005, Sandia National Laboratories, Albuquerque, NM (1992).
2. Mandell, J.F., Reed, R.M. Jr. ,Samborsky, D.D., and Pan, Q., "Fatigue Performance of Wind Turbine Blade Materials," in SED-Vol 14, Wind Energy 93, S. Hock, ed., ASME, New York, 191-198. (1993).
3. Mandell, J.F., Creed, R.M. Jr., Pan, Q., Combs, D.W., and Shrinivas, M., "Fatigue of Fiberglass Generic Materials and Substructures," in SED-Vol 15, Wind Energy 94, W.D. Musial, S.M. Hock and D.E. Berg, eds., ASME, New York, 207-213 (1994).
4. Mandell, J.F., Combs, D.E., and Samborsky, D., "Fatigue of Fiberglass Beam Substructures," Wind Energy 1995, W.D. Musial, S.M. Hock, D.E. Berg (eds), SED-Vol. 16, ASME, 99-106 (1995).
5. Sutherland, H.J., and Mandell, J.F., "Application of the U.S. High Cycle Fatigue Database To Wind Turbine Blade Lifetime Predictions," Wind Energy 1996, ASME, 78-84 (1996).
6. Samborsky, D., and Mandell, J.F., "Fatigue Resistant Fiberglass Laminates for Wind Turbine Blades," Wind Energy 1996, ASME, 46-51 (1996).
7. Cairns, D.S., Mandell, J.F., Scott, M.E., and Macagnano, J.Z., "Design Considerations for Ply Drops in Composite Wind Turbine Blades," Wind Energy 1997, January 1997 (to be published).
8. Mandell, J.F., Samborsky, D.D., and Cairns, D.S., "Advanced Wind Turbine Blade Structure Development Program at Montana State University," Wind Energy 1997 (to be published).
9. Reed, R.M., "Long Term Fatigue of Glass Fiber Reinforced Materials for Wind Turbine Blades," M.S. Thesis, Dept. of Chem. Engr., Montana State University (1991).
10. Creed, R.F., Jr., "High Cycle Tensile Fatigue of Unidirectional Fiberglass Composite Tested at High Frequency," M.S. Thesis, Dept. of Chem. Engr., Montana State University (1993).
11. Shrinivas, M., "Three Dimensional Finite Element Analysis of Matrix Cracks in Multidirectional Composite Laminates," M.S. Thesis, Dept. of Chem. Engr., Montana State University (1993).
12. Pan, Rena Q., "Fatigue Behavior of Glass fiber Reinforced Composite Materials for Wind Turbine Blades," M.S. Thesis, Dept. of Chem. Engr., Montana State University (1994).
13. Belinky, A.J., "High Cycle Compressive Fatigue of Unidirectional Glass/Polyester Performed at High Frequency," M.S. Thesis, Dept. of Chem. Engr., Montana State University (1994).
14. Hedley, C.W., "Mold Filling Parameters in Resin Transfer Molding," M.S. Thesis, Dept. of Chem. Engr., Montana State University, (1994).
15. Wei, G., "High Cycle Longitudinal and Transverse Fatigue of Unidirectional Glass/Polyester Composites," M.S. Thesis, Dept. of Chem. Engr., Montana State University (1995).
16. Humbert, D.R., "Modeling of Resin Transfer Molding of Composite Materials With Oriented Unidirectional Plies," M.S. Thesis, Dept. of Chem. Engr., Montana State University, (1996).
17. DeSmet, B.J. and Bach, P.W., DATABASE FACT: Fatigue of Composites for Wind Turbines, ECN-C-94-045, ECN, Petten, the Netherlands (1994).

18. Camponeschi, E.T., Jr., "Compression of Composite Materials: A Review," in Composite Materials: Fatigue and Fracture (3rd volume), ASTM STP 1110, T.K. O'Brien, ed., ASTM, Phil., 550-578 (1991).
19. Adams, D.F. and Lewis, E.Q., Experimental Mechanics, vol. 31, 14-20 (1991).
20. Mandell, J.F., "Fatigue Behavior of Short Fiber Composite Materials," in The Fatigue Behavior of Composite Materials, K.L. Reifsnider, ed, Elsevier, 232-237 (1991).
21. Tsai, S.W., "Composites Design, Fourth Edition," Think Composites, Dayton (1985).
22. Halpin, J.C. and Tsai, S.W., "Effects of Environmental Factors on Composite Materials," AFML-TR 67-243, June (1969).
23. Mandell, J.F., Composite Reliability, ASTM STP 580, 515 (1980).
24. Rotem, A. and Nelson, H.G., in "Fatigue of Fibrous Composite Materials", ASTM STP 723, 152 (1981).
25. Van Delft, D.V.R., de Winkel, G.D., and Joosse, P.A., "Fatigue Behavior of Fiberglass Wind Turbine Blade Material Under Variable Amplitude Loading," in 1997 ASME Wind Energy Symposium Papers, W.D. Musial, ed., AIAA, Reston, VA (1997) 180-188.
26. Broek, D., Elementary Engineering Fracture Mechanics, 4th Edition, Martinus Nihoff, Dordrecht, The Netherlands (1986).
27. Mandell, J.F., Huang, D.D. and McGarry, F.J., Compos. Tech. Rev., 3 (1981) 93.
28. Mandell, J.F., etal., "Fatigue of Composite Material Beam Elements Representative of Wind Turbine Blade Substructure," NREL Contractors Report (in review).
29. Kensche, C.W., "Effects of Environment," Ch 5 in Design of Composite Structures Against Fatigue, R.M. Mayer, ed, Antony Rowe Ltd., Chippenham, Wiltshire, G.B. (1996) 65-87.

Table 1. Summary of E - Glass fabrics

E - glass fabric	Description	Total weight g/m^2	Dry thickness mm	Manufacturer
A060	woven 0^O	206	0.35	Knytex
A130		444	0.53	
A260		868	0.91	
CDB200	$0^O/\pm45^O$	759	0.86	
CM1701	0^O plus mat	587	0.78	
D072A	0^O	230	0.40	
D092		310	0.48	
D155		527	0.53	
DB120	45^O	393	0.53	
DB240		837	0.86	
DB400		1,349	1.24	
TVM3408	$0^O/\pm45^O$	1,150	1.42	Brunswick

Table 2. Summary of resin matrix materials

Resin	Manufacturer	Catalyst (MEKP)	Promoter	Cure cycle
CoRezyn 63-AX-051	Interplastics Corp.	2% by vol.	----------	minimum 4 hours in the mold plus 2 hours at 60^OC
Derakane 411-C-50	DOW Chemical	1.5% by vol.	0.3% CoNap 0.05% DMA	
Epon 9410	Shell Chemical	Epon 9450 - 35% by wt.		10 hours at 80^OC

Table 3. Summary of test coupon geometries

Test	% zero's in composite	Testing geometry
Static tensile and fatigue at R = 0.1	< 50%	rectangular, as cut
	50% to 84%	width tapered
	100%	thickness tapered
Static compressive and fatigue at R = 10, R = -1	All cases	rectangular, as cut

Table 4. Summary of Tab Materials

Material	Description
Protoboard	Radio Shack catalog number 276-1396, 1.6 mm epoxy sheet with 1 mm diameter holes spaced 2.5 mm in a rectangular grid.
Fiberglass	Plastifab G10, 1.6 mm, $[0/90]_7$, $V_F = 35\%$. With and without 10^O tapered ends.
Fiberglass	3M SP250 prepreg, $[\pm 45]_{10}$, $V_F = 55\%$.
Aluminum	6061-T6, 2.5 mm with 10^O tapered ends with resin impregnated chopped mat (170 g/m^2) between the aluminum and the composite.

Table 5. Summary of mechanical testing equipment

Machine	Actuator Control	Capacity	Stroke	Servo valve capacity
Instron 1350	Servo hydraulic	100 kN	± 51 mm	0.32 L/s
Instron 8562	Servo electric	100 kN	± 51 mm	--------
Instron 8501	Servo hydraulic	100 kN	± 51 mm	0.64 L/s
Instron 8511	Servo hydraulic	10 kN	± 25 mm	0.32 L/s
MTS 880	Servo hydraulic	225 kN	± 140 mm	0.64 L/s

Table 6. Summary of extensometers

Extensometer	Range	Gage Length	Machine
Instron 2620-524	± 5 mm	12.70 mm	Instron 1350
Instron 2620-525	± 5 mm	12.70 mm	Instron 8501
Instron 2620-528	± 1.3 mm	12.70 mm	Instron 8511
Instron 2620-826	± 2.5 mm	12.70 mm	Instron 8501
MTS 632.12B	+13/-2.5 mm	25.40 mm	MTS 880

Table 7 - Summary of strain gages

Company	Catalogue Number
BLH	FAE-25-35-S13EL FAET-2SA-3S-S13 PA - 7
Micro Measurements	CEA-00-250UW-350 EA-00-015EH-350 EA-06-250-BF-350 ED-DY-125AD-350 WA-00-015-EH-350 WK-06-250AF-350 WK-00-250-BG-350

Table 8 - Summary of applicable bending standards for uniaxial testing machines testing composite coupons

Standard	Maximum allowed bending strain (% of axial strain)
ASTM E 1012	Not stated
ASTM D 3039	5%
General Electric S-400	10% for ductile materials 5% for brittle
Military Standard 1312B	6%

TABLE 9a. Static Ply Properties: Longitudinal, Transverse and Simulated Shear Elastic Constants, Ultimate Strength and Strains

Static Longitudinal, Transverse and Simulated Shear Properties for E - Glass fabrics used in the MSU RTM composites

			Longitudinal Direction									Transverse Direction			
			Elastic Constants				Tension		Compression		Shear	Tension		Compression	
Fabric	layup	V_F %	E_L GPa	E_T GPa	υ_{LT}	G_{LT} GPa	UTS_L MPa	ϵ_U %	UCS_L MPa	ϵ_U %	τ_{TU} MPa	UTS_T MPa	ϵ_U %	UCS_T MPa	ϵ_U %
A130	$[0]_8$	45	36.3	8.76	0.32	3.48	868	2.53	-334	-0.92	87.1	33.8	0.39	-93.3	-1.05
D092	$[0]_{10}$	45	35.3	8.76	0.31	4.15	952	2.98	-773	-2.19	142	38.5	0.44	-133	-1.52
D155	$[0]_6$	45	37.0	8.99	0.31	4.10	986	2.83	-746	-2.02	94.2	27.2	0.30	-129	-1.67
DB120*	$[0]_{16}$	44	26.5	7.52	0.39	4.12	610	2.49	-551	-2.08	84.9	24.9	0.33	-90.8	-1.21
DB240*	$[0]_8$	46	31.0	7.38	0.35	3.74	697	2.64	-538	-1.74	68.7	19.7	0.27	-122	-1.69
0/90ROV*	$[0/90]_7$	46	23.9	23.9	0.26	4.08	382	2.27	-223	-0.93	99.9	382	2.27	-223	-0.93

Notes: E_L - Longitudinal modulus, υ_{LT} - Poisson's ratio, G_{LT} and τ_{TU} - Shear modulus and ultimate shear stress from a simulated shear (±45) ASTM D 3518 test. UTS_L - Ultimate longitudinal tensile strength, ϵ_U - Ultimate tensile strain, UCS_L - Ultimate longitudinal compressive strength, ϵ_U - Ultimate compressive strain.
Coupons had a 100 mm gage length and tested with a 0.02 mm/s testing velocity. * DB120 and DB240 fabrics were separated into a +45 and a -45 orientation and then rotated to 0 degrees to form a unidirectional material. The 0/90 ROV material was tested as a 0/90 fabric.

TABLE 9b. Physical Elastic Constants and Strengths for Unidirectional Material D155 at a V_F = 36%*

Physical Elastic Constants of Material D155, V_F = 36%			
Property and test plane	Test Values	Average	s.d.
E_L,(LT plane),GPa	28.1, 27.0, 29.8	28.3	1.4
E_L, (LZ plane), GPa	28.0, 28.3, 27.6	28.0	0.4
E_T, (TZ plane), GPa	8.00, 7.31, 7.93	7.75	0.38
E_Z, (ZX plane), GPa	7.10, 7.65, 7.38	7.38	0.28
υ_{LT}	0.329, 0.320, 0.301	0.32	0.01
υ_{LZ}	0.305, 0.338, 0.331	0.33	0.02
υ_{TZ}	0.466, 0.395, 0.449	0.44	0.04
G_{LT}, GPa	3.31, 3.35, 3.23	3.30	0.06
G_{LZ}, GPa	3.03, 2.72, 2.70	2.82	0.19
G_{TZ}, GPa	2.78, 3.12, 1.76	2.55	0.71

Ultimate Strengths of Material D155, V_F = 36%			
Property and test plane	Test Values	Average	s.d.
UTS_L, (LT plane), MPa	891, 814, 883, 838	856	37
UTS_L, (LZ plane), MPa	679, 672, 685, 646	671	17
UTS_T, (TZ plane), MPa	26.6, 36.0, 30.4, 32.9, 29.0	31.0	3.6
UTS_Z, (ZT plane), MPa	21.7, 18.7, 20.4, 18.1	19.7	1.6
UTS_Z, (ZL plane), MPa	19.4, 17.7, 22.3, 17.1, 15.2	18.4	2.7
τ_{LT}, MPa	95.1, 82.1, 78.8	85.3	8.7
τ_{LZ}, MPa	79.6, 77.3, 77.1, 63.2	74.3	7.5
τ_{TZ}, MPa	19.9, 17.6, 12.0	16.5	4.0

*Shear properties listed were determined by notched beam, ASTM D5379

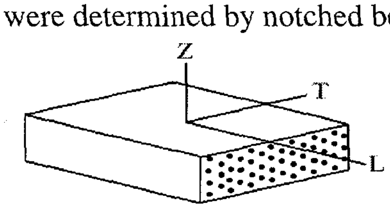


TABLE 9c. Physical Elastic Constants and Strengths for Unidirectional Material D155 at a $V_F = 44\%$*

Physical Elastic Constants of Material D155, $V_F = 44\%$			
Property and test plane	Test Values	Average	s.d.
E_L, (LT plane), GPa	31.9, 35.4, 33.6	33.6	1.8
E_L, (LZ plane), GPa	34.5, 34.3, 34.5	34.4	0.1
E_T, (TZ plane), GPa	8.14, 8.96, 7.52	8.21	0.72
E_Z, (ZX plane), GPa	7.58, 8.00, 8.00	7.86	0.24
υ_{LT}	0.289, 0.291, 0.290	0.29	0.01
υ_{LZ}	0.302, 0.314, 0.308	0.31	0.01
υ_{TZ}	0.373, 0.371, 0.366	0.37	0.01
G_{LT}, GPa	5.76, 3.94, 3.74	4.48	1.11
G_{LZ}, GPa	3.88, 4.40, 3.07	3.78	0.67
G_{TZ}, GPa	2.96, 2.70, 2.20	2.62	0.39
Ultimate Strengths of Material D155, $V_F = 44\%$			
Property and test plane	Test Values	Average	s.d.
UTS_L, (LT plane), MPa	991, 1000, 1045	1,012	29
UTS_L, (LZ plane), MPa	881, 855, 896	877	21
UTS_T, (TZ plane), MPa	33.3, 29.3, 28.6, 32.1, 29.7	30.6	2.0
UTS_Z, (ZT plane), MPa	12.0, 13.4, 13.4, 12.3	12.8	0.7
τ_{LT}, MPa	67.5, 79.1, 73.1	73.2	5.8
τ_{LZ}, MPa	75.0, 66.2, 70.8	70.7	4.4
τ_{TZ}, MPa	13.6, 17.0, 20.1	16.9	3.3

*Shear properties listed were determined by notched beam, ASTM D5379

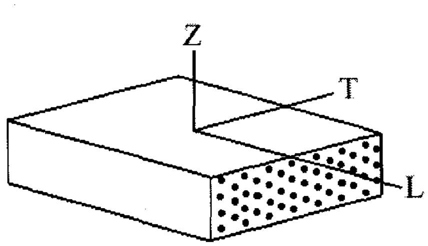


TABLE 10. Summary of Fatigue Results: Tensile (R = 0.1), Compressive (R = 10) and Reversed Loading (R = -1)

Properties of Selected Materials Tested at R = 0.1, 10 and -1										
				R = 0.1		R = 10		R = -1		
Material	Layup	V_F, %	% 0^o	b_T	strain for 10^6 cycles, %	b_C	strain for 10^6 cycles, %	b_R	strain for 10^6 cycles, %	E, GPa
H	$[(\pm45/0)_3]_S$	37	70	0.114	0.52	0.100	-0.72	0.136	0.45	24.0
N	$[0/\pm45]_4$	38	50	0.140	0.46	0.096	-0.70	0.135	0.30	21.0
P	$[0/\pm45/M/0]_S$	40	48	0.134	0.48	0.099	-0.66	0.133	0.42	28.9
AA	$[(\pm45/0)_3(\mp45/0)_2]$	35	50	0.140	0.50	0.081	-0.95	0.139	0.40	18.8
EEAP	$[M/\pm45/0]_S$	48	70	0.101	0.82	0.088	-1.25	0.068	0.70	28.2
DD4	$[0/\pm45/0]_S$	48	72	0.140	0.65	----	----	0.123	0.50	31.0
DD5E	$[0/\pm45/0]_S$	36	72	0.102	1.20	0.056	-1.42	0.123	0.66	22.9
DD5P	$[0/\pm45/0]_S$	36	72	0.101	1.15	0.070	-1.30	0.135	0.62	23.6

TABLE 11. Comparison of Tabbed and Thickness Tapered Tensile Fatigue Results.

Comparison of ASTM D3039 and Thickness Tapered Unidirectional Coupons					
Material	V_F, %	UTS, MPa	b_T	strain for 10^6 cycles, %	E, GPa
A (D 3039)	30	566	0.111	0.87	21.5
A (tapered)	30	571	0.100	0.98	24.6
L (D 3039)	50	742	0.135	0.70	33.6
L (tapered)	50	752	0.127	0.65	38.6

Table 12. Linear Regression Constants for Fit to Equation 7, High Frequency Database, Longitudinal Direction.

Linear Regression for Longitudinal $N \geq 10^3$ Data.

R	B	n	Goodness of Fit (R^2)
0.1	0.969	11.60	0.8748
0.5	0.977	16.05	0.8817
-1*	0.477	12.90	0.8649
-1#	1.124	13.25	0.8649
10	0.862	22.47	0.9895
2	0.869	47.85	0.5131

Linear Regression for Longitudinal $N \geq 10^5$ Data.

R	B	n	Goodness of Fit (R^2)
0.1	0.740	14.31	0.8987
0.5	0.977	16.05	0.8817
-1*	0.477	13.25	0.8649
-1#	1.124	13.25	0.8649
10	0.802	24.88	0.9976
2	0.802	61.73	0.8490

Note: (a) * signifies the normalization performed with tensile strength.
(b) # signifies the normalization performed with compressive strength.

Table 13 Average Strength and Modulus Values for High Frequency Database (Different Batches of Material Were Used for Different R-Values in Some Cases)

Coupons	Type of Test	Fiber Volume %	Average Modulus, GPa	Average Ultimate Strength, MPa
Longitudinal Direction				
R = 0.1 Batch	Tension	67	46.2	1471
R = 0.5 Batch	Tension	49	39.2	1338
R = -1 Batch	Tension	49	39.2	1379
	Compression	49	41.1	586
R = 10 Batch	Compression	52	35.7	722
R = 2 Batch	Compression	52	35.4	722
Transverse Direction				
R = 0.1, 0.5, and -1.0	Tension	39	8.62	21.5
R = 10, 2 Batches	Compression	39	8.96	117

Table 14. Power Law Fit of Longitudional Strain Data in High Frequency Database to Equation (9).

Power Law Coefficients with Range of Applicability						
R - Value	1 to 10^8 cycles		10^3 to 10^8 cycles		10^5 to 10^8 cycles	
	C	m	C	m	C	m
0.1	1	11.3	0.969	11.6	0.740	14.3
0.5	1	15.4	0.977	16.0	0.977	16.0
-1	1	14.9	1.124	13.2	1.124	13.2
10	1	18.0	0.862	22.5	0.802	24.9
2	1	31.2	0.859	47.8	0.802	61.7

Table 15

Ratio of Ultimate Tensile Strain to Absolute Ultimate Compressive Strain for Typical Materials					
Material	Ply Configuration	V_F, %	ϵ_{UTS}, %	ϵ_{UCS}, %	Ratio $\epsilon_{UTS} / \epsilon_{UCS}$
DD7	$[0/\pm45/0]_S$	54	2.74	1.46	1.87
DD5	$[0/\pm45/0]_S$	38	2.87	2.12	1.35
CH16	$[\pm45/0/\pm45]_S$	40	1.95	1.67	1.17
CH4	$[(\pm45)_3]_S$	35	1.36	1.50	0.91
D155B	$[0]_7$	39	2.64	2.18	1.21
D155C	$[0]_{12}$	51	3.21	2.04	1.57
A130C	$[0]_5$	35	2.53	1.39	1.82
A130G	$[0]_7$	55	2.43	1.09	2.23
AA	$[(0/\pm45)_3(0/\mp45)_2]$	35	2.14	1.85	1.16
AA3	$[(0/\pm45)_3(0/\mp45)_2]$	51	1.93	1.13	1.71
A	$[0]_5$	30	2.56	1.46	1.75
L	$[0]_3$	50	2.20	1.21	1.82
P	$[0/\pm45/M/0]_S$	36	2.47	1.61	1.53
EEA	$[M/\pm45/0]_S$	48	2.15	2.29	0.94
X	$[0_2/M/\pm45/0_2]$	35	2.57	1.74	1.48
Average					1.50

Table 16 Linear Regression Constants for Fit to Equation 7, Transverse High Frequency Tests.

Linear Regression for Transverse $N \geq 10^3$ Data.

R	B	n	Goodness of Fit (R^2)
0.1	0.7924	41.53	0.8918
0.5	0.9768	48.10	0.8891
-1*	0.6067	33.56	0.6123
10	0.8036	35.65	0.9100
2	1.0170	40.03	0.8166

Linear Regression for Transverse $N \geq 10^5$ Data.

R	c	b	Goodness of Fit (R^2)
0.1	0.9512	28.25	0.8534
0.5	1.0230	33.39	0.8917
-1*	0.7658	22.45	0.8166
10	0.8576	31.10	0.8905
2	1.0170	40.03	0.8166

Note: * signifies the normalization performed with tensile strength

Table 17. Predicted and Measured Percent Decrease in Longitudinal Modulus due to Cracking of the ±45 plies

Predicted and Measured Percent Decrease in Longitudinal Modulus due to Cracking of the ±45 plies in fatigue (n/N < 0.5)				
			% Decrease in longitudinal modulus due to cracking of the ±45 plies	
Material	Layup	V_F, %	Predicted	Measured
DD5	$[0/\pm45/0]_S$	38	6.2	10
N	$[0/\pm45]_4$	36	16	10 - 20
CH3	$[\pm45/0/\pm45]_S$	36	31	31 - 42

FIGURE 1 (a). Lamina (plies) and Laminate description

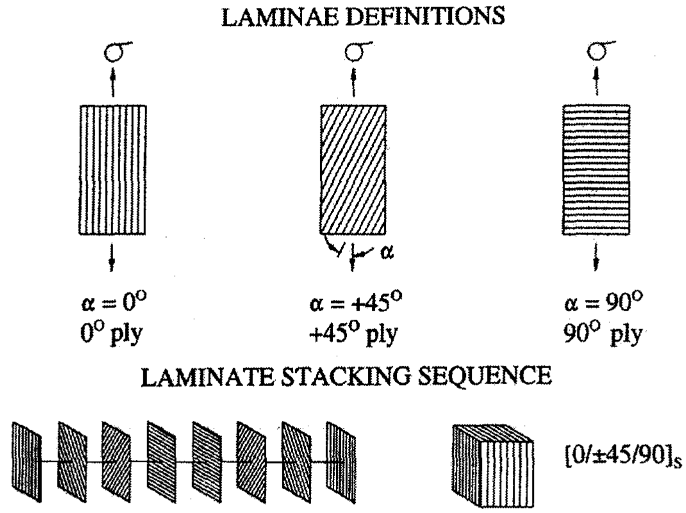


FIGURE 1 (b). Fabric D155

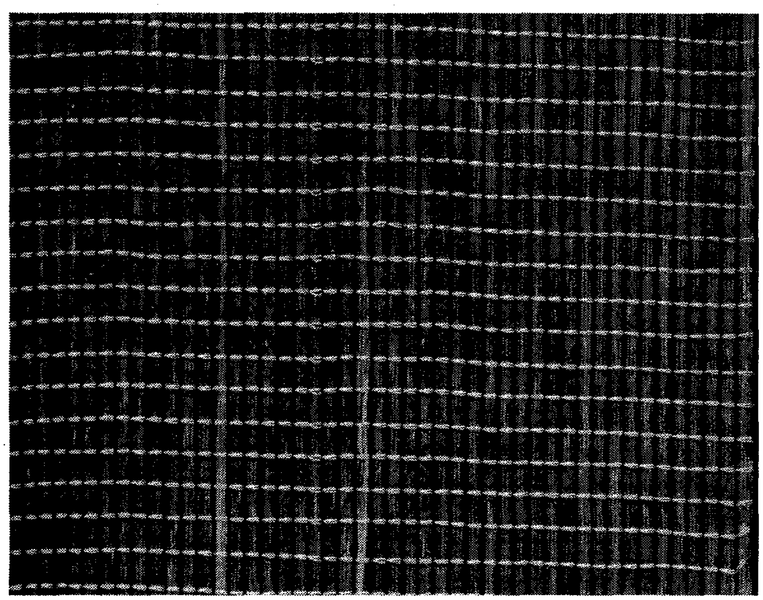


FIGURE 1 (c). Fabric A130

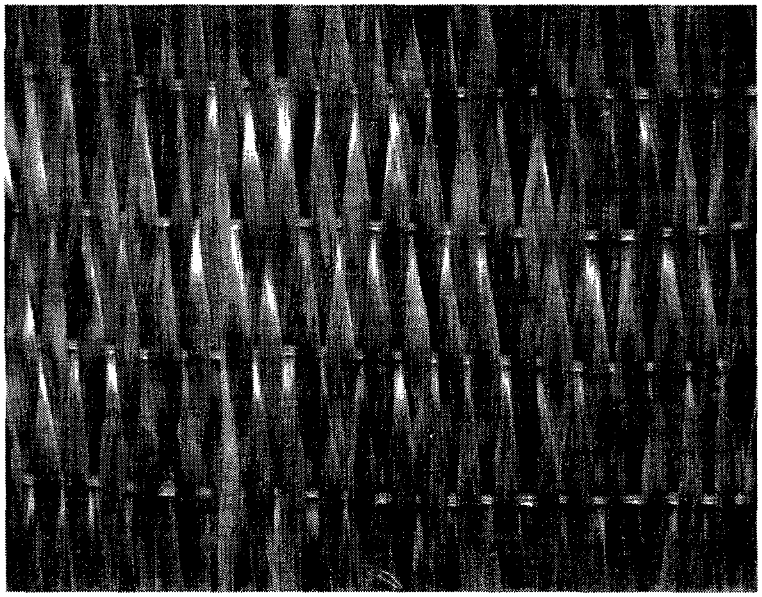


FIGURE 1 (d). Fabric DB120

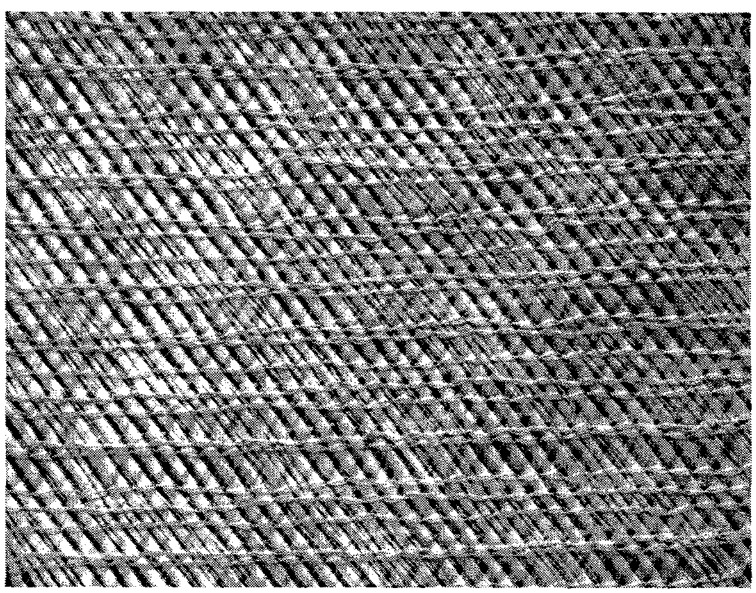


FIGURE 1 (e). Nesting of D177 layers in a $[0]_7$ laminate

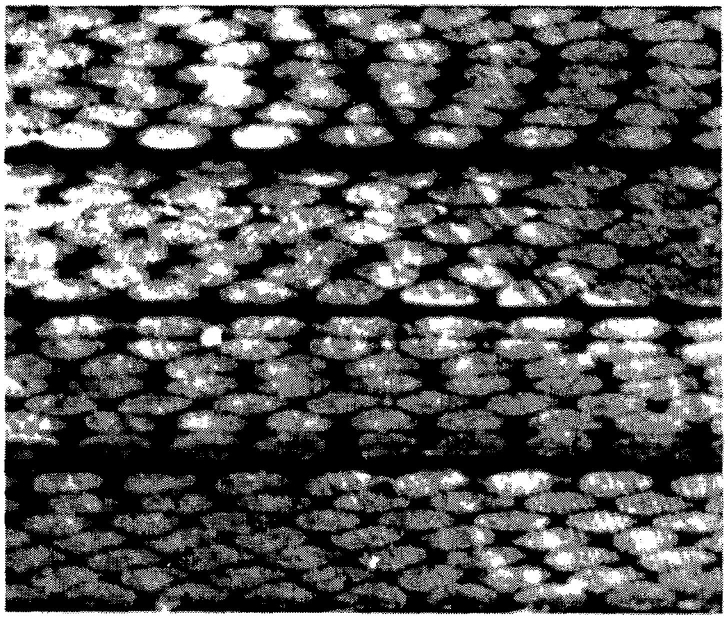


FIGURE 1 (f). Micrograph of triax material cross - section with porosity, matrix cracks and failed 0^{o} strands along stitching line.

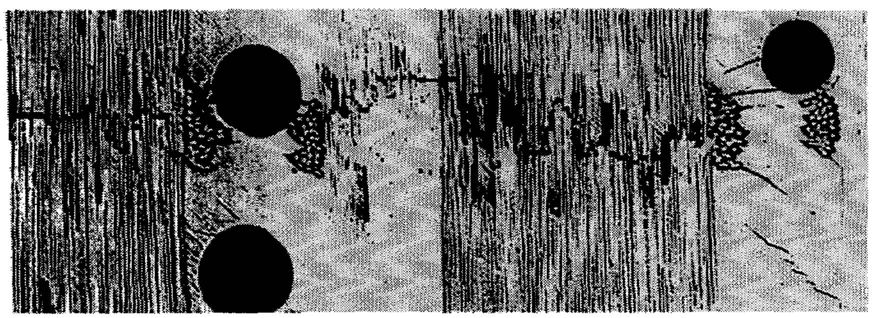


Figure 2. Flat plate RTM mold

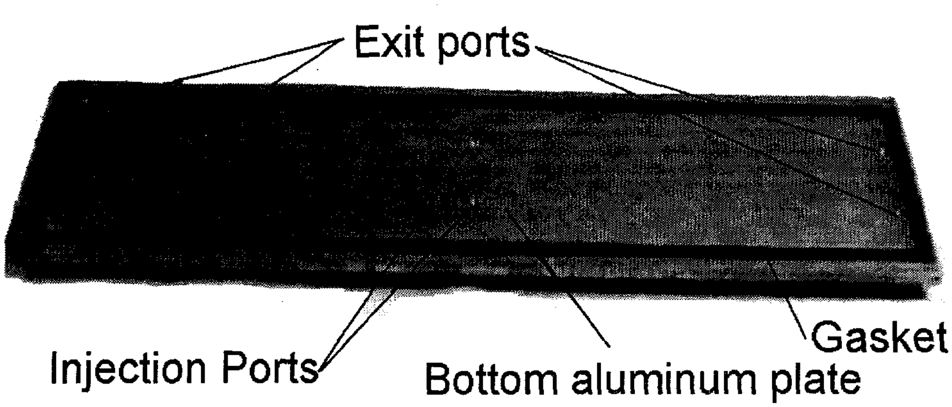
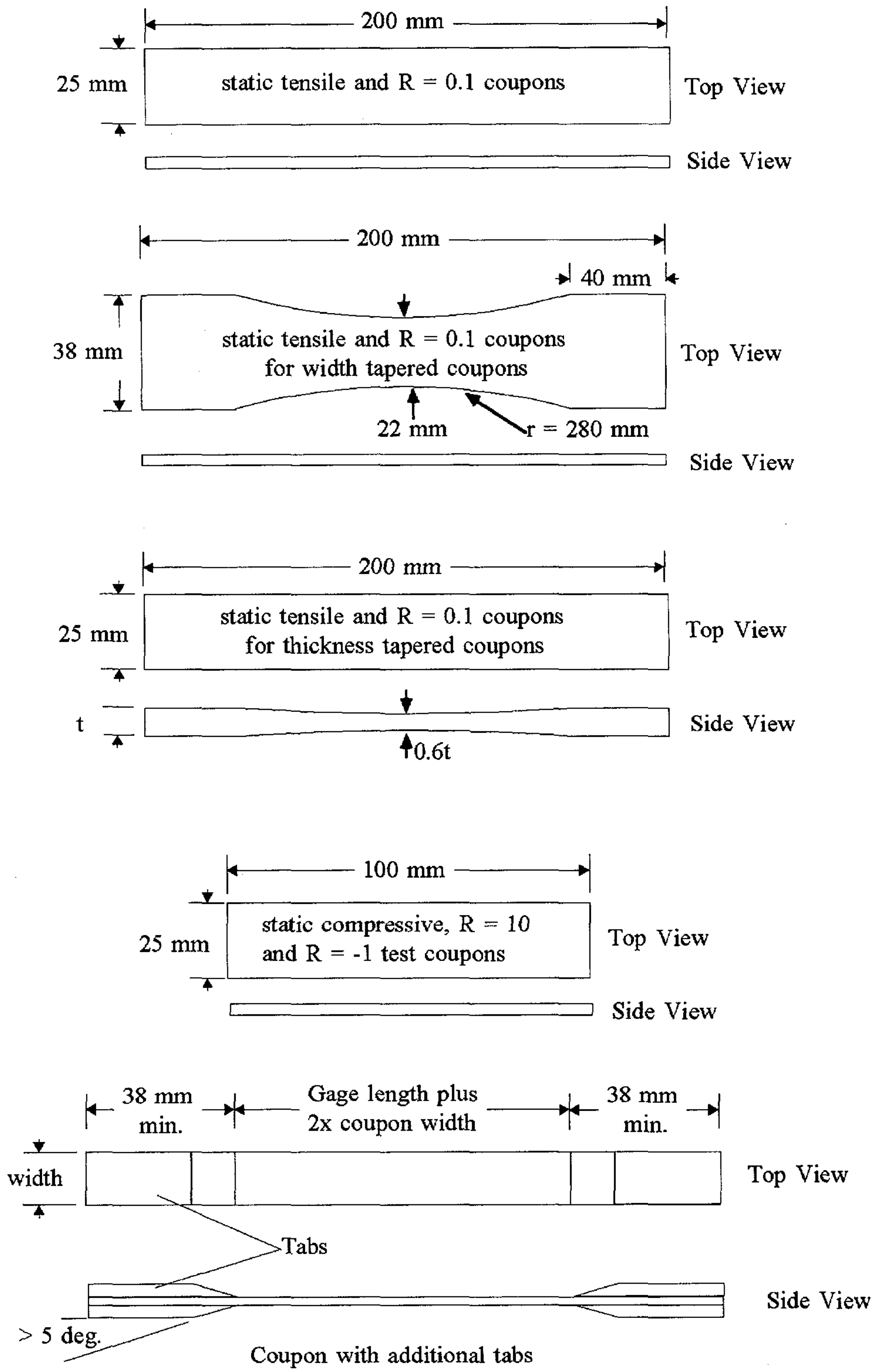


FIGURE 3. Test coupon geometries



Coupon with additional tabs

Figure 4. Matrix cracks in tensile strain gage, Beam 29

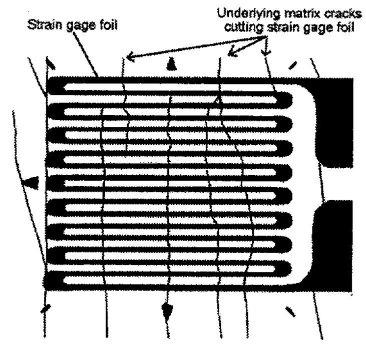


Figure 5. Clip strain gage

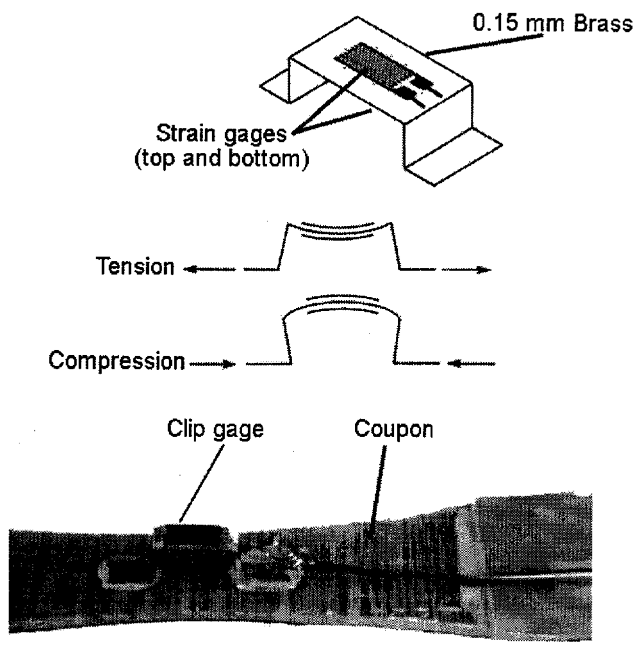


Figure 6. Width tapered coupon with edge splitting

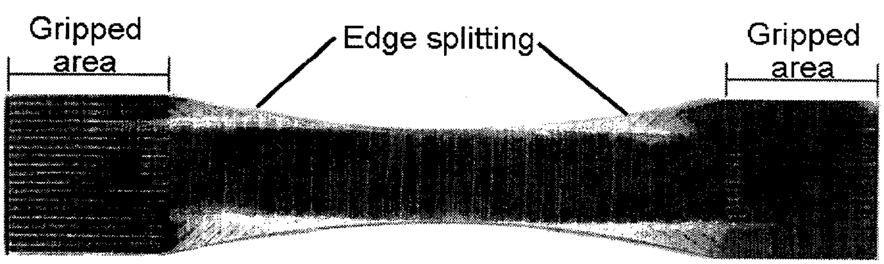
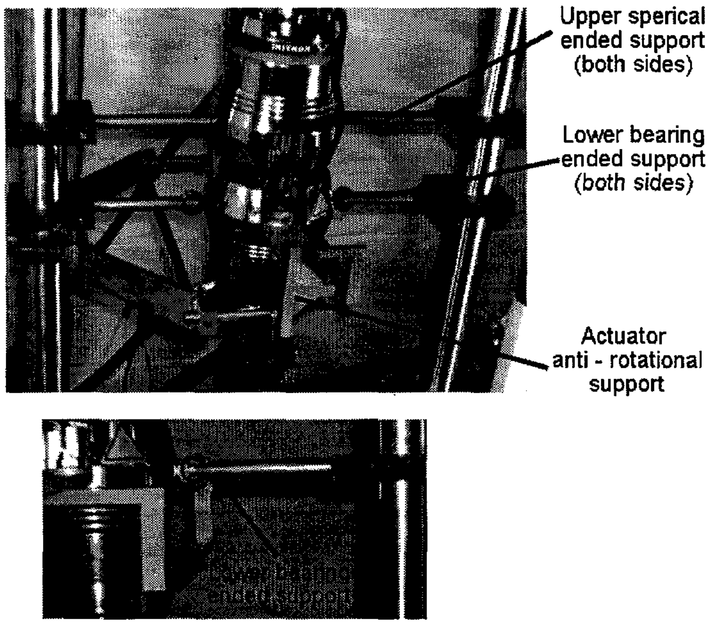


FIGURE 7. Anti - translational and rotation devices



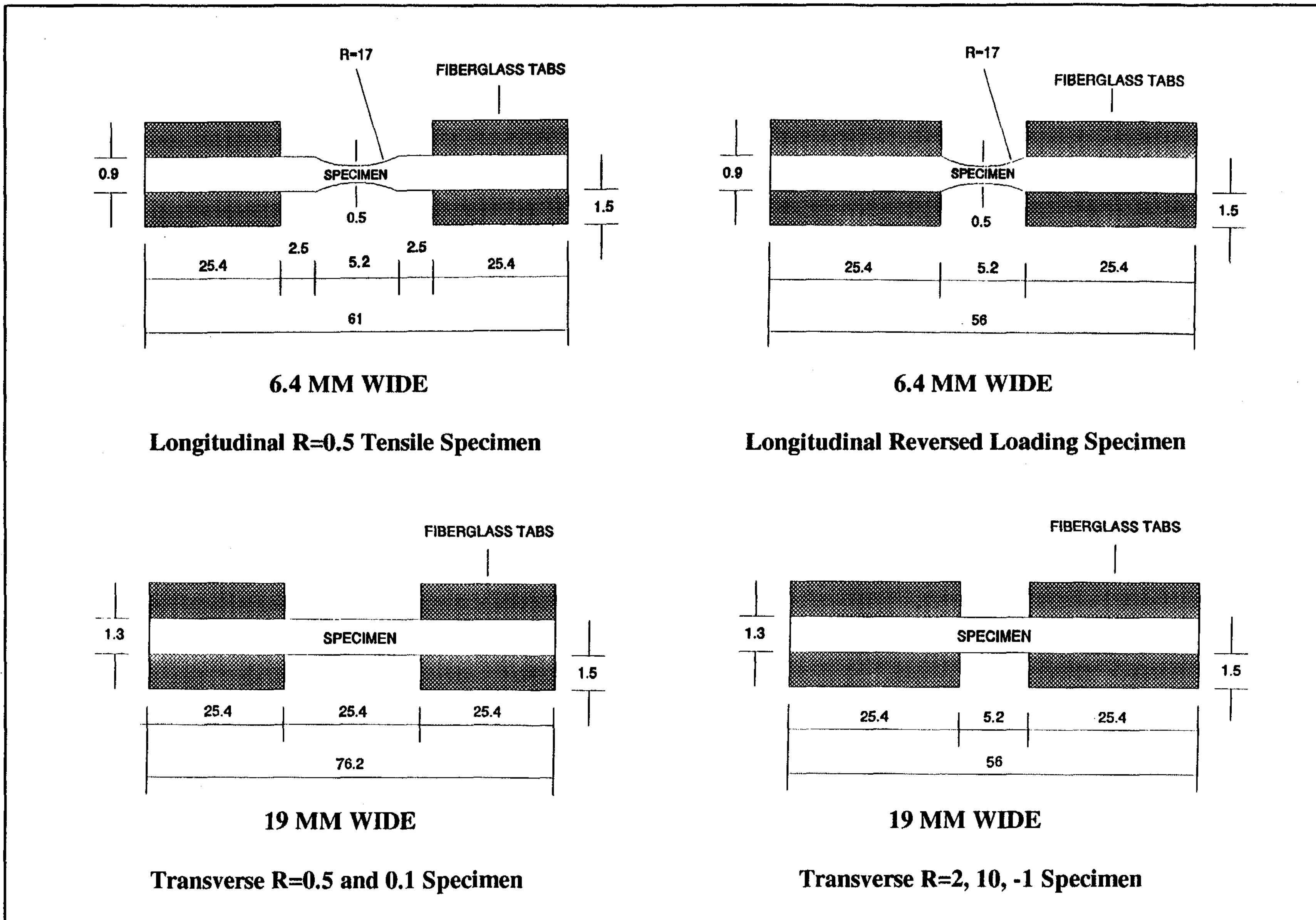
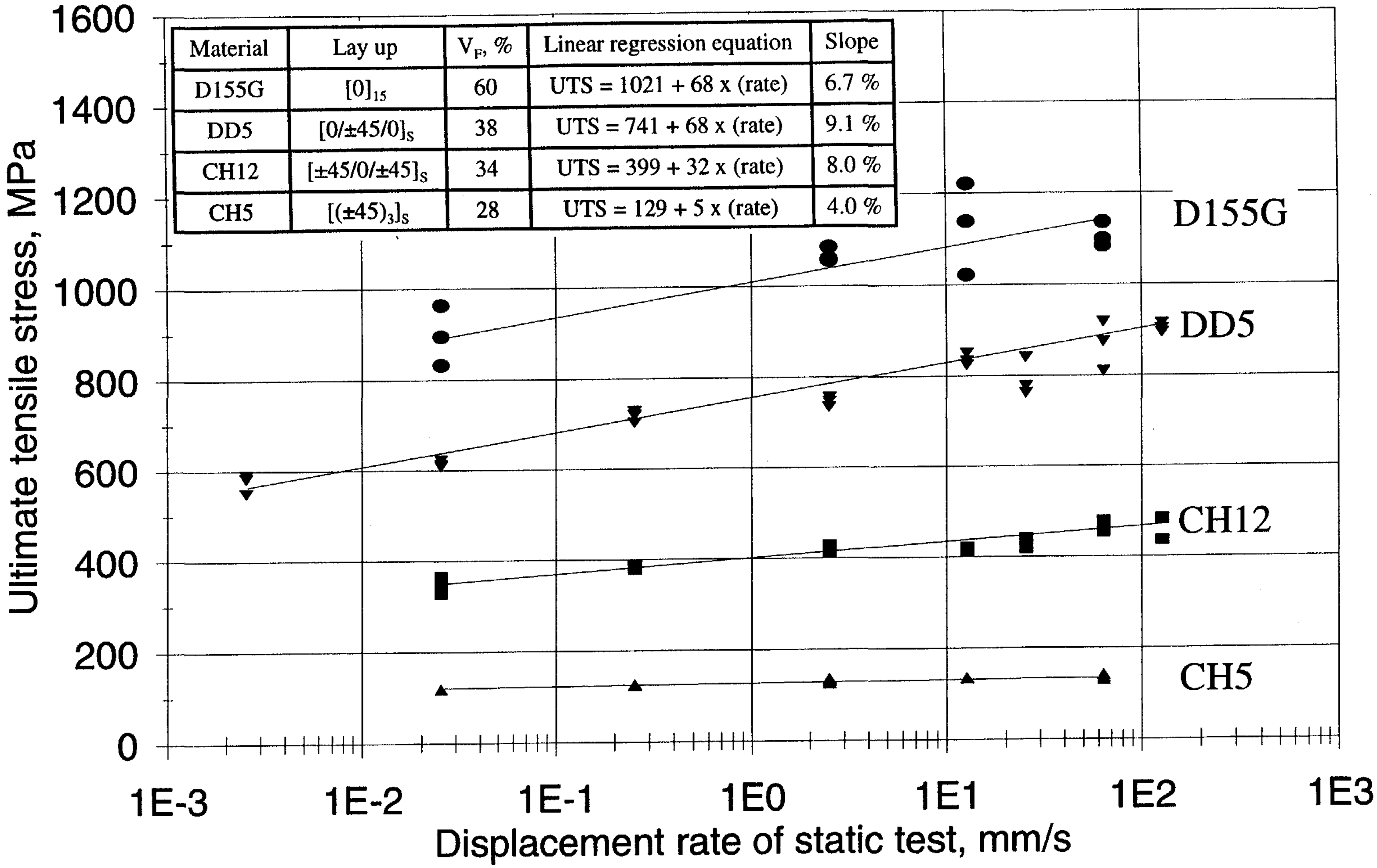


Figure 8. High Frequency Test Specimens (All Dimensions in mm).

Ultimate Tensile Stress vs. Displacement Rate of Static Test
25 mm width, 100 mm gage length



Material	Lay up	V_F, %	Linear regression equation	Slope
D155G	$[0]_{15}$	60	UTS = 1021 + 68 x (rate)	6.7 %
DD5	$[0/\pm45/0]_S$	38	UTS = 741 + 68 x (rate)	9.1 %
CH12	$[\pm45/0/\pm45]_S$	34	UTS = 399 + 32 x (rate)	8.0 %
CH5	$[(\pm45)_3]_S$	28	UTS = 129 + 5 x (rate)	4.0 %

FIGURE 9

Micromechanics Prediction for Longitudinal Modulus (E_L), Transverse Modulus (E_T), Shear Modulus (G_{LT}) and Poisson's Ratio (υ_{LT}) vs. Fiber Volume for Material D155

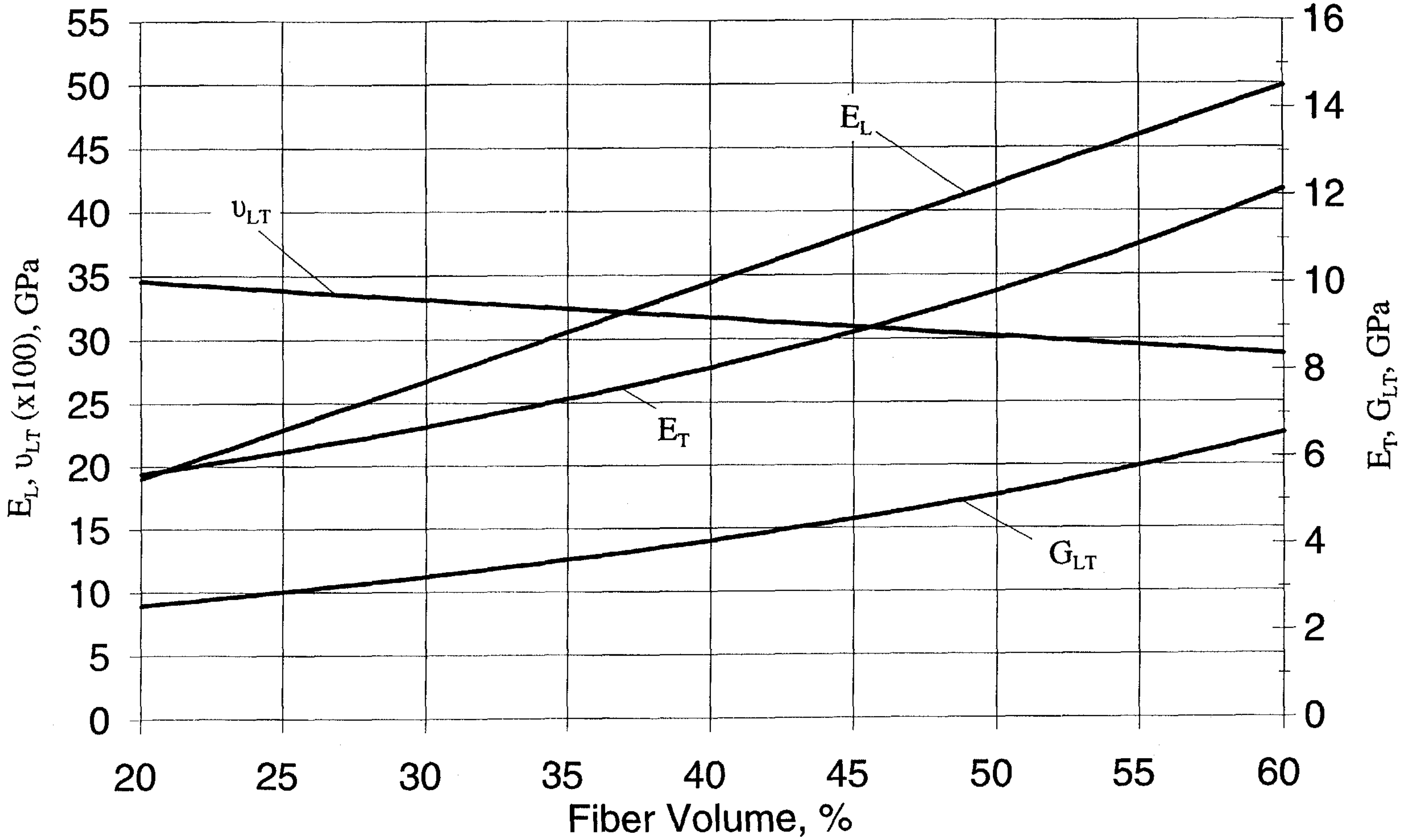


FIGURE 10

Ultimate Tensile Strength (UTS), Ultimate Compressive Strength (UCS) and Longitudional Modulus (E_X) vs. Fiber Volume % for DD Materials Having the Ply Arrangement $[0/\pm45/0]_S$

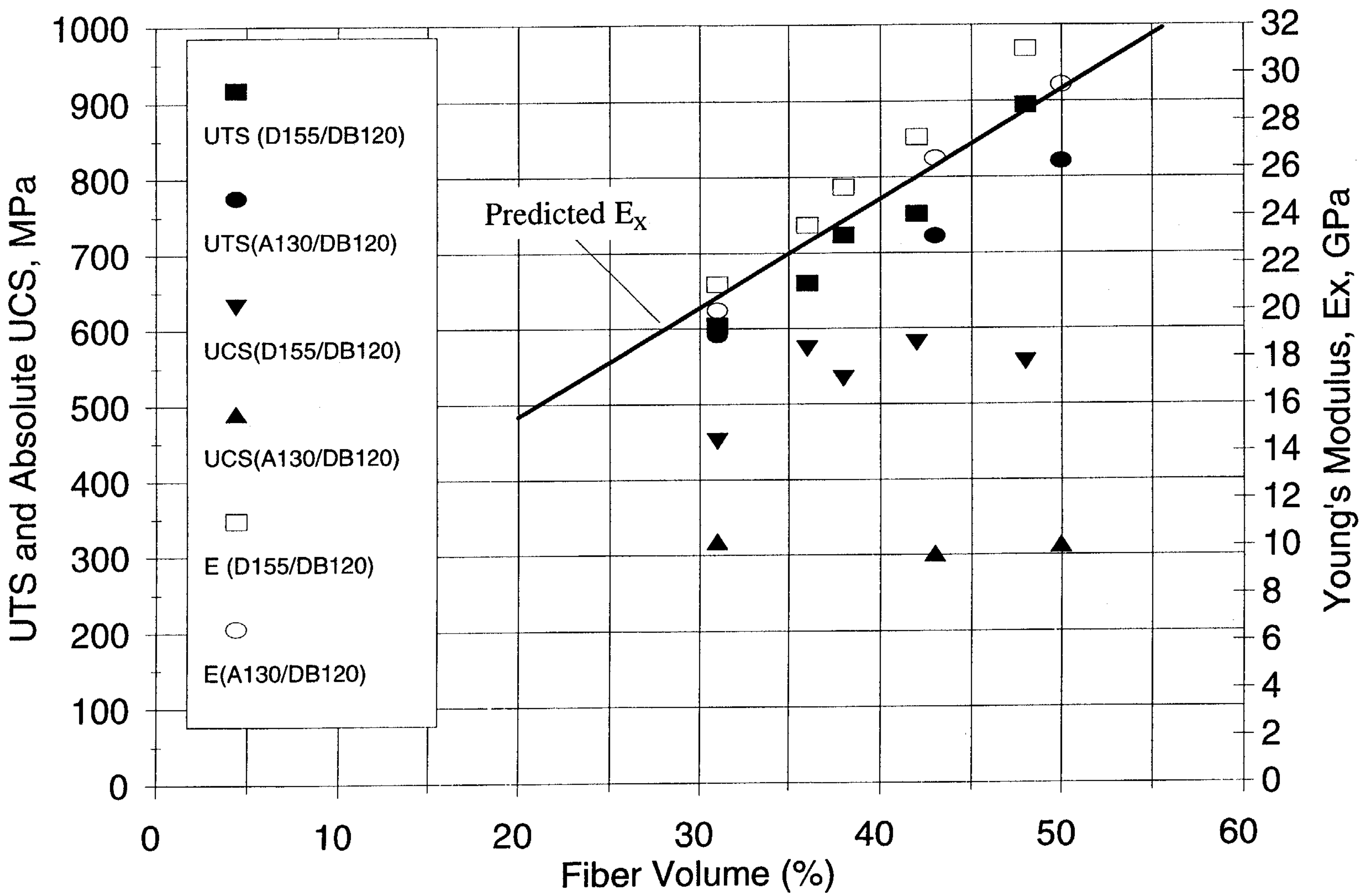


FIGURE 11

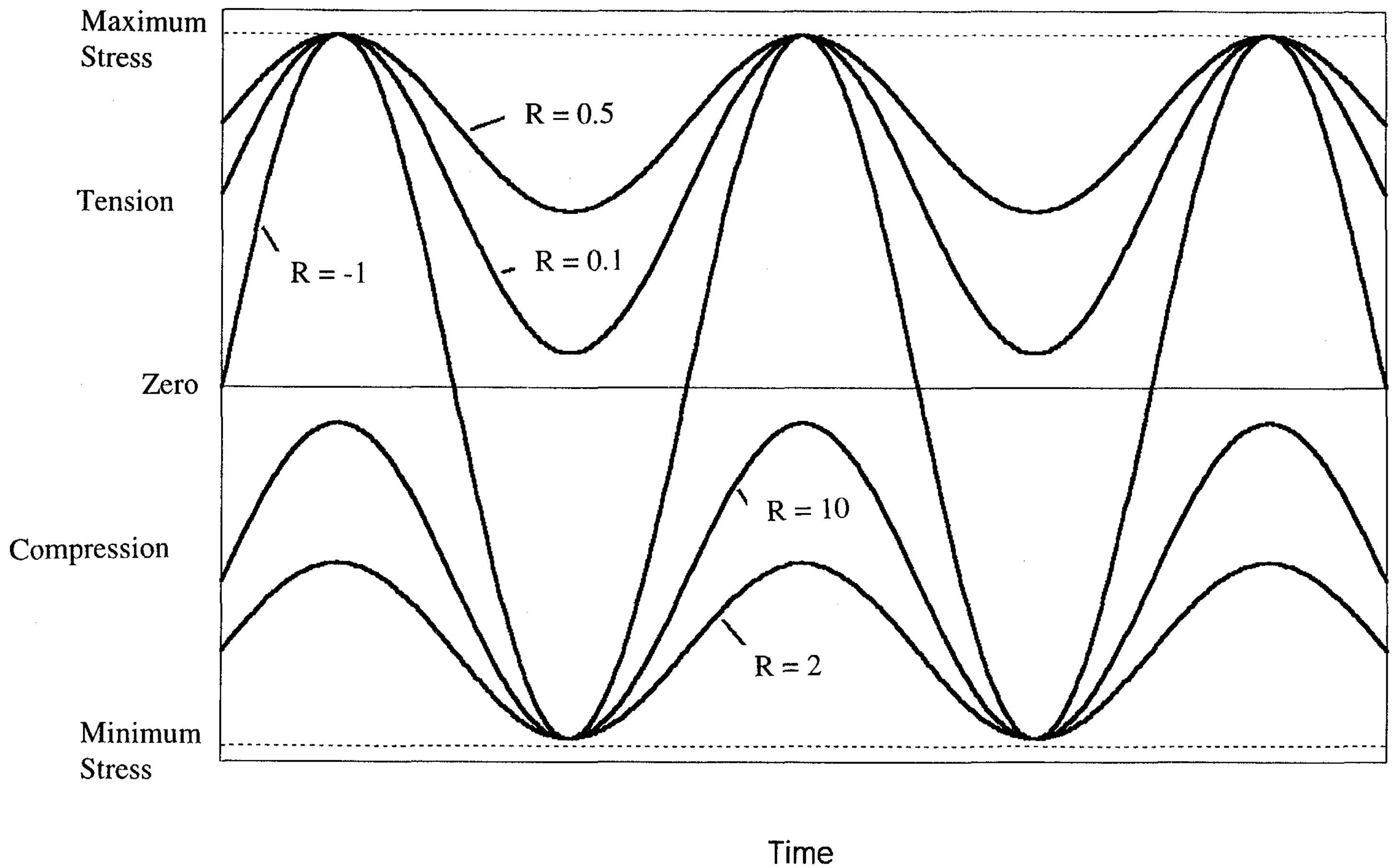


FIGURE 12. Constant Stress Amplitude Sine Waveforms for Different R Values

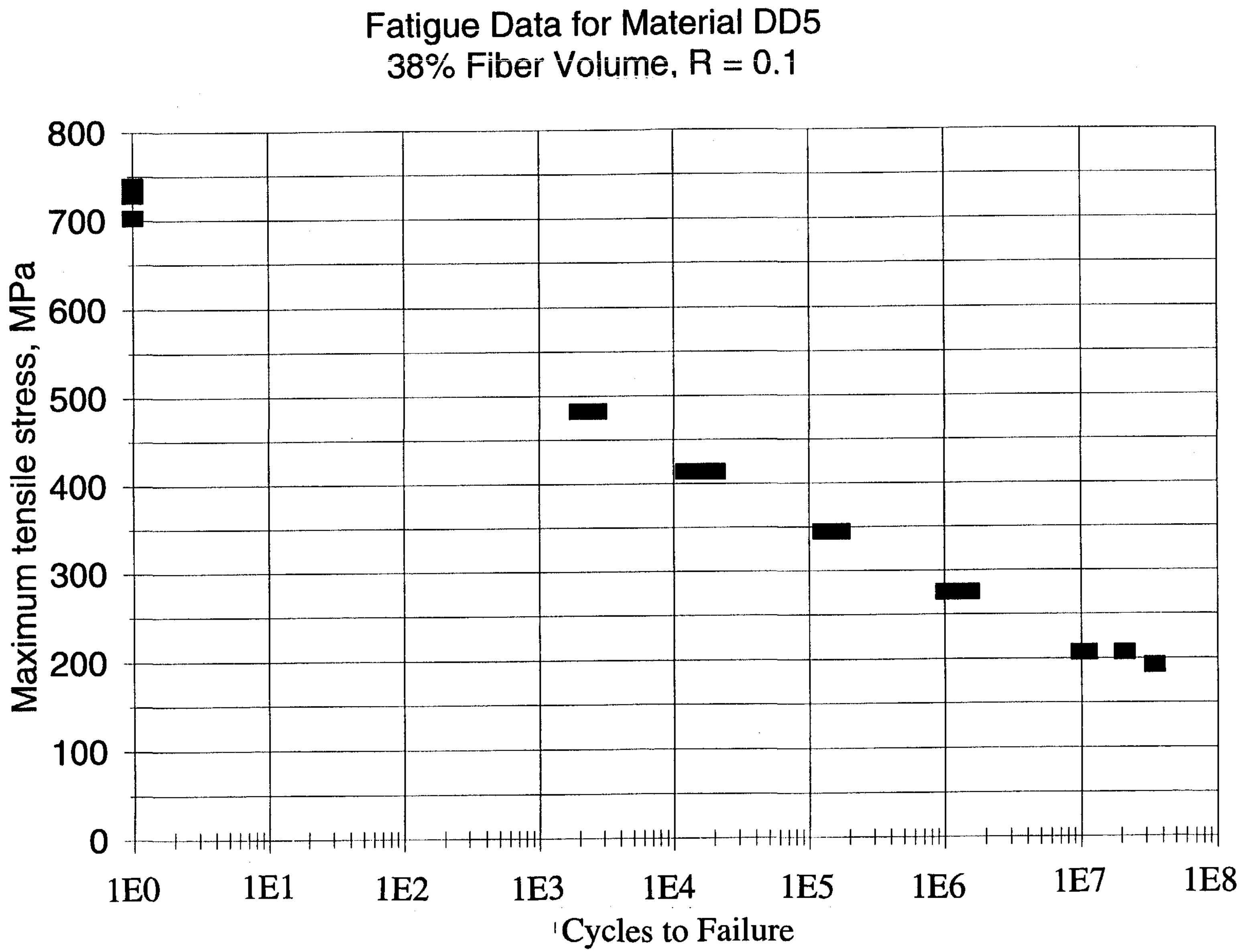

Fatigue Data for Material DD5
38% Fiber Volume, R = 0.1
Maximum tensile stress, MPa
800
700
600
500
400
300
200
100
0
1E0
1E1
1E2
1E3
1E4
1E5
1E6
1E7
1E8
Cycles to Failure

FIGURE 13 (a)

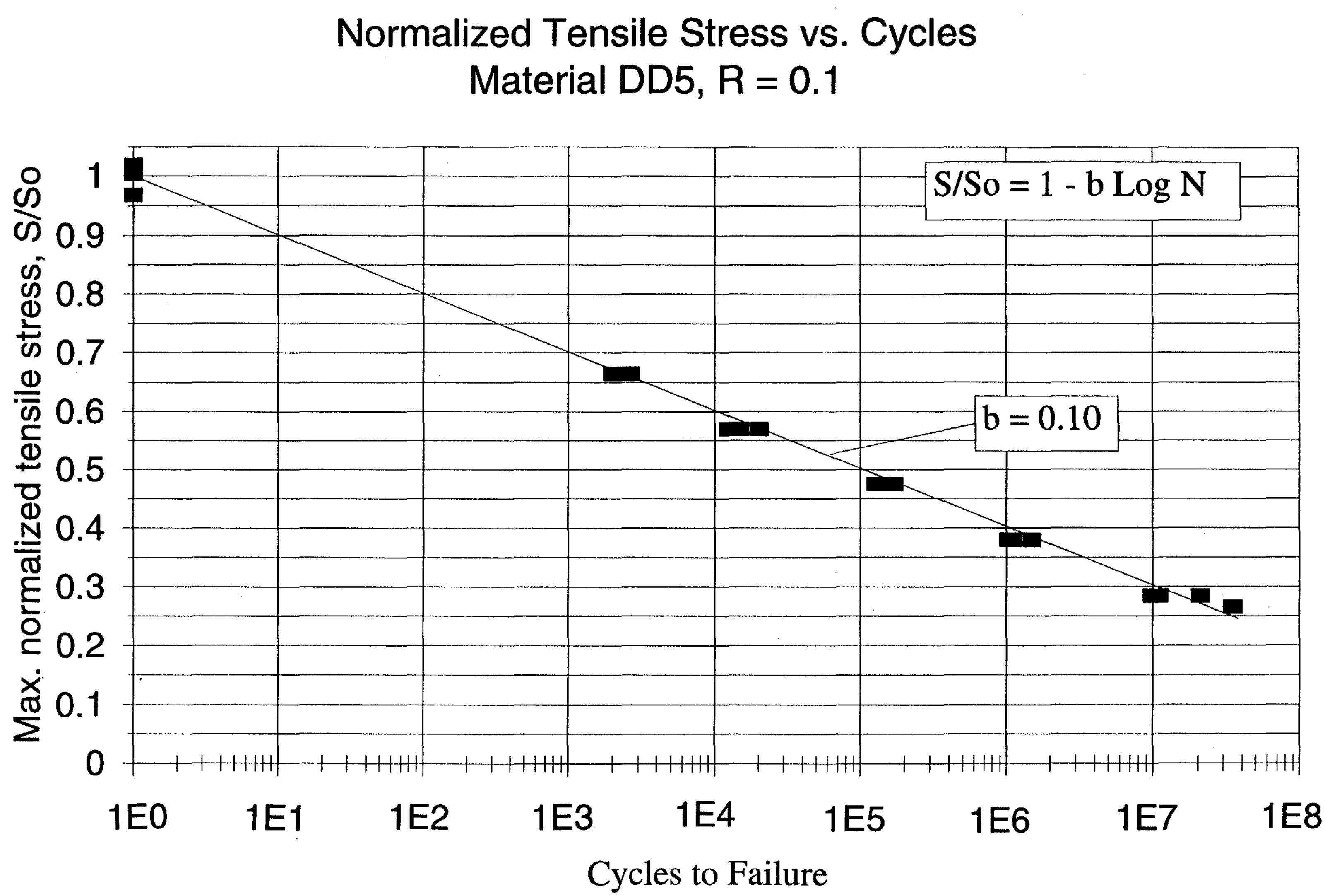
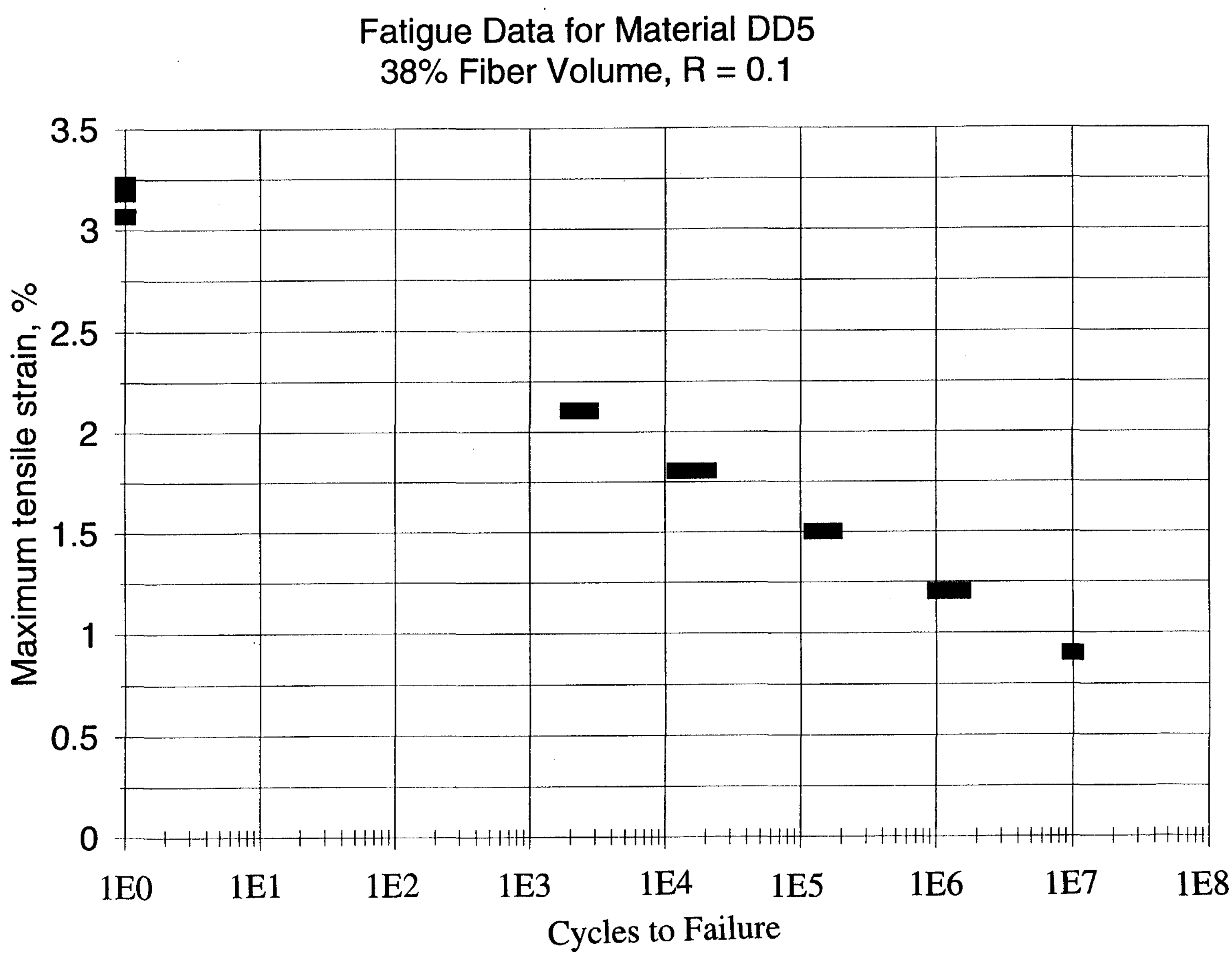

Normalized Tensile Stress vs. Cycles
Material DD5, R = 0.1
S/So = 1 - b Log N
b = 0.10
Max. normalized tensile stress, S/So
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1E0
1E1
1E2
1E3
1E4
1E5
1E6
1E7
1E8
Cycles to Failure

FIGURE 13 (b)



Fatigue Data for Material DD5
38% Fiber Volume, R = 0.1
Maximum tensile strain, %
3.5
3
2.5
2
1.5
1
0.5
0
1E0
1E1
1E2
1E3
1E4
1E5
1E6
1E7
1E8
Cycles to Failure

FIGURE 14

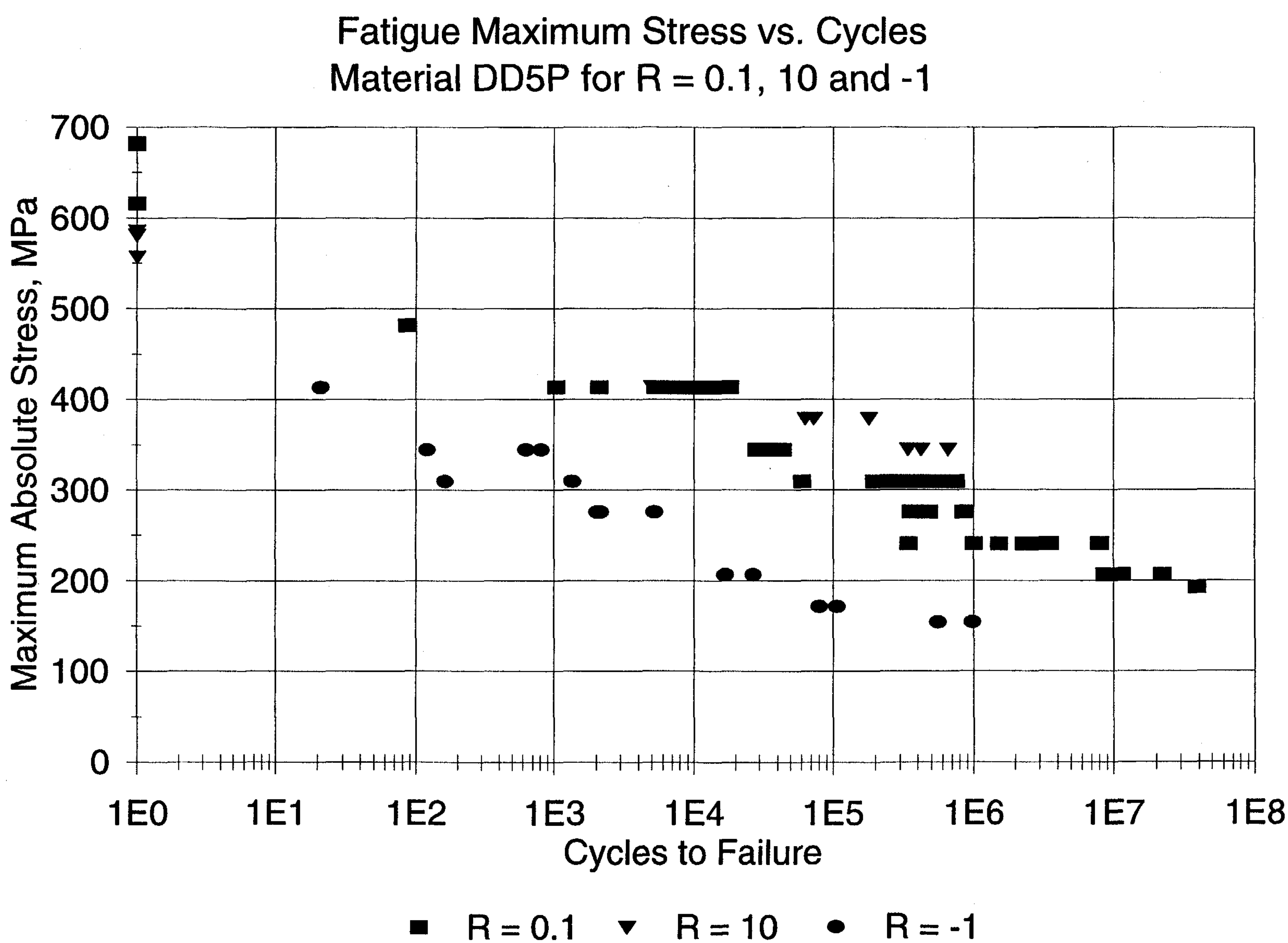

Fatigue Maximum Stress vs. Cycles
Material DD5P for R = 0.1, 10 and -1
Maximum Absolute Stress, MPa
0
100
200
300
400
500
600
700
1E0
1E1
1E2
1E3
1E4
1E5
1E6
1E7
1E8
Cycles to Failure
R = 0.1
R = 10
R = -1

FIGURE 15

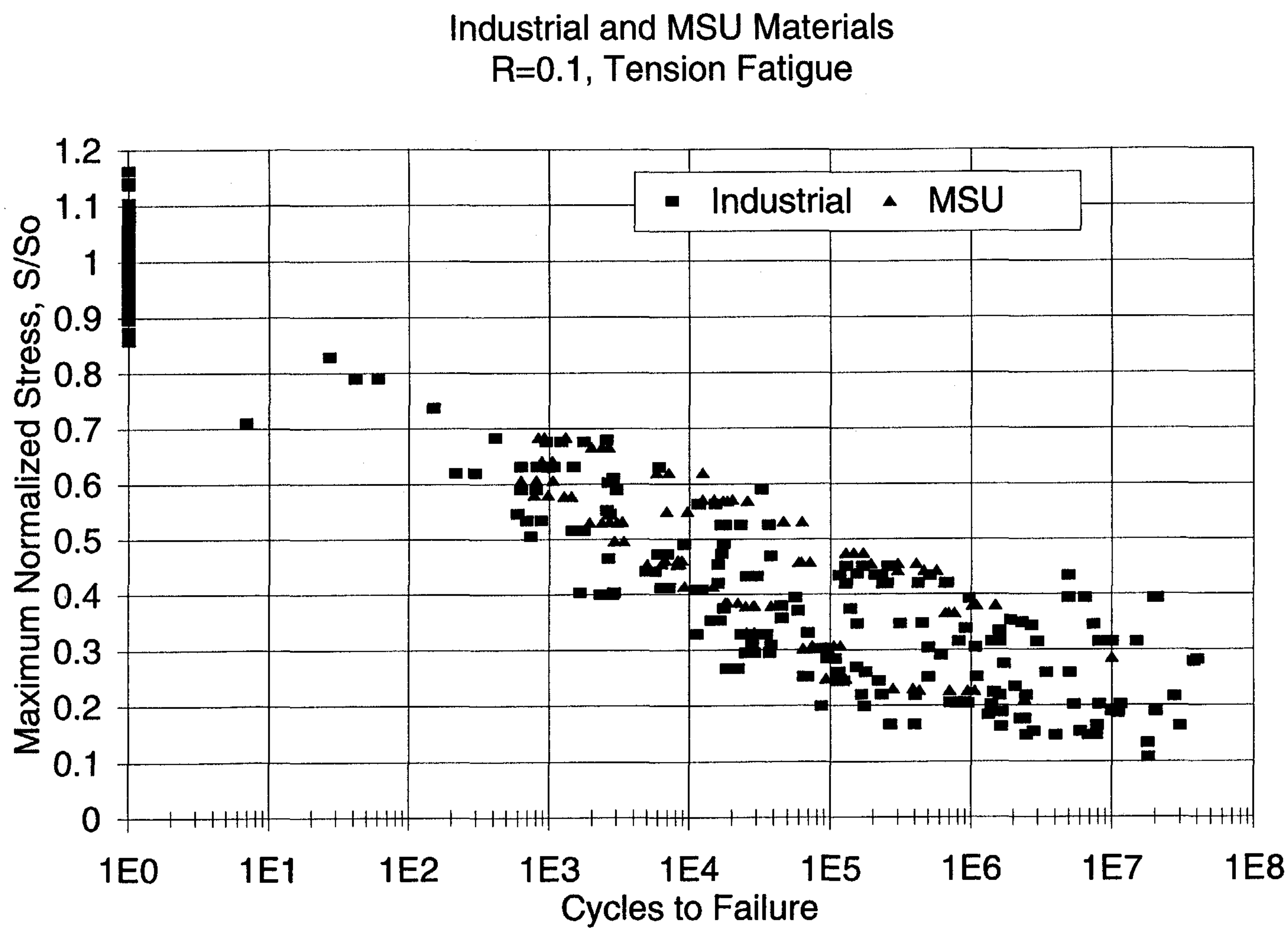

Industrial and MSU Materials
R=0.1, Tension Fatigue
Industrial
MSU
Maximum Normalized Stress, S/So
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
1E0
1E1
1E2
1E3
1E4
1E5
1E6
1E7
1E8
Cycles to Failure

FIGURE 16.

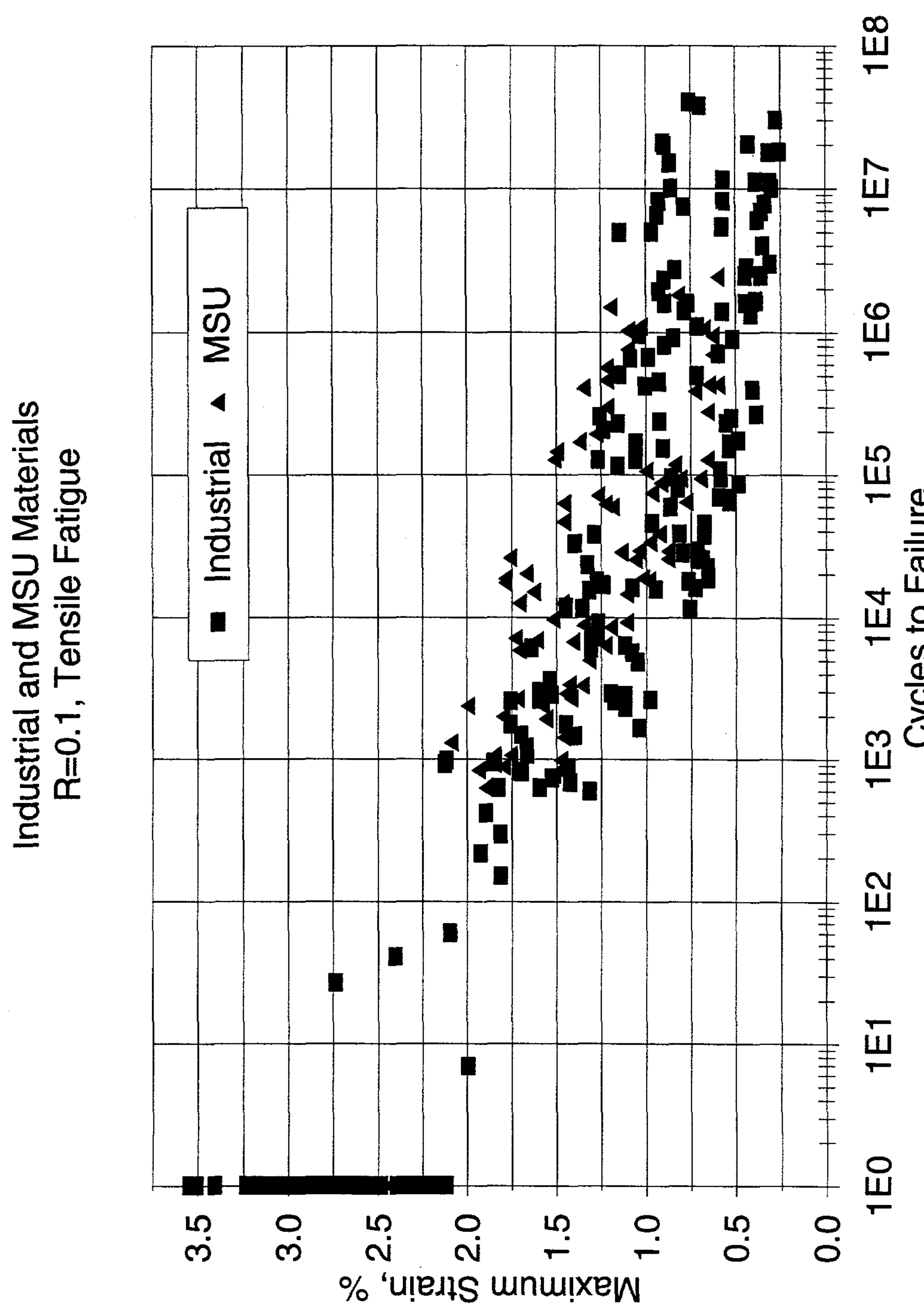

Industrial and MSU Materials
R=0.1, Tensile Fatigue
Industrial
MSU
Maximum Strain, %
3.5
3.0
2.5
2.0
1.5
1.0
0.5
0.0
1E0
1E1
1E2
1E3
1E4
1E5
1E6
1E7
1E8
Cycles to Failure

FIGURE 17.

Extremes of Normalized S-N Tensile Fatigue Data (R = 0.1) for Fiberglass Laminates With at Least 25% of the Fiber in the Zero Degree Direction

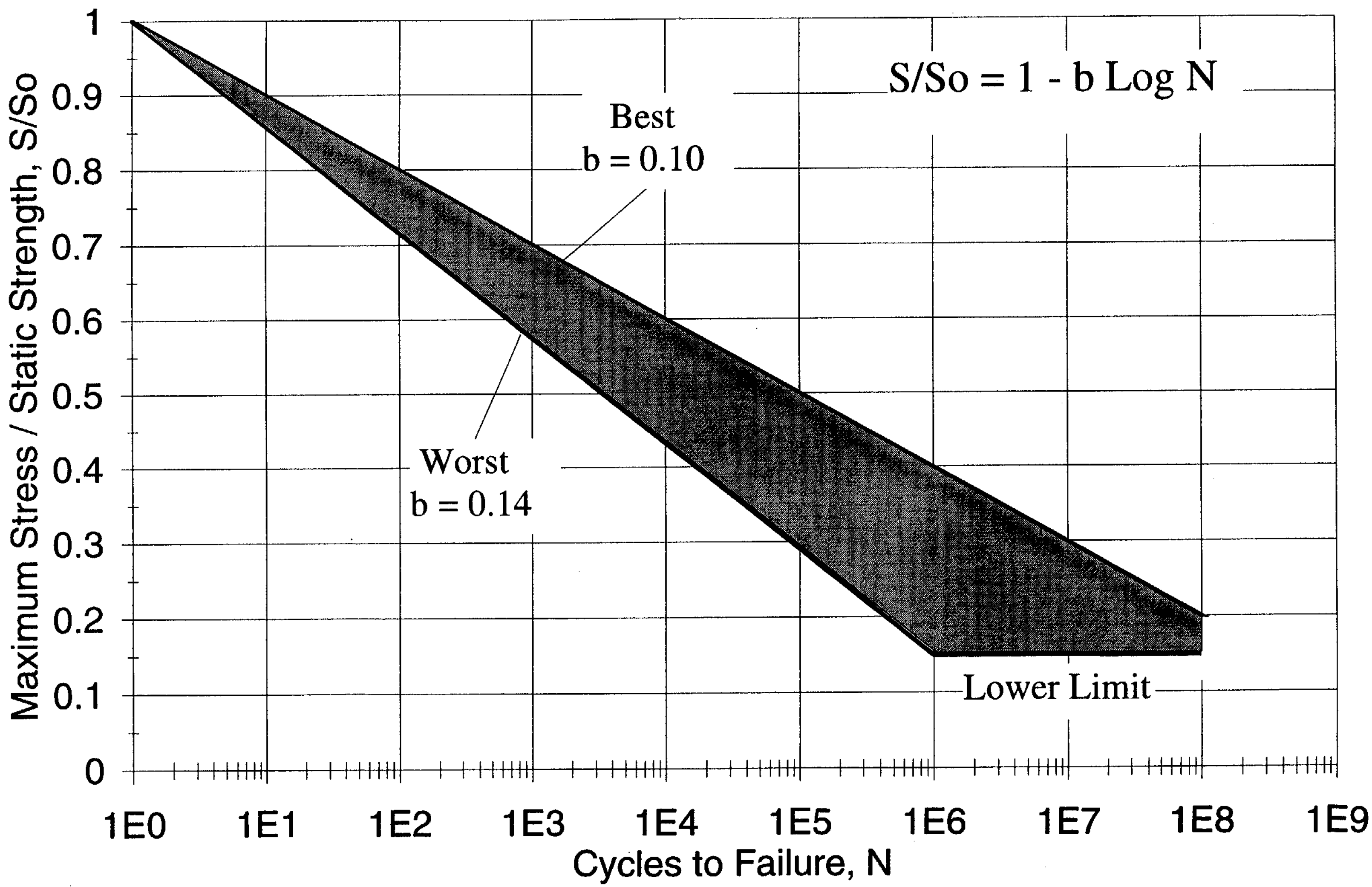
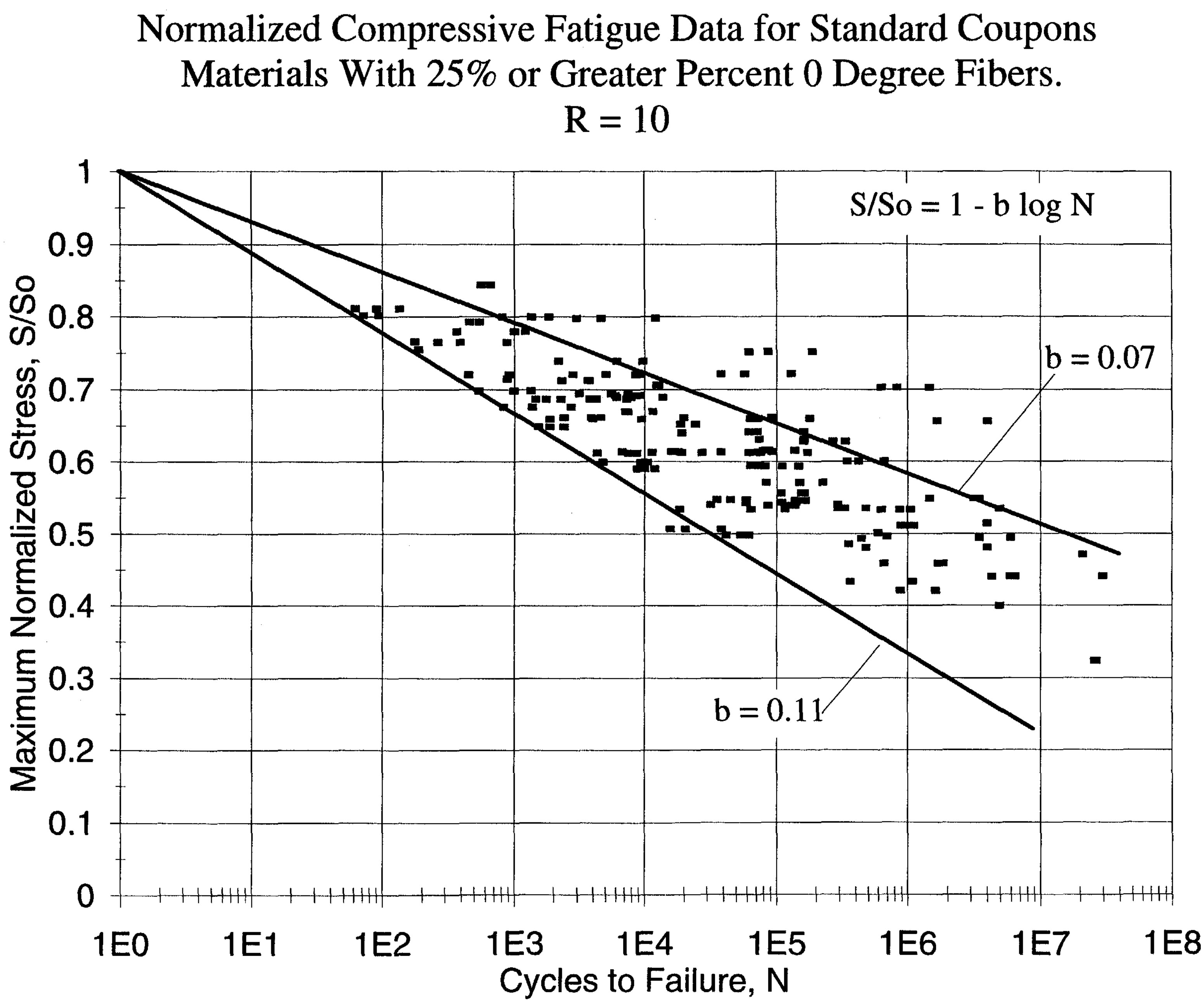


FIGURE 18.



Normalized Compressive Fatigue Data for Standard Coupons
Materials With 25% or Greater Percent 0 Degree Fibers.
R = 10
S/So = 1 - b log N
b = 0.07
b = 0.11
Maximum Normalized Stress, S/So
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
1E0
1E1
1E2
1E3
1E4
1E5
1E6
1E7
1E8
Cycles to Failure, N

FIGURE 19.

Reversed Loading Fatigue Data Normalized by the Compressive Strength
Materials With 25% or Greater Percent 0 Degree Fibers.
R = -1

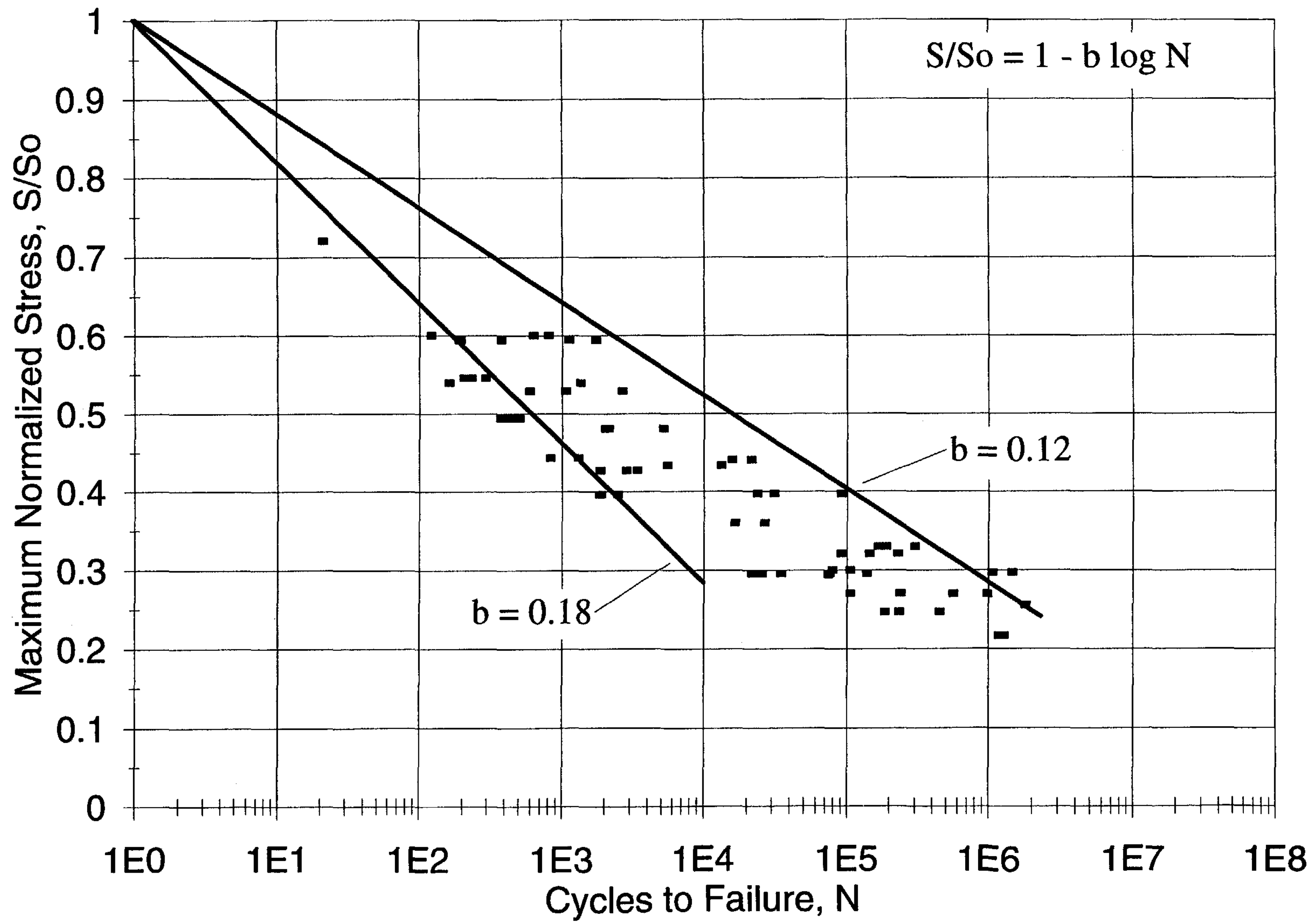


FIGURE 20.

Reversed Loading Fatigue Data Normalized by the Tensile Strength Materials With 25% or Greater Percent 0 Degree Fibers.
R = -1

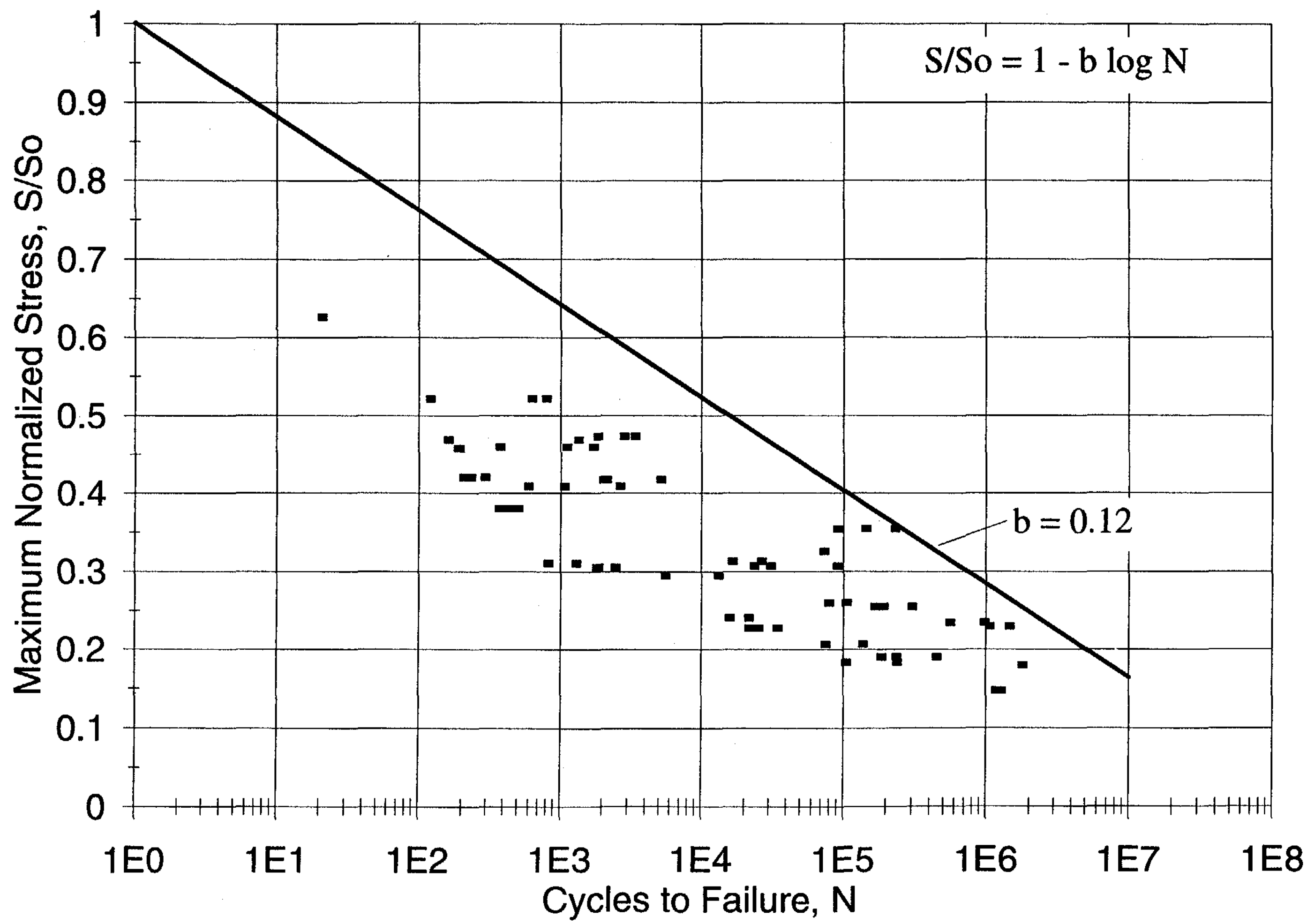


FIGURE 21.

	STRESS CONCENTRATION IN 0° PLY DUE TO A 90° PLY CRACK
NO MATRIX INTERLAYER	2.46
0.01 h INTERLAYER CRACKED	1.71
0.01 h INTERLAYER NOT CRACKED	1.39
h = PLY THICKNESS	

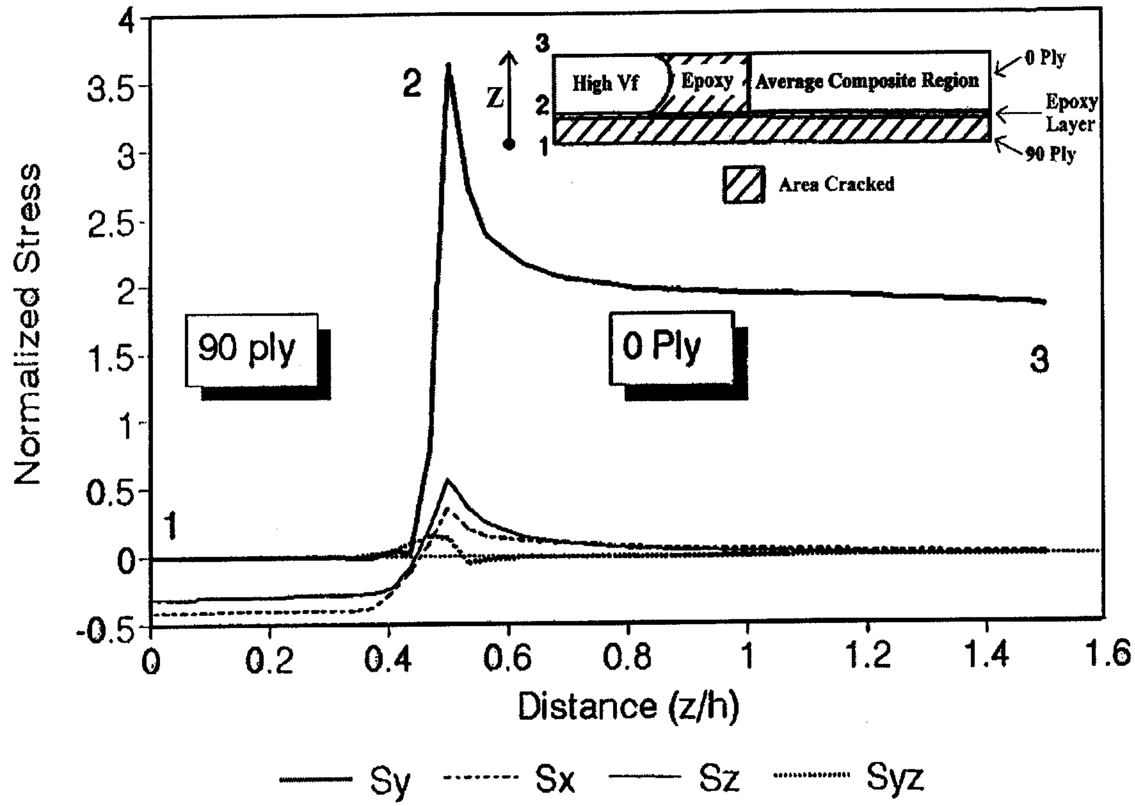


FIGURE 22. Effect of Matrix Layer on Local Stress Concentrations Near Strands (Assuming Matrix Layer is Cracked) From Finite Element Analysis

Strain Fatigue Data Correlation for $[\pm 45]_S$ and $[0/\pm 45/0]_S$ Materials
R = 0.1

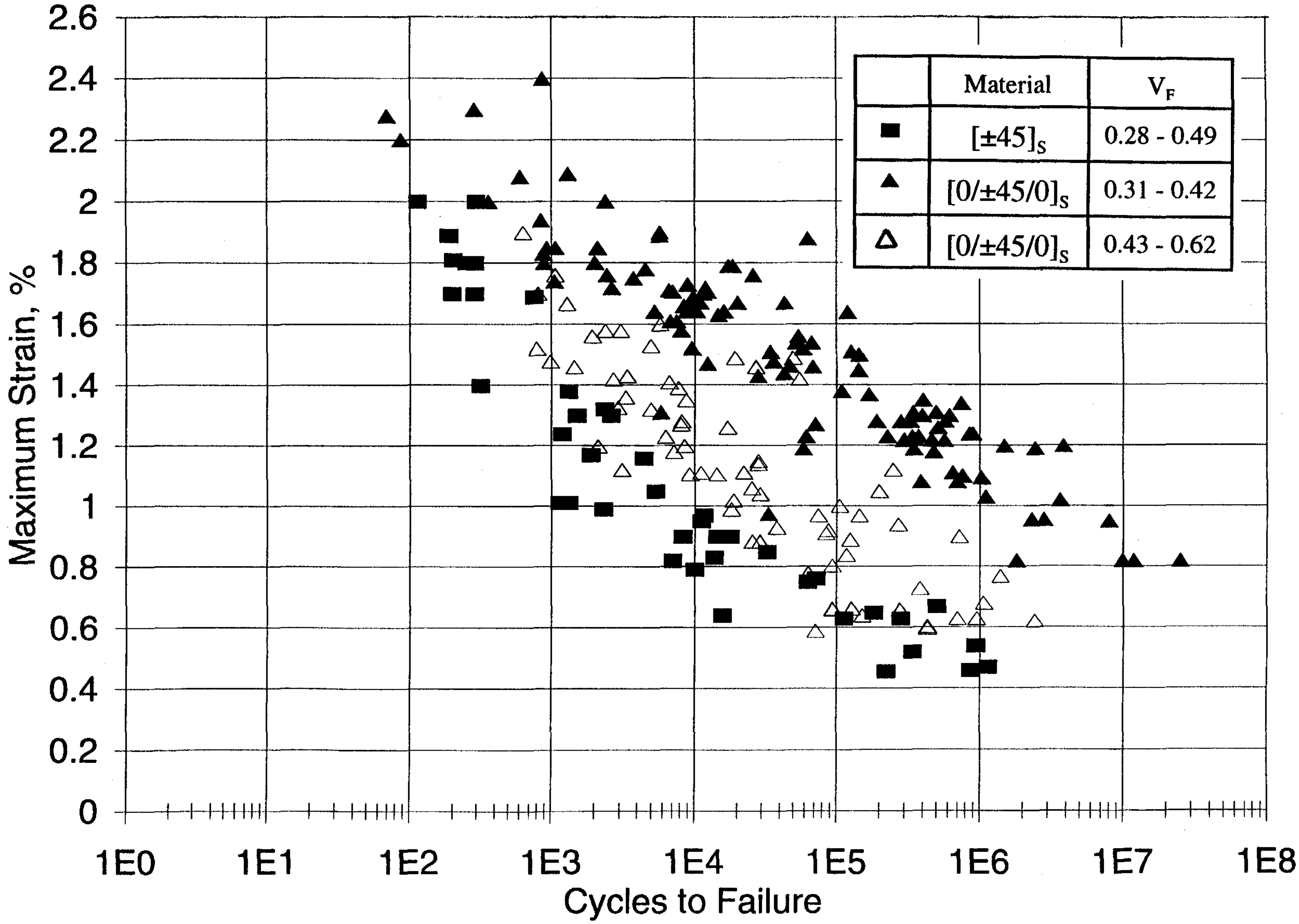
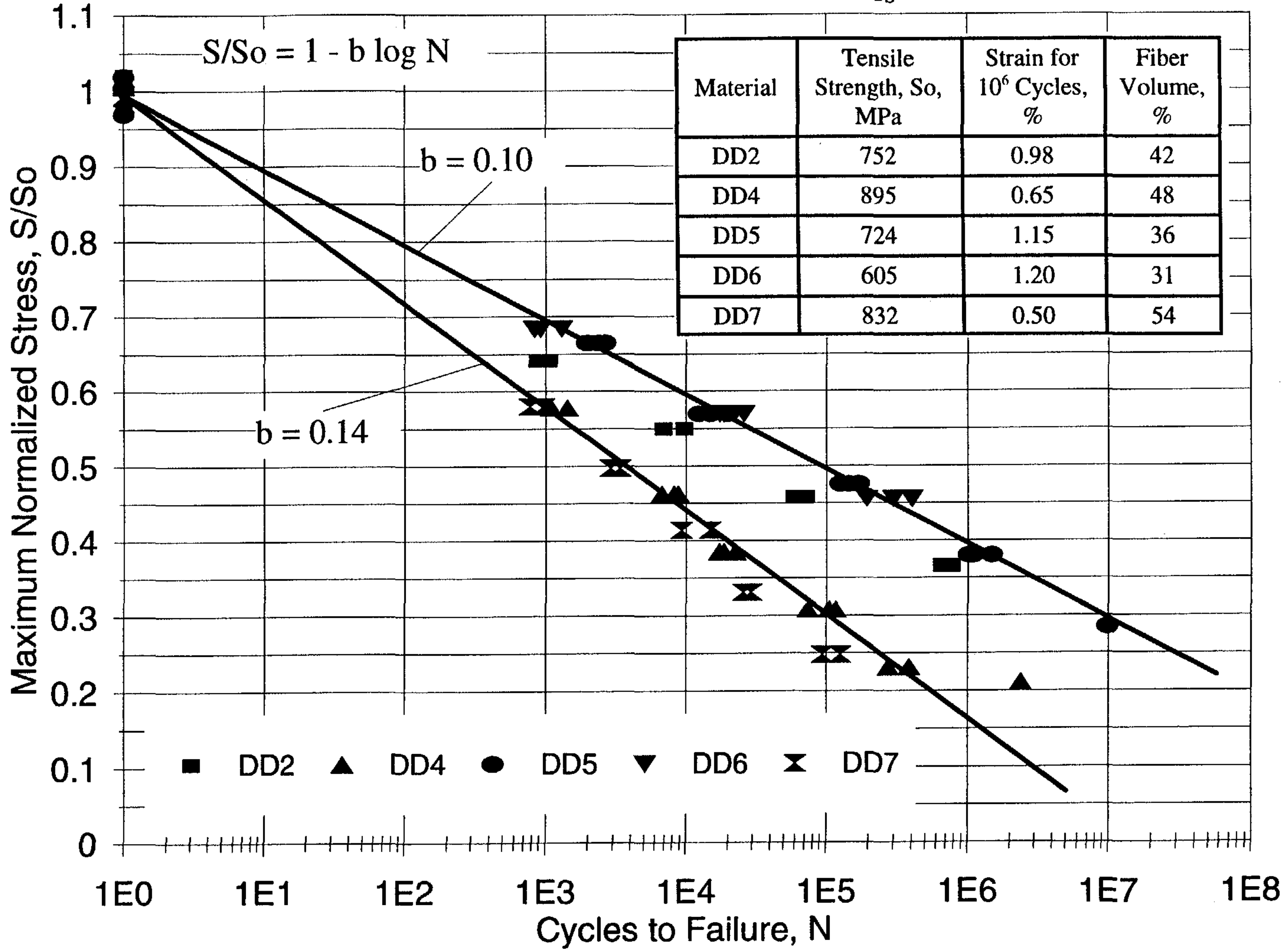


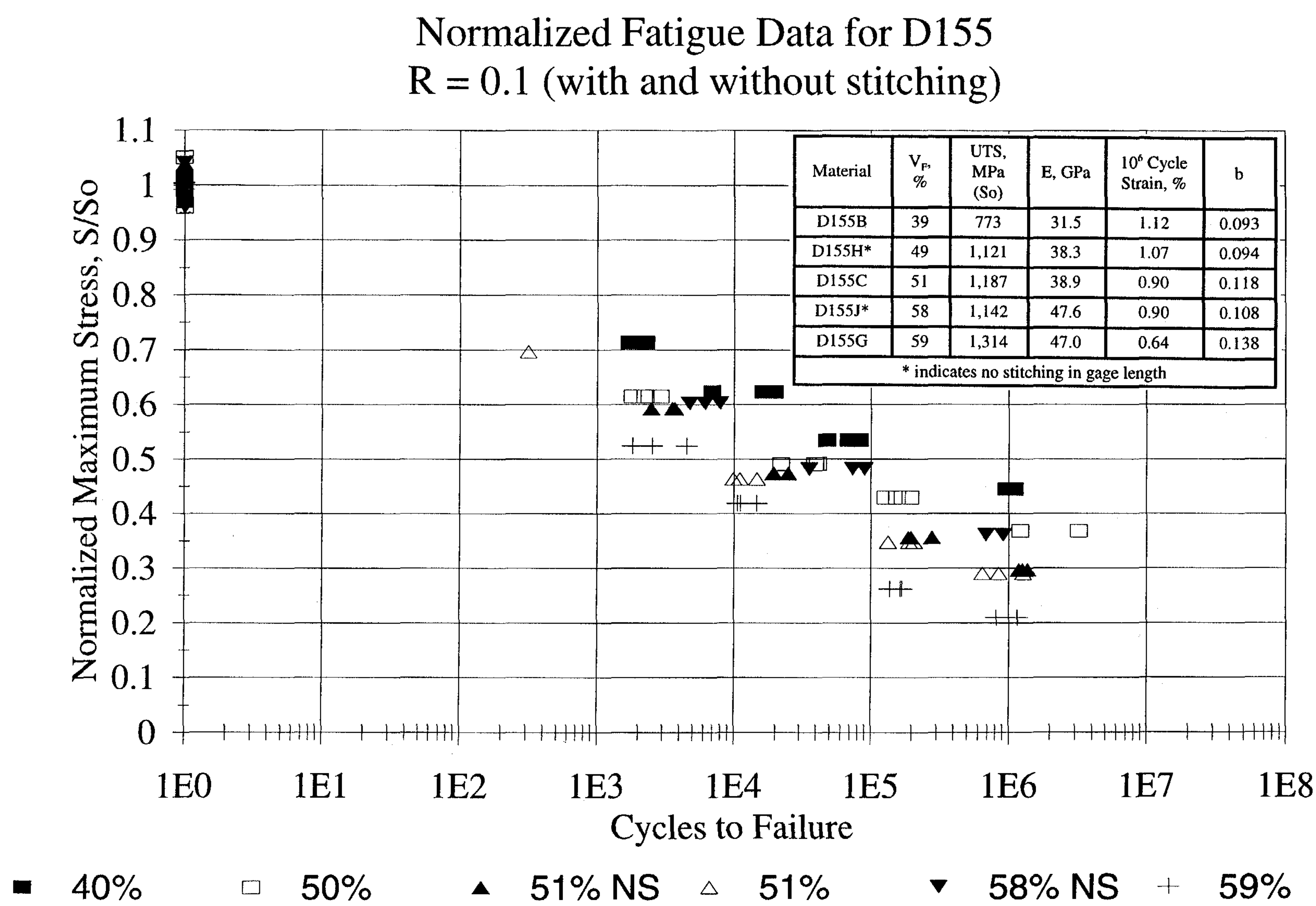
FIGURE 23.

Effect of Fiber Content on the Normalized S - N Data, R = 0.1
for DD Materials $[0/\pm45/0]_S$



Material	Tensile Strength, So, MPa	Strain for 10^6 Cycles, %	Fiber Volume, %
DD2	752	0.98	42
DD4	895	0.65	48
DD5	724	1.15	36
DD6	605	1.20	31
DD7	832	0.50	54

FIGURE 24



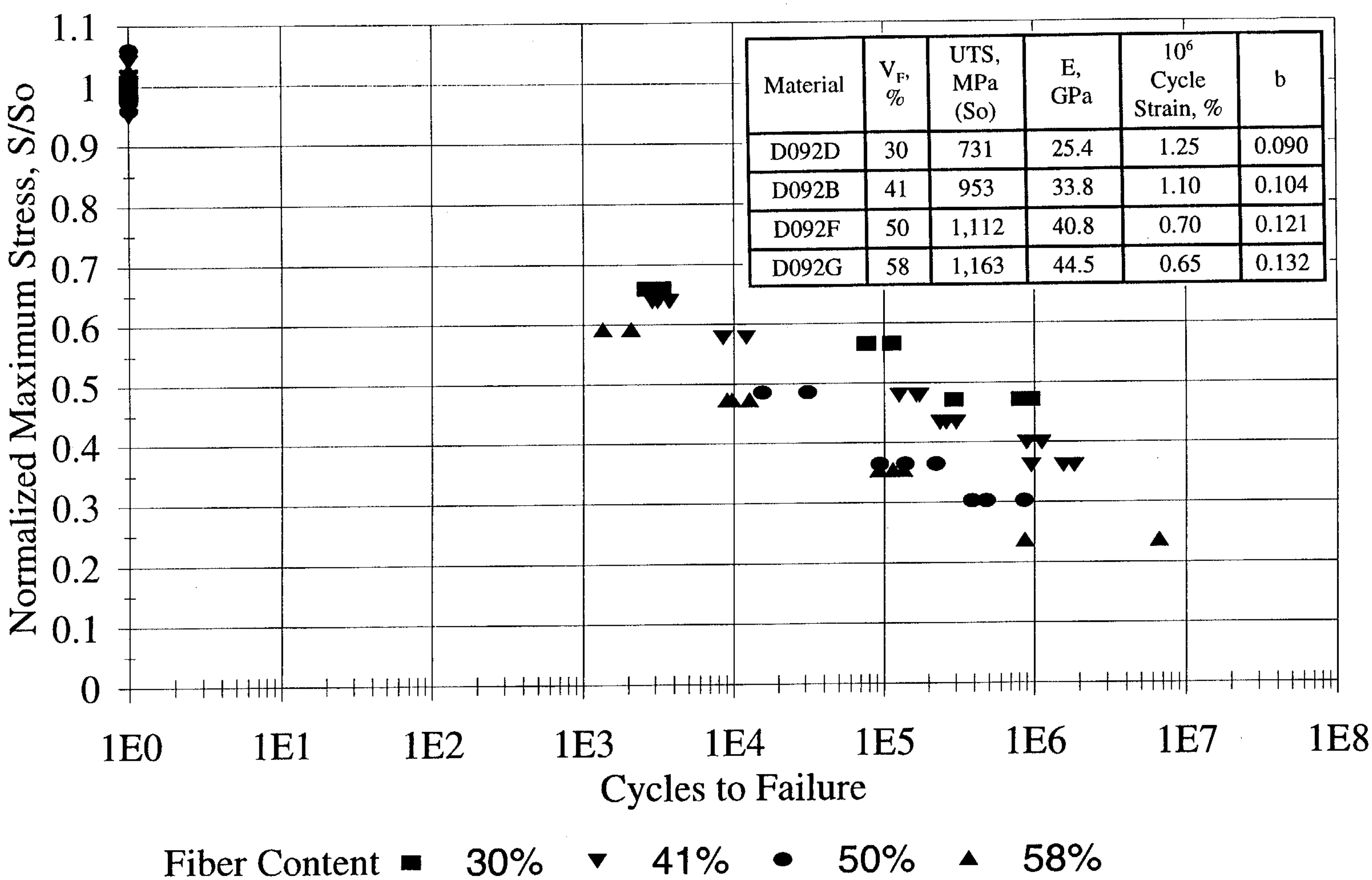
Material	V_F, %	UTS, MPa (So)	E, GPa	10^6 Cycle Strain, %	b
D155B	39	773	31.5	1.12	0.093
D155H*	49	1,121	38.3	1.07	0.094
D155C	51	1,187	38.9	0.90	0.118
D155J*	58	1,142	47.6	0.90	0.108
D155G	59	1,314	47.0	0.64	0.138

* indicates no stitching in gage length

FIGURE 25

Normalized Fatigue Data for D092

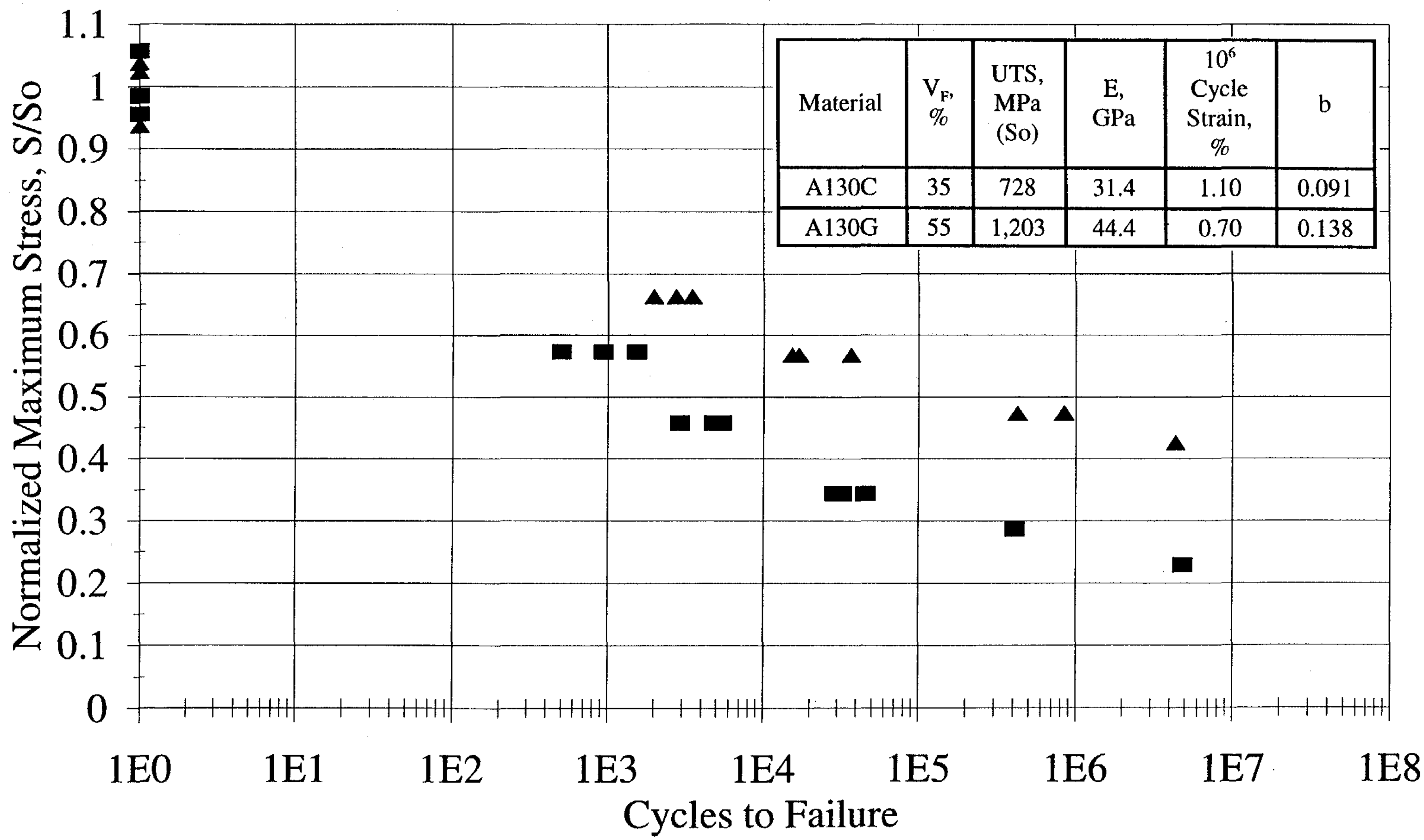
R = 0.1



Material	V_F, %	UTS, MPa (So)	E, GPa	10^6 Cycle Strain, %	b
D092D	30	731	25.4	1.25	0.090
D092B	41	953	33.8	1.10	0.104
D092F	50	1,112	40.8	0.70	0.121
D092G	58	1,163	44.5	0.65	0.132

FIGURE 26

Normalized Fatigue Data for A130
R = 0.1



Material	V_F, %	UTS, MPa (So)	E, GPa	10^6 Cycle Strain, %	b
A130C	35	728	31.4	1.10	0.091
A130G	55	1,203	44.4	0.70	0.138

FIGURE 27

Fiber Content vs. Fatigue Coefficient, b
S/So = 1 - b Log N, A130, D092, D155, DD and Triax Materials, R = 0.1

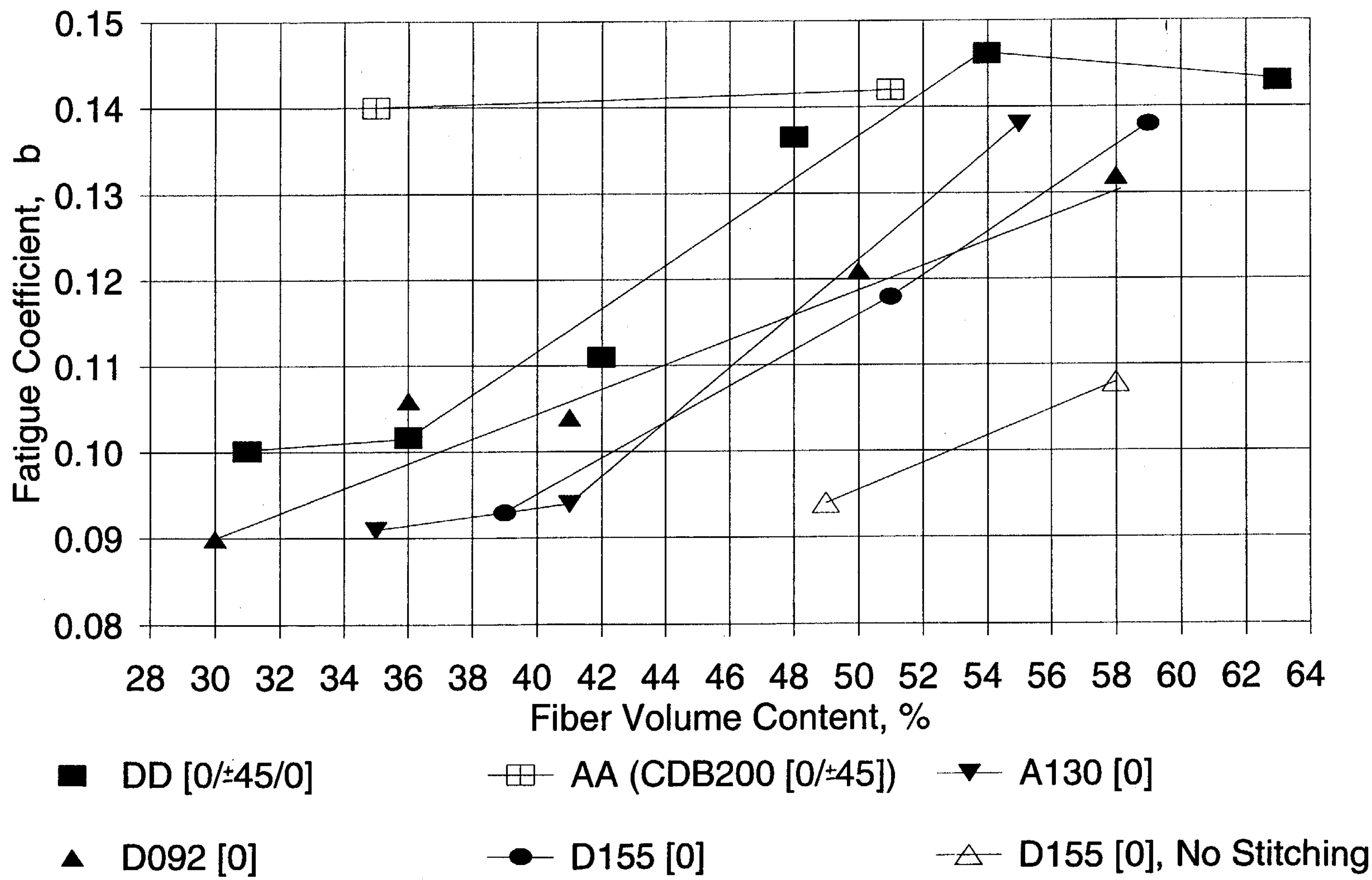
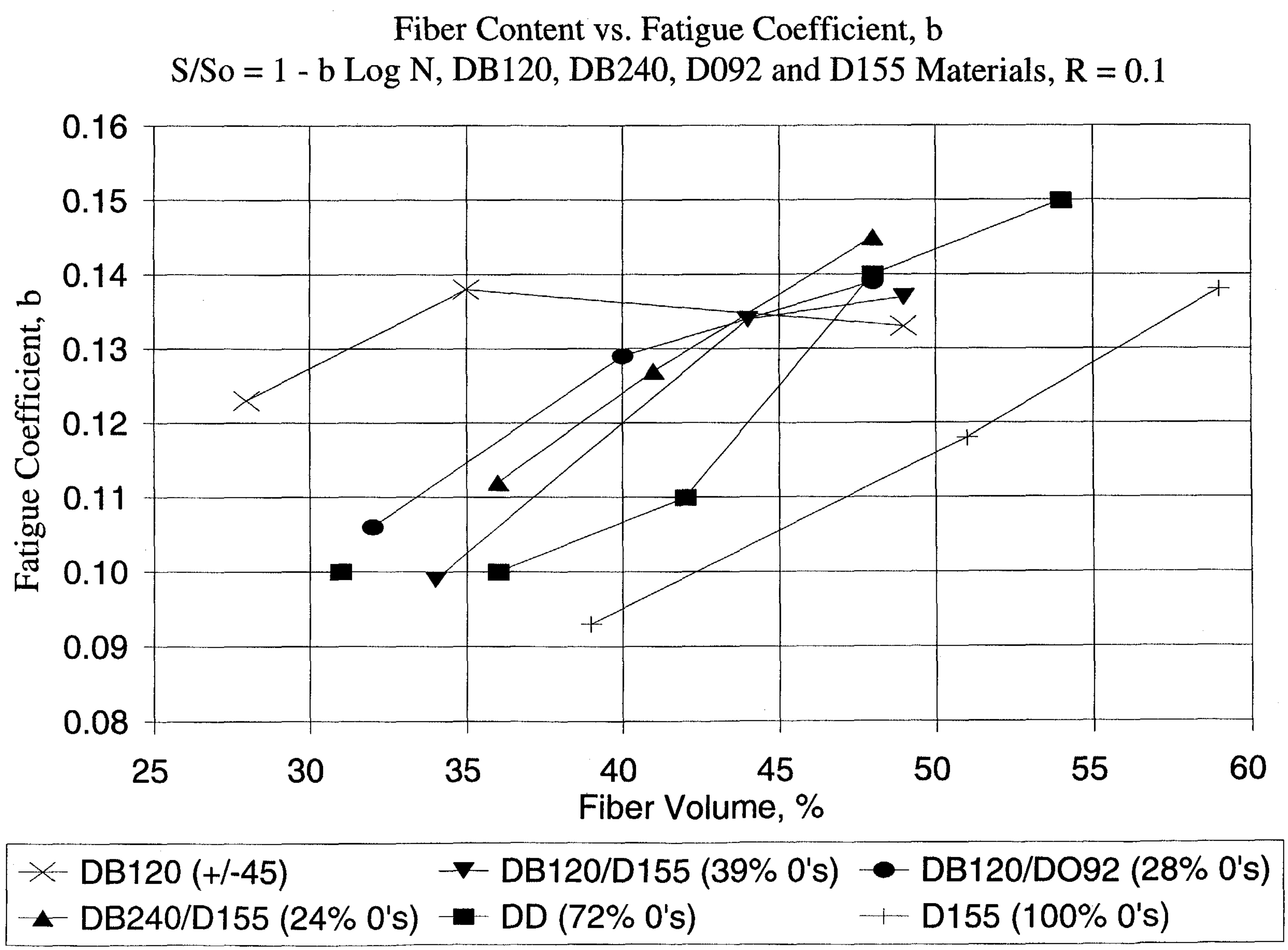
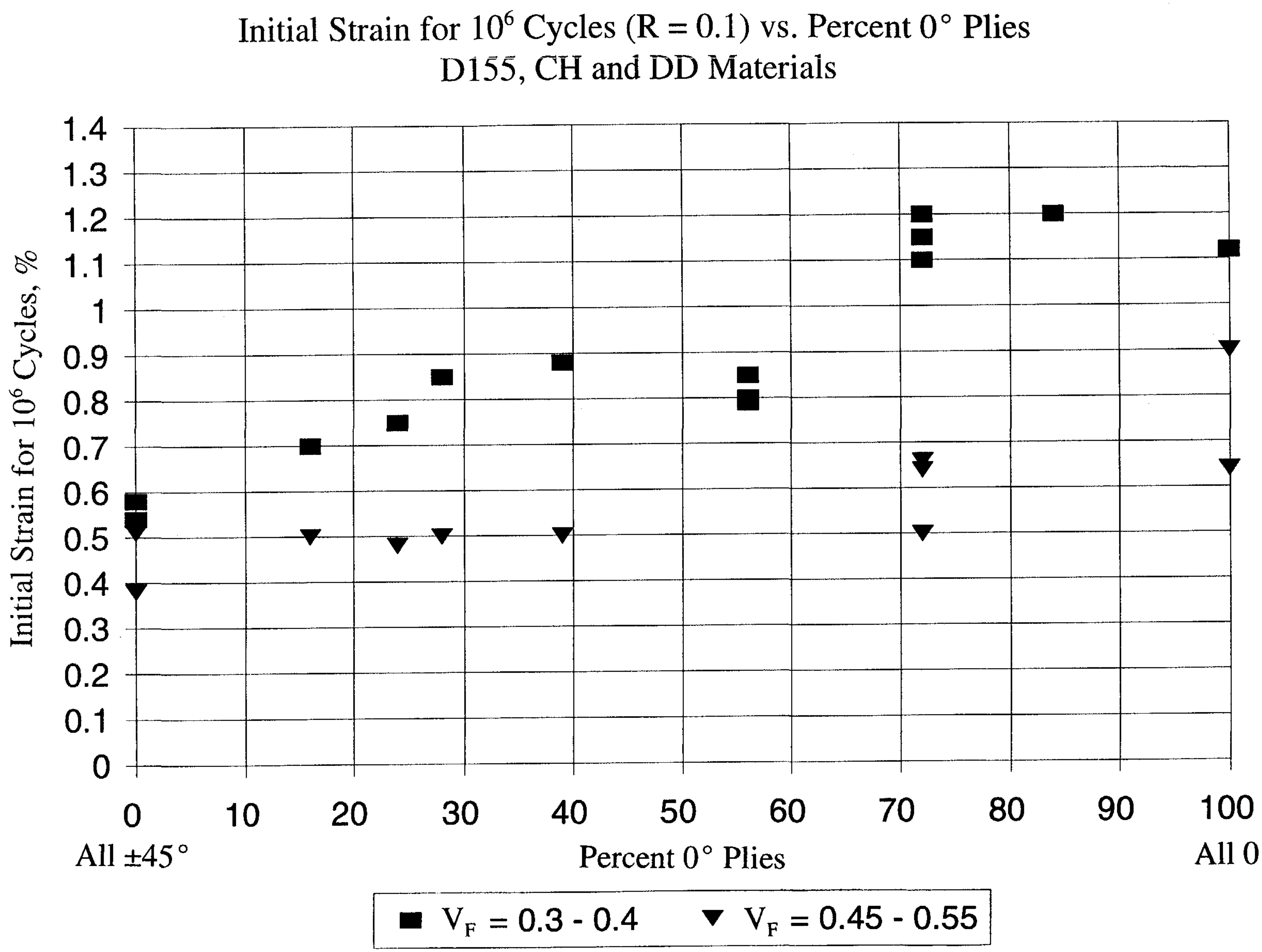


FIGURE 28



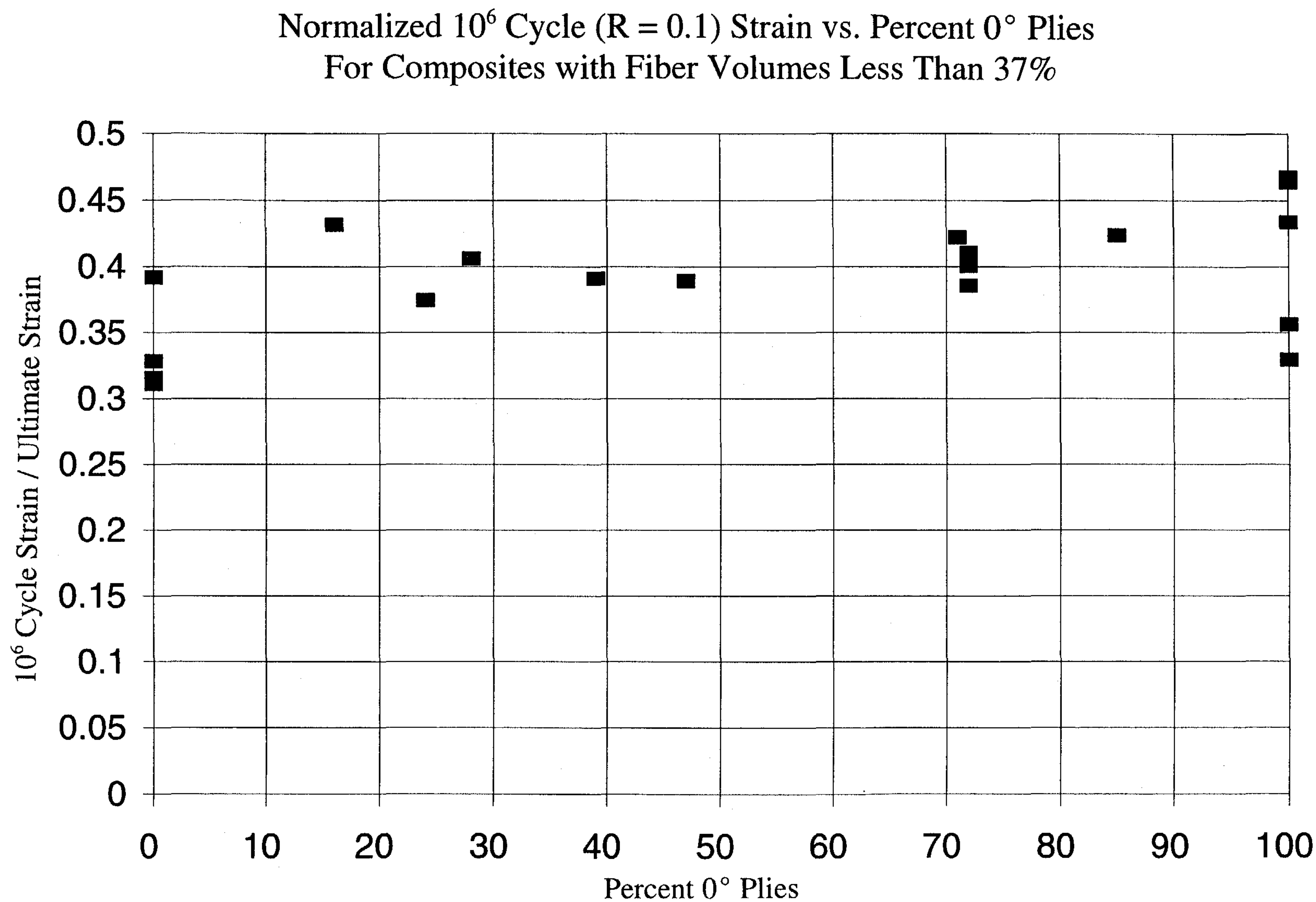
Fiber Content vs. Fatigue Coefficient, b
S/So = 1 - b Log N, DB120, DB240, D092 and D155 Materials, R = 0.1
Fatigue Coefficient, b
0.16
0.15
0.14
0.13
0.12
0.11
0.10
0.09
0.08
25
30
35
40
45
50
55
60
Fiber Volume, %
DB120 (+/-45)
DB120/D155 (39% 0's)
DB120/DO92 (28% 0's)
DB240/D155 (24% 0's)
DD (72% 0's)
D155 (100% 0's)

FIGURE 29.



Initial Strain for 10^6 Cycles (R = 0.1) vs. Percent 0° Plies
D155, CH and DD Materials
Initial Strain for 10^6 Cycles, %
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
10
20
30
40
50
60
70
80
90
100
All ±45°
Percent 0° Plies
All 0°
V_F = 0.3 - 0.4
V_F = 0.45 - 0.55

FIGURE 30.



Normalized 10^6 Cycle (R = 0.1) Strain vs. Percent 0° Plies
For Composites with Fiber Volumes Less Than 37%
0.5
0.45
0.4
0.35
0.3
0.25
0.2
0.15
0.1
0.05
0
10^6 Cycle Strain / Ultimate Strain
0
10
20
30
40
50
60
70
80
90
100
Percent 0° Plies

FIGURE 31.

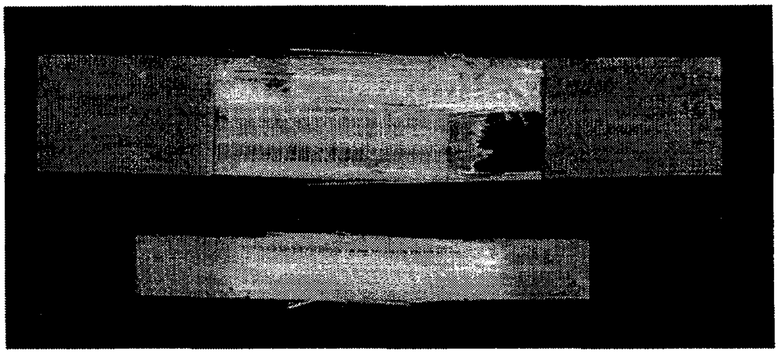


FIGURE 32 (a) Comparison of tensile fatigue test coupons, unidirectional Material A ($V_F = 30\%$). Standard test coupon (top) and thickness tapered coupon (bottom).

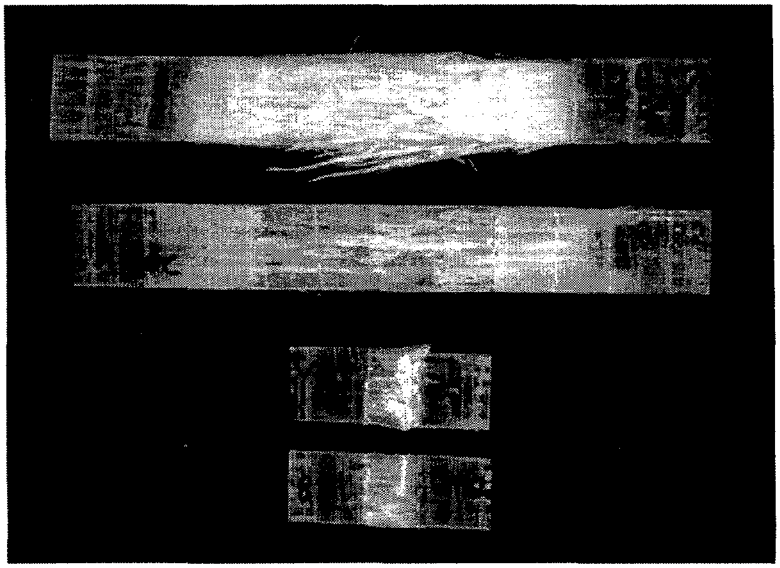


FIGURE 32 (b) Unidirectional materials based on A130 fabric (Material A130C, $V_F = 35\%$), From top to bottom: Static tensile coupon; tensile fatigue (R = 0.1, 345 MPa); Static compression, and compression fatigue (R = 10, 276 MPa)

FIGURE 32 Failure Modes

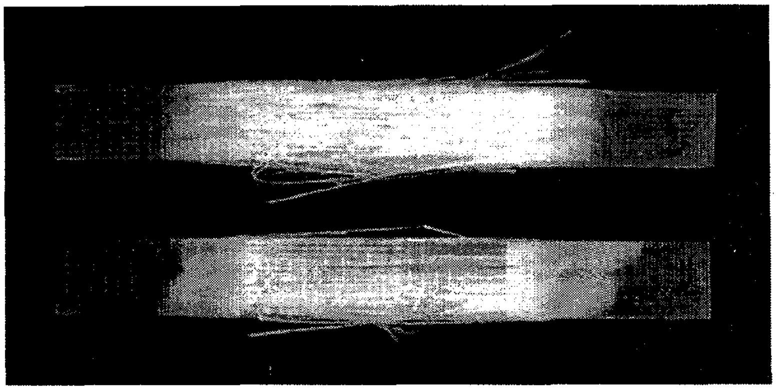


FIGURE 32 (c) Unidirectional low fiber content materials based on D155 fabric (Material D155B, $V_F = 39\%$). Static coupon (top), tensile fatigue R = 0.1, 345 MPa (bottom)

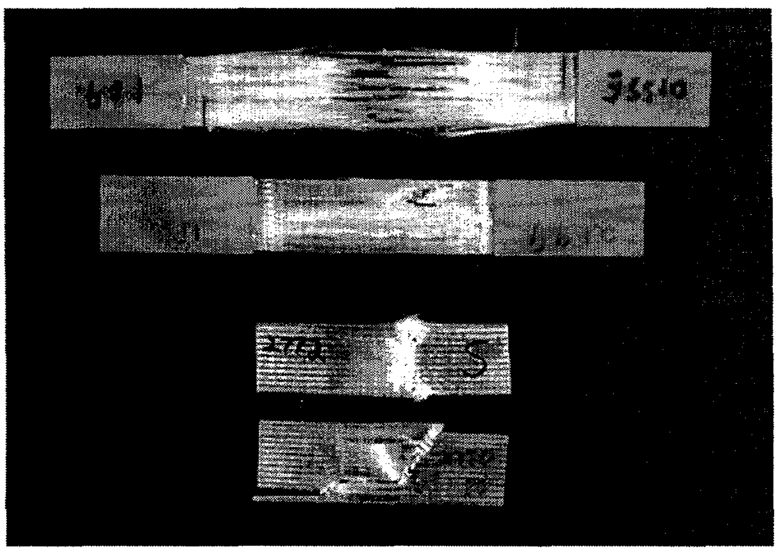


FIGURE 32 (d) Unidirectional high fiber content materials based on D155 fabric (Material D155G, $V_F = 59\%$). From top to bottom: tensile fatigue, R = 0.1 coupons tested at 552 and 276 MPa; static compression and compression fatigue (R = 10, 483 MPa).

FIGURE 32 Failure Modes

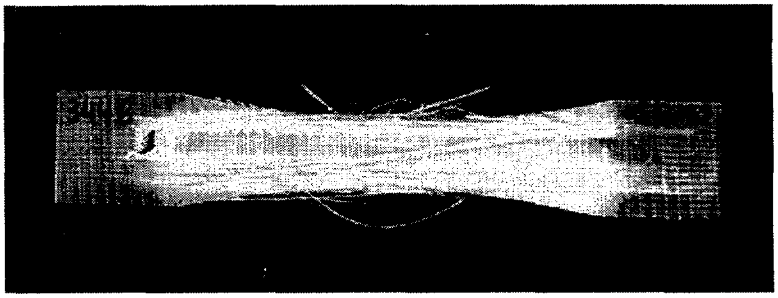


FIGURE 32 (e) Material GG ($V_F = 40\%$) with 84% 0° in the loading direction showing heavy brooming upon failure, tensile fatigue (R = 0.1, 345 MPa).

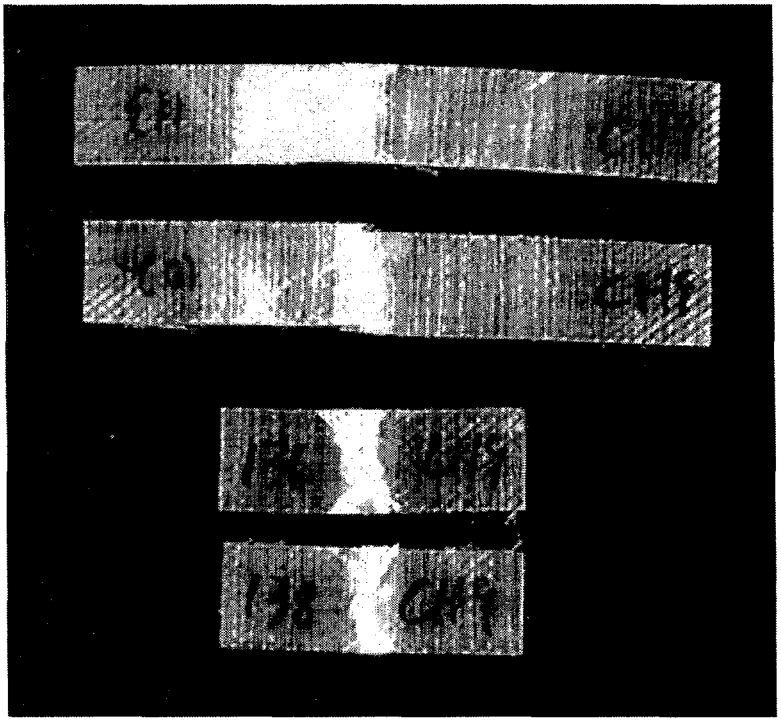


FIGURE 32 (f) Material CH9, ($V_F = 49\%$, all ±45 layers), from top to bottom; Static tensile coupon, tensile fatigue, (R = 0.1, 86 MPa); static compression and compression fatigue (R = 10, 86 MPa).

FIGURE 32 Failure Modes

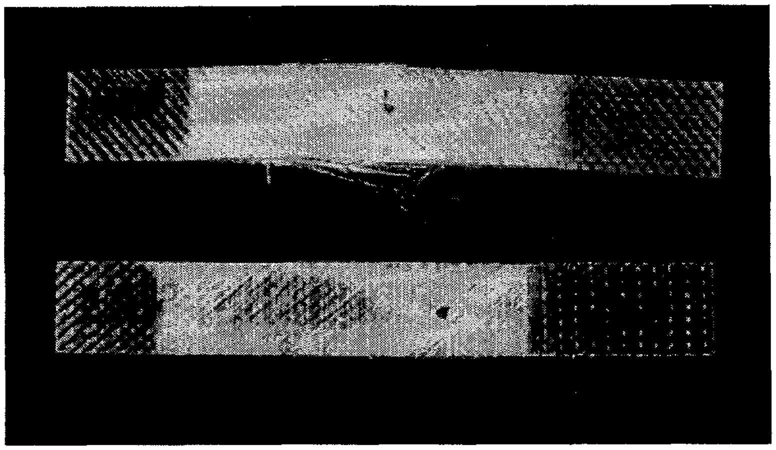


FIGURE 32 (g) Low fiber content, low percent 0's. Material CH3 (V_F = 36%, 24% 0's). Static tension coupon (top) and tensile fatigue (R = 0.1, 72 MPa).

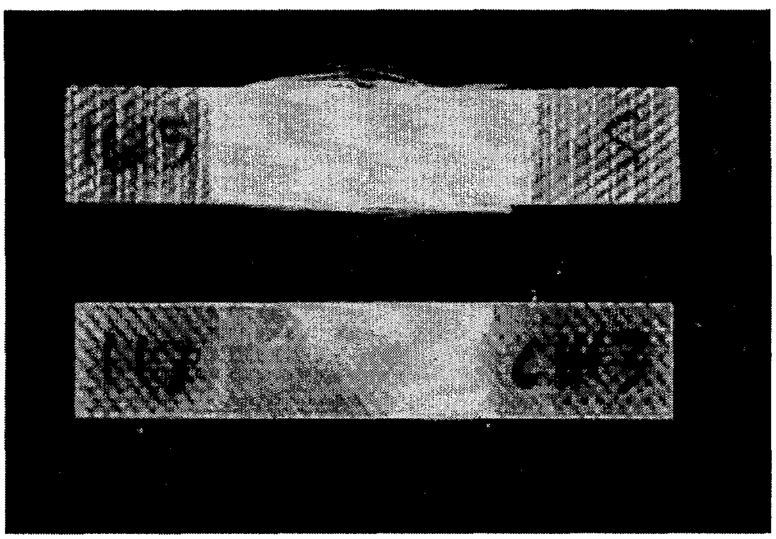


FIGURE 32 (h) High fiber content, low percent 0's. Material CH13 (V_F = 48%, 24% 0's). Static tensile coupon (top) and tensile fatigue (R = 0.1, 172 MPa).

FIGURE 32 Failure Modes

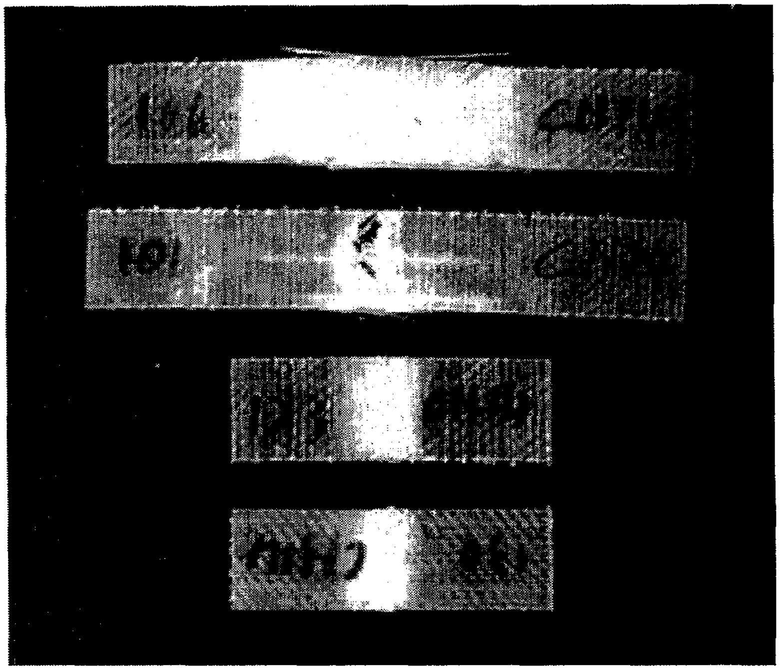


FIGURE 32 (i) Moderate fiber content and percent 0's. Material CH14 ($V_F = 44\%$, 39% 0's). From top to bottom; Static tensile coupon; tensile fatigue (R = 0.1 172 MPa); Static compression; and compression fatigue (R = 10, 241 MPa).

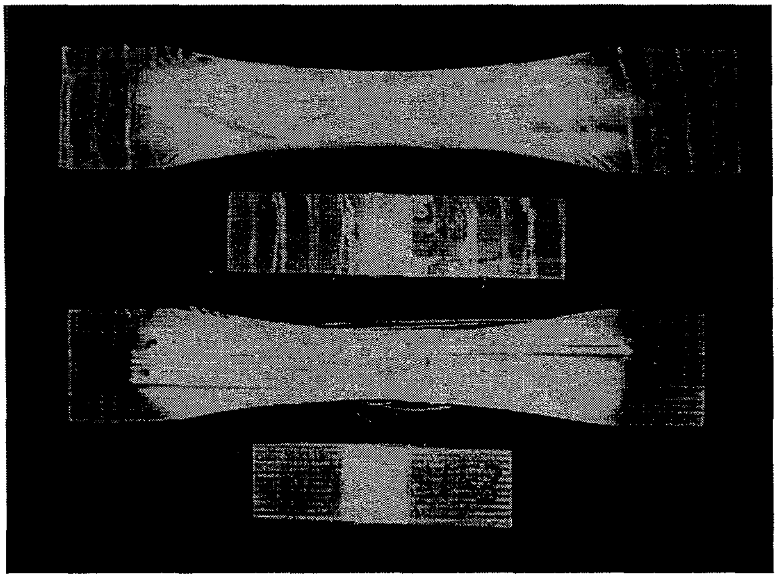


FIGURE 32 (j) Standard structural material at low fiber content, 72% 0's. From top to bottom; Material DD11 (A130 fabric 0's, $V_F = 31\%$); tensile fatigue (R = 0.1, 276 MPa); compression fatigue (R = 10, 172 MPa); and Material DD6 (D155 fabric 0's, $V_F = 31\%$); tensile fatigue (R = 0.1, 276 MPa); and compression fatigue (R = 10, 379 MPa).

FIGURE 32 Failure Modes

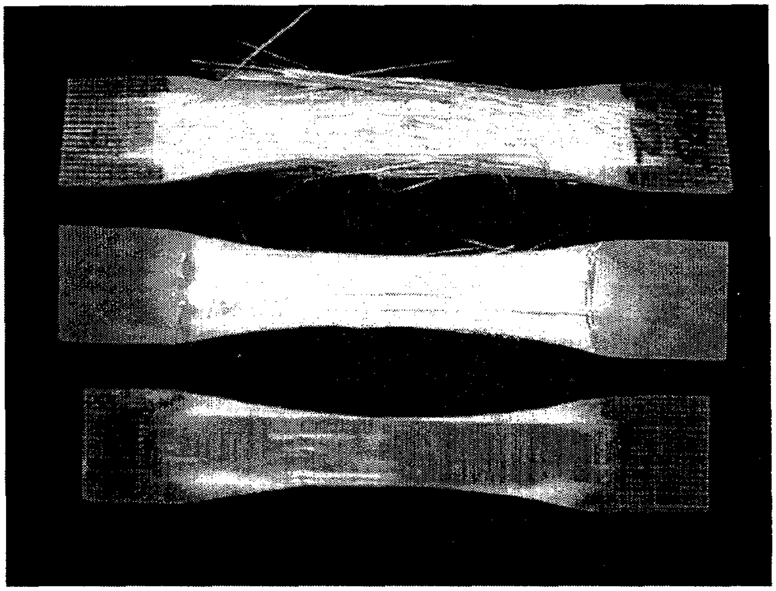


FIGURE 32 (k) Standard structural material with 72% 0's, (Material DD5, $V_F = 38\%$). From top to bottom: static tension, tension fatigue (R = 0.1) 310 MPa and 276 MPa.

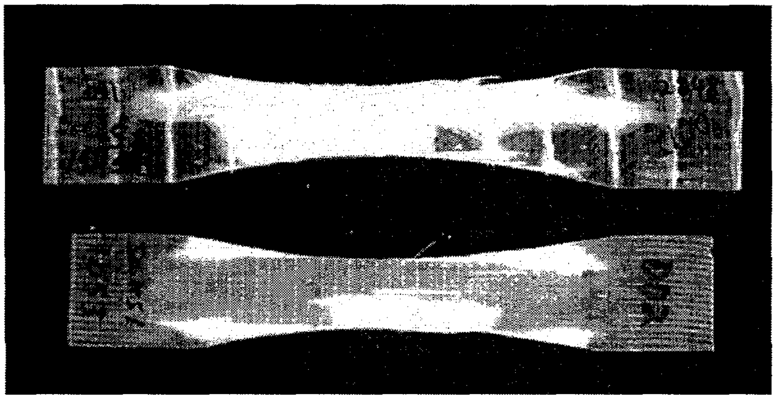


FIGURE 32 (l) Standard structural material at moderate fiber content, Material DD12 (71% A130 0° fabric, $V_F = 43\%$), tensile fatigue (R = 0.1, 241 MPa) and DD5 (72% D155 0° fabric, $V_F = 38\%$) tensile fatigue (R = 0.1, 345 MPa).

FIGURE 32 Failure Modes

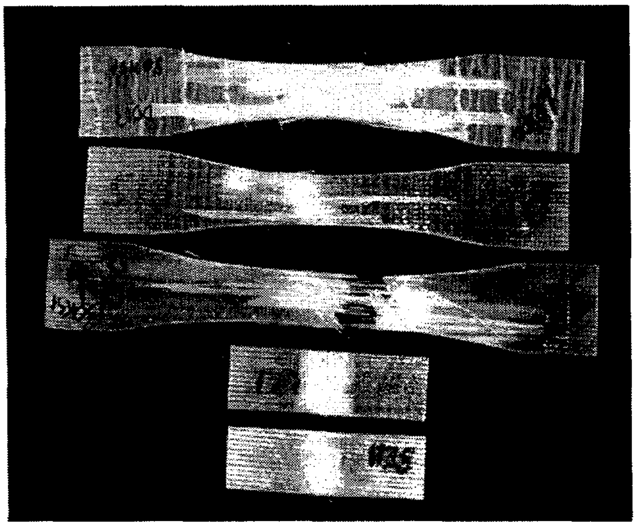


FIGURE 32 (m) Standard structural materials at higher fiber content, from top to bottom: Material DD13 (71% A130 fabric, $V_F = 50\%$), tensile fatigue (R = 0.1, 345 MPa); Material DD7 (72% D155 fabric, $V_F = 54\%$), tensile fatigue (R = 0.1, 207 MPa); Material DD9 (72% D155 fabric, stitching removed, $V_F = 54\%$), tensile fatigue (R = 0.1, 207 MPa); Material DD7 static compression, and compression fatigue (R = 10, 345 MPa).

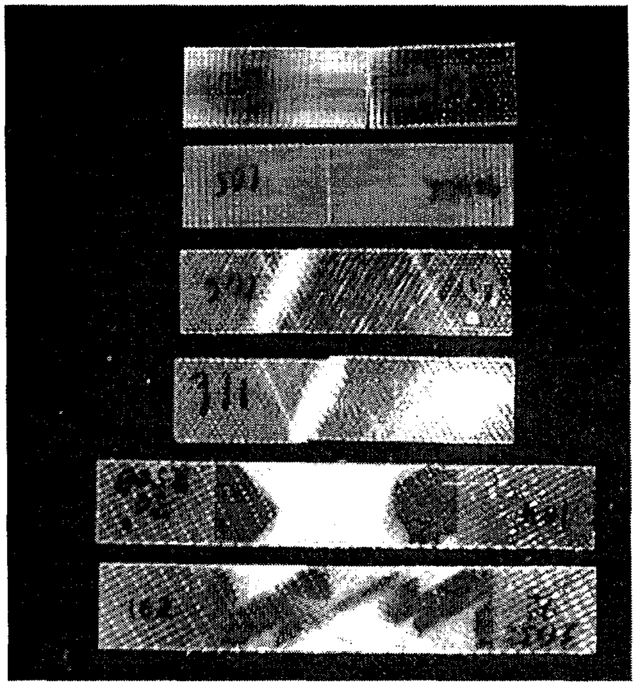


FIGURE 32 (n) D155 fabric, angled composites in static tension and tension fatigue (V_F = 38 to 40%) from top to bottom: $\pm 90^{O}$ tensile fatigue (R = 0.1, 17.2 MPa); and static tension; $\pm 60^{O}$, static tension and tension fatigue (R = 0.1, 19 MPa); $\pm 30^{O}$ static tension and tension fatigue (R = 0.1, 121 MPa).

FIGURE 32 Failure Modes

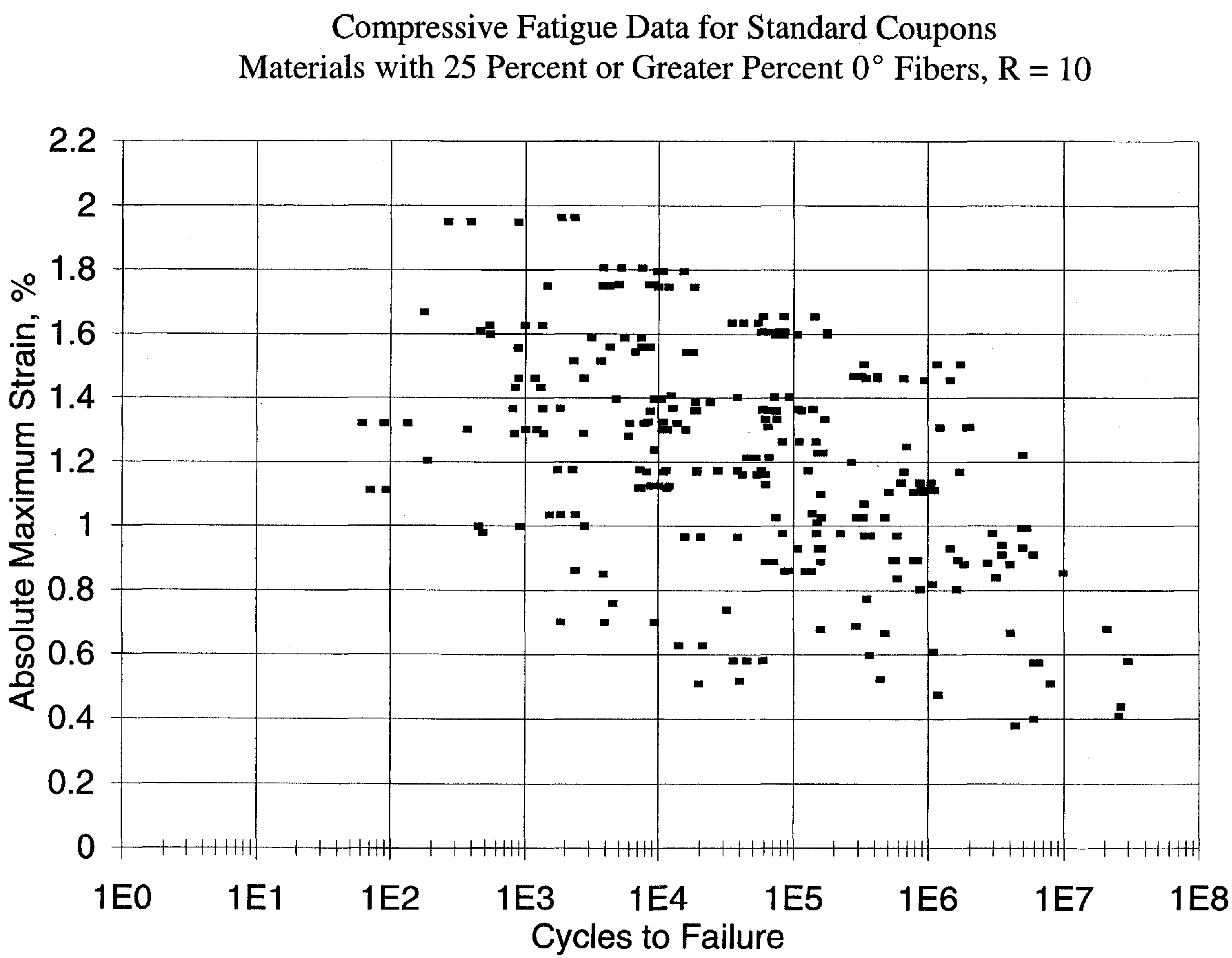

Compressive Fatigue Data for Standard Coupons
Materials with 25 Percent or Greater Percent 0° Fibers, R = 10
Absolute Maximum Strain, %
2.2
2
1.8
1.6
1.4
1.2
1
0.8
0.6
0.4
0.2
0
1E0
1E1
1E2
1E3
1E4
1E5
1E6
1E7
1E8
Cycles to Failure

FIGURE 33.

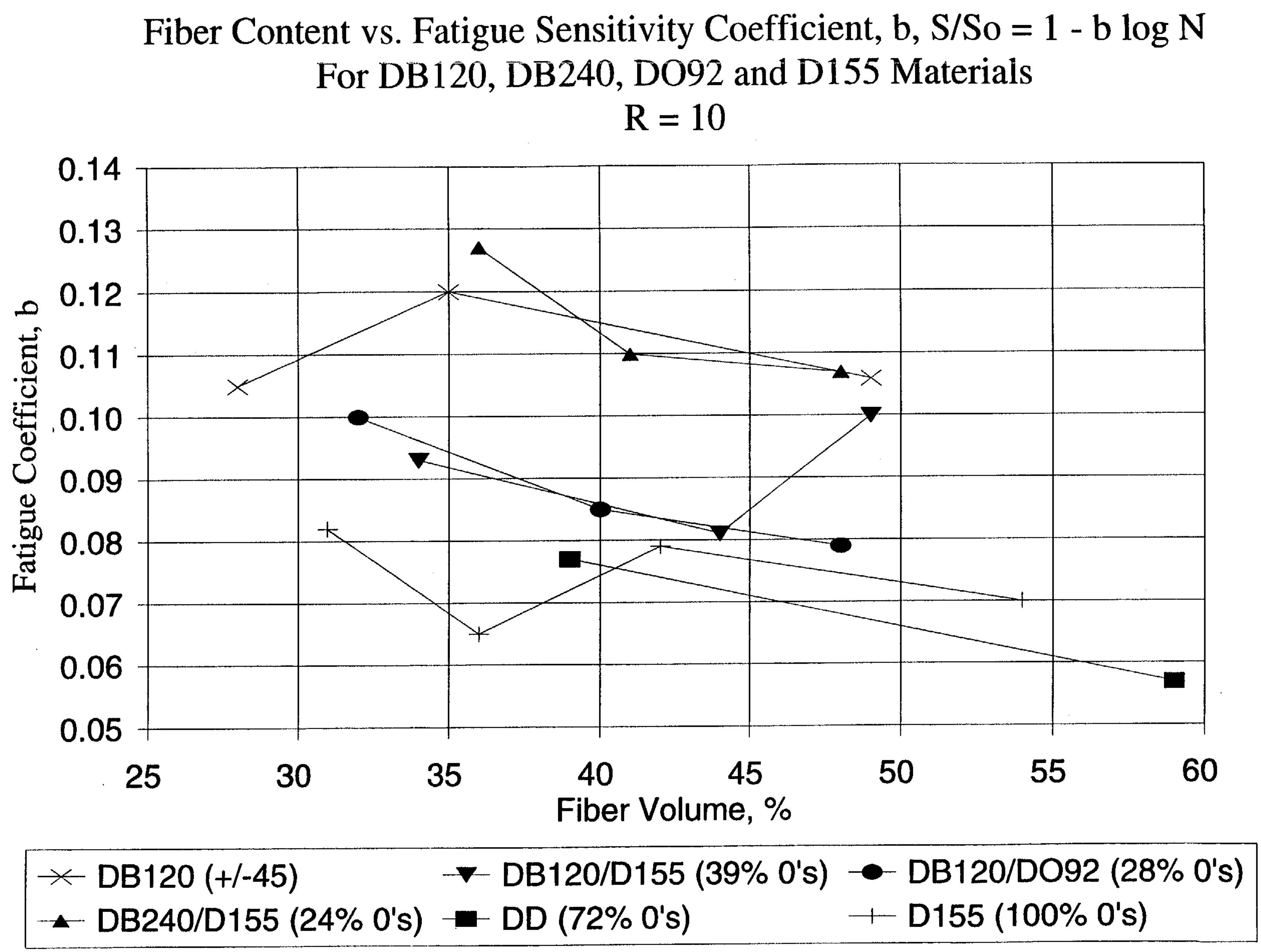
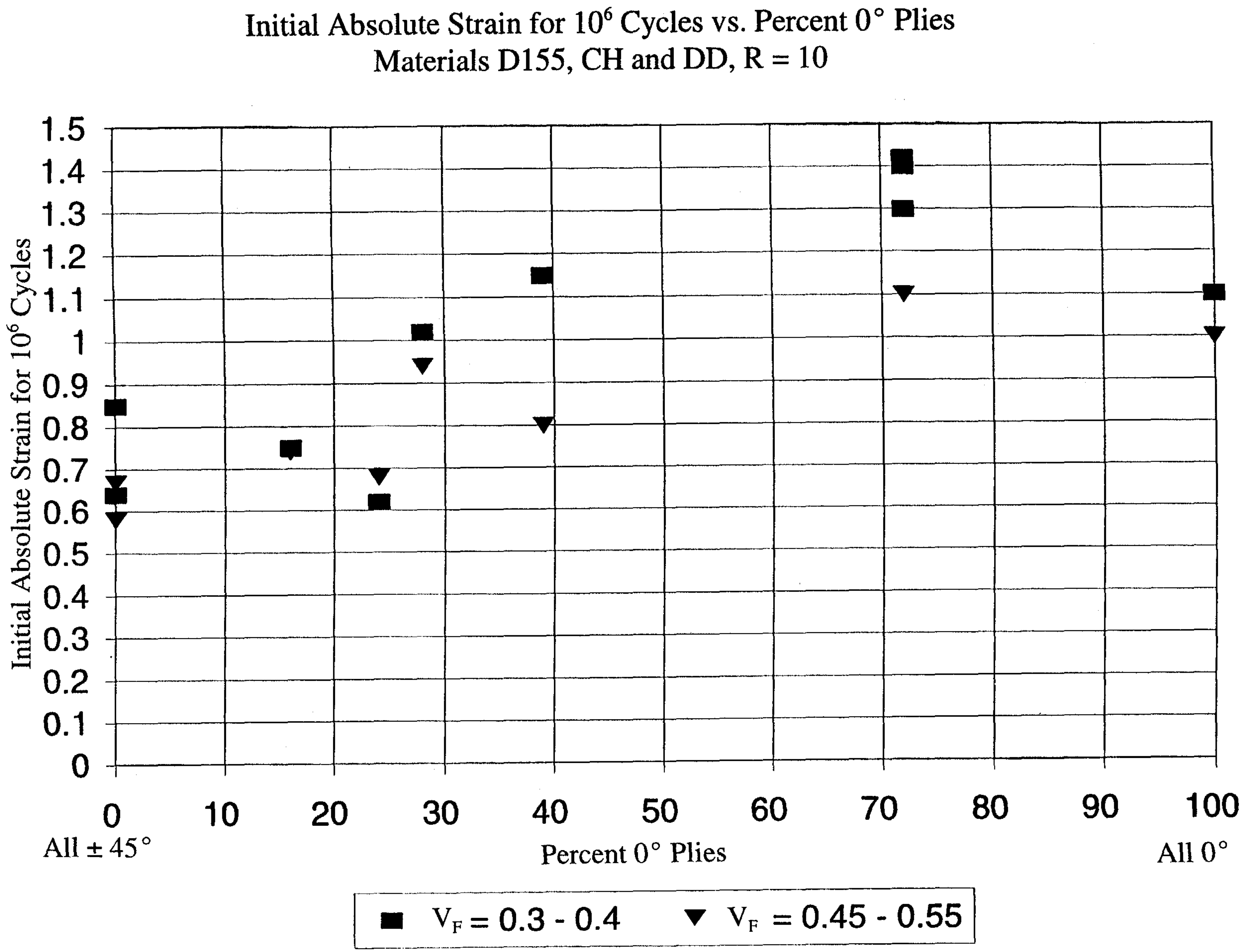

Fiber Content vs. Fatigue Sensitivity Coefficient, b, S/So = 1 - b log N
For DB120, DB240, DO92 and D155 Materials
R = 10
0.14
0.13
0.12
0.11
0.10
0.09
0.08
0.07
0.06
0.05
Fatigue Coefficient, b
25
30
35
40
45
50
55
60
Fiber Volume, %
DB120 (+/-45)
DB120/D155 (39% 0's)
DB120/DO92 (28% 0's)
DB240/D155 (24% 0's)
DD (72% 0's)
D155 (100% 0's)

FIGURE 34 (a).



Initial Absolute Strain for 10^6 Cycles vs. Percent 0° Plies
Materials D155, CH and DD, R = 10
Initial Absolute Strain for 10^6 Cycles
1.5
1.4
1.3
1.2
1.1
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0
0
10
20
30
40
50
60
70
80
90
100
All ± 45°
Percent 0° Plies
All 0°
V_F = 0.3 - 0.4
V_F = 0.45 - 0.55

FIGURE 34 (b)

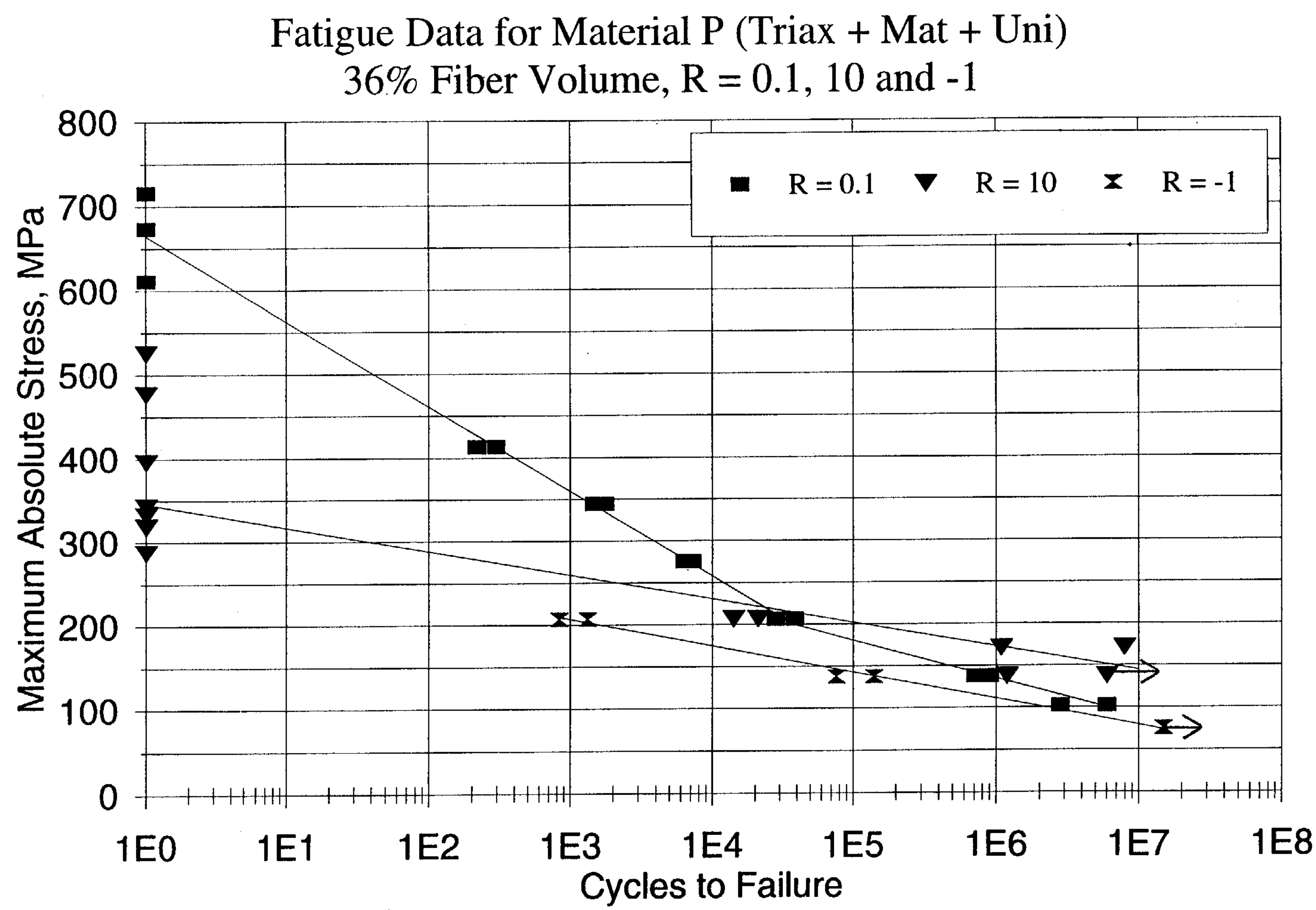

Fatigue Data for Material P (Triax + Mat + Uni)
36% Fiber Volume, R = 0.1, 10 and -1
Maximum Absolute Stress, MPa
800
700
600
500
400
300
200
100
0
1E0
1E1
1E2
1E3
1E4
1E5
1E6
1E7
1E8
Cycles to Failure
R = 0.1
R = 10
R = -1

FIGURE 35

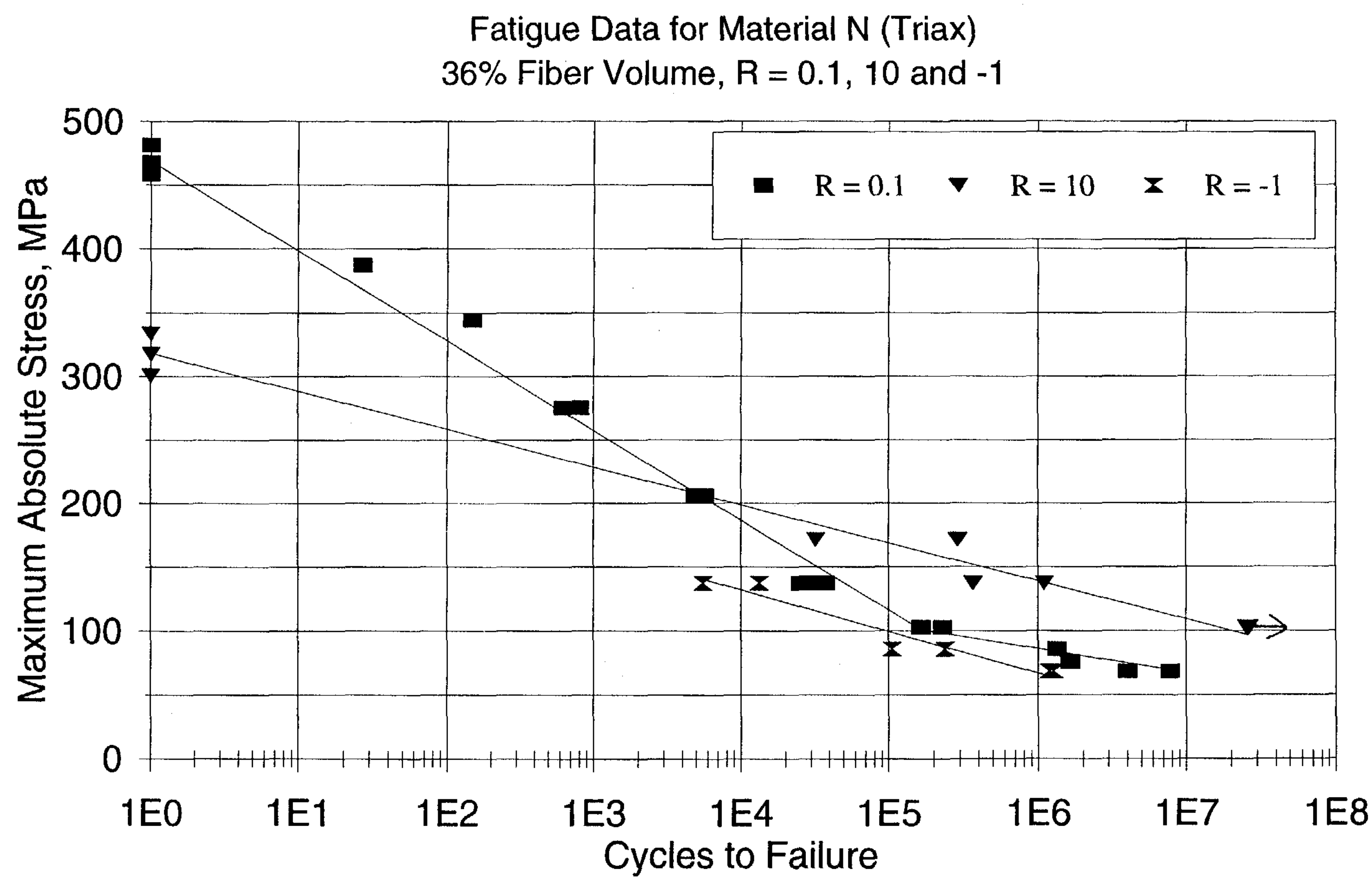
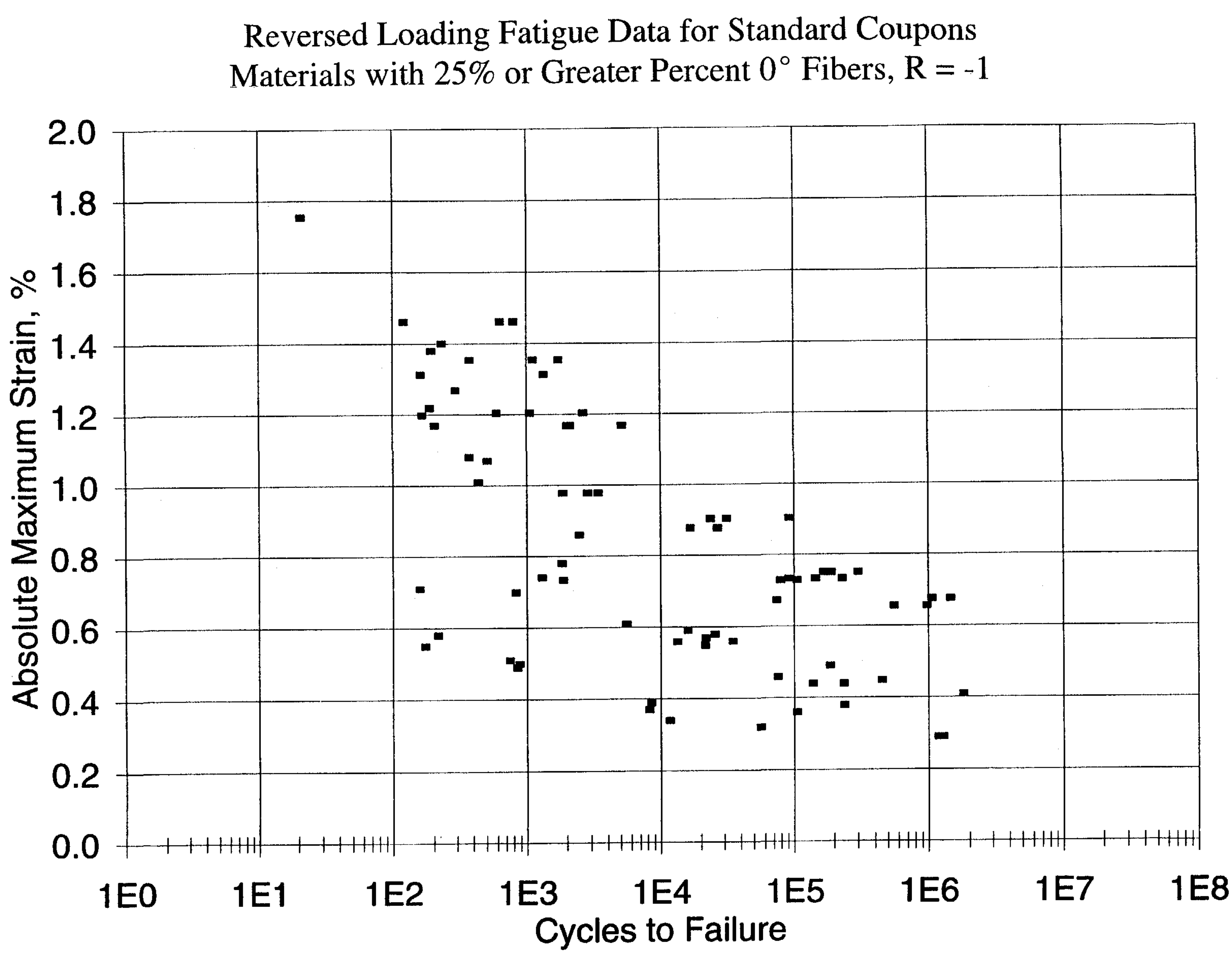

Fatigue Data for Material N (Triax)
36% Fiber Volume, R = 0.1, 10 and -1
Maximum Absolute Stress, MPa
500
400
300
200
100
0
1E0
1E1
1E2
1E3
1E4
1E5
1E6
1E7
1E8
Cycles to Failure
R = 0.1
R = 10
R = -1

FIGURE 36



Reversed Loading Fatigue Data for Standard Coupons
Materials with 25% or Greater Percent 0° Fibers, R = -1
Absolute Maximum Strain, %
2.0
1.8
1.6
1.4
1.2
1.0
0.8
0.6
0.4
0.2
0.0
1E0
1E1
1E2
1E3
1E4
1E5
1E6
1E7
1E8
Cycles to Failure

FIGURE 37.

Effect of Matrix on Fatigue for DD5P Materials
R = 0.1

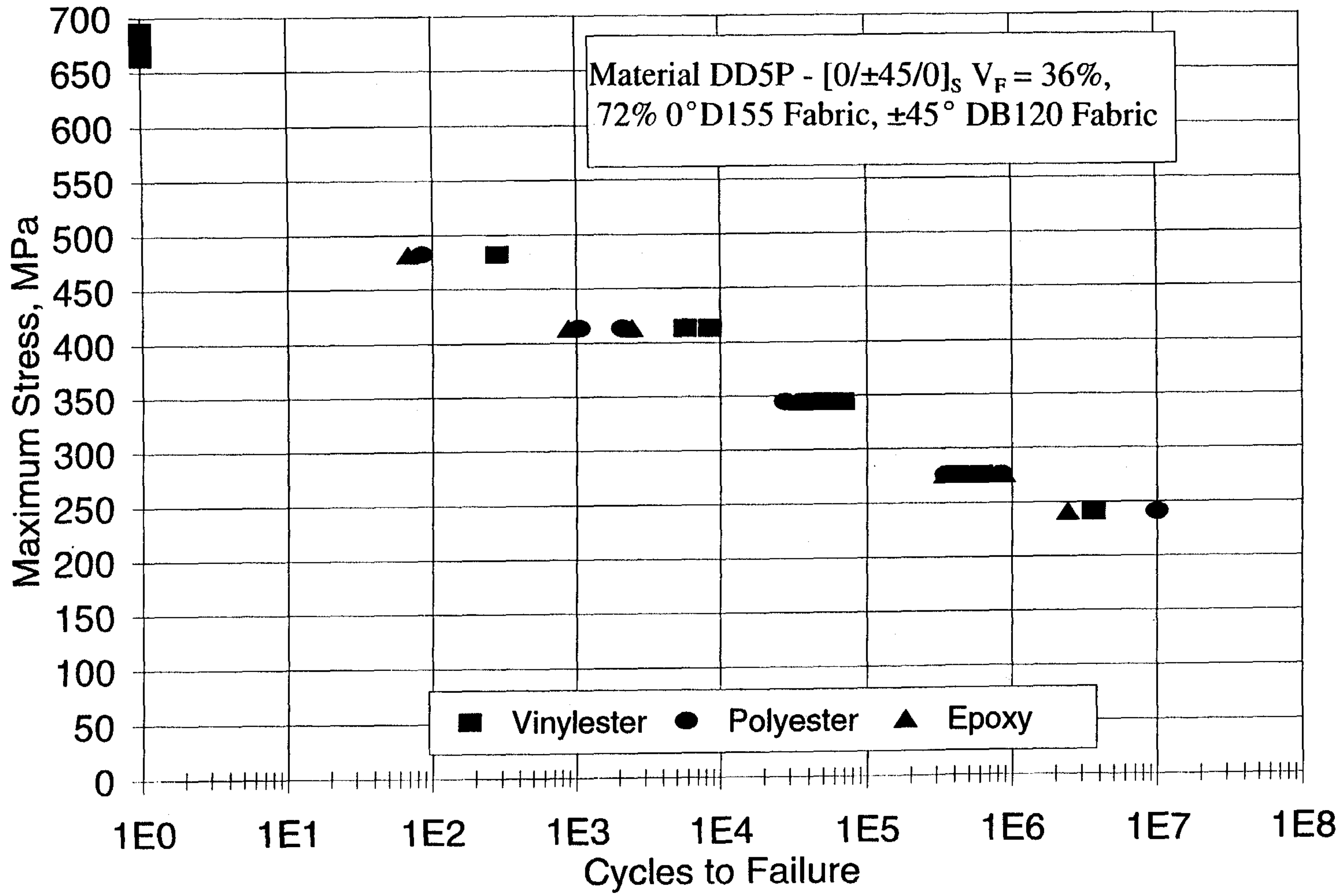
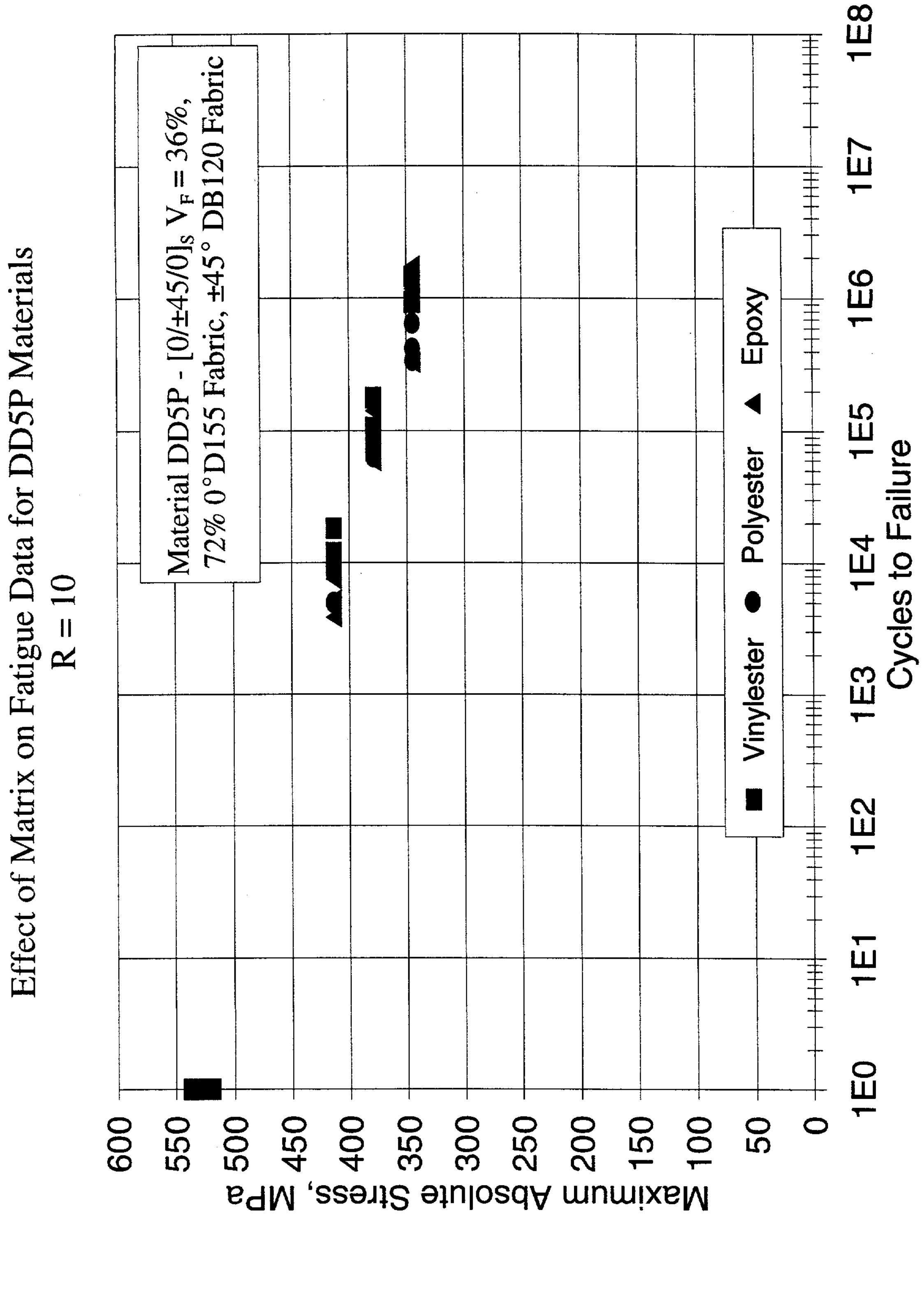


FIGURE 38.



Effect of Matrix on Fatigue Data for DD5P Materials
R = 10
Material DD5P - [0/±45/0]s VF = 36%,
72% 0°D155 Fabric, ±45° DB120 Fabric
Vinylester
Polyester
Epoxy
Maximum Absolute Stress, MPa
0
50
100
150
200
250
300
350
400
450
500
550
600
Cycles to Failure
1E0
1E1
1E2
1E3
1E4
1E5
1E6
1E7
1E8

FIGURE 39.

Measured and Predicted Longitudinal Modulus vs. Fiber Angle,
±θ Laminates

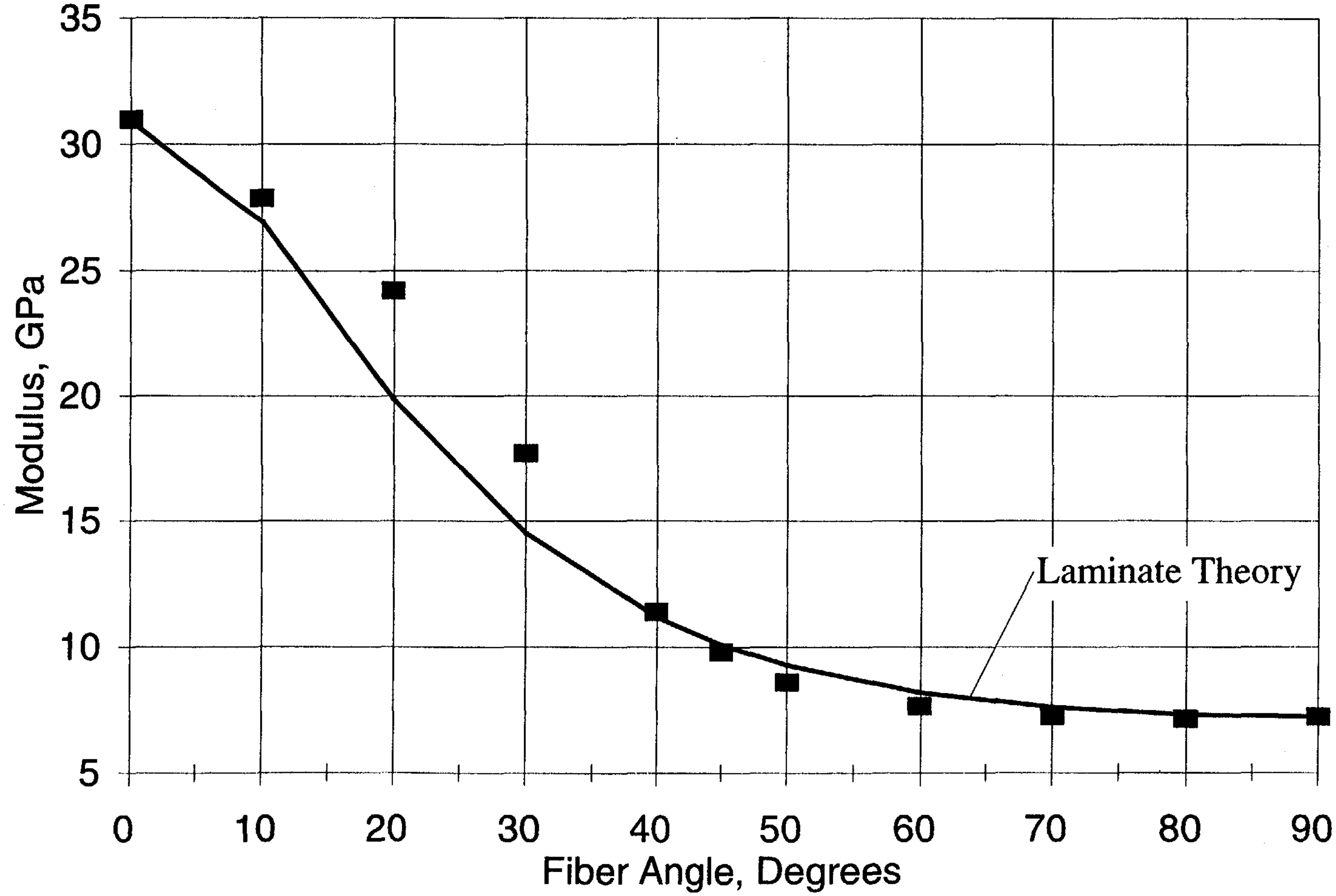


FIGURE 40

Measured and Predicted Static Tensile Strengths vs. Fiber Angle, ±θ Laminates

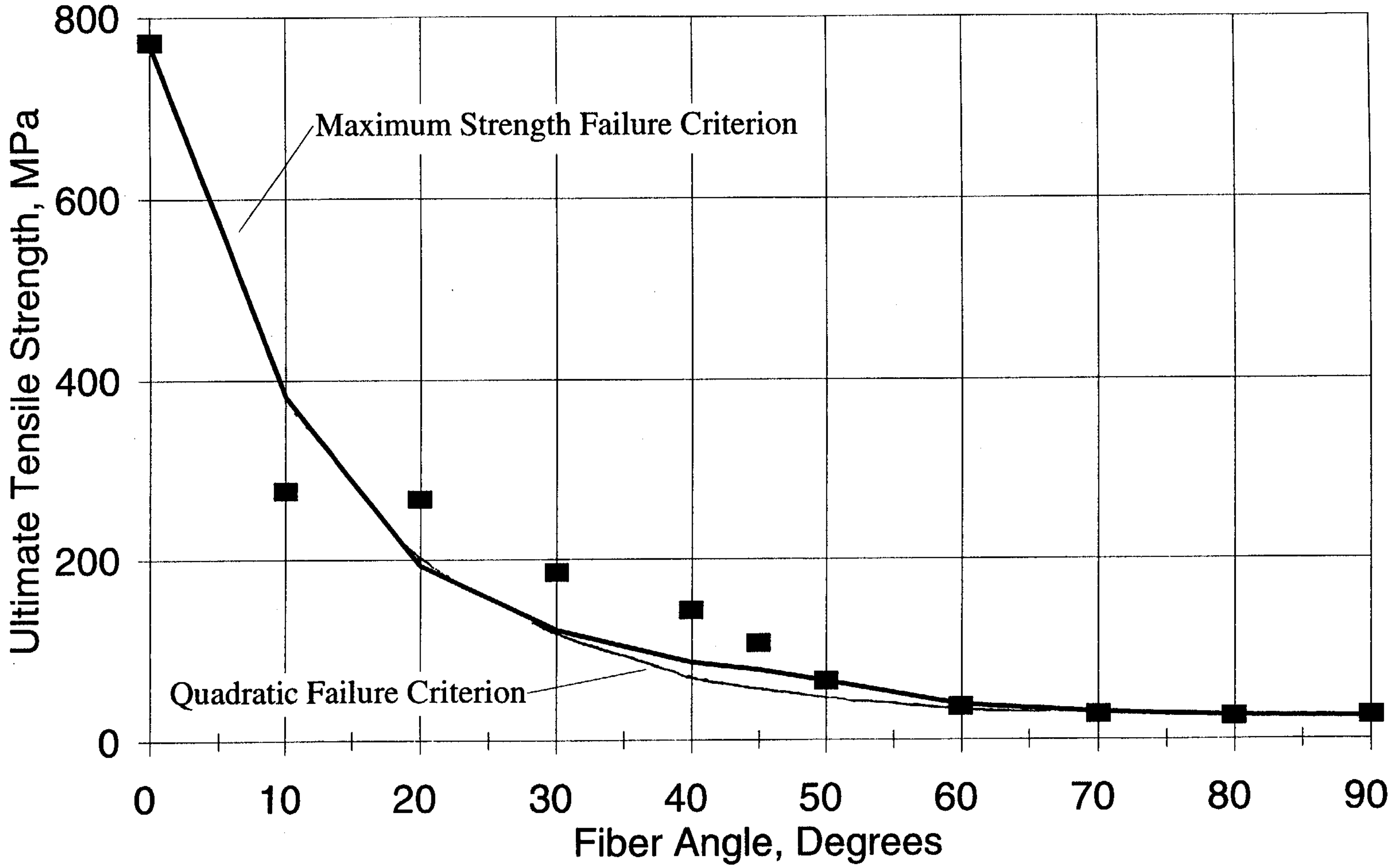


FIGURE 41(a)

Measured and Predicted Static Compressive Strengths vs. Fiber Angle, ±θ Laminates

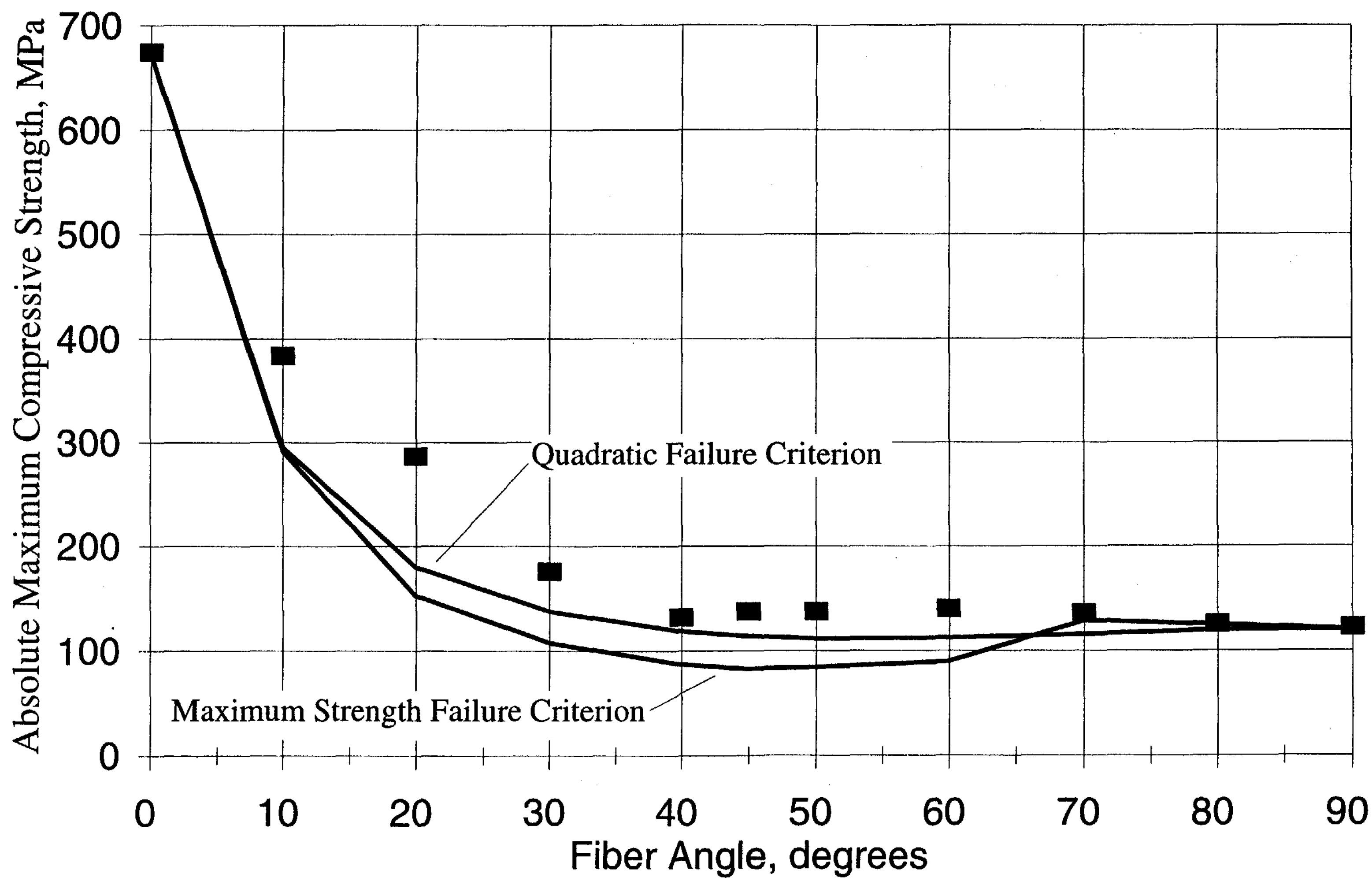


FIGURE 41(b)

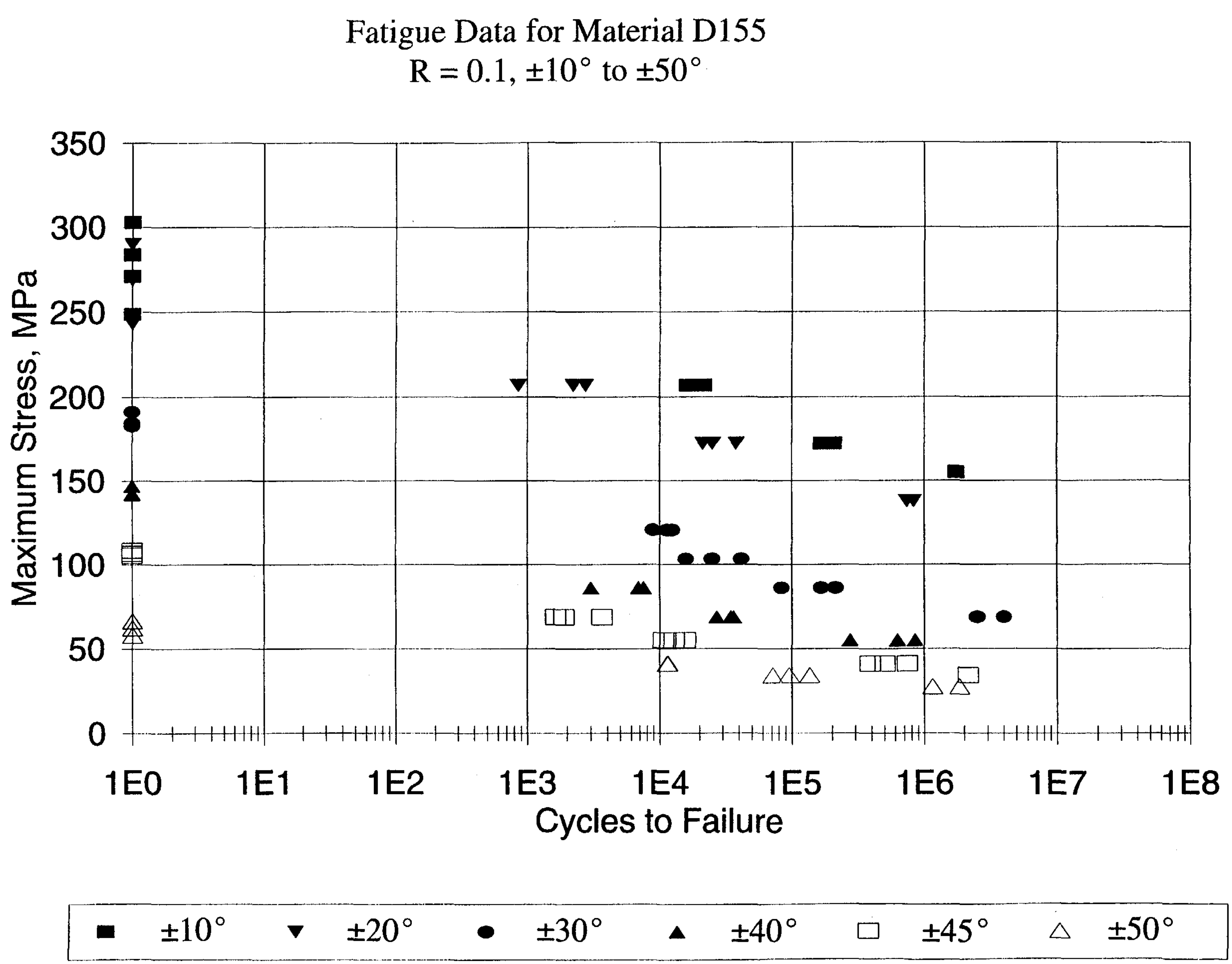

Fatigue Data for Material D155
R = 0.1, ±10° to ±50°
Maximum Stress, MPa
350
300
250
200
150
100
50
0
1E0
1E1
1E2
1E3
1E4
1E5
1E6
1E7
1E8
Cycles to Failure
±10°
±20°
±30°
±40°
±45°
±50°

FIGURE 42 (a).

Fatigue Data for Material D155
R = 0.1, ±60° to ±90°

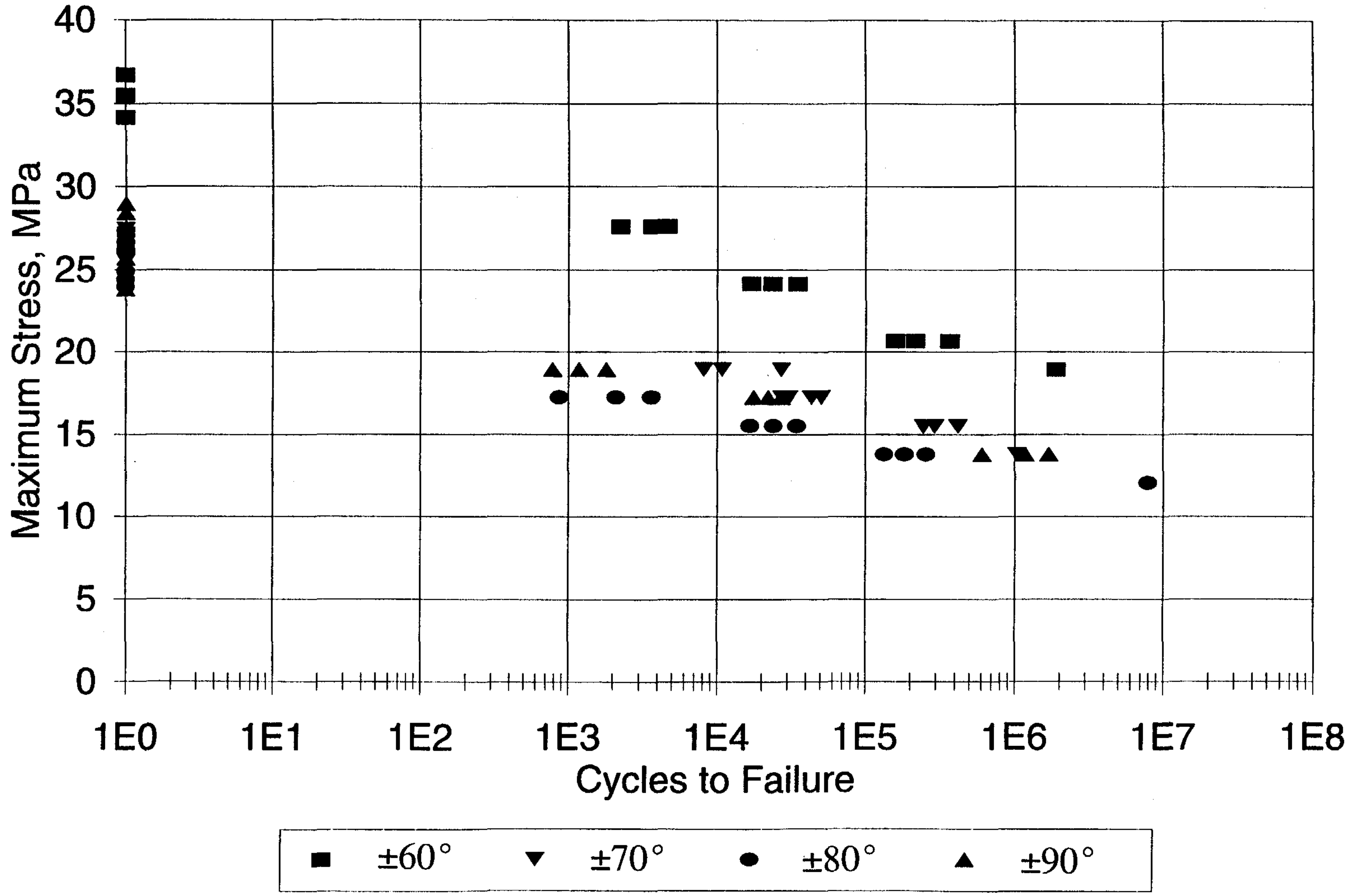


FIGURE 42 (b).

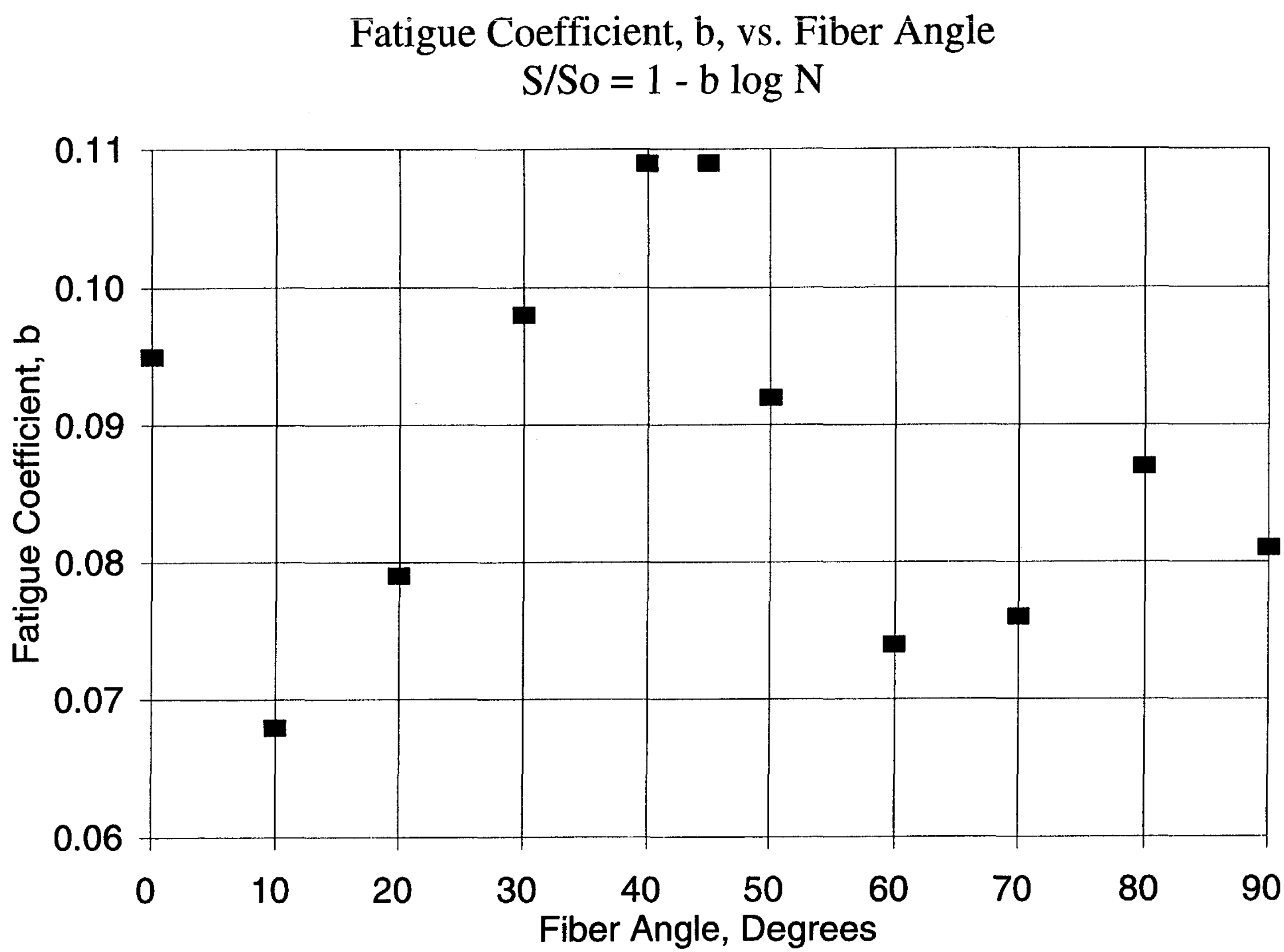

Fatigue Coefficient, b, vs. Fiber Angle
S/So = 1 - b log N
Fatigue Coefficient, b
0.11
0.10
0.09
0.08
0.07
0.06
0
10
20
30
40
50
60
70
80
90
Fiber Angle, Degrees

FIGURE 43(a)

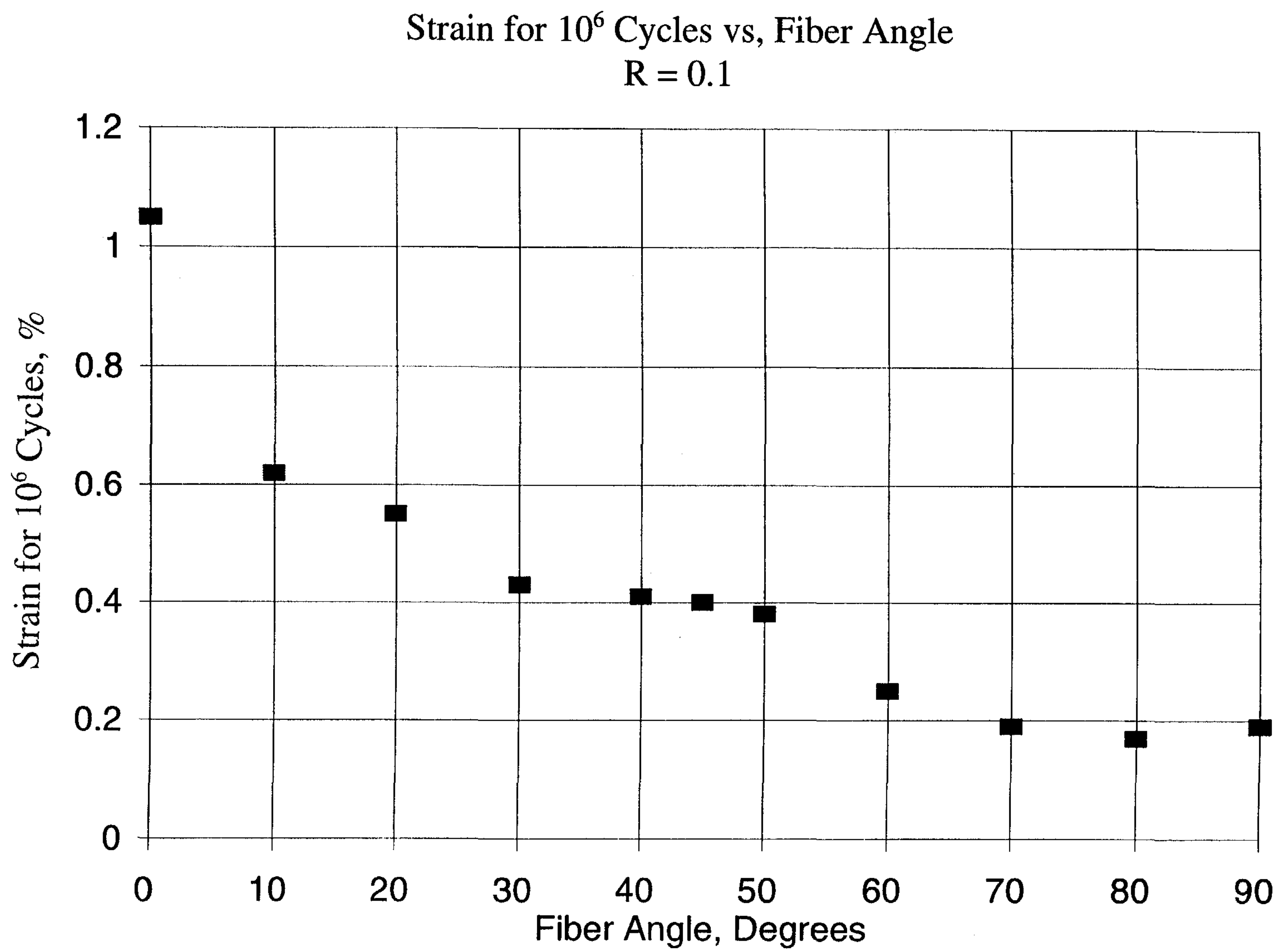

Strain for 10^6 Cycles vs, Fiber Angle
R = 0.1
1.2
1
0.8
0.6
0.4
0.2
0
Strain for 10^6 Cycles, %
0
10
20
30
40
50
60
70
80
90
Fiber Angle, Degrees

FIGURE 43 (b).

Properties of Pultruded EE Blade Materials (EEAP = polyester matrix, all others vinyl ester)										
		R = -1		R = 10			R = 0.1			
Material	V_F %	b_R	strain for 10^6 cycles, %	UCS, MPa	b_C	strain for 10^6 cycles, %	UTS, MPa	b_T	strain for 10^6 cycles, %	E, GPa
EEAP	48	----	----	-729	0.088	-1.25	511	0.101	0.82	29.0
EEAV	49	0.068	0.70	-645	0.077	-1.30	583	0.100	0.75	28.2
EEB	43	----	----	-417	----	-----	515	0.100	0.75	26.6
EEC	49	----	----	-419	----	-----	526	0.100	0.70	28.3

Static Failure Strains		
Material	Compressive strain to failure, %	Tensile strain to failure, %
EEAP	2.5	1.9
EEAV	2.3	2.1
EEB	1.6	2.2
EEC	1.5	2.0

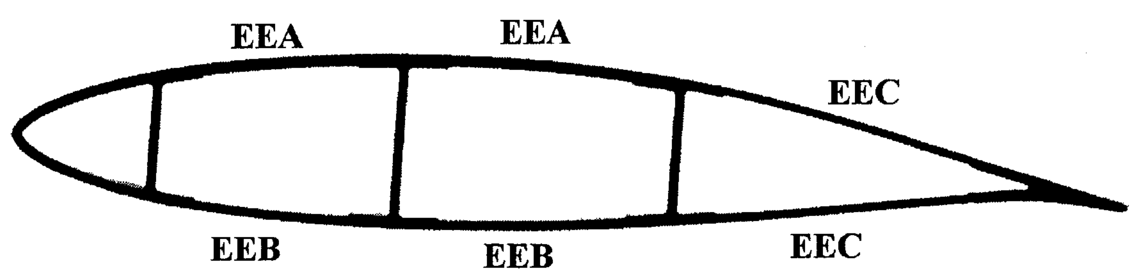


FIGURE 44

Fatigue Data for Pultruded Material EEA, R = 0.1, 10 and -1
Vinyl ester and Polyester Matrix Materials

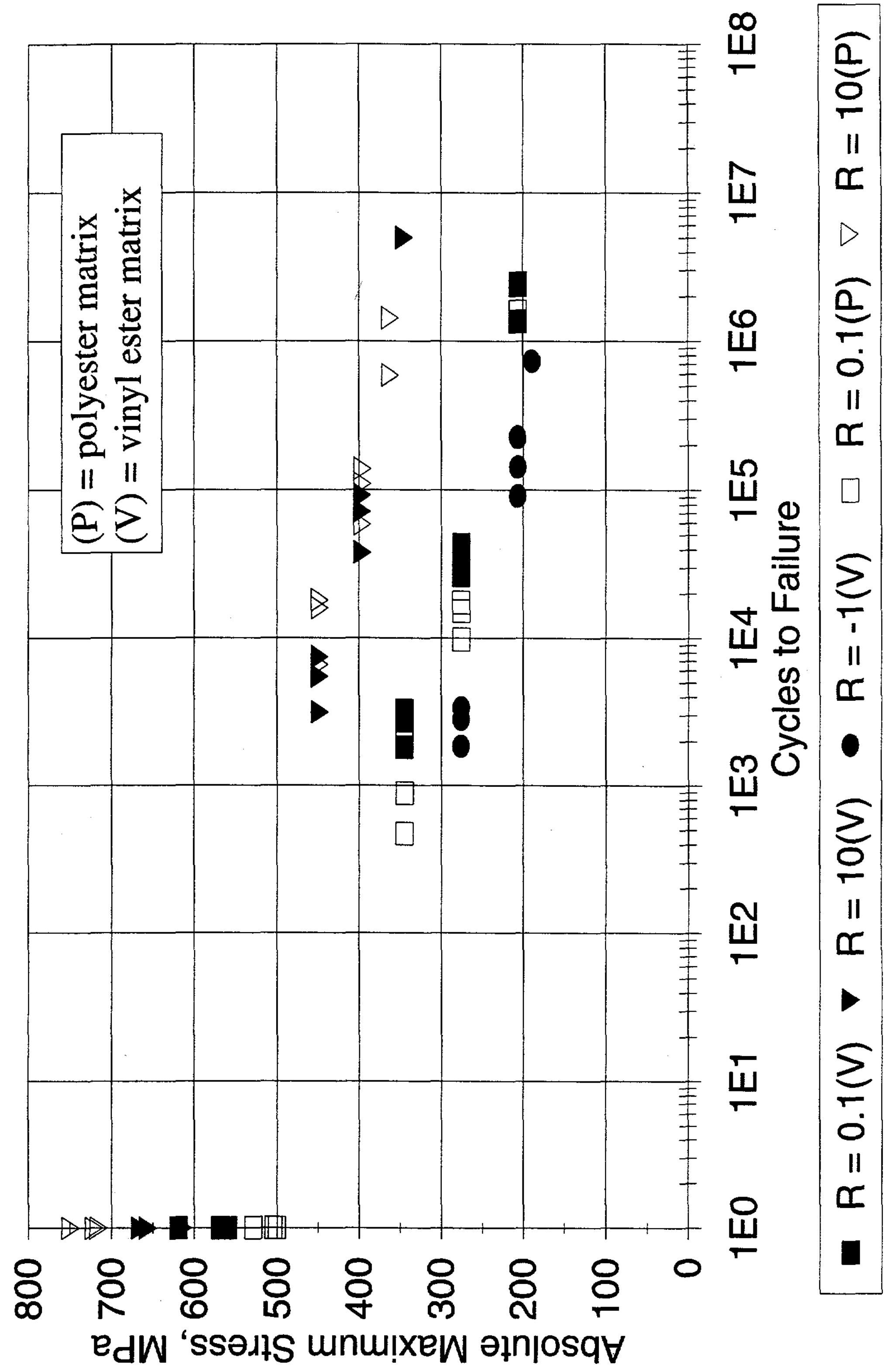


FIGURE 45.

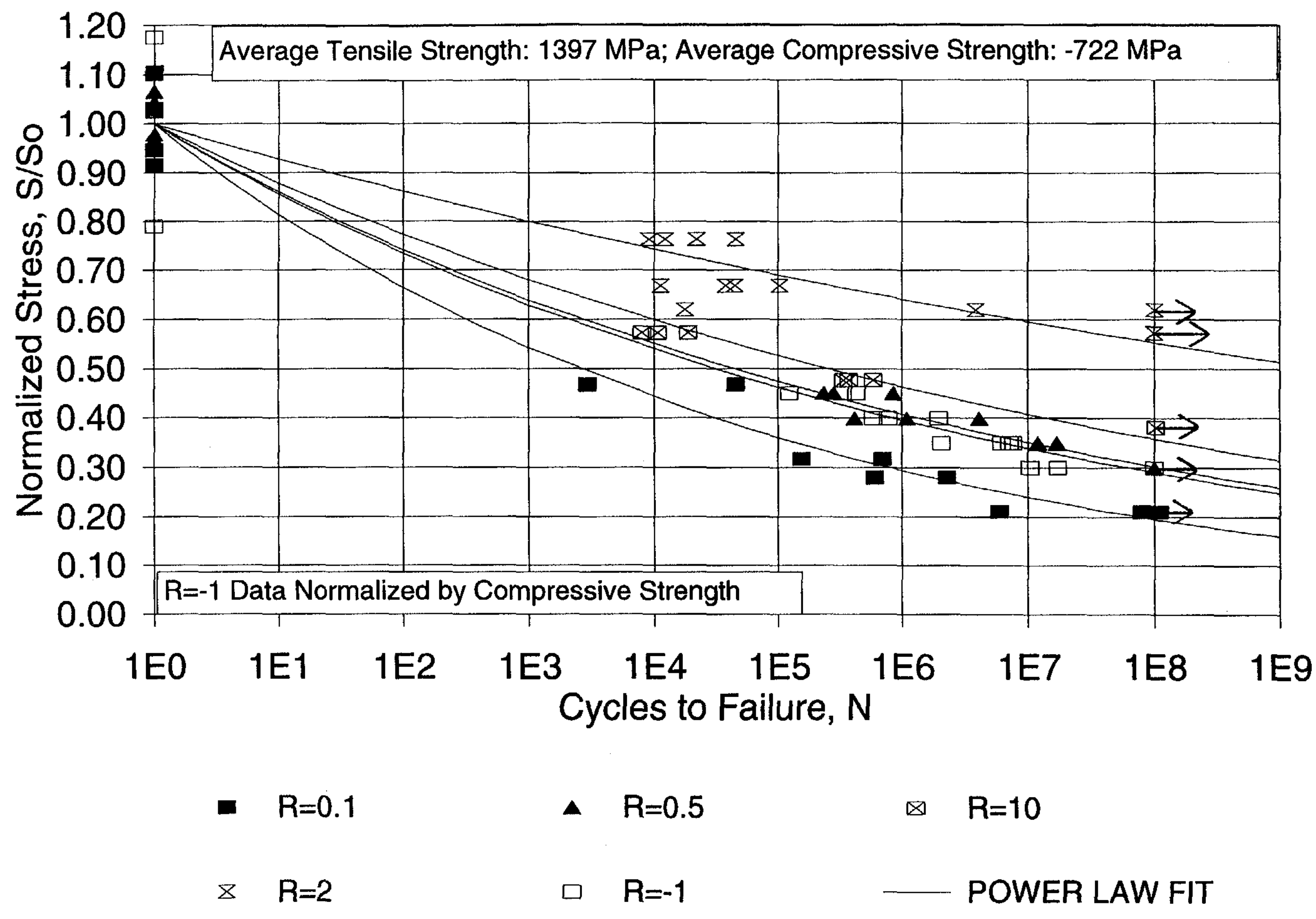


Figure 46. Normalized Longitudinal S-N Data for R=0.1, 0.5, -1, 10, 2.

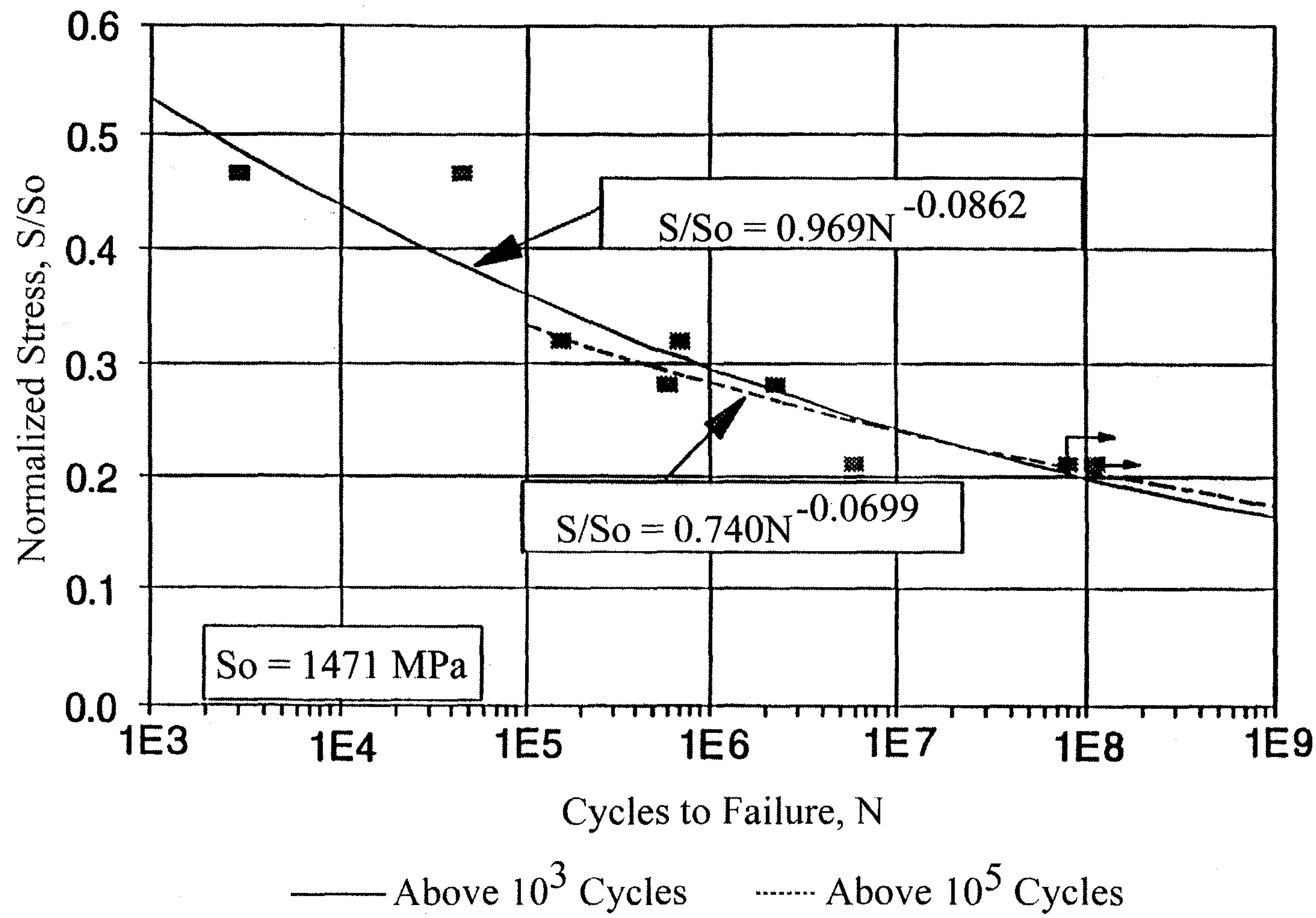


Figure 47. Power Law Fits of S-N Data for Longitudinal R=0.1 Above 10^3 and Above 10^5 Cycles.

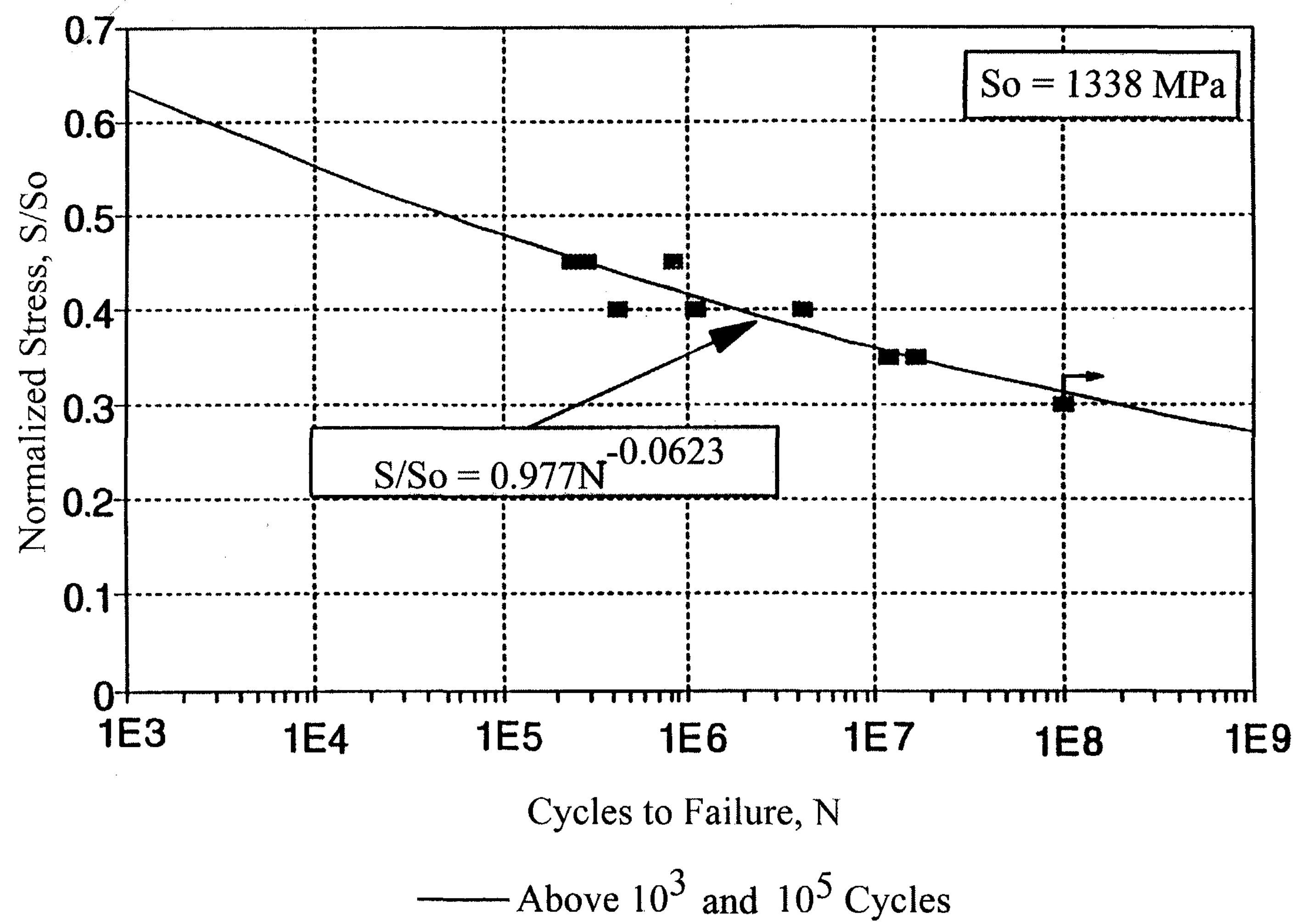


Figure 48. Power Law Fits of S-N Data for Longitudinal R=0.5 Above 10^3 and Above 10^5 Cycles.

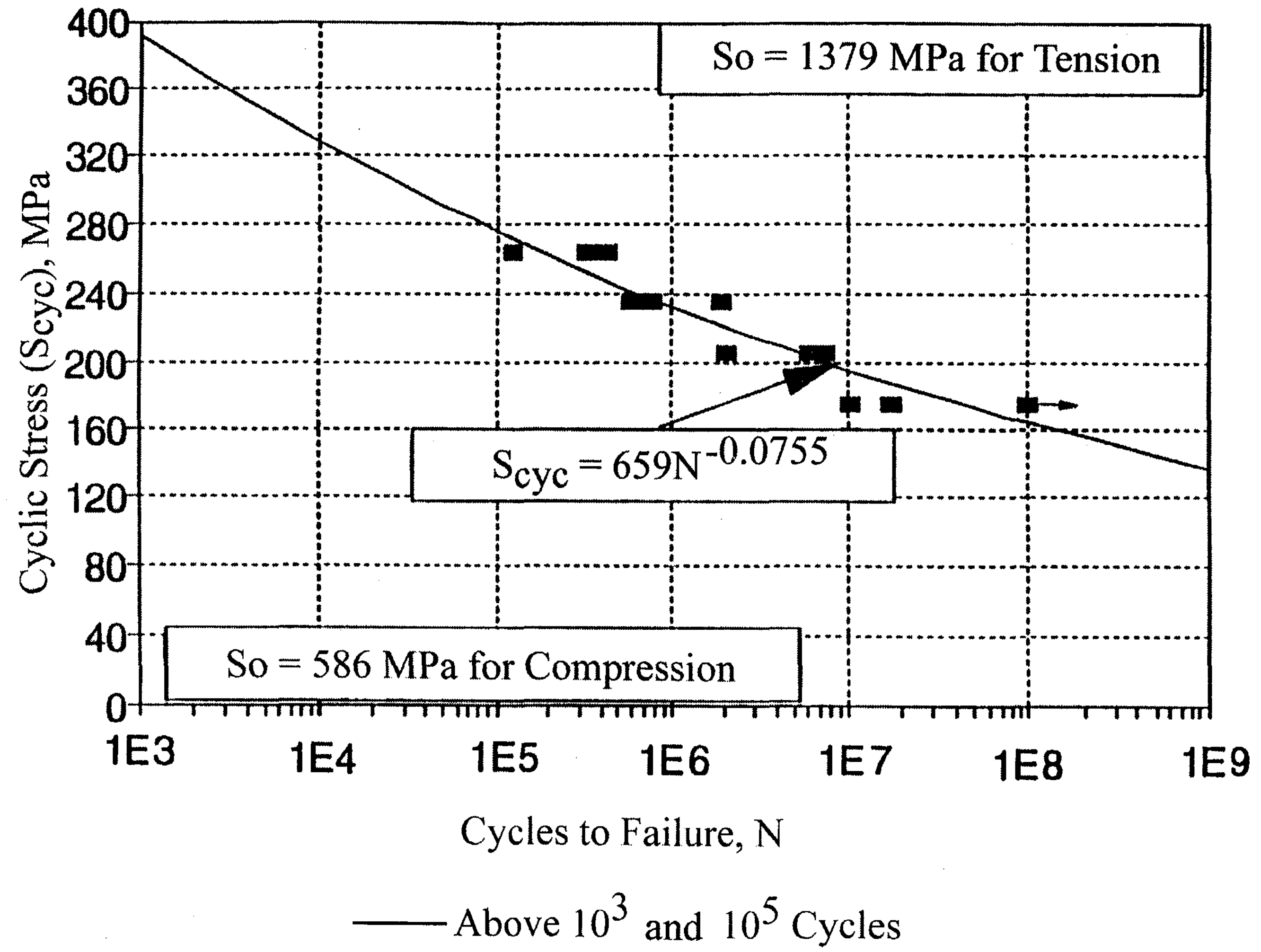


Figure 49. Power Law Fits of S-N Data for Longitudinal R=-1 Above 10^3 and Above 10^5 Cycles.

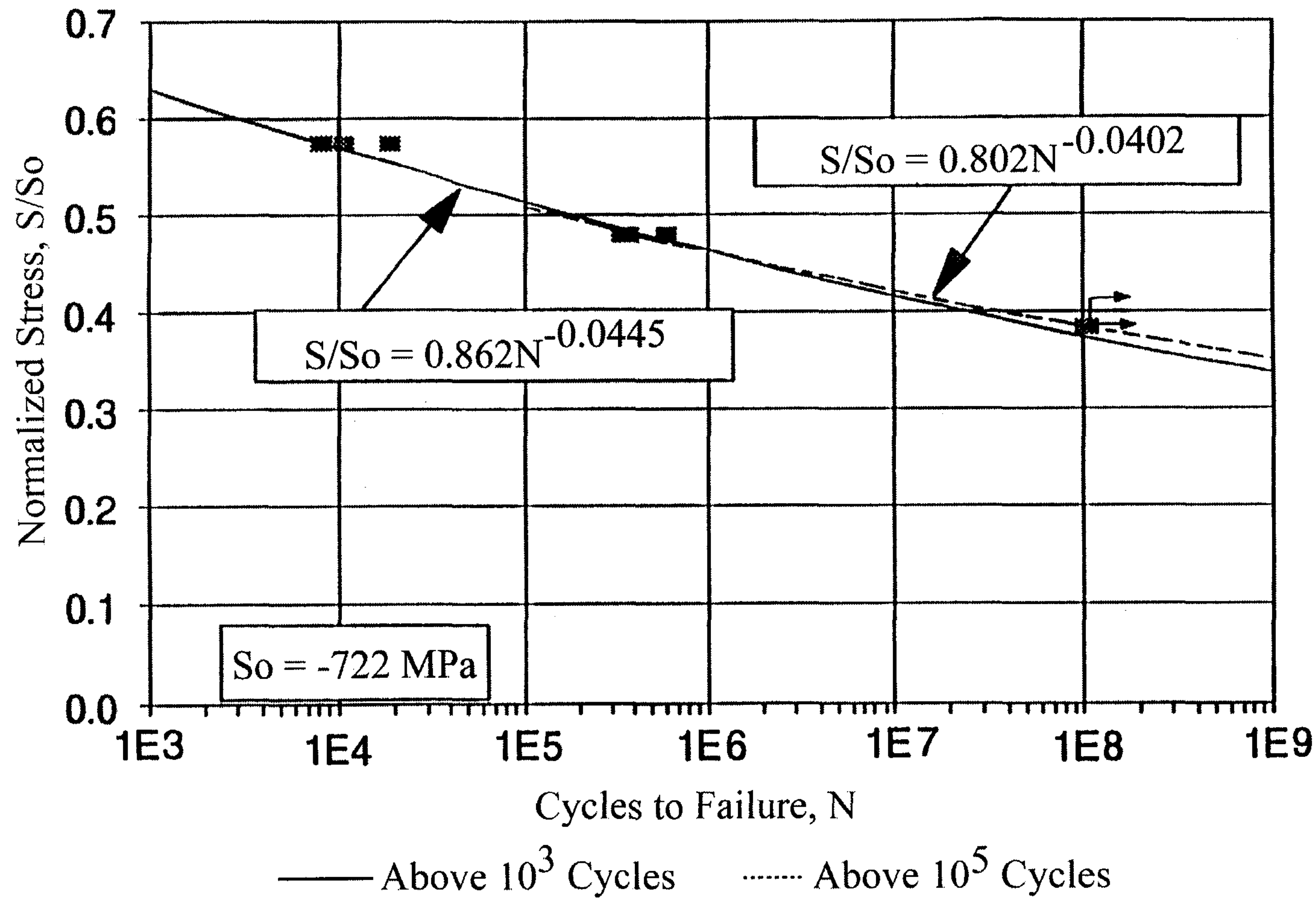


Figure 50. Power Law Fits of S-N Data for Longitudinal R=10 Above 10^3 and Above 10^5 Cycles.

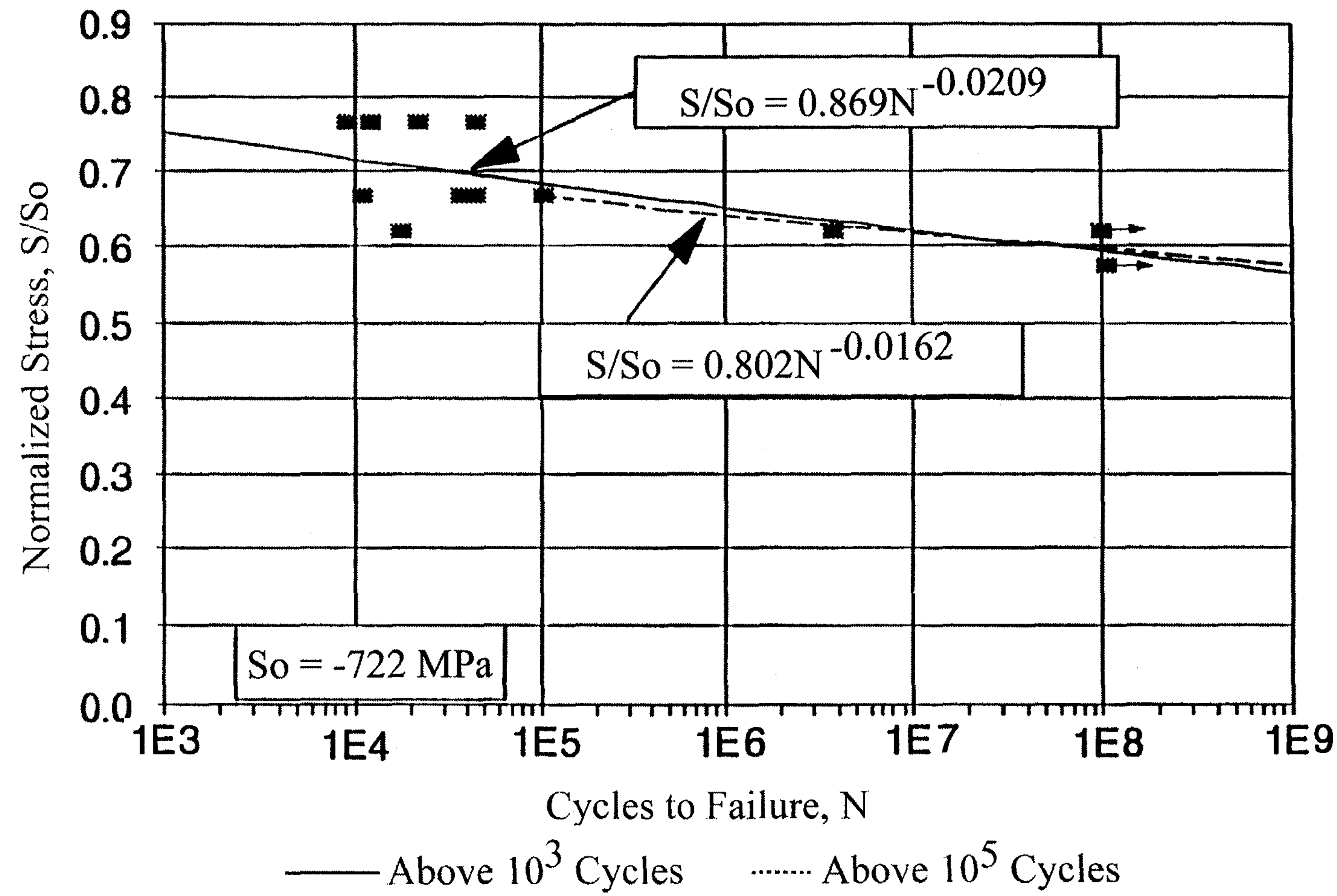


Figure 51. Power Law Fits of S-N Data for Longitudinal R=2 Above 10^3 and Above 10^5 Cycles.

Comparison of High Frequency R = 0.1 Data with Figure 18
for Standard Coupons

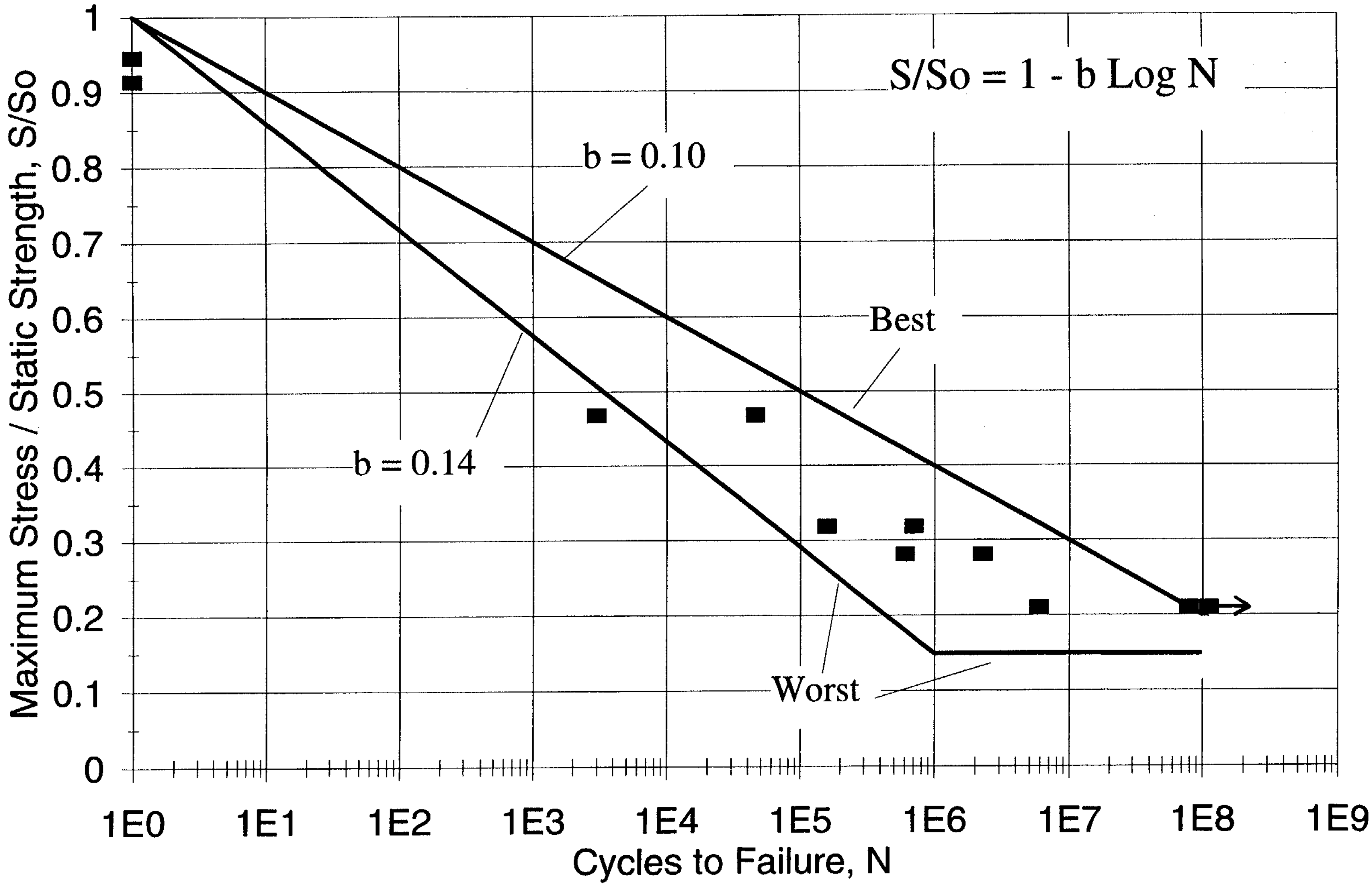


FIGURE 52.

Comparison of High Frequency R = 10 Data with Figure 19 for Standard Coupons

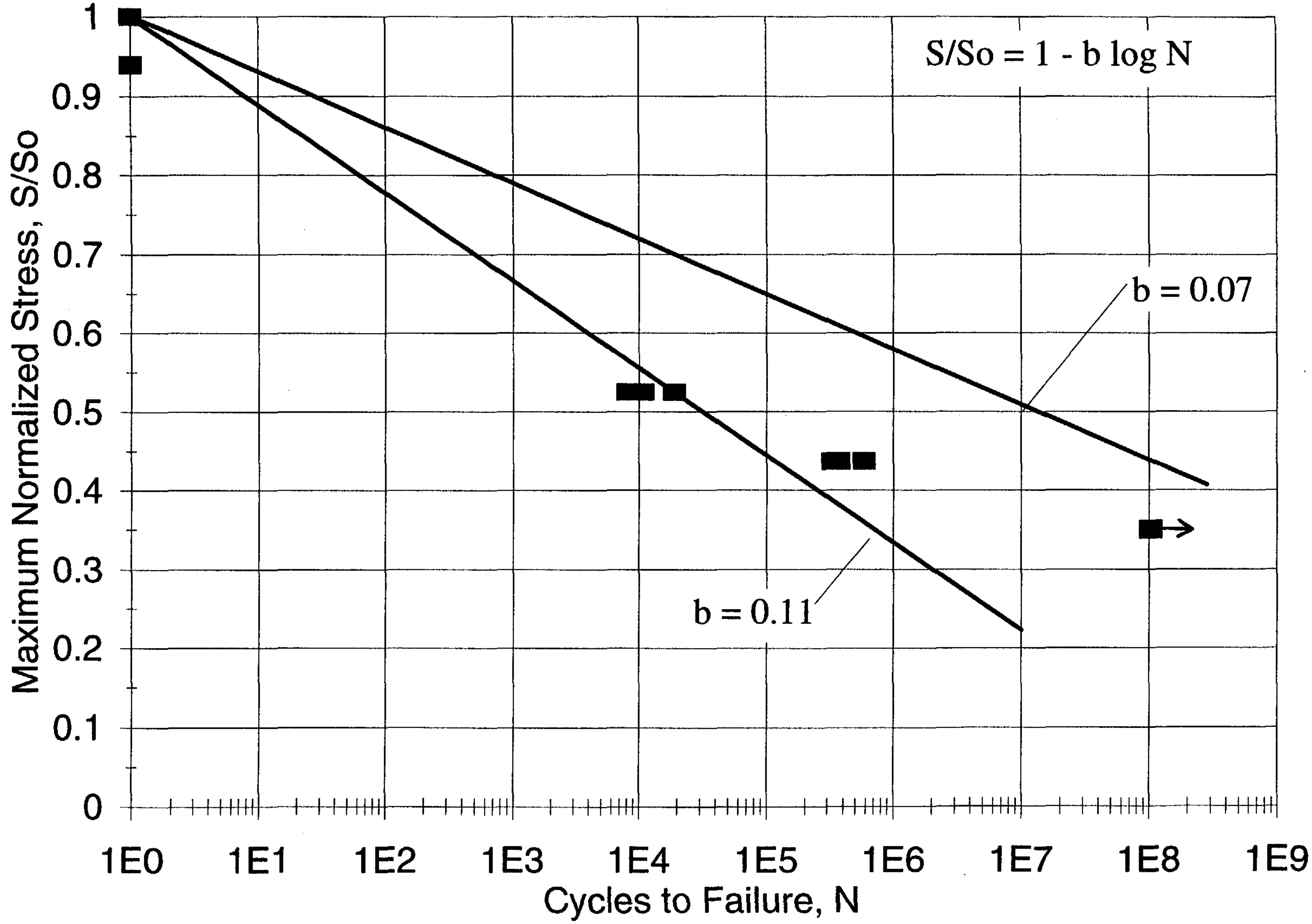


FIGURE 53.

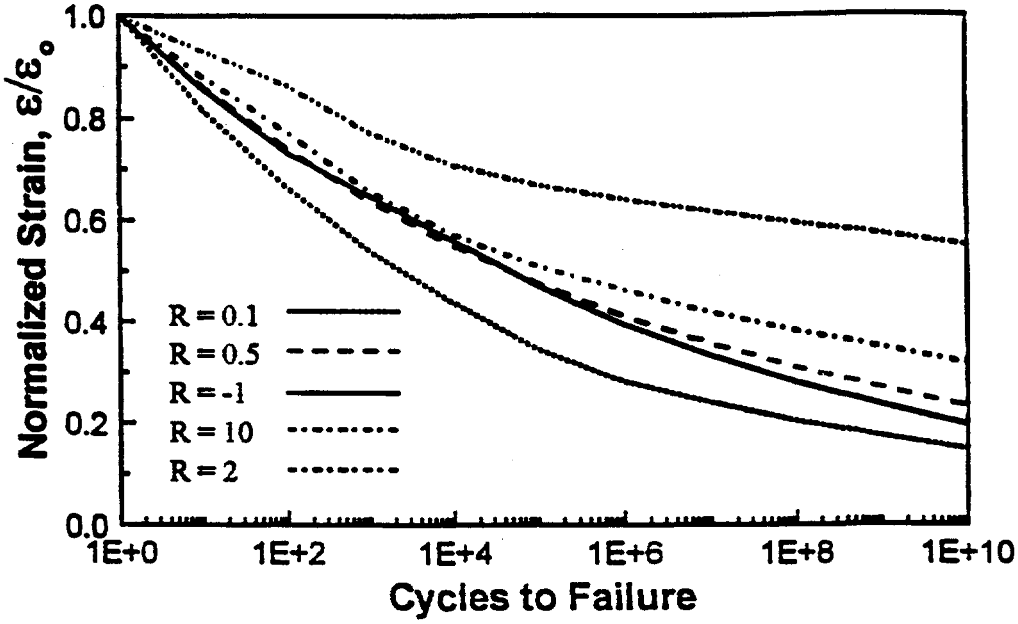


Figure 54a Semi-log Plot of Longitudinal Normalized Strain Data.

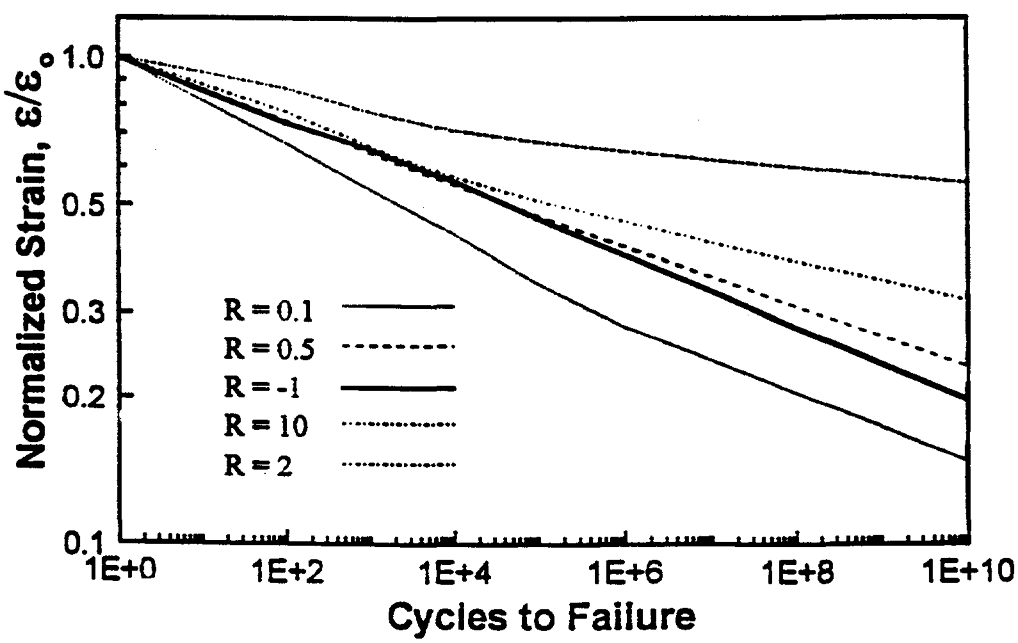


Figure 54b Log-log Plot of Longitudinal Normalized Strain Data.

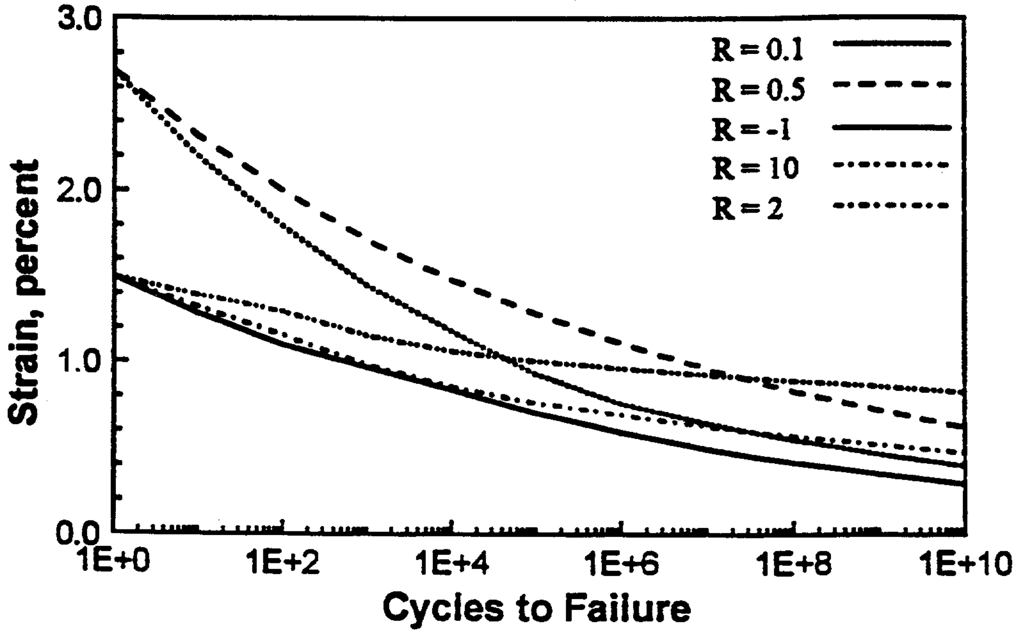


Figure 55 Unnormalized Semi-log Longitudinal Strain Curves.

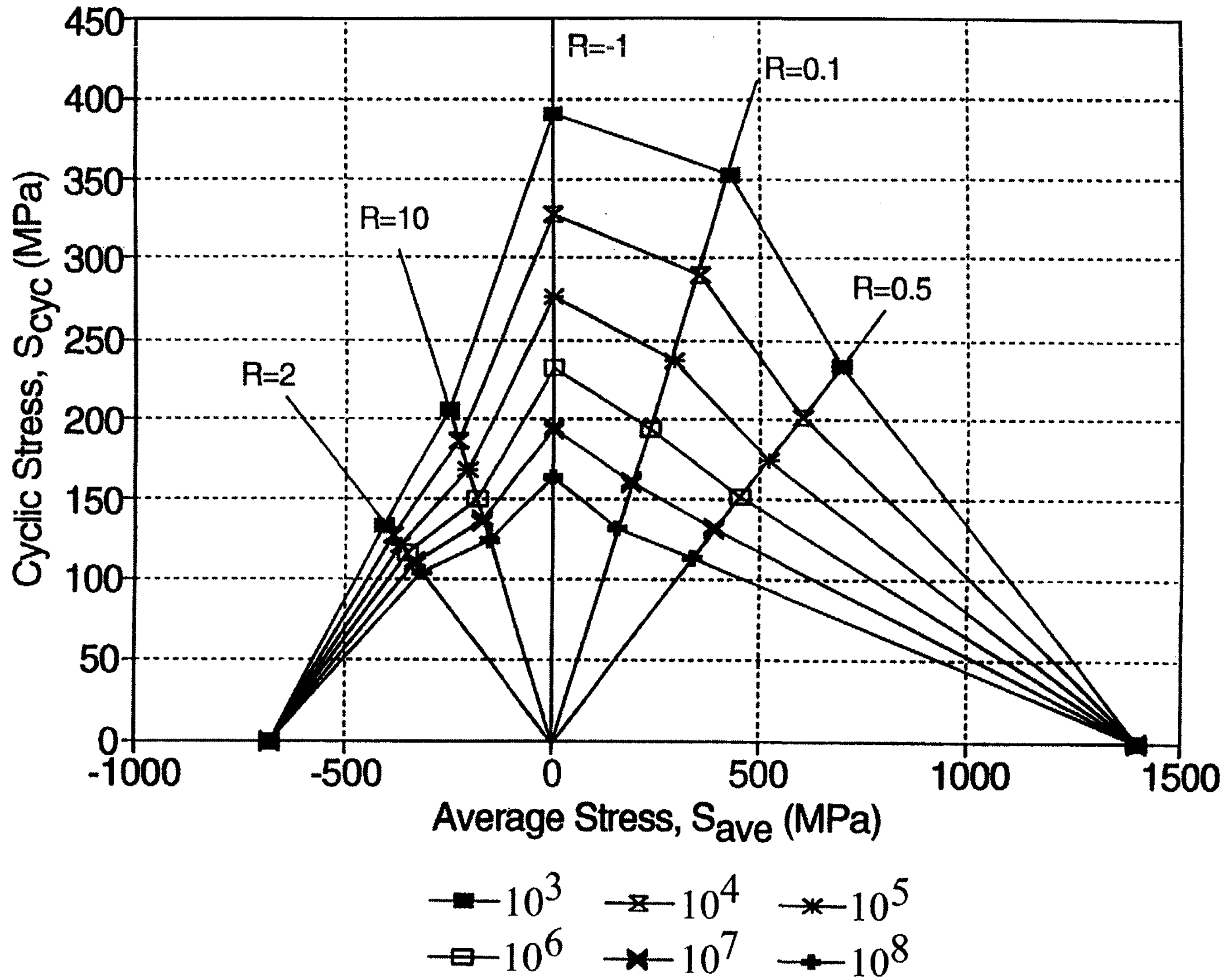


Figure 56. Longitudinal Stress-based Goodman Diagram Above 10^3 Cycles.

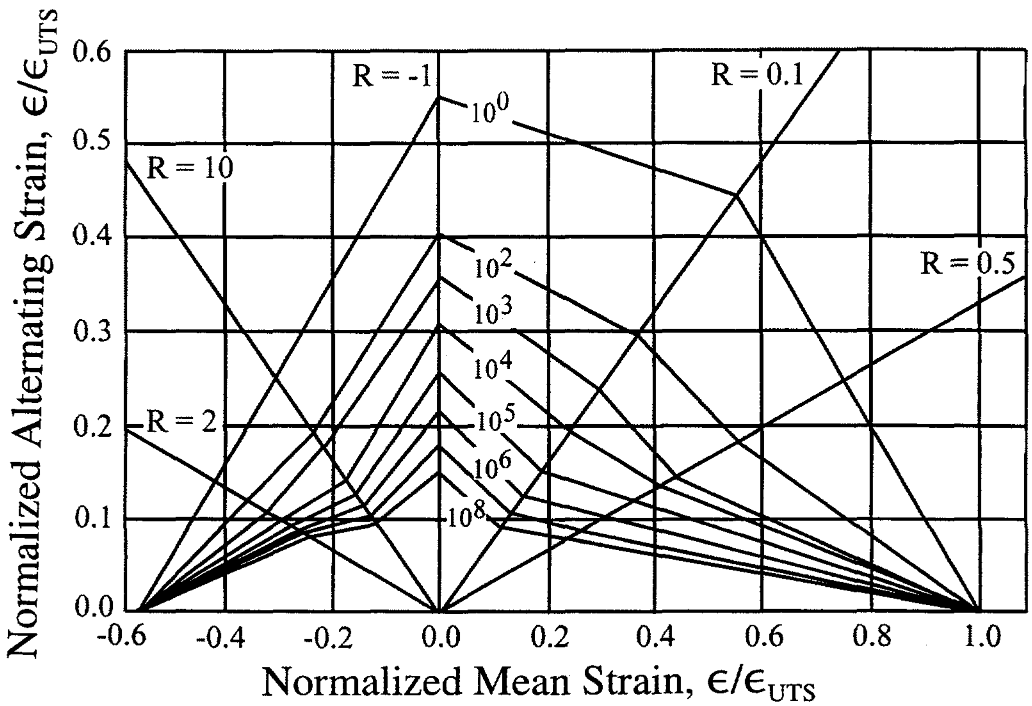


Figure 57. Normalized Goodman Diagram for Fiberglass Composites Based on the MSU/DOE High Frequency Longitudinal Direction Database.

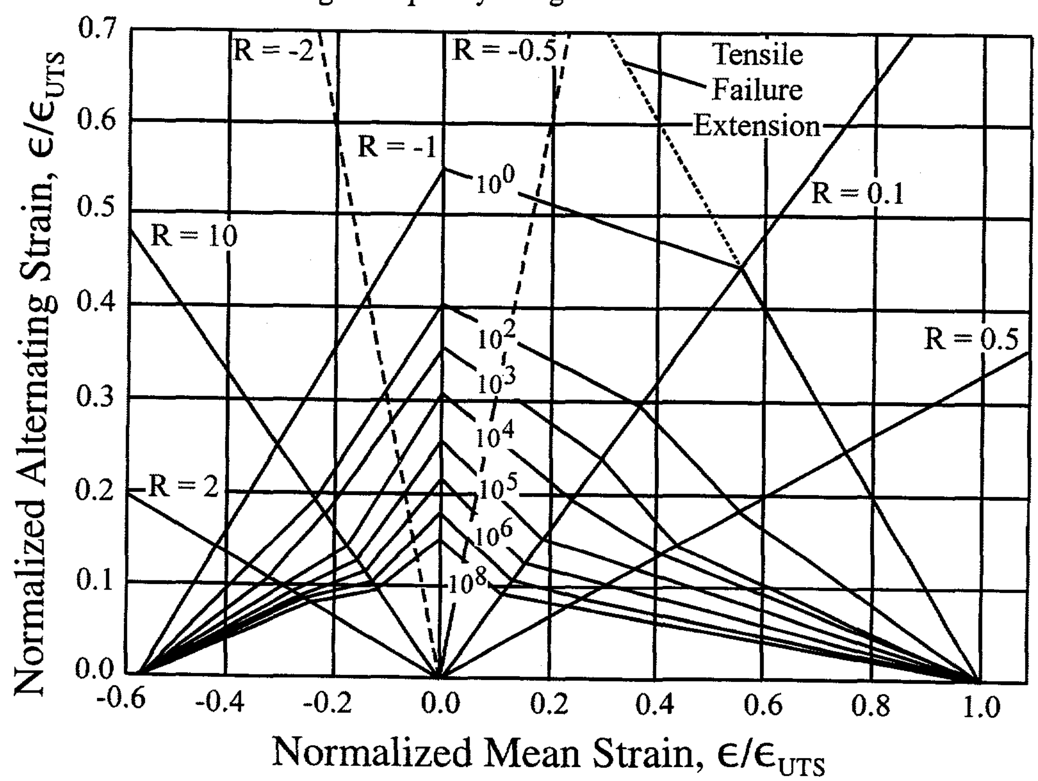


Figure 58. Goodman Diagram with Tensile Failure Extension and Constant R Values Based on the MSU/DOE High Frequency Longitudinal Direction Database.

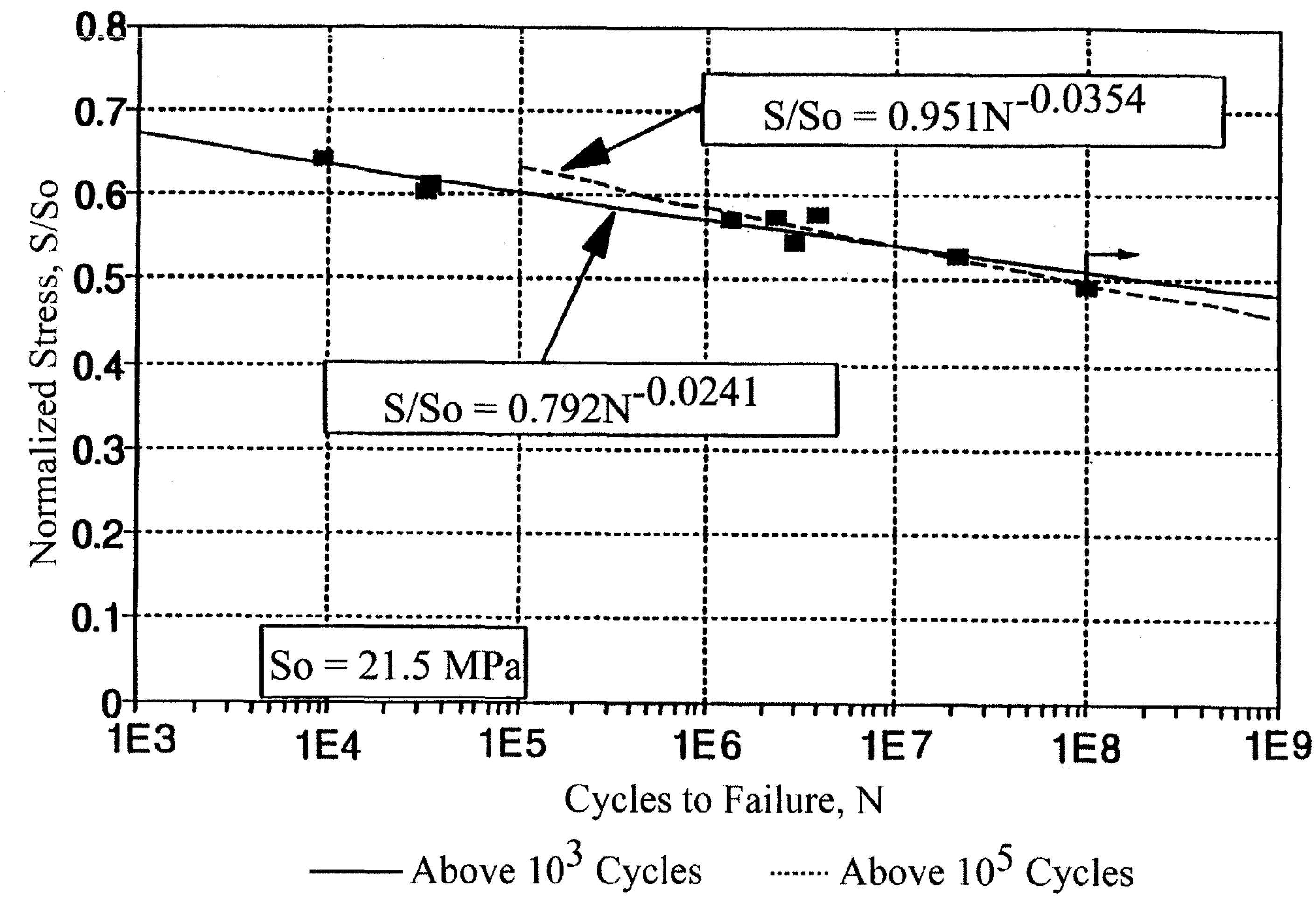


Figure 59. Power Law Fits of S-N Data for Transverse R=0.1 Above 10^3 and Above 10^5 Cycles.

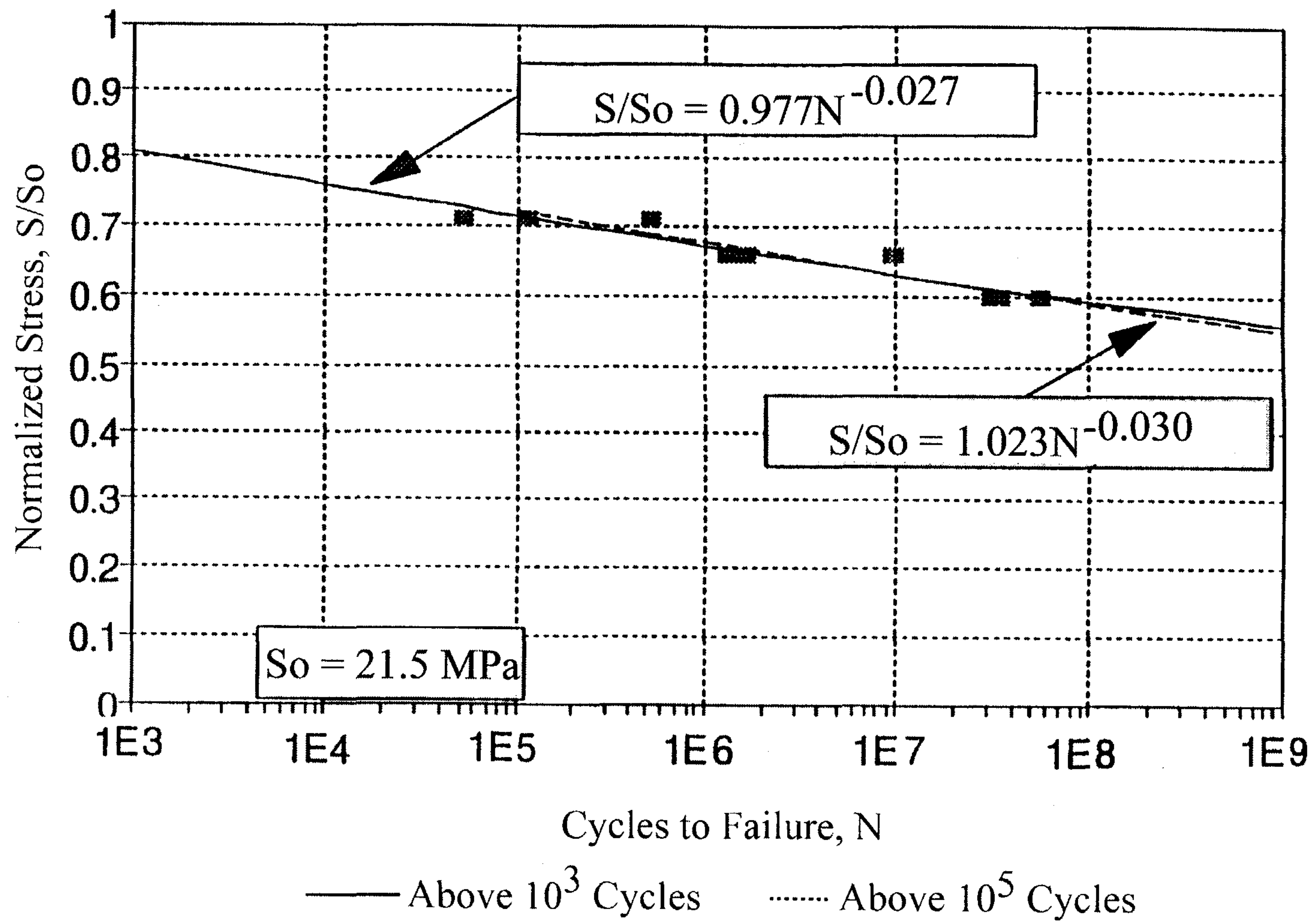


Figure 60. Power Law Fits of S-N Data for Transverse R=0.5 Above 10^3 and Above 10^5 Cycles.

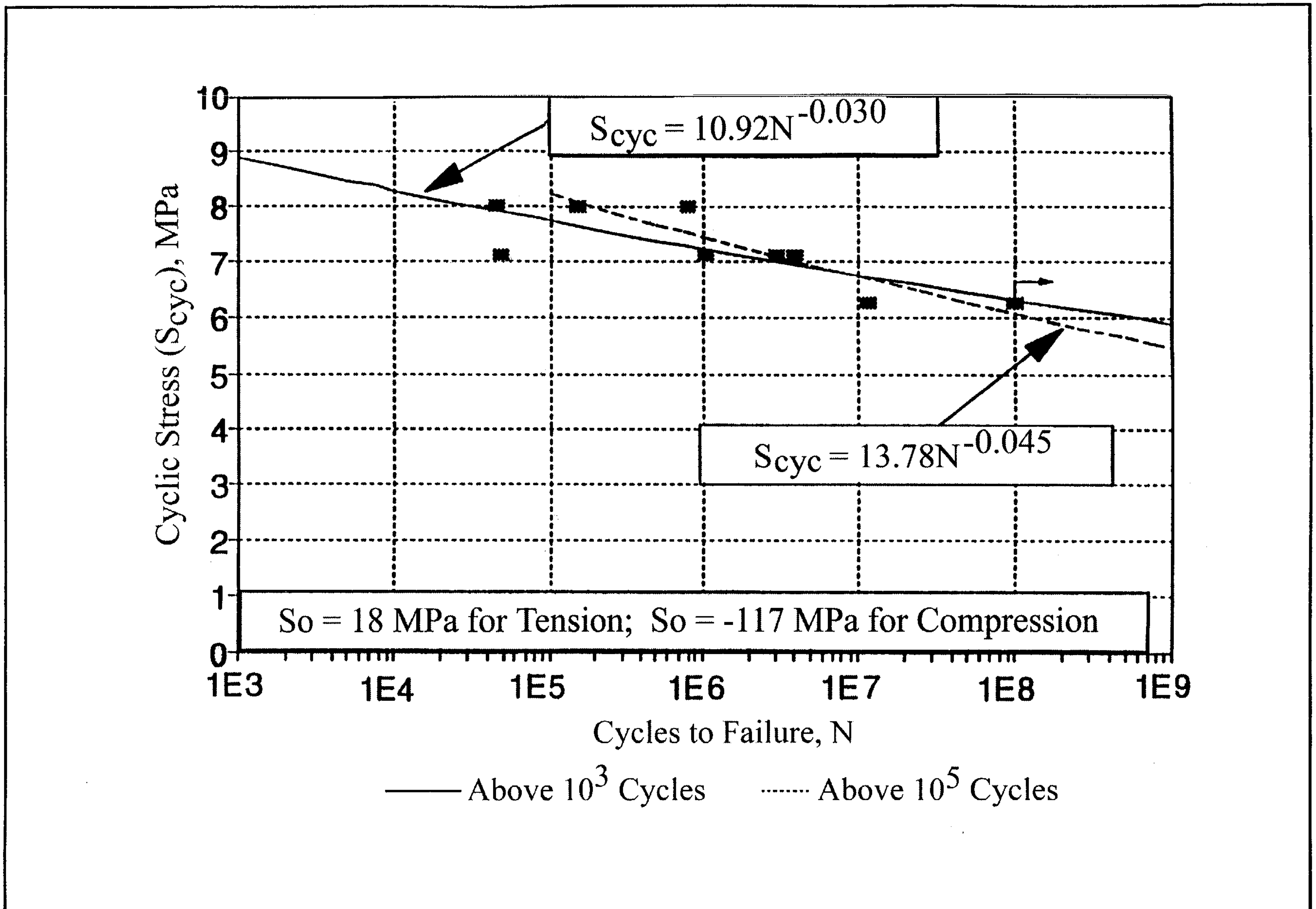


Figure 61. Power Law Fits of S-N Data for Transverse R=-1 Above 10^3 and Above 10^5 Cycles.

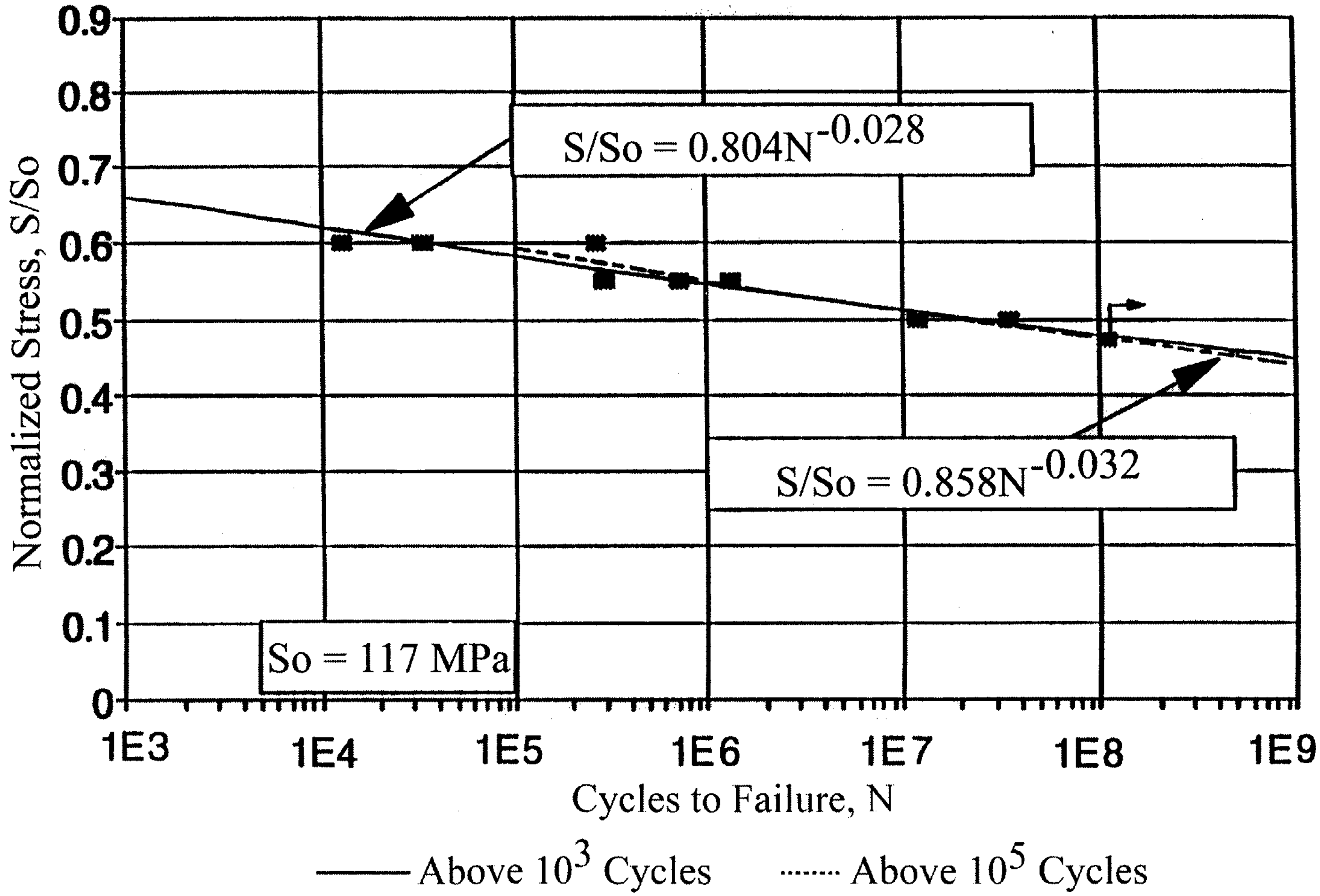


Figure 62. Power Law Fits of S-N Data for Transverse R=10 Above 10^3 and Above 10^5 Cycles.

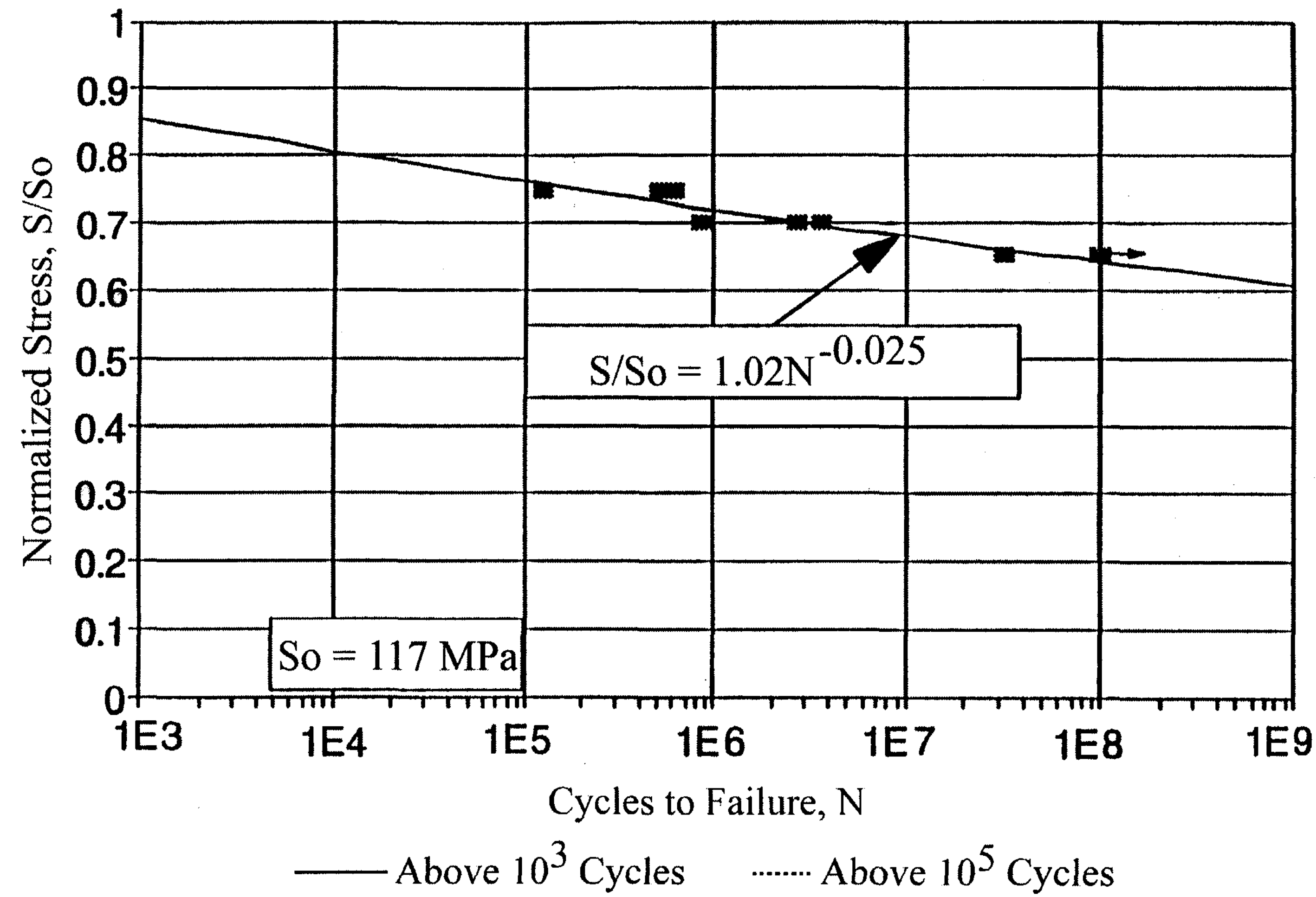


Figure 63. Power Law Fits of S-N Data for Transverse R=2 Above 10^3 and Above 10^5 Cycles.

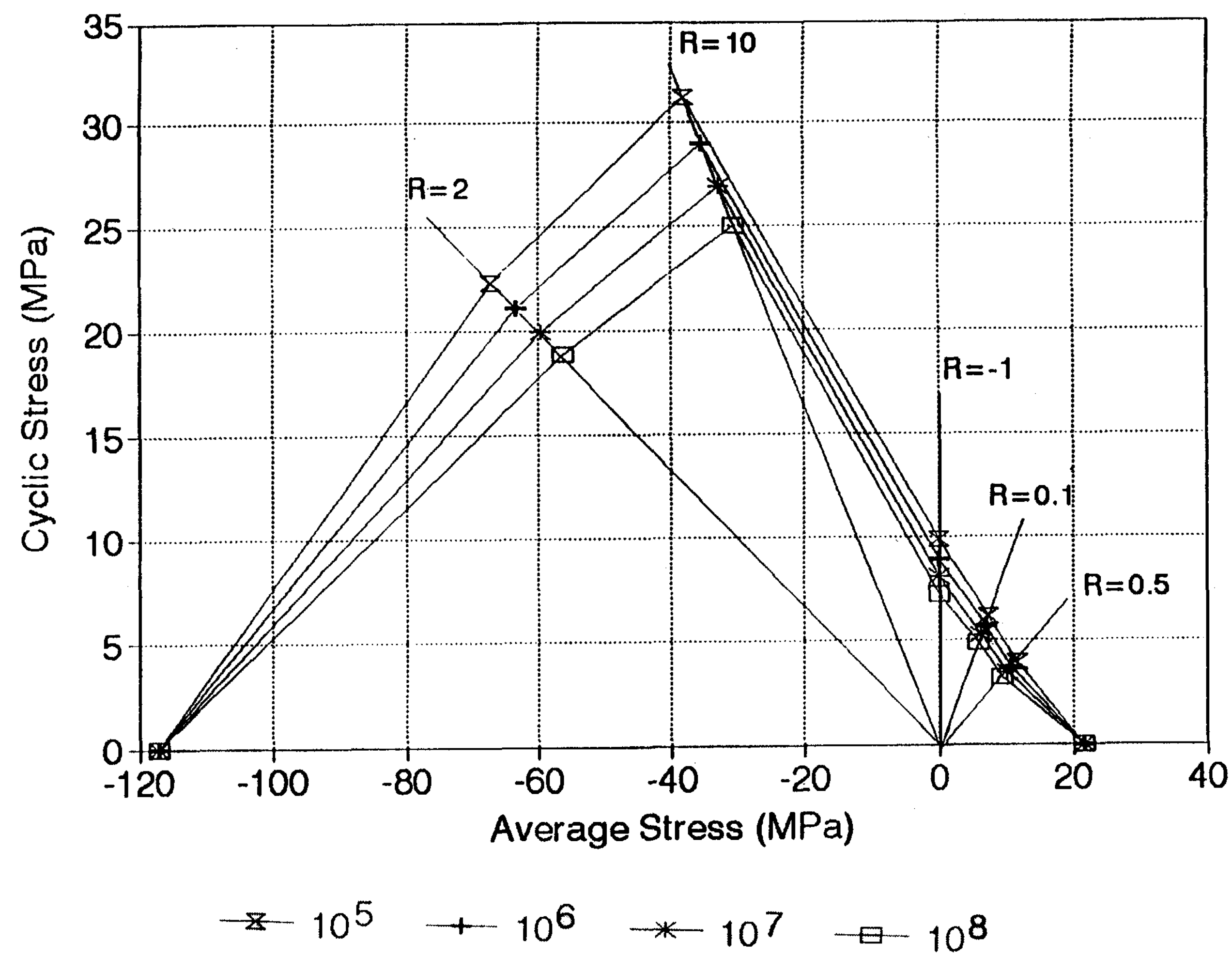


Figure 64. Transverse Stress-based Goodman Diagram Above 10^5 Cycles.

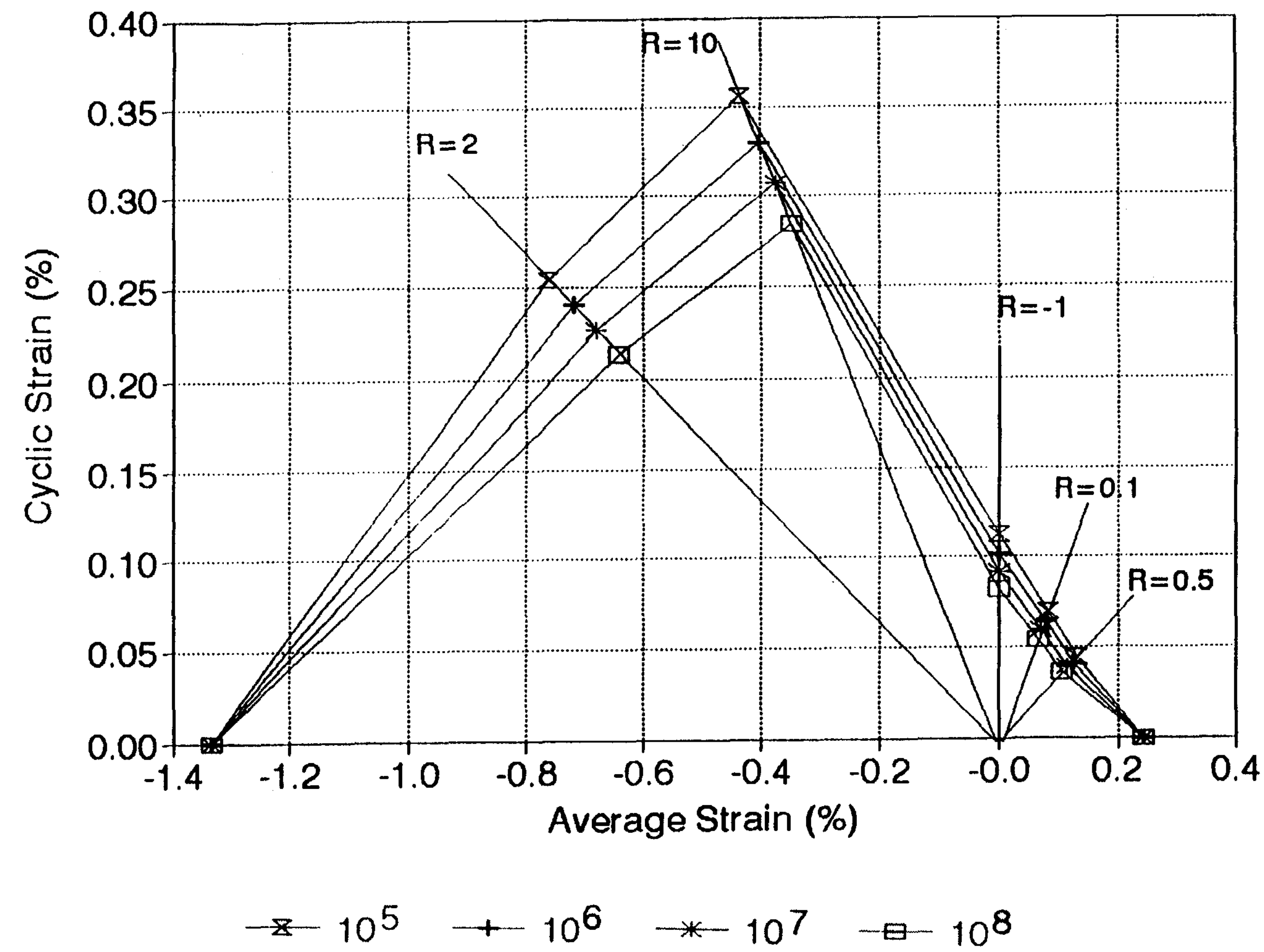


Figure 65. Transverse Strain-based Goodman Diagram Above 10^5 Cycles.

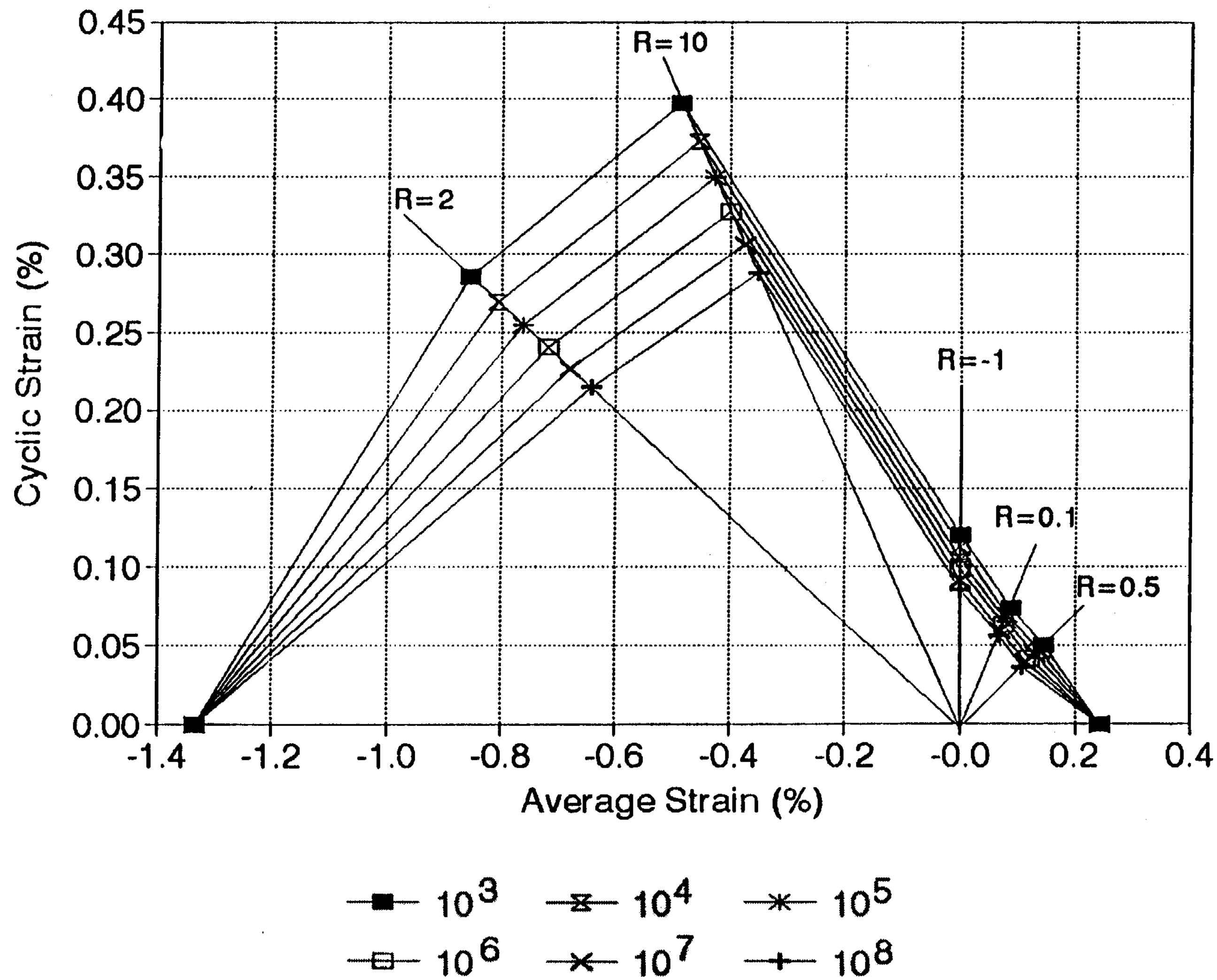


Figure 66. Transverse Strain-based Goodman Diagram Above 10^3 Cycles.

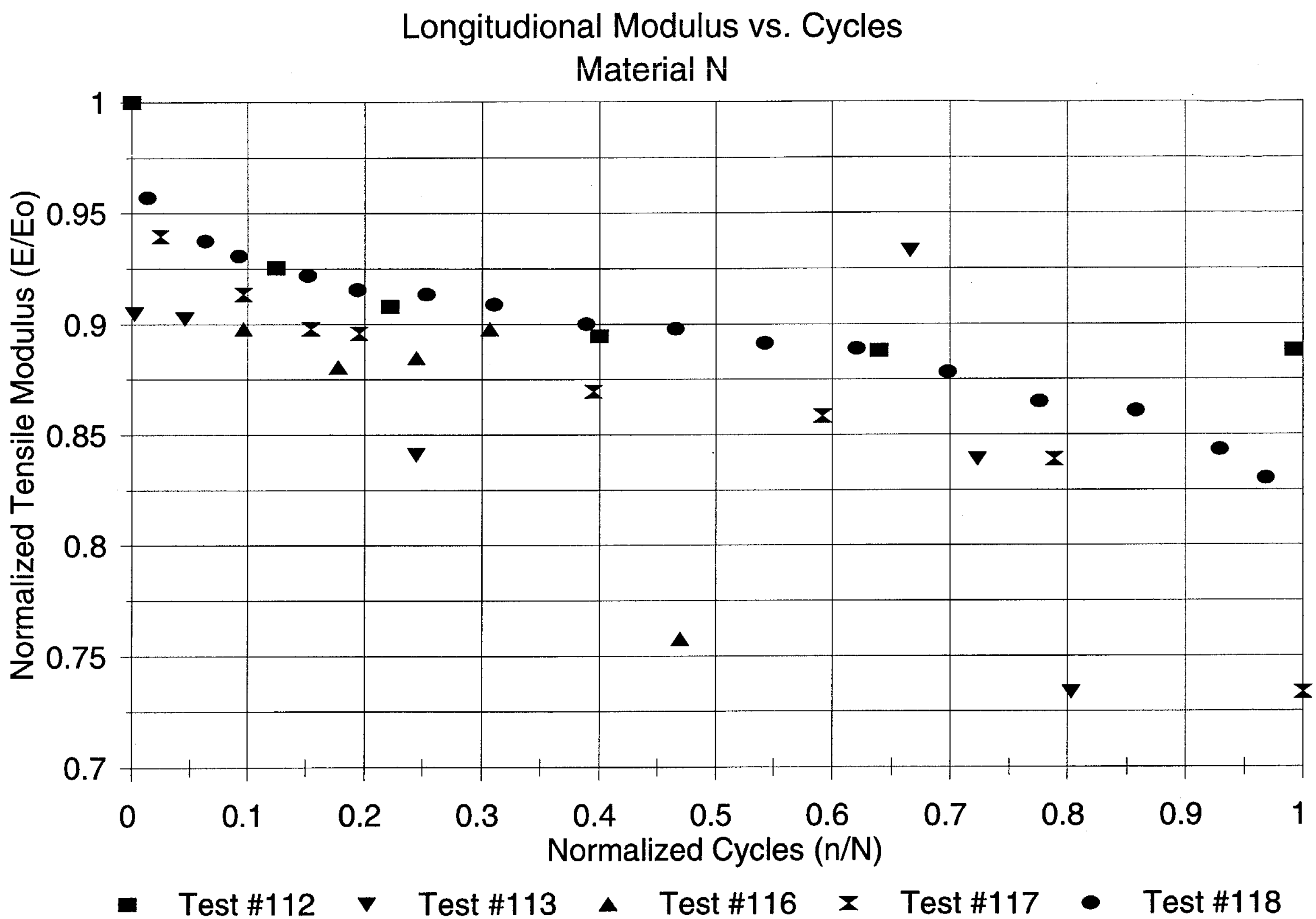

Longitudional Modulus vs. Cycles
Material N
Normalized Tensile Modulus (E/Eo)
1
0.95
0.9
0.85
0.8
0.75
0.7
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1
Normalized Cycles (n/N)
Test #112
Test #113
Test #116
Test #117
Test #118

FIGURE 67.

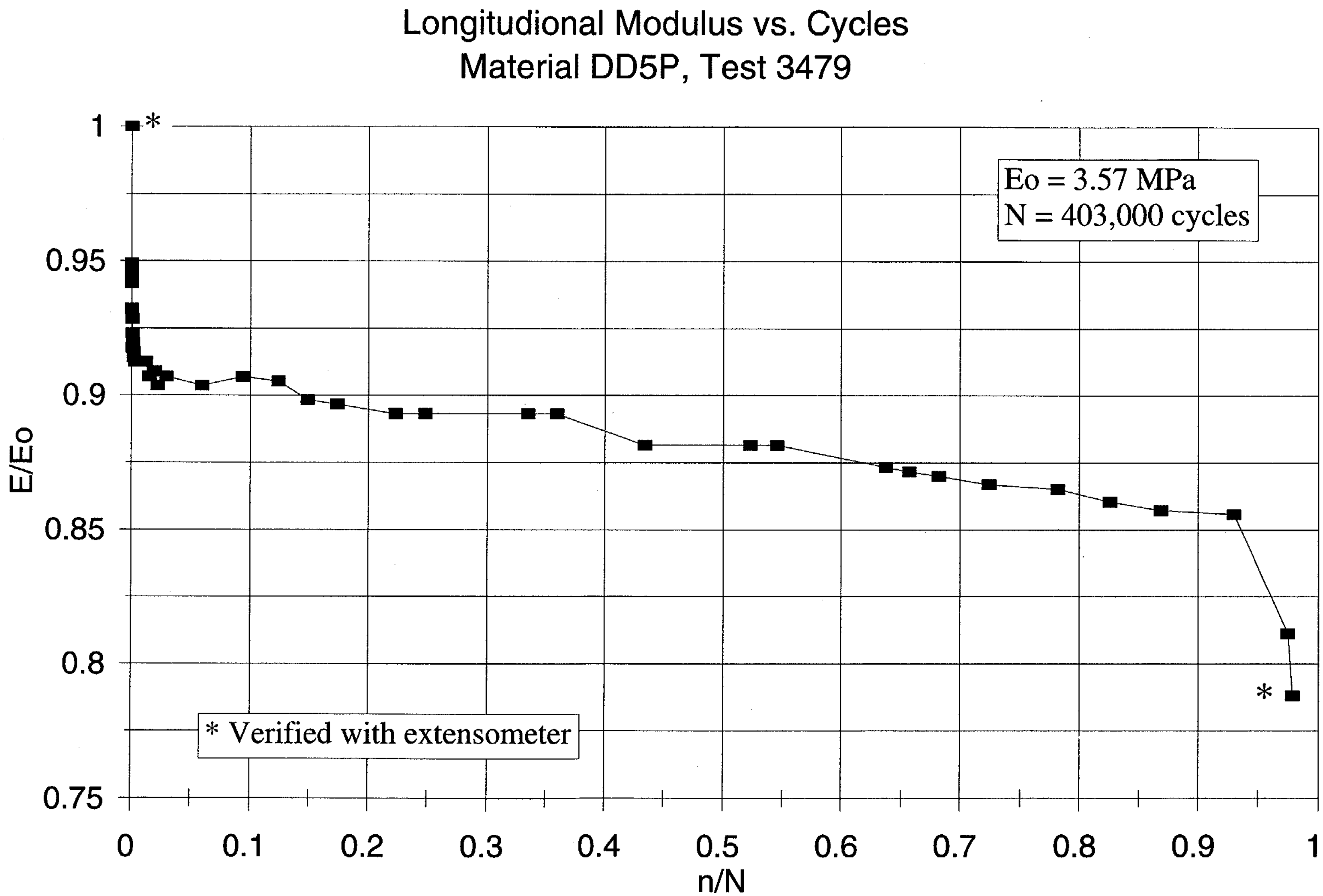
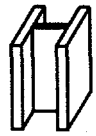
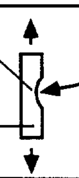

Longitudional Modulus vs. Cycles
Material DD5P, Test 3479
Eo = 3.57 MPa
N = 403,000 cycles
* Verified with extensometer
E/Eo
n/N
1
0.95
0.9
0.85
0.8
0.75
0
0.1
0.2
0.3
0.4
0.5
0.6
0.7
0.8
0.9
1

FIGURE 68.

Detail	Sketch		F
Simple Coupon (Straight Material)			1.0
Bonded Stiffener (Beam - Web)			1.2
Cracked Transverse 90° Patch			1.0
Single Interior 0° Ply Drop		$V_F < 0.4$	- - -
		$V_F > 0.4$	1.2
Double Interior 0° Ply Drop		$V_F < 0.4$	1.6
		$V_F > 0.4$	1.0
Locally Higher Fiber Content D155 / DB120 Fabrics (2 - 90° plies in center)	 $V_F = 47\%$; $V_F = 34\%$		1.4
Surface Indentation A130 / DB120 Fabrics (V_f increased, thickness reduced by 25%)	$V_F = 52\%$; $V_F = 37\%$  r = 6mm		1.8
Surface Indentation D155 / DB120 Fabrics (V_f increased, thickness reduced by 25%)	$V_F = 52\%$; $V_F = 36\%$  r = 6mm		2.5

$$10^6 \text{ Cycle Strain} = \frac{(\text{Coupon } 10^6 \text{ Cycle Strain})}{F}$$

FIGURE 69. Preliminary Tensile Fatigue Knock - Down Factors for Selected Structural Details Relative to Simple Coupons of DD5 Material

DOE / MSU WIND TURBINE BLADE COMPOSITE MATERIAL FATIGUE DATABASE

November 12, 1997

 This version of the database supersedes all previous versions due to continuous testing and data refinement.

TABLE OF CONTENTS PAGE

DOE/MSU Fiberglass Composite Database Notes

The database begins with a listing of material details, followed by a summary of static and fatigue properties for each material system. A full listing of individual test results follows.

Presently there are 22 industrial and 88 Montana State University - Bozeman (MSU) manufactured fiberglass composites which have been fatigue tested for this database. Materials presently include layup combinations of 0^o, $\pm 45^o$ and $0^o/\pm 45^o$ fabrics tested in the strongest (longitudinal) and weakest (transverse) directions. The database contains results from cyclic fatigue tests using a constant stress amplitude sine waveform with R - values of 0.1, 10 and -1, the high cycle, high frequency part of the database has R - values of: 0.1, 0.5, 2, 10, -0.5 and -1. Where the R - value is defined by:

$$R = \frac{Minimum\ cyclic\ stress}{Maximum\ cyclic\ stress}$$

and the compressive stress are negative.

Each test material was given a letter or, letter and number designation which identified the material and individual test coupons. All materials are E - glass fabric reinforced thermoset polymer matrix composites. A brief description of the database structure and the description of each composite is given below. Further information about this composite fatigue program can be found in literature listed at the end of this section.

The individual test results are listed and summarized using eight columns with the following data structure:

(Col.1)	(Col.2)	(Col.3)	(Col.4)	(Col.5)	(Col.6)	(Col.7)	(Col.8)
TEST & SAMPLE ID #	MAXIMUM STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	NOTES
(Col.1)	(Col.2)	(Col.3)	(Col.4)	(Col.5)	(Col.6)	(Col.7)	(Col.8)
63 102J	561	*	25	23.7	1.60	1	25
70 105J	129	0.1	10	26.2	0.31	11,000,000	25R
86 101NT	54	0.1	1	8.62	1.34	6,479	25
149 132N	86	-1	5	22.8	0.36	105,505	25
215 125P	-207	10	10	28.0	-0.63	14,121	25

Col. 1: Lists the MSU mechanical test reference number and the test coupon reference label. If the sample ID label is succeeded by the letter T, the material was tested in the transverse direction or ninety degrees to the major zero degree fiber direction.

Col. 2: This column indicates the maximum stress in megapascals (MPa) which was applied to the coupon. A positive number indicates tension while a negative number indicates compression. For a compression test the stress listed as maximum is actually the minimum stress.

Col. 3: Indicates the R - value of the fatigue test. An asterisk indicates a static, single cycle tension or compression test.

Col. 4: Lists the cyclic sine wave frequency (Hz) at which the coupon was tested in fatigue or, in the case of a static test, the constant displacement ramp rate in millimeters per second (mm/s).

Col. 5: Lists the initial measured elastic modulus (E) of the coupon in gigapascals (GPa).

Col. 6: Indicates the initial absolute maximum fatigue running strain (e) in percent or the percent strain to failure for a static test.

Col. 7: Indicates the total cycles to failure for the test coupon, where failure is defined as the inability of the test coupon to support the maximum absolute applied fatigue load.

Col. 8: Lists the test coupon width in millimeters (mm) and any other notation for comments.

The notations used in column 8 are summarized below:

H - Coupon has a 12.7 mm diameter circular hole in the middle of the gage length
R - Run out, coupon has significant fatigue cycles but has not yet failed, test stopped.
Z - Double coupon thickness, two coupons bonded together to increase thickness
- Coupons were post cured at a temperature of 110 degrees Celsius which was higher than the standard curing temperature of 60 degrees Celsius.
±45 - Test coupon was tested with all the fibers orientated in the ±45 direction to obtain shear properties.
ZERO - Test coupon was tested with all fibers orientated in the zero degree load axis.
90 - Test coupon was tested with all the fibers orientated in the 90 degree or transverse to the axis of loading.
tab - Coupon has additional tab material in the gripped area of the composite
---- - Indicates that a value was unavailable.

Other notations used in the test material summary tables include:

V_F - Fiber volume content of the material in percent
UCS - Ultimate Compressive Strength of the material in MPa
UTS - Ultimate Tensile Strength of the material in MPa
b - fatigue sensitivity coefficient from a linear regression curve fit to the S - N data. Assuming a linear S - N curve on the semi - log plot, yields the equation, $S / S_0 = 1 - b \log N$, where S is the maximum stress, S_0 is the single cycle strength and N is the total cycles to failure.
b_C - Slope of the compressive fatigue (R - 10) trend line on a semi - log graph (compressive fatigue sensitivity coefficient)

b_T - Slope of the tensile fatigue (R = 0.1) trend line on a semi - log graph (tensile fatigue sensitivity coefficient)

b_R - Slope of the reversed loading (R = -1) fatigue trend line on a semi - log graph (completely reversed loading fatigue sensitivity coefficient)

E - Epoxy matrix material is used in the composite

P - Polyester matrix material is used in the composite

V - Vinylester matrix material is used in the composite

Some of the fatigue data and the testing procedures followed were discussed in the Sandia Contractors Report, SAND92-7005, UC-261, "Fatigue of Fiberglass Wind Turbine Blade Materials", August 1992, Mandell, Reed, Samborsky., "Fatigue of Fiberglass Beam Substructures", Wind Energy 1995, Mandell, J.F., Combs, D.W., and Samborsky, D.D., 1995, ASME SED -Vol. 16, pp 99-106., "Fatigue Resistant Fiberglass Laminates for Wind Turbine Blades", Wind Energy 1996, Samborsky, D.D. and Mandell, J.F., 1996. A Sandia Contractors Report with full details of the results will be available in early 1997.

The high cycle fatigue data involved thin unidirectional fiberglass tested in the longitudinal and transverse fiber directions for various R values. These were tested with a polyester matrix. The high cycle fatigue database was described in "High Cycle Tensile and Compressive Fatigue of Glass Fibers - Dominated Composites" , J.F. Mandell, H. Sutherland, R. Creed, A. Belinky, K. Wei, ASTM Symposium, Fatigue of Composite Materials, March 1995. and J.F. Mandell, R.F. Creed, Jr., Q. Pan, D.W. Combs, and M. Shrinivas, "Fatigue of Fiberglass Generic Materials and Substructures" in SED-Vol 15, Wind Energy 94, W.D. Musial, S.M. Hock, and D.E. Berg, eds., ASME, New York, pp. 207-213 (1994)

Laminates contained only individual Knytex fabrics were constructed and their static properties in the longitudinal, transverse and simulated shear to obtain basic material lamina properties for laminate analysis. The comments column indicates these tests with the notations: zero, ±45 and 90. Comments on the angle of testing are listed in the comments column with the angle being the glass fiber angle in degrees away from the axis of loading.

The MSU resin transferred molded composites involving fabrics Axxx, Dxxx, DBxxx, CDBxxx, CDMxxx were obtained from Knytex. Co. 1851 South Seguin St., New Braunfels, Texas, 78130. Where xxx divided by 10 is the approximate fabric weight, in ounces, per square yard of fabric where 1 oz/yd^2 = 33.9 g/m^2. For example D155 is a directional fabric with a weight of 15.5 oz/yd^2 or 525 g/m^2.

Layup of Industrial Fiberglass Materials

Material	V_F %	Ply Configuration	Matrix	Description
A	30	$[0]_5$	P	407 g/m^2 0's
B	30	$[0]_5$	V	
F	36	$[(\pm45/0)_3]_S$	P	1,120 g/m^2 Triax (48%- 0's) Center two plies dropped off (6 → 4)
G	36	$[(0/\pm45)_3]_S$	P	
H	39	$[(\pm45/0)_3]_S$	P	1,086 g/m^2 Triax (70%- 0's, 30%- ±45's) Center two plies have butt joint (6 → 4)
J	43	$[(0/\pm45)_3]_S$	P	
L	50	$[0]_3$	P	0's - A260's
M	38	$[0/\pm45]_4$	V	747 g/m^2 Triax (50%-0's)
N	36	$[0/\pm45]_4$	P	
P	36	$[0/\pm45/M/0]_S$	V	747 g/m^2 Triax, 6-oz Mat(M), 0's -A260
R	32	$[0/\pm45]_4$	P	0's - DN105, 45 - DB120 (47%-0's)
T	30	$[0/\pm45]_4$	P	Folded edge Triax (CDB200)
U	29	$[0/\pm45]_4$	P	Cut edge Triax (CDB200)
V	32	$[0/\pm45]_4$	P	Folded edge Triax (CDB222)
W	33	$[0/\pm45]_4$	P	Cut edge Triax (CDB222)
X	35	$[0_2/M/\pm45/0_2]$	P	85%-0's (A260), 10%-±45's (12-oz), 5%-Mat(M) (6-oz)
Y	39	$[0_2/M/\pm45/0_2]$	E	
EE	54	$[M/\pm45/0]_S$	E	65%-0's, 18%- 45's, 17%- Mat
EEAV	48	$[M/\pm45/0]_S$	V	71%-0's, 18%- 45's, 11%- Mat
EEAP	49	$[M/\pm45/0]_S$	P	70%-0's, 19%- 45's, 11%- Mat
EEB	43	$[M/\pm45/0]_S$	V	57%-0's, 26%- 45's, 17%- Mat
EEC	49	$[M/\pm45/0]_S$	V	65%-0's, 20%- 45's, 15%- Mat

Matrix Abbreviations: E - Epoxy , P - Polyester, V- Vinylester

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Material	V_F %	Ply Configuration	Matrix	Description
AA	35	$[(\pm45/0)_3(\mp45/0)_2]$	P	CDB-200 Triax
AA2	40	$[(0/\pm45)_2]_S$	P	CDB-200 Triax
AA3	51	$[(\pm45/0)_3]_S$	P	CDB - 200 Triax
AA4	38	$[(\pm45/0)_2]_S$	P	TV-3400 Triax
BB	42	$[\pm45/0_2/\pm45/0_2/\mp45]$	P	0's-A130 (62%), 45's-DB120
CC	39	$[\pm45/0_2/\pm45/0_2/\mp45]$	P	0's-D100 (55%), 45's-DB120
CC2	45	$[\pm45/0_3/\pm45/0_3/\mp45]$	P	0's-D100 (63%), 45's-DB120
CC3	45	$[0/\pm45/0_2/\pm45/0_2/\mp45/0]$	P	0's-D100 (63%), 45's-DB120
CH	45	$[(\pm45)_3]_S$	P	45's-DB240
CH2	41	$[\pm45/0/\pm45]_S$	P	0's-D155 (24%), 45's-DB240
CH3	36	$[\pm45/0/\pm45]_S$	P	0's-D155 (24%), 45's-DB240
CH4	37	$[(\pm45)_3]_S$	P	45's-DB120
CH5	28	$[(\pm45)_3]_S$	P	45's-DB120
CH6	49	$[\pm45/0/\pm45]_S$	P	0's-D155 (39%), 45's-DB120
CH7	55	$[(\pm45)_3]_S$	P	45's-DB400
CH8	39	$[(\pm45)_3]_S$	P	45's-DB400
CH9	49	$[(\pm45)_3]_S$	P	45's-DB120
CH10	33	$[(\pm45)_3]_S$	P	45's-DB240
CH11	54	$[(\pm45)_3]_S$	P	45's-DB240
CH12	34	$[\pm45/0/\pm45]_S$	P	0's-D155 (39%), 45's-DB120
CH13	48	$[\pm45/0/\pm45]_S$	P	0's-D155 (24%), 45's-DB240
CH14	44	$[\pm45/0/\pm45]_S$	P	0's-D155 (39%), 45's-DB120
CH15	32	$[\pm45/0/\pm45]_S$	P	0's-D092 (28%), 45's-DB120
CH16	40	$[\pm45/0/\pm45]_S$	P	0's-D092 (28%), 45's-DB120

Layup of MSU Manufactured (RTM) Fiberglass Materials

Matrix Abbreviations: E - Epoxy , P - Polyester, V- Vinylester

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Material	V_F, %	Ply Configuration	Matrix	Description
CH17	48	$[\pm45/0/\pm45]_S$	P	0's-D092 (28%), 45's-DB120
CH18	47	$[\pm45/0/\pm45]_S$	P	0's-D092 (16%), 45's-DB240
CH19	33	$[\pm45/0/\pm45]_S$	P	0's-D092 (16%), 45's-DB240
CH20	25	$[(\pm45_3)]_S$	P	45's-DBM1204B
CH23	32	$[\pm45/0/\pm45]_S$	P	0's-D155 (39%), 45's-DBM1204B
DD	49	$(0/\pm45/0_3/\pm45/0)$	P	0's-D155 (76%), 45's-DB120
DD2	42	$(0/\pm45/0)_S$	P	0's-D155 (72%), 45's-DB120
DD4	50	$(0/\pm45/0)_S$	P	
DD5	38	$(0/\pm45/0)_S$	P	
DD5E	36	$(0/\pm45/0)_S$	E	
DD5P	36	$(0/\pm45/0)_S$	P	
DD5V	36	$(0/\pm45/0)_S$	V	
DD6	31	$(0/\pm45/0)_S$	P	
DD7	54	$(0/\pm45/0)_S$	P	
DD8	42	$(0/\pm45/0)_S$	P	0's-D155 (72%), 45's-DB120 All fabric stitching yarn removed
DD9	54	$(0/\pm45/0)_S$	P	
DD10	62	$(0/\pm45/0)_S$	P	
DD11	31	$(0/\pm45/0)_S$	P	0's-A130 (68%), 45's-DB120
DD11A	31	$(\pm45/0_4/\mp45)$	P	
DD12	43	$(0/\pm45/0)_S$	P	
DD13	50	$(0/\pm45/0)_S$	P	
DD14	25	$(0/\pm45/0)_S$	P	0'S-CM1701 (72%), 45'S-DB120
DD15	35	$(0/\pm45/0)_S$	P	

Layup of MSU Manufactured (RTM) Fiberglass Materials

Matrix Abbreviations: E - Epoxy , P - Polyester, V- Vinylester

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Layup of MSU Manufactured (RTM) Fiberglass Materials

Material	V_F, %	Ply Configuration	Matrix	Description
DD16	36	$(90/0/\pm45/0)_S$	P	0's-D155 (53%), 90's-D155 (26%) 45's-DB120 (21%)
DD17	37/52	$(0/\pm45/0)_S$	P	0's-D155 (72%), 45's-DB120 Has surface indentation (flaw)
DD17A	35/42	$(0/\pm45/0)_S$	P	0's-A130 (68%), 45's-DB120 Has surface indentation (flaw)
DD18	34/40	$(0/\pm45/0)_S$	P	0's-D155 (72%), 45's-DB120 Has center flaw, one 90° (D155) tow
DD18A	36/43	$(0/\pm45/0)_S$	P	0's-D155 (68%), 45's-DB120 Has center flaw, one 90°(D155) tow
DD19	34/47	$(0/\pm45/0)_S$	P	0's-D155 (72%), 45's-DB120 Has center flaw, two 90° (D155) tows
DD19A	36/50	$(0/\pm45/0)_S$	P	0's-A130 (68%), 45's-DB120 Has center flaw, two 90°(D155) tows
FFA	38	$(\pm45/0/0/\pm45)_S$	P	0's-D155 (56%), 45's-DB120
FFB	38	$(0/\pm45/0/\pm45)_S$	P	
FFC	38	$(0/\pm45/\pm45/0)_S$	P	
FFD	38	$(0/0/\pm45/\pm45)_S$	P	
FFF	38	$(\pm45/\pm45/0/0)_S$	P	
GG	40	$(0_2/\pm45/0_2)$	P	0's-D155 (84%), 45's-DB120

Matrix Abbreviations: E - Epoxy , P - Polyester, V- Vinylester

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Layup of MSU Manufactured (RTM) Fiberglass Materials

Material (fabric)	V_F, %	Ply Configuration	Matrix	Description
A060	41	$[0]_{10}$	P	0's - A060 (100%)
A130	45	$[0]_8$	P	0's - A130 (100%)
A130C	35	$[0]_5$	P	
A130G	55	$[0]_{14}$	P	
A260	35	$[0]_4$	P	0's - A260 (100%)
CM1701	38	$[0]_6$	P	0's - CM1701A (100%)
DO72A	36	$[0]_{10}$	P	0's - DO72 (100%)
DO92	45	$[0]_{10}$	P	0's - DO92 (100%)
DO92B	41	$[0]_8$	P	
DO92D	30	$[0]_7$	P	
DO92F	50	$[0]_{10}$	P	
DO92G	58	$[0]_9$	P	
D155	45	$[0]_6$	P	0's-D155 (100%)
D155B	39	$[0]_5$	P	
D155C	51	$[0]_7$	P	
D155G	59	$[0]_{15}$	P	
D155H	49	$[0]_7$	P	0's-D155 (100%) All fabric stitching yarn removed
D155J	58	$[0]_6$	P	
D155K	33	$[0]_7$	P	0's-D155 (100%)

Matrix Abbreviations: E - Epoxy , P - Polyester, V- Vinylester
The fabric designation refers to Knytex or Brunswick fabrics.

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Layup of MSU Manufactured (RTM) Fiberglass Materials Angle Plies

Material	V_F, %	Ply Configuration	Matrix	Description
10D155	38	$[\pm10]_3$	P	D155 (100%)
20D155	39	$[\pm20]_3$	P	
30D155	40	$[\pm30]_3$	P	
40D155	40	$[\pm40]_3$	P	
45D155	38	$[\pm45]_3$	P	
50D155	39	$[\pm50]_3$	P	
60D155	40	$[\pm60]_3$	P	
70D155	40	$[\pm70]_3$	P	
80D155	38	$[\pm80]_3$	P	
90D155	38	$[\pm90]_3$	P	

Matrix Abbreviations: E - Epoxy , P - Polyester, V- Vinylester

Layup of MSU High Cycle Materials

Material	V_F, %	Ply Orientation	Matrix	Description
Longitudinal	49 - 67	$(0)_2$	P	0's - D155 (100%)
Transverse	39	$(90)_4$	P	90's - D100 (100%)

Matrix Abbreviations: E - Epoxy , P - Polyester, V- Vinylester

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Properties of Industrial Materials

		R = 10			R = 0.1			
Material	V_F %	UCS, MPa	b_C	strain for 10^6 cycles, %	UTS, MPa	b_T	strain for 10^6 cycles, %	E, GPa
A	30	-313	----	----	566	0.111	0.87	21.5
B	30	-287	----	----	581	0.135	0.99	21.0
F	36	-364	----	----	357	0.130	0.48	17.2
G	36	-258	----	----	365	0.129	0.45	19.3
H	37	-403	0.10	-0.72	573	0.114	0.52	24.0
J	37	-410	----	----	609	0.118	0.52	24.2
L	50	-407	----	----	742	0.135	0.70	33.6
M	38	-286	----	----	516	0.141	0.40	20.7
N	36	-318	0.096	-0.70	468	0.140	0.46	19.3
NT	40	-131	----	----	87	0.100	0.43	8.1
P	40	-466	0.099	-0.66	667	0.134	0.42	28.9
R	31	-330	----	----	441	0.104	1.04	16.5
T	28	-290	----	----	365	0.116	0.65	17.7
U	29	-354	----	----	372	0.138	0.36	21.2
V	32	-379	----	----	374	0.133	0.43	20.0
W	33	-336	----	----	341	0.116	0.64	19.3
X	35	-439	0.070	-0.99	612	0.100	1.03	25.2
XT	35	-159	----	----	43	0.110	0.23	8.3
Y	39	-367	0.050	-1.06	595	0.100	1.00	24.4
YT	39	-107	----	----	34	0.106	0.17	7.0

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Static Longitudinal, Transverse and Simulated Shear Properties for E - Glass fabrics used in the MSU RTM composites																
			Longitudinal Direction										Transverse Direction			
			Elastic Constants				Tension		Compression		Shear	Tension		Compression		
Fabric	layup	V_F %	E_L GPa	E_T GPa	υ_{LT}	G_{LT} GPa	UTS_L MPa	ϵ_U %	UCS_L MPa	ϵ_U %	τ_{TU} MPa	UTS_T MPa	ϵ_U %	UCS_T MPa	ϵ_U %
A130	$[0]_8$	45	36.3	8.76	0.32	3.48	868	2.53	-334	-0.92	87.1	33.8	0.39	-93.3	-1.05
D092	$[0]_{10}$	45	35.3	8.76	0.31	4.15	952	2.98	-773	-2.19	142	38.5	0.44	-133	-1.52
D155	$[0]_6$	45	37.0	8.99	0.31	4.10	986	2.83	-746	-2.02	94.2	27.2	0.30	-129	-1.67
DB120*	$[0]_{16}$	44	26.5	7.52	0.39	4.12	610	2.49	-551	-2.08	84.9	24.9	0.33	-90.8	-1.21
DB240*	$[0]_8$	46	31.0	7.38	0.35	3.74	697	2.64	-538	-1.74	68.7	19.7	0.27	-122	-1.69
0/90ROV*	$[0/90]_7$	46	23.9	23.9	0.26	4.08	382	2.27	-223	-0.93	99.9	382	2.27	-223	-0.93

Notes: E_L - Longitudional modulus, υ_{LT} - Poisson's ratio, G_{LT} and τ_{TU} - Shear modulus and ultimate shear stress from a simulated shear (±45) ASTM D 3518 test. UTS_L - Ultimate longitudional tensile strength, ϵ_U - Ultimate tensile strain, UCS_L - Ultimate longitudional compressive strength, ϵ_U - Ultimate compressive strain.
Coupons had a 100 mm gage length and tested with a 0.02 mm/s testing velocity. * DB120 and DB240 fabrics were separated into a +45 and a -45 orientation and then rotated to 0 degrees to form a unidirectional material. The 0/90 ROV material was tested as a 0/90 fabric.

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Properties of Industrial Materials								
		R = 10			R = 0.1			
Material	V_F %	UCS, MPa	b_C	strain for 10^6 cycles, %	UTS, MPa	b_T	strain for 10^6 cycles, %	E, GPa
EE	55	-538	----	----	543	0.132	0.60	31.4
EEAV	49	-645	0.077	-1.30	583	0.100	0.75	28.2
EEAP	48	-729	0.088	-1.25	511	0.101	0.82	29.0
EEB	43	-417	----	----	515	0.100	0.75	26.6
EEC	49	-419	----	----	526	0.100	0.70	28.3

Properties of MSU (RTM) Manufactured Materials								
		R = 10			R = 0.1			
Material	V_F %	UCS, MPa	b_c	strain for 10^6 cycles, %	UTS, MPa	b_T	strain for 10^6 cycles, %	E, GPa
AA	35	-348	0.081	-0.95	452	0.140	0.50	18.8
AA3	51	-284	----	----	478	0.142	0.42	25.2
AA4	37	-449	----	----	399	0.105	0.67	20.4
BB	42	-308	----	----	725	0.140	0.82	25.2
BBT	42	-248	----	----	105	----	----	11.7
CC	39	-459	----	----	570	0.110	0.90	21.7
CC2	45	-526	----	----	715	0.116	0.91	26.6
CC3	45	-541	----	----	682	0.116	0.85	26.3
CH	45	-178	0.105	-0.50	145	0.104	0.46	13.6
CH2	41	-342	0.110	-0.78	362	0.127	0.65	16.7
CH3	36	-306	0.127	-0.62	336	0.112	0.75	16.8
CH4	37	-171	0.120	-0.50	155	0.138	0.43	11.4
CH5	28	-190	0.105	-0.85	139	0.123	0.54	8.5
CH6	49	-408	0.100	-0.80	502	0.137	0.50	21.4
CH7	55	-168	0.113	-0.30	114	0.110	0.27	17.0
CH8	39	-146	0.151	-0.35	93	0.113	0.38	10.0
CH9	49	-174	0.106	-0.67	151	0.133	0.51	10.3
CH10	33	-163	0.126	-0.64	120	0.108	0.58	8.1
CH11	54	-189	0.106	-0.58	134	0.114	0.38	13.4
CH12	34	-451	0.093	-1.15	398	0.099	0.88	17.7
CH13	48	-385	0.107	-0.68	423	0.145	0.48	23.2
CH14	44	-412	0.081	-1.00	517	0.134	0.75	21.2

Properties of MSU (RTM) Manufactured Materials								
		R = 10			R = 0.1			
Material	V_F %	UCS, MPa	b_C	strain for 10^6 cycles, %	UTS, MPa	b_T	strain for 10^6 cycles, %	E, GPa
CH15	32	-345	0.100	-1.02	309	0.106	0.85	14.8
CH16	40	-309	0.085	-0.80	360	0.129	0.68	18.5
CH17	48	-301	0.079	-0.94	359	0.139	0.50	17.6
CH18	47	-298	0.105	-0.74	294	0.131	0.50	17.2
CH19	33	-252	0.130	-0.75	193	0.102	0.70	11.9
CH20	25	-230	----	----	133	0.118	0.38	10.9
CH23	32	-448	0.106	-0.80	394	0.133	0.46	18.9
DD	49	-788	----	----	910	0.140	0.65	31.3
DD2	42	-581	0.079	-1.15	752	0.110	0.98	27.3
DD4	50	-556	----	----	895	0.140	0.65	31.0
DD5	38	-534	----	----	724	0.100	1.15	25.2
DD5E	36	-521	0.056	-1.42	674	0.102	1.20	22.9
DD5P	36	-574	0.070	-1.30	661	0.101	1.15	23.6
DD5PT	36	-148	----	----	66	0.100	0.30	8.80
DD5V	36	-530	0.057	-1.40	675	0.102	1.10	23.7
DD6	31	-505	0.082	-1.30	605	0.100	1.15	21.1
DD7	54	-581	0.070	-1.10	832	0.150	0.50	31.2
DD8	42	-582	----	----	778	0.095	1.10	28.3
DD9	54	-556	----	----	907	0.137	0.55	34.3
DD10	62	-552	0.053	-0.89	956	0.143	0.35	42.2

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Properties of MSU (RTM) Manufactured Materials								
		R = 10			R = 0.1			
Material	V_F %	UCS, MPa	b_C	strain for 10^6 cycles, %	UTS, MPa	b_T	strain for 10^6 cycles, %	E, GPa
DD11	31	-319	0.090	-0.65	592	0.101	1.25	20.0
DD11A	31	-350	----	----	604	----	----	19.5
DD12	43	-302	----	----	723	0.113	0.85	26.4
DD13	50	-314	0.094	-0.45	821	0.130	0.80	29.5
DD14	25	-428	----	----	----	----	----	----
DD15	35	-439	----	----	----	----	----	----
DD16	36	-418	----	----	432	----	----	18.2
DD17	37 52	----	----	----	782	0.148	0.47	25.0
DD17A	35 42	----	----	----	646	0.117	0.81	23.4
DD18	34 40	-508	----	----	730	0.116	1.00	22.6
DD18A	36 43	----	----	----	700	0.120	0.83	22.7
DD19	34 47	-375	----	----	710	0.129	0.75	22.0
DD19A	36 50	----	----	----	651	0.138	0.60	23.2
FFA	38	-553	----	----	716	0.123	0.85	23.9
FFB	38	-506	----	----	621	0.119	0.79	
FFC	38	-499	----	----	624	0.121	0.79	
FFD	38	-542	----	----	636	0.120	0.85	
FFF	38	-596	----	----	664	0.123	0.80	
GG	40	-628	----	----	793	0.117	1.20	28.0

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Properties of MSU (RTM) Manufactured Materials Single Fabric Materials								
		R = 10			R = 0.1			
Material	V_F %	UCS MPa	b_C	strain for 10^6 cycles, %	UTS, MPa	b_T	strain for 10^6 cycles, %	E, GPa
A060	41	-315	----	----	579	0.094	0.80	31.4
A130C	35	-430	0.080	-0.77	728	0.091	1.10	31.0
A130G	55	-486	----	-----	1,203	0.138	0.70	44.4
A260A	35	-392	----	-----	776	0.092	1.11	32.5
CDB200 AA / AA3	35	-348	0.081	-0.95	452	0.140	0.50	18.8
	51	-284	----	-----	478	0.142	0.42	25.2
AA4	37	-449	----	----	399	0.105	0.67	20.4
CM1701	38	-573	0.084	-0.93	796	0.126	0.64	30.5
DO72A	36	-560	0.075	-1.11	799	0.106	1.10	28.3
DO92B	41	-675	----	-----	953	0.104	1.10	33.8
DO92D	30	-540	----	-----	731	0.090	1.25	25.4
DO92F	50	-679	----	-----	1,112	0.121	0.70	40.8
DO92G	58	-901	0.085	-0.97	1,163	0.132	0.65	44.5
D155B	39	-675	0.077	-1.10	802	0.093	1.12	31.0
D155C	51	-794	----	-----	1,187	0.118	0.90	38.9
D155G	59	-765	0.057	-1.00	1,314	0.138	0.64	47.0
D155H	49	-755	----	-----	1,121	0.094	1.07	38.3
D155J	58	-776	----	-----	1,142	0.108	0.90	47.6
D155K	33	-551	----	----	831	0.114	0.98	28.1

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Properties of MSU (RTM) Manufactured Materials
D155 Angled Plies

		R = 10			R = 0.1			
Angle	V_F %	UCS MPa	b_C	strain for 10^6 cycles, %	UTS, MPa	b_T	strain for 10^6 cycles, %	E, GPa
D155B (0)	39	-675	0.077	-1.10	773	0.093	1.12	31.0
±10	38	-384	----	-----	277	0.068	0.62	27.9
±20	39	-287	----	-----	268	0.079	0.55	24.2
±30	40	-176	----	-----	186	0.098	0.43	17.7
±40	40	-132	----	-----	144	0.109	0.41	11.4
±45	38	-138	----	-----	107	0.109	0.40	9.79
±50	39	-138	----	-----	65.4	0.092	0.38	8.62
±60	40	-141	----	-----	36.7	0.074	0.25	7.65
±70	40	-136	----	-----	27.4	0.076	0.19	7.24
±80	38	-126	----	-----	25.8	0.087	0.17	7.16
±90	38	-123	----	-----	26.5	0.081	0.19	7.24

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Properties of R = -1 Tested Materials

		R = -1		
Material	V_F, %	b_R	strain for 10^6 cycles, %	E, GPa
H	37	0.136	0.45	24.0
N	38	0.135	0.30	21.0
P	40	0.133	0.41	28.9
EEAV	48	0.068	0.70	28.2
AA	35	0.139	0.40	18.8
DD4	48	0.123	0.50	31.0
DD5E	36	0.123	0.66	22.9
DD5P	36	0.135	0.62	23.6

Properties of High Cycle Materials							
Direction of Testing	R	V_F, %	UTS, MPa	UCS, MPa	strain for 10^6 cycles, %	strain for 10^7 cycles, %	E, GPa
Longitudinal	0.1	67	1470	----	0.90	0.70	46
	0.5	49	1357	----	1.36	1.00	39
	-1	49	1390	-584	0.55	0.42	39
	10	52	----	-789	-0.90	-0.80	36
	2	52	----	-789	-1.3	-1.2	35
	-0.5	----	----	-716	----	----	--
Transverse	0.1	39	21.3	----	0.14	0.12	8.6
	0.5	39	21.7	----	0.16	----	8.7
	-1	39	18.2	----	----	----	---
	10	39	----	-117	-0.70	-0.62	9.0
	2	39	----	-116	-0.95	-0.85	9.0
Longitudinal layup - $[0]_2$, D155 fabric, transverse layup - $[0]_4$, D100 fabric							

Fatigue Properties of 3M SP-250 Prepreg Materials								
		R = 10			R = 0.1			
Layup	V_F %	UCS MPa	b_C	strain for 10^6 cycles, %	UTS, MPa	b_T	strain for 10^6 cycles, %	E, GPa
PP	56	-788	----	----	1,288	0.119	0.81	47.0
PP45	54	-160	----	----	155	0.102	0.35	17.9
PPDD5	56	----	----	----	1,088	0.122	0.75	39.6

SUMMARY OF COMMERCIAL MATERIAL FATIGUE TESTS

MATERIAL A

Layup = $[0]_5$, V_F = 0.30, Ave. thickness = 3.68 mm, S.D. = 0.13 mm, Polyester

TEST &	SAMPLE ID #	MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
5	105A	125	0.1	10	----	----	2,000,000	25 tab
6	108A	190	0.1	5	----	----	590,000	25 tab
7	110A	335	0.1	1	----	----	670	25 tab
23	111A	279	0.1	5	20.0	1.40	17,700	25 tab
25	112A	212	0.1	10	22.3	----	138,596	25 tab
30	121A	591	*	13	22.4	2.83	1	25 tab
31	120A	567	*	13	19.9	2.82	1	25 tab
32	119A	544	*	13	20.4	2.64	1	25 tab
36	114A	189	0.1	10	21.0	0.90	1,612,585	25 tab
37	113A	192	0.1	10	22.6	0.85	920,132	25 tab
97	137A	548	*	6	22.0	2.20	1	25 tab
98	136A	579	*	6	23.2	2.30	1	25 tab
180	138A	-323	*	6	----	----	1	25 tab
181	139A	-319	*	6	----	----	1	25 tab
182	140A	-298	*	6	----	----	1	25 tab
2914	301A	551	*	13	----	----	1	25 tab
2915	309A	552	*	13	----	----	1	25 tab
2916	303A	611	*	13	----	----	1	25 tab
2917	305A	345	0.1	2	22.8	1.63	2,080	25 tab
2918	304A	345	0.1	2	25.8	1.44	1,244	25 tab
2919	308A	345	0.1	2	25.8	1.35	779	25 tab
2920	306A	276	0.1	4	22.4	1.23	19,034	25 tab
2921	311A	276	0.1	4	24.0	1.12	38,474	25 tab
2922	307A	190	0.1	12	23.8	0.66	18,865,901	25 tab
2923	310A	207	0.1	12	28.9	0.72	3,000,000	25R tab
2924	312A	276	0.1	5	22.2	1.20	21,100	25 tab
2925	316A	207	0.1	12	----	----	8,266,515	25 tab

MATERIAL B

Layup = $[0]_5$, V_F = 0.30, Ave. thickness = 3.45 mm, S.D. = 0.26 mm, Vinylester

9	103B	370	0.1	1	----	----	2,584	25 tab
12	108B	267	0.1	5	----	----	9,173	25 tab
13	109B	328	0.1	5	20.9	1.6	2,640	25 tab
15	111B	387	0.1	0.1	18.6	2	7	25 tab
16	112B	256	0.1	5	20.1	1.29	38,133	25 tab
17	113B	332	0.1	5	21.4	1.53	2,841	25 tab
18	114B	372	0.1	1	19.5	1.90	415	25 tab
20	116B	321	0.1	5	19.2	1.6	3,008	25 tab
21	107B	321	0.1	4	22.6	1.4	32,640	25 tab
22	117B	229	0.1	10	----	----	655,147	25 tab
24	118B	343	0.1	1	16.3	2.12	981	25 tab
26	119B	571	*	13	22.3	2.36	1	25 tab

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
27	123B	622	*	13	21.4	2.73	1	25 tab
28	124B	571	*	13	21.2	2.76	1	25 tab
29	125B	583	*	13	22.8	2.77	1	25 tab
33	120B	229	0.1	10	21.2	1.08	16,156	25 tab
34	121B	237	0.1	5	19.2	1.24	206,864	25 tab
35	122B	229	0.1	10	23.1	0.99	671,333	25 tab
38	126B	190	0.1	10	20.8	0.90	2,310,849	25 tab
39	129B	154	0.1	15	19.9	0.76	40,000,000	25R tab
40	130B	188	0.1	10	22.6	0.79	7,475,243	25 tab
56	135B	187	0.1	10	22.3	0.84	2,720,584	25 tab
57	133B	152	0.1	15	21.7	0.70	37,906,456	25R tab
58	127B	619	*	25	22.4	2.90	1	25 tab
61	137B	568	*	25	20.3	2.79	1	25 tab
64	138B	245	*	25	----	----	1	25 tab
66	138B	343	0.1	1	20.9	1.64	6,085	25 tab
99	128B	560	*	6	19.9	2.82	1	25 tab
100	131B	559	*	6	24.4	2.29	1	25 tab
183	139B	-265	*	6	----	----	1	25 tab
184	140B	-283	*	6	----	----	1	25 tab
185	141B	-278	*	6	----	----	1	25 tab
186	142B	-303	*	6	----	----	1	25 tab
187	143B	-307	*	6	----	----	1	25 tab

MATERIAL F

Layup = $[(\pm 45/0)_3]_S$, $V_F = 0.36$, Has two center plies dropped, Ave. thickness = 4.88 mm (thin), 7.24 mm (thick), S.D. = 0.13 mm (thin) 0.16 mm (thick), Polyester

41	105F	370	*	13	17.8	2.08	1	25 tab
44	106F	363	*	13	14.6	3.55	1	25 tab
45	108F	339	*	13	19.2	1.77	1	25 tab
47	109F	195	0.1	5	----	----	2,689	25 tab
49	101F	102	0.1	5	----	----	95,101	25 tab
51	104F	78	0.1	10	----	----	1,615,838	25 tab
53	103F	78	0.1	10	----	----	2,487,507	25 tab
55	111F	102	0.1	10	----	----	108,029	25 tab
188	119F	-373	*	6	----	----	1	25 tab
189	120F	-364	*	6	----	----	1	25 tab
190	121F	-340	*	6	----	----	1	25 tab
191	122F	-378	*	6	----	----	1	25 tab

MATERIAL G

Layup = $[(0/\pm 45)_3]_S$, $V_F = 0.36$, Has two center plies dropped, Ave. thickness = 4.83 mm (thin), 7.26 mm (thick), S.D. = 0.13 mm (thin) 0.17 mm (thick), Polyester

42	105G	397	*	13	15.9	2.49	1	25 tab
43	106G	366	*	13	16.4	3.51	1	25 tab
46	108G	332	*	25	----	----	1	25 tab
48	107G	190	0.1	5	----	----	2,637	25 tab

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
50	101G	103	0.1	10	----	----	69,052	25 tab
52	102G	77	0.1	10	----	----	1,669,945	25 tab
54	109G	103	0.1	10	----	----	65,372	25 tab
67	110G	78	0.1	10	17.8	0.43	11,160,358	25 tab
108	105G	536	*	6	20.4	1.75	1	25 tab
1925	200G	-266	*	13	----	----	1	25 tab
1926	201G	-228	*	13	----	----	1	25 tab
1927	202G	-280	*	13	----	----	1	25 tab

MATERIAL H

Layup = $[(\pm 45/0)_3]_S$, $V_F = 0.39$, Ave. thickness = 6.58 mm, S.D. = 0.4 mm, Polyester

59	101H	643	*	25	25.8	3.24	1	25 tab
60	102H	597	*	25	18.8	2.12	1	25 tab
69	104H	259	0.1	5	25.2	0.68	45,360	25 tab
75	110HT	44	*	6	----	----	1	25 tab
76	105H	130	0.1	10	28.5	0.30	10,000,000	25R tab
89	111H	130	0.1	15	23.4	0.43	20,500,167	25 tab
91	113H	310	0.1	1	26.6	0.73	16,100	25 tab
92	114H	226	0.1	10	24.0	0.60	69,425	25 tab
95	115H	244	0.1	10	20.6	0.76	11,417	25 tab
144	121H	103	-1	5	25.0	0.41	1,824,012	25 tab
147	122H	138	-1	5	25.2	0.55	21,713	25 tab
148	117H	138	-1	5	23.2	0.59	15,930	25 tab
192	116H	-431	*	6	----	----	1	25 tab
193	117H	-425	*	6	----	----	1	25 tab
221	117H	-352	*	30	----	----	1	25 tab
222	119H	-207	10	5	----	----	2,400	25R tab
235	123H	-207	10	15	25.8	-0.51	19,996	25 tab
236	126H	-138	10	20	24.5	-0.38	4,385,009	25R tab
238	120H	-207	10	15	27.7	----	91,656	25 tab
239	116H	-138	10	15	24.5	----	6,000,000	25R tab
240	119H	-138	10	20	23.5	-0.58	30,000,000	25R tab
241	133H	138	0.1	15	----	----	1,401,491	25 tab
242	137H	138	0.1	15	----	----	5,420,000	25R tab
243	136H	172	0.1	10	----	----	502,598	25 tab
244	131H	172	0.1	10	----	----	1,104,989	25 tab
245	132H	207	0.1	10	24.8	0.86	96,327	25 tab
246	135H	207	0.1	10	25.0	0.83	79,610	25 tab
247	130H	241	0.1	10	25.7	0.95	15,703	25 tab
248	139H	276	0.1	5	23.2	1.20	2,921	25 tab
249	143H	276	0.1	5	27.7	1.04	1,668	25 tab
250	140H	345	0.1	5	23.4	1.53	742	25 tab
251	138H	-207	10	15	26.8	-0.76	4,578	25 tab
252	141H	-207	10	15	24.6	-0.85	3,918	25 tab
253	149H	138	0.1	20	23.8	0.57	8,222,998	25 tab
254	150H	138	0.1	15	----	----	11,500,000	25R tab
258	118H	707	*	6	24.2	----	1	25 tab
259	150H	733	*	6	27.7	----	1	25 tab

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
260	151H	744	*	6	28.8	----	1	25 tab
269	125H	669	*	6	24.2	----	1	25 tab

MATERIAL J

Layup = $[(0/\pm45)_3]_S$, V_F = 0.43, Ave. thickness = 6.63 mm, S.D. = 0.52 mm, Polyester

62	101J	658	*	25	24.6	3.23	1	25 tab
63	102J	561	*	25	23.7	2.60	1	25 tab
65	103J	490	*	25	----	----	1	25 tab
68	104J	259	0.1	5	23.8	0.77	17,882	25 tab
70	105J	129	0.1	10	26.2	0.31	11,000,000	25R tab
81	106J	74	0.1	15	22.6	0.26	18,000,000	25R tab
82	107J	113	0.1	15	27.3	0.28	30,300,000	25R tab
93	108J	186	0.1	10	23.1	0.54	153,500	25R tab
94	109J	188	*	--	22.6	0.82	1	25R tab
127	110J	155	0.1	15	24.2	0.42	1,460,000	25 tab
194	111J	-403	*	6	----	----	1	25 tab
195	112J	-417	*	6	----	----	1	25 tab
223	114J	-138	10	10	----	----	6,500,000	25R tab
261	140J	723	*	6	26.3	----	1	25 tab
262	141J	711	*	6	25.7	----	1	25 tab
263	142J	689	*	6	24.2	----	1	25 tab
268	115J	670	*	6	24.5	----	1	25 tab

MATERIAL L

Layup = $[0]_3$, V_F = 0.50, Ave. thickness = 2.46 mm, S.D. = 0.26 mm, Polyester

77	101L	410	0.1	1	35.4	1.18	2,580	25 tab
78	103L	406	0.1	1	30.9	1.32	593	25 tab
79	102L	276	0.1	5	31.5	0.87	59,081	25 tab
80	104L	266	0.1	5	29.0	0.97	45,848	25 tab
83	109L	325	0.1	10	34.5	0.91	153,402	25 tab
84	127L	259	0.1	10	32.4	0.93	450,000	25R tab
101	117L	740	*	6	30.8	2.40	1	25 tab
102	119L	745	*	6	36.6	2.21	1	25 tab
196	122L	-325	*	6	----	----	1	25 tab
197	123L	-332	*	6	----	----	1	25 tab
198	125L	-328	*	6	----	----	1	25 tab
199	126L	-351	*	6	----	----	1	25 tab
231	126L	-361	*	6	----	----	1	50 tab
232	127L	-444	*	6	----	----	1	50 tab
233	128L	-416	*	6	----	----	1	50 tab
2926	130L	807	*	13	37.4	2.20	1	25 tab
2927	134L	767	*	13	31.9	2.45	1	25 tab
2928	133L	683	*	13	39.6	1.75	1	25 tab
2929	131L	414	0.1	2	39.4	1.10	1,651	25 tab
2930	106L	414	0.1	2	40.0	1.09	2,814	25 tab
2931	125L	414	0.1	2	43.3	1.03	4,755	25 tab

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
2932	111L	345	0.1	4	38.5	0.92	14,578	25 tab
2933	135L	345	0.1	4	39.1	0.91	9,731	25 tab
2934	129L	276	0.1	10	38.4	0.74	187,213	25 tab

MATERIAL M

Layup = $[0/\pm45]_4$, V_F = 0.38, Ave. thickness = 3.10 mm, S.D. = 0.10 mm, Vinylester

129	101M	69	0.1	15	21.4	0.32	17,764,694	25 tab
130	102M	76	0.1	15	21.0	0.36	6,899,599	25 tab
131	104M	525	*	60	21.0	3.00	1	25 tab
132	113M	507	*	60	20.2	2.90	1	25 tab
133	112M	138	0.1	10	21.6	0.66	18,650	25 tab
134	106M	138	0.1	10	21.2	0.66	22,360	25 tab
135	109M	207	0.1	5	19.3	1.12	2,319	25 tab
136	103M	207	0.1	5	19.1	1.12	2,855	25 tab
137	114M	276	0.1	5	20.1	1.43	687	25 tab
138	105M	276	0.1	5	19.2	1.44	879	25 tab
139	115M	103	0.1	15	21.0	0.49	86,249	25 tab
140	107M	103	0.1	15	20.9	0.49	174,168	25 tab
141	118M	86	0.1	15	20.5	0.41	397,000	25 tab
142	110M	86	0.1	15	22.4	0.39	266,000	25 tab
143	108M	76	0.1	15	21.4	0.36	2,498,512	25 tab
200	124M	-275	*	6	----	----	1	25 tab
201	123M	-295	*	6	----	----	1	25 tab
202	122M	-289	*	6	----	----	1	25 tab
203	125M	-284	*	6	----	----	1	25 tab
228	126M	-267	*	3	----	----	1	50 tab
229	127M	-291	*	6	----	----	1	50 tab
230	128M	-301	*	6	----	----	1	50 tab

MATERIAL N

Layup = $[0/\pm45]_4$, V_F = 0.36, Ave. thickness = 3.23 mm, S.D. = 0.08 mm, Polyester

85	111NT	86	*	6	----	3.30	1	25 tab
86	101NT	54	0.1	1	8.62	1.34	6,479	25 tab
87	102NT	68	0.1	1	7.86	1.70	470	25 tab
88	104NT	35	0.1	5	8.55	0.45	511,047	25 tab
96	103NT	21	0.1	15	23.1	0.28	34,000,000	25R tab
103	011N	482	*	6	20.9	2.97	1	25 tab
104	012N	468	*	6	20.9	2.84	1	25 tab
105	113NT	87	*	6	6.90	3.82	1	25 tab
106	114NT	90	*	6	9.17	2.29	1	25 tab
109	111NT	54	0.1	1	8.83	1.15	7,950	25 tab
110	112NT	68	0.1	1	6.69	1.42	711	25 tab
111	117N	388	0.1	1	17.0	2.74	27	25 tab
112	116N	276	0.1	1	18.2	1.60	626	25 tab
113	120N	276	0.1	5	17.3	1.70	811	25 tab
114	114NT	35	0.1	15	8.20	0.42	1,634,579	25 tab

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
115	118N	207	0.1	15	19.2	1.08	5,684	25 tab
116	119N	207	0.1	5	19.7	1.05	4,871	25 tab
117	010N	138	0.1	10	20.1	0.69	25,371	25 tab
118	009N	138	0.1	10	19.5	0.71	25,781	25 tab
119	129N	138	0.1	10	20.4	0.68	37,597	25 tab
120	128N	138	0.1	10	19.2	0.72	29,230	25 tab
121	131N	103	0.1	15	18.4	0.56	231,826	25 tab
122	130N	86	0.1	15	19.8	0.42	1,336,695	25 tab
123	006N	345	0.1	1	19.2	1.82	150	25 tab
124	126N	76	0.1	15	19.7	0.39	1,648,137	25 tab
125	008N	69	0.1	15	19.9	0.34	7,825,000	25 tab
126	121N	103	0.1	15	19.0	0.54	165,980	25 tab
128	127N	69	0.1	15	19.3	0.35	4,005,593	25 tab
145	116N	462	*	60	20.2	2.81	1	25 tab
146	117N	459	*	60	18.9	2.75	1	25 tab
149	132N	86	-1	5	22.8	0.36	105,505	25 tab
150	133N	86	-1	10	21.5	0.38	240,528	25 tab
151	134N	138	-1	5	21.5	0.61	5,570	25 tab
152	137N	138	-1	5	24.6	0.56	13,337	25 tab
153	135N	69	-1	15	21.9	0.29	1,189,053	25 tab
154	136N	69	-1	15	23.4	0.29	1,282,726	25 tab
155	138N	-138	10	15	23.5	-0.61	1,098,374	25 tab
156	139N	-103	10	20	23.5	-0.44	26,707,000	25R tab
158	145N	-103	10	20	25.6	-0.41	25,738,868	25 tab
159	140N	-138	10	15	23.5	-0.60	367,505	25 tab
160	143N	-172	10	10	25.0	-0.69	292,181	25 tab
161	142N	-172	10	10	23.7	-0.74	32,227	25 tab
208	151N	-318	*	13	----	----	1	25 tab
209	152N	-334	*	13	----	----	1	25 tab
210	153N	-301	*	13	----	----	1	25 tab
3054	201NT	-131	*	13	----	----	1	25 tab

MATERIAL P

Layup = $[0/\pm45/M/0]_S$, V_F = 0.36, Ave. thickness = 3.78 mm, S.D. = 0.23 mm, Vinylester

163	108P	612	*	60	28.1	2.73	1	25 tab
164	107P	716	*	60	26.8	2.89	1	25 tab
165	105P	103	0.1	15	23.3	0.44	2,808,490	25 tab
166	108P	103	0.1	15	27.8	0.38	5,985,000	25 tab
168	101P	276	0.1	5	22.1	1.27	7,251	25 tab
169	103P	276	0.1	5	24.6	1.12	6,354	25 tab
170	102P	207	0.1	10	26.1	0.82	38,469	25 tab
171	106P	207	0.1	10	26.3	0.80	28,198	25 tab
172	107P	345	0.1	5	25.9	1.40	1,467	25 tab
173	104P	345	0.1	5	24.0	1.45	1,773	25 tab
174	111P	414	0.1	5	19.0	2.22	296	25 tab
175	112P	138	0.1	15	26.9	0.52	900,000	25 tab
176	126P	674	*	60	28.8	1.78	1	25 tab
177	115P	414	0.1	5	29.1	0.93	216	25 tab

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
178	113P	138	0.1	15	23.4	0.60	715,000	25 tab
179	116P	76	-1	20	29.2	0.26	15,000,000	25R tab
204	132P	-288	*	6	----	----	1	25 tab
205	133P	-333	*	6	----	----	1	25 tab
206	136P	-319	*	6	----	----	1	25 tab
207	137P	-343	*	6	----	----	1	25 tab
211	120P	138	-1	10	29.4	0.44	139,604	25 tab
212	123P	207	-1	5	29.5	0.70	839	25 tab
213	121P	207	-1	5	27.2	0.74	1,320	25 tab
214	122P	138	-1	10	28.3	0.46	76,483	25 tab
215	125P	-207	10	10	28.0	-0.63	14,121	25 tab
216	124P	-138	10	20	30.9	-0.40	6,000,000	25R tab
217	119P	-207	10	10	30.4	-0.63	21,177	25 tab
218	117P	-172	10	20	25.0	-0.82	1,094,359	25 tab
219	118P	-172	10	20	31.4	-0.51	8,020,000	25R tab
224	119P	-138	10	20	----	----	1,189,000	25R tab
225	130P	-396	*	3	----	----	1	50 tab
226	131P	-477	*	6	----	----	1	50 tab
227	132P	-526	*	6	----	----	1	50 tab

MATERIAL R

Layup = $[0/\pm45]_4$, V_F = 0.32, Ave. thickness = 2.53 mm, S.D. = 0.07 mm, Polyester

255	101R	412	*	6	16.6	2.50	1	25 tab
256	102R	427	*	6	16.6	----	1	25 tab
257	107R	138	0.1	15	17.0	0.31	3,000,000	25R tab
264	105R	276	0.1	5	14.8	2.13	925	25 tab
265	111R	483	*	6	17.7	3.41	1	25 tab
266	108R	207	0.1	10	16.3	1.31	6,967	25 tab
267	104R	207	0.1	10	16.9	1.31	6,035	25 tab
270	109R	138	0.1	15	16.0	0.93	8,170,168	25 tab
271	103R	138	0.1	15	15.7	0.90	820,000	25 tab
272	112R	172	0.1	15	17.1	----	972,000	25 tab
273	106R	190	0.1	10	----	----	230,233	25 tab
274	110R	190	0.1	10	----	----	115,056	25 tab
275	113R	155	0.1	15	----	----	1	25 tab
276	114R	190	0.1	15	----	----	4,932,613	25 tab
277	118R	345	0.1	1	17.4	----	60	25 tab
278	117R	345	0.1	1	----	----	41	25 tab
279	125R	276	0.1	2	----	----	1,072	25 tab
280	126R	207	0.1	7	----	----	17,096	25 tab
281	119R	190	0.1	10	----	----	505,551	25 tab
282	124R	155	0.1	15	----	----	1,942,442	25 tab
284	120R	436	*	6	----	----	1	25 tab
285	121R	426	*	6	----	----	1	25 tab
1928	200R	-287	*	13	----	----	1	25 tab
1929	201R	-297	*	13	----	----	1	25 tab
1930	202R	-286	*	13	----	----	1	25 tab
3080	403R	-317	*	13	----	----	1	25 tab

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
3081	402R	-321	*	13	----	----	1	25 tab
3082	401R	-353	*	13	----	----	1	25 tab

MATERIAL T

Layup = [0/±45]$_4$, V_F = 0.30, Ave. thickness = 4.34 mm, S.D. = 0.22 mm, Polyester

1306	T1	366	*	6	----	----	1	50 tab
1307	T2T	145	0.1	15	----	----	64,333	50 tab
1308	T3T	100	0.1	15	----	----	701,345	50 tab
1309	T5	86	0.1	15	----	----	2,069,625	50 tab
1310	T6	101	0.1	15	----	----	1,731,348	50 tab
1311	T7	145	0.1	10	----	----	56,979	50 tab
1312	T8	107	0.1	15	----	----	615,110	50 tab
1313	T9	369	*	6	----	----	1	50 tab
1916	T200	252	*	13	17.7	3.47	1	25 tab
1917	T201	-313	*	13	----	----	1	25 tab
1918	T202	-267	*	13	----	----	1	25 tab

MATERIAL U

Layup = [0/±45]$_4$, V_F = 0.29, Ave. thickness = 4.55 mm, S.D. = 0.18 mm, Polyester

1314	U1	336	*	6	----	----	1	50 tab
1315	U2	138	0.1	--	----	----	14,573	50 tab
1316	U3	102	0.1	--	----	----	114,237	50 tab
1317	U4	86	0.1	15	----	----	400,500	50 tab
1318	U5	69	0.1	15	----	----	2,278,230	50 tab
1319	U6	102	0.1	15	----	----	178,679	50 tab
1320	U7	69	0.1	10	----	----	2,422,608	50 tab
1321	U8	138	0.1	10	----	----	16,591	50 tab
1322	U9	421	*	6	----	----	1	50 tab
1931	U200	416	*	13	21.2	2.51	1	25 tab
1932	U201	-364	*	13	----	----	1	25 tab
1933	U202	-345	*	13	----	----	1	25 tab

MATERIAL V

Layup = [0/±45]$_4$, V_F = 0.32, Ave. thickness = 3.33 mm, S.D. = 0.30 mm, Polyester

1323	V1	460	*	6	----	----	1	50 tab
1324	V2	489	*	6	----	----	1	50 tab
1325	V3	138	0.1	5	----	----	28,861	50 tab
1326	V4	138	0.1	5	----	----	35,501	50 tab
1327	V5	172	0.1	1	----	----	11,273	50 tab
1328	V6	172	0.1	1	----	----	12,339	50 tab
1329	V7	103	0.1	10	----	----	123,370	50 tab
1330	V8	103	0.1	10	----	----	111,873	50 tab
1331	V9	86	0.1	15	----	----	950,987	50 tab
1332	V10	86	0.1	15	----	----	871,319	50 tab
1333	V11	69	0.1	15	----	----	7,871,024	50 tab

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
1334	V15	86	0.1	15	----	----	848,378	50 tab
1335	V16	86	0.1	15	----	----	791,827	50 tab
1336	V17	103	0.1	10	----	----	222,481	50 tab
1337	V18	172	0.1	1	----	----	11,370	50 tab
1338	V20	138	0.1	5	----	----	23,829	50 tab
1339	V27	382	*	6	18.5	----	1	25 tab
1340	V30	377	*	6	19.7	----	1	25 tab
1341	V31	393	*	6	20.1	----	1	25 tab
1919	V200	-363	*	13	----	----	1	25 tab
1920	V201	-392	*	13	----	----	1	25 tab
1921	V202	-383	*	13	----	----	1	25 tab

MATERIAL W

Layup = [0/±45]$_4$, V_F = 0.33, Ave. thickness = 3.43 mm, S.D. = 0.07 mm, Polyester

1342	W1	172	0.1	2	19.0	----	25,839	50 tab
1343	W2	172	0.1	2	19.1	----	30,040	50 tab
1344	W5	138	0.1	10	----	----	311,392	50 tab
1345	W6	138	0.1	10	----	----	154,745	50 tab
1346	W7	103	0.1	15	----	----	5,040,762	50 tab
1347	W8	359	*	6	----	----	1	50 tab
1348	W9	435	*	6	----	----	1	50 tab
1349	W10	121	0.1	10	----	----	502,900	50 tab
1350	W11	121	0.1	10	----	----	1,071,927	50 tab
1351	W12	103	0.1	15	----	----	3,464,238	50 tab
1352	W13	86	0.1	15	----	----	27,537,000	50R tab
1922	W200	-302	*	13	----	----	1	25 tab
1923	W201	-355	*	13	----	----	1	25 tab
1924	W202	-351	*	13	----	----	1	25 tab

MATERIAL X

Layup = [0_2/M/±45/0_2], V_F = 0.35, Ave. thickness = 4.52 mm, S.D. = 0.24 mm, Polyester

304	107X	624	*	13	25.6	2.59	1	25 tab
305	102X	595	*	13	23.7	2.15	1	25 tab
306	103X	617	*	13	24.6	2.97	1	25 tab
309	112X	276	0.1	10	23.0	1.26	255,862	25 tab
310	105X	414	0.1	5	25.5	1.76	1,753	25 tab
311	106X	414	0.1	5	23.0	1.86	953	25 tab
312	104X	345	0.1	5	25.9	1.32	15,414	25 tab
313	108X	345	0.1	5	25.2	1.36	11,550	25 tab
314	101X	241	0.1	20	25.4	0.94	6,492,710	25 tab
315	109X	276	0.1	10	26.3	1.06	127,309	25 tab
316	116XT	39	*	13	7.7	0.83	1	25 tab
317	118XT	45	*	13	7.6	0.72	1	25 tab
318	117XT	43	*	13	7.9	0.92	1	25 tab
319	119XT	28	0.1	2	9.0	0.28	1,083	25 tab
320	124XT	21	0.1	15	8.3	0.24	50,606	25 tab

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
321	110X	241	0.1	20	25.0	0.97	5,000,000	25R tab
322	114X	241	0.1	20	26.0	0.91	21,000,000	25R tab
323	113X	241	0.1	20	26.7	0.90	20,000,000	25R tab
327	151X	-241	10	10	27.4	-0.84	3,175,600	25 tab
328	126XT	19	0.1	15	9.1	0.25	614,730	50 tab
329	142X	-207	10	25	26.3	-0.68	21,000,000	25R tab
330	130XT	19	0.1	10	8.6	0.27	436,440	50 tab
331	132XT	17	0.1	20	8.3	0.21	785,700	50 tab
332	128XT	17	0.1	20	8.5	0.23	1,132,780	50 tab
333	134XT	28	0.1	2	8.3	0.37	2,074	50 tab
334	129XT	28	0.1	2	8.4	0.34	1,545	50 tab
335	135XT	17	0.1	20	7.3	0.24	897,103	50 tab
336	144X	-241	10	10	26.7	-0.94	3,500,000	25R tab
337	133XT	14	0.1	15	8.0	0.19	10,377,400	50 tab
378	159X	-435	*	13	25.0	-1.74	1	25 tab
379	158X	-430	*	13	26.8	-1.70	1	25 tab
380	165X	-450	*	13	26.1	-1.98	1	25 tab
381	161X	-310	10	2	23.4	-1.41	12,455	25 tab
382	164X	-310	10	2	25.7	-1.37	12,865	25 tab
383	157X	-276	10	5	24.8	-1.20	271,161	25 tab
384	160X	-276	10	5	24.2	-1.07	333,581	25 tab
385	156X	-276	10	10	25.9	-1.10	161,397	25 tab
386	162X	-241	10	10	26.1	-0.93	1,472,970	25 tab
482	139X	414	0.1	5	25.6	1.67	1,223	25 tab
483	152X	345	0.1	5	25.7	1.45	11,786	25 tab
484	153X	276	0.1	10	26.6	1.06	169,031	25 tab
485	136XT	24	0.1	5	9.3	0.26	21,745	50 tab
486	123XT	24	0.1	5	9.0	0.25	15,040	50 tab
487	125XT	47	*	13	10.1	0.52	1	50 tab
488	120XT	24	0.1	5	10.1	0.24	18,858	50 tab
489	121XT	19	0.1	10	9.5	0.22	587,181	50 tab
705	177X	-310	10	2	24.5	1.39	14,129	25 tab
1837	201XT	-170	*	13	----	----	1	25 tab
1838	127XT	-149	*	13	----	----	1	25 tab

MATERIAL Y

Layup = $[0_2/M/\pm45/0_2]$, $V_F = 0.39$, Ave. thickness = 4.62 mm, S.D. = 0.48 mm, Epoxy

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
289	112Y	276	0.1	25	27.4	0.53	251,141	25 tab
290	108Y	207	0.1	25	24.4	0.79	1,412,113	25 tab
291	118Y	345	0.1	15	23.6	1.33	23,109	25 tab
292	113Y	345	0.1	15	25.9	1.28	18,000	25 tab
293	104Y	345	0.1	15	23.9	1.24	16,762	25 tab
294	116Y	414	0.1	4	27.2	1.83	628	25 tab
296	102Y	414	0.1	4	22.4	1.71	821	25 tab
297	107Y	276	0.1	25	20.8	1.27	128,578	25 tab
298	115Y	276	0.1	25	20.4	0.93	237,864	25 tab
299	119Y	207	0.1	25	25.9	0.77	1,607,127	25 tab
300	114Y	661	*	13	24.3	2.80	1	25 tab

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
301	110Y	687	*	13	28.1	2.54	1	25 tab
302	109Y	620	*	13	24.2	2.56	1	25 tab
303	101Y	207	0.1	15	25.3	0.87	15,000,000	25R tab
481	170Y	-276	10	5	24.3	1.13	62,517	25 tab
490	125Y	414	0.1	4	29.7	1.70	1,486	25 tab
491	121Y	345	0.1	5	29.7	1.54	36,812	25 tab
493	123Y	276	0.1	5	28.7	1.01	423,059	25 tab
494	127Y	207	0.1	15	26.6	0.86	10,000,000	25R tab
495	141YT	29	*	13	7.7	0.38	1	25 tab
496	145YT	29	*	13	7.5	0.38	1	25 tab
497	146YT	30	*	13	6.8	0.45	1	25 tab
498	152YT	21	0.1	2	7.1	0.48	4,103	50 tab
499	144YT	21	0.1	2	7.0	0.41	2,716	50 tab
500	147YT	17	0.1	10	6.5	0.34	26,513	50 tab
501	143YT	17	0.1	10	7.5	0.29	47,049	50 tab
502	140YT	24	0.1	1	7.2	1.35	208	50 tab
503	151YT	24	0.1	1	7.1	1.22	277	50 tab
504	148YT	14	0.1	15	6.9	0.25	252,205	50 tab
505	142YT	14	0.1	15	6.3	0.22	432,161	50 tab
506	149YT	14	0.1	15	6.9	0.20	657,472	50 tab
507	157YT	24	0.1	1	7.2	1.37	173	50 tab
508	153YT	21	0.1	2	6.6	0.37	2,033	50 tab
509	155YT	17	0.1	10	6.6	0.26	31,204	50 tab
510	159YT	33	*	13	7.6	----	1	50 tab
511	161YT	32	*	13	7.5	----	1	50 tab
512	160YT	35	*	13	7.5	----	1	50 tab
543	168Y	-391	*	13	----	----	1	25 tab
544	181Y	-389	*	13	----	----	1	25 tab
545	176Y	-341	*	13	----	----	1	25 tab
546	171Y	-369	*	13	----	----	1	25 tab
547	172Y	-276	10	10	----	----	87,235	25 tab
548	167Y	-310	10	5	----	----	354	25 tab
549	166Y	-241	10	20	21.5	1.18	4,000,000	25R tab
581	170Y	-276	10	5	24.3	1.13	62,517	25 tab
689	178Y	-310	10	2	----	----	568	25 tab
690	197Y	-293	10	2	----	----	12,145	25 tab
691	200Y	-293	10	5	----	----	3,011	25 tab
692	190Y	-293	10	2	----	----	4,652	25 tab
693	187Y	-310	10	2	----	----	672	25 tab
694	199Y	-276	10	10	----	----	187,512	25 tab
695	196Y	-483	*	25	----	----	1	25 tab
696	193Y	-450	*	25	----	----	1	25 tab
697	192Y	-431	*	25	----	----	1	25 tab
699	201Y	-258	10	15	----	----	632,624	25 tab
701	173Y	-258	10	15	23.9	-1.09	833,939	25 tab
702	169Y	-258	10	15	26.3	-0.98	1,477,548	25 tab
706	195Y	-241	10	20	----	----	1,672,575	25 tab
1839	201YT	-95	*	13	----	----	1	25 tab
1840	202YT	-116	*	13	----	----	1	25 tab

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
1841	203YT	-112	*	13	----	----	1	25 tab

MATERIAL EE

Layup = $[M/\pm45/0]_S$, V_F = 0.54, Ave. thickness = 3.53 mm, S.D. = 0.10 mm, Epoxy

1178	EE101	565	*	13	28.8	2.23	1	13 tab
1179	EE102	546	*	13	34.5	1.76	1	13 tab
1180	EE103	518	*	13	30.7	1.78	1	13 tab
1181	EE104	345	0.1	2	32.1	1.14	570	13 tab
1182	EE112	310	0.1	4	29.2	1.07	1,085	13 tab
1183	EE105	276	0.1	5	30.1	0.93	4,076	13 tab
1184	EE111	207	0.1	10	32.8	0.653	4,583	13 tab
1185	EE110	138	0.1	20	33.2	0.43	1,857,630	13 tab
1186	EE107	345	0.1	2	----	----	402	13 tab
1187	EE109	276	0.1	5	----	----	2,936	13 tab
1188	EE108	310	0.1	5	----	----	2,033	13 tab
1189	EE106	207	0.1	10	----	----	23,385	13 tab
1190	EE119	310	0.1	5	----	----	1,840	13 tab
1191	EE121	276	0.1	5	----	----	2,377	13 tab
1192	EE114	207	0.1	10	----	----	58,110	13 tab
1193	EE115	172	0.1	15	----	----	496,094	13 tab
1194	EE120	172	0.1	15	----	----	287,688	13 tab
1195	EE125	241	0.1	5	----	----	10,021	13 tab
1196	EE126	241	0.1	5	----	----	8,786	13 tab
1197	EE116	172	0.1	20	----	----	224,138	13 tab
1198	EE128	-546	*	13	----	----	1	13 tab
1199	EE129	-550	*	13	----	----	1	13 tab
1200	EE113	138	0.1	20	----	----	3,804,099	13 tab
1201	EE131	-519	*	13	----	----	1	13 tab
1202	EE118	138	0.1	20	----	----	4,622,485	13 tab
1203	EE128	510	*	13	----	----	1	13 tab

MATERIAL EEAV

Layup = $[M/\pm45/0]_S$, V_F = 0.48, Ave. thickness = 3.36 mm, S.D. = 0.24 mm, Vinyl ester

2716	EEAV105	619	*	13	29.0	2.15	1	25
2717	EEAV106	559	*	13	26.3	2.10	1	25
2718	EEAV101	569	*	13	26.6	2.20	1	25
2719	EEAV107	345	0.1	2	29.0	1.30	1,836	25
2720	EEAV109	345	0.1	2	28.1	1.31	3,260	25
2721	EEAV103	276	0.1	5	27.7	1.01	27,047	25
2722	EEAV108	276	0.1	5	29.2	1.01	43,424	25
2723	EEAV102	207	0.1	12	27.2	0.79	2,414,147	25
2724	EEAV144	207	0.1	20	28.6	0.74	1,366,767	25
2725	EEAV143	345	0.1	4	28.9	1.29	2,811	25
2726	EEAV145	276	0.1	5	29.8	1.00	35,462	25
2737	EEAV114	-657	*	13	----	----	1	25
2738	EEAV125	-666	*	13	----	----	1	25

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
2739	EEAV110	-614	*	13	----	----	1	25
2746	EEAV124	-448	10	5	----	----	7,498	25
2747	EEAV126	-448	10	5	----	----	5,539	25
2748	EEAV111	-448	10	5	----	----	3,169	25
2749	EEAV115	-345	10	20	----	----	5,000,000	25R
2750	EEAV113	-396	10	12	----	----	93,149	25
2751	EEAV112	-396	10	12	----	----	38,280	25
2752	EEAV117	-396	10	12	----	----	72,451	25
2753	EEAV116	207	-1	5	----	----	145,367	25
2754	EEAV122	207	-1	10	----	----	231,003	25
2755	EEAV123	276	-1	2	----	----	1,866	25
2756	EEAV121	276	-1	2	----	----	3,412	25
2757	EEAV120	276	-1	2	----	----	2,875	25
2758	EEAV119	207	-1	5	----	----	92,539	25
2759	EEAV118	190	-1	10	----	----	74,105	25
2760	EEAV204T	76	*	13	15.9	0.48	1	25
2761	EEAV203T	81	*	13	14.6	0.63	1	25
2762	EEAV201T	86	*	13	14.2	0.71	1	25
2763	EEAV205T	-195	*	13	----	----	1	25
2764	EEAV206T	-197	*	13	----	----	1	25
2765	EEAV207T	-192	*	13	----	----	1	25

MATERIAL EEAP

Layup = $[M/\pm45/0]_S$, V_F = 0.49, Ave. thickness = 3.64 mm, S.D. = 0.10 mm, Polyester

2797	EEAP101	505	*	13	29.5	1.80	1	25
2798	EEAP106	501	*	13	27.8	1.90	1	25
2799	EEAP109	529	*	13	30.2	1.80	1	25
2800	EEAP112	345	0.1	2	30.0	1.15	1,958	25
2801	EEAP102	345	0.1	2	27.0	1.20	890	25
2802	EEAP108	345	0.1	2	29.1	1.24	573	25
2803	EEAP111	276	0.1	4	31.2	0.90	9,912	25
2804	EEAP105	276	0.1	5	27.6	1.04	17,575	25
2805	EEAP104	276	0.1	5	29.2	1.03	15,403	25
2806	EEAP103	207	0.1	15	28.8	0.74	1,596,779	25
2807	EEAP110	207	0.1	15	28.3	0.73	2,483,304	25
2809	EEAP122	-716	*	13	----	----	1	25
2810	EEAP119	-750	*	13	----	----	1	25
2811	EEAP125	-721	*	13	----	----	1	25
2812	EEAP123	-448	10	4	----	----	6,703	25
2813	EEAP121	-448	10	4	----	----	16,229	25
2814	EEAP124	-448	10	4	----	----	18,158	25
2815	EEAP118	-396	10	10	----	----	110,507	25
2816	EEAP116	-396	10	10	----	----	140,415	25
2817	EEAP115	-362	10	10	----	----	696,647	25
2818	EEAP120	-396	10	10	----	----	59,096	25
2819	EEAP130	-362	15	15	----	----	1,445,447	25

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes

MATERIAL EEB

Layup = $[M/\pm45/0]_S$, V_F = 0.43, Ave. thickness = 2.90 mm, S.D. = 0.04 mm, Vinyl ester

2727	EEB103	512	*	13	27.8	1.80	1	25
2728	EEB101	513	*	13	27.5	1.90	1	25
2729	EEB102	520	*	13	27.5	1.90	1	25
2730	EEB105	276	0.1	5	24.6	1.21	8,392	25
2731	EEB108	276	0.1	5	25.2	1.22	11,375	25
2732	EEB106	345	0.1	2	27.5	1.40	504	25
2733	EEB107	345	0.1	2	26.1	1.44	358	25
2734	EEB109	207	0.1	10	26.8	0.81	365,195	25
2735	EEB104	207	0.1	12	27.5	0.80	462,172	25
2736	EEB141	276	0.1	4	25.8	1.20	12,141	25
2740	EEB125	-412	*	13	----	----	1	25
2741	EEB126	-449	*	13	----	----	1	25
2742	EEB112	-390	*	13	----	----	1	25

MATERIAL EEC

Layup = $[M/\pm45/0]_S$, V_F = 0.49, Ave. thickness = 2.48 mm, S.D. = 0.10 mm, Vinyl ester

2703	EEC123	546	*	13	27.4	2.00	1	25
2704	EEC122	505	*	13	29.8	1.70	1	25
2705	EEC132	526	*	13	27.9	1.90	1	25
2706	EEC133	345	0.1	2	29.5	1.35	257	25
2707	EEC128	345	0.1	2	27.5	1.41	149	25
2708	EEC131	345	0.1	2	28.6	1.49	86	25
2709	EEC126	276	0.1	4	28.4	1.07	5,070	25
2710	EEC125	276	0.1	4	28.9	1.04	2,474	25
2711	EEC130	276	0.1	4	27.3	1.08	3,114	25
2712	EEC118	207	0.1	10	28.0	0.77	285,157	25
2713	EEC120	207	0.1	10	29.0	0.77	141,150	25
2714	EEC129	207	0.1	10	29.4	0.76	159,441	25
2715	EEC127	172	0.1	20	27.1	0.68	1,293,553	25
2743	EEC136	-434	*	13	----	----	1	25
2744	EEC101	-436	*	13	----	----	1	25
2745	EEC143	-387	*	13	----	----	1	25

SUMMARY OF MSU MANUFACTURED MATERIAL FATIGUE TESTS

MATERIAL AA

Layup = $[(\pm45/0)_2, (\pm45/0),(\pm45/0)_2]$, V_F = 0.35, Ave. thickness = 4.37 mm, S.D. = 0.11 mm, Polyester

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
339	101AA	443	*	13	17.3	2.20	1	25
340	102AA	453	*	13	16.7	2.00	1	25
341	103AA	448	*	13	17.0	1.72	1	25
342	104AA	387	*	13	16.7	2.65	1	25
343	110AA	241	0.1	5	16.9	1.53	1,741	25
344	111AA	241	0.1	5	17.5	1.61	1,459	25
345	106AA	172	0.1	10	17.9	1.08	11,293	25
346	108AA	172	0.1	10	16.8	1.12	14,316	25
347	109AA	103	0.1	20	17.0	0.63	366,798	25
348	105AA	138	0.1	15	18.1	0.82	81,207	25
349	107AA	241	0.1	15	17.3	1.65	1,051	25
350	112AA	103	0.1	20	16.8	0.64	352,093	25
351	116AA	138	0.1	20	16.7	0.90	55,485	25
352	113AA	138	0.1	15	16.9	0.86	65,926	25
353	123AA	-288	*	13	17.1	-1.06	1	25
354	129AA	-284	*	13	18.4	-1.02	1	25
355	119AA	-310	*	13	19.2	-0.90	1	25
356	122AA	-138	10	15	20.1	-0.68	160,000	25R
357	126AA	-241	10	5	18.8	-1.36	8,700	25
358	118AA	-241	10	5	19.9	-1.24	9,419	25
359	128AA	-207	10	10	19.2	-1.31	64,783	25
360	127AA	-207	10	10	19.3	-1.36	75,000	25
361	121AA	-172	10	15	20.0	-0.91	6,000,000	25R
362	124AA	-172	10	10	18.2	-0.91	3,477,199	25
364	134AA	-327	*	13	19.4	-1.75	1	25Z
365	133AA	-347	*	13	17.7	-2.00	1	25Z
366	137AA	-366	*	13	19.1	----	1	25Z
367	132AA	-276	10	3	19.6	-1.60	547	25Z
368	131AA	-276	10	3	18.3	-1.61	462	25Z
369	135AA	-241	10	5	----	----	5,973	25Z
370	125AA	-190	10	10	18.3	-1.23	167,058	25Z
371	120AA	-190	10	10	18.4	-1.04	139,700	25Z
372	141AA	207	0.1	13	18.3	0.83	1,200	50
373	130AA	-190	10	5	----	----	151,283	25Z
375	145AA	121	0.1	5	19.7	0.48	42,000	50R
376	146AA	121	0.1	10	18.8	0.49	34,500	50R
377	144AA	103	0.1	15	19.7	0.40	97,692	50H
387	150AA	444	*	13	19.4	2.04	1	25
388	152AA	468	*	13	17.9	2.47	1	25
389	153AA	373	*	13	19.7	2.70	1	50H#
390	161AA	369	*	13	20.5	2.80	1	50H#
391	160AA	370	*	13	21.6	2.60	1	50H#
392	159AA	241	0.1	2	19.8	1.18	328	50H#

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TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
393	157AA	241	0.1	2	20.9	1.11	270	50H#
394	156AA	172	0.1	5	19.7	0.86	5,032	50H#
395	155AA	172	0.1	5	20.4	0.75	4,620	50H#
396	158AA	138	0.1	5	20.2	0.64	19,409	50H#
397	154AA	138	0.1	5	20.3	0.66	24,375	50H#
398	163AA	103	0.1	15	21.3	0.49	168,606	50H#
399	164AA	103	0.1	15	21.2	0.48	154,275	50H#
400	167AA	241	0.1	2	17.4	1.36	392	50H#
401	165AA	172	0.1	5	17.9	0.91	2,163	50H#
402	182AA	352	*	13	----	----	1	50H
403	181AA	350	*	13	18.7	2.31	1	50H
404	168AA	353	*	13	18.3	2.57	1	50H
405	169AA	103	0.1	15	20.2	0.41	100,806	50H
406	166AA	172	0.1	2	18.8	0.86	2,030	50H
407	184AA	241	0.1	2	19.7	1.14	280	50H
408	183AA	86	0.1	20	18.9	0.46	355,500	50H
409	170AA	-205	*	13	19.8	-1.38	1	50H
410	185AA	86	0.1	20	18.3	0.37	395,450	50H
411	173AA	-257	*	13	20.8	-1.00	1	50HZ
412	175AA	-257	*	13	19.5	-1.25	1	50HZ
413	178AA	-243	*	13	20.0	-1.70	1	50HZ
414	176AA	-207	10	2	19.9	-0.98	483	50HZ
415	180AA	-138	10	5	19.0	-0.52	39,859	50HZ
416	188AA	103	0.1	20	18.9	0.57	289,500	25
417	185AA	103	0.1	25	16.6	0.62	252,137	25
418	162AA	86	0.1	20	22.6	0.44	152,641	50H
419	190AA	138	0.1	5	17.2	0.68	7,527	50H
420	189AA	138	0.1	5	17.3	0.66	7,294	50H
421	192AA	-207	10	2	19.4	-0.70	508	50HZ
422	196AA	-138	10	5	20.8	-0.45	45,064	50HZ
423	187AA	86	0.1	10	19.8	0.46	1,097,890	25
424	197AA	86	0.1	15	16.5	0.54	1,110,190	25
425	196AA	-207	10	10	18.7	-1.08	59,130	25Z
426	191AA	-207	10	2	19.8	-0.69	446	50HZ
427	193AA	-138	10	5	20.0	-0.48	45,833	50HZ
428	194AA	-172	10	5	18.3	-0.66	8,338	50HZ
429	202AA	-371	*	13	17.9	-2.41	1	25Z
430	203AA	-327	*	13	19.0	-2.20	1	25Z
431	195AA	-172	10	10	18.6	-0.64	5,439	50HZ
432	204AA	-190	10	10	18.1	-1.05	172,910	25Z
433	200AA	-121	10	10	19.2	-0.46	1,400,699	50HZ
434	186AA	86	0.1	20	19.2	0.46	1,063,690	25
435	205AA	-190	10	25	16.9	-1.11	240,000	25Z
436	198AA	-121	10	15	15.2	-0.48	820,290	50HZ
437	187AA	172	0.1	10	16.6	1.04	17,149	25
438	209AA	241	0.1	2	16.9	1.43	187	50H
439	210AA	103	10	15	16.7	0.62	61,628	50H
440	207AA	172	0.1	10	18.1	0.72	2,757	50H

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TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
441	211AA	172	0.1	5	18.9	0.76	2,700	50H
442	206AA	138	0.1	5	17.8	0.63	9,650	50H
443	208AA	86	0.1	15	17.9	0.45	276,248	50H
444	213AA	241	0.1	2	18.6	1.15	237	50H
445	218AA	-276	10	1	18.1	-1.56	380	25Z
446	238AA	-241	10	5	18.6	-1.57	11,145	25HZ
447	199AA	-172	10	5	21.3	-0.64	7,345	50HZ
449	240AA	207	-1	1	19.0	1.38	195	25Z
450	230AA	207	-1	1	20.8	1.22	191	25Z
451	239AA	190	-1	2	17.9	1.27	296	25Z
452	232AA	172	-1	1	17.4	1.07	509	25Z
453	221AA	172	-1	1	18.3	1.01	438	25Z
454	216AA	138	-1	1	19.0	0.78	1,850	25Z
455	217AA	138	-1	1	17.3	0.86	2,493	25Z
456	241AA	190	-1	1	17.9	1.40	232	25Z
457	136AA	138	-1	1	----	----	1,897	25Z
458	224AA	138	-1	1	19.6	0.51	753	50HZ
459	231AA	86	-1	1	21.8	0.28	33,341	50HZ
460	222AA	172	-1	1	16.3	0.71	160	50HZ
461	228AA	172	-1	1	21.7	0.58	218	50HZ
462	227AA	172	-1	1	22.7	0.55	176	50HZ
463	229AA	138	-1	1	19.7	0.49	860	50HZ
464	225AA	138	-1	1	20.5	0.50	891	50HZ
465	223AA	103	-1	1	20.1	0.39	8,513	50HZ
466	236AA	103	-1	1	19.7	0.37	8,262	50HZ
467	235AA	86	-1	1	22.0	0.29	33,347	50HZ
468	237AA	103	-1	1	19.1	0.34	11,756	50HZ
469	242AA	207	-1	1	19.0	1.20	168	25Z
470	226AA	190	-1	1	18.0	1.17	208	25Z
471	242AA	172	-1	1	18.4	1.08	376	25Z
472	220AA	103	-1	1	18.6	0.58	25,488	25Z
473	219AA	103	-1	1	18.8	0.57	21,992	25Z
474	234AA	86	-1	2	19.2	0.32	56,945	50HZ
476	274AA	-190	10	15	18.5	-1.23	153,542	25Z
477	115AA	86	-1	5	18.8	0.45	456,549	25Z
478	117AA	86	-1	5	17.4	0.49	187,649	25Z
479	269AA	86	-1	5	20.5	0.44	236,152	25Z
480	271AA	103	-1	2	18.5	0.56	34,956	25Z
513	275AA	506	*	13	22.8	2.25	1	25
514	276AA	510	*	13	21.6	2.36	1	25
515	277AA	518	*	13	22.1	2.35	1	25
516	278AA	524	*	13	22.5	2.34	1	25
517	279AA	517	*	13	21.9	2.37	1	25
518	280AA	552	*	13	23.0	2.40	1	25
519	281AA	530	*	13	23.5	2.26	1	25
520	282AA	540	*	13	22.4	2.41	1	25
521	283AA	491	*	13	22.4	2.20	1	25
522	284AA	557	*	13	23.7	2.35	1	25

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TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
523	285AA	536	*	13	22.8	2.35	1	25
524	286AA	542	*	13	23.3	2.32	1	25
525	287AA	506	*	13	24.0	2.10	1	25
526	288AA	512	*	13	21.4	2.39	1	25
527	289AA	507	*	13	23.0	2.21	1	25
528	296AA	476	*	6	21.1	2.24	1	13
529	301AA	511	*	6	22.6	2.27	1	13
530	293AA	479	*	6	21.9	2.19	1	13
531	299AA	579	*	6	23.7	2.75	1	13
532	298AA	501	*	6	22.3	2.25	1	13
533	304AA	500	*	6	22.7	2.21	1	13
534	297AA	554	*	6	25.9	2.29	1	13
535	290AA	526	*	6	22.1	2.39	1	13
536	303AA	513	*	6	23.7	2.17	1	13
537	295AA	543	*	6	23.7	2.30	1	13
538	291AA	498	*	6	23.2	2.14	1	13
539	300AA	484	*	6	24.0	2.02	1	13
540	292AA	478	*	6	23.2	2.05	1	13
541	294AA	517	*	6	22.1	2.33	1	13
542	302AA	538	*	6	23.2	2.10	1	13
550	306AA	551	*	19	22.0	2.60	1	38
551	310AA	537	*	19	20.8	2.59	1	38
552	314AA	539	*	19	21.2	2.54	1	38
553	312AA	578	*	19	23.9	2.43	1	38
554	307AA	534	*	19	22.4	2.39	1	38
555	318AA	539	*	19	21.4	2.52	1	38
556	316AA	530	*	19	21.9	2.42	1	38
557	320AA	509	*	19	22.3	2.28	1	38
558	308AA	584	*	19	22.8	2.56	1	38
559	315AA	541	*	19	23.0	2.35	1	38
560	305AA	559	*	19	23.0	2.43	1	38
561	311AA	548	*	19	21.5	2.54	1	38
562	319AA	555	*	19	21.4	2.59	1	38
563	313AA	519	*	19	21.2	2.45	1	38
564	309AA	552	*	19	22.6	2.45	1	38
565	336AA	529	*	19	20.8	2.54	1	38
566	324AA	533	*	25	21.0	2.54	1	50
567	329AA	540	*	25	20.7	2.62	1	50
568	334AA	547	*	25	20.8	2.63	1	50
569	322AA	557	*	25	21.6	2.58	1	50
570	333AA	550	*	25	21.5	2.55	1	50
571	331AA	511	*	25	21.1	2.42	1	50
572	327AA	544	*	25	22.0	2.47	1	50
573	325AA	514	*	25	22.4	2.29	1	50
574	330AA	523	*	25	21.8	2.40	1	50
575	321AA	546	*	25	21.8	2.50	1	50
576	332AA	548	*	25	22.1	2.48	1	50
577	326AA	528	*	25	20.8	2.50	1	50

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TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
578	323AA	561	*	25	23.4	2.39	1	50
579	337AA	518	*	25	21.9	2.37	1	50
580	335AA	550	*	25	21.8	2.53	1	50
581	338AA	517	*	3	----	----	1	6
582	339AA	503	*	3	----	----	1	6
583	340AA	468	*	3	----	----	1	6
584	341AA	490	*	3	----	----	1	6
585	342AA	546	*	3	----	----	1	6
586	343AA	508	*	3	----	----	1	6
587	344AA	559	*	3	----	----	1	6
588	345AA	569	*	3	----	----	1	6
589	346AA	539	*	3	----	----	1	6
590	347AA	535	*	3	----	----	1	6
591	348AA	524	*	3	----	----	1	6
592	349AA	473	*	3	----	----	1	6
593	350AA	555	*	3	----	----	1	6
594	351AA	571	*	3	----	----	1	6
595	352AA	498	*	3	----	----	1	6
596	353AA	481	*	6	----	----	1	13
597	354AA	575	*	6	----	----	1	13
598	355AA	519	*	6	----	----	1	13
599	356AA	506	*	6	----	----	1	13
600	357AA	568	*	6	----	----	1	13
601	358AA	508	*	6	----	----	1	13
602	359AA	573	*	6	----	----	1	13
603	360AA	482	*	6	----	----	1	13
604	361AA	532	*	6	----	----	1	13
605	362AA	491	*	6	----	----	1	13
606	363AA	519	*	6	----	----	1	13
607	364AA	522	*	6	----	----	1	13
608	365AA	497	*	6	----	----	1	13
609	366AA	490	*	6	----	----	1	13
610	367AA	528	*	6	----	----	1	13
611	368AA	556	*	10	----	----	1	19
612	369AA	528	*	10	----	----	1	19
613	370AA	536	*	10	----	----	1	19
614	371AA	565	*	10	----	----	1	19
615	372AA	483	*	10	----	----	1	19
616	373AA	528	*	10	----	----	1	19
617	374AA	544	*	10	----	----	1	19
618	375AA	547	*	10	----	----	1	19
619	376AA	561	*	10	----	----	1	19
620	377AA	506	*	10	----	----	1	19
621	378AA	559	*	10	----	----	1	19
622	379AA	563	*	10	----	----	1	19
623	380AA	532	*	10	----	----	1	19
624	381AA	543	*	10	----	----	1	19
625	382AA	530	*	10	----	----	1	19

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
626	383AA	539	*	16	----	----	1	32
627	384AA	572	*	16	----	----	1	32
628	385AA	549	*	16	----	----	1	32
629	386AA	508	*	16	----	----	1	32
630	387AA	554	*	16	----	----	1	32
631	388AA	533	*	16	----	----	1	32
632	389AA	555	*	16	----	----	1	32
633	390AA	526	*	16	----	----	1	32
634	391AA	503	*	16	----	----	1	32
635	392AA	520	*	16	----	----	1	32
636	393AA	525	*	16	----	----	1	32
637	394AA	497	*	16	----	----	1	32
638	395AA	527	*	16	----	----	1	32
639	396AA	511	*	16	----	----	1	32
640	397AA	519	*	16	----	----	1	32
641	398AA	525	*	19	----	----	1	38
642	399AA	509	*	19	----	----	1	38
643	400AA	555	*	19	----	----	1	38
644	401AA	553	*	19	----	----	1	38
645	402AA	544	*	19	----	----	1	38
646	403AA	491	*	19	----	----	1	38
647	404AA	521	*	19	----	----	1	38
648	405AA	514	*	19	----	----	1	38
649	406AA	532	*	19	----	----	1	38
650	407AA	513	*	19	----	----	1	38
651	408AA	527	*	19	----	----	1	38
652	409AA	542	*	19	----	----	1	38
653	410AA	492	*	19	----	----	1	38
654	411AA	522	*	19	----	----	1	38
655	412AA	477	*	19	----	----	1	38
656	413AA	380	*	2	----	----	1	3
657	414AA	468	*	2	----	----	1	3
658	415AA	389	*	2	----	----	1	3
659	416AA	357	*	2	----	----	1	3
660	417AA	365	*	2	----	----	1	3
661	418AA	448	*	2	----	----	1	3
662	419AA	378	*	2	----	----	1	3
663	420AA	476	*	2	----	----	1	3
664	421AA	456	*	2	----	----	1	3
665	422AA	384	*	2	----	----	1	3
666	423AA	354	*	2	----	----	1	3
667	424AA	441	*	2	----	----	1	3
668	425AA	394	*	2	----	----	1	3
669	426AA	437	*	2	----	----	1	3
670	427AA	386	*	2	----	----	1	3
671	428AA	537	*	22	----	----	1	44
672	429AA	528	*	22	----	----	1	44
673	430AA	503	*	22	----	----	1	44

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
674	431AA	540	*	22	----	----	1	44
675	432AA	520	*	22	----	----	1	44
676	433AA	546	*	22	----	----	1	44
677	434AA	535	*	22	----	----	1	44
678	435AA	546	*	22	----	----	1	44
679	436AA	559	*	22	----	----	1	44
680	437AA	525	*	22	----	----	1	44
681	438AA	547	*	22	----	----	1	44
682	439AA	533	*	22	----	----	1	44
683	440AA	523	*	22	----	----	1	44
684	441AA	520	*	22	----	----	1	44
685	442AA	552	*	22	----	----	1	44
707	464AA	-323	*	13	----	----	1	3
708	465AA	-371	*	13	----	----	1	3
709	466AA	-311	*	13	----	----	1	3
710	467AA	-313	*	13	----	----	1	3
711	468AA	-330	*	13	----	----	1	3
712	469AA	-305	*	13	----	----	1	3
713	470AA	-319	*	13	----	----	1	3
714	471AA	-304	*	13	----	----	1	3
715	472AA	-326	*	13	----	----	1	3
716	473AA	-334	*	13	----	----	1	3
717	474AA	-311	*	13	----	----	1	25
718	475AA	-313	*	13	----	----	1	25
719	476AA	-311	*	13	----	----	1	25
720	477AA	-302	*	13	----	----	1	25
721	478AA	-307	*	13	----	----	1	25
722	479AA	-306	*	13	----	----	1	25
723	480AA	-302	*	13	----	----	1	25
724	481AA	-320	*	13	----	----	1	25
725	482AA	-316	*	13	----	----	1	25
726	483AA	-313	*	13	----	----	1	25
727	484AA	-321	*	13	----	----	1	19
728	485AA	-334	*	13	----	----	1	19
729	486AA	-333	*	13	----	----	1	19
730	487AA	-329	*	13	----	----	1	19
731	488AA	-337	*	13	----	----	1	19
732	489AA	-314	*	13	----	----	1	19
733	490AA	-325	*	13	----	----	1	19
734	491AA	-322	*	13	----	----	1	19
735	492AA	-331	*	13	----	----	1	19
736	493AA	-323	*	13	----	----	1	19
737	494AA	-320	*	13	----	----	1	19
738	495AA	-318	*	13	----	----	1	19
739	496AA	-316	*	13	----	----	1	19
740	497AA	-331	*	13	----	----	1	19
741	498AA	-323	*	13	----	----	1	19
742	499AA	-332	*	13	----	----	1	19

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
743	500AA	-327	*	13	----	----	1	19
744	501AA	-313	*	13	----	----	1	19
745	502AA	-322	*	13	----	----	1	19
746	503AA	-320	*	13	----	----	1	19
747	504AA	-358	*	13	----	----	1	13
748	505AA	-330	*	13	----	----	1	13
749	506AA	-347	*	13	----	----	1	13
750	507AA	-335	*	13	----	----	1	13
751	508AA	-351	*	13	----	----	1	13
752	509AA	-353	*	13	----	----	1	13
753	510AA	-355	*	13	----	----	1	13
754	511AA	-329	*	13	----	----	1	13
755	512AA	-339	*	13	----	----	1	13
756	513AA	-354	*	13	----	----	1	13
757	514AA	-264	*	13	----	----	1	44
758	515AA	-262	*	13	----	----	1	44
759	516AA	-265	*	13	----	----	1	44
760	517AA	-263	*	13	----	----	1	44
761	518AA	-267	*	13	----	----	1	44
762	519AA	-273	*	13	----	----	1	44
763	520AA	-266	*	13	----	----	1	44
764	521AA	-264	*	13	----	----	1	44
765	522AA	-269	*	13	----	----	1	44
766	523AA	-266	*	13	----	----	1	44
1233	443AA	-254	*	13	----	----	1	50
1234	444AA	-250	*	13	----	----	1	50
1235	445AA	-250	*	13	----	----	1	50
1236	446AA	-250	*	13	----	----	1	50
1237	447AA	-249	*	13	----	----	1	50
1238	448AA	-251	*	13	----	----	1	50
1239	449AA	-252	*	13	----	----	1	50
1240	450AA	-256	*	13	----	----	1	50
1241	451AA	-249	*	13	----	----	1	50
1242	452AA	-250	*	13	----	----	1	50
1243	453AA	-374	*	13	----	----	1	6
1244	454AA	-356	*	13	----	----	1	6
1245	455AA	-368	*	13	----	----	1	6
1246	456AA	-375	*	13	----	----	1	6
1247	457AA	-390	*	13	----	----	1	6
1248	458AA	-366	*	13	----	----	1	6
1249	459AA	-356	*	13	----	----	1	6
1250	460AA	-366	*	13	----	----	1	6
1251	461AA	-380	*	13	----	----	1	6
1252	462AA	-364	*	13	----	----	1	6
1253	463AA	-372	*	13	----	----	1	6

MATERIAL AA2

Layup = $[(0/\pm45)_2]_S$, V_F = 0.39, Ave. thickness = 2.63 mm, S.D. = 0.07 mm, Polyester

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
767	524AA2	-298	*	13	----	----	1	50
768	525AA2	-298	*	13	----	----	1	50
769	526AA2	-301	*	13	----	----	1	50
770	527AA2	-312	*	13	----	----	1	50
771	528AA2	-315	*	13	----	----	1	50
772	529AA2	-294	*	13	----	----	1	50
773	530AA2	-300	*	13	----	----	1	50
774	531AA2	-298	*	13	----	----	1	50
775	532AA2	-305	*	13	----	----	1	50
776	533AA2	-319	*	13	----	----	1	50
777	534AA2	-308	*	13	----	----	1	25
778	535AA2	-315	*	13	----	----	1	25
779	536AA2	-315	*	13	----	----	1	25
780	537AA2	-307	*	13	----	----	1	25
781	538AA2	-317	*	13	----	----	1	25
782	539AA2	-328	*	13	----	----	1	25
783	540AA2	-313	*	13	----	----	1	25
784	541AA2	-313	*	13	----	----	1	25
785	542AA2	-322	*	13	----	----	1	25
786	543AA2	-322	*	13	----	----	1	25
787	544AA2	-315	*	13	----	----	1	13
788	545AA2	-337	*	13	----	----	1	13
789	546AA2	-327	*	13	----	----	1	13
790	547AA2	-300	*	13	----	----	1	13
791	548AA2	-330	*	13	----	----	1	13
792	549AA2	-324	*	13	----	----	1	13
793	550AA2	-340	*	13	----	----	1	13
794	551AA2	-298	*	13	----	----	1	13
795	552AA2	-305	*	13	----	----	1	13
796	553AA2	-309	*	13	----	----	1	13
797	554AA2	-310	*	13	----	----	1	38
798	555AA2	-317	*	13	----	----	1	38
799	556AA2	-289	*	13	----	----	1	38
800	557AA2	-293	*	13	----	----	1	38
801	558AA2	-299	*	13	----	----	1	38
802	559AA2	-295	*	13	----	----	1	38
803	560AA2	-296	*	13	----	----	1	38
804	561AA2	-312	*	13	----	----	1	38
805	562AA2	-301	*	13	----	----	1	38
806	563AA2	-282	*	13	----	----	1	38
807	564AA2	-311	*	13	----	----	1	19
808	565AA2	-290	*	13	----	----	1	19
809	566AA2	-286	*	13	----	----	1	19
810	567AA2	-282	*	13	----	----	1	19

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
811	568AA2	-286	*	13	----	----	1	19
812	569AA2	-282	*	13	----	----	1	19
813	570AA2	-314	*	13	----	----	1	19
814	571AA2	-276	*	13	----	----	1	19
815	572AA2	-275	*	13	----	----	1	19
816	573AA2	-276	*	13	----	----	1	19
817	574AA2	-287	*	13	----	----	1	19
818	575AA2	-266	*	13	----	----	1	19
819	576AA2	-314	*	13	----	----	1	19
820	577AA2	-252	*	13	----	----	1	19
821	578AA2	-288	*	13	----	----	1	19
822	579AA2	-297	*	13	----	----	1	19
823	580AA2	-318	*	13	----	----	1	19
824	581AA2	-278	*	13	----	----	1	19
825	582AA2	-281	*	13	----	----	1	19
826	583AA2	-302	*	13	----	----	1	19
827	584AA2	-310	*	13	----	----	1	19
828	585AA2	-209	*	13	----	----	1	6
829	586AA2	-230	*	13	----	----	1	6
830	587AA2	-215	*	13	----	----	1	6
831	588AA2	-213	*	13	----	----	1	6
832	589AA2	-221	*	13	----	----	1	6
833	590AA2	-211	*	13	----	----	1	6
834	591AA2	-226	*	13	----	----	1	6
835	592AA2	-244	*	13	----	----	1	6
836	593AA2	-216	*	13	----	----	1	6
837	594AA2	-221	*	13	----	----	1	6
838	595AA2	-281	*	13	----	----	1	4
839	596AA2	-239	*	13	----	----	1	4
840	597AA2	-252	*	13	----	----	1	4
841	598AA2	-271	*	13	----	----	1	4
842	599AA2	-222	*	13	----	----	1	4
843	600AA2	-235	*	13	----	----	1	4
844	601AA2	-236	*	13	----	----	1	4
845	602AA2	-241	*	13	----	----	1	4
846	603AA2	-260	*	13	----	----	1	4
847	604AA2	-232	*	13	----	----	1	4
848	605AA2	-318	*	13	----	----	1	32
849	606AA2	-293	*	13	----	----	1	32
850	607AA2	-281	*	13	----	----	1	32
851	608AA2	-275	*	13	----	----	1	32
852	609AA2	-272	*	13	----	----	1	32
853	610AA2	-283	*	13	----	----	1	32
854	611AA2	-320	*	13	----	----	1	32
855	612AA2	-262	*	13	----	----	1	32
856	613AA2	-304	*	13	----	----	1	32
857	614AA2	-303	*	13	----	----	1	32
858	615AA2	-268	*	13	----	----	1	44

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
859	616AA2	-304	*	13	----	----	1	44
860	617AA2	-322	*	13	----	----	1	44
861	618AA2	-294	*	13	----	----	1	44
862	619AA2	-306	*	13	----	----	1	44
863	620AA2	-269	*	13	----	----	1	44
864	621AA2	-283	*	13	----	----	1	44
865	622AA2	-309	*	13	----	----	1	44
866	623AA2	-305	*	13	----	----	1	44
867	624AA2	-317	*	13	----	----	1	44
868	625AA2	423	*	13	----	----	1	25
869	630AA2	448	*	13	----	----	1	25
870	626AA2	517	*	13	23.0	2.67	1	25
871	627AA2	462	*	13	23.2	2.10	1	25
872	628AA2	494	*	13	22.7	2.18	1	25
873	629AA2	463	*	13	22.1	2.10	1	25
877	630AA2	430	*	13	21.1	2.04	1	25
879	631AA2	478	*	13	----	----	1	25
880	632AA2	478	*	13	----	----	1	25
881	633AA2	431	*	13	----	----	1	25
882	634AA2	489	*	13	----	----	1	25
883	635AA2	563	*	13	----	----	1	25
884	636AA2	420	*	13	----	----	1	25
885	637AA2	529	*	13	----	----	1	25
886	638AA2	524	*	13	----	----	1	25
887	639AA2	448	*	13	----	----	1	25
888	640AA2	446	*	13	----	----	1	25
890	642AA2	506	*	13	----	----	1	13
891	643AA2	486	*	13	----	----	1	13
892	644AA2	494	*	13	----	----	1	13
893	645AA2	494	*	13	----	----	1	13
895	647AA2	462	*	13	----	----	1	13
896	648AA2	437	*	13	----	----	1	13
897	649AA2	439	*	13	----	----	1	13
898	650AA2	506	*	13	----	----	1	13
900	652AA2	428	*	13	----	----	1	13
901	653AA2	469	*	13	----	----	1	13
902	654AA2	479	*	13	----	----	1	13
903	655AA2	472	*	13	----	----	1	13
904	656AA2	509	*	13	----	----	1	13
905	657AA2	474	*	13	----	----	1	13
906	658AA2	451	*	13	----	----	1	13
907	659AA2	-297	*	13	----	----	1	32
908	660AA2	-297	*	13	----	----	1	32
909	661AA2	-295	*	13	----	----	1	32
910	662AA2	-297	*	13	----	----	1	32
911	663AA2	-299	*	13	----	----	1	32
912	664AA2	-290	*	13	----	----	1	32
913	665AA2	-303	*	13	----	----	1	32

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
914	666AA2	-292	*	13	----	----	1	32
915	667AA2	-294	*	13	----	----	1	32
916	668AA2	-296	*	13	----	----	1	32
917	669AA2	-277	*	13	----	----	1	38
918	670AA2	-279	*	13	----	----	1	38
919	671AA2	-282	*	13	----	----	1	38
920	672AA2	-281	*	13	----	----	1	38
921	673AA2	-283	*	13	----	----	1	38
922	674AA2	-278	*	13	----	----	1	38
923	675AA2	-287	*	13	----	----	1	38
924	676AA2	-276	*	13	----	----	1	38
925	677AA2	-281	*	13	----	----	1	38
926	678AA2	-276	*	13	----	----	1	38

MATERIAL AA3

Layup = $[(\pm45/0)_3]_S$, V_F = 0.51, Ave. thickness = 3.45 mm, S.D. = 0.15 mm, Polyester

2367	AA3104	482	*	0.5	23.7	2.03	1	25
2368	AA3110	463	*	0.5	25.2	1.83	1	25
2369	AA3109	489	*	0.5	25.3	1.92	1	25
2370	AA3106	241	0.1	4	26.5	0.91	3,572	25
2371	AA3113	241	0.1	4	25.8	0.94	4,447	25
2372	AA3111	241	0.1	4	22.7	1.06	2,986	25
2373	AA3114	172	0.1	8	23.9	0.81	25,183	25
2374	AA3108	172	0.1	8	29.5	0.57	17,683	25
2375	AA3102	172	0.1	8	23.4	0.81	23,753	25
2376	AA3107	103	0.1	15	25.2	0.44	900,000	25R
2377	AA3115	310	0.1	2	26.5	1.39	493	25
2378	AA3112	310	0.1	2	24.7	1.26	626	25
2379	AA3103	310	0.1	2	25.2	1.23	812	25
2627	AA3301	-340	*	13	----	----	1	25
2628	AA3302	-283	*	13	----	----	1	25
2629	AA3303	-280	*	13	----	----	1	25
2630	AA3304	-233	*	13	----	----	1	25

MATERIAL AA4

Layup = $[(\pm45/0)_2]_S$, V_F = 0.37, Ave. thickness = 5.12 mm, S.D. = 0.13 mm, Polyester

3513	AA4104	310	*	13	22.0	2	1	25
3514	AA4101	427	*	13	21.9	2.10	1	25
3515	AA4102	365	*	13	21.4	1.85	1	25
3516	AA4107	404	*	13	20.5	2.19	1	25
3517	AA4109	241	0.1	2	18.3	1.36	1,203	25
3518	AA4113	241	0.1	2	21.2	1.19	3,002	25
3519	AA4111	241	0.1	2	19.5	1.42	2,752	25
3520	AA4110	207	0.1	4	22.0	1.08	24,288	25
3521	AA4112	207	0.1	4	19.1	1.15	19,180	25

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
3522	AA4116	207	0.1	4	18.5	1.26	15,966	25
3523	AA4120	172	0.1	5	20.5	0.90	179,566	25
3524	AA4118	172	0.1	5	----	----	127,836	25
3829	AA4136	-413	*	13	----	----	1	25
3830	AA4133	-442	*	13	----	----	1	25
3831	AA4131	-493	*	13	----	----	1	25

MATERIAL BB

Layup = $[(\pm45/0_2/\pm45/0_2/\pm45)]$, V_F = 0.42, Ave. thickness = 2.67 mm, S.D. = 0.06 mm, Polyester

927	BB101	734	*	13	23.9	2.77	1	25 tab
928	BB102	728	*	13	24.8	2.76	1	25 tab
929	BB103	735	*	13	24.8	2.70	1	25 tab
930	BB113	703	*	13	25.9	2.62	1	25 tab
931	BB109	414	0.1	2	25.4	1.63	550	25 tab
932	BB119	414	0.1	2	23.8	1.74	673	25 tab
933	BB118	414	0.1	2	25.0	1.71	512	25 tab
934	BB117	345	0.1	5	26.5	1.23	1,810	25 tab
935	BB124	345	0.1	5	27.3	1.26	2,415	25 tab
936	BB115	345	0.1	5	23.8	1.45	2,585	25 tab
937	BB123	276	0.1	10	26.8	1.09	18,755	25 tab
938	BB112	276	0.1	10	24.1	1.14	12,437	25 tab
939	BB114	276	0.1	10	25.2	1.20	11,302	25 tab
940	BB110	207	0.1	15	26.3	0.85	494,149	25 tab
941	BB116	207	0.1	15	25.8	0.80	197,629	25 tab
942	BB111	207	0.1	15	25.8	0.81	390,137	25 tab
943	BB108	241	0.1	15	24.6	1.12	66,612	25 tab
944	BB121	241	0.1	15	24.3	1.02	47,939	25 tab
945	BB107	241	0.1	15	24.3	1.09	84,343	25 tab
946	BB122	193	0.1	20	25.2	0.78	1,100,000	25 tab
947	BB106	193	0.1	20	25.2	0.78	921,400	25 tab
948	BB120	193	0.1	20	25.6	0.82	1,320,150	25 tab
949	BB113T	101	*	13	11.3	1.00	1	25 tab
950	BB112T	104	*	13	11.3	0.94	1	25 tab
951	BB111T	111	*	13	11.3	0.95	1	25 tab
952	BB120T	-225	*	13	12.5	1.81	1	25
953	BB128T	-229	*	13	11.2	1.86	1	25
954	BB127T	-244	*	13	12.2	1.99	1	25
955	BB135T	-294	*	13	----	----	1	25
956	BB141	-325	*	13	----	----	1	25
957	BB143	-291	*	13	----	----	1	25
958	BB105	193	0.1	15	26.0	0.84	707,401	25 tab

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes

MATERIAL CC

Layup = [(±45/0_2/±45/0_2/±45)], V_F = 0.39, Ave. thickness = 2.44 mm, S.D. = 0.07 mm, Polyester

959	CC105	574	*	13	21.0	2.74	1	25 tab
960	CC107	562	*	13	21.1	2.70	1	25 tab
961	CC102	574	*	13	20.6	2.78	1	25 tab
962	CC119	345	0.1	2	22.5	1.63	174	25 tab
963	CC108	345	0.1	2	21.0	1.84	223	25 tab
964	CC121	345	0.1	2	21.7	1.79	223	25 tab
965	CC118	276	0.1	4	21.9	1.55	1,787	25 tab
966	CC113	276	0.1	4	23.3	1.47	2,637	25 tab
967	CC104	276	0.1	4	21.2	1.30	3,029	25 tab
968	CC116	241	0.1	10	21.6	1.12	8,838	25 tab
969	CC117	241	0.1	10	23.3	1.14	6,956	25 tab
970	CC103	241	0.1	10	22.3	1.08	12,015	25 tab
971	CC112	207	0.1	15	21.9	0.99	25,203	25 tab
972	CC120	207	0.1	15	21.9	1.02	48,080	25 tab
973	CC124	207	0.1	15	21.6	1.05	32,670	25 tab
974	CC106	172	0.1	10	21.8	0.84	228,453	25 tab
975	CC114	172	0.1	15	23.2	0.74	205,864	25 tab
976	CC110	241	0.1	10	----	----	27,772	25
977	CC115	207	0.1	10	----	----	158,287	25
978	CC123	207	0.1	15	----	----	133,440	25
979	CC109	207	0.1	15	----	----	243,962	25
980	CC137	207	0.1	15	----	----	531,499	25
981	CC135	207	0.1	15	20.7	1.00	631,495	25 tab
982	CC130	207	0.1	15	20.2	1.02	486,225	25 tab
983	CC134	276	0.1	10	----	----	50,289	25
984	CC131	276	0.1	10	----	----	30,467	25
985	CC133	276	0.1	10	----	----	38,977	25
986	CC132	345	0.1	2	----	----	2,979	25
987	CC143	345	0.1	2	----	----	4,476	25
988	CC144	345	0.1	2	----	----	4,807	25
989	CC142	531	*	13	----	----	1	25
990	CC140	562	*	13	----	----	1	25
3052	CC160	-475	*	13	----	----	1	25
3053	CC161	-442	*	13	----	----	1	25

MATERIAL CC2

Layup = [(0/±45/0_2/±45/0_2/±45/0)], V_F = 0.45, Ave. thickness = 2.69 mm, S.D. = 0.03 mm, Polyester

991	CC2101	746	*	13	27.0	2.78	1	25
992	CC2103	730	*	13	26.9	2.86	1	25
993	CC2102	701	*	13	27.0	2.61	1	25
994	CC2105	414	0.1	5	25.6	1.62	4,104	25
995	CC2106	276	0.1	15	----	----	168,303	25
996	CC2116	276	0.1	10	----	----	132,591	25

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
997	CC2108	276	0.1	10	----	----	176,536	25
998	CC2111	414	0.1	15	----	----	2,231	25
999	CC2113	414	0.1	4	----	----	2,820	25
1000	CC2107	345	0.1	10	----	----	21,413	25
1001	CC2117	345	0.1	10	----	----	16,914	25
1002	CC2110	345	0.1	10	----	----	21,965	25
1003	CC2109	207	0.1	20	----	----	1,873,767	25
1004	CC2115	683	*	13	----	----	1	25
1005	CC2114	695	*	13	----	----	1	25
1006	CC2112	735	*	13	----	----	1	25

MATERIAL CC3

Layup = $[0/\pm45/0_2/\pm45/0]_S$, V_F = 0.45, Ave. thickness = 2.74 mm, S.D. = 0.06 mm, Polyester

1007	CC3101	690	*	0.5	26.1	2.64	1	25
1008	CC3102	657	*	0.5	25.8	2.54	1	25
1009	CC3103	700	*	0.5	26.9	2.60	1	25
1010	CC3107	414	0.1	5	----	----	1,324	25
1011	CC3104	414	0.1	5	----	----	5,122	25
1012	CC3105	414	0.1	5	----	----	4,241	25
1013	CC3108	276	0.1	10	----	----	186,787	25
1014	CC3106	276	0.1	10	----	----	226,915	25
1015	CC3109	276	0.1	10	----	----	169,059	25
1016	CC3111	414	0.1	5	----	----	4,469	25
1017	CC3110	345	0.1	5	----	----	26,235	25
1018	CC3113	345	0.1	5	----	----	31,512	25
1019	CC3112	345	0.1	5	----	----	28,465	25
1020	CC3121	241	0.1	15	----	----	371,472	25
1021	CC3120	241	0.1	20	----	----	428,636	25
1022	CC3124	207	0.1	15	----	----	2,016,665	25

MATERIAL CH

Layup = [$(\pm45)_3$]s, V_F = 0.45, Ave. thickness = 3.86 mm, S.D. = 0.04 mm, Polyester

1254	CH108	135	*	13	15.4	0.88	1	25
1255	CH119	162	*	13	13.7	1.18	1	25
1256	CH112	139	*	13	12.8	1.09	1	25
1257	CH111	103	0.1	2	13.4	0.97	3,591	25
1258	CH105	103	0.1	2	12.3	0.93	1,545	25
1259	CH116	86	0.1	5	13.5	0.64	2,886	25
1260	CH109	69	0.1	5	13.5	0.51	37,378	25
1261	CH117	52	0.1	15	11.7	0.44	3,000,000	25R
1262	CH114	103	0.1	2	13.6	0.94	920	25
1263	CH113	86	0.1	4	14.1	0.91	5,340	25
1264	CH107	86	0.1	4	14.3	0.92	4,604	25
1265	CH104	69	0.1	5	13.8	0.59	73,763	25
1266	CH106	69	0.1	5	14.3	0.64	28,432	25

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
1267	CH128	137	*	13	13.7	1.00	1	25
1268	CH125	62	0.1	10	14.1	0.51	327,862	25
1269	CH126	62	0.1	10	13.0	0.60	250,000	25 R
1270	CH110	62	0.1	10	14.0	0.55	171,332	25
1271	CH131	-190	*	0.1	----	----	1	25
1272	CH141	-179	*	0.1	----	----	1	25
1273	CH152	-171	*	0.1	----	----	1	25
1274	CH137	-124	10	2	----	----	433	25
1275	CH134	-124	10	2	----	----	870	25
1276	CH136	-86	10	5	----	----	61,185	25
1277	CH138	-86	10	10	----	----	31,317	25
1278	CH139	-69	10	20	----	----	1,317,352	25
1279	CH145	-103	10	5	----	----	5,030	25
1280	CH144	-103	10	5	----	----	9,428	25
1281	CH152	-124	10	2	----	----	956	25
1282	CH132	-103	10	5	----	----	6,653	25
1283	CH133	-69	10	20	----	----	1,125,335	25
1284	CH135	-86	10	10	----	----	76,452	25

MATERIAL CH2

Layup = $[(\pm45/0/\pm45)]_S$, V_F = 0.41, Ave. thickness = 3.78 mm, S.D. = 0.10 mm, Polyester

1353	CH2116	354	*	13	16.0	2.21	1	25
1354	CH2101	365	*	13	17.2	2.12	1	25
1355	CH2107	367	*	13	17.9	2.05	1	25
1356	CH2103	241	0.1	2	16.2	2.20	221	25
1357	CH2109	207	0.1	4	16.6	1.79	2,148	25
1358	CH2115	207	0.1	4	16.5	1.77	1,917	25
1359	CH2113	172	0.1	5	15.9	1.34	11,276	25
1360	CH2106	138	0.1	5	16.7	1.10	40,073	25
1361	CH2111	103	0.1	20	17.2	0.64	1,855,170	25
1362	CH2117	207	0.1	2	16.8	1.72	1,342	25
1363	CH2114	172	0.1	4	17.0	1.25	9,910	25
1364	CH2105	172	0.1	4	17.4	1.23	8,987	25
1365	CH2110	138	0.1	10	14.8	1.14	54,659	25
1366	CH2108	138	0.1	5	16.9	0.97	37,586	25
1367	CH2102	121	0.1	10	18.0	0.77	97,564	25
1368	CH2149T	117	*	13	12.4	----	1	25
1369	CH2104	370	*	13	16.5	2.85	1	25
1370	CH2146T	134	*	13	12.6	----	1	25
1371	CH2147T	122	*	13	12.3	----	1	25
1372	CH2129	-342	*	13	----	----	1	25
1373	CH2130	-333	*	13	----	----	1	25
1374	CH2128	-350	*	13	----	----	1	25
1375	CH2146T	-171	*	13	----	----	1	25
1376	CH2127	-276	10	2	----	----	39	25
1377	CH2156	-207	10	2	----	----	848	25

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
1378	CH2126	-207	10	2	----	----	1,972	25
1379	CH2118	-207	10	2	----	----	2,458	25
1380	CH2141	-172	10	5	----	----	19,691	25
1381	CH2122	-172	10	5	----	----	15,420	25
1382	CH2119	-138	10	20	----	----	871,785	25
1383	CH2121	-172	10	5	----	----	14,149	25
1384	CH2133	-155	10	10	----	----	166,026	25
1385	CH2125	-155	10	15	----	----	83,700	25
1844	CH2119	-522	*	13	----	----	1	25

MATERIAL CH3

Layup = $[(\pm45/0/\pm45)]_S$, V_F = 0.36, Ave. thickness = 4.19 mm, S.D. = 0.07 mm, Polyester

1386	CH3105	-326	*	13	----	----	1	25
1387	CH3117	-319	*	13	----	----	1	25
1388	CH3111	-309	*	13	----	----	1	25
1389	CH3106	-207	10	2	----	----	238	25
1390	CH3109	-207	10	2	----	----	159	25
1391	CH3110	-172	10	5	----	----	1,331	25
1392	CH3115	-172	10	4	----	----	760	25
1393	CH3108	-138	10	5	----	----	23,189	25
1394	CH3102	-138	10	5	----	----	14,301	25
1395	CH3103	-207	10	2	----	----	264	25
1396	CH3104	-172	10	4	----	----	982	25
1397	CH3107	-138	10	10	----	----	27,750	25
1398	CH3101	-121	10	15	----	----	141,901	25
1399	CH3112	-121	10	15	----	----	81,244	25
1400	CH3118	-121	10	20	----	----	164,715	25
1472	CH3124	333	*	13	17.3	2.71	1	25
1473	CH3135	340	*	13	16.5	2.85	1	25
1474	CH3131	336	*	13	16.1	2.74	1	25
1475	CH3125	241	0.1	2	16.6	2.23	173	25
1476	CH3132	241	0.1	2	16.1	2.85	174	25
1477	CH3136	241	0.1	2	15.9	2.26	134	25
1478	CH3122	207	0.1	2	16.8	1.59	1,166	25
1479	CH3134	207	0.1	2	17.0	1.69	1,270	25
1480	CH3128	207	0.1	2	15.6	1.82	814	25
1481	CH3119	172	0.1	5	17.8	1.19	8,478	25
1482	CH3129	172	0.1	4	16.6	1.35	12,387	25
1483	CH3123	172	0.1	5	18.3	1.25	14,410	25
1484	CH3126	138	0.1	10	17.2	0.95	282,621	25
1485	CH3121	138	0.1	5	15.7	1.04	200,174	25
1486	CH3130	138	0.1	10	18.1	0.91	429,020	25

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	ε %	CYCLES TO FAIL	WIDTH (mm) and Notes
MATERIAL CH4								
Layup = [(±45)$_3$]s, V_F = 0.37, Avc. thickness = 2.92 mm, S.D. = 0.08 mm, Polyester								
1445	CH4123	-173	*	13	----	----	1	25
1446	CH4133	-171	*	13	----	----	1	25
1447	CH4129	-173	*	13	----	----	1	25
1448	CH4140	-124	10	2	----	----	144	25
1449	CH4134	-124	10	1	----	----	188	25
1450	CH4141	-124	10	1	----	----	256	25
1451	CH4137	-103	10	2	----	----	1,313	25
1452	CH4142	-103	10	2	----	----	1,883	25
1453	CH4126	-103	10	2	----	----	873	25
1454	CH4128	-86	10	5	----	----	21,748	25
1455	CH4130	-86	10	5	----	----	13,364	25
1456	CH4131	-86	10	4	----	----	11,200	25
1457	CH4125	-69	10	15	----	----	206,018	25
1458	CH4135	-69	10	10	----	----	564,767	25
1459	CH4122	-69	10	15	----	----	485,632	25
1509	CH4106	160	*	13	11.0	6.41	1	25
1510	CH4114	157	*	13	11.2	5.15	1	25
1511	CH4115	149	*	13	11.4	6.35	1	25
1512	CH4117	103	0.1	2	11.4	1.70	198	25
1513	CH4107	103	0.1	2	11.0	1.80	287	25
1514	CH4110	103	0.1	2	12.4	1.40	314	25
1515	CH4118	86	0.1	4	11.7	1.38	1,319	25
1516	CH4111	86	0.1	2	12.1	0.99	2,311	25
1517	CH4113	86	0.1	4	10.9	1.24	1,186	25
1518	CH4102	69	0.1	10	11.2	0.82	7,072	25
1519	CH4119	69	0.1	10	10.7	0.79	10,172	25
1520	CH4103	69	0.1	10	12.2	0.64	15,843	25
1521	CH4101	52	0.1	20	11.1	0.52	342,135	25
1522	CH4116	52	0.1	20	----	----	224,519	25
1523	CH4104	52	0.1	20	12.2	0.47	1,136,938	25
MATERIAL CH5								
Layup = [(±45)$_3$]s, V_F = 0.28, Avc. thickness = 3.05 mm, S.D. = 0.09 mm, Polyester								
1460	CH5126	-190	*	13	----	----	1	25
1461	CH5123	-190	*	13	----	----	1	25
1462	CH5119	-190	*	13	----	----	1	25
1463	CH5127	-86	10	10	----	----	131,302	25
1464	CH5128	-121	10	2	----	----	1,548	25
1465	CH5129	-121	10	2	----	----	2,777	25
1466	CH5125	-121	10	2	----	----	2,989	25
1467	CH5118	-103	10	4	----	----	12,027	25
1468	CH5120	-103	10	5	----	----	9,130	25
1469	CH5121	-103	10	5	----	----	18,621	25

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	ε %	CYCLES TO FAIL	WIDTH (mm) and Notes
1470	CH5122	-86	10	15	----	----	329,191	25
1471	CH5124	-86	10	15	----	----	277,202	25
1524	CH5112	147	*	13	9.8	4.12	1	25
1525	CH5103	134	*	13	7.5	----	1	25
1526	CH5105	137	*	13	9.0	----	1	25
1527	CH5115	86	0.1	2	8.3	----	1,140	25
1528	CH5101	86	0.1	2	8.3	----	1,310	25
1529	CH5106	86	0.1	2	8.1	1.69	749	25
1530	CH5102	69	0.1	4	8.1	0.95	11,184	25
1531	CH5113	69	0.1	5	8.8	0.90	17,929	25
1532	CH5104	69	0.1	4	9.0	0.90	14,588	25
1533	CH5114	52	0.1	15	8.7	0.63	113,426	25
1534	CH5107	52	0.1	12	8.5	0.63	282,007	25
1535	CH5111	52	0.1	10	8.3	0.65	181,712	25
3557	CH5121	-194	*	0.025	----	----	1	25 tab
3558	CH5144	-202	*	0.025	----	----	1	25 tab
3559	CH5142	-189	*	0.025	----	----	1	25 tab
3560	CH5122	-214	*	0.254	----	----	1	25 tab
3561	CH5123	-207	*	0.254	----	----	1	25 tab
3562	CH5135	-213	*	0.254	----	----	1	25 tab
3563	CH5145	-213	*	2.54	----	----	1	25 tab
3564	CH5147	-206	*	2.54	----	----	1	25 tab
3565	CH5146	-219	*	2.54	----	----	1	25 tab
3566	CH5148	-230	*	6.35	----	----	1	25 tab
3567	CH5124	-225	*	6.35	----	----	1	25 tab
3568	CH5133	-216	*	6.35	----	----	1	25 tab
3569	CH5140	-223	*	12.7	----	----	1	25 tab
3570	CH5141	-225	*	12.7	----	----	1	25 tab
3571	CH5143	-243	*	12.7	----	----	1	25 tab
3572	CH5118	-227	*	19.1	----	----	1	25 tab
3573	CH5125	-224	*	19.1	----	----	1	25 tab
3574	CH5132	-207	*	19.1	----	----	1	25 tab
3575	CH5120	-242	*	25.4	----	----	1	25 tab
3576	CH5136	-242	*	25.4	----	----	1	25 tab
3577	CH5137	-211	*	25.4	----	----	1	25 tab
3578	CH5138	-223	*	63.5	----	----	1	25 tab
3579	CH5139	-238	*	63.5	----	----	1	25 tab
3580	CH5116	-215	*	63.5	----	----	1	25 tab
3581	CH5136	-241	*	127	----	----	1	25 tab
3582	CH5126	-239	*	127	----	----	1	25 tab
3583	CH5127	-228	*	127	----	----	1	25 tab
3584	CH5105	120	*	0.025	----	----	1	25 tab
3585	CH5114	120	*	0.025	----	----	1	25 tab
3586	CH5111	120	*	0.025	----	----	1	25 tab
3587	CH5112	125	*	0.254	----	----	1	25 tab
3588	CH5110	126	*	0.254	----	----	1	25 tab
3589	CH5109	126	*	0.254	----	----	1	25 tab
3590	CH5107	126	*	2.54	----	----	1	25 tab

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
3591	CH5108	137	*	2.54	----	----	1	25 tab
3592	CH5102	131	*	2.54	----	----	1	25 tab
3593	CH5103	137	*	12.7	----	----	1	25 tab
3594	CH5113	135	*	12.7	----	----	1	25 tab
3595	CH5106	136	*	12.7	----	----	1	25 tab
3596	CH5101	137	*	63.5	----	----	1	25 tab
3597	CH5104	142	*	63.5	----	----	1	25 tab
3598	CH5114	131	*	63.5	----	----	1	25 tab

MATERIAL CH6

Layup = (±45/0/±45)s, V_F = 0.49, Ave. thickness = 2.26 mm, S.D. = 0.09 mm, Polyester

1416	CH6106	-413	*	13	----	----	1	25
1417	CH6114	-381	*	13	----	----	1	25
1418	CH6105	-428	*	13	----	----	1	25
1419	CH6103	-207	10	5	----	----	15,707	25
1420	CH6117	-207	10	10	----	----	20,605	25
1421	CH6107	-207	10	5	----	----	38,711	25
1422	CH6101	-241	10	4	----	----	10,088	25
1423	CH6112	-241	10	4	----	----	11,950	25
1424	CH6102	-241	10	4	----	----	8,842	25
1425	CH6109	-276	10	2	----	----	2,727	25
1426	CH6110	-276	10	2	----	----	1,373	25
1427	CH6119	-276	10	2	----	----	840	25
1428	CH6104	-172	10	20	----	----	880,742	25
1429	CH6118	-172	10	20	----	----	1,628,900	25
1487	CH6123	510	*	13	22.5	3.34	1	25
1488	CH6128	500	*	13	21.6	2.98	1	25
1489	CH6133	495	*	13	22.9	3.24	1	25
1490	CH6140	345	0.1	2	20.9	2.11	284	25
1491	CH6127	345	0.1	2	20.0	2.24	189	25
1492	CH6134	345	0.1	2	21.2	2.04	246	25
1493	CH6139	310	0.1	2	20.3	1.81	561	25
1494	CH6124	310	0.1	2	20.9	1.76	758	25
1495	CH6138	310	0.1	2	20.5	1.78	619	25
1496	CH6130	276	0.1	4	20.3	1.64	2,224	25
1497	CH6131	276	0.1	4	21.1	1.60	1,490	25
1498	CH6125	276	0.1	4	22.4	1.41	2,153	25
1499	CH6126	241	0.1	5	21.8	1.30	4,278	25
1500	CH6129	241	0.1	10	21.0	1.29	6,877	25
1501	CH6135	207	0.1	10	23.0	1.04	13,309	25
1502	CH6132	207	0.1	5	22.1	1.04	15,150	25
1503	CH6141	207	0.1	5	22.4	1.06	11,807	25
1504	CH6122	172	0.1	5	21.7	0.87	44,634	25
1505	CH6136	172	0.1	10	22.1	0.86	37,335	25
1506	CH6137	138	0.1	10	22.5	0.67	224,743	25
1507	CH6142	138	0.1	10	21.1	0.69	138,170	25

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
1508	CH6148	121	0.1	20	20.5	0.59	419,563	25

MATERIAL CH7

Layup = [(±45)$_3$]s, V_F = 0.55, Ave. thickness = 2.86 mm, S.D. = 0.05 mm, Polyester

1401	CH7110	-174	*	13	----	----	1	25
1402	CH7114	-164	*	13	----	----	1	25
1403	CH7109	-165	*	13	----	----	1	25
1404	CH7107	-103	10	2	----	----	1,918	25
1405	CH7102	-103	10	2	----	----	1,763	25
1406	CH7106	-103	10	2	----	----	3,055	25
1407	CH7108	-86	10	5	----	----	16,492	25
1408	CH7104	-86	10	5	----	----	20,747	25
1409	CH7111	-86	10	5	----	----	15,719	25
1410	CH7150	-69	10	20	----	----	96,260	25
1411	CH7112	-69	10	20	----	----	278,521	25
1412	CH7101	-69	10	15	----	----	167,393	25
1413	CH7122	112	*	13	13.8	1.75	1	25
1414	CH7126	107	*	13	15.4	----	1	25
1415	CH7128	113	*	13	15.4	----	1	25
1536	CH7115	115	*	13	15.7	4.80	1	25
1537	CH7117	116	*	13	17.9	----	1	25
1538	CH7127	112	*	13	18.6	----	1	25
1539	CH7125	69	0.1	5	16.3	0.55	4,943	25
1540	CH7120	69	0.1	5	17.2	0.49	3,145	25
1541	CH7119	69	0.1	5	17.5	0.49	3,797	25
1542	CH7121	52	0.1	10	17.8	0.32	92,285	25
1543	CH7116	52	0.1	10	16.5	0.34	62,832	25
1544	CH7123	52	0.1	10	15.2	0.34	116,214	25
1545	CH7130	83	0.1	2	19.0	0.70	418	25
1546	CH7118	83	0.1	2	18.2	0.57	521	25

MATERIAL CH8

Layup = [(±45)$_3$]s, V_F = 0.39, Ave. thickness = 5.89 mm, S.D. = 0.12 mm, Polyester

1430	CH8141	-145	*	13	----	----	1	25
1431	CH8128	-145	*	13	----	----	1	25
1432	CH8122	-148	*	13	----	----	1	25
1433	CH8136	-103	10	4	----	----	191	25
1434	CH8126	-103	10	2	----	----	99	25
1435	CH8125	-103	10	2	----	----	215	25
1436	CH8129	-86	10	2	----	----	1,242	25
1437	CH8121	-86	10	2	----	----	862	25
1438	CH8127	-86	10	2	----	----	719	25
1439	CH8130	-69	10	4	----	----	2,509	25
1440	CH8139	-69	10	4	----	----	3,894	25
1441	CH8135	-69	10	4	----	----	1,784	25

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
1442	CH8124	-52	10	5	----	----	11,312	25
1443	CH8123	-52	10	5	----	----	8,752	25
1444	CH8132	-52	10	5	----	----	36,219	25
1547	CH8107	91	*	13	9.4	5.86	1	25
1548	CH8104	97	*	13	9.8	6.70	1	25
1549	CH8118	90	*	13	11.9	7.43	1	25
1550	CH8116	52	0.1	4	9.0	0.61	8,968	25
1551	CH8102	52	0.1	4	10.0	0.60	9,804	25
1552	CH8106	52	0.1	5	8.6	0.65	10,105	25
1553	CH8105	62	0.1	2	12.4	0.60	1,756	25
1554	CH8113	62	0.1	2	9.5	0.90	1,333	25
1555	CH8119	62	0.1	2	9.2	0.82	1,691	25
1556	CH8115	41	0.1	10	10.7	0.42	59,831	25
1557	CH8114	41	0.1	10	11.1	0.40	50,912	25
1558	CH8103	41	0.1	10	9.4	0.43	70,962	25
1559	CH8101	34	0.1	15	9.3	0.37	1,480,988	25

MATERIAL CH9

Layup = [(±45)$_3$]s, V_F = 0.49, Ave. thickness = 2.13 mm, S.D. = 0.07 mm, Polyester

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
1560	CH9106	157	*	13	10.4	7.70	1	25
1561	CH9113	144	*	13	10.1	5.17	1	25
1562	CH9105	151	*	13	10.6	9.15	1	25
1563	CH9110	103	0.1	2	10.0	1.80	250	25
1564	CH9101	103	0.1	2	10.6	1.70	285	25
1565	CH9114	103	0.1	2	10.8	2.00	294	25
1566	CH9108	86	0.1	2	10.1	1.30	1,503	25
1567	CH9112	86	0.1	2	10.8	1.17	1,901	25
1568	CH9103	86	0.1	2	10.4	1.32	2,357	25
1569	CH9107	69	0.1	5	9.7	0.97	11,702	25
1570	CH9109	52	0.1	20	11.5	0.46	868,713	25
1571	CH9102	69	0.1	5	8.1	0.90	8,369	25
1572	CH9115	69	0.1	5	10.3	0.83	13,987	25
1573	CH9116	52	0.1	15	10.1	0.54	937,400	25
1643	CH9144	-172	*	13	----	----	1	25
1644	CH9136	-176	*	13	----	----	1	25
1645	CH9133	-175	*	13	----	----	1	25
1646	CH9132	-121	10	2	----	----	299	25
1647	CH9137	-121	10	4	----	----	738	25
1648	CH9145	-121	10	2	----	----	352	25
1649	CH9143	-103	10	4	----	----	5,842	25
1650	CH9140	-103	10	4	----	----	1,801	25
1651	CH9134	-103	10	2	----	----	2,917	25
1652	CH9130	-86	10	10	----	----	68,643	25
1653	CH9138	-86	10	10	----	----	39,626	25
1654	CH9131	-86	10	5	----	----	46,815	25
1655	CH9141	-76	10	10	----	----	522,908	25

MATERIAL CH10

Layup = [(±45)$_3$]s, V_F = 0.33, Ave. thickness = 5.56 mm, S.D. = 0.08 mm, Polyester

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
1574	CH10114	124	*	13	7.6	7.17	1	25
1575	CH10105	122	*	13	7.4	6.42	1	25
1576	CH10115	116	*	13	7.7	8.12	1	25
1577	CH10113	69	0.1	4	8.1	1.16	4,432	25
1578	CH10119	69	0.1	4	7.9	1.30	2,609	25
1579	CH10110	69	0.1	2	8.3	1.05	5,331	25
1580	CH10109	86	0.1	1	8.2	1.81	201	25
1581	CH10104	86	0.1	1	7.3	2.00	114	25
1582	CH10118	86	0.1	1	7.8	1.89	187	25
1583	CH10117	52	0.1	5	8.5	0.67	506,181	25
1584	CH10103	59	0.1	5	9.2	0.76	72,644	25
1585	CH10108	59	0.1	5	9.1	0.75	63,552	25
1586	CH10121	59	0.1	4	8.0	0.85	32,735	25
1668	CH10153	-167	*	13	----	----	1	25
1669	CH10132	-158	*	13	----	----	1	25
1670	CH10142	-164	*	13	----	----	1	25
1671	CH10130	-121	10	1	----	----	93	25
1672	CH10149	-121	10	1	----	----	48	25
1673	CH10151	-121	10	1	----	----	62	25
1674	CH10139	-103	10	1	----	----	510	25
1675	CH10146	-103	10	1	----	----	843	25
1676	CH10133	-103	10	1	----	----	709	25
1677	CH10138	-86	10	2	----	----	2,914	25
1678	CH10131	-86	10	2	----	----	3,996	25
1679	CH10155	-86	10	2	----	----	1,948	25
1680	CH10135	-69	10	5	----	----	25,535	25
1681	CH10144	-69	10	5	----	----	15,850	25
1682	CH10134	-69	10	5	----	----	20,095	25
1683	CH10145	-52	10	15	----	----	948,262	25

MATERIAL CH11

Layup = [(±45)$_3$]s, V_F = 0.54, Ave. thickness = 2.41 mm, S.D. = 0.05 mm, Polyester

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
1587	CH11114	128	*	13	13.0	6.78	1	25
1588	CH11111	143	*	13	13.0	6.00	1	25
1589	CH11105	132	*	13	13.0	----	1	25
1590	CH11113	86	0.1	4	14.0	0.98	861	25
1591	CH11109	86	0.1	4	13.8	1.00	1,207	25
1592	CH11101	86	0.1	4	13.1	0.97	1,310	25
1593	CH11102	69	0.1	4	15.2	0.58	13,430	25
1594	CH11107	69	0.1	4	14.0	0.60	18,411	25
1595	CH11106	69	0.1	4	12.0	0.73	11,934	25
1596	CH11103	59	0.1	12	14.0	0.49	85,334	25
1597	CH11104	59	0.1	15	13.6	0.48	120,347	25

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
1598	CH11110	59	0.1	15	12.8	0.51	68,035	25
1599	CH11112	52	0.1	15	13.0	0.42	356,380	25
1656	CH11120	-190	*	13	----	----	1	25
1657	CH11129	-188	*	13	----	----	1	25
1658	CH11125	-188	*	13	----	----	1	25
1659	CH11116	-121	10	2	----	----	1,285	25
1660	CH11115	-121	10	2	----	----	1,821	25
1661	CH11118	-121	10	2	----	----	1,122	25
1662	CH11124	-103	10	5	----	----	16,602	25
1663	CH11123	-103	10	5	----	----	12,602	25
1664	CH11121	-103	10	5	----	----	21,683	25
1665	CH11117	-86	10	10	----	----	71,004	25
1666	CH11128	-86	10	12	----	----	168,236	25
1667	CH11126	-86	10	10	----	----	302,383	25

MATERIAL CH12

Layup = [±45/0/±45]s, V_F = 0.34, Ave. thickness = 3.00 mm, S.D. = 0.10 mm, Polyester

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
1600	CH12114	391	*	13	15.8	5.49	1	25
1601	CH12109	412	*	13	18.0	6.82	1	25
1602	CH12116	393	*	13	16.0	5.92	1	25
1603	CH12121	276	0.1	2	11.4	1.94	2,415	25
1604	CH12108	276	0.1	2	17.7	1.99	1,325	25
1605	CH12118	276	0.1	2	17.9	1.85	2,803	25
1606	CH12102	207	0.1	10	18.6	1.20	108,802	25
1607	CH12101	207	0.1	10	18.6	1.29	65,123	25
1608	CH12117	207	0.1	10	18.2	1.29	82,951	25
1609	CH12107	190	0.1	10	18.8	1.13	244,866	25
1610	CH12119	172	0.1	15	16.3	1.19	476,154	25
1611	CH12106	241	0.1	4	17.9	1.49	9,523	25
1612	CH12105	241	0.1	4	17.5	1.60	4,914	25
1613	CH12120	172	0.1	10	18.7	1.00	389,771	25
1684	CH12143	-442	*	13	----	----	1	25
1685	CH12144	-455	*	13	----	----	1	25
1686	CH12133	-455	*	13	----	----	1	25
1687	CH12123	-276	10	4	----	----	4,326	25
1688	CH12135	-276	10	2	----	----	7,611	25
1689	CH12124	-276	10	4	----	----	8,723	25
1690	CH12147	-241	10	12	----	----	18,512	25
1693	CH12137	-241	10	15	----	----	116,437	25
1694	CH12129	-207	10	15	----	----	1,712,433	25
1695	CH12126	-207	10	15	----	----	663,181	25
1696	CH12131	-310	10	2	----	----	4,295	25
1697	CH12140	-310	10	2	----	----	3,815	25
1698	CH12127	-310	10	2	----	----	1,465	25
1699	CH12128	-241	10	10	----	----	64,663	25
1700	CH12146	-345	10	1	----	----	887	25

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
1701	CH12144	-345	10	1	----	----	266	25
1702	CH12145	-345	10	1	----	----	394	25
3199	CH1225	331	*	13	----	----	1	51
3200	CH1226	317	*	13	----	----	1	51
3201	CH1227	295	*	13	----	----	1	51
3202	CH1231	321	*	13	----	----	1	38
3203	CH1232	316	*	13	----	----	1	38
3204	CH1233	299	*	13	----	----	1	38
3205	CH1234	308	*	13	----	----	1	32
3206	CH1235	304	*	13	----	----	1	32
3207	CH1236	310	*	13	----	----	1	32
3208	CH1237	304	*	13	----	----	1	25
3209	CH1238	304	*	13	----	----	1	25
3210	CH1239	301	*	13	----	----	1	25
3211	CH1240	306	*	13	----	----	1	19
3212	CH1241	297	*	13	----	----	1	19
3213	CH1242	309	*	13	----	----	1	19
3214	CH1243	287	*	13	----	----	1	13
3215	CH1244	273	*	13	----	----	1	13
3216	CH1245	278	*	13	----	----	1	13
3217	CH1246	251	*	13	----	----	1	6
3218	CH1247	255	*	13	----	----	1	6
3219	CH1248	219	*	13	----	----	1	6
3220	CH121	-312	*	13	----	----	1	51
3221	CH122	-323	*	13	----	----	1	51
3222	CH123	-330	*	13	----	----	1	51
3223	CH124	-333	*	13	----	----	1	44
3224	CH125	-288	*	13	----	----	1	44
3225	CH126	-335	*	13	----	----	1	44
3226	CH127	-336	*	13	----	----	1	38
3227	CH128	-397	*	13	----	----	1	38
3228	CH129	-401	*	13	----	----	1	38
3229	CH1210	-384	*	13	----	----	1	32
3230	CH1211	-401	*	13	----	----	1	32
3231	CH1212	-382	*	13	----	----	1	32
3232	CH1213	-359	*	13	----	----	1	25
3233	CH1214	-358	*	13	----	----	1	25
3234	CH1215	-352	*	13	----	----	1	25
3235	CH1216	-356	*	13	----	----	1	19
3236	CH1217	-351	*	13	----	----	1	19
3237	CH1218	-354	*	13	----	----	1	19
3238	CH1219	-354	*	13	----	----	1	13
3239	CH1220	-328	*	13	----	----	1	13
3240	CH1221	-334	*	13	----	----	1	13
3241	CH1222	-308	*	13	----	----	1	6
3242	CH1223	-352	*	13	----	----	1	6
3243	CH1224	-299	*	13	----	----	1	6
3301	CH12001	366	*	0.025	----	----	1	25

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
3302	CH12002	328	*	0.025	----	----	1	25
3303	CH12003	345	*	0.025	----	----	1	25
3304	CH12004	387	*	0.25	----	----	1	25
3305	CH12005	388	*	0.25	----	----	1	25
3306	CH12006	379	*	0.25	----	----	1	25
3307	CH12007	430	*	2.54	----	----	1	25
3308	CC12008	413	*	2.54	----	----	1	25
3309	CH12009	419	*	2.54	----	----	1	25
3310	CH12010	440	*	25	----	----	1	25
3311	CH12011	420	*	25	----	----	1	25
3312	CH12012	443	*	25	----	----	1	25
3313	CH12013	455	*	64	----	----	1	25
3314	CH12014	480	*	64	----	----	1	25
3315	CH12015	472	*	64	----	----	1	25
3316	CH12016	437	*	127	----	----	1	25
3317	CH12017	485	*	127	----	----	1	25
3318	CH12018	484	*	127	----	----	1	25
3319	CH12025	-408	*	0.025	----	----	1	25
3320	CH12026	-444	*	0.025	----	----	1	25
3321	CH12027	-377	*	0.025	----	----	1	25
3322	CH12028	-415	*	0.25	----	----	1	25
3323	CH12029	-426	*	0.25	----	----	1	25
3324	CH12030	-443	*	0.25	----	----	1	25
3325	CH12031	-447	*	2.54	----	----	1	25
3326	CH12032	-468	*	2.54	----	----	1	25
3327	H12033	-424	*	2.54	----	----	1	25
3232	CH12013	-359	*	13	----	----	1	25
3233	CH12014	-358	*	13	----	----	1	25
3234	CH12015	-352	*	13	----	----	1	25
3328	CH12034	-482	*	25	----	----	1	25
3329	CH12035	-500	*	25	----	----	1	25
3330	CH12036	-492	*	25	----	----	1	25
3331	CH12037	-438	*	64	----	----	1	25
3332	CH12038	-402	*	64	----	----	1	25
3333	CH12039	-402	*	64	----	----	1	25
3334	CH12040	-455	*	127	----	----	1	25
3335	CH12041	-449	*	127	----	----	1	25
3336	CH12042	-454	*	127	----	----	1	25

MATERIAL CH13

Layup = [±45/0/±45]s, V_F = 0.48, Ave. thickness = 3.28 mm, S.D. = 0.05 mm, Polyester

1614	CH13113	428	*	13	23.0	----	1	25
1615	CH13108	420	*	13	23.2	----	1	25
1616	CH13107	420	*	13	22.6	2.81	1	25
1617	CH13104	276	0.1	2	22.5	1.68	449	25
1618	CH13114	276	0.1	1	24.4	1.75	301	25

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
1619	CH13111	276	0.1	1	23.5	1.81	363	25
1620	CH13103	207	0.1	4	23.2	1.24	4,078	25
1621	CH13109	207	0.1	4	23.0	1.24	3,466	25
1622	CH13106	207	0.1	4	23.3	1.24	4,587	25
1623	CH13112	138	0.1	10	23.2	0.70	37,685	25
1624	CH13102	138	0.1	5	23.1	0.74	31,299	25
1625	CH13105	138	0.1	5	23.8	0.70	44,571	25
1626	CH13101	103	0.1	20	23.2	0.50	1,067,315	25
1703	CH13127	-406	*	13	----	----	1	25
1704	CH13128	-378	*	13	----	----	1	25
1705	CH13126	-370	*	13	----	----	1	25
1706	CH13125	-241	10	2	----	----	933	25
1707	CH13121	-241	10	2	----	----	2,759	25
1708	CH13115	-241	10	4	----	----	4,163	25
1709	CH13116	-207	10	10	----	----	8,887	25
1710	CH13123	-138	10	15	----	----	2,000,000	25R
1711	CH13119	-207	10	10	----	----	10,738	25
1712	CH13120	-207	10	10	----	----	15,164	25
1713	CH13122	-172	10	15	----	----	109,685	25
1714	CH13118	-172	10	10	----	----	61,058	25
1715	CH13124	-172	10	10	----	----	228,268	25
1716	CH13117	-276	10	1	----	----	174	25
1717	CH13110	-276	10	1	----	----	104	25
1718	CH13140	-276	10	1	----	----	212	25

MATERIAL CH14

Layup = [±45/0/±45]s, V_F = 0.44, Ave. thickness = 2.49 mm, S.D. = 0.09 mm, Polyester

1627	CH14112	548	*	13	23.0	3.06	1	25
1628	CH14106	499	*	13	21.3	3.41	1	25
1629	CH14105	504	*	13	22.5	3.69	1	25
1630	CH14104	345	0.1	1	20.6	2.05	283	25
1631	CH14103	345	0.1	1	22.1	1.87	121	25
1632	CH14116	345	0.1	2	21.0	2.17	266	25
1633	CH14107	276	0.1	4	19.7	1.65	2,344	25
1634	CH14110	276	0.1	4	20.0	1.56	1,280	25
1635	CH14113	276	0.1	4	21.2	1.56	1,709	25
1636	CH14118	207	0.1	10	20.1	1.12	11,600	25
1637	CH14119	207	0.1	10	21.6	1.10	17,423	25
1638	CH14102	207	0.1	10	21.4	1.00	22,579	25
1639	CH14115	138	0.1	20	19.8	0.73	2,054,772	25
1640	CH14120	172	0.1	10	17.7	0.90	69,782	25
1641	CH14111	172	0.1	10	21.7	0.89	57,256	25
1642	CH14101	172	0.1	10	22.7	0.84	57,107	25
1719	CH14134	-398	*	13	----	----	1	25
1720	CH14124	-401	*	13	----	----	1	25
1721	CH14123	-437	*	13	----	----	1	25

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
1722	CH14139	-310	10	2	----	----	903	25
1723	CH14140	-310	10	2	----	----	2,756	25
1724	CH14129	-310	10	2	----	----	1,188	25
1725	CH14133	-276	10	5	----	----	10,716	25
1726	CH14125	-276	10	4	----	----	16,008	25
1727	CH14128	-276	10	5	----	----	11,756	25
1728	CH14131	-341	10	10	----	----	58,134	25
1729	CH14132	-341	10	5	----	----	86,421	25
1730	CH14130	-341	10	10	----	----	78,283	25
1731	CH14126	-207	10	20	----	----	3,000,000	25R

MATERIAL CH15

Layup = [±45/0/±45]s, V_F = 0.32, Ave. thickness = 2.51 mm, S.D. = 0.11 mm, Polyester

1732	CH15139	-332	*	0.5	----	----	1	25
1733	CH15138	-374	*	0.5	----	----	1	25
1734	CH15128	-331	*	0.5	----	----	1	25
1735	CH15142	-241	10	2	----	----	996	25
1736	CH15143	-241	10	2	----	----	542	25
1737	CH15147	-241	10	2	----	----	1,345	25
1738	CH15141	-207	10	4	----	----	4,825	25
1739	CH15123	-207	10	4	----	----	9,366	25
1740	CH15122	-207	10	5	----	----	10,507	25
1741	CH15145	-172	10	5	----	----	61,865	25
1742	CH15144	-172	10	10	----	----	54,046	25
1743	CH15137	-172	10	10	----	----	41,806	25
1744	CH15136	-138	10	20	----	----	5,000,000	25R
1800	CH15105	327	*	13	14.0	3.45	1	25
1801	CH15121	308	*	13	15.3	----	1	25
1802	CH15114	296	*	13	15.2	3.79	1	25
1803	CH15118	207	0.1	2	13.6	2.10	403	25
1804	CH15116	207	0.1	2	15.0	1.87	608	25
1805	CH15113	207	0.1	2	14.3	2.09	270	25
1806	CH15115	172	0.1	4	14.5	1.44	18,054	25
1807	CH15117	172	0.1	4	13.4	1.56	16,456	25
1808	CH15104	172	0.1	4	15.0	1.58	11,511	25
1889	CH15103	138	0.1	10	15.7	1.07	132,279	25
1810	CH15106	138	0.1	10	16.4	0.99	350,007	25
1811	CH15102	138	0.1	10	15.3	1.01	465,775	25
1812	CH15101	121	0.1	12	15.4	0.88	1,029,975	25

MATERIAL CH16

Layup = [±45/0/±45]s, V_F = 0.40, Ave. thickness = 2.36 mm, S.D. = 0.06 mm, Polyester

1745	CH16136	-325	*	0.5	----	----	1	25
1746	CH16122	-295	*	0.5	----	----	1	25
1747	CH16133	-307	*	0.5	----	----	1	25

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
1748	CH16123	-241	10	1	----	----	371	25
1749	CH16129	-241	10	2	----	----	1,216	25
1750	CH16138	-241	10	1	----	----	1,010	25
1751	CH16124	-207	10	4	----	----	7,458	25
1752	CH16130	-207	10	4	----	----	11,541	25
1753	CH16128	-207	10	4	----	----	7,137	25
1754	CH16139	-172	10	5	----	----	162,300	25
1755	CH16132	-172	10	12	----	----	109,008	25
1756	CH16135	-172	10	10	----	----	155,530	25
1757	CH16120	-155	10	15	----	----	596,803	25
1813	CH16102	366	*	13	19.4	3.13	1	25
1814	CH16104	362	*	13	17.1	----	1	25
1815	CH16105	353	*	13	18.3	2.43	1	25
1816	CH16101	241	0.1	1	18.8	1.73	151	25
1817	CH16115	241	0.1	1	18.3	1.89	421	25
1818	CH16118	241	0.1	1	19.9	1.66	580	25
1819	CH16106	207	0.1	2	18.5	1.51	2,805	25
1820	CH16112	207	0.1	2	19.0	1.48	1,746	25
1821	CH16116	207	0.1	2	17.9	1.59	1,203	25
1822	CH16119	172	0.1	4	17.3	1.21	5,928	25
1823	CH16103	172	0.1	4	20.8	1.07	3,595	25
1824	CH16109	172	0.1	4	21.6	1.01	4,508	25
1825	CH16107	138	0.1	5	17.5	0.89	36,647	25
1826	CH16110	138	0.1	5	17.7	0.93	47,119	25
1827	CH16108	138	0.1	5	16.3	0.95	34,528	25
1828	CH16113	121	0.1	10	18.2	0.75	163,247	25
1829	CH16140	103	0.1	15	17.1	0.66	1,247,001	25

MATERIAL CH17

Layup = [±45/0/±45]s, V_F = 0.48, Ave. thickness = 1.96 mm, S.D. = 0.09 mm, Polyester

1758	CH17130	-303	*	13	----	----	1	25
1759	CH17142	-309	*	13	----	----	1	25
1760	CH17144	-292	*	13	----	----	1	25
1761	CH17154	-241	10	2	----	----	822	25
1762	CH17123	-241	10	2	----	----	1,359	25
1763	CH17125	-241	10	2	----	----	1,847	25
1764	CH17141	-207	10	5	----	----	2,279	25
1765	CH17138	-207	10	4	----	----	1,767	25
1766	CH17140	-207	10	4	----	----	7,278	25
1767	CH17124	-172	10	5	----	----	227,223	25
1768	CH17134	-172	10	15	----	----	149,828	25
1769	CH17146	-172	10	10	----	----	83,725	25
1770	CH17137	-155	10	20	----	----	4,030,851	25
1901	CH17201	363	*	13	16.0	4.28	1	25
1902	CH17217	345	*	13	17.7	3.14	1	25
1903	CH17202	369	*	13	18.1	3.32	1	25

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
1904	CH17205	207	0.1	2	18.0	1.53	1,521	25
1905	CH17209	207	0.1	2	18.6	1.40	841	25
1906	CH17212	207	0.1	2	15.7	1.70	657	25
1907	CH17213	172	0.1	4	18.0	1.20	4,397	25
1908	CH17206	172	0.1	5	18.7	1.17	2,826	25
1909	CH17216	172	0.1	5	17.1	1.26	5,024	25
1910	CH17214	138	0.1	5	17.6	0.89	28,190	25
1911	CH17210	138	0.1	5	16.6	1.02	34,959	25
1912	CH17203	138	0.1	5	17.4	0.98	21,682	25
1913	CH17208	121	0.1	5	18.7	0.74	44,730	25
1914	CH17207	103	0.1	5	18.5	0.61	183,268	25
1915	CH17215	103	0.1	5	17.2	0.65	196,692	25

MATERIAL CH18

Layup = [±45/0/±45]s, V_F = 0.47, Ave. thickness = 3.10 mm, S.D. = 0.05 mm, Polyester

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
1771	CH18125	-300	*	13	----	----	1	25
1772	CH18127	-280	*	13	----	----	1	25
1773	CH18129	-313	*	13	----	----	1	25
1774	CH18124	-241	10	1	----	----	120	25
1775	CH18121	-241	10	1	----	----	99	25
1776	CH18120	-241	10	1	----	----	94	25
1777	CH18122	-207	10	2	----	----	1,077	25
1778	CH18123	-207	10	2	----	----	783	25
1779	CH18138	-207	10	2	----	----	1,103	25
1780	CH18118	-172	10	4	----	----	17,383	25
1781	CH18117	-172	10	5	----	----	14,090	25
1782	CH18136	-172	10	10	----	----	18,452	25
1783	CH18128	-138	10	15	----	----	64,880	25
1784	CH18119	-138	10	10	----	----	82,563	25
1785	CH18126	-121	10	15	----	----	1,295,428	25
1872	CH18214	286	*	13	14.0	3.24	1	25
1873	CH18203	302	*	13	17.5	2.98	1	25
1874	CH18212	295	*	13	17.0	3.10	1	25
1875	CH18202	207	0.1	2	17.1	1.87	343	25
1876	CH18208	207	0.1	2	16.1	1.93	187	25
1877	CH18205	207	0.1	2	17.5	1.87	269	25
1878	CH18206	172	0.1	4	17.6	1.45	1,360	25
1879	CH18209	172	0.1	4	18.1	1.44	1,424	25
1880	CH18207	172	0.1	4	17.7	1.40	1,875	25
1881	CH18211	138	0.1	4	15.8	1.12	12,279	25
1882	CH18201	138	0.1	5	20.3	0.94	7,623	25
1883	CH18220	138	0.1	4	17.7	1.10	8,671	25
1884	CH18204	103	0.1	5	17.7	0.69	119,853	25
1885	CH18210	103	0.1	5	17.3	0.73	73,139	25
1886	CH18213	86	0.1	10	17.4	0.56	585,178	25

MATERIAL CH19

Layup = [±45/0/±45]s, V_F = 0.33, Ave. thickness = 4.60 mm, S.D. = 0.19 mm, Polyester

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
1786	CH19142	-256	*	13	----	----	1	25
1787	CH19128	-253	*	13	----	----	1	25
1788	CH19127	-245	*	13	----	----	1	25
1789	CH19147	-172	10	1	----	----	167	25
1790	CH19134	-176	10	1	----	----	82	25
1791	CH19136	-172	10	1	----	----	56	25
1792	CH19125	-138	10	2	----	----	476	25
1793	CH19141	-138	10	1	----	----	801	25
1794	CH19132	-138	10	1	----	----	1,702	25
1795	CH19143	-103	10	4	----	----	28,708	25
1796	CH19122	-103	10	5	----	----	14,379	25
1797	CH19137	-103	10	10	----	----	51,234	25
1798	CH19130	-86	10	10	----	----	928,343	25
1799	CH19120	-86	10	15	----	----	622,350	25
1887	CH19201	192	*	13	11.7	3.88	1	25
1888	CH19210	196	*	13	10.8	3.85	1	25
1889	CH19207	191	*	13	11.6	3.87	1	25
1890	CH19202	121	0.1	4	12.3	1.21	5,507	25
1891	CH19214	121	0.1	2	12.1	1.35	4,586	25
1892	CH19206	121	0.1	2	11.9	1.13	5,100	25
1893	CH19209	103	0.1	5	12.3	1.05	32,613	25
1894	CH19204	103	0.1	5	12.7	0.99	17,152	25
1895	CH19203	86	0.1	10	11.7	0.78	324,779	25
1896	CH19205	103	0.1	5	11.7	1.05	27,183	25
1897	CH19208	86	0.1	10	11.2	0.83	278,576	25
1898	CH19220	86	0.1	12	12.2	0.82	423,198	25
1899	CH19211	138	0.1	1	12.0	1.43	850	25
1900	CH19212	138	0.1	1	11.7	1.55	1,414	25

MATERIAL CH20

Layup = [(±45)$_3$]s, V_F = 0.25, Ave. thickness = 3.76 mm, S.D. = 0.15 mm, Polyester

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
3003	CH20116	136	*	13	10.9	1.60	1	25
3004	CH20121	141	*	13	10.2	1.40	1	25
3005	CH20115	124	*	13	10.6	1.70	1	25
3006	CH20101	51.7	0.1	12	12.0	0.52	136,994	25
3007	CH20107	86.2	0.1	2	10.5	1.09	1,458	25
3008	CH20105	86.2	0.1	2	11.9	0.96	1,169	25
3009	CH20106	86.2	0.1	2	10.0	1.25	1,456	25
3010	CH20119	69.0	0.1	4	11.3	0.76	9,530	25
3011	CH20113	51.7	0.1	4	10.4	0.56	199,855	25
3012	CH20110	69.0	0.1	5	10.6	0.83	10,324	25
3013	CH20114	69.0	0.1	4	10.4	0.82	7,214	25
3014	CH20131	-232	*	13	----	----	1	25

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
3015	CH20130	-233	*	13	----	----	1	25
3016	CH20132	-224	*	13	----	----	1	25

MATERIAL CH23

Layup = [±45/0/±45]s, V_F = 0.32, Ave. thickness = 2.95 mm, S.D. = 0.13 mm, Polyester

3017	CH23111	410	*	13	20.0	2.15	1	25
3018	CH23112	369	*	13	17.0	2.37	1	25
3019	CH23103	402	*	13	20.6	2.10	1	25
3020	CH23104	276	0.1	2	21.2	1.51	331	25
3021	CH23118	207	0.1	4	17.2	1.35	2,311	25
3022	CH23119	207	0.1	4	17.8	1.29	2,596	25
3023	CH23110	207	0.1	4	18.3	1.24	3,577	25
3024	CH23114	138	0.1	5	19.5	0.76	84,094	25
3025	CH23106	138	0.1	5	18.2	0.79	69,137	25
3026	CH23147	-207	10	5	----	----	147,440	25
3027	CH23141	-207	10	5	----	----	81,067	25
3028	CH23160	-444	*	13	----	----	1	25
3029	CH23148	-464	*	13	----	----	1	25
3030	CH23144	-435	*	13	----	----	1	25
3031	CH23168	-276	10	4	----	----	7,443	25
3032	CH23143	-276	10	4	----	----	1,786	25
3033	CH23161	-276	10	4	----	----	6,288	25
3034	CH23143	-207	10	10	----	----	128,233	25
3035	CH23121	276	0.1	1	----	----	77	25
3036	CH23109	276	0.1	2	----	----	403	25
3037	CH23115	138	0.1	10	----	----	98,304	25

MATERIAL DD

Layup = [0/±45/0_3/±45/0], V_F = 0.49, Ave. thickness = 2.67 mm, S.D. = 0.07 mm, Polyester

1023	DD101	903	*	13	31.9	2.84	1	22
1024	DD103	893	*	13	29.0	2.91	1	22
1025	DD102	934	*	13	30.6	3.00	1	22
1026	DD112	552	0.1	2	31.4	1.76	1,065	22
1027	DD114	552	0.1	2	32.3	1.70	807	22
1028	DD108	552	0.1	2	28.9	1.90	631	22
1029	DD118	483	0.1	5	30.5	1.58	3,044	22
1030	DD113	483	0.1	5	30.9	1.56	1,937	22
1031	DD117	483	0.1	5	30.5	1.58	2,377	22
1032	DD116	414	0.1	5	31.3	1.32	4,997	22
1033	DD119	414	0.1	5	32.4	1.27	8,143	22
1034	DD115	345	0.1	5	32.4	1.06	25,503	22
1035	DD104	345	0.1	5	30.1	1.14	28,657	22
1036	DD110	276	0.1	15	35.2	0.78	64,373	22
1037	DD111	276	0.1	15	29.7	0.92	87,936	22
1038	DD106	207	0.1	15	32.7	0.63	704,401	22

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
1039	DD109	207	0.1	15	30.6	0.68	1,062,397	22
1040	DD107	207	0.1	20	32.6	0.63	947,447	22

MATERIAL DD2

Layup = $[0/\pm45/0]_S$, V_F = 0.42, Ave. thickness = 2.64 mm, S.D. = 0.07 mm, Polyester

1043	DD2106	767	*	13	28.6	2.70	1	22
1044	DD2102	757	*	13	30.0	2.53	1	22
1045	DD2114	731	*	13	25.7	2.80	1	22
1046	DD2105	414	0.1	5	27.2	1.52	9,691	25
1047	DD2113	414	0.1	5	25.9	1.61	6,904	22
1048	DD2107	483	0.1	4	27.9	1.80	883	22
1049	DD2117	483	0.1	4	26.1	1.85	1,055	22
1050	DD2108	276	0.1	15	25.2	1.10	766,525	22
1051	DD2110	345	0.1	15	27.2	1.27	71,702	22
1052	DD2111	345	0.1	20	28.9	1.19	59,123	22
1053	DD2109	345	0.1	15	27.9	1.23	62,149	22
1060	DD2115	276	0.1	15	24.7	1.11	655,028	22
1078	DD2116	276	0.1	20	25.5	1.08	697,390	22
1285	DD2171	-579	*	13	----	----	1	25
1286	DD2164	-609	*	13	----	----	1	25
1287	DD2170	-554	*	13	----	----	1	25
1288	DD2163	-414	10	2	----	----	2,311	25
1289	DD2169	-414	10	5	----	----	3,675	25
1290	DD2168	-379	10	5	----	----	24,450	25
1291	DD2167	-379	10	5	----	----	18,781	25
1292	DD2152	-345	10	15	----	----	82,800	25
1293	DD2153	-372	10	10	----	----	19,205	25
1294	DD2161	-310	10	20	----	----	636,142	25
1295	DD2158	-310	10	20	----	----	868,215	25
1296	DD2173	-345	10	15	----	----	111,458	25
1297	DD2176	-414	10	5	----	----	3,775	25
1298	DD2162	-345	10	10	----	----	147,520	25
1299	DD2165	-310	10	20	----	----	1,054,781	25

MATERIAL DD4

Layup = $[0/\pm45/0]_S$, V_F = 0.50, Ave. thickness = 2.36 mm, S.D. = 0.07 mm, Polyester

1061	DD4108	276	0.1	15	27.7	1.00	106,008	22
1062	DD4103	276	0.1	15	28.6	0.97	74,777	22
1063	DD4102	414	0.1	5	29.3	1.41	6,714	22
1064	DD4113	414	0.1	5	32.2	1.28	8,257	22
1065	DD4109	414	0.1	5	30.7	1.35	8,821	22
1066	DD4117	903	*	13	27.9	2.90	1	22
1067	DD4101	901	*	13	31.0	2.91	1	22
1068	DD4114	880	*	13	29.4	2.99	1	22
1069	DD4110	517	0.1	4	35.5	1.46	1,438	22

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
1070	DD4120	517	0.1	4	----	----	1,284	22
1071	DD4104	345	0.1	10	33.9	1.02	18,821	22
1072	DD4111	345	0.1	10	34.8	0.99	18,293	22
1073	DD4106	345	0.1	10	----	----	22,542	22
1074	DD4118	276	0.1	15	32.7	0.84	118,241	22
1075	DD4115	207	0.1	15	31.6	0.66	278,835	22
1076	DD4116	207	0.1	20	28.3	0.73	386,766	22
1077	DD4105	193	0.1	20	----	----	2,426,414	22
1304	DD4130	-515	*	13	----	----	1	25
1305	DD4131	-519	*	13	----	----	1	25
3083	DD4163	-590	*	13	----	----	1	25
3084	DD4156	-514	*	13	----	----	1	25
3085	DD4151	-566	*	13	----	----	1	25
3105	DD4191	345	-1	2	----	----	972	25
3106	DD4160	345	-1	2	----	----	793	25
3107	DD4165	345	-1	2	----	----	1,436	25
3108	DD4106	861	*	--	----	----	1	25
3109	DD4158	207	-1	5	----	----	83,385	25
3110	DD4157	276	-1	4	----	----	13,351	25
3111	DD4167	276	-1	4	----	----	17,873	25
3112	DD4159	276	-1	4	----	----	9,178	25
3113	DD4150	172	-1	8	----	----	218,504	25
3114	DD4162	207	-1	5	----	----	47,671	25 tab
3115	DD4152	207	-1	4	----	----	63,270	25 tab
3116	DD4161	138	-1	12	----	----	2,000,000	25 R tab

MATERIAL DD5

Layup = $[0/\pm45/0]_S$, V_F = 0.38, Ave. thickness = 2.97 mm, S.D. = 0.06 mm, Polyester

1079	DD5113	703	*	13	26.6	2.78	1	22
1080	DD5108	740	*	13	23.8	3.00	1	22
1081	DD5112	729	*	13	23.7	2.91	1	22
1082	DD5109	207	0.1	20	25.2	0.82	1,820,826	22 R
1083	DD5107	483	0.1	2	24.1	2.00	2,386	22
1084	DD5116	483	0.1	2	27.9	1.72	2,650	22
1085	DD5106	483	0.1	2	26.8	1.80	1,996	22
1086	DD5119	414	0.1	5	24.7	1.67	20,246	22
1087	DD5117	276	0.1	20	24.1	1.20	1,500,000	22R
1088	DD5104	414	0.1	15	25.4	1.63	14,980	22
1089	DD5102	414	0.1	15	28.1	1.47	12,469	22
1090	DD5118	276	0.1	20	26.7	1.03	1,103,247	22
1091	DD5114	345	0.1	15	22.9	1.51	127,898	22
1092	DD5103	345	0.1	15	23.0	1.50	145,581	22
1093	DD5105	345	0.1	15	25.2	1.37	169,754	22
1094	DD5115	276	0.1	20	----	----	1,033,583	22
1302	DD5130	-553	*	13	----	----	1	25
1303	DD5131	-514	*	13	----	----	1	25

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
1835	DD5105	-781	*	13	----	----	1	25
1836	DD5201	-795	*	13	----	----	1	25

MATERIAL DD5E

Layup = $[0/\pm45/0]_S$, V_F = 0.36, Ave. thickness = 3.10 mm, S.D. = 0.07 mm, Epoxy

1859	DD5E406	680	*	13	22.8	2.93	1	22
1860	DD5E403	662	*	13	22.8	2.90	1	22
1861	DD5E408	682	*	13	24.4	2.80	1	22
1940	DD5E419	-528	*	13	27.2	----	1	25
1942	DD5E415	-531	*	13	27.2	----	1	25
1943	DD5E418	-503	*	13	25.3	----	1	25
1962	DD5E424	-345	10	10	----	----	334,460	25
1963	DD5E424	-345	10	5	----	----	1,176,784	25
1964	DD5E420	-379	10	4	----	----	85,056	25
1965	DD5E426	-379	10	4	----	----	59,318	25
1966	DD5E422	-379	10	4	----	----	143,526	25
1967	DD5E416	-414	10	2	----	----	5,232	25
1968	DD5E425	-414	10	2	----	----	7,541	25
1970	DD5E421	-345	10	10	----	----	1,740,718	25 R
1971	DD5E428	-414	10	4	----	----	3,855	25
1982	DD5E411	276	0.1	10	23.3	1.19	348,038	22 tab
1983	DD5E409	276	0.1	10	21.5	1.31	498,494	22 tab
1984	DD5E401	276	0.1	10	23.9	1.24	899,308	22 tab
1985	DD5E412	345	0.1	5	23.4	1.51	34,642	22 tab
1986	DD5E405	345	0.1	5	22.3	1.54	67,480	22 tab
1987	DD5E410	414	0.1	2	22.7	1.83	878	22 tab
1988	DD5E414	414	0.1	2	24.4	1.76	2,429	22
1989	DD5E407	345	0.1	5	22.7	1.54	52,731	22
1990	DD5E402	483	0.1	1	21.8	2.28	69	22 tab
1991	DD5E413	241	0.1	15	21.6	1.19	2,441,330	22
2986	DD5E251	310	-1	2	----	----	1,745	25
2987	DD5E261	310	-1	2	----	----	380	25
2988	DD5E254	310	-1	2	----	----	1,130	25
2989	DD5E252	207	-1	4	----	----	23,990	25
2990	DD5E259	207	-1	4	----	----	31,172	25
2991	DD5E252	207	-1	4	----	----	92,394	25
2992	DD5E260	172	-1	5	----	----	191,803	25
2993	DD5E258	276	-1	2	----	----	1,072	25
2994	DD5E256	276	-1	2	----	----	601	25
2995	DD5E257	276	-1	2	----	----	2,665	25
2996	DD5E262	155	-1	10	----	----	1,060,993	25
2997	DD5E263	172	-1	10	----	----	168,947	25
2998	DD5E250	172	-1	10	----	----	305,106	25
2999	DD5E270	155	-1	12	----	----	1,463,729	25
3000	DD5E286T	76	*	13	7.31	1.04	1	25
3001	DD5E281T	73	*	13	8.76	0.84	1	25

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
3002	DD5E280T	64	*	13	7.24	0.89	1	25

MATERIAL DD5P

Layup = $[0/\pm45/0]_S$, $V_F = 0.36$, Ave. thickness = 3.02 mm, S.D. = 0.08 mm, Polyester

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
1853	DD5P206	683	*	13	23.6	2.94	1	22
1854	DD5P209	682	*	13	24.7	2.76	1	22
1855	DD5P214	617	*	13	22.3	2.78	1	22
1871	DD5P201	241	0.1	15	25.7	0.95	8,000,000	22 R
1937	DD5P221	-581	*	13	26.3	----	1	25
1938	DD5P228	-557	*	13	25.0	----	1	25
1939	DD5P219	-586	*	13	25.2	----	1	25
1953	DD5P215	-414	10	2	----	----	5,041	25
1954	DD5P224	-414	10	2	----	----	9,422	25
1955	DD5P218	-414	10	2	----	----	8,491	25
1956	DD5P223	-379	10	5	----	----	178,704	25
1957	DD5P225	-379	10	5	----	----	63,853	25
1958	DD5P216	-379	10	4	----	----	72,641	25
1959	DD5P217	-345	10	10	----	----	344,570	25
1960	DD5P226	-345	10	10	----	----	424,220	25
1961	DD5P227	-345	10	15	----	----	661,103	25
1973	DD5P207	483	0.1	1	24.3	2.20	86	22 tab
1974	DD5P205	414	0.1	2	23.5	1.85	2,102	22 tab
1975	DD5P208	414	0.1	2	24.3	1.74	1,045	22 tab
1976	DD5P212	345	0.1	4	23.9	1.48	36,290	22 tab
1977	DD5P204	345	0.1	5	23.5	1.67	43,703	22 tab
1978	DD5P203	345	0.1	5	24.4	1.43	28,269	22
1979	DD5P210	276	0.1	10	22.7	1.24	857,025	22
1980	DD5P211	276	0.1	10	23.0	1.22	357,553	22 tab
1981	DD5P213	276	0.1	10	21.3	1.18	481,129	22 tab
2965	DD5P255	414	-1	2	----	----	21	25
2966	DD5P259	345	-1	2	----	----	634	25
2967	DD5P260	345	-1	1	----	----	121	25
2968	DD5P251	345	-1	2	----	----	810	25
2969	DD5P250	310	-1	2	----	----	1,360	25
2970	DD5P254	310	-1	1	----	----	163	25
2971	DD5P252	276	-1	2	----	----	5,179	25
2972	DD5P253	276	-1	2	----	----	2,038	25
2973	DD5P257	276	-1	2	----	----	2,131	25
2974	DD5P256	207	-1	4	----	----	16,718	25
2975	DD5P261	207	-1	4	----	----	26,796	25
2976	DD5P258	155	-1	10	----	----	986,000	25R
2977	DD5P262	172	-1	5	----	----	106,267	25
2978	DD5P257	172	-1	4	----	----	79,563	25
2979	DD5P162	155	-1	10	----	----	561,486	25
2980	DD5P263T	53	*	13	8.96	0.59	1	25
2981	DD5P264T	54	*	13	8.83	0.61	1	25

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
2982	DD5P265T	56	*	13	8.89	0.63	1	25
2983	DD5P269T	-170	*	13	----	----	1	25
2984	DD5P267T	-153	*	13	----	----	1	25
2985	DD5P266T	-163	*	13	----	----	1	25
3150	DD5P001	-591	*	13	----	----	1	51
3151	DD5P002	-662	*	13	----	----	1	51
3152	DD5P003	-674	*	13	----	----	1	51
3153	DD5P004	-622	*	13	----	----	1	51
3154	DD5P005	-624	*	13	----	----	1	44
3155	DD5P006	-616	*	13	----	----	1	44
3156	DD5P007	-671	*	13	----	----	1	44
3157	DD5P008	-649	*	13	----	----	1	44
3158	DD5P009	-597	*	13	----	----	1	38
3159	DD5P010	-604	*	13	----	----	1	38
3160	DD5P011	-638	*	13	----	----	1	38
3161	DD5P012	-695	*	13	----	----	1	38
3162	DD5P013	-649	*	13	----	----	1	32
3163	DD5P014	-648	*	13	----	----	1	32
3164	DD5P015	-666	*	13	----	----	1	32
3165	DD5P016	-650	*	13	----	----	1	32
3166	DD5P061	-687	*	13	----	----	1	25
3167	DD5P062	-634	*	13	----	----	1	25
3168	DD5P063	-671	*	13	----	----	1	25
3169	DD5P021	-588	*	13	----	----	1	19
3170	DD5P022	-580	*	13	----	----	1	19
3171	DD5P023	-630	*	13	----	----	1	19
3172	DD5P024	-610	*	13	----	----	1	19
3173	DD5P025	-614	*	13	----	----	1	13
3174	DD5P026	-550	*	13	----	----	1	13
3175	DD5P027	-581	*	13	----	----	1	13
3176	DD5P028	-607	*	13	----	----	1	13
3177	DD5P029	-495	*	13	----	----	1	6
3178	DD5P030	-549	*	13	----	----	1	6
3179	DD5P031	-539	*	13	----	----	1	6
3180	DD5P032	-519	*	13	----	----	1	6
3181	DD5P28	853	*	13	----	----	1	38
3182	DD5P29	861	*	13	----	----	1	38
3183	DD5P30	825	*	13	----	----	1	38
3184	DD5P31	824	*	13	----	----	1	32
3185	DD5P32	843	*	13	----	----	1	32
3186	DD5P33	840	*	13	----	----	1	32
3187	DD5P13	852	*	13	----	----	1	25
3188	DD5P14	774	*	13	----	----	1	25
3189	DD5P15	825	*	13	----	----	1	25
3190	DD5P037	787	*	13	----	----	1	19
3191	DD5P038	814	*	13	----	----	1	19
3192	DD5P039	792	*	13	----	----	1	19
3193	DD5P040	737	*	13	----	----	1	13

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
3194	DD5P041	792	*	13	----	----	1	13
3195	DD5P042	683	*	13	----	----	1	13
3196	DD5P043	536	*	13	----	----	1	6
3197	DD5P044	526	*	13	----	----	1	6
3198	DD5P045	537	*	13	----	----	1	6
3244	DD5P17	-502	*	0.0025	----	----	1	25
3245	DD5P18	-492	*	0.0025	----	----	1	25
3246	DD5P19	-497	*	0.0025	----	----	1	25
3247	DD5P40	-582	*	0.025	----	----	1	25
3248	DD5P41	-591	*	0.025	----	----	1	25
3249	DD5P42	-528	*	0.025	----	----	1	25
3250	DD5P43	-626	*	0.25	----	----	1	25
3251	DD5P44	-592	*	0.25	----	----	1	25
3252	DD5P45	-547	*	0.25	----	----	1	25
3253	DD5P46	-585	*	1.27	----	----	1	25
3254	DD5P47	-578	*	1.27	----	----	1	25
3255	DD5P48	-577	*	1.27	----	----	1	25
3256	DD5P49	-588	*	2.54	----	----	1	25
3257	DD5P50	-628	*	2.54	----	----	1	25
3258	DD5P51	-581	*	2.54	----	----	1	25
3259	DD5P52	-653	*	6.35	----	----	1	25
3260	DD5P53	-624	*	6.35	----	----	1	25
3261	DD5P54	-674	*	6.35	----	----	1	25
3262	DD5P55	-671	*	13	----	----	1	25
3263	DD5P56	-662	*	13	----	----	1	25
3264	DD5P57	-656	*	13	----	----	1	25
3265	DD5P58	-697	*	19	----	----	1	25
3266	DD5P59	-689	*	19	----	----	1	25
3267	DD5P60	-676	*	19	----	----	1	25
3268	DD5P61	-678	*	25	----	----	1	25
3269	DD5P62	-692	*	25	----	----	1	25
3270	DD5P63	-675	*	25	----	----	1	25
3271	DD5P64	-692	*	64	----	----	1	25
3272	DD5P65	-671	*	64	----	----	1	25
3273	DD5P66	-709	*	64	----	----	1	25
3274	DD5P67	-697	*	127	----	----	1	25
3275	DD5P68	-704	*	127	----	----	1	25
3276	DD5P69	-665	*	127	----	----	1	25
3277	DD5P1	552	*	0.0025	----	----	1	25
3278	DD5P2	592	*	0.0025	----	----	1	25
3279	DD5P3	585	*	0.0025	----	----	1	25
3280	DD5P4	624	*	0.025	----	----	1	25
3281	DD5P5	614	*	0.025	----	----	1	25
3282	DD5P6	610	*	0.025	----	----	1	25
3283	DD5P7	730	*	0.25	----	----	1	25
3284	DD5P8	722	*	0.25	----	----	1	25
3285	DD5P9	705	*	0.25	----	----	1	25
3286	DD5P10	748	*	2.54	----	----	1	25

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
3287	DD5P11	736	*	2.54	----	----	1	25
3288	DD5P12	757	*	2.54	----	----	1	25
3289	DD5P13	852	*	13	----	----	1	25
3290	DD5P14	834	*	13	----	----	1	25
3291	DD5P15	825	*	13	----	----	1	25
3292	DD5P16	763	*	25	----	----	1	25
3293	DD5P17	778	*	25	----	----	1	25
3294	DD5P18	841	*	25	----	----	1	25
3295	DD5P19	810	*	64	----	----	1	25
3296	DD5P20	919	*	64	----	----	1	25
3297	DD5P21	876	*	64	----	----	1	25
3298	DD5P22	916	*	127	----	----	1	25
3299	DD5P23	903	*	127	----	----	1	25
3300	DD5P24	895	*	127	----	----	1	25
3455	DD5P550	414	0.1	2	26.7	1.58	8,157	22
3456	DD5P520	414	0.1	2	26.6	1.64	12,185	22
3457	DD5P524	414	0.1	2	23.6	1.70	11,533	22
3458	DD5P511	414	0.1	2	23.6	1.71	6,716	22
3459	DD5P555	414	0.1	2	24.2	1.72	12,041	22
3460	DD5P510	414	0.1	2	26.0	1.61	7,640	22
3461	DD5P501	414	0.1	2	23.5	1.67	11,085	22
3462	DD5P551	414	0.1	2	25.3	1.65	9,930	22
3463	DD5P533	414	0.1	2	25.3	1.66	9,191	22
3464	DD5P517	414	0.1	2	24.2	1.73	9,067	22
3465	DD5P542	310	0.1	10	25.9	1.26	514,201	22
3466	DD5P508	310	0.1	10	23.1	1.28	285,386	22
3467	DD5P521	310	0.1	10	23.6	1.22	351,717	22
3468	DD5P560	310	0.1	10	24.0	1.31	345,652	22
3469	DD5P519	310	0.1	10	24.3	1.34	749,084	22
3470	DD5P544	310	0.1	10	24.3	1.28	579,002	22 tab
3471	DD5P504	414	0.1	2	23.5	1.69	9,912	22 tab
3472	DD5P564	414	0.1	2	----	----	16,271	22 tab
3473	DD5P503	414	0.1	2	----	----	5,305	22 tab
3474	DD5P515	414	0.1	2	----	----	10,499	22 tab
3475	DD5P525	310	0.1	10	----	----	342,738	22 tab
3476	DD5P540	310	0.1	10	----	----	228,420	22 tab
3477	DD5P506	310	0.1	10	----	----	376,933	22 tab
3478	DD5P541	414	0.1	2	----	----	8,883	22 tab
3479	DD5P502	310	0.1	10	24.6	1.30	403,000	22 tab
3498	DD5P605	241	0.1	30	----	----	2,820,426	8 tab
3499	DD5P601	207	0.1	40	----	0.89	10,027,337	8 tab
3500	DD5P602	241	0.1	20	----	----	1,548,025	8 tab
3501	DD5P601	241	0.1	25	----	----	348,666	8 tab
3502	DD5P606	241	0.1	20	----	----	1,016,251	8 tab
3503	DD5P614	241	0.1	25	23.6	1.04	2,312,896	8 tab
3525	DD5P612	207	0.1	40	----	0.91	22,002,386	8 tab
3525	DD5P603	193	0.1	45	23.6	0.82	39,082,107	8 tab
3526	DD5P610	414	0.1	2	----	----	8,123	8 tab

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
3527	DD5P604	414	0.1	2	----	----	18,264	8 tab
3528	DD5P613	414	0.1	2	----	----	8,358	8 tab
3529	DD5P643	241	0.1	10	----	----	2,668,144	8 tab
3532	DD5P628	241	0.1	10	----	----	2,823,516	8 tab
3533	DD5P599	241	0.1	10	----	----	3,554,421	8 tab
3534	DD5P635	310	0.1	10	----	----	594,298	8 tab
3535	DD5P634	310	0.1	10	----	----	537,593	8 tab
3536	DD5P631	310	0.1	10	----	----	252,317	8 tab
3537	DD5P637	310	0.1	10	----	----	296,456	8 tab
3538	DD5P636	310	0.1	10	----	----	275,551	8 tab
3539	DD5P627	310	0.1	10	----	----	261,531	8 tab
3540	DD5P638	310	0.1	5	----	----	379,674	8 tab
3541	DD5P629	310	0.1	5	----	----	240,098	8 tab
3542	DD5P642	310	0.1	5	----	----	458,684	8 tab
3543	DD5P570	310	0.1	2	----	----	304,764	8 tab
3544	DD5P571	310	0.1	2	----	----	227,372	8 tab
3545	DD5P563	310	0.1	2	----	----	247,249	8 tab
3546	DD5P633	310	0.1	20	----	----	404,285	8 tab
3547	DD5P622	310	0.1	20	----	----	432,281	8 tab
3548	DD5P630	310	0.1	20	----	----	731,478	8 tab
3549	DD5P620	310	0.1	2	----	----	196,929	8 tab
3550	DD5P623	310	0.1	30	----	----	59,971	8 tab
3554	DD5P509	310	0.1	1	25.6	1.21	284,133	22 tab
3555	DD5P580	310	0.1	1	----	----	213,190	22 tab
3556	DD5P581	310	0.1	1	----	----	198,210	22 tab
3850	DD5P624T	-145	*	13	----	----	1	25
3851	DD5P633T	-142	*	13	----	----	1	25
3852	DD5P625T	-158	*	13	----	----	1	25
3853	DD5P601T	66.8	*	13	9.21	1.33	1	25
3854	DD5P602T	65.3	*	13	8.84	1.28	1	25
3855	DD5P603T	66.2	*	13	9.31	1.35	1	25
3856	DD5P604T	24.1	0.1	10	8.46	0.29	3,846,149	25
3857	DD5P605T	31.0	0.1	5	8.62	0.45	160,829	25
3858	DD5P606T	31.0	0.1	5	8.33	0.48	84,821	25
3859	DD5P607T	34.5	0.1	5	9.20	0.57	39,239	25
3860	DD5P608T	31.0	0.1	5	8.61	0.50	105,856	25
3861	DD5P609T	27.6	0.1	5	8.33	0.33	329,077	25
3862	DD5P610T	34.5	0.1	5	8.67	0.54	25,383	25
3863	DD5P611T	34.5	0.1	5	8.63	0.65	39,867	25
3864	DD5P617T	37.9	0.1	2	8.73	1.10	4,765	25
3865	DD5P612T	37.9	0.1	2	9.05	1.09	10,816	25
3866	DD5P615T	41.4	0.1	2	8.93	1.25	7,778	25
3867	DD5P614T	27.6	0.1	5	9.37	0.32	4,025,994	25
3868	DD5P616T	27.6	0.1	7	8.84	0.34	930,682	25
3869	DD5P613T	37.9	0.1	4	8.40	----	9,712	25

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes

MATERIAL DD5V

Layup = $[0/\pm45/0]_S$, V_F = 0.36, Ave. thickness = 3.05 mm, S.D. = 0.09 mm, Vinyl ester

1856	DD5V311	688	*	13	23.4	3.00	1	22
1857	DD5V308	672	*	13	22.5	3.39	1	22
1858	DD5V303	664	*	13	21.7	2.68	1	22
1862	DD5V309	483	0.1	2	22.5	2.30	283	22
1863	DD5V306	414	0.1	4	22.1	1.89	5,751	22
1864	DD5V301	414	0.1	2	28.3	1.66	8,529	22
1865	DD5V302	276	0.1	10	25.8	1.08	392,541	22
1866	DD5V312	345	0.1	5	22.9	1.56	54,570	22
1867	DD5V313	345	0.1	5	24.3	1.46	68,513	22
1868	DD5V314	345	0.1	5	24.2	1.52	58,782	22
1869	DD5V310	241	0.1	15	23.4	1.02	3,673,144	22
1870	DD5V350	276	0.1	5	23.0	1.30	618,125	22
1934	DD5V315	-519	*	13	----	----	1	25
1935	DD5V318	-533	*	13	----	----	1	25
1936	DD5V316	-538	*	13	----	----	1	25
1944	DD5V329	-414	10	5	----	----	9,981	25
1945	DD5V317	-414	10	4	----	----	18,310	25
1946	DD5V327	-414	10	5	----	----	11,920	25
1947	DD5V325	-345	10	10	----	----	1,462,167	25
1948	DD5V325	-345	10	20	----	----	943,258	25
1949	DD5V319	-379	10	5	----	----	179,421	25
1950	DD5V324	-379	10	5	----	----	84,516	25
1951	DD5V322	-379	10	5	----	----	73,591	25
1952	DD5V321	-379	10	5	----	----	107,610	25
1972	DD5V304	345	0.1	5	23.9	1.44	42,916	22 tab

MATERIAL DD6

Layup = $[0/\pm45/0]_S$, V_F = 0.31, Ave. thickness = 3.53 mm, S.D. = 0.05 mm, Polyester

1095	DD6116	602	*	13	20.9	2.88	1	22
1096	DD6104	609	*	13	22.6	2.69	1	22
1097	DD6106	603	*	13	23.8	2.53	1	22
1098	DD6101	414	0.1	5	22.3	1.85	928	22
1099	DD6108	414	0.1	2	21.4	1.94	841	22
1100	DD6111	414	0.1	2	19.8	2.09	1,302	22
1101	DD6113	345	0.1	5	19.3	1.79	17,421	22
1102	DD6103	345	0.1	10	19.5	1.76	26,109	22
1103	DD6112	345	0.1	10	19.2	1.79	18,696	22
1104	DD6102	276	0.1	15	21.5	1.28	193,637	22
1105	DD6110	276	0.1	10	20.4	1.35	406,267	22
1106	DD6107	276	0.1	15	22.7	1.22	300,000	22R
1121	DD6121	-447	*	13	----	----	1	25
1122	DD6150	-448	*	13	----	----	1	25
1126	DD6126	-447	*	13	----	----	1	25

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
1127	DD6143	-448	*	13	----	----	1	25
1128	DD6130	-449	*	13	----	----	1	25
1129	DD6128	-460	*	13	----	----	1	25
1140	DD6118	-276	10	15	----	----	1,918,022	25
1142	DD6125	-276	10	20	----	----	1,223,779	25
1145	DD6124	-345	10	10	----	----	54,759	25
1146	DD6123	-345	10	15	----	----	35,062	25
1153	DD6109	-379	10	10	----	----	15,355	25
1154	DD6114	-379	10	10	----	----	10,750	25
1158	DD6133	-345	10	10	----	----	42,786	25
1159	DD6132	-310	10	15	----	----	423,811	25
1160	DD6105	-379	10	5	----	----	9,779	25
1161	DD6131	-310	10	15	----	----	324,531	25
1166	DD6141	-475	*	13	----	----	1	25
1167	DD6139	-310	10	20	----	----	284,644	25
1170	DD6115	-276	10	20	----	----	2,012,851	25
1171	DD6130	-414	10	4	----	----	1,883	25
1172	DD6148	-414	10	4	----	----	2,341	25
1300	DD6143	-510	*	13	----	----	1	25
1301	DD6145	-529	*	13	----	----	1	25

MATERIAL DD7

Layup = $[0/\pm45/0]_S$, V_F = 0.54, Ave. thickness = 2.11 mm, S.D. = 0.06 mm, Polyester

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
1107	DD7105	837	*	13	36.5	2.80	1	22
1108	DD7113	824	*	13	30.7	2.69	1	22
1109	DD7107	826	*	13	30.3	2.73	1	22
1110	DD7112	839	*	13	32.4	2.59	1	22
1111	DD7108	483	0.1	2	32.5	1.48	978	22
1112	DD7103	483	0.1	2	32.4	1.52	784	22
1113	DD7111	414	0.1	5	28.9	1.43	3,379	22
1114	DD7110	414	0.1	5	----	----	2,916	22
1115	DD7106	345	0.1	10	----	----	9,304	22
1116	DD7109	345	0.1	10	----	----	14,481	22
1117	DD7104	276	0.1	10	----	----	29,331	22
1118	DD7114	276	0.1	10	----	----	25,746	22
1119	DD7102	207	0.1	20	----	----	127,887	22
1120	DD7115	207	0.1	20	----	----	94,292	22
1143	DD7131	-276	10	20	----	----	2,761,322	25
1144	DD7129	-310	10	20	----	----	4,919,032	25
1147	DD7124	-577	*	13	----	----	1	25
1148	DD7133	-605	*	13	----	----	1	25
1149	DD7118	-562	*	13	----	----	1	25
1155	DD7101	-379	10	10	----	----	45,445	25
1156	DD7131	-379	10	10	----	----	66,177	25
1157	DD7132	-379	10	10	----	----	52,848	25
1163	DD7122	-345	10	10	----	----	928,436	25

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
1164	DD7128	-345	10	15	----	----	511,438	25
1165	DD7133	-448	10	4	----	----	843	25
1168	DD7140	-345	10	20	----	----	781,113	25
1169	DD7130	-448	10	4	----	----	1,307	25
1173	DD7117	-414	10	5	----	----	10,902	25
1174	DD7119	-414	10	5	----	----	8,454	25
1175	DD7137	-310	10	20	----	----	5,322,151	25

MATERIAL DD8

Layup = $[0/\pm45/0]_S$, V_F = 0.42, Ave. thickness = 2.67 mm, S.D. = 0.06 mm, Polyester

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
1204	DD8105	483	0.1	4	----	----	12,460	22
1206	DD8106	483	0.1	4	----	----	7,139	22
1207	DD8109	414	0.1	10	22.0	1.88	63,076	22
1209	DD8102	414	0.1	10	----	----	46,816	22
1210	DD8101	345	0.1	10	----	----	298,339	22
1211	DD8111	345	0.1	15	----	----	567,522	22
1212	DD8103	483	0.1	4	22.9	1.31	5,846	22
1213	DD8104	276	0.1	15	----	----	33,425	22R
1214	DD8121	345	0.1	10	----	----	462,481	22
1215	DD8108	741	*	13	30.3	2.44	1	22
1216	DD8115	698	*	13	30.8	2.27	1	22
1217	DD8120	818	*	13	28.3	2.33	1	22
1218	DD8117	856	*	13	28.1	2.44	1	22
1833	DD8112	-587	*	13	----	----	1	25
1834	DD8143	-576	*	13	----	----	1	25

MATERIAL DD9

Layup = $[0/\pm45/0]_S$, V_F = 0.54, Ave. thickness = 2.03 mm, S.D. = 0.04 mm, Polyester

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
1219	DD9101	414	0.1	10	34.5	1.20	8,603	22
1220	DD9109	483	0.1	5	33.9	1.42	2,695	22
1221	DD9116	414	0.1	5	33.8	1.23	6,359	22
1223	DD9103	345	0.1	10	33.2	1.04	29,276	22
1224	DD9104	207	0.1	15	34.6	0.60	432,809	22
1226	DD9107	944	*	13	----	----	1	22
1227	DD9109	903	*	13	----	----	1	22
1228	DD9110	873	*	13	----	----	1	22
1229	DD9114	483	0.1	4	35.6	1.36	3,294	22
1230	DD9113	345	0.1	10	36.8	0.93	38,377	22
1231	DD9106	276	0.1	10	----	----	94,262	22
1232	DD9113	207	0.1	10	----	----	432,480	22
1830	DD9200	-513	*	13	----	----	1	25
1831	DD9202	-603	*	13	----	----	1	25
1832	DD9201	-552	*	13	----	----	1	25

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes

MATERIAL DD10

Layup = $[0/\pm45/0]_S$, V_F = 0.62, Ave. thickness = 1.73 mm, S.D. = 0.08 mm, Polyester

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
2820	DD10110	1,045	*	13	42.8	2.45	1	22
2821	DD10109	888	*	13	42.6	2.08	1	22
2822	DD10108	935	*	13	39.1	2.40	1	22
2823	DD10107	483	0.1	4	43.0	1.12	3,132	22
2824	DD10105	483	0.1	4	40.0	1.20	2,128	22
2825	DD10102	414	0.1	5	42.6	1.18	7,291	22
2826	DD10101	414	0.1	5	43.7	1.11	11,251	22
2827	DD10103	276	0.1	10	43.7	0.59	72,116	22
2828	DD10104	276	0.1	10	43.2	0.66	94,297	22
2829	DD10106	276	0.1	10	44.6	0.64	152,411	22
2866	DD10127	-525	*	13	----	----	1	25
2867	DD10121	-557	*	13	----	----	1	25
2868	DD10125	-607	*	13	----	----	1	25
2869	DD10124	-362	10	20	----	----	10,000,000	25 R
2870	DD10122	-414	10	2	----	----	266	25
2871	DD10123	-379	10	12	----	----	798,311	25
2872	DD10128	-379	10	12	----	----	576,424	25
2873	DD10126	-379	10	12	----	----	1,678,467	25
2874	DD10130	-518	*	13	----	----	1	25
2875	DD10131	-553	*	13	----	----	1	25
2963	DD10401	-379	10	12	----	----	844,707	has stitch
2964	DD10402	-379	10	12	----	----	553,651	has stitch

MATERIAL DD11

Layup = $[0/\pm45/0]_S$, V_F = 0.31, Ave. thickness = 3.19 mm, S.D. = 0.07 mm, Polyester

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
2853	DD11101	543	*	13	20.1	2.70	1	22
2854	DD11110	642	*	13	19.3	3.20	1	22
2855	DD11102	589	*	13	18.8	3.13	1	22
2856	DD11103	276	0.1	5	21.7	1.28	328,394	22
2857	DD11104	276	0.1	5	20.0	1.45	144,473	22
2858	DD11105	414	0.1	1	19.9	2.08	602	22
2859	DD11107	414	0.1	1	17.4	2.40	859	22
2860	DD11108	414	0.1	1	21.0	2.00	359	22
2861	DD11109	345	0.1	2	19.0	1.90	5,733	22
2862	DD11106	345	0.1	2	20.3	1.78	4,560	22
2863	DD11114	241	0.1	12	20.7	1.20	3,880,803	22
2864	DD11111	276	0.1	5	20.1	1.38	109,080	22
2865	DD11118	345	0.1	2	20.8	1.75	3,741	22
2876	DD11128	-331	*	13	----	----	1	25
2877	DD11129	-314	*	13	----	----	1	25
2878	DD11120	-310	*	13	----	----	1	25
2879	DD11125	-241	10	1	----	----	189	25
2880	DD11127	-207	10	2	----	----	2,411	25

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
2881	DD11122	-207	10	2	----	----	1,882	25
2882	DD11121	-207	10	2	----	----	1,530	25
2883	DD11124	-172	10	10	----	----	137,454	25
2884	DD11126	-172	10	10	----	----	87,211	25
2885	DD11123	-172	10	10	----	----	123,600	25
2886	DD11131	-155	10	12	----	----	356,114	25

MATERIAL DD11A

Layup = $(\pm45/0_4/\mp45)$, V_F = 0.31, Ave. thickness = 3.38 mm, S.D. = 0.14 mm, Polyester

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
2953	DD11A102	-309	*	13	----	----	1	25
2954	DD11A101	-413	*	13	----	----	1	25
2955	DD11A106	-327	*	13	----	----	1	25
3931	DD11A112	629	*	13	18.3	3.40	1	25
3932	DD11A110	595	*	13	20.4	2.93	1	25
3933	DD11A111	589	*	13	19.9	3.03	1	25

MATERIAL DD12

Layup = $[0/\pm45/0]_S$, V_F = 0.43, Ave. thickness = 2.40 mm, S.D. = 0.11 mm, Polyester

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
2842	DD12108	708	*	13	26.0	2.71	1	22
2843	DD12110	731	*	13	26.7	2.73	1	22
2844	DD12112	729	*	13	26.7	2.74	1	22
2845	DD12103	414	0.1	2	26.4	1.53	4,967	22
2846	DD12107	276	0.1	12	29.3	0.94	272,993	22
2847	DD12109	276	0.1	12	24.6	1.12	252,590	22
2848	DD12104	241	0.1	12	26.3	0.90	721,943	22
2849	DD12111	345	0.1	5	24.7	1.46	27,280	22
2850	DD12106	345	0.1	5	25.8	1.42	55,126	22
2851	DD12105	345	0.1	5	26.6	1.49	50,100	22
2852	DD12101	276	0.1	5	27.0	1.05	199,436	22
2897	DD12132	-339	*	13	----	----	1	25
2898	DD12131	-273	*	13	----	----	1	25
2899	DD12130	-293	*	13	----	----	1	25

MATERIAL DD13

Layup = $[0/\pm45/0]_S$, V_F = 0.50, Ave. thickness = 2.13 mm, S.D. = 0.12 mm, Polyester

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
2830	DD13111	855	*	13	29.6	2.89	1	22
2831	DD13110	799	*	13	30.4	2.63	1	22
2832	DD13113	809	*	13	32.9	2.56	1	22
2833	DD13101	414	0.1	4	26.2	1.60	5,769	22
2834	DD13102	414	0.1	4	29.0	1.39	7,805	22
2835	DD13107	345	0.1	5	29.3	1.26	17,253	22
2836	DD13108	207	0.1	12	27.6	0.77	1,397,049	22
2837	DD13106	345	0.1	5	31.2	1.15	28,437	22
2838	DD13105	345	0.1	5	26.9	1.49	19,323	22

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
2839	DD13113	276	0.1	10	28.9	0.97	145,120	22
2840	DD13114	276	0.1	10	30.2	0.91	85,412	22
2841	DD13115	276	0.1	10	31.7	0.89	124,822	22
2887	DD13129	-319	*	13	----	----	1	25
2888	DD13122	-311	*	13	----	----	1	25
2889	DD13124	-312	*	13	----	----	1	25
2890	DD13130	-207	10	2	----	----	1,870	25
2891	DD13123	-207	10	2	----	----	9,529	25
2892	DD13127	-207	10	2	----	----	4,017	25
2893	DD13120	-172	10	10	----	----	59,117	25
2894	DD13131	-172	10	10	----	----	35,801	25
2895	DD13128	-172	10	12	----	----	45,057	25
2896	DD13126	-155	10	10	----	----	443,122	25

MATERIAL DD14

Layup = $[0/\pm45/0]_S$, V_F = 0.25, Ave. thickness = 3.13 mm, S.D. = 0.18 mm, Polyester

2956	DD14301	-452	*	13	----	----	1	25
2957	DD14303	-385	*	13	----	----	1	25
2958	DD14302	-447	*	13	----	----	1	25

MATERIAL DD15

Layup = $[0/\pm45/0]_S$, V_F = 0.35, Ave. thickness = 2.71 mm, S.D. = 0.07 mm, Polyester

2959	DD15302	-435	*	13	----	----	1	25
2960	DD15301	-411	*	13	----	----	1	25
2961	DD15303	-471	*	13	----	----	1	25

MATERIAL DD16

Layup = $[90/0/\pm45/0]_S$, V_F = 0.36, Ave. thickness = 4.62 mm, S.D. = 0.07 mm, Polyester

3650	DD16102	414	0.1	2	17.1	1.83	32,965	25
3654	DD16108	310	0.1	10	18.1	1.26	844,744	25
3655	DD16101	310	0.1	10	18.9	1.24	274,618	25
3656	DD16103	310	0.1	10	18.2	1.27	658,704	25
3657	DD16106	310	0.1	10	18.6	1.30	523,116	25
3690	DD16200	310	0.1	10	----	----	560,000	25 R
3691	DD16202	310	0.1	10	----	----	396,989	25
3832	DD16150	-266	*	13	----	----	1	25
3833	DD16151	-282	*	13	----	----	1	25
3834	DD16152	-309	*	13	----	----	1	25

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes

MATERIAL DD17

Layup = $[0/\pm45/0]_S$, V_F = 0.36, 0.52 , Ave. thickness = 2.90 mm, 2.09 mm (indentation) S.D. = 0.05 mm, 0.07 mm (indentation), Polyester, This material has a surface indentation to raise the V_F.

3694	DD17104	414	0.1	2	----	----	1,317	25 tab
3696	DD17106	414	0.1	2	----	----	1,210	25 tab
3697	DD17107	414	0.1	2	----	----	8,591	25 tab
3698	DD17108	414	0.1	2	----	----	7,151	25 tab
3699	DD17109	155	0.1	10	----	----	198,817	25 tab
3700	DD17110	103	0.1	12	----	----	889,958	25 tab
3701	DD17111	103	0.1	12	----	----	2,048,532	25 tab
3702	DD17112	155	0.1	12	----	----	218,200	25 tab
3703	DD17101	787	*	13	----	----	1	25 tab
3704	DD17102	784	*	13	----	----	1	25 tab
3705	DD17103	775	*	13	----	----	1	25 tab
3706	DD17118	155	0.1	10	----	----	225,558	25 tab
3707	DD17118	310	0.1	2	----	----	5,342	25 tab

MATERIAL DD17A

Layup = $[0/\pm45/0]_S$, V_F = 0.35, 0.42, Ave. thickness = 2.83 mm, 2.30 mm (indentation) S.D. = 0.15 mm, 0.06 mm (indentation), Polyester, This material has a surface indentation to raise the V_F.

3875	DD17A127	414	0.1	2	24.3	1.87	870	25
3876	DD17A106	414	0.1	2	24.5	1.88	993	25
3877	DD17A116	414	0.1	2	22.5	2.10	440	25R
3878	DD17A112	345	0.1	4	23.1	1.65	1,637	25
3879	DD17A103	345	0.1	4	26.1	1.52	7,677	25
3880	DD17A113	345	0.1	4	23.2	1.60	3,156	25
3881	DD17A102	345	0.1	4	23.8	1.52	2,866	25
3882	DD17A109	276	0.1	5	22.4	1.30	23,820	25
3883	DD17A101	276	0.1	4	22.1	1.33	52,327	25
3884	DD17A107	276	0.1	4	22.1	1.29	15,558	25
3885	DD17A111	207	0.1	5	23.2	0.97	385,099	25
3886	DD17A128	207	0.1	5	24.3	0.92	186,232	25
3887	DD17A110	207	0.1	5	22.6	0.96	119,502	25
3888	DD17A122	207	0.1	5	25.5	0.97	170,000	25R
3889	DD17A125	681	*	13	23.2	3.05	1	25
3890	DD17A121	621	*	13	22.5	3.01	1	25
3891	DD17A120	636	*	13	24.3	2.92	1	25
3892	DD17A123	207	0.1	5	23.0	0.96	584,702	25 tab
3893	DD17A104	276	0.1	2	25.2	1.18	65,356	25 tab
3894	DD17A108	190	0.1	8	22.6	0.86	843,279	25 tab
3895	DD17A119	190	0.1	8	21.1	0.94	510,998	25 tab
3896	DD17A117	172	0.1	8	22.9	0.80	6,125,824	25 tab
3897	DD17A115	345	0.1	2	24.3	1.64	2,414	25 tab
3898	DD17A126	345	0.1	3	22.5	1.70	12,349	25 tab
3899	DD17A114	276	0.1	4	23.6	1.20	43,591	25 tab

TEST #	SAMPLE ID #	MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes

MATERIAL DD18

Layup = $[0/\pm45/0]_S$, V_F = 0.34, 0.40, Ave. thickness = 3.35 mm, S.D. = 0.07 mm, Polyester
This material has a mid-laminate 90 degree D155 ply, 4 mm wide, to locally raise the V_F.

TEST #	SAMPLE ID #	MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
3722	DD18107	241	0.1	10	21.2	1.12	268,555	25
3723	DD18112	241	0.1	10	22.5	1.15	328,011	25
3724	DD18111	241	0.1	10	21.5	1.24	463,110	25
3725	DD18110	414	0.1	2	24.6	1.91	12,899	25
3726	DD18109	414	0.1	2	22.8	1.99	10,402	25
3727	DD18108	414	0.1	2	22.9	2.05	8,310	25
3728	DD18105	345	0.1	5	23.0	1.66	49,566	25
3729	DD18104	345	0.1	5	23.7	1.47	25,373	25
3730	DD18106	345	0.1	5	22.1	1.48	45,228	25
3731	DD18103	754	*	13	22.3	3.40	1	25
3732	DD18102	708	*	13	21.8	3.30	1	25
3733	DD18101	727	*	13	22.2	----	1	25
3734	DD18140	207	0.1	12	23.3	0.90	2,661,881	25
3835	DD18150	-575	*	13	----	----	1	25
3836	DD18151	-466	*	13	----	----	1	25
3837	DD18152	-484	*	13	----	----	1	25

MATERIAL DD18A

Layup = $[0/\pm45/0]_S$, V_F = 0.36, 0.43, Ave. thickness = 2.78 mm, S.D. = 0.08 mm, Polyester
This material has a mid-laminate 90 degree D155 ply, 4 mm wide, to locally raise the V_F.

TEST #	SAMPLE ID #	MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
3900	DD18A115	190	0.1	10	21.0	0.95	1,750,000	25 tab
3901	DD18A112	414	0.1	2	22.2	2.13	913	25 tab
3902	DD18A101	345	0.1	4	21.5	1.79	5,846	25 tab
3903	DD18A108	276	0.1	5	23.1	1.18	78,800	25 tab
3904	DD18A104	414	0.1	2	22.6	1.96	1,508	25 tab
3905	DD18A113	414	0.1	2	21.7	2.00	815	25 tab
3906	DD18A106	207	0.1	8	22.0	1.15	654,689	25 tab
3907	DD18A110	345	0.1	4	22.3	1.67	3,418	25 tab
3908	DD18A114	345	0.1	3	24.3	1.55	8,292	25 tab
3909	DD18A105	276	0.1	5	24.4	1.22	65,338	25 tab
3910	DD18A103	276	0.1	5	22.5	1.29	67,612	25 tab
3911	DD18A102	207	0.1	8	23.2	0.99	3,000,000	25 R tab
3913	DD18A150	716	*	13	23.1	3.20	1	25 tab
3914	DD18A151	716	*	13	23.3	3.07	1	25 tab
3915	DD18A152	667	*	13	23.3	3.06	1	25 tab

MATERIAL DD19

Layup = $[0/\pm45/0]_S$, V_F = 0.34, 0.47, Ave. thickness = 3.39 mm, S.D. = 0.11 mm, Polyester
This material has two mid-laminate 90 degree plies, 4 mm wide, to locally raise the V_F.

TEST #	SAMPLE ID #	MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
3710	DD19107	414	0.1	2	22.0	2.17	2,235	25
3711	DD19106	241	0.1	8	21.8	1.23	57,266	25
3712	DD19109	241	0.1	5	21.4	1.24	92,441	25

TEST #	SAMPLE ID #	MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
3713	DD19108	241	0.1	5	21.8	1.20	77,008	25
3714	DD19111	155	0.1	12	22.6	0.75	1,354,001	25
3715	DD19110	155	0.1	12	24.3	0.68	955,238	25
3716	DD19101	155	0.1	12	20.5	0.83	3,104,534	25
3717	DD19112	345	0.1	2	----	----	9,055	25
3718	DD19119	345	0.1	1	----	----	8,722	25
3719	DD19105	716	*	13	21.2	----	1	25
3720	DD19104	706	*	13	21.5	----	1	25
3721	DD19103	707	*	13	22.4	----	1	25
3838	DD19120	-400	*	13	----	----	1	25
3839	DD19121	-332	*	13	----	----	1	25
3840	DD19126	-392	*	13	----	----	1	25

MATERIAL DD19A

Layup = $[0/\pm45/0]_S$, V_F = 0.36, 0.50, Ave. thickness = 2.78 mm, S.D. = 0.03 mm, Polyester
This material has two mid-laminate 90 degree plies, 4 mm wide, to locally raise the V_F.

TEST #	SAMPLE ID #	MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
3916	DD19A140	207	0.1	7	23.7	0.88	31,090	25 tab
3917	DD19A117	138	0.1	6	23.9	0.58	1,250,000	25 R tab
3918	DD19A118	345	0.1	2	24.0	1.50	877	25 tab
3919	DD19A106	345	0.1	2	24.6	1.61	1,088	25 tab
3920	DD19A128	345	0.1	2	21.9	1.69	1,590	25 tab
3921	DD19A127	276	0.1	4	22.4	1.34	8,594	25 tab
3922	DD19A121	276	0.1	4	22.8	1.35	31,283	25 tab
3923	DD19A122	276	0.1	5	23.5	1.36	11,012	25 tab
3924	DD19A111	207	0.1	7	23.4	0.96	108,773	25 tab
3925	DD19A116	207	0.1	7	22.2	1.11	72,092	25 tab
3926	DD19A119	172	0.1	8	23.9	0.83		25 tab
3927	DD19A110	646	*	13	23.3	3.01	1	25 tab
3928	DD19A114	647	*	13	21.8	3.18	1	25 tab
3929	DD19A115	661	*	13	22.6	22.6	1	25 tab

MATERIAL FFA

Layup = $[\pm45/0/0/\pm45]_S$, V_F =0.38, Ave. thickness = 3.78 mm, S.D. = 0.07 mm, Polyester

TEST #	SAMPLE ID #	MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
3337	FFA104	721	*	13	24.3	3.00	1	25
3338	FFA112	717	*	13	23.6	3.03	1	25
3339	FFA106	710	*	13	24.8	2.90	1	25
3340	FFA109	414	0.1	2	23.6	1.98	1,832	25
3341	FFA102	414	0.1	2	23.8	2.14	757	25
3342	FFA114	414	0.1	2	25.0	2.05	926	25
3343	FFA111	345	0.1	4	24.9	1.63	4,233	25
3344	FFA118	276	0.1	4	25.9	1.21	30,201	25
3345	FFA115	345	0.1	2	24.8	1.63	4,642	25
3346	FFA107	276	0.1	4	24.3	1.29	37,675	25
3347	FFA113	345	0.1	2	24.9	1.63	2,420	25
3348	FFA105	276	0.1	4	23.6	1.28	18,064	25
3349	FFA103	172	0.1	10	23.9	0.78	10,000,000	25R

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	ε %	CYCLES TO FAIL	WIDTH (mm) and Notes
3350	FFA110	207	0.1	10	23.7	0.93	1,123,713	25
3351	FFA116	207	0.1	12	23.7	0.99	372,007	25
3352	FFA117	207	0.1	12	22.8	1.02	612,692	25
3370	FFA153	207	0.1	12	----	----	926,563	25
3371	FFA108	345	0.1	2	----	----	2,039	25
3373	FFA160	207	0.1	20	----	----	42,809	25
3374	FFA155	345	0.1	20	----	----	820	25
3375	FFA152	276	0.1	20	----	----	5,899	25
3376	FFA151	172	0.1	20	----	----	157,623	25
3377	FFA154	138	0.1	20	----	----	5,000,000	25
3424	FFA150	-557	*	13	----	----	1	25
3425	FFA152	-558	*	13	----	----	1	25
3426	FFA151	-544	*	13	----	----	1	25

MATERIAL FFB

Layup = $[0/\pm45/0/\pm45/0]_S$, V_F =0.38, Ave. thickness = 3.81 mm, S.D. = 0.05 mm, Polyester

3353	FFB136	599	*	13	24.1	3	1	25
3354	FFB132	607	*	13	23.4	2.9	1	25
3355	FFB138	657	*	13	24.9	2.8	1	25
3356	FFB128	414	0.1	2	23.6	1.97	803	25
3357	FFB141	414	0.1	2	23.9	2.04	1,391	25
3358	FFB134	345	0.1	2	23.4	1.68	2,293	25
3359	FFB130	345	0.1	2	23.4	1.68	1.909	25
3360	FFB142	276	0.1	4	22.3	1.41	16,986	25
3361	FFB140	276	0.1	2	24.4	1.23	22,313	25
3362	FFB131	207	0.1	12	23.3	0.98	486,273	25
3363	FFB127	207	0.1	12	21.0	1.03	393,660	25
3364	FFB139	207	0.1	12	23.6	0.95	540,700	25
3365	FFB137	276	0.1	4	----	----	54,111	25
3366	FFB133	207	0.1	12	----	----	849,853	25
3367	FFB129	414	0.1	1	----	----	925	25
3368	FFB125	345	0.1	2	----	----	5,420	25
3369	FFB135	635	*	13	----	----	1	25
3427	FFB114	-517	*	13	----	----	1	25
3428	FFB109	-507	*	13	----	----	1	25
3429	FFB115	-495	*	13	----	----	1	25

MATERIAL FFC

Layup = $[0/\pm45/\pm45/0]_S$, V_F =0.38, Ave. thickness = 3.81 mm, S.D. = 0.05 mm, Polyester

3378	FFC117	648	*	13	23.6	2.90	1	25
3379	FFC111	620	*	13	----	----	1	25
3380	FFC104	604	*	13	----	----	1	25
3381	FFC114	414	0.1	1	23.1	2.00	508	25
3382	FFC110	414	0.1	1	----	----	692	25
3383	FFC107	345	0.1	2	22.6	1.71	1,621	25

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	ε %	CYCLES TO FAIL	WIDTH (mm) and Notes
3384	FFC108	345	0.1	2	----	----	3,371	25
3385	FFC109	276	0.1	4	----	----	31,551	25
3386	FFC118	276	0.1	4	----	----	24,762	25
3387	FFC103	414	0.1	1	----	----	788	25
3388	FFC115	345	0.1	2	----	----	2,895	25
3389	FFC105	276	0.1	4	----	----	27,395	25
3390	FFC101	207	0.1	12	----	----	417,819	25
3391	FFC112	207	0.1	12	----	----	414,180	25
3392	FFC113	207	0.1	21	22.4	0.93	649,406	25
3430	FFC134	-517	*	13	----	----	1	25
3431	FFC128	-476	*	13	----	----	1	25
3432	FFC136	-505	*	13	----	----	1	25

MATERIAL FFD

Layup = $[0/0/\pm45/\pm45]_S$, V_F =0.38, Ave. thickness = 3.83 mm, S.D. = 0.04 mm, Polyester

3393	FFD112	676	*	13	24.0	2.90	1	25
3394	FFD106	630	*	13	----	----	1	25
3395	FFD107	602	*	13	----	----	1	25
3396	FFD110	414	0.1	2	22.2	2.18	533	25
3397	FFD111	414	0.1	2	----	----	793	25
3398	FFD104	414	0.1	2	----	----	912	25
3399	FFD102	345	0.1	2	----	----	3,683	25
3400	FFD105	345	0.1	2	----	----	2,923	25
3401	FFD114	345	0.1	2	----	----	3,993	25
3402	FFD115	276	0.1	4	----	----	24,441	25
3403	FFD116	276	0.1	4	----	----	32,380	25
3404	FFD101	276	0.1	4	----	----	21,567	25
3405	FFD103	207	0.1	12	----	----	1,099,442	25
3406	FFD117	207	0.1	12	----	----	466,758	25
3407	FFD104	207	0.1	12	----	----	650,603	25
3433	FFD133	-547	*	13	----	----	1	25
3434	FFD141	-549	*	13	----	----	1	25
3435	FFD138	-530	*	13	----	----	1	25

MATERIAL FFF

Layup = $[\pm45/\pm45/0/0]_S$, V_F =0.38, Ave. thickness = 3.77 mm, S.D. = 0.05 mm, Polyester

3408	FFF110	640	*	13	----	----	1	25
3409	FFF106	643	*	13	----	----	1	25
3410	FFF122	708	*	13	----	----	1	25
3411	FFF108	414	0.1	1	----	----	683	25
3412	FFF107	414	0.1	1	----	----	810	25
3413	FFF114	414	0.1	2	----	----	1,587	25
3415	FFF112	345	0.1	2	----	----	7,694	25
3416	FFF117	345	0.1	2	----	----	5,602	25
3417	FFF113	345	0.1	2	----	----	8,381	25

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
3418	FFF115	276	0.1	4	----	----	30,596	25
3419	FFF109	276	0.1	5	----	----	30,569	25
3420	FFF132	276	0.1	5	----	----	26,561	25
3421	FFF116	207	0.1	12	----	----	374,533	25
3422	FFF111	207	0.1	12	----	----	665,573	25
3423	FFF143	207	0.1	20	----	----	684,496	25
3436	FFF125	-605	*	13	----	----	1	25
3437	FFF134	-627	*	13	----	----	1	25
3438	FFF129	-555	*	13	----	----	1	25

MATERIAL GG

Layup = $[0_2/\pm45/0_2]$, V_F =0.40, Ave. thickness = 2.46 mm, S.D. = 0.10 mm, Polyester

3439	GG110	1087	*	13	----	----	1	22
3440	GG104	933	*	13	27.8	3.2	1	22
3441	GG102	891	*	13	27.3	3.0	1	22
3442	GG107	483	0.1	2	28.3	2.00	16,881	22
3443	GG106	483	0.1	2	29.0	2.01	7,897	22
3444	GG101	414	0.1	2	27.6	1.68	47,335	22
3445	GG105	414	0.1	4	27.3	1.73	62,970	22
3446	GG108	345	0.1	5	27.1	1.35	390,948	22
3447	GG109	345	0.1	5	28.4	1.26	680,831	22
3448	GG103	345	0.1	5	28.5	1.31	814,868	22
3449	GG116	483	0.1	2	28.4	1.97	13,403	22
3450	GG117	414	0.1	2	28.3	1.66	42,910	22
3451	GG130	-623	*	13	----	----	1	25
3452	GG131	-644	*	13	----	----	1	25
3453	GG132	-617	*	13	----	----	1	25
3454	GG118	980	*	13	28.5	3.30	1	22

0° UNIDIRECTIONAL TESTS

Materials A130, D092A, D155A, DB120A and DB240A were tested in the longitudional (0°), transverse (90°) and (±45°) fiber directions for material properties. Fabrics DB120A and DB240A were unstitched into +45° and -45° plies, rotated to the 0°direction and tested as a unidirectional fabric. In the notes column, ZERO indicates a unidirectional 0° test, 90 indicates a transverse test and ±45 indicates a simulated shear test (ASTM D3518).

MATERIAL A060

Layup = $[0]_{10}$, V_F = 0.41, Ave. thickness = 1.76 mm, S.D. = 0.10 mm, Polyester

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
3038	A060104	-317	*	13	----	----	1	25
3039	A060106	-278	*	13	----	----	1	25
3040	A060101	-219	*	13	----	----	1	25
3041	A060119	-440	*	13	----	----	1	25Z
3042	A060120	-322	*	13	----	----	1	25Z
3068	A060117	624	*	13	31.4	2.00	1	25
3069	A060113	586	*	13	29.4	2.05	1	25
3070	A060114	529	*	13	32.0	1.70	1	25
3071	A060116	345	0.1	5	27.6	1.21	13,952	25
3072	A060118	345	0.1	5	33.9	1.04	7,687	25
3073	A060110	241	0.1	12	31.8	0.72	1,900,000	25R
3074	A060118	241	0.1	12	32.5	0.74	1,284,494	25
3075	A060111	345	0.1	5	32.5	1.14	36,913	25
3076	A060115	310	0.1	10	31.4	0.99	84,367	25

MATERIAL A130

Layup = $[0]_8$, V_F = 0.45, Ave. thickness = 2.62 mm, S.D. = 0.04 mm, Polyester

2036	A13001	840	*	13	38.8	2.20	1	ZERO tab
2037	A13002	852	*	13	38.4	2.80	1	ZERO tab
2038	A13003	881	*	13	37.5	2.60	1	ZERO tab
2039	A13004	81.0	*	13	11.2	----	1	±45 tab
2040	A13005	87.3	*	13	11.4	----	1	±45 tab
2041	A13006	88.0	*	13	11.4	----	1	±45 tab
2042	A13007	-300	*	13	29.1	----	1	ZERO tab
2043	A13008	-337	*	13	28.4	----	1	ZERO tab
2044	A13009	-364	*	13	32.1	----	1	ZERO tab
2045	A13010	-91.4	*	13	11.9	----	1	±45 tab
2046	A13011	-85.0	*	13	11.9	----	1	±45 tab
2047	A13012	-90.2	*	13	10.6	----	1	±45 tab
2048	A13013	-98.4	*	13	7.79	----	1	90 tab
2049	A13014	-88.8	*	13	6.69	----	1	90 tab
2050	A13015	-92.7	*	13	8.27	----	1	90 tab
2051	A13016	33.9	*	13	8.48	0.37	1	90 tab
2052	A13017	33.6	*	13	9.03	0.36	1	90 tab
2053	A13050	900	*	13	35.3	2.71	1	ZERO tab
2054	A13051	92.0	*	13	11.0	----	1	±45 tab

MATERIAL A130C

Layup = $[0]_6$, V_F = 0.35, Ave. thickness = 2.97 mm, S.D. = 0.12 mm, Polyester, Three coupons were manufactured with epoxy

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
2415	A130C110	682	*	13	29.9	2.30	1	25
2416	A130C112	756	*	13	30.2	2.50	1	25
2417	A130C113	745	*	13	29.9	2.50	1	25
2418	A130C104	414	0.1	5	31.0	1.33	15,268	25
2419	A130C109	414	0.1	5	33.1	1.25	17,020	25
2420	A130C106	483	0.1	2	34.1	1.42	2,781	25
2421	A130C108	483	0.1	2	32.0	1.51	1,986	25
2422	A130C102	345	0.1	8	29.8	1.16	425,772	25
2423	A130C103	483	0.1	2	32.5	1.49	3,521	25
2424	A130C111	414	0.1	5	31.5	1.31	37,072	25
2425	A130C101	345	0.1	10	33.9	1.12	854,215	25
2426	A130C118	310	0.1	10	31.6	0.98	4,377,528	25
2427	A130C119	345	0.1	10	31.6	1.09	841,256	25
2631	A130C301	-456	*	13	----	----	1	25
2632	A130C302	-447	*	13	----	----	1	25
2633	A130C303	-394	*	13	----	----	1	25
2634	A130C304	-424	*	13	----	----	1	25
2900	A130C144	-207	10	12	----	----	484,312	25
2901	A130C141	-207	10	12	----	----	4,000,000	25R
2902	A130C148	-276	10	5	----	----	161,152	25
2903	A130C145	-442	*	13	----	----	1	25
2904	A130C146	-345	10	1	----	----	94	25
2905	A130C143	-310	10	2	----	----	2,799	25
2906	A130C149	-310	10	2	----	----	916	25
2907	A130C147	-310	10	2	----	----	452	25
2908	A130C142	-276	10	10	----	----	71,475	25
2909	A130C149	-345	10	1	----	----	71	25
2910	A130C151	-276	10	10	----	----	62,465	25
3077	A130C103E	-287	*	13	----	----	1	25Epoxy
3078	A130C102E	-262	*	13	----	----	1	25Epoxy
3079	A130C301E	-296	*	13	----	----	1	25Epoxy

MATERIAL A130G

Layup = $[0]_6$, V_F = 0.55, Ave. thickness = 4.38 mm, S.D. = 0.12 mm, Polyester

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
2401	A130G113	1186	*	13	45.3	2.61	1	25
2402	A130G103	1150	*	13	43.7	2.60	1	25
2403	A130G109	1272	*	13	47.6	2.67	1	25
2404	A130G114	690	0.1	2	48.0	1.43	938	25
2405	A130G108	690	0.1	2	45.2	1.52	507	25
2406	A130G112	690	0.1	2	48.3	1.44	1,546	25
2407	A130G107	552	0.1	4	45.0	1.22	5,452	25
2408	A130G110	552	0.1	4	43.2	1.28	2,952	25
2409	A130G105	552	0.1	4	40.0	1.37	4,864	25

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
2410	A130G101	414	0.1	5	42.4	0.97	45,710	25
2411	A130G102	414	0.1	5	40.0	1.03	32,282	25
2412	A130G115	276	0.1	15	46.9	0.57	4,847,670	25R
2413	A130G104	414	0.1	4	45.5	0.91	28,621	25
2114	A130G106	345	0.1	8	40.5	0.85	413,627	25
2635	A130G301	-488	*	13	----	----	1	25
2636	A130G302	-514	*	13	----	----	1	25
2637	A130G303	-469	*	13	----	----	1	25
2638	A130G304	-472	*	13	----	----	1	25

MATERIAL A260

Layup = $[0]_4$, V_F = 0.35, Ave. thickness = 3.71 mm, S.D. = 0.13 mm, Polyester

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
3086	A260109	-396	*	13	----	----	1	25
3087	A260118	-357	*	13	----	----	1	25
3088	A260105	-540	*	13	----	----	1	25
3089	A260102	-422	*	13	----	----	1	25
3090	A260108	-460	*	13	----	----	1	25
3091	A260120	-470	*	13	----	----	1	25
3092	A260124	833	*	13	31.2	2.70	1	25
3093	A260122	690	*	13	23.4	2.90	1	25
3094	A260126	805	*	13	27.3	2.90	1	25
3095	A260127	345	0.1	5	29.9	0.99	3,000,000	25 R
3096	A260123	448	0.1	5	29.0	1.35	51,850	25
3097	A260125	448	0.1	8	32.1	1.42	27,702	25
3098	A260128	448	0.1	5	28.5	1.40	17,163	25
3099	A260121	379	0.1	10	31.9	1.14	191,959	25
3100	A260133	552	0.1	2	35.9	1.36	4,207	25
3101	A260120	552	0.1	2	32.5	1.79	1,448	25
3102	A260130	552	0.1	2	36.4	1.52	3,348	25
3103	A260132	379	0.1	10	32.1	1.21	640,153	25
3104	A260134	379	0.1	10	34.3	1.20	455,258	25

MATERIAL CM1701A

Layup = $[0]_6$, V_F = 0.38, Ave. thickness = 3.20 mm, S.D. = 0.10 mm, Polyester

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
2911	CMA101	-604	*	13	----	----	1	25
2912	CMA102	-573	*	13	----	----	1	25
2913	CMA103	-542	*	13	----	----	1	25
2935	CMA116	874	*	13	32.4	2.70	1	25
2936	CMA113	784	*	13	28.6	2.75	1	25
2937	CMA107	730	*	13	29.2	2.50	1	25
2938	CMA112	483	0.1	2	29.8	1.63	784	25
2939	CMA106	483	0.1	2	38.3	1.29	1,940	25
2940	CMA105	483	0.1	2	33.2	1.46	1,574	25
2941	CMA111	414	0.1	5	29.3	1.54	17,955	25
2943	CMA110	414	0.1	4	26.8	1.60	6,418	25
2945	CMA117	345	0.1	5	28.0	1.19	26,217	25

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
2946	CMA108	345	0.1	5	32.3	1.00	38,086	25
2947	CMA114	276	0.1	10	28.8	0.89	81,998	25
2948	CMA119	276	0.1	10	29.1	0.92	117,831	25
2911	CMA101	-604	*	13	----	----	1	25
2912	CMA102	-573	*	13	----	----	1	25
2913	CMA103	-542	*	13	----	----	1	25
2949	CMA121	-345	10	4	----	----	42,588	25
2950	CMA125	-345	10	4	----	----	13,272	25
2951	CMA127	-345	10	4	----	----	80,669	25
2952	CMA123	-310	10	10	----	----	105,995	25
2953	CMA132	-310	10	12	----	----	532,367	25
2962	CMA134	-310	10	10	----	----	460,941	25

MATERIAL D072A

Layup = $[0]_{10}$, $V_F = 0.36$, Ave. thickness = 3.30 mm, S.D. = 0.05 mm, Polyester

3043	D072A118	-608	*	13	----	----	1	25
3044	D072A123	-562	*	13	----	----	1	25
3045	D072A122	-508	*	13	----	----	1	25
3046	D072A120	-345	10	5	----	----	87,741	25
3047	D072A119	-414	10	3	----	----	9,757	25
3048	D072A117	-414	10	4	----	----	2,192	25
3049	D072A116	-345	10	5	----	----	79,404	25
3050	D072A121	-414	10	4	----	----	6,097	25
3051	D072A115	-345	10	5	----	----	136,908	25
3055	D072A110	812	*	13	28.3	2.60	1	25
3056	D072A109	789	*	13	29.3	2.70	1	25
3057	D072A108	796	*	13	27.8	2.90	1	25
3058	D072A107	483	0.1	4	26.8	1.83	9,586	25
3059	D072A106	483	0.1	4	26.7	1.91	8,838	25
3060	D072A105	310	0.1	10	28.2	0.96	929,460	25
3061	D072A101	483	0.1	4	31.7	1.63	5,993	25
3062	D072A102	345	0.1	5	27.7	1.14	195,791	25
3063	D072A111	414	0.1	5	31.3	1.32	28,168	25
3064	D072A112	414	0.1	5	26.9	1.47	34,247	25
3065	D072A121	414	0.1	5	28.4	1.40	23,522	25
3066	D072A118	345	0.1	10	26.3	1.30	162,352	25
3067	D072A123	345	0.1	10	27.7	1.29	237,010	25

MATERIAL D092A

Layup = $[0]_{10}$, $V_F = 0.46$, Ave. thickness = 3.10 mm, S.D. = 0.07 mm, Polyester

1992	D09201	929	*	13	35.1	2.82	1	ZERO tab
1993	D09202	926	*	13	36.8	2.87	1	ZERO tab
1994	D09203	911	*	13	34.3	3.14	1	ZERO tab
1995	D09204	134	*	13	12.2	----	1	±45 tab
1996	D09205	36.9	*	13	10.1	0.35	1	90 tab
1997	D09208	-761	*	13	28.4	-2.01	1	ZERO tab

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
1998	D09209	-745	*	13	30.6	-2.12	1	ZERO tab
1999	D09210	-783	*	13	31.8	-1.80	1	ZERO tab
2000	D09211	-130	*	13	12.3	----	1	±45 tab
2001	D09212	-129	*	13	10.9	----	1	±45 tab
2002	D09213	-130	*	13	11.1	----	1	±45 tab
2003	D09214	-141	*	13	7.38	-1.72	1	90 tab
2004	D09215	40.3	*	13	7.10	0.36	1	90 tab
2005	D09216	-130	*	13	7.65	-1.91	1	90 tab
2006	D09217	150	*	13	9.44	----	1	±45 tab
2007	D09250	-816	*	13	32.5	-1.63	1	ZERO tab
2008	D09251	-758	*	13	31.4	-1.47	1	ZERO tab
2009	D09252	-127	*	13	6.62	-1.92	1	90 tab
2010	D09253	-129	*	13	14.2	----	1	±45 tab
2011	D09254	1041	*	13	34.9	3.09	1	ZERO tab
2012	D09255	140	*	13	12.5	----	1	±45 tab
2013	D09256	38.2	*	13	9.79	0.37	1	90 tab

MATERIAL D092B

Layup = $[0]_9$, $V_F = 0.41$, Ave. thickness = 2.76 mm, S.D. = 0.12 mm, Polyester

2144	D092B105	994	*	13	35.6	2.80	1	25
2145	D092B104	907	*	13	32.9	2.86	1	25
2146	D092B106	959	*	13	34.7	2.80	1	25
2147	D092B107	552	0.1	4	36.1	1.60	8,610	25
2148	D092B109	552	0.1	4	32.9	1.70	12,301	25
2149	D092B110	414	0.1	15	36.8	1.13	302,338	25
2150	D092B103	414	0.1	15	32.6	1.21	259,952	25
2151	D092B111	414	0.1	15	31.9	1.30	236,479	25
2152	D092B108	345	0.1	15	33.9	1.04	1,557,555	25
2153	D092B101	345	0.1	15	32.0	1.09	957,554	25
2154	D092B102	345	0.1	15	35.7	0.98	1,847,878	25
2380	D092B230	878	*	13	33.4	2.62	1	25
2381	D092B208	875	*	13	34.3	2.55	1	25
2382	D092B204	834	*	13	34.1	2.45	1	25
2383	D092B216	552	0.1	4	34.0	1.62	2,914	25
2384	D092B210	552	0.1	4	32.2	1.71	3,142	25
2385	D092B201	552	0.1	4	33.9	1.63	3,756	25
2386	D092B213	414	0.1	10	32.9	1.26	126,113	25
2387	D092B203	414	0.1	5	33.9	1.22	165,310	25
2388	D092B205	345	0.1	12	33.7	1.02	892,557	25
2389	D092B209	345	0.1	12	32.4	1.06	1,112,027	25
2390	D092B211	414	0.1	10	33.2	1.25	171,967	25
2639	D092B301	-684	*	13	----	----	1	25
2640	D092B302	-710	*	13	----	----	1	25
2641	D092B303	-708	*	13	----	----	1	25
2642	D092B305	-630	*	13	----	----	1	25
2643	D092B306	-610	*	13	----	----	1	25
2644	D092B308	-705	*	13	----	----	1	25

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes

MATERIAL D092D

Layup = $[0]_7$, V_F = 0.30, Ave. thickness = 2.64 mm, S.D. = 0.11 mm, Polyester

2391	D092D105	736	*	13	25.4	2.89	1	25
2392	D092D107	722	*	13	25.6	2.81	1	25
2393	D092D111	734	*	13	25.8	2.84	1	25
2394	D092D108	482	0.1	2	24.4	1.98	3,342	25
2395	D092D110	482	0.1	4	23.6	2.04	2,650	25
2396	D092D103	414	0.1	8	25.4	1.63	113,301	25
2397	D092D109	345	0.1	10	25.6	1.35	813,359	25
2398	D092D104	414	0.1	8	27.4	1.51	75,856	25
2399	D092D102	345	0.1	12	24.3	1.42	291,147	25
2400	D092D106	345	0.1	15	26.1	1.30	948,810	25
2645	D092D301	-574	*	13	----	----	1	25
2646	D092D302	-515	*	13	----	----	1	25
2647	D092D303	-532	*	13	----	----	1	25
2648	D092D304	-538	*	13	----	----	1	25

MATERIAL D092F

Layup = $[0]_{12}$, V_F = 0.50, Ave. thickness = 3.00 mm, S.D. = 0.04 mm, Polyester

2178	D092F110	1090	*	13	35.9	2.96	1	25
2179	D092F112	1105	*	13	40.5	2.85	1	25
2180	D092F103	1141	*	13	41.8	2.85	1	25
2181	D092F111	1203	*	13	42.2	2.86	1	25
2182	D092F107	414	0.1	15	44.1	0.97	221,920	25
2183	D092F109	414	0.1	15	39.9	1.03	92,864	25
2184	D092F105	414	0.1	15	37.2	1.12	138,489	25
2185	D092F106	345	0.1	15	42.6	0.81	864,540	25
2186	D092F101	345	0.1	15	38.3	0.90	387,503	25
2187	D092F102	552	0.1	4	41.8	1.32	15,665	25
2188	D092F124	552	0.1	4	44.6	1.24	31,284	25
2653	D092F123	-615	*	13	----	----	1	25
2654	D092F126	-692	*	13	----	----	1	25
2655	D092F122	-697	*	13	----	----	1	25
2656	D092F121	-712	*	13	----	----	1	25

MATERIAL D092G

Layup = $[0]_{15}$, V_F = 0.58, Ave. thickness = 3.25 mm, S.D. = 0.05 mm, Polyester

2155	D092G113	1,130	*	13	42.2	2.70	1	25
2156	D092G105	1,206	*	13	43.3	2.80	1	25
2157	D092G103	1,182	*	13	41.8	2.80	1	25
2158	D092G109	690	0.1	2	43.2	1.62	484	25
2159	D092G112	414	0.1	4	44.1	0.94	12,691	25
2160	D092G106	414	0.1	4	45.0	0.90	15,436	25
2161	D092G101	552	0.1	1	46.0	1.31	2,113	25
2162	D092G104	552	0.1	2	45.4	1.22	2,942	25

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
2163	D092G102	414	0.1	2	43.4	0.97	11,735	25
2164	D092G110	552	0.1	2	47.2	1.20	2,700	25
2165	D092G108	276	0.1	10	6.79	0.62	261,247	25
2166	D092G111	207	0.1	10	44.0	0.47	3,000,000	25 R
2167	D092G114	276	0.1	10	47.7	0.58	159,725	25
2168	D092G107	276	0.1	10	50.0	0.55	95,939	25
2169	D092G205	276	0.1	15	50.7	0.55	472,372	25
2170	D092G207	276	0.1	10	51.1	0.56	494,104	25
2171	D092G206	276	0.1	10	50.7	0.53	368,039	25
2173	D092G201	414	0.1	10	46.8	0.90	36,932	25
2174	D092G202	414	0.1	4	49.2	0.90	29,096	25
2175	D092G-204	276	0.1	10	49.1	0.56	700,000	25
2177	D092G105	345	0.1	12	46.1	0.81	478,382	25
2354	D092G205	1196	*	13	44.5	2.89	1	25
2355	D092G209	1133	*	13	43.4	2.61	1	25
2356	D092G201	1161	*	13	45.0	2.60	1	25
2357	D092G212	276	0.1	12	47.8	0.58	874,379	25
2358	D092G207	552	0.1	5	47.5	1.16	12,811	25
2359	D092G202	552	0.1	5	41.5	1.33	9,807	25
2360	D092G211	552	0.1	5	45.2	1.22	9,091	25
2361	D092G216	690	0.1	2	42.1	1.64	1,360	25
2362	D092G215	690	0.1	2	45.9	1.50	2,083	25
2363	D092G214	414	0.1	10	41.9	0.99	113,852	25
2364	D092G210	414	0.1	10	43.0	0.96	92,451	25
2365	D092G213	276	0.1	15	45.6	0.60	6,654,291	25
2366	D092G203	414	0.1	10	44.5	0.93	135,121	25
2649	D092G301	-816	*	13	----	----	1	25
2650	D092G302	-918	*	13	----	----	1	25
2651	D092G303	-925	*	13	----	----	1	25
2652	D092G304	-945	*	13	----	----	1	25
2785	D092G129	-690	10	1	----	----	4	25
2786	D092G130	-621	10	4	----	----	13,859	25
2787	D092G120	-621	10	5	----	----	7,978	25
2789	D092G126	-621	10	5	----	----	6,124	25
2790	D092G131	-552	10	12	----	----	19,386	25
2791	D092G123	-552	10	12	----	----	27,412	25
2792	D092G124	-552	10	12	----	----	11,391	25
2793	D092G132	-414	10	12	----	----	1,864,286	25
2794	D092G128	-483	10	10	----	----	481,468	25
2795	D092G121	-483	10	10	----	----	298,071	25
2796	D092G127	-483	10	10	----	----	331,041	25

MATERIAL D155

Layup = $[0]_6$, V_F = 0.45, Ave. thickness = 2.74 mm, S.D. = 0.10 mm, Polyester

2014	D15501	984	*	13	39.0	2.90	1	ZERO tab
2015	D15502	898	*	13	36.3	2.69	1	ZERO tab
2016	D15503	976	*	13	38.9	2.87	1	ZERO tab

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	ε %	CYCLES TO FAIL	WIDTH (mm) and Notes
2017	D15504	92.5	*	13	12.8	----	1	±45 tab
2018	D15505	24.9	*	13	12.8	0.43	1	90 tab
2019	D15506	29.5	*	13	9.24	0.37	1	90 tab
2020	D15507	-598	*	13	31.2	-1.94	1	ZERO tab
2021	D15508	-619	*	13	32.0	-1.72	1	ZERO tab
2022	D15509	-109	*	13	14.0	-3.2	1	±45 tab
2023	D15510	-106	*	13	15.1	-3.72	1	±45 tab
2024	D15511	-122	*	13	7.31	-1.62	1	90 tab
2025	D15512	-118	*	13	7.65	-1.43	1	90 tab
2026	D15513	-727	*	13	32.1	-2.48	1	ZERO tab
2027	D15514	-710	*	13	31.8	-1.77	1	ZERO tab
2028	D15515	-756	*	13	29.6	-1.34	1	ZERO tab
2029	D15516	104	*	13	12.3	----	1	±45 tab
2030	D15517	103	*	13	10.8	----	1	±45 tab
2031	D15550	-730	*	13	32.3	-2.18	1	ZERO tab
2032	D15551	-807	*	13	33.0	-2.14	1	ZERO tab
2033	D15552	-147	*	13	7.72	-1.96	1	90 tab
2034	D15553	1088	*	13	39.0	2.85	1	ZERO tab
2035	D15554	85.8	*	13	13.2	----	1	±45 tab

MATERIAL D155B

Layup = $[0]_5$, V_F = 0.39, Ave. thickness = 2.70 mm, S.D. = 0.11 mm, Polyester

2110	D155B65	935	*	13	34.8	2.80	1	25
2111	D155B71	961	*	13	29.6	3.15	1	25
2112	D155B61	911	*	13	33.8	2.80	1	25
2113	D155B60	552	0.1	2	31.9	1.86	1,831	25
2114	D155B72	552	0.1	2	29.8	1.92	3,911	25
2115	D155B63	414	0.1	5	31.9	1.44	85,156	25
2116	D155B70	414	0.1	10	28.6	1.49	108,103	25
2117	D155B69	276	0.1	20	28.5	1.08	8,000,000	25
2118	D155B68	552	0.1	4	30.9	1.83	6,582	25
2119	D155B66	690	0.1	1	32.2	2.32	139	25
2120	D155B62	345	0.1	10	33.0	1.10	1,230,231	25
2121	D155B64	414	0.1	10	33.0	1.28	75,774	25
2122	D155B67	345	0.1	12	29.5	1.19	721,864	25
2123	D155B81	345	0.1	10	32.5	1.15	572,173	25
2203	D155B200	755	*	13	31.1	2.43	1	25 tab
2204	D155B209	779	*	13	28.2	2.76	1	25 tab
2205	D155B215	785	*	13	28.5	2.75	1	25 tab
2206	D155B201	483	0.1	4	32.6	1.48	6,979	25 tab
2207	D155B207	483	0.1	4	33.1	1.46	16,497	25 tab
2208	D155B205	414	0.1	7	32.2	1.28	82,605	25 tab
2209	D155B203	414	0.1	8	36.8	1.13	68,483	25 tab
2236	D155B212	345	0.1	15	33.6	1.02	967,901	25 tab
2237	D155B210	345	0.1	15	30.1	1.15	1,104,634	25 tab
2338	D155B202	483	0.1	5	30.4	1.59	19,814	25 tab
2339	D155B213	552	0.1	3	32.2	1.71	2,141	25 tab

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	ε %	CYCLES TO FAIL	WIDTH (mm) and Notes
2340	D155B208	552	0.1	4	30.3	1.82	2,305	25 tab
2341	D155B211	552	0.1	4	31.8	1.73	1,733	25 tab
2342	D155B214	414	0.1	10	30.8	1.34	48,181	25 tab
2657	D155B301	-620	*	13	----	----	1	25
2658	D155B302	-666	*	13	----	----	1	25
2659	D155B303	-642	*	13	----	----	1	25
2660	D155B304	-656	*	13	----	----	1	25
2776	D155B174	-681	*	13	----	----	1	25
2777	D155B177	-517	10	1	----	----	178	25
2778	D155B175	-414	10	10	----	----	76,348	25
2779	D155B178	-414	10	10	----	----	61,956	25
2780	D155B180	-345	10	12	----	----	954,990	25
2781	D155B176	-345	10	12	----	----	893,962	25
2782	D155B173	-345	10	12	----	----	1,121,768	25
2783	D155B181	-414	10	10	----	----	172,874	25
2784	D155B179	-483	10	2	----	----	886	25
3735	D155B222	831	*	13	32.8	----	1	25
3736	D155B223	845	*	13	----	----	1	25
3737	D155B218	775	*	13	----	----	1	25
3738	D155B218	843	*	13	----	----	1	25

MATERIAL D155C

Layup = $[0]_7$, V_F = 0.51, Ave. thickness = 2.99 mm, S.D. = 0.09 mm, Polyester

2124	D155C111	1189	*	13	33.6	3.27	1	25
2125	D155C109	1184	*	13	32.3	3.28	1	25
2126	D155C107	1188	*	13	34.6	3.10	1	25
2127	D155C101	827	0.1	2	32.5	2.55	315	25
2128	D155C105	552	0.1	5	34.0	1.59	11,103	25
2129	D155C110	552	0.1	5	33.4	1.62	10,021	25
2130	D155C106	414	0.1	12	33.7	1.24	189,546	25
2131	D155C104	345	0.1	15	35.6	1.01	1,276,914	25
2132	D155C108	414	0.1	10	37.0	1.23	133,885	25
2133	D155C100	414	0.1	10	34.3	1.24	206,447	25
2134	D155C114	552	0.1	4	32.1	1.68	14,762	25
2135	D155C102	345	0.1	12	35.1	0.99	854,271	25
2136	D155C103	345	0.1	12	32.2	1.04	644,464	25
2220	D155C202	1129	*	13	43.0	2.62	1	25
2221	D155C205	1208	*	13	42.6	2.83	1	25
2222	D155C203	1152	*	13	43.8	2.63	1	25
2223	D155C206	552	0.1	5	46.7	1.18	19,546	25
2224	D155C207	552	0.1	5	43.0	1.28	19,611	25
2225	D155C209	552	0.1	5	46.7	1.09	25,014	25
2227	D155C210	345	0.1	10	41.4	0.83	1,369,554	25
2228	D155C213	345	0.1	12	43.4	0.75	1,251,972	25
2229	D155C211	690	0.1	2	42.5	1.65	3,370	25
2230	D155C208	690	0.1	2	42.8	1.61	2,480	25
2231	D155C201	414	0.1	5	45.0	0.92	196,825	25

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
2232	D155C212	414	0.1	10	43.4	0.95	278,697	25
2233	D155C204	414	0.1	10	41.8	0.99	188,541	25
2234	D155C216	690	0.1	2	40.5	1.70	3,610	25
2235	D155C217	345	0.1	15	42.4	0.81	1,182,710	25
2661	D155C301	-847	*	13	----	----	1	25
2662	D155C302	-734	*	13	----	----	1	25
2663	D155C303	-752	*	13	----	----	1	25
2664	D155C304	-841	*	13	----	----	1	25

MATERIAL D155G

Layup = $[0]_8$, V_F = 0.59, Ave. thickness = 2.81 mm, S.D. = 0.08 mm, Polyester

2189	D155G104	1318	*	13	48.4	2.72	1	25
2190	D155G110	1320	*	13	48.2	2.74	1	25
2191	D155G115	1303	*	13	46.7	2.80	1	25
2192	D155G103	690	0.1	4	49.8	1.39	4,546	25
2193	D155G107	690	0.1	2	46.3	1.49	1,839	25
2194	D155G106	552	0.1	5	49.0	1.13	14,842	25
2195	D155G109	552	0.1	5	51.3	1.08	10,796	25
2196	D155G108	345	0.1	12	52.6	0.66	137,665	25
2197	D155G105	345	0.1	12	46.2	0.75	164,363	25
2198	D155G114	276	0.1	12	44.2	0.62	1,154,036	25
2199	D155G102	276	0.1	12	41.4	0.66	817,204	25
2200	D155G101	345	0.1	10	44.5	0.78	169,202	25
2201	D155G112	690	0.1	2	45.2	1.53	2,546	25
2202	D155G113	552	0.1	5	43.7	1.26	11,201	25
2665	D155G301	-729	*	13	----	----	1	25
2666	D155G302	-647	*	13	----	----	1	25
2667	D155G303	-698	*	13	----	----	1	25
2668	D155G354	-783	*	13	----	----	1	25
2766	D155G305	-552	10	12	----	----	38,446	25
2767	D155G306	-552	10	12	----	----	130,068	25
2768	D155G309	-552	10	12	----	----	57,998	25
2770	D155G307	-483	10	12	----	----	161,615	25
2771	D155G305	-483	10	12	----	----	74,321	25
2772	D155G304	-730	*	13	----	----	1	25
2773	D155G316	-621	10	1	----	----	90	25
2774	D155G320	-621	10	1	----	----	136	25
2775	D155G310	-621	10	1	----	----	62	25
3599	D155G314	-627	*	0.025	----	----	1	25 tab
3600	D155G321	-660	*	0.025	----	----	1	25 tab
3601	D155G323	-654	*	0.025	----	----	1	25 tab
3602	D155G311	-739	*	2.54	----	----	1	25 tab
3603	D155G322	-723	*	2.54	----	----	1	25 tab
3604	D155G324	-701	*	2.54	----	----	1	25 tab
3605	D155G317	-673	*	12.7	----	----	1	25 tab
3606	D155G313	-762	*	12.7	----	----	1	25 tab
3607	D155G319	-784	*	12.7	----	----	1	25 tab

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
3608	D155G335	-757	*	25.4	----	----	1	25 tab
3609	D155G330	-776	*	25.4	----	----	1	25 tab
3610	D155G333	-768	*	25.4	----	----	1	25 tab
3611	D155G332	-735	*	127	----	----	1	25 tab
3612	D155G331	-796	*	127	----	----	1	25 tab
3613	D155G336	-755	*	127	----	----	1	25 tab
3614	D155G217	964	*	0.025	----	----	1	25 tab
3615	D155G219	833	*	0.025	----	----	1	25 tab
3616	D155G214	897	*	0.025	----	----	1	25 tab
3617	D155G216	1086	*	2.54	----	----	1	25 tab
3618	D155G221	1057	*	2.54	----	----	1	25 tab
3619	D155G222	1061	*	2.54	----	----	1	25 tab
3620	D155G223	1140	*	12.7	----	----	1	25 tab
3621	D155G226	1222	*	12.7	----	----	1	25 tab
3622	D155G225	1024	*	12.7	----	----	1	25 tab
3623	D155G224	1086	*	63.5	----	----	1	25 tab
3624	D155G218	1100	*	63.5	----	----	1	25 tab
3625	D155G220	1136	*	63.5	----	----	1	25 tab

MATERIAL D155H

Layup = $[0]_7$, V_F = 0.49, Ave. thickness = 2.93 mm, S.D. = 0.10 mm, Polyester, No Stitching

2210	D155H106	961	*	13	34.3	2.80	1	25
2211	D155H111	886	*	13	33.1	2.68	1	25
2212	D155H103	903	*	13	34.7	2.61	1	25
2215	D155H108	552	0.1	5	34.4	1.60	39,227	25
2216	D155H109	552	0.1	5	35.4	1.56	22,154	25
2217	D155H122	1076	*	13	40.1	2.98	1	has stitch
2218	D155H121	1178	*	13	40.7	2.89	1	has stitch
2219	D155H120	1109	*	13	40.5	2.74	1	has stitch
2226	D155H102	552	0.1	5	33.9	1.62	41,215	25
2344	D155H210	483	0.1	10	37.0	1.30	156,200	25
2345	D155H115	834	*	13	36.7	----	1	25
2346	D155H204	1101	*	13	41.7	2.63	1	25
2347	D155H203	483	0.1	15	38.8	1.24	128,523	25
2348	D155H208	483	0.1	12	39.7	1.21	195,322	25
2349	D155H209	414	0.1	15	40.0	1.04	3,219,571	25
2350	D155H201	414	0.1	15	40.5	1.02	1,211,477	25
2351	D155H212	690	0.1	4	42.0	1.64	2,953	25
2352	D155H206	690	0.1	4	41.4	1.67	2,264	25
2353	D155H207	690	0.1	4	40.7	1.70	1,822	25
2669	D155H301	-718	*	13	----	----	1	25
2670	D155H302	-686	*	13	----	----	1	25
2671	D155H303	-623	*	13	----	----	1	has stitch
2672	D155H304	-864	*	13	----	----	1	has stitch
2673	D155H305	-795	*	13	----	----	1	has stitch
2674	D155H306	-846	*	13	----	----	1	has stitch

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes

MATERIAL D155J

Layup = $[0]_6$, V_F = 0.58, Ave. thickness = 3.54 mm, S.D. = 0.11 mm, Polyester, No Stitching

2428	D155J111	1,098	*	13	49.8	2.65	1	25
2429	D155J114	1,190	*	13	47.5	2.51	1	25
2430	D155J101	1,140	*	13	48.6	2.43	1	25
2431	D155J103	690	0.1	5	44.9	1.54	6,213	25
2432	D155J115	690	0.1	5	50.0	1.38	7,977	25
2433	D155J106	690	0.1	5	46.8	1.47	4,784	25
2434	D155J108	552	0.1	5	50.0	----	20,345	25
2435	D155J105	552	0.1	5	50.0	1.10	73,109	25
2436	D155J109	414	0.1	12	47.0	0.88	684,350	25
2437	D155J113	552	0.1	5	47.8	1.15	35,652	25
2438	D155J116	414	0.1	12	47.8	0.79	912,579	25
2439	D155J107	552	0.1	5	45.2	1.22	89,980	25
2440	D155J104	414	0.1	12	47.3	0.86	485,216	25
2675	D155J301	-826	*	13	----	----	1	25
2676	D155J302	-704	*	13	----	----	1	25
2677	D155J303	-796	*	13	----	----	1	25
2678	D155J304	-777	*	13	----	----	1	25

MATERIAL D155K

Layup = $[0]_7$, V_F = 0.33, Ave. thickness = 4.45 mm, S.D. = 0.10 mm, Polyester

3673	D155K110	872	*	13	28.5	3.15	1	25
3674	D155K111	881	*	13	29.6	----	1	25
3675	D155K109	830	*	13	28.5	----	1	25
3676	D155K108	414	0.1	2	27.1	1.58	7,569	25
3677	D155K112	414	0.1	4	28.7	1.54	13,447	25
3678	D155K101	414	0.1	4	26.3	1.59	6,267	25
3679	D155K113	276	0.1	12	28.5	0.97	764,138	25
3680	D155K102	276	0.1	12	26.7	1.01	1,305,237	25
3681	D155K103	276	0.1	12	28.6	0.96	1,733,768	25
3682	D155K105	345	0.1	6	30.1	1.18	175,689	25
3683	D155K104	345	0.1	6	27.9	1.26	106,359	25
3684	D155K107	345	0.1	6	26.9	1.29	152,853	25
3685	D155K106	483	0.1	1	28.1	2.12	576	25
3686	D155K120	483	0.1	1	27.3	1.90	2,594	25
3687	D155K121T	23.8	*	13	8.00	0.30	1	25
3688	D155K122T	24.9	*	13	8.36	0.29	1	25
3689	D155K123T	18.9	*	13	8.52	0.22	1	25
3841	D155K125	-500	*	13	----	----	1	25
3842	D155K126	-624	*	13	----	----	1	25
3843	D155K127	-527	*	13	----	----	1	25

MATERIAL DB120A

Layup = $[0]_{16}$, V_F = 0.43, Ave. thickness = 2.69 mm, S.D. = 0.10 mm, Polyester
±45 degree fabric was separated into +45 and -45 degree plies and rotated to 0 degrees.

2055	DB12001	610	*	13	26.5	2.65	1	ZERO tab
2056	DB12002	596	*	13	26.8	2.41	1	ZERO tab
2057	DB12003	82.9	*	13	9.45	----	1	±45 tab
2058	DB12004	84.5	*	13	9.10	----	1	±45 tab
2059	DB12005	85.1	*	13	9.86	----	1	±45 tab
2060	DB12006	87.0	*	13	8.89	----	1	±45 tab
2061	DB12007	25.7	*	13	7.24	0.39	1	90 tab
2062	DB12008	-554	*	13	18.9	----	1	ZERO tab
2063	DB12009	-555	*	13	19.7	----	1	ZERO tab
2064	DB12010	-545	*	13	19.4	----	1	ZERO tab
2065	DB12011	-116	*	13	8.83	----	1	±45 tab
2066	DB12012	-120	*	13	9.86	----	1	±45 tab
2067	DB12013	-123	*	13	9.31	----	1	±45 tab
2068	DB12014	-120	*	13	6.96	-2.20	1	90 tab
2069	DB12015	-117	*	13	6.41	-1.70	1	90 tab
2070	DB12016	-104	*	13	6.55	-2.10	1	90 tab
2071	DB12017	616	*	13	24.8	2.60	1	ZERO tab
2072	DB12018	24.0	*	13	7.72	0.32	1	90 tab
2073	DB12050	619	*	13	28.2	2.30	1	ZERO tab
2074	DB12051	104	*	13	9.72	----	1	±45 tab

MATERIAL DB240A

Layup = $[0]_8$, V_F = 0.46, Ave. thickness = 2.77 mm, S.D. = 0.12 mm, Polyester
±45 degree fabric was separated into +45 and -45 degree plies and rotated to 0 degrees.

2075	DB24001	701	*	13	30.8	2.60	1	ZERO tab
2076	DB24002	715	*	13	30.1	2.60	1	ZERO tab
2077	DB24003	669	*	13	31.1	2.50	1	ZERO tab
2078	DB24004	68.9	*	13	10.9	----	1	±45 tab
2079	DB24005	69.1	*	13	10.1	----	1	±45 tab
2080	DB24006	68.0	*	13	9.90	----	1	±45 tab
2081	DB24007	-551	*	13	25.9	-1.60	1	ZERO tab
2082	DB24008	-507	*	13	24.8	-1.70	1	ZERO tab
2083	DB24009	-557	*	13	25.6	-1.60	1	ZERO tab
2084	DB24010	-122	*	13	11.0	----	1	±45 tab
2085	DB24011	-101	*	13	10.3	----	1	±45 tab
2086	DB24012	-128	*	13	10.3	----	1	±45 tab
2087	DB24013	-125	*	13	6.32	-1.80	1	90 tab
2088	DB24014	-118	*	13	6.69	-1.65	1	90 tab
2089	DB24015	-122	*	13	1.08	-1.62	1	90 tab
2090	DB24016	20.1	*	13	7.58	0.29	1	90 tab
2091	DB24017	19.2	*	13	7.10	0.26	1	90 tab
2092	DB24050	703	*	13	32.2	2.85	1	ZERO tab
2093	DB24051	69.9	*	13	10.1	----	1	±45 tab

ANGLE PLY TESTING

MATERIAL D155B

Layup = $[0]_5$, V_F = 0.39, Ave. thickness = 2.70 mm, S.D. = 0.11 mm, Polyester

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
2203	D155B200	755	*	13	31.1	2.43	1	25
2204	D155B209	779	*	13	28.2	2.76	1	25
2205	D155B215	785	*	13	28.5	2.75	1	25
2206	D155B201	483	0.1	4	32.6	1.48	6,979	25
2207	D155B207	483	0.1	4	33.1	1.46	16,497	25
2208	D155B205	414	0.1	7	32.2	1.28	82,605	25
2209	D155B203	414	0.1	8	36.8	1.13	68,483	25
2236	D155B212	345	0.1	15	33.6	1.02	967,901	25
2237	D155B210	345	0.1	15	30.1	1.15	1,104,634	25
2338	D155B202	483	0.1	5	30.4	1.59	19,814	25
2339	D155B213	552	0.1	3	32.2	1.71	2,141	25
2340	D155B208	552	0.1	4	30.3	1.82	2,305	25
2341	D155B211	552	0.1	4	31.8	1.73	1,733	25
2342	D155B214	414	0.1	10	30.8	1.34	48,181	25

MATERIAL 10D155

Layup = $[\pm10]_3$, V_F = 0.38, Ave. thickness = 3.47 mm, S.D. = 0.17 mm, Polyester

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
2513	10D155122	271	*	13	28.6	0.90	1	25
2514	10D155127	303	*	13	28.5	1.00	1	25
2515	10D155120	249	*	13	25.5	0.95	1	25
2566	10D155128	172	0.1	10	27.9	0.60	167,538	25
2569	10D155213	172	0.1	8	26.1	0.94	178,266	25
2570	10D155208	172	0.1	10	29.2	0.64	207,957	25
2571	10D155205	284	*	13	29.0	0.98	1	25
2572	10D155209	207	0.1	5	29.4	0.71	18,193	25
2573	10D155210	207	0.1	5	32.3	0.64	21,780	25
2574	10D155212	207	0.1	5	29.3	0.72	16,360	25
2575	10D155215	155	0.1	12	29.5	0.53	1,764,883	25
2583	10D155114	-405	*	13	----	----	1	25
2584	10D155106	-343	*	13	----	----	1	25
2585	10D155112	-406	*	13	----	----	1	25
2586	10D155113	-381	*	13	----	----	1	25

MATERIAL 20D155

Layup = $[\pm20]_3$, V_F = 0.39, Ave. thickness = 3.21 mm, S.D. = 0.14 mm, Polyester

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
2510	20D155101	244	*	13	24.3	1.08	1	25
2511	20D155104	269	*	13	23.2	1.20	1	25
2512	20D155107	290	*	13	25.1	1.40	1	25
2558	20D155113	172	0.1	5	26.9	0.71	21,427	25
2559	20D155112	172.	0.1	7	25.3	0.69	38,475	25
2560	20D155111	138	0.1	12	24.5	0.58	835,986	25

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
2561	20D155108	172	0.1	7	24.8	0.76	25,475	25
2562	20D155106	207	0.1	2	27.0	0.83	2,244	25
2563	20D155110	207	0.1	2	23.8	0.90	860	25
2564	20D155116	207	0.1	2	25.8	0.88	2,779	25
2565	20D155102	138	0.1	15	24.1	0.56	742,154	25
2587	20D155301	-284	*	13	----	----	1	25
2588	20D155302	-289	*	13	----	----	1	25
2589	20D155303	-271	*	13	----	----	1	25
2590	20D155304	-303	*	13	----	----	1	25

MATERIAL 30D155

Layup = $[\pm30]_3$, V_F = 0.40, Ave. thickness = 3.11 mm, S.D. = 0.14 mm, Polyester

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
2507	30D155107	183	*	13	17.8	1.40	1	25
2508	30D155104	184	*	13	16.1	1.60	1	25
2509	30D155113	141	*	13	18.1	1.60	1	25
2537	30D155114	103	0.1	5	18.3	0.56	15,975	25
2538	30D155110	103	0.1	8	17.2	0.63	25,545	25
2539	30D155112	69.0	0.1	15	19.7	0.37	2,525,000	25 R
2540	30D155111	69.0	0.1	25	17.0	0.37	2,000,000	25 R
2541	30D155109	86.2	0.1	20	16.4	0.52	84,851	25
2542	30D155108	86.2	0.1	20	18.8	0.42	214,208	25
2543	30D155115	86.2	0.1	20	17.4	0.50	168,607	25
2544	30D155116	121	0.1	5	17.1	0.78	9,028	25
2545	30D155101	121	0.1	6	18.0	0.74	12,509	25
2546	30D155102	121	0.1	5	18.6	0.71	11,345	25
2547	30D155103	103	0.1	6	16.8	0.62	42,426	25
2591	30D155301	-195	*	13	----	----	1	25
2592	30D155302	-168	*	13	----	----	1	25
2593	30D155303	-169	*	13	----	----	1	25
2594	30D155304	-173	*	13	----	----	1	25

MATERIAL 40D155

Layup = $[\pm40]_3$, V_F = 0.40, Ave. thickness = 3.17 mm, S.D. = 0.09 mm, Polyester

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
2504	40D155110	147	*	13	11.5	4.00	1	25
2505	40D155105	142	*	13	11.2	16.0	1	25
2506	40D155102	142	*	13	11.4	11.0	1	25
2516	40D155103	86.2	0.1	4	10.8	0.89	7,598	25
2517	40D155104	86.2	0.1	4	11.8	0.97	6,950	25
2518	40D155106	86.2	0.1	4	12.2	0.93	3,054	25
2519	40D155107	69.0	0.1	5	11.7	0.69	27,264	25
2520	40D155108	55.2	0.1	12	12.3	0.46	631,703	25
2521	40D155109	55.2	0.1	15	11.9	0.49	275,777	25
2522	40D155111	69.0	0.1	5	11.8	0.67	36,776	25
2523	40D155112	69.0	0.1	8	12.0	0.62	34,920	25
2524	40D155113	55.2	0.1	20	11.1	0.52	857,164	25
2595	40D155301	-131	*	13	----	----	1	25

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
2596	40D155302	-135	*	13	----	----	1	25
2597	40D155303	-127	*	13	----	----	1	25
2598	40D155304	-134	*	13	----	----	1	25

MATERIAL 45D155

Layup = $[\pm45]_3$, V_F = 0.38, Ave. thickness = 3.17 mm, S.D. = 0.06 mm, Polyester

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
2441	45D155112	106	*	13	9.66	22.0	1	25
2442	45D155105	107	*	13	10.3	24.9	1	25
2443	45D155108	108	*	13	9.97	24.0	1	25
2444	45D155104	55.2	0.1	12	10.2	0.65	12,908	25
2445	45D155106	55.2	0.1	10	9.55	0.68	15,899	25
2446	45D155113	41.4	0.1	15	10.4	0.41	394,632	25
2447	45D155111	55.2	0.1	10	9.91	0.64	10,671	25
2448	45D155110	41.4	0.1	20	9.33	0.43	748,125	25
2449	45D155102	34.5	0.1	20	9.10	0.38	2,167,690	25 R
2450	45D155107	41.4	0.1	12	10.6	0.42	507,811	25
2451	45D155114	69.0	0.1	2	9.06	0.92	1,885	25
2452	45D155109	69.0	0.1	2	9.65	0.97	1,639	25
2453	45D155103	69.0	0.1	2	9.40	0.99	3,669	25
2599	45D155301	-139	*	13	----	----	1	25
2600	45D155302	-135	*	13	----	----	1	25
2601	45D155303	-135	*	13	----	----	1	25
2602	45D155304	-142	*	13	----	----	1	25

MATERIAL 50D155

Layup = $[\pm50]_3$, V_F = 0.39, Ave. thickness = 3.23 mm, S.D. = 0.11 mm, Polyester

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
2454	50D155114	66.8	*	13	8.33	39.0	1	25
2455	50D155113	66.9	*	13	8.39	34.0	1	25
2456	50D155107	62.6	*	13	8.43	20.0	1	25
2457	50D155104	34.5	0.1	20	8.62	0.41	136,803	25
2458	50D155116	34.5	0.1	15	9.00	0.41	72,943	25
2459	50D155115	34.5	0.1	15	8.32	0.42	96,273	25
2460	50D155111	27.6	0.1	15	8.11	0.36	1,855,523	25
2461	50D155106	41.4	0.1	5	8.81	0.48	11,555	25
2462	50D155108	41.4	0.1	7	8.74	0.52	11,608	25
2463	50D155112	41.4	0.1	4	8.90	0.53	11,509	25
2464	50D155105	27.6	0.1	15	8.42	0.37	1,159,160	25
2465	50D155101	58.3	*	13	8.43	30.0	1	25
2466	50D155102	66.5	*	13	9.52	22.2	1	25
2603	50D155301	-132	*	13	----	----	1	25
2604	50D155302	-142	*	13	----	----	1	25
2605	50D155303	-139	*	13	----	----	1	25
2606	50D155304	-138	*	13	----	----	1	25

MATERIAL 60D155

Layup = $[\pm60]_3$, V_F = 0.40, Ave. thickness = 3.11 mm, S.D. = 0.14 mm, Polyester

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
2482	60D155103	36.7	*	13	7.02	0.65	1	25
2483	60D155106	34.2	*	13	7.04	0.65	1	25
2484	60D155101	35.5	*	13	7.44	0.62	1	25
2576	60D155146	40.4	*	13	7.99	0.60	1	25
2548	60D155108	24.1	0.1	10	8.00	0.31	23,872	25
2549	60D155115	24.1	0.1	15	8.33	0.32	35,211	25
2550	60D155113	24.1	0.1	10	8.26	0.32	17,122	25
2551	60D155104	20.7	0.1	20	7.81	0.27	160,347	25
2552	60D155105	20.7	0.1	15	8.30	0.25	369,336	25
2553	60D155109	27.6	0.1	4	8.20	0.38	4,716	25
2554	60D155107	27.6	0.1	5	7.75	0.37	3,715	25
2555	60D155110	27.6	0.1	5	7.23	0.36	2,270	25
2556	60D155116	19.0	0.1	15	7.24	0.25	1,915,213	25
2557	60D155102	20.7	0.1	10	7.33	0.27	217,771	25
2607	60D155301	-144	*	13	----	----	1	25
2608	60D155302	-133	*	13	----	----	1	25
2609	60D155303	-143	*	13	----	----	1	25
2610	60D155304	-144	*	13	----	----	1	25

MATERIAL 70D155

Layup = $[\pm70]_3$, V_F = 0.40%, Ave. thickness = 3.17 mm, S.D. = 0.04 mm, Polyester

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
2485	70D155101	27.5	*	13	6.67	0.49	1	25
2486	70D155104	27.2	*	13	6.86	0.46	1	25
2487	70D155107	25.5	*	13	6.51	0.44	1	25
2577	70D155141	29.6	*	13	7.51	0.49	1	25
2525	70D155111	17.2	0.1	10	7.84	0.21	30,672	25
2526	70D155109	17.2	0.1	12	8.16	0.19	51,196	25
2527	70D155106	17.2	0.1	12	7.90	0.23	43,825	25
2528	70D155110	13.8	0.1	20	7.31	0.19	1,045,443	25
2529	70D155108	17.2	0.1	15	7.14	0.28	27,455	25
2530	70D155103	15.5	0.1	20	7.47	0.20	296,781	25
2531	70D155102	19.0	0.1	5	7.09	0.27	8,217	25
2532	70D155134	19.0	0.1	5	7.21	0.26	10,888	25
2533	70D155123	19.0	0.1	5	7.19	0.27	27,256	25
2534	70D155121	15.5	0.1	15	6.66	0.24	246,630	25
2535	70D155122	15.5	0.1	15	7.17	0.22	421,514	25
2611	70D155301	-133	*	13	----	----	1	25
2612	70D155302	-136	*	13	----	----	1	25
2613	70D155303	-138	*	13	----	----	1	25
2614	70D155304	-138	*	13	----	----	1	25

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes

MATERIAL 80D155

Layup = $[\pm 80]_3$, V_F = 0.38, Ave. thickness = 3.32 mm, S.D. = 0.10 mm, Polyester

2488	80D155105	26.7	*	13	7.79	0.38	1	25
2489	80D155103	24.9	*	13	7.00	0.34	1	25
2490	80D155101	24.0	*	13	7.05	0.37	1	25
2578	80D155141	26.6	*	13	7.75	0.38	1	25
2580	80D155201	26.2	*	13	9.30	0.30	1	25
2581	80D155202	26.1	*	13	8.15	0.34	1	25
2582	80D155203	27.4	*	13	8.65	0.34	1	25
2494	80D155120	26.0	*	13	6.95	0.35	1	25
2495	80D155122	24.4	*	13	6.43	0.35	1	25
2491	80D155102	17.2	0.1	2	7.59	0.24	2,096	25
2492	80D155112	17.2	0.1	2	6.79	0.25	865	25
2493	80D155104	17.2	0.1	2	7.35	0.24	3,673	25
2496	80D155121	12.1	0.1	25	7.49	0.15	8,000,000	25R
2497	80D155106	15.5	0.1	5	8.42	0.19	34,973	25
2498	80D155109	15.5	0.1	15	7.02	0.20	16,756	25
2499	80D155111	15.5	0.1	10	7.81	0.20	24,111	25
2500	80D155123	13.8	0.1	10	7.42	0.18	135,541	25
2501	80D155145	13.8	0.1	10	7.06	0.18	261,230	25
2502	80D155146	13.8	0.1	10	7.20	0.18	186,407	25
2619	80D155205	-148	*	13	----	----	1	25
2620	80D155206	-146	*	13	----	----	1	25
2621	80D155207	-156	*	13	----	----	1	25
2622	80D155208	-162	*	13	----	----	1	25

MATERIAL 90D155

Layup = $[\pm 90]_3$, V_F = 0.38, Ave. thickness = 3.32 mm, S.D. = 0.12 mm, Polyester

2467	90D155105	27.4	*	13	7.21	0.38	1	25
2468	90D155110	25.7	*	13	7.30	0.34	1	25
2469	90D155104	23.8	*	13	6.44	0.34	1	25
2579	90D155141	29.0	*	13	9.04	0.34	1	25
2470	90D155101	17.2	0.1	5	7.23	0.24	17,903	25
2471	90D155102	17.2	0.1	5	7.60	0.24	22,344	25
2472	90D155103	17.2	0.1	5	7.00	0.25	27,113	25
2473	90D155107	13.8	0.1	15	7.31	0.17	612,541	25
2474	90D155108	19.0	0.1	2	7.62	0.25	783	25
2475	90D155113	19.0	0.1	2	7.58	0.24	1,800	25
2476	90D155109	19.0	0.1	2	7.05	0.25	1,179	25
2477	90D155125	13.8	0.1	20	6.97	0.20	1,190,051	25
2578	90D155130	13.8	0.1	20	7.45	0.19	1,712,400	25
2479	90D155120	28.4	*	13	7.50	0.41	1	25
2480	90D155122	27.5	*	13	7.24	0.40	1	25
2481	90D155121	26.6	*	13	6.89	0.40	1	25
2623	90D155112	-108	*	13	----	----	1	25
2624	90D155111	-129	*	13	----	----	1	25

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
2625	90D155301	-126	*	13	----	----	1	25
2626	90D155302	-128	*	13	----	----	1	25

MATERIAL 0/90 ROVING

Layup = $[0/90]_7$, V_F = 0.47, Ave. thickness = 2.96 mm, S.D. = 0.16 mm, Polyester

2094	ROV01	380	*	13	22.8	2.40	1	ZERO tab
2095	ROV02	364	*	13	22.5	2.20	1	ZERO tab
2096	ROV03	374	*	13	24.8	2.20	1	ZERO tab
2097	ROV04	96.8	*	13	11.0	----	1	±45 tab
2098	ROV05	102	*	13	11.4	----	1	±45 tab
2099	ROV06	98.6	*	13	11.4	----	1	±45 tab
2100	ROV07	-213	*	13	20.3	----	1	ZERO tab
2101	ROV08	-230	*	13	21.6	----	1	ZERO tab
2102	ROV09	-240	*	13	23.9	----	1	ZERO tab
2103	ROV10	98.0	*	13	10.6	----	1	±45 tab
2104	ROV11	-100	*	13	11.2	----	1	±45 tab
2105	ROV12	-96.5	*	13	11.3	----	1	±45 tab
2106	ROV50	-207	*	13	13.7	----	1	ZERO tab
2107	ROV51	410	*	13	25.4	---	1	ZERO tab
2108	ROV52	102	*	13	13.9	----	1	±45 tab

HIGH CYCLE FATIGUE DATABASE

LONGITUDINAL RESULTS

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
001	CT4	1627	*	20	46	3.53	1	6 tab
002	AT2	1516	*	20	46	3.28	1	6 tab
003	AT26	1392	*	20	46	3.01	1	6 tab
004	CT3	1344	*	20	46	2.91	1	6 tab
005	AT27	689	0.1	20	46	1.49	2,982	6 tab
006	CT1	689	0.1	20	46	1.49	45,845	6 tab
007	AT19	469	0.1	60	46	1.01	157,502	6 tab
008	AT18	469	0.1	60	46	1.01	702,844	6 tab
009	AT23	414	0.1	80	46	0.90	602,984	6 tab
010	AT20	414	0.1	80	46	0.90	2,269,945	6 tab
011	CT5	310	0.1	100	46	0.67	5,902,329	6 tab
012	CT6	310	0.1	100	46	0.67	78,810,903	6 tab
013	CT2	310	0.1	100	46	0.67	110,539,817	6R tab
014	TF513	1296	*	20	39	3.31	1	6 tab
015	TF512	1426	*	20	39	3.64	1	6 tab
016	TF515	1396	*	20	39	3.56	1	6 tab
017	TF516	1310	*	20	39	3.34	1	6 tab
018	TF525	602	0.5	60	39	1.54	235,881	6 tab
019	TF526	602	0.5	60	39	1.54	284,150	6 tab
020	TF527	606	0.5	60	39	1.54	850,428	6 tab
021	TF521	535	0.5	80	39	1.36	417,082	6 tab
022	TF528	535	0.5	80	39	1.36	1,095,381	6 tab
023	TF522	535	0.5	80	39	1.36	4,112,276	6 tab
024	TF529	468	0.5	100	39	1.19	11,927,857	6 tab
025	TF520	468	0.5	100	39	1.19	16,711,593	6 tab
026	TF519	401	0.5	100	39	1.02	100,000,000	6R tab
027	AC14	-742	*	20	36	-2.09	1	6 tab
028	AC17	-741	*	20	36	-2.09	1	6 tab
029	AC13	-883	*	20	36	-1.93	1	6 tab
030	AC11	-414	10	40	36	-1.17	8,226	6 tab
031	AC12	-414	10	40	36	-1.17	10,886	6 tab
032	AC8	-414	10	40	36	-1.17	19,210	6 tab
033	AC15	-345	10	60	36	-0.97	337,992	6 tab
034	AC16	-345	10	60	36	-0.97	375,478	6 tab
035	AC7	-345	10	60	36	-0.97	587,407	6 tab
036	AC30	-276	10	100	36	-0.78	103,112,335	6R tab
037	AC10	-277	10	100	36	-0.78	103,573,682	6R tab
038	AC19	-552	2	60	35	-1.56	9,255	6 tab
039	AC26	-552	2	60	35	-1.56	12,319	6 tab
040	AC29	-552	2	60	35	-1.56	22,071	6 tab
041	AC20	-552	2	60	35	-1.56	46,085	6 tab
042	AC21	-483	2	80	35	-1.36	11,347	6 tab
043	AC24	-483	2	80	35	-1.36	38,158	6 tab
044	AC31	-483	2	80	35	-1.36	45,312	6 tab

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
045	AC22	-483	2	80	35	-1.36	103,970	6 tab
046	AC32	-448	2	100	35	-1.26	17,937	6 tab
047	AC35	-448	2	100	35	-1.26	3,891,657	6 tab
048	AC25	-448	2	100	35	-1.26	100,081,219	6R tab
049	AC23	-414	2	100	35	-1.17	107,413,026	6R tab
050	TCT1	1367	*	20	39	3.49	1	6 tab
051	TCT2	1387	*	20	39	3.54	1	6 tab
052	TCT3	1279	*	20	39	3.26	1	6 tab
053	TCT4	1527	*	20	39	3.89	1	6 tab
054	TCC1	-646	*	20	41	-1.57	1	6 tab
055	TCC2	-463	*	20	41	-1.13	1	6 tab
056	TCC3	-689	*	20	41	-1.68	1	6 tab
057	TCC4	-537	*	20	41	-1.30	1	6 tab
058	TC15	264	-1	30	40	0.66	124,952	6 tab
059	TC16	264	-1	30	40	0.66	337,226	6 tab
060	TC13	264	-1	30	40	0.66	437,113	6 tab
061	TC11	234	-1	30	40	0.58	591,914	6 tab
062	TC7	234	-1	30	40	0.58	781,045	6 tab
063	TC9	234	-1	30	40	0.58	1,981,821	6 tab
064	TC22	205	-1	40	40	0.51	2,037,672	6 tab
065	TC18	205	-1	40	40	0.51	6,141,627	6 tab
066	TC6	205	-1	40	40	0.51	7,080,727	6 tab
067	TC10	205	-1	40	40	0.51	7,605,707	6 tab
068	TC21	176	-1	50	40	0.44	10,382,631	6 tab
069	TC19	176	-1	50	40	0.44	17,272,745	6 tab
070	TC20	176	-1	50	40	0.44	100,000,000	6R tab
071	TC601	1618	*	20	40	4.02	1	6 tab
072	TC602	1382	*	20	40	3.44	1	6 tab
073	TC603	1410	*	20	40	3.51	1	6 tab
074	TC604	-746	*	20	40	-1.86	1	6 tab
075	TC605	-716	*	20	40	-1.78	1	6 tab
076	TC606	-687	*	20	40	-1.71	1	6 tab
077	TC608	294	-0.5	20	--	----	54,401	6 tab
078	TC609	294	-0.5	20	--	----	151,631	6 tab
079	TC613	294	-0.5	20	--	----	2,215,625	6 tab
080	TC610	257	-0.5	20	--	----	338,635	6 tab
081	TC611	257	-0.5	20	--	----	677,151	6 tab
082	TC616	257	-0.5	20	--	----	4,237,939	6 tab
083	TC614	257	-0.5	20	--	----	4,554,382	6 tab
084	TC612	220	-0.5	20	--	----	3,089,148	6 tab
085	TC615	220	-0.5	20	--	----	11,113,718	6R tab

TRANSVERSE RESULTS

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
086	90CF6T	-127	*	20	9	----	1	13 tab
087	90CF5T	-112	*	20	9	----	1	13 tab
088	90CF7T	-111	*	20	9	----	1	13 tab
089	90CF10T	-70	10	50	9	-0.79	13,122	13 tab
090	90CF17T	-70	10	50	9	-0.79	33,632	13 tab

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
091	90CF15T	-70	10	50	9	-1.79	268,262	13 tab
092	90CF12T	-64	10	70	9	-0.72	290,250	13 tab
093	90CF11T	-64	10	70	9	-0.72	697,512	13 tab
094	90CF18T	-64	10	70	9	-0.72	1,330,488	13 tab
095	90CF21T	-59	10	100	9	-0.65	12,000,998	13 tab
096	90CF9T	-59	10	100	9	-0.65	34,986,168	13 tab
097	90CF20T	-55	10	100	9	-0.62	107,839,549	13R tab
098	CF501T	-113	*	20	9	----	1	13 tab
099	CF502T	-113	*	20	9	----	1	13 tab
100	CF503T	-121	*	20	9	----	1	13 tab
101	CF504T	-115	*	20	9	----	1	13 tab
102	CF518T	-88	2	40	9	-0.98	121,730	13 tab
103	CF514T	-88	2	40	9	-0.98	511,744	13 tab
104	CF517T	-88	2	40	9	-0.98	621,878	13 tab
105	CF513T	-82	2	60	9	-0.92	853,552	13 tab
106	CF512T	-82	2	60	9	-0.92	2,675,404	13 tab
107	CF507T	-82	2	60	9	-0.92	3,705,190	13 tab
108	CF511T	-76	2	80	9	-0.85	31,971,669	13 tab
109	CF523T	-76	2	80	9	-0.85	100,682,804	13R tab
110	90FT5T	22	*	20	6	0.25	1	13 tab
111	90FT6T	18	*	20	6	0.21	1	13 tab
112	90FT7T	23	*	20	9	0.27	1	13 tab
113	90FT1T	22	*	20	9	0.36	1	13 tab
114	90FT1T	14	0.1	60	9	0.16	9,383	13 tab
115	90FT19T	13	0.1	60	9	0.15	34,592	13 tab
116	90FT3T	13	0.1	60	9	0.15	31,952	13 tab
117	90FT16T	12	0.1	80	9	0.14	3,895,837	13 tab
118	90FT17T	12	0.1	80	9	0.14	2,372,150	13 tab
119	90FT15T	12	0.1	80	9	0.14	1,351,172	13 tab
120	90FT8T	12	0.1	100	9	0.14	2,987,855	13 tab
121	90FT4T	11	0.1	100	9	0.13	21,111,725	13 tab
122	90FT11T	11	0.1	100	9	0.12	102,350,298	13R tab
123	TI501T	21	*	20	9	0.24	1	13 tab
124	TI502T	21	*	20	9	0.25	1	13 tab
125	TI503T	23	*	20	9	0.27	1	13 tab
126	TI509T	15	0.5	60	9	0.18	53,275	13 tab
127	TI507T	15	0.5	60	9	0.18	114,090	13 tab
128	TI505T	15	0.5	60	9	0.18	523,634	13 tab
129	TI508T	14	0.5	80	9	0.16	1,308,671	13 tab
130	TI504T	14	0.5	80	9	0.16	1,665,220	13 tab
131	TI506T	14	0.5	80	9	0.16	9,806,694	13 tab
132	TI514T	13	0.5	80	9	0.15	31,443,023	13 tab
132	TI515T	13	0.5	80	9	0.15	34,693,646	13 tab
133	TI513T	13	0.5	80	9	0.15	50,666,199	13 tab
134	TCH1T	18	*	20	9	0.21	1	13 tab
135	TCH2T	19	*	20	9	0.19	1	13 tab
136	TCH3T	17	*	20	9	0.19	1	13 tab
137	TCH12T	8	-1	20	--	----	45,172	13 tab
138	TCH12T	8	-1	30	--	----	151,463	13 tab

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
139	TCH10T	8	-1	30	--	----	794,513	13 tab
140	TCH14T	7	-1	60	--	----	47,385	13 tab
141	TCH13T	7	-1	60	--	----	1,043,369	13 tab
142	TCH16T	7	-1	60	--	----	3,009,395	13 tab
143	TCH7T	7	-1	60	--	----	3,973,407	13 tab
144	TCH15T	6	-1	80	--	----	11,733,016	13 tab
145	TCH19T	6	-1	100	--	----	100,153,319	13R tab

FIBERGLASS PREPREG (3M - 250) MATERIALS

MATERIAL PP

Layup = $[0]_{15}$, V_F = 0.56, Ave. thickness = 1.65 mm, S.D. = 0.03 mm, Epoxy

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
3480	PP112	1,251	*	13	44.0	2.60	1	25
3481	PP114	1,279	*	13	49.0	2.70	1	25
3482	PP115	1,332	*	13	51.6	2.70	1	25
3483	PP116	758	0.1	4	52.0	1.52	4,545	25
3484	PP101	758	0.1	2	46.5	1.68	7,252	25
3485	PP117	758	0.1	2	46.0	1.65	4,825	25
3486	PP104	414	0.1	12	47.4	0.84	839,263	25
3487	PP118	414	0.1	12	48.7	0.83	491,518	25
3488	PP105	414	0.1	12	42.5	0.92	631,118	25
3489	PP111	620	0.1	4	43.0	1.40	11,696	25
3490	PP113	621	0.1	4	50.5	1.27	13,690	25
3491	PP110	620	0.1	4	44.3	1.36	26,209	25
3492	PP107	517	0.1	8	45.6	1.09	88,979	25
3493	PP104	517	0.1	8	----	----	125,521	25
3494	PP103	517	0.1	8	----	----	56,119	25
3495	PP102	517	0.1	10	45.9	1.14	124,781	25
3496	PP106	621	0.1	4	47.6	----	17,314	25
3497	PP108	414	0.1	12	----	----	269,211	25
3844	PP131	-829	*	13	----	----	1	25
3845	PP126	-842	*	13	----	----	1	25
3846	PP136	-694	*	13	----	----	1	25

MATERIAL PP45

Layup = $[(\pm 45)_2]_S$, V_F = 0.54, Ave. thickness = 1.65 mm, S.D. = 0.04 mm, Epoxy

3503	PP45201	153	*	13	16.0	----	1	25
3504	PP45210	153	*	13	18.0	0.85	1	25
3505	PP45209	158	*	13	17.7	----	1	25
3506	PP45208	83	0.1	10	18.6	0.55	27,509	25
3507	PP45207	83	0.1	10	20.0	0.52	45,091	25
3508	PP45203	83	0.1	10	18.2	0.56	19,125	25
3509	PP45206	69	0.1	15	18.9	0.40	473,337	25
3510	PP45205	69	0.1	20	15.7	0.51	209,295	25
3511	PP45204	69	0.1	20	18.6	0.43	402,619	25
3512	PP45202	103	0.1	2	17.4	0.86	737	25
3847	PP45212	-160	*	13	----	----	1	25

MATERIAL PPDD5

Layup = $[(0)_3/\pm 45/(0)_3]_S$, V_F = 0.56, Ave. thickness = 3.31mm, S.D. = 0.09 mm, Epoxy

3658	PPDD5118	----	*	13	39.2	----	1	15
3659	PPDD5119	----	*	13	41.6	----	1	15
3660	PPDD5120	----	*	13	38.0	----	1	15

TEST & SAMPLE ID #		MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
3662	PPDD5104	1,115	*	13	----	----	1	6
3663	PPDD5106	1,070	*	13	----	----	1	6
3664	PPDD5110	1,080	*	13	----	----	1	6
3665	PPDD5112	483	0.1	12	----	----	33,888	6
3666	PPDD5109	345	0.1	12	----	----	633,893	6
3667	PPDD5114	345	0.1	12	----	----	408,106	6
3668	PPDD5111	345	0.1	12	----	----	320,402	6
3669	PPDD5117	414	0.1	10	----	----	66,207	6
3670	PPDD5116	621	0.1	2	----	----	3,119	6
3671	PPDD5115	621	0.1	2	----	----	4,786	6
3672	PPDD5101	621	0.1	2	----	----	2,517	6
3708	PPDD5108	483	0.1	10	----	----	62,141	6
3709	PPDD5105	483	0.1	5	----	----	32,975	6

LIST OF TESTS OMITTED FROM THE DATABASE LIST DUE TO TESTING IRREGULARITIES, PREMATURE BUCKLING, FIBER ORIENTATION OR GRIPPING PROBLEMS CAUSING AN INVALID TEST.

TEST &	SAMPLE ID #	MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
A1	102A	454	*	0.02	----	----	1	50tab
A3	101A	423	*	0.02	----	----	1	50tab
A4	103A	347	*	----	----	----	1	50tab
1	104A	185	0.5	----	----	----	1,400	50tab
2	105A	130	0.1	10	----	----	155,201	50tab
3	106A	333	0.1	0.5	----	----	210	50tab
4	107A	288	0.1	1	----	----	873	50tab
5	106B	338	*	----	----	----	----	50tab
8	101B	361	0.1	0.5	----	----	1,860	50tab
10	104B	408	0.1	0.1	----	----	40	50tab
11	105B	420	0.1	0.1	----	----	160	50tab
14	110B	356	0.1	0.1	----	----	480	50tab
19	115B	399	0.1	0.1	18.3	----	180	50tab
286	111Y	583	*	107	23.1	----	1	25tab
287	117Y	591	*	107	21.3	2.12	1	25tab
288	105Y	611	*	107	22.5	2.53	1	25tab
295	106Y	276	0.1	25	25.1	1.11	73,530	25tab
307	115X	345	0.1	5	25.1	1.42	1,441	25tab
308	111X	345	0.1	5	23.6	1.46	2,114	25tab
324	148X	-332	*	13	26.8	2.3	1	25tab
325	146X	-378	*	13	25.9	1.73	1	25tab
326	149X	-326	*	13	24.0	1.39	1	25tab
338	155X	-241	10	10	30.9	0.74	2,000	25tab
448	243AA	241	-1	2	18.9	----	17	25tab
481	273AA	----	10	25	----	----	91,520	25tab
686	193Y	-329	*	13	----	----	1	25tab
687	182Y	-359	*	13	----	----	1	25tab
688	184Y	-355	*	13	----	----	1	25tab
698	165Y	-246	10	5	----	----	31	25tab
700	174Y	-246	10	10	25.7	1.07	235	25tab
703	171X	-345	10	2	----	----	137	25tab
704	165X	-345	10	1	----	----	178	25tab
Material DD3 had random mat in between the 0° and ±45°, $(0/M/\pm45/M/0)_S$, $V_F = 0.48$, thickness = 2.92 mm, D155 and DB120 fabrics with an unknown mat.								
1054	DD3104	792	*	13	29.3	2.70	1	22
1055	DD3106	483	0.1	2	29.0	1.66	687	22
1056	DD3105	483	0.1	2	27.4	1.76	869	22
1057	DD3103	414	0.1	5	27.4	1.50	1,932	22
1058	DD3102	345	0.1	10	----	----	6,629	22
1059	DD3101	345	0.1	10	----	----	4,909	22
1130	DD7130	-448	*	13	----	----	1	25
1131	DD7126	-460	*	13	----	----	1	25
1132	DD7121	-463	*	13	----	----	1	25
1133	DD7120	-451	*	13	----	----	1	25
1134	DD6127	-310	10	5	----	----	84,387	25

TEST &	SAMPLE ID #	MAX. STRESS MPa	R	Q Hz	E GPa	e %	CYCLES TO FAIL	WIDTH (mm) and Notes
1135	DD6119	-345	10	5	----	----	13,297	25
1136	DD6120	-345	10	5	----	----	10,844	25
1137	DD7123	-345	10	10	----	----	89,517	25
1138	DD7122	-345	10	10	----	----	73,744	25
1139	DD7125	-345	10	15	----	----	100,821	25
1141	DD6122	-310	10	25	----	----	110,395	25
1150	DD6134	-480	*	13	----	----	1	25
1151	DD6117	-461	*	13	----	----	1	25
1152	DD6126	-379	10	10	----	----	6,797	25
1162	DD7127	-379	10	10	----	----	1,735	25
1176	DD6142	-425	*	13	----	----	1	25
1177	DD7149	-577	*	13	----	----	1	25
1205	DD8107	483	0.1	5	15.0	----	--	22
1208	DD8110	414	0.1	5	----	----	30	22
1222	DD9115	483	0.1	5	33.4	----	17	22
1225	DD9105	276	0.1	5	33.2	----	8,873	22
Material D155D - D155 fabric, $V_F = 0.29$, has fiber wash and fiber misalignment								
2137	D155D201	680	*	13	25.2	2.8	1	25
2138	D155D205	746	*	13	29.0	2.7	1	25
2139	D155D211	763	*	13	29.3	----	1	25
2140	D155D210	414	0.1	1	26.1	1.65	--	25
2213	D155H105	552	0.1	4	35.9	1.54	8,460	25
2214	D155H104	552	0.1	2	28.4	----	277	25
2769	D155G308	-500	10	5	----	----	46,980	25
Material 10D155 with a gage length of 100 mm (too short)								
2567	10D155125	172	0.1	5	27.6	0.66	1,747	25
2568	10D155126	172	0.1	5	21.2	0.87	9,287	25

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