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COMPOSITE HEAT DAMAGE

PART 1. MECHANICAL TESTING OF IM6/3501-6 LAMINATES

PART 2. NONDESTRUCTIVE EVALUATION STUDIES OF IM6/3501-6 LAMINATES

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Oak Ridge National Laboratory

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Oak Ridge Gaseous Diffusion Plant

May 1990

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ABSTRACT

The matrix-dominated mechanical properties of heat-damaged and nonheat-damaged IM6/3501-6 laminates are presented in Part 1. "Wet" and "dry" preconditioned laminates were exposed on one side to temperatures ranging from room temperature to 750°F for 0 to 60 min and subsequently tested at ambient conditions in accordance with American Society for Testing and Materials (ASTM) standards, including compression - ASTM D3410-87, flexure - ASTM D790-87, short-beam shear - ASTM D2344-84, and shore-D hardness -ASTM D2240-86. Shore-D-hardness testing was a poor indicator of mechanical strength loss. Heat-damaged 0° compression specimens were the least sensitive to strength degradation compared with the other properties that were tested. Heat-damaged specimens that were tested in shear and flexure suffered significant strength reduction and degradation at exposure temperatures ≥ 550°F for 5 to 60 min. The percent weight loss, micrometer measurements, and visual differences of IM6/3501-6 specimens as a function of elevated temperature exposure are reported. The results of heat-degradation effects on IM6/3501-6 specimens utilizing various nondestructive evaluation (NDE) techniques, including digital pulse (broadband), tone burst (monochromatic), ultrasonic color C scanning, and "leaky" Lamb waves are presented in Part 2. Preliminary results indicated that the "leaky" Lamb-wave technique appeared to be the most promising NDE tool for characterizing the level of heat damage in IM6/3501-6 laminates. This technique is capable of detecting relative changes in a given sample at a particular location; however, it does not appear to have the capability of providing absolute results on random samples.

PART 1. MECHANICAL TESTING OF IM6/3501-6 LAMINATES

INTRODUCTION

Part 1 of the report is concerned specifically with the effects of preconditioning and elevated temperature/time on the matrix-dominated mechanical properties of IM6/3501-6 composite laminates tested at room temperature.

A series of 21-ply laminate test specimens were separated into two groups—one group was preconditioned in a humid or "wet" environment, and the other group was preconditioned in a "dry" environment and allowed to weight stabilize according to American Society for Testing and Materials (ASTM) D570-81. Subsequent to the preconditioning phase, the specimens were exposed to elevated temperatures (on only one side) for preset periods of time followed by a cool down to ambient conditions. After the specimens were cooled to room temperature, they were mechanically tested in compression, flexure, short-beam shear (SBS), and shore D.

The mechanical properties were tested in accordance with ASTM standards and included compression - ASTM D3410-87, flexure - ASTM D790-87, SBS - ASTM D2344-84, and shore D - ASTM D2240-86.

EXPERIMENTAL

SAMPLE MATERIALS

All investigative work was performed on laminate specimens that were cut from fabricated panels composed of Hercules IM6G/3501-6 unidirectional prepreg tape (12 in. wide, 147 to 148 g/m^2, and 36 wt % resin content).

PANEL FABRICATION

The IM6/3501-6 prepreg tapes were cut into plies with the desired fiber orientations and dimensions shown in Fig. 1. The 5.5- to 6-mil-thick plies were then laid up by hand into 30- by 10-in.-sized panels (nominal thickness = 0.125 in.) according to the following 21-ply stacking sequence, which is representative of the aft-spar lay-up on the V-22 Osprey: $[+45°, 90°, (-45°, +45°)_4, 0°, (+45°, -45°)_4, 90°, +45°]$.

The IM6/3501-6 prepreg panels were vacuum-bag cured in an autoclave according to the following process specification, which is based on Hercules' recommendations for this material.

1. Place vacuum-bagged lay-up in autoclave.

2. Apply full vacuum.

3. Apply 100 psi.

4. At a rate of 3 to 5°F/min, raise the laminate temperature to 240°F ± 10°F. Hold for 60 to 70 min.

5. At a rate of 3 to 5°F/min, raise the laminate temperature to 350°F ±10°F. Hold for 110 to 130 min.

6. Allow laminate to cool at a maximum rate of 5°F/min to below 200°F. Release vacuum and autoclave pressure.

7. Remove lay-up from autoclave and unbag.

Following cure, the panels were cut into appropriately sized test specimens using a diamond-impregnated saw (Fig. 2).

PRECONDITIONING OF SPECIMENS

To compare the effects of moisture on the composite mechanical properties, both "dry" and "wet" preconditioned test specimens were prepared. Prior to heat exposure, one-half of the specimens were preconditioned in a vacuum oven at 120°F (dry), while the other half were placed in a humidity chamber at 120°F and 98% relative humidity (wet). Selected samples from each group were monitored weekly to determine when the specimens were saturated according to ASTM D570-81. Figure 3 is representative of the weight gain (wet specimens) or weight loss (dry specimens) vs time of one series of test specimens during the preconditioning phase. Table 1 is a compilation of the preconditioning data for the test specimens from a given panel that were tested in flexure (FLEX), shore D, and SBS.

The specimens that were tested in Compression were also closely monitored according to ASTM D570-81 but are not included in Table 1 due to the potential erroneous data resulting from the concomitant absorption or desorption of moisture from both the composite and the fiberglass tab material. The average percent weight gain or weight loss of the compression specimens during the preconditioning phase is assumed to be in close approximation to the flexure and shore-D specimens.

HEAT EXPOSURE OF SPECIMENS

Radiant-heat exposure was performed on only one face of the wet and dry preconditioned test specimens at a fixed temperature for a specified time without load.

Table 1. Preconditioning data of IM6/3501-6 specimens

Panel number	Preconditioning time (days)	Average weight gain for "wet" specimens (5-spec./panel)	Average weight loss for "dry" specimens (5 spec./panel)	Mechanical property
2	56	0.75	0.28	Flex/shore
3	56	1.12	0.16	Flex/shore
5	56	0.81	0.24	Flex/shore
8	56	0.84	0.27	Flex/shore
Average	56	0.87	0.24	
16	56	0.85	0.27	SBS
18	36	0.74	0.06	Flex/shore
19	36	0.89	0.08	Flex/shore
20	36	0.64	0.06	Flex/shore
21	36	0.77	0.08	Flex/shore
Average	36	0.76	0.07	
22	28	0.99	0.10	SBS
23	28	0.97	0.04	SBS
10	28	0.87	0.32	SBS
Average	28	0.94	0.15	
19	82	1.2 (1 spec.)	0.11 (2 spec.)	Flex
20	82	0.93 (1 spec.)	0.08 (2 spec.)	Flex
21	82	1.0 (2 spec.)	0.11 (3 spec.)	Flex
Average	82	1.05	0.10	

Groups of the preconditioned test specimens, except the room temperature control specimens, were exposed to one of the following conditions of temperature and exposure times.

1. 350, 450, 550, and 650°F for 60 min;

2. 550, 650, and 750°F for 5 and 30 min; and

3. 750°F for 10 min.

Following heat exposure, the specimens were removed from the heating chamber to a room-temperature environment and allowed to cool to ambient conditions prior to mechanical testing.

The heat source was a manually controlled, radiant-quartz heater (Figs. 4 and 5) equipped with six thermocouples (six thermocouples were bonded to the top, middle, and bottom heat-exposed faces of two test specimens located on opposite sides of the heating chamber) and was used to simulate a sudden one-sided heat blast from a jet engine. The ramp-up to the exposure temperature was achieved as quickly as possible. Figure 6 is a representative example of the ramp-up rate and temperature control of one series of test specimens during heat exposure.

The dry and wet room-temperature control specimens were removed from the environmental chambers and allowed to cool to ambient conditions before mechanical testing.

MECHANICAL PROPERTY TESTING

The mechanical property testing was performed by the Mechanical Testing Laboratory at the Oak Ridge Gaseous Diffusion Plant in Oak Ridge, Tennessee. The mechanical property tests that were dominated by the matrix or matrix/fiber interface were the ones investigated in this project because these properties were the most likely to be first influenced by heat damage.

All testing was carried out in accordance with ASTM test constraints, including ambient pressure, 73.4 ± 3.6°F ambient temperature, and 50 ± 5% relative humidity.

COMPRESSION TESTING

Nominal 5.5- by 1-in. fiberglass-tabbed specimens were tested according to ASTM D3410-87, procedure B, utilizing the IITRI fixture (Fig. 7). The specimens were cut so that the middle 0° ply fibers were parallel with the long side of the specimen.

The specimens had a gage length of 0.50 in., and testing was performed on an Instron machine at a rate of 0.05 in./min. Five specimens were tested to yield an average

compression strength. Prior to heat exposure, the tabbed section of the specimens was wrapped with reflective aluminum tape to protect the tabs against heat damage and from delaminating from the composite.

Figure 8 and Appendix A summarize the 0° compressive property and statistical results for the IM6/3501-6 test specimens according to ASTM D3410-87.

SHORT-BEAM-SHEAR TESTING

A three-point bend test was conducted on 0.75- by 0.25-in.-sized specimens to quantify the interlaminar shear strength by the short-beam method according to ASTM D2344-84 (Fig. 9). The specimens were cut either with the middle 0° ply fibers parallel with the long side of the specimen (0° properties) or with the middle 0° ply fibers perpendicular to the long side of the specimen (90° properties).

Testing was carried out on an Instron machine at a rate of 0.05 in./min on specimens having a span:depth ratio of 4:1 (support span = 0.50 in., nominal depth = 0.125 in.). The specimens were tested with the heat-exposed side down to obtain an average short-beam-shear strength.

Figure 10 and Appendix B summarize the 0° short-beam-shear property and statistical results for the IM6/3501-6 test specimens according to ASTM D2344-84. Specimens exposed to temperatures above 650°F separated into fragments upon removal from the heating chamber and were not tested.

Figure 11 and Appendix C summarize the 90° short-beam-shear property and statistical results for the IM6/3501-6 test specimens according to ASTM D2344-84. Specimens exposed to temperatures above 650°F separated into fragments upon removal from the heating chamber and were not tested.

In addition, percent weight loss data were generated on 0° IM6/3501-6 short-beam-shear specimens by weighing (using a Mettler analytical balance) immediately before and after heat exposure in an attempt to correlate interlaminar shear strength degradation with weight loss as a function of temperature/time. Figure 12 and Appendix D summarize the percent weight loss data and statistical results for the 0° short-beam-shear IM6/3501-6 specimens.

FLEXURAL TESTING

A four-point bend test was performed on nominal 3- by 1-in.-sized specimens according to ASTM D790-87, method 2, procedure A (Fig. 13). The specimens were cut with either the middle 0° ply fibers parallel with the long side of the specimen (0° properties) or with the middle 0° ply fibers perpendicular with the long side of the specimen (90° properties).

The flexural specimens had a span:depth ratio of 16:1 (support span = 2 in., load span = 0.67 in., nominal depth = 0.125 in.), and testing was done on an Instron machine at a

rate of 0.06 in./min. The specimens were tested with the heat-exposed side down (in tension) to yield average flexural strength results.

Figure 14 and Appendix E summarize the 0° flexural property and statistical results for the IM6/3501-6 specimens according to ASTM D790-87.

Figure 15 and Appendix F summarize the 90° flexural property and statistical results for the IM6/3501-6 specimens according to ASTM D790-87.

In addition, 90° flexural testing was performed on IM6/3501-6 specimens that were preconditioned for an extended period of 82 d. The average percent weight change for the wet and dry specimens after 82 d was +1.05 and -0.10%, respectively.

Appendix J summarizes the 90° flexural property and statistical results for the IM6/3501-6 specimens according to ASTM D790-87 after an extended preconditioning time.

SHORE-D-HARDNESS TESTING

A Shore digital durometer hardness tester, Model 71600, was utilized to obtain shore-D hardness values on nominal 3- by 1-in.-sized specimens to determine the effects of heat exposure on composite hardness according to ASTM D2240-86 (Fig. 16). An average shore-D hardness value was obtained for each temperature/time set point, and each specimen was tested at six different locations (at least 0.25 in. apart) on the heat-exposed side.

Figure 17 and Appendix G summarize the average shore-D hardness values, percent strength retention, and percent coefficient of variation for the dry and wet preconditioned IM6/3501-6 specimens, respectively, according to ASTM D2240-86.

In addition, thickness measurements were performed on both wet and dry preconditioned flexural and shore-D test specimens. Using a micrometer, thickness readings were taken between opposite faces of the specimen at their thickest section. Readings were performed on specimens from panels 2, 3, 5, 8, 17, 18, 19, 20, and 21.

Figure 18 and Appendix H summarize the micrometer measurements at maximum thickness on flexural and shore-D IM6/3501-6 specimens after heat exposure.

STATISTICAL t TESTING

To determine whether there was any statistically significant difference between the mechanical strength averages of the wet and dry preconditioned IM6/3501-6 specimens, t tests were performed at each specific temperature/time for compression, flexure, short-beam shear, and shore D.

Large values of t (experimental) (all equations and critical values for t are given in Appendix I) occur when the difference in the sample averages is large compared with the standard deviation for this difference. A large value for t (experimental) indicated that the observed difference in sample averages was too large to be explained by sampling error alone. Therefore, when t (experimental) was larger than t (critical) in absolute value, there was a statistically significant difference (at the 95% confidence level) between the strength averages of the wet and dry preconditioned test specimens.

Appendix I is a summary of the t test results performed on the mechanical strength averages of the wet and dry preconditioned IM6/3501-6 specimens at each temperature/time.

CONCLUSIONS

There appears to be only a small statistically significant difference between the mean mechanical strength and mean shore-D hardness of the wet and dry preconditioned IM6/3501-6 specimens that were tested. A total of 64 combined wet- and dry-strength/hardness means were determined. Of these, 9.4% of the wet and 21.9% of the dry averages were statistically significantly greater (at the 95% confidence level) than their corresponding dry and wet means at the same temperature/time, respectively.

Shore-D hardness and 0° compressive-strength properties were the least affected by elevated temperature exposure. Shore-D-hardness testing was a very poor indicator of loss in mechanical strength of the IM6/3501-6 material after exposure to elevated temperatures. No significant decrease in shore-D hardness was realized until ~ 650° F, but by the time the material reached that temperature, it had lost ~ 65 to 98% of its 0° and 90° interlaminar shear and flexural strength. The interlaminar shear and flexural strength of the IM6/3501-6 specimens were lowered dramatically (retained only ~ 20 to 90% of their room-temperature strength) after exposure to 550° F.

At elevated temperatures, the 0° SBS and 0° flexural specimens retained a larger percentage of their room-temperature strengths compared with the 90° SBS and 90° flexural specimens, especially above an exposure temperature of 450° F.

No visual damage or thickness increase of the IM6/3501-6 3- by 1-in.-sized specimens was apparent at exposure temperatures of 550° F and below. Delamination, translaminar cracking, and an increase in specimen thickness were first visually observed at exposure temperatures of 650° F. At an exposure temperature of 650° F for 60 min, the thickness of the 3- by 1-in. specimens almost doubled compared with specimens exposed to 550° F and below. The thickness increase that was manifested at 650° F was accompanied by large weight losses of ~ 4 to 11%, depending on specimens' exposure time.

A drop-off in the 550° F wet and dry 90° flexural-strength averages of the IM6/3501-6 specimens after an extended preconditioning time of 82 days is unexplainable. Additional testing performed after various preconditioning intervals is needed before this finding can be substantiated because only a limited number of specimens were tested at one exposure temperature.

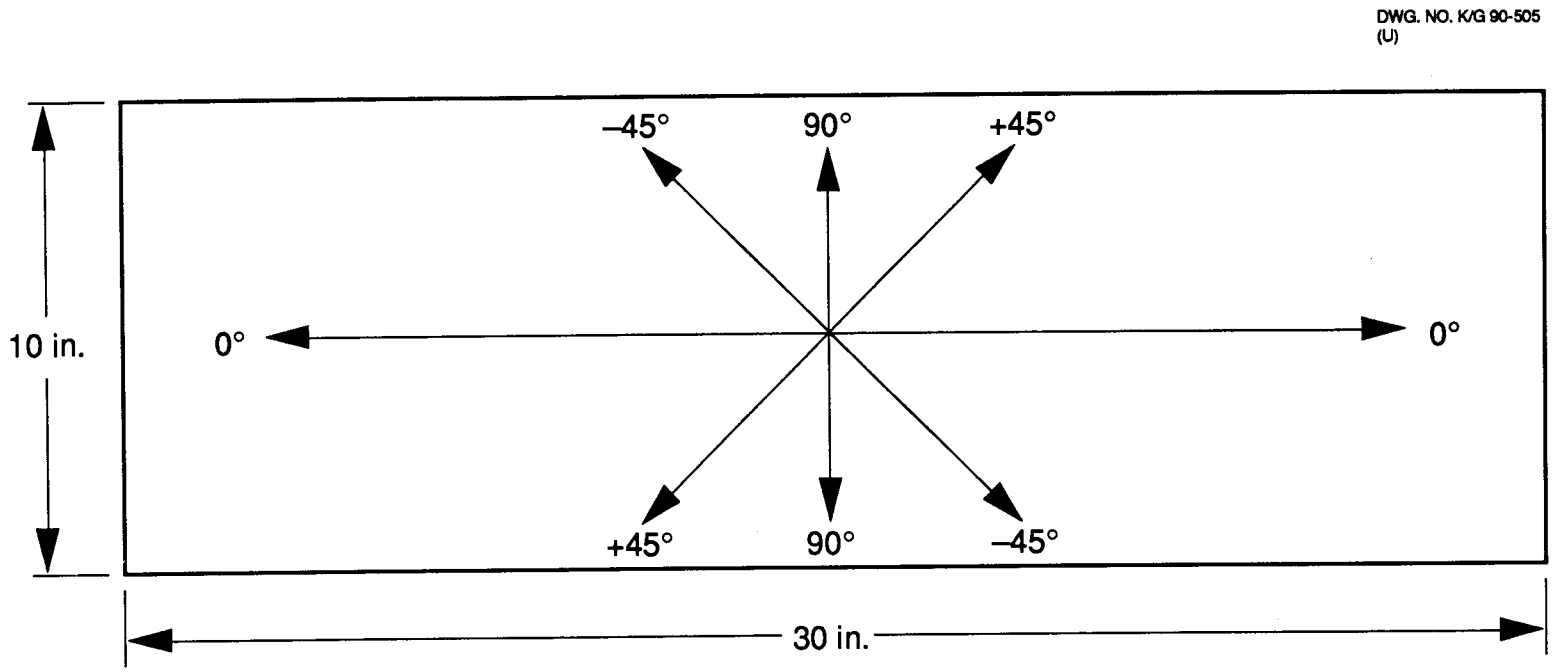


Fig. 1. Panel fiber orientation.

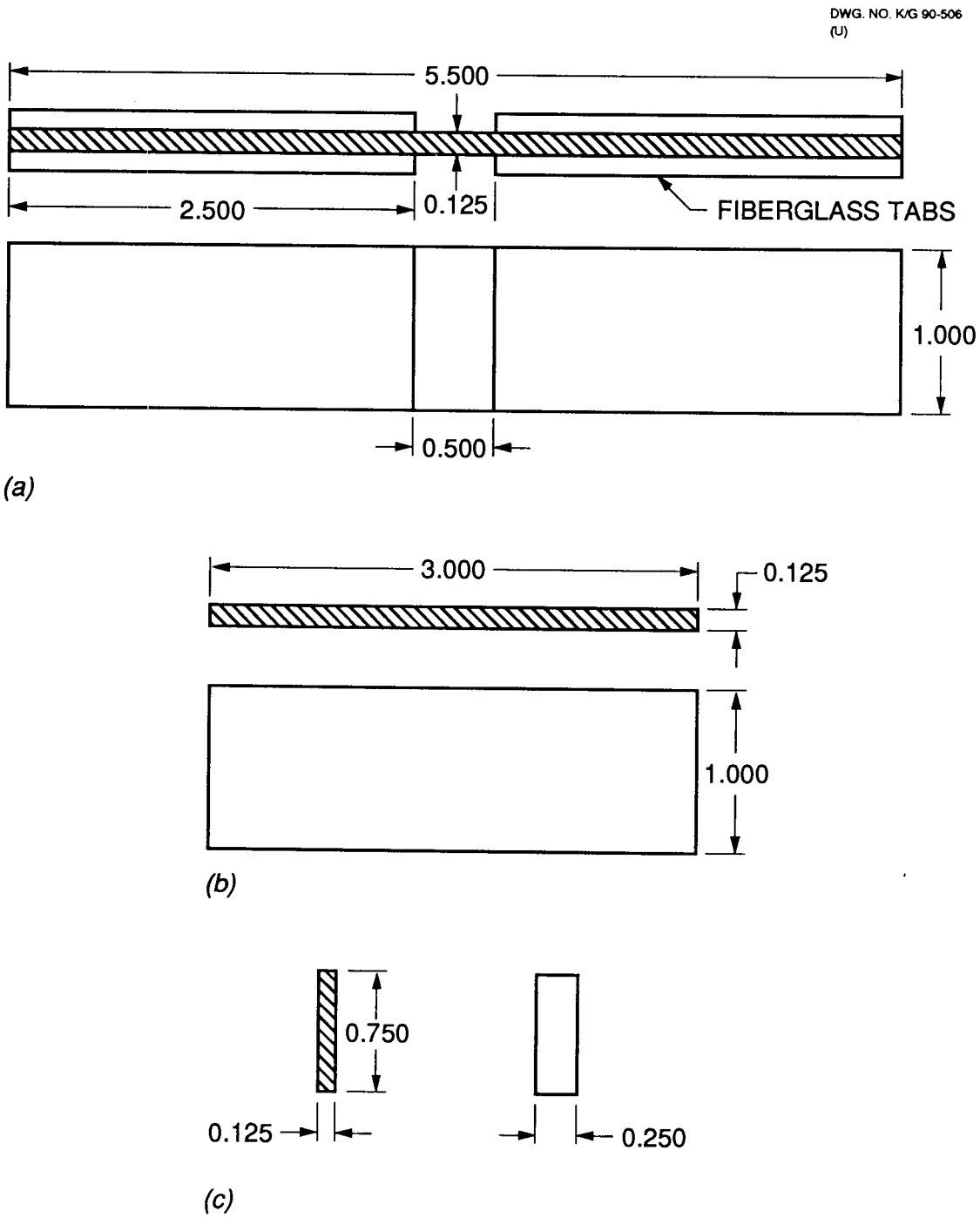


Fig. 2. Geometry of specimens for *(a)* compression, *(b)* flexure/shore-D, *(c)* short-beam-shear testing.

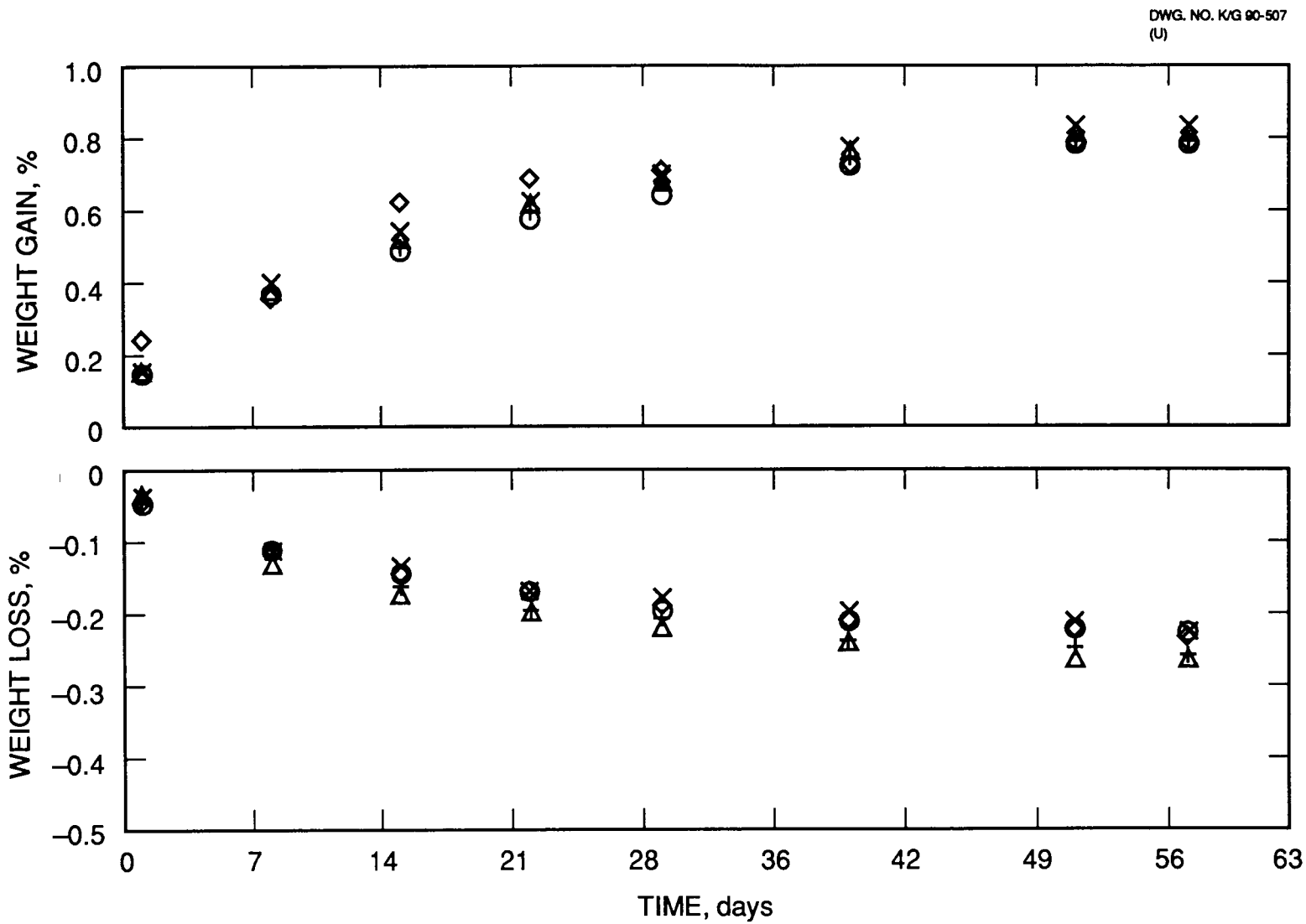


Fig. 3. Preconditioning profile of wet and dry IM6/3501-6 specimens, panel 5 data.

Fig. 4. Specimen heating chamber.

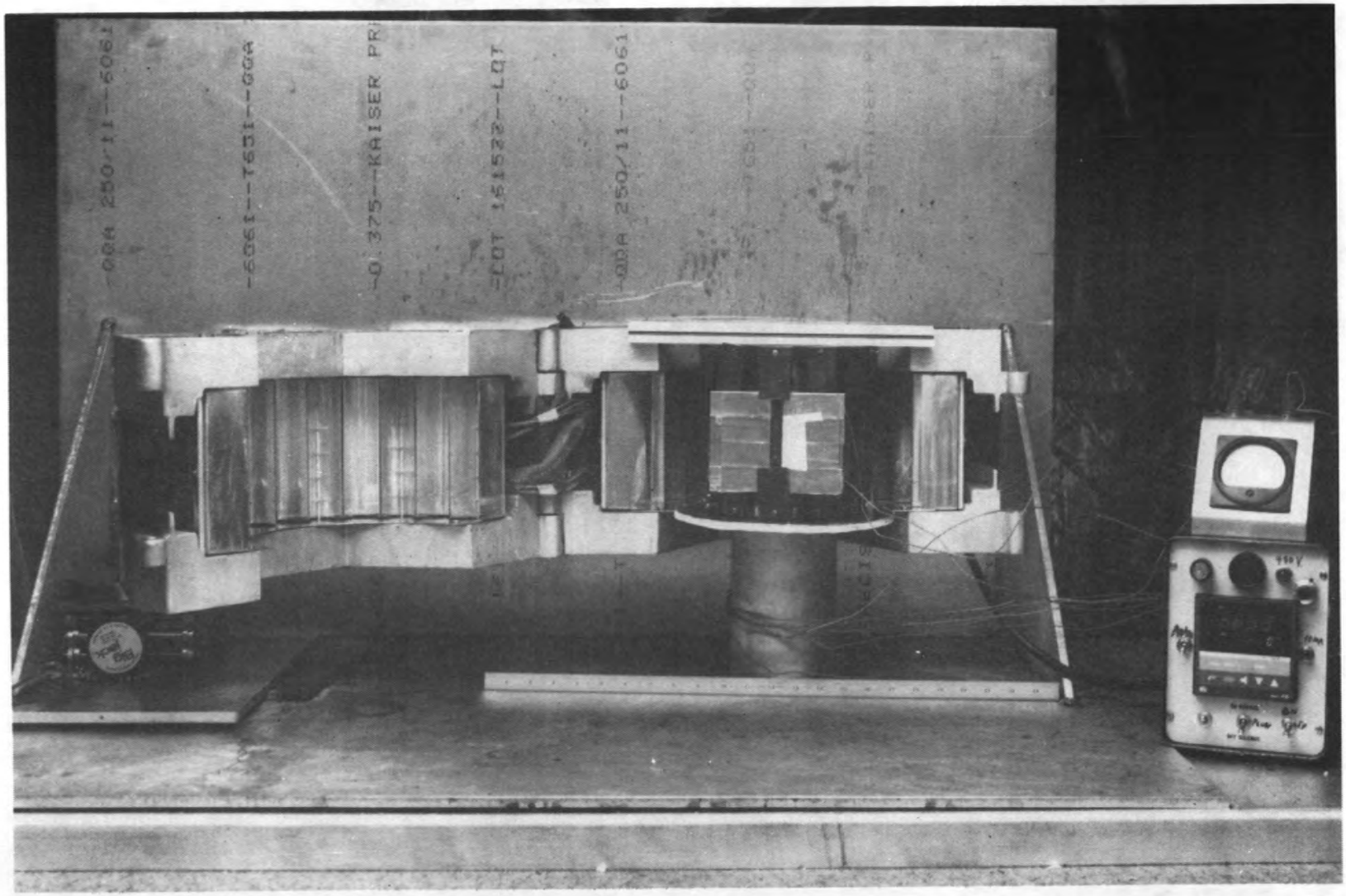


Fig. 5. Close-up view of specimen heating chamber.

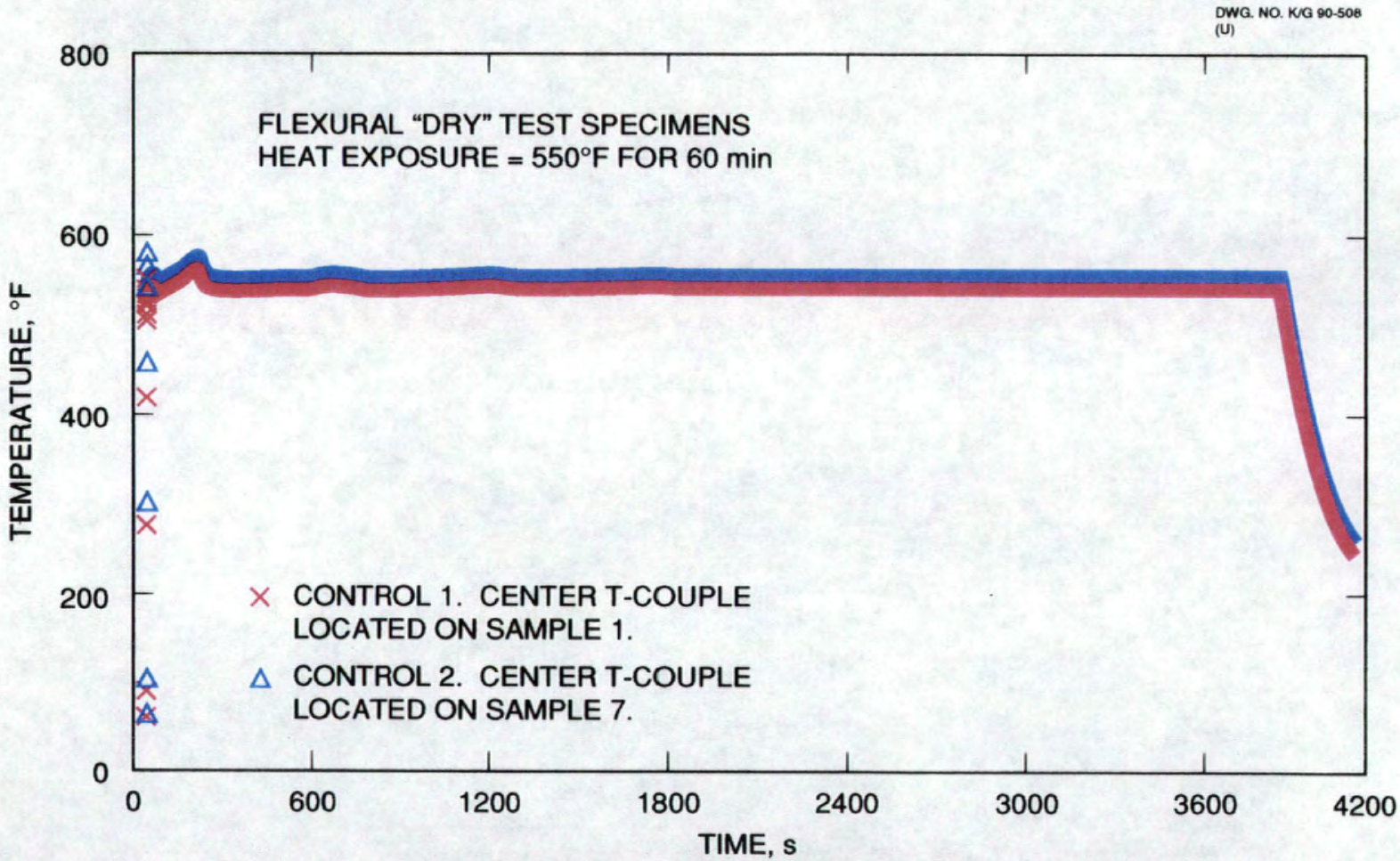


Fig. 6. Temperature monitoring of IM6/3501-6 specimens during heat exposure.

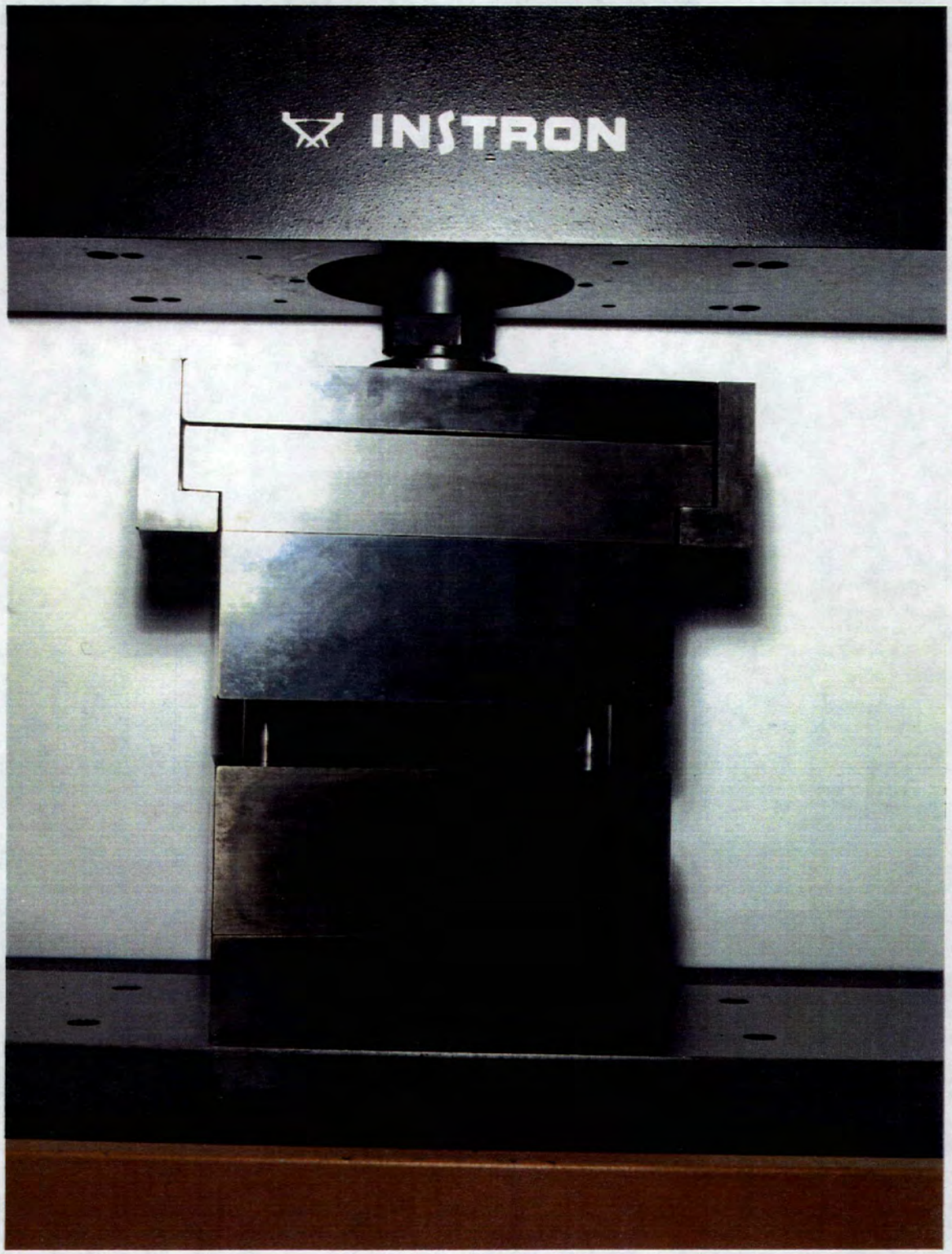
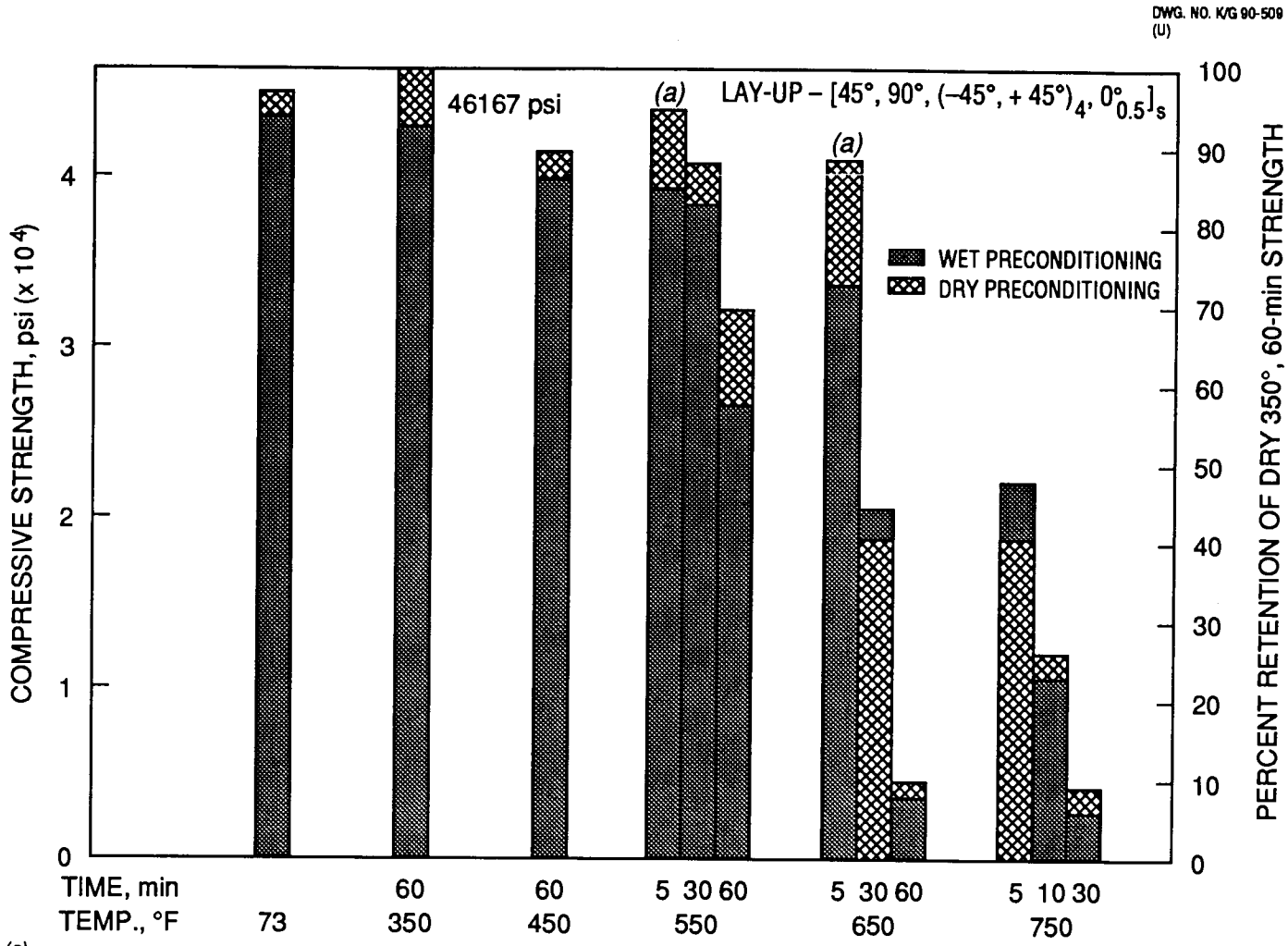


Fig. 7. IITRI fixture.



(a) WET AND DRY STRENGTH AVERAGES ARE STATISTICALLY SIGNIFICANTLY DIFFERENT AT THE 95% CONFIDENCE LEVEL.

Fig. 8. Test results for IM6/3501-6: ASTM D3410. Zero-degree compressive strength vs heat exposure temperature/time for wet and dry preconditioned specimens.

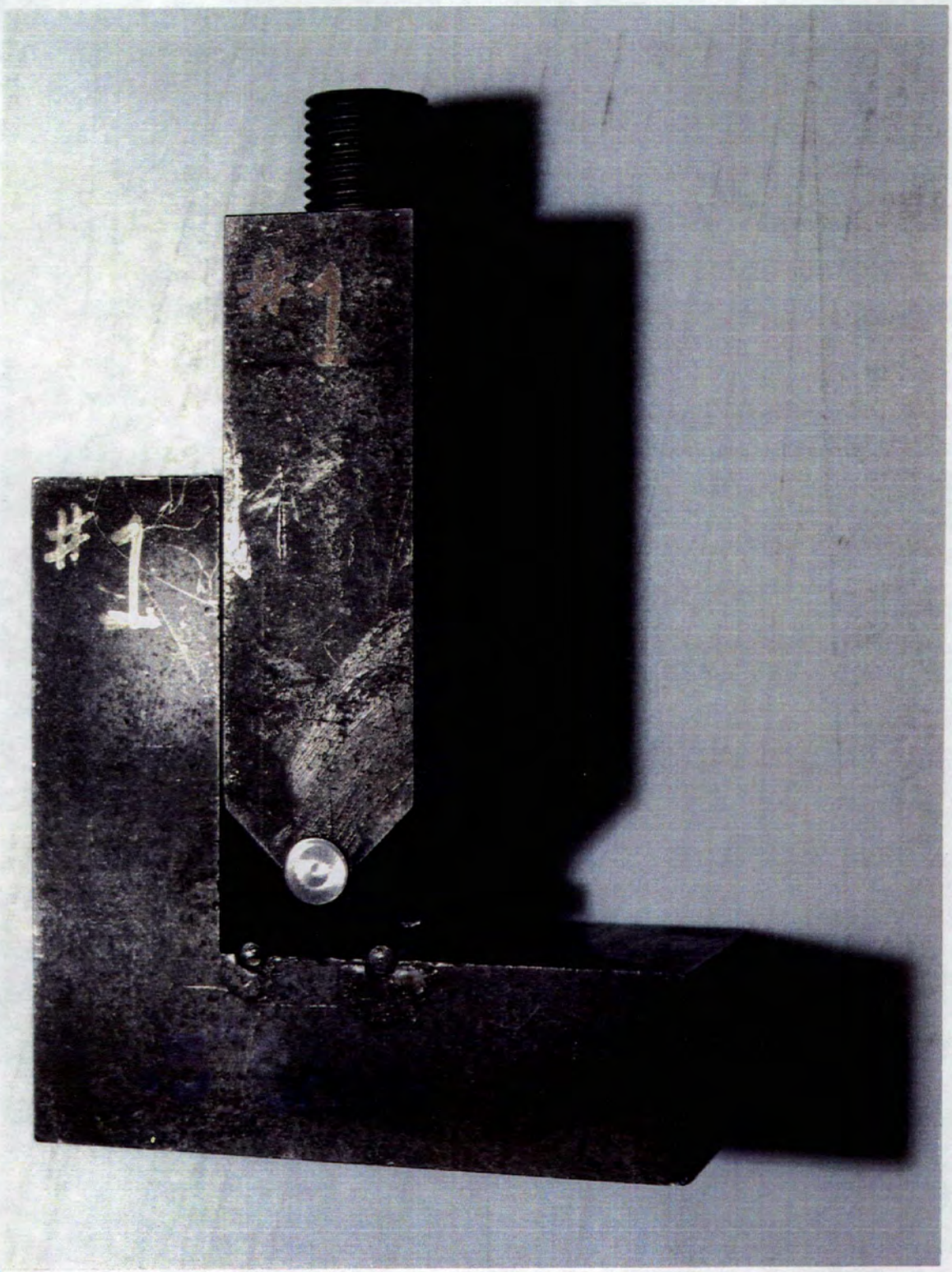
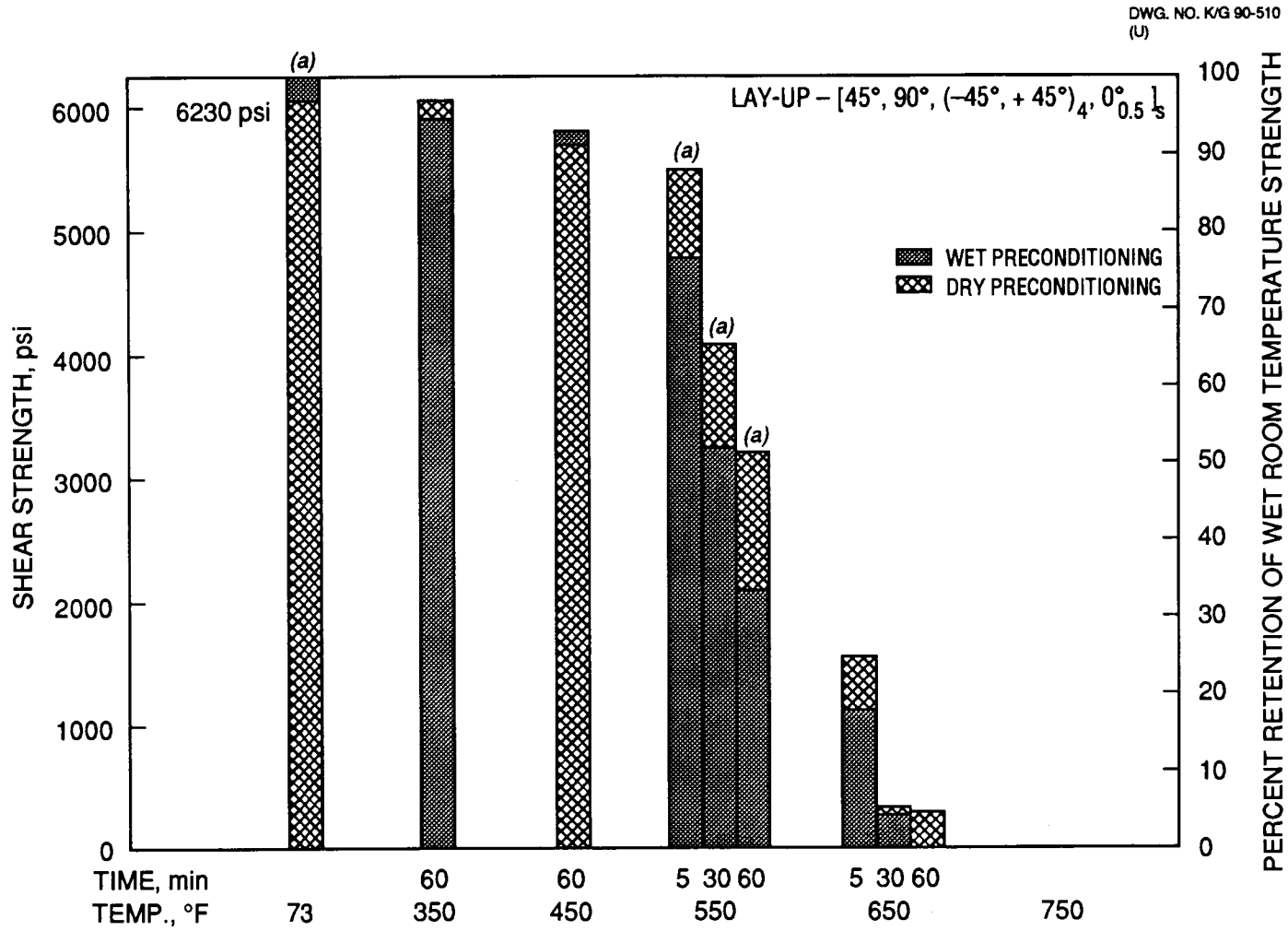
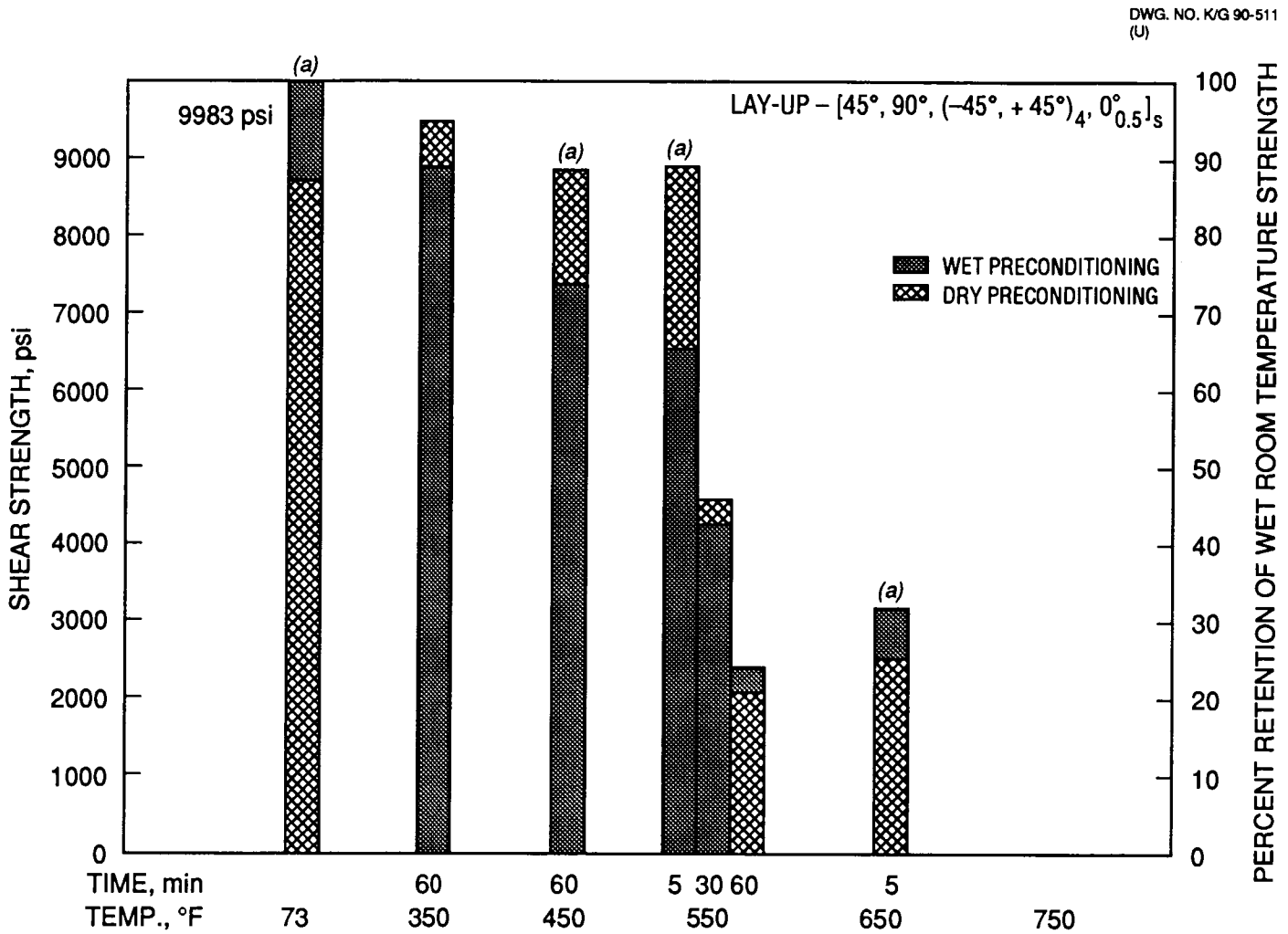


Fig. 9. Short-beam-shear fixture.



(a)WET AND DRY STRENGTH AVERAGES ARE STATISTICALLY SIGNIFICANTLY DIFFERENT AT THE 95% CONFIDENCE LEVEL.

Fig. 10. Test results for IM6/3501-6: ASTM D2344. Zero-degree short-beam-shear strength vs heat-exposure temperature/time for wet and dry preconditioned specimens.



(a) WET AND DRY STRENGTH AVERAGES ARE STATISTICALLY SIGNIFICANTLY DIFFERENT AT THE 95% CONFIDENCE LEVEL.

Fig. 11. Test results for IM6/3501-6: ASTM D2344. Ninety-degree short-beam-shear strength vs heat-exposure temperature/time for wet and dry preconditioned specimens.

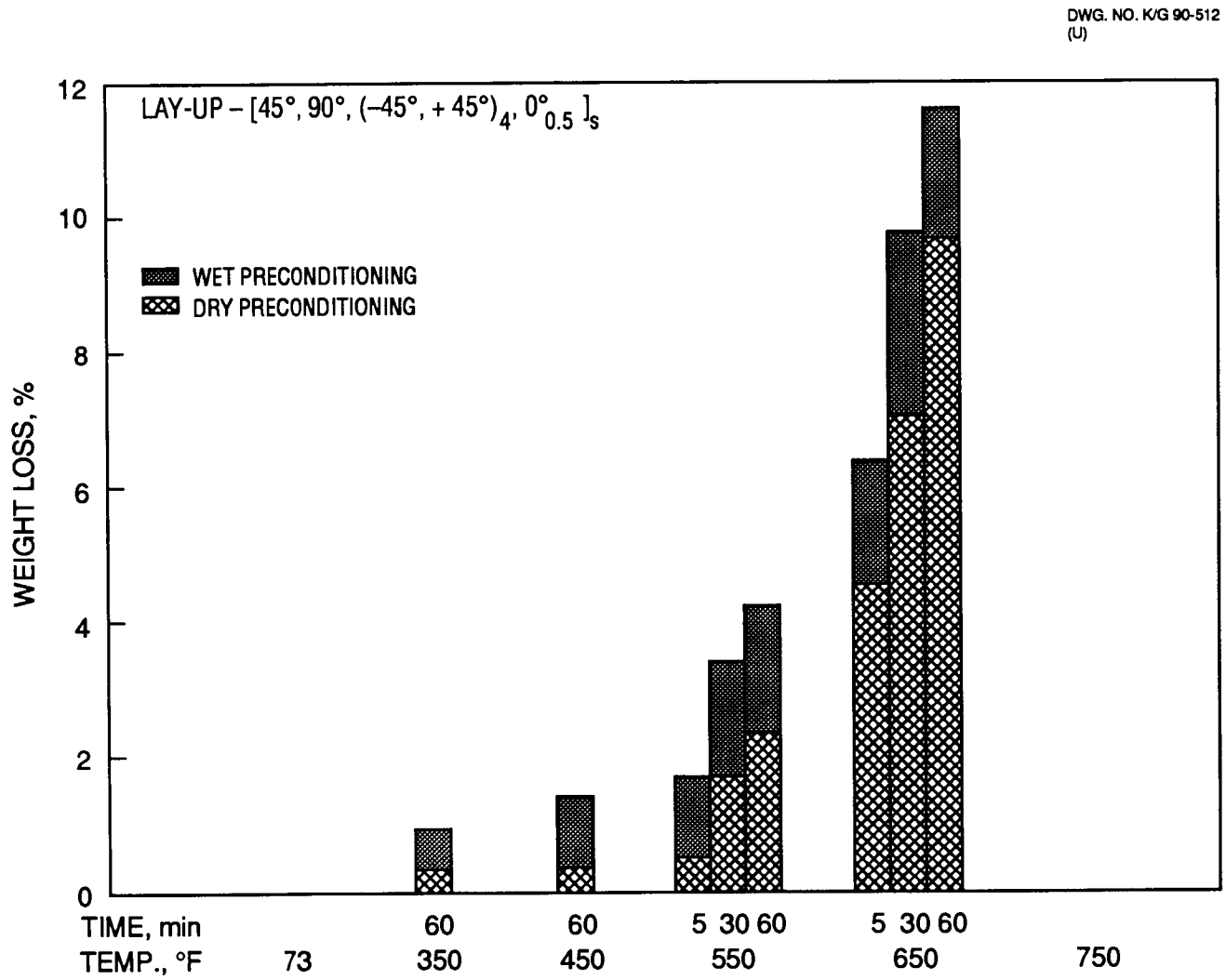


Fig. 12. Test results for IM6/3501-6. Percent weight loss vs heat exposure temperature/time for wet and dry preconditioned zero-degree short-beam-shear specimens.

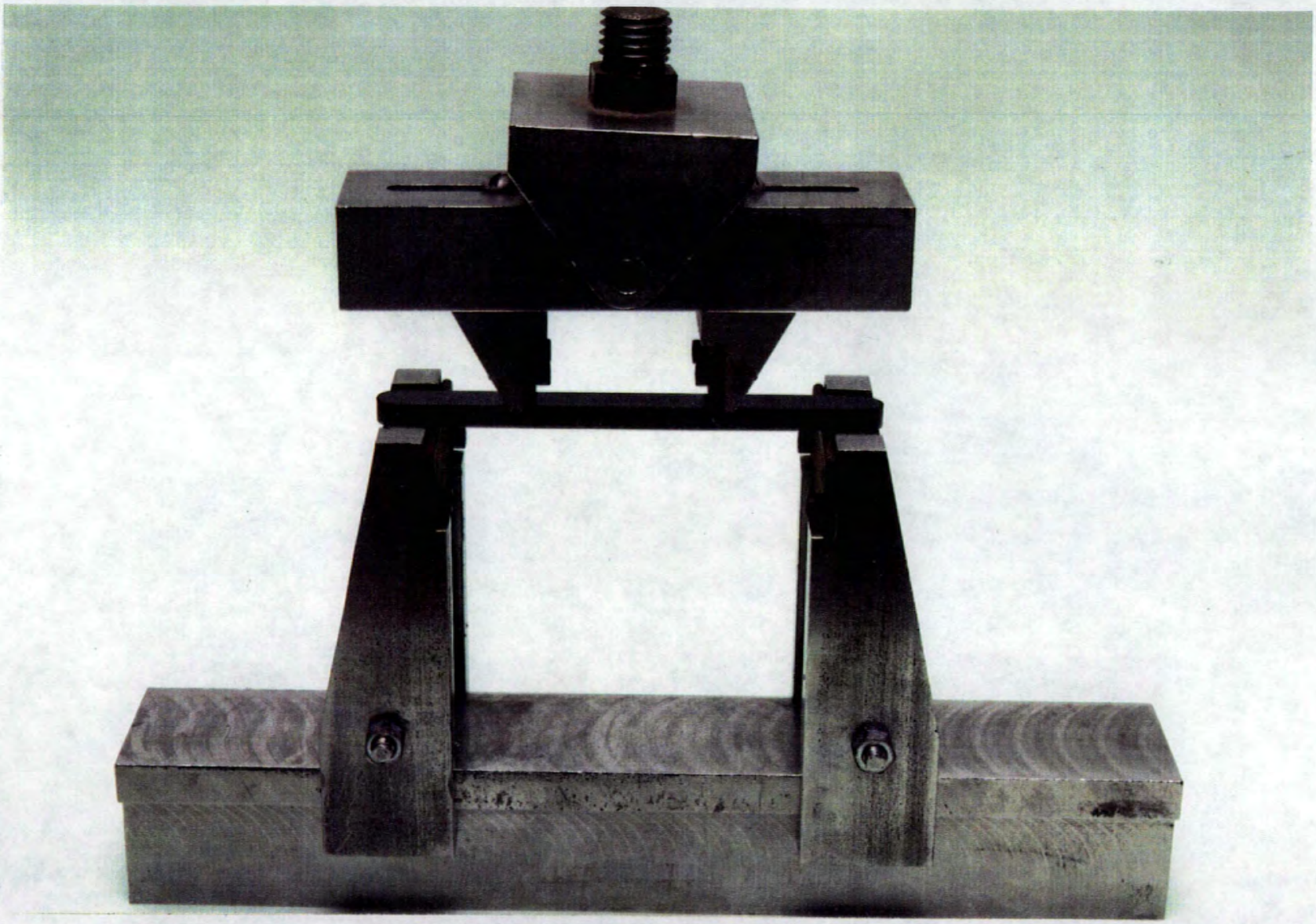
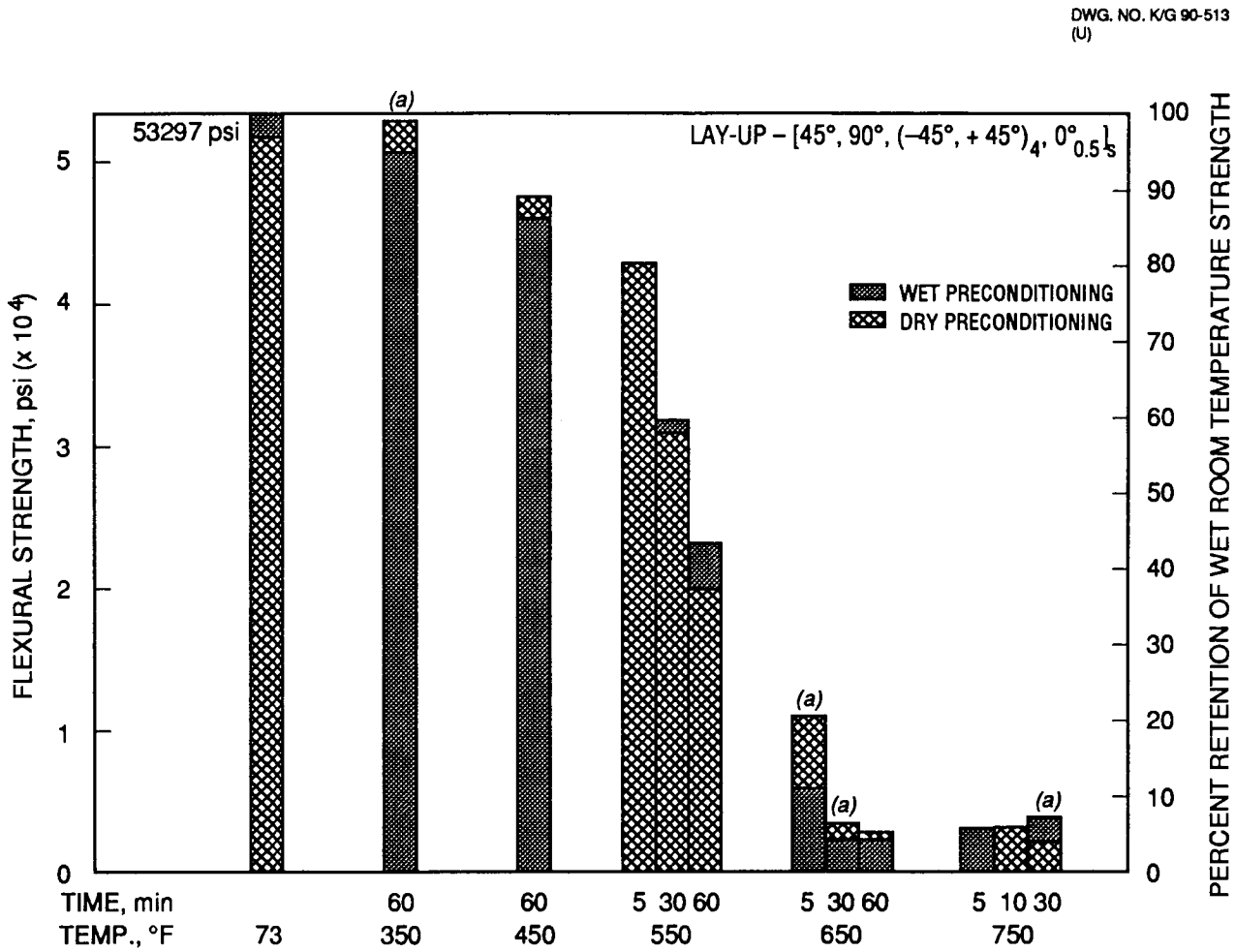
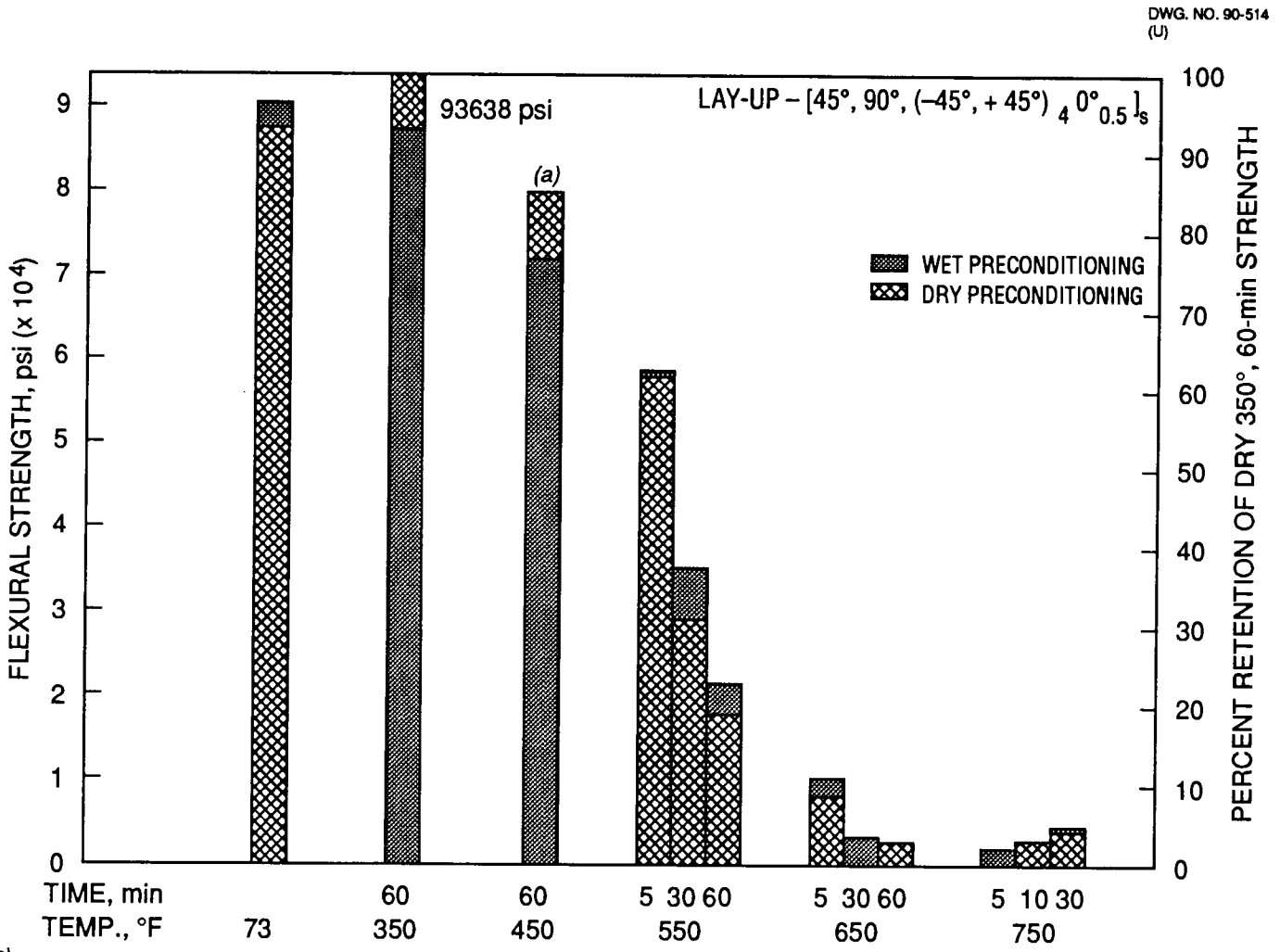


Fig. 13. Four-point-bend fixture.



[a] WET AND DRY STRENGTH AVERAGES ARE STATISTICALLY SIGNIFICANTLY DIFFERENT AT THE 95% CONFIDENCE LEVEL.

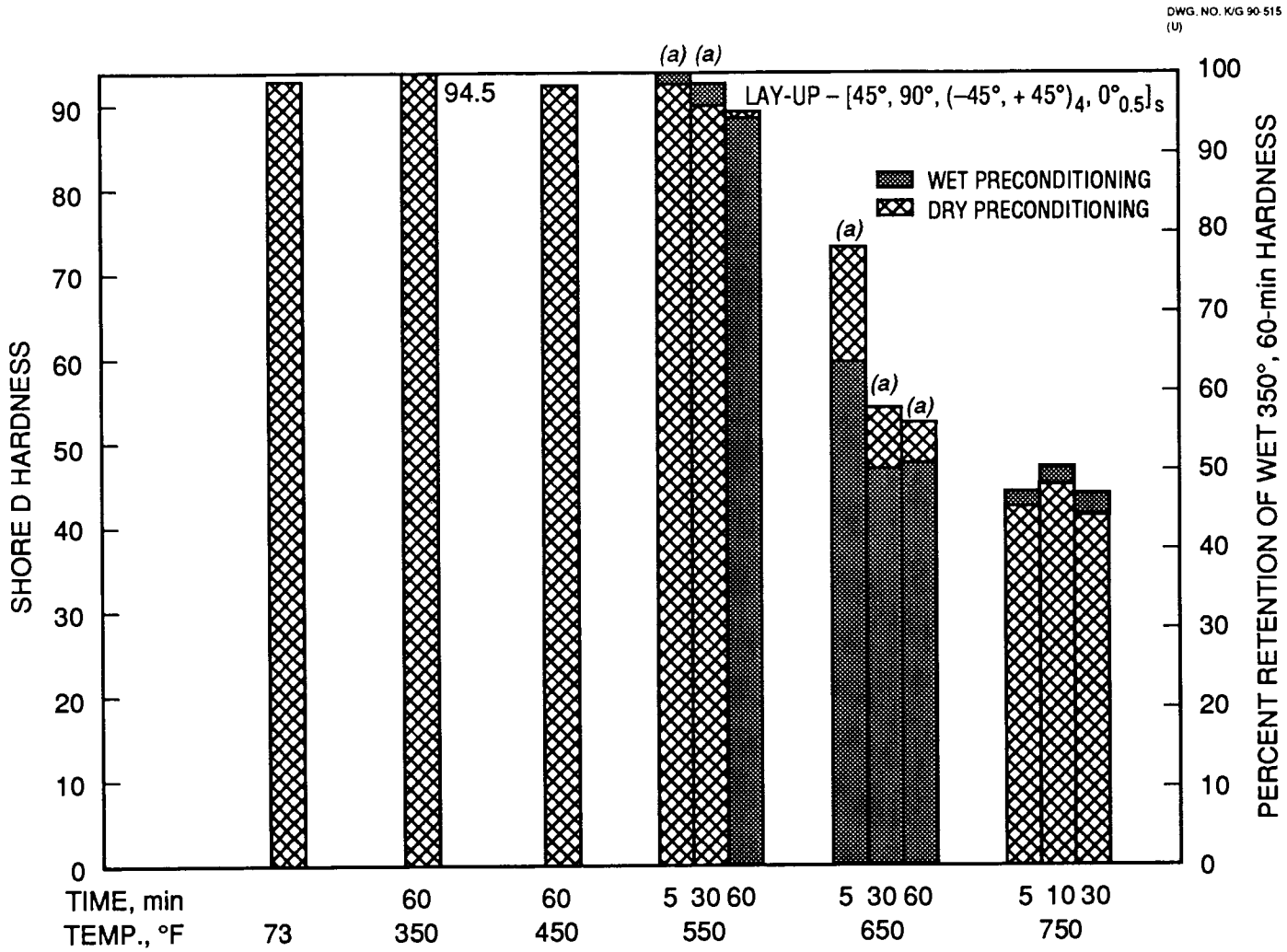
Fig. 14. Test results for IM6/3501-6: ASTM D790. Zero-degree flexural strength vs heat-exposure temperature/time for wet and dry preconditioned specimens.



(a)WET AND DRY STRENGTH AVERAGES ARE STATISTICALLY SIGNIFICANTLY DIFFERENT AT THE 95% CONFIDENCE LEVEL.

Fig. 15. Test results for IM6/3501-6: ASTM D790. Ninety-degree flexural strength vs heat-exposure temperature/time for wet and dry preconditioned specimens.

Fig. 16. Shore-D hardness tester.



(a) WET AND DRY STRENGTH AVERAGES ARE STATISTICALLY SIGNIFICANTLY DIFFERENT AT THE 95% CONFIDENCE LEVEL.

Fig. 17. Test results for IM6/3501-6: ASTM D2440. Shore-D hardness vs heat-exposure temperature/time for wet and dry preconditioned specimens.

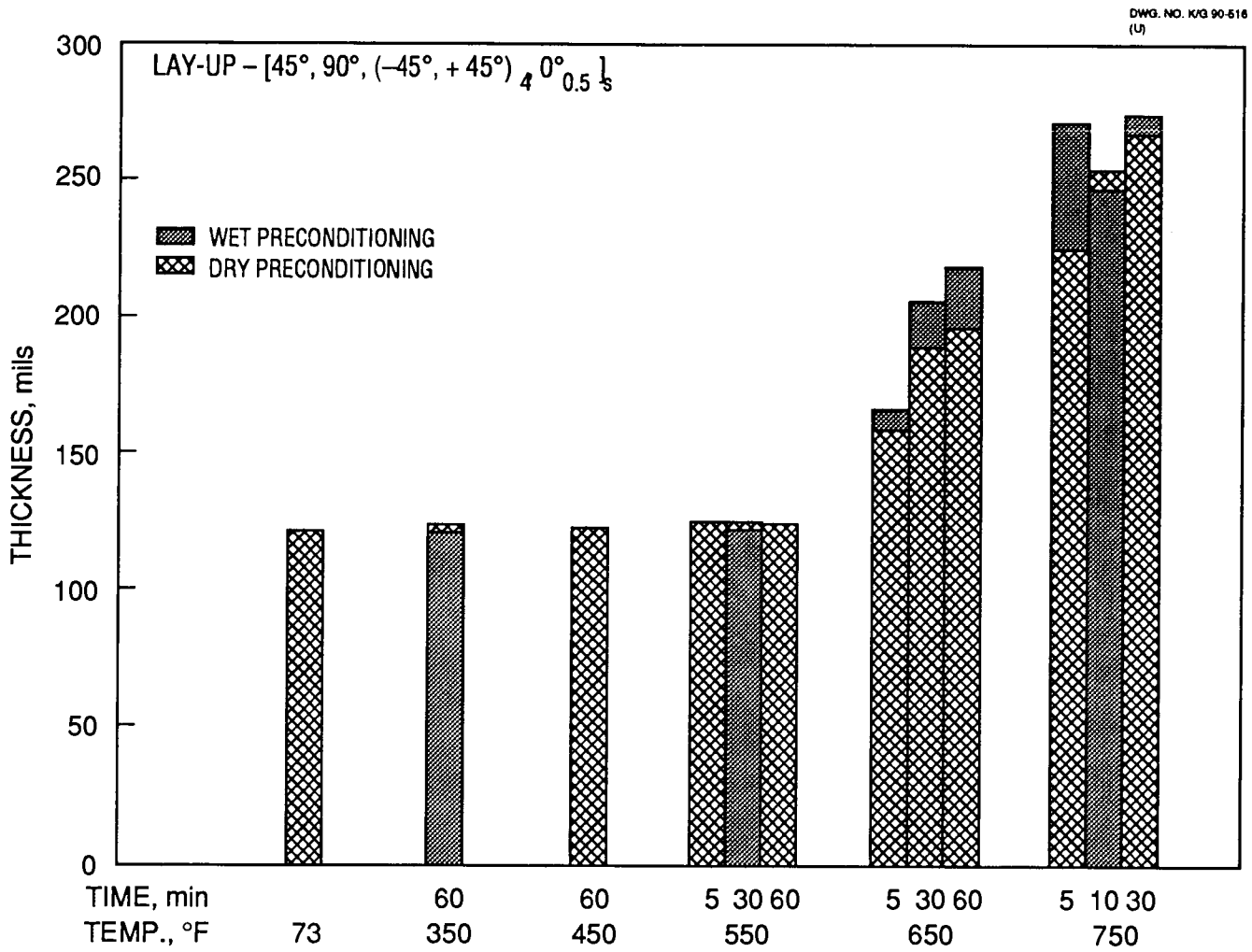


Fig. 18. Tests results for IM6/3501-6. Maximum thickness vs heat-exposure temperature/time for wet and dry preconditioned specimens.

PART 2.

NONDESTRUCTIVE EVALUATION STUDIES ON IM6/3501-6 LAMINATES

INTRODUCTION

Advanced composite structures, because of their superior strength-to-weight ratios, are finding application in many structural areas traditionally reserved for metals. The poor cross-fiber strength of early unidirectional fiber-reinforced composites has been supplanted by the exceptional in-plane strength of alpha-ply lay-ups consisting of stacks of plies having some prescribed rotation of the fiber orientation from ply to ply. This arrangement typically yields a transversely isotropic structure whose plane of isotropy is the plane in which the anticipated stress is to act. Unfortunately, the intentional misalignment of basic structures whose intrinsic elastic symmetry is typically orthotropic produces a final product which, from the standpoint of an elastic wave used to probe the composite, is horribly inhomogeneous. This, in turn, means that traditional methods of nondestructive evaluation (NDE) cannot generally be applied with reasonable success to the evaluation of composite materials.

Fortunately, for discrete but uniform variations in the elastic properties of a medium on a scale small with respect to the wavelength of the probing elastic wave, the material can be adequately represented as anisotropic rather than inhomogeneous, and the former can be treated rather easily. The low frequencies required to ensure the elastic conditions described above, however, lead once again to numerous problems, chief among them resolution, when traditional methods of NDE are employed.

In the last few years, several unconventional NDE techniques have been applied to the evaluation and characterization of advanced composite materials. These have ranged from quasi-conventional approaches using high-energy pulsers and narrow bandwidth receivers to probabilistic techniques which seek to identify damage through identification of a characteristic signature, usually obtained by comparing a number of "feature vectors," or scattering parameters, characteristic of scattering from known examples of damage, with those obtained on samples whose condition is unknown. None of these approaches has been particularly successful. In the last year, however, several promising studies[1,2] have indicated that approaches based on the response of the composite structure to some form of guided elastic wave may prove efficacious, at least for detecting certain types of damage.

The carbon/epoxy composite of our studies is a 21-ply structure having mirror symmetry with respect to the center ply. From either surface inward to the center layer, the plies, in order, are +45°, +90°, four repeated sequences of -45° and +45°, and a 0° center ply. This presumably yields a structure transversely isotropic in the plane of the plies. In addition to the usual problems evident in all composite materials, one surface of this structure is subject to heat damage as well. Interest in this material lay in identifying techniques for detecting and quantifying such heat damage nondestructively. Work toward this goal is described in this report.

VELOCITY

Because work with this particular composite had not been done previously, an attempt to characterize the velocity behavior of the structure was made. Because of the construction of this material, it was anticipated that there would be considerable velocity anisotropy present. In addition, carbon fiber composites typically exhibit a very high degree of attenuation for elastic waves of frequencies >1 MHz, and this attenuation is often quite variable from point to point on a given sample. In addition, complex structures such as composites often exhibit velocity dispersion as well. For all of these reasons, it is often necessary to use monochromatic radiation in order to get an accurate measure of the ultrasonic velocity in composites. This requirement is also necessary for utilizing pulse overlap techniques, which are among the more accurate techniques for ultrasonic-velocity determination. A number of digital-pulse (broadband) and tone-burst (monochromatic) systems for the measurement of velocity in structural materials are available. These systems are capable of operating over the frequency range from 1 to 100 MHz, and transducers are available for the entire range.

An as-received (no heat exposure) sample using a 2.25-MHz compressional wave transducer in a pulse-echo configuration was first examined. The sample was ~ 95 by 150 mm with a thickness of 3 mm. Surprisingly, only a very weak and distorted echo could be obtained at any point on the sample. For many locations, no discernable echo could be obtained at all. A second sample produced no better result. A special, high-intensity pulser capable of generating 400-V pulses was then used. The results were slightly improved, but there was still insufficient signal and too much distortion for accurate analysis. An attempt was then made to use a monochromatic source. Unfortunately, this system is limited to a peak transducer driving amplitude of only about 75 V. No measurable signal could be detected down to the low-frequency limit of 1 MHz.

Because the losses in an ultrasonic-velocity measurement could be minimized using through-transmission contact techniques, several samples using this configuration were also examined. For the monochromatic source, the results were again negative; no discernable signals could be transmitted through the samples. However, for the high-intensity pulse source, a reasonably good through-transmission signal could be obtained over much of the area of some of the as-received samples at 2.25 MHz. This signal yielded an estimate of ~3 km/s for the compressional-wave velocity in the through-thickness direction of the carbon/epoxy material. This value, in combination with the relatively low density of the composite, meant that the acoustic impedance of the material was relatively low and that the reflection coefficient for ultrasonic waves would also be low (and thus the transmission coefficient concomitantly high). This, in turn, suggested that measuring the velocity in immersion with a reflector behind the sample might be advantageous. This was found to be the case. Using a stainless-steel reflector (reflection coefficient: 0.88) behind the sample in a water-immersion system yielded a reasonably clean signal and improved the estimate for the compressional wave velocity to 3.1 km/s. This value did not vary over the area of the sample.

An attempt was made to determine the compressional wave velocity at 5 MHz to assess the degree of dispersion present. Unfortunately, even with the pulse system adjusted

to provide relatively long pulses and using a narrow-band, 5-MHz transducer, no accurate results could be obtained because of the high attenuation presented by the samples at this frequency.

Having obtained a reasonably accurate value for the compressional wave velocity in the through direction of the composite, an attempt to measure the shear-wave velocities was made. These measurements should provide the first indications of the degree of elastic anisotropy in the composite samples because the velocity of a shear wave in a given direction in an anisotropic medium may depend as well on the direction of polarization of the wave. In addition, even though the elastic wave was introduced to the sample at normal incidence, it was still possible for the wave energy to refract at an angle inside the sample because the phase and group velocities were not, in general, collinear in an anisotropic medium. This could make it difficult to predict the path of the wave through the sample if the elastic symmetry tensor was unknown in advance. In the present case, however, knowledge of the fact that the fiber direction lay in the plane of the sample surfaces for each ply in the structure allowed an estimate of the symmetry of the sample to be made. In any event, the relative thinness (3 mm) of each sample ensured that the deviation of the beam from the through-thickness direction could not be very great.

Each of the as-received samples was examined using 1- to 5-MHz shear-wave transducers and employing both pulse and monochromatic sources. In no instance was there any indication whatsoever of shear wave transmission through the specimens. The system allowed the transducers to be aligned on either side of the sample and the sample to be rotated, thus varying the polarization angle of the shear wave. No transmission was seen for any angle. Because some compressional wave transmission at frequencies as high as 5 MHz and reasonably good compressional wave transmission at 2.25 MHz had previously been observed, similar shear wave results at 1 to 2 MHz were expected to be seen, assuming simple wavelength dependence of losses. This was decidedly not the case. Using shear-wave transducers, the only signals transmitted through the material were extremely weak compressional waves. These latter waves are not unusual because most shear-wave transducers will produce a small amount of compressional wave excitation.

With no shear-wave-velocity data, it was impossible to say anything about the elastic anisotropy of the carbon/epoxy material. Shear-wave attenuation as great as that encountered in the present case had previously been observed only in a carbon-carbon composite having a high degree of porosity. Because the carbon/epoxy did not appear to be highly porous, the cause of such severe loss was unknown.

ATTENUATION

Elastic-wave attenuation has long been recognized as a sensitive indicator of the microstructural state of materials. The presence of porosity, grain-boundary irregularities, precipitates, microstructural-phase changes, anisotropy, and numerous other effects has been noted in studies of the attenuation behavior of structural materials. One of the most powerful techniques for acquiring this behavior is through use of the material-transfer function, a concept that was developed at Oak Ridge National Laboratory. In this approach, a broad band of elastic-wave frequencies is transmitted through a material, and the modification of these frequencies by the material is quantified. To achieve this result,

it is necessary to make corrections for a number of losses that do not depend on the specimen, e.g., transducer beamspread (diffraction), acoustic impedance mismatches, and frequency-dependent contact-coupling losses (caused by the finite thickness of the coupling layer in contact measurements). When this is done, however, the result is a true material attenuation-vs-frequency characteristic that is independent of sample thickness and indicative of the microstructural state of the host. The process by which the attenuation behavior is obtained, though complex, is well suited for computer automation. This process has been incorporated into a large computer program that can, in a matter of seconds, acquire the transfer function for any material that can support an elastic-wave bandwidth of at least a few megahertz.

For those composite materials (including carbon/epoxy) that are grainless, the attenuation behavior is indicative of the presence of porosity, the state of the fiber/matrix interface, the presence of cracking in the matrix, and, perhaps, changes in the elastic properties of either fiber or matrix. Several of these conditions have been demonstrated for an S2-glass/epoxy composite[3] subjected to spin testing. There, the transfer function was determined before testing and after the application of stress induced by spin testing a sample of the material at rotational speeds up to 40,000 rpm. Figure 19 shows the transfer curve results obtained on a sample in the as-received condition and after testing at a high rpm. Note the increase in the slope of the attenuation-vs-frequency curve after testing. Intermediate-test revolutions per minute values gave intermediate slopes for the transfer curve, indicating that there was good correlation between the slope of the transfer curve and the maximum rpm to which the material was subjected. In this case, damage was accumulating via separation of the glass fibers from the matrix and from matrix cracking, both of which were reflected in the attenuation behavior of the material.

When samples of the carbon/epoxy composite were first received, it was thought that a similar correlation might be found between the attenuation behavior of the material and the degree of heat damage sustained. It quickly became evident, however, that the severe bandwidth limitations of the carbon/epoxy structure would preclude obtaining a transfer function for this material. In addition, the point-to-point variation of the attenuation indicated that such information, even if it were available, would be extremely location dependent; i.e., measurements would always have to be compared with previous ones made at fixed, designated locations on the specimen because, even in the unexposed material, the point-to-point variation in the attenuation approximates that between exposed and unexposed samples. In other words, such a measurement would be relative rather than absolute.

Although a full-material-transfer curve would be out of the question for the carbon/epoxy composite, a relative measure of the attenuation, such as that afforded by simple ultrasonic C scans, might still provide some useful information. Therefore, each of the available samples were scanned using a 2.25-MHz through-transmission technique. The samples included specimens in the as-received condition as well as ones that had been exposed to 350, 450, 550, 650, and 750°F for 5 min. Three of these samples were chosen for more detailed analysis. They included an unexposed sample, one exposed to 450°F, and one exposed to 750°F. The transmitted ultrasonic field amplitude was digitized, and a color was assigned to the value. The results showed no transmission whatsoever through the

750°F sample, which was not surprising because this sample exhibited considerable visible damage and was severely delaminated.

The 450°F sample showed no visible signs of damage.

A second result obtained by scanning the samples was that the 450°F sample was actually less attenuative than the unexposed specimen. The scan results show that the transmission through the former sample was at the maximum digitizer level over fully one-third of its area, while the latter reached similar levels only in a small area near one end of the sample. As noted earlier during the velocity measurements, the attenuation was highly variable over the total area of the specimens. For both samples, there were increased losses in the region of the thermocouple attachment points.

The 650°F sample also exhibited heat damage on the ultrasonic data, but the damage was not quite as severe as that for the 750°F specimen.

A second set of samples whose exposure was 30 min to 1 h was also available, and the results were similar to those obtained on the 5-min exposures.

These results illustrated the major problem attendant to using attenuation to quantify heat damage in the carbon/epoxy composite; viz., there appeared to be no sensitivity to damage less than that required to delaminate the material. Once delamination had occurred, its presence was easily detected by the ultrasonic attenuation, but there was no apparent effect on the attenuation when the damage was less severe.

Because a direct measurement of neither velocity nor attenuation appeared to be efficacious for quantifying heat damage in carbon/epoxy composite material, other techniques had to be considered. The most likely approach in this case would appear to be some form of guided elastic wave.

GUIDED WAVES

The topic of elastic-guided waves is a relatively broad one that has been investigated by numerous authors, including the present one.[4] In general, the term refers to waves that are constrained to propagate along a free boundary of an elastic medium or within a layer of finite thickness. In the latter case, the wave will be dispersive; i.e., the velocity will be a function of frequency. The best-known example of such a wave is the Lamb wave, which is, strictly speaking, a guided wave that propagates in an elastic plate having free surfaces. When the plate is fluid loaded, i.e., when it is immersed in a fluid, some of the mode energy "leaks" into the surrounding fluid at the critical angle and may be detected there. This type of wave is termed a leaky Lamb wave. However, it has long been assumed that the propagation of such waves in a fluid-loaded plate is practically identical to that for the free plate. This has recently been shown to be false,[5] however, when the acoustic impedances of plate and fluid are similar, a condition which is satisfied for many composites including carbon/epoxy.

In the case of Lamb waves, the elastic-wave propagation is different from bulk elastic waves in that, for a given phase velocity of the wave, only a single frequency can propagate in the plate. Conversely, if one has established a wave of some particular frequency in the plate, then that wave will have a very precise phase velocity that will change as the frequency is altered. In other words, the propagation of Lamb waves within a plate is governed by a dispersion relationship that defines a series of normal modes, much as in the electromagnetic case. For the present case, the property of Lamb waves that is most useful is that, once established in a medium, they have been shown to propagate with relatively low attenuation, good rejection of small-scale discontinuities such as porosity, and high sensitivity to certain types of defects, particularly planar damage such as delamination. Recent studies[1,2] have also established that they appear to be particularly useful in delineating damage in high-attenuation materials such as advanced composites.

Figures 20 and 21 show the mode structure of Lamb waves in a ceramic plate. These modes are designated symmetric or antisymmetric depending on the symmetry of the wave with respect to the centerline of the plate in which they are propagating. If a horizontal line is drawn across these figures at some particular phase velocity, that line will intersect several modes, all of which will have the same phase velocity. A broadband source could then excite all of these modes simultaneously. Figure 22 shows this result for a ceramic plate and reveals that five distinct modes have been excited.

The above results are strictly valid only for isotropic media. This is because the theoretical foundation of Lamb-wave propagation had been applied only to isotropic media because of the mathematical difficulties. Recently, however, the treatment has been extended to cover the case of waves propagating in anisotropic media,[6-8] of which the carbon/epoxy composite is an example. However, a number of generalizations that will still be valid for anisotropic media without detailed knowledge of the specific mode structure can be made: for propagation in a given direction, the dispersion relation will produce a number of resonances (modes) that relate the velocity of a wave to its frequency in a manner similar to the isotropic case, and the phase velocity will vary with propagation direction. With these characteristics in mind, the Lamb-wave-mode structure may be investigated experimentally to advantage.

Lamb-wave studies of carbon/epoxy composite were conducted using the configuration depicted in Fig. 23. This arrangement ensured that the ultrasonic energy traversed the same area of the sample after reflection. It also allowed the studies to be performed with a single transducer, the angle of incidence to be easily changed, and did not require careful alignment, as is necessary with dual transducers. Finally, because the time-domain signal is often extremely confusing when using Lamb waves on highly scattering media, all signal analysis was performed in the frequency domain, where the mode structure was usually easily observed.

Studies were begun using broadband 2.25- and 5-MHz transducers. Instead of the rich spectrum (see Fig. 22) of leaky Lamb waves usually encountered using such transducers, however, the spectrum for carbon/epoxy was relatively sparse. For most angles of incidence, the transmitted spectrum was relatively broadband and weak, indicating that the energy did not originate from resonances. At an angle of incidence of ~23°, however, a strong, relatively sharp resonance at 1.5 MHz was noted. This peak almost assuredly corresponded

to excitation of a leaky Lamb mode. Figure 24 shows the spectrum obtained with this mode. The peak is well below the frequency of maximum energy for either transducer used in the studies.

By exciting a particular leaky Lamb mode and monitoring the energy "leaked" into the fluid medium, it was possible to image the composite specimen using the mode energy. Figure 25 shows the result obtained on one of the unexposed samples. This specimen contained two manufactured "flaws" in the form of a square and a circular hole cut into one surface of the sample. The round hole was 25 mm in diameter and was approximately three-quarters of the way through the specimen. The square hole was 21 mm on a side and extended halfway through the sample. Although these defects were, of course, quite large, it was obvious that much smaller defects could have been detected. Regarding the depth of these holes, delamination of the same area at a single ply should have been just as effective. These particular defects were made rather deep for studies to be described later in this report.

It should be emphasized that, while both manufactured flaws could be detected using a conventional pulse-echo test that monitors the amplitude of the back-surface signal, the contrast was very much less than that evident in Fig. 25 because of the extreme point-to-point variability of the through-transmission signal.

Although the 1.5-MHz leaky Lamb mode appears to be a good choice for imaging delamination-type defects (such as impact damage) in the carbon/epoxy composite, currently there is more interest in detecting and characterizing heat damage, which is probably more nearly representative of changes in the resin properties. Accordingly, several of the unexposed samples were scanned, as well as those that had been exposed to 450° and 550° F and which therefore contain no visible damage using the 1.5-MHz leaky Lamb wave. Unfortunately, no obvious differences in the intensity of the mode from sample to sample were noted. Those specimens that exhibited visible damage (650° F and higher exposure), however, would not support the wave in the regions of delamination, which could then be imaged. It is known that the sensitivity of leaky Lamb waves to a given type of material property variation depends on the mode,[9] however, and it is quite possible that higher-order modes may be more sensitive to the particular changes representative of heat damage. It remains to identify and determine the heat-damage sensitivity of other leaky Lamb modes of the carbon/epoxy composite.

Although the studies just described appear promising for inspection of carbon/epoxy, the technique, as depicted in Fig. 23, is not suitable because it requires access to both sides of the specimen. However, it is well known that excitation of a guided mode in a medium is accompanied by enhanced backscattering at the critical angle. Thus, the Rayleigh critical angle is easily measured for a semi-infinite medium simply by adjusting the angle of incidence to obtain a backscattering maximum. This method requires access only to a single surface, requires one transducer, and provides the additional advantage that the phase velocity of the excited wave may be obtained from Snell's law using the measured value of the critical angle and the known fluid velocity.

The technique just described was applied to the backscattering from carbon/epoxy. A single transducer insonified the sample at an angle of 23° along the fiber direction of the

0° layer, and the frequency content of the backscattered energy was monitored. Instead of a sharp resonance at 1.5 MHz, however, a larger, even sharper resonance was found at ~7.5 MHz. This peak grew rapidly, and the frequency of the peak energy decreased as the angle of incidence was increased and reached a maximum at an angle of ~27.5°. Thereafter, the intensity, as well as the frequency, of the maximum decreased as the angle of incidence increased. The frequency of maximum backscattering occurred at ~6.9 MHz. When the sample was rotated 90°, a similar resonance that peaked at ~5.5 MHz was found, again at an angle of incidence of 27.5°. Neither of these resonances could be detected in the transmitted energy.

Figure 26 shows the spectral content of the transducer used to insonify the samples. It is a typical broadband, 5-MHz unit. Figure 27 shows the backscattered spectrum obtained along the direction which is coincident with the fiber direction of the 0° ply and illustrates the sharpness of the 6.9-MHz resonance. Note that all the frequency-domain plots are normalized; i.e., the frequency of the maximum is normalized to an amplitude of unity. The actual amplitude of the 6.9-MHz peak is considerably less than the peak amplitude in Fig. 26. In fact, it must be less than or equal to the transducer amplitude at the same frequency.

Figure 28 shows the backscattering observed at right angles to the fiber direction of the 0° ply. The 5.5-MHz resonance appears to be just as sharp as that for the 0° ply direction.

It is well known that composite materials containing arrays of fibers will exhibit enhanced backscattering at certain angles when insonified over a range of azimuthal (i.e., with respect to the fiber direction) angles.[10] While such backscattering is relative sharp with respect to angle, it is not usually highly monochromatic. That the frequency spectrum is so narrow is generally indicative of excitation of some form of dispersive guided wave. It is therefore believed that both of the resonances described above originated from a guided wave in the composite.

The exposed and unexposed samples were next scanned while monitoring the amplitudes of the two backscattering resonances. It was immediately found that the unexposed samples exhibited strong resonances, while those exposed to 450° and above had reduced or missing resonances. The 350°F sample appeared quite similar to the unexposed specimens. It was noted that the strength of the backscattering varied considerably from point to point on all of the samples, thus it was difficult to determine if there was a gradation in amplitude with the degree of heat exposure. One unexposed sample yielded as little backscattering as the 750°F specimen. However, this same sample had much greater attenuation for normal incidence compressional waves and may be defective in some manner, such as incomplete curing, etc.

Because both the 5.5- and 6.9-MHz backscattering resonances seemed to be sensitive to heat exposure in the carbon/epoxy material, the nature of the waves whose presence they might signify was investigated. This study was confined to the unexposed samples. Each sample was first scanned from both sides, noting that, in each case, the results were different on the two sides. This implied that the resonances were not representative of the complete thickness of the samples. In addition, it was also noted that the azimuthal direction of

maximum scattering was slightly different (10 to 15°) from side to side. In fact, this direction was not exactly along the edge of any of the samples, as though the specimens had been cut at a slight angle with respect to the fiber direction of the 0° ply. Therefore, assuming that these resonances interrogate half or less than half of the sample thickness, the plies in the lower half, which are supposed to be mirror images of the those in the upper half, appeared to be slightly misaligned, assuming that the scattering maximum indicates the fiber direction, or average fiber direction, of whatever plies are being interrogated. The conclusion that these resonances interrogate no more than half the sample thickness was strengthened by the occurrence, in two specimens, of small areas in which a second, simultaneous resonance suddenly appeared *which was exactly half the frequency of the primary resonance*. Figure 29 shows the backscattered spectrum obtained in one of these areas (note: the value of 6.9 MHz for the higher-frequency resonance is a nominal value that depends on the local angle of incidence. Figure 29 indicates that the resonances occur more nearly at 3.2 and 6.4 MHz for the region interrogated, probably because of warpage of the sample).

The half-frequency resonance described earlier suggests that the backscattering resonances originate from some sort of guided wave that is confined to exactly one-half of the sample thickness, although this is difficult to support theoretically. Those areas where the half-frequency component was present would then presumably be regions where, perhaps because of better alignment of the plies in the upper and lower halves of the specimen, the guided wave could penetrate throughout the whole sample thickness. To test this conjecture, the sample described earlier was prepared. A square hole, 21 mm on a side, was cut exactly halfway through one specimen. If the backscattering resonances represent waves that penetrate only halfway through the structure, then this hole should not be detected when the sample is insonified from the intact side. This was found to be the case. No hint of the presence of the hole was found by either the 5.5- or 6.9-MHz resonance.

Next, a second hole was cut in the same sample. This hole was circular, 25 mm in diameter, and extended at least three-fourths of the way through the specimen. Surprisingly, this hole was not detected by either resonance. Thus, it was obvious that any guided waves giving rise to the backscattering resonances could not exist in more than a few plies, probably in a single ply.

To gain a little insight into the origin of the 5.5- and 6.9-MHz resonances, the peak frequency-vs-angle relationship for the latter was examined. As was stated earlier, the frequency of the scattering maximum increased as the angle of incidence was decreased. By changing to higher-frequency transducers, the resonance could be followed up to 30 MHz and down to ~5 MHz. At the higher frequencies, very little change in the incident angle was necessary to peak the resonance, while considerable change was necessary near 5 MHz. This behavior is consistent with the shape of the modes depicted in Figs. 20 and 21; i.e., near the cutoff (low frequency) end of most of the modes, the velocity (related to the incident angle) changes rapidly for a small change in frequency as the curve becomes nearly vertical, while near the asymptotic (high frequency) end of all the modes, the velocity changes very little with frequency as the curve becomes horizontal. The experimental behavior of the resonances is thus consistent with some type of guided wave mode.

All of the evidence obtained on the carbon/epoxy composite suggests that the backscattering resonances originate in waves propagating in a single ply or at most a few plies. This conclusion was tested by obtaining a fully cured single-ply specimen. When insonified at 27.5°, strong backscattering resonances were obtained at 6.9 MHz for propagation at right angles to the fiber direction and at 5.5 MHz for propagation along the fiber direction. The resonances are thus unquestionably related to a single ply. It now appears that they originate from the 90° plies because these plies are the most shallow plies whose fiber orientation is correct for the observed single-ply behavior. What is not clear, however, is why the strongest resonances do not occur for propagation along and at right angles to the fiber direction of the two surface plies because they are the first encountered by the incident beam. Weak resonances were detected at ±45°, but they were considerably smaller than those at 0° and 90° and much smaller than those obtained from the single-ply specimen. One possible explanation of this behavior is that, while the elastic boundary conditions are symmetric for the 90° plies (being sandwiched between +45° and -45° plies which, for orthotropic materials, is symmetric), they are not symmetric for the surface plies. It is unknown if this condition would affect the single-ply resonances. There are, of course, other plies within the structure that have symmetric boundary conditions, but they are all deeper within the sandwich and must be insonified through the upper layers.

Heat damage in an actual in-service sample would be expected to occur first at the exterior surface, hence any technique that can detect changes in the surface ply might be of potential usefulness. The single-ply resonances have indeed shown a sensitivity to heat exposure, may be excited with access only to the outer surface, and are insensitive to the thickness variations of the sample. Deeper damage, such as that occurring from delamination of one or more plies, could then be detected by excitation of a lower-frequency, full-thickness mode such as the 1.5-MHz leaky Lamb wave described earlier.

SUMMARY AND RECOMMENDATIONS

Samples of carbon/epoxy composite in the as-fabricated state and after exposure to heat ranging from 350 to 750°F were examined using several ultrasonic techniques. An attempt was made to measure the through-thickness shear and compressional-wave velocities directly, but only the latter could be determined. A value of ~3.1 km/s was found for the compressional wave velocity using a double-transmission pulse-echo technique.

Attenuation maps were made of the unexposed samples and several of the exposed specimens, and the through-thickness attenuation was very severe and highly inhomogeneous. Visible damage, represented by delamination of one or more plies, was easily detected in these studies, but there appeared to be no correlation between attenuation and the degree of heat exposure. One of the 450°F samples exhibited less attenuation than most of the unexposed samples.

The most useful approach for detecting and quantifying damage in many types of composites appears to be a leaky Lamb wave. A double-transmission, single-transducer technique was used on the carbon/epoxy samples to generate a 1.5-MHz leaky mode.

Laminar-type damage was easily detected and imaged using this wave, and the same results could have been obtained from one surface of the samples using dual transducers. No clear evidence of higher-frequency modes was noted.

To take advantage of single-transducer, one-sided generation of leaky Lamb waves, use was made of the fact that enhanced backscattering of the excitation frequency can usually be detected at the critical angle for generation of such waves. For the carbon/epoxy composite, the backscattered energy contained two relatively strong resonances. For an incident angle of 27.5°, the stronger of these resonances occurred at 6.9 MHz and corresponded to propagation along the fiber direction of the 0° ply. The weaker resonance occurred at 5.5 MHz for the same incident angle and corresponded to propagation orthogonal to the fiber direction of the 0° ply. Weaker resonances were also detected at ±45° but were not investigated extensively. Both of the major resonances appeared to be sensitive to heat exposure because they were either reduced or missing in those samples that had received heat exposure of at least 450°F. The variability of the backscattering across the area of a sample made it difficult to determine if there was a significant difference between the backscattering from the 350° samples and the unexposed ones.

A sample containing two manufactured defects was examined in backscattering using the two resonances. One of the defects was cut halfway through the sample and the other extended three-quarters of the way through. The specimen was insonified from the intact side. Neither defect was detected, indicating that the resonances originate in one-quarter of the sample thickness or less.

Both of these resonances, for an incident angle of 27.5°, correspond to a phase velocity for the presumed guided wave of ~3.2 km/s and would thus have effective wavelengths much less than the thickness of a sample.

The behavior of both of the backscattered resonances was investigated as the angle of incidence was varied. By changing transducers to provide broad frequency coverage, the higher-frequency resonance could be followed up to 30 MHz and down to ~5 MHz. The behavior of this mode with incident angle was consistent with that of a typical guided- mode dispersion curve.

A fully cured sample consisting of a single ply was obtained. When insonified at an incident angle of 27.5°, two strong backscattering resonances were observed. The stronger occurred at a frequency of 6.9 MHz and corresponded to propagation at right angles to the fiber direction. The weaker resonance occurred at 5.5 MHz and corresponded to propagation along the fiber direction. This result establishes definitively that the resonances described earlier for samples of full thickness originate in a single ply, probably the 90° ply. Why the surface plies, which are +45° plies, do not yield the strongest resonances is unknown. One possible explanation is because the boundary conditions are not symmetric for these plies. The 90° ply, which is only one ply deep in the samples studied, is sandwiched between a +45° and a -45° ply, which, because of the orthotropic symmetry of a single ply, should mean identical elastic conditions at each boundary. The surface plies, on the other hand, have differing elastic properties at their boundaries. There are, of course, other plies within the structure that have symmetric boundary conditions, but they are more deeply embedded and thus more difficult to insonify.

This work has identified at least one characteristic of the carbon/epoxy composite which may be useful in detecting the presence of heat damage, viz., the backscattering strength of the single-ply resonances. This characteristic may be monitored from the exterior surface of the material, requires only a single transducer, and is independent of sample thickness variations because it appears to interrogate only the top two plies. The latter characteristic renders it insensitive to deeper lying damage, but such damage could be detected using a full-thickness, leaky Lamb mode simultaneously, although such a mode would be sensitive to thickness variations in the sample.

No attempt was made during this study to determine theoretically the leaky Lamb wave mode structure of the carbon/epoxy composite. This should certainly be done, however, because it would provide an estimate of the expected frequencies and angles of incidence necessary to excite a given mode in the structure. All of these modes should then be studied experimentally because some of these modes may be more sensitive to heat damage than the 1.5-MHz mode identified experimentally in this work.

The results of this study and of those cited earlier are encouraging and indicate that the use of leaky Lamb waves appears to be one of the most promising tools in the panoply of techniques assembled to characterize advanced composite structures. The fact that leaky Lamb waves are sensitive to thickness variations in the host material is certainly a drawback, but, at the worst, it merely means that measurements would be relative; i.e., they would have to be made at designated points on the structure both before and after heat exposure. This requirement could easily be met by using a template to locate the sites to be evaluated. Because the thickness at a given site would presumably not change (if it did, it would probably signify delamination, which is also a detrimental condition), any variations could then be assigned to damage. In any event, it seems a small price to pay if the required information could be obtained in this manner and in no other.

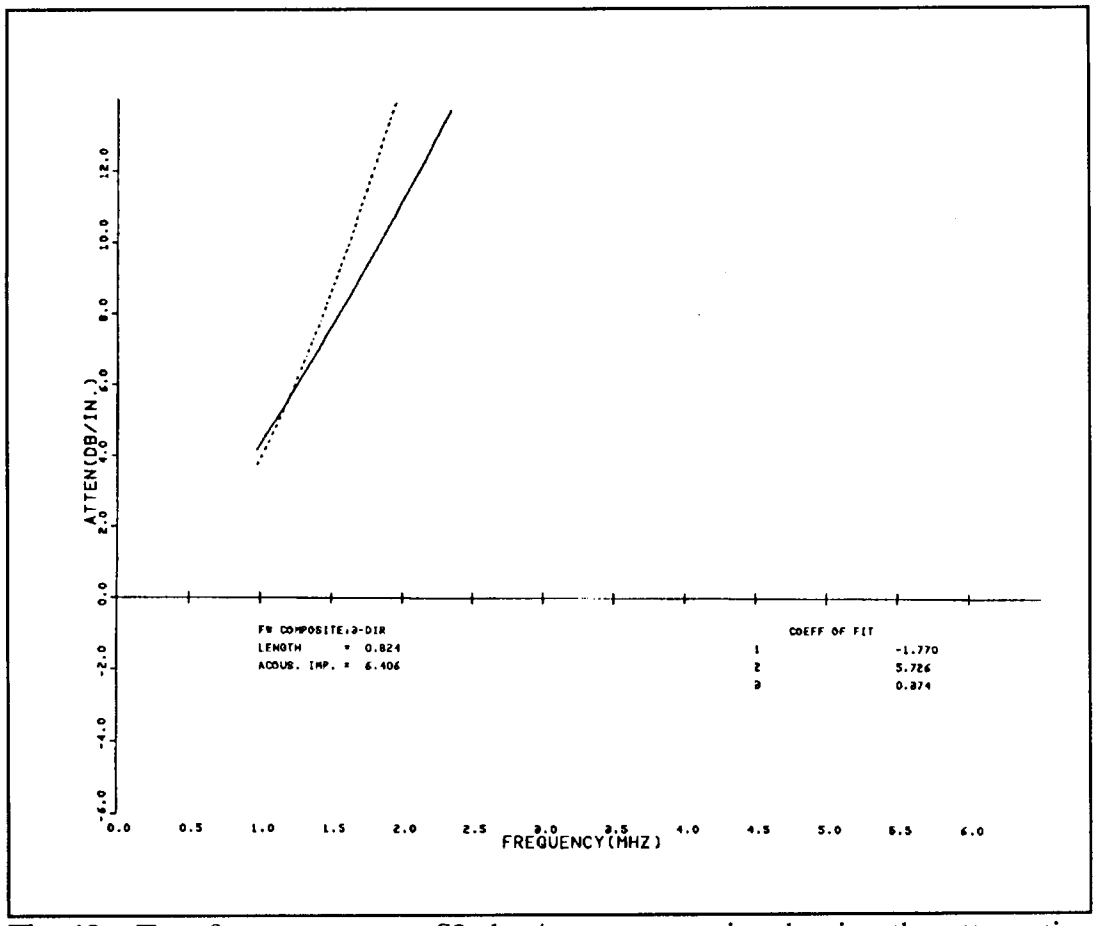


Fig. 19. Transfer curve on an S2-glass/epoxy composite showing the attenuation before (solid curve) and after (dashed curve) stressing.

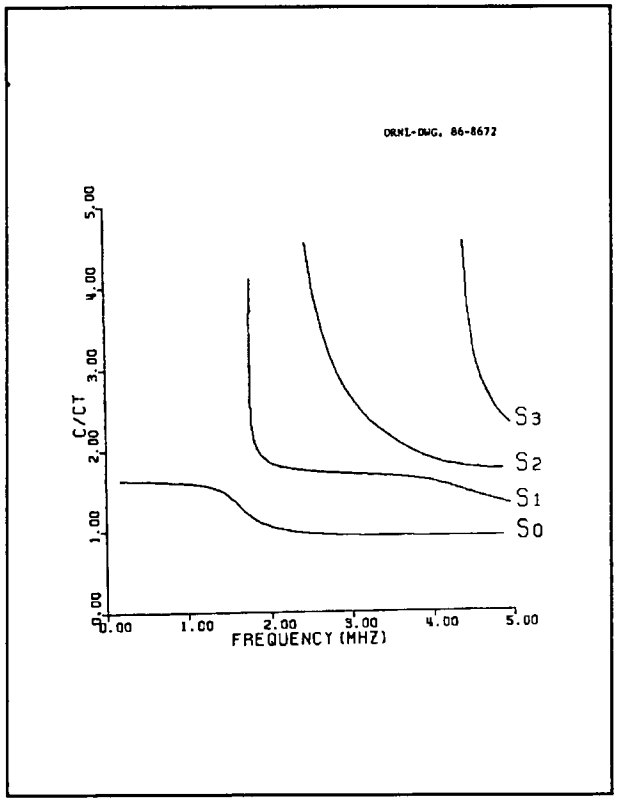


Fig. 20. Dispersion curve for symmetric Lamb modes in a ceramic plate.

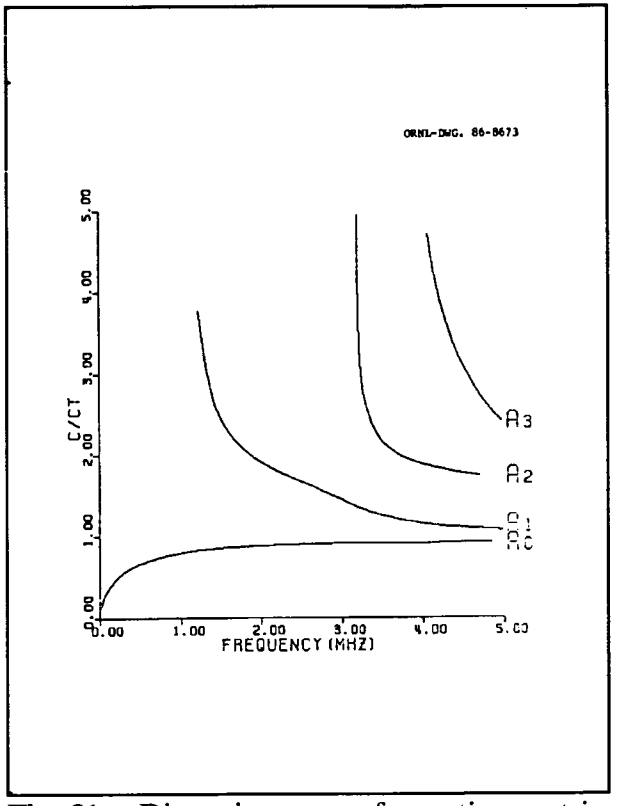


Fig. 21. Dispersion curve for antisymmetric-Lamb modes in a ceramic plate.

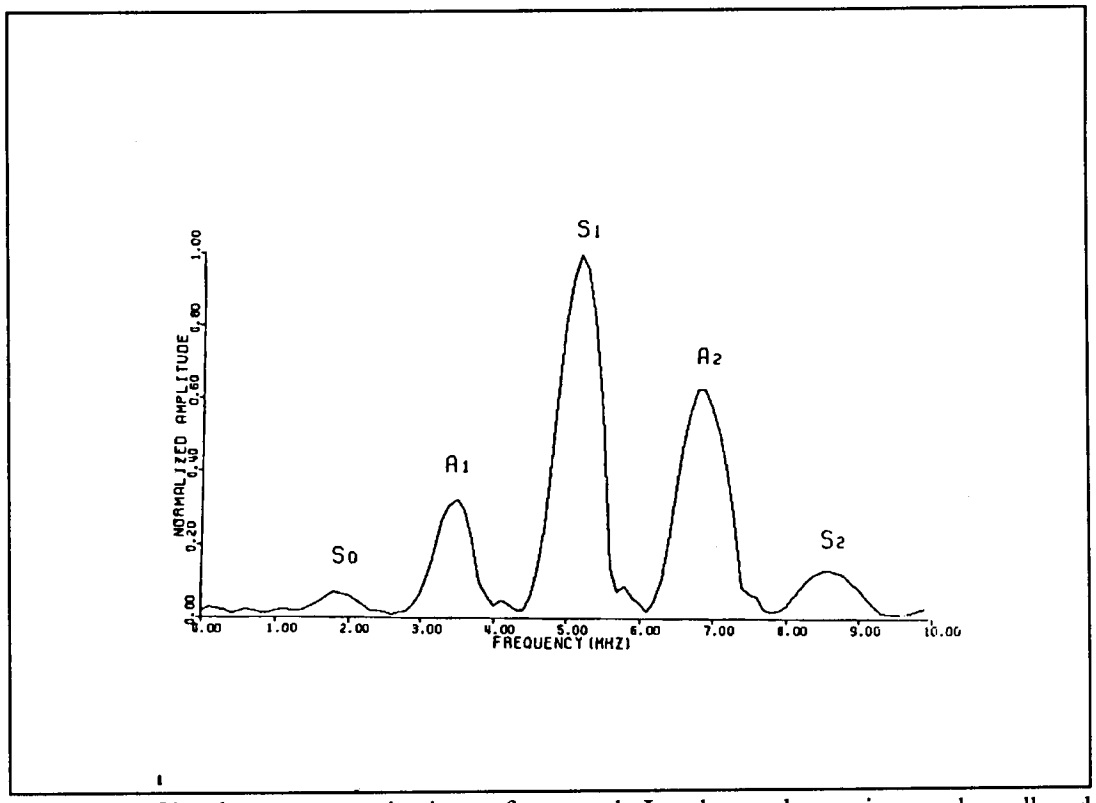


Fig. 22. Simultaneous excitation of several Lamb modes using a broadband transducer.

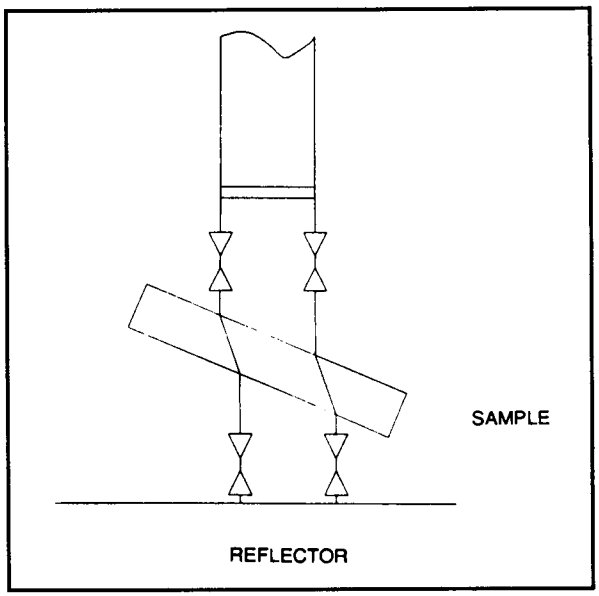


Fig. 23. Configuration used to study leaky Lamb wave spectrum of carbon/epoxy composite.

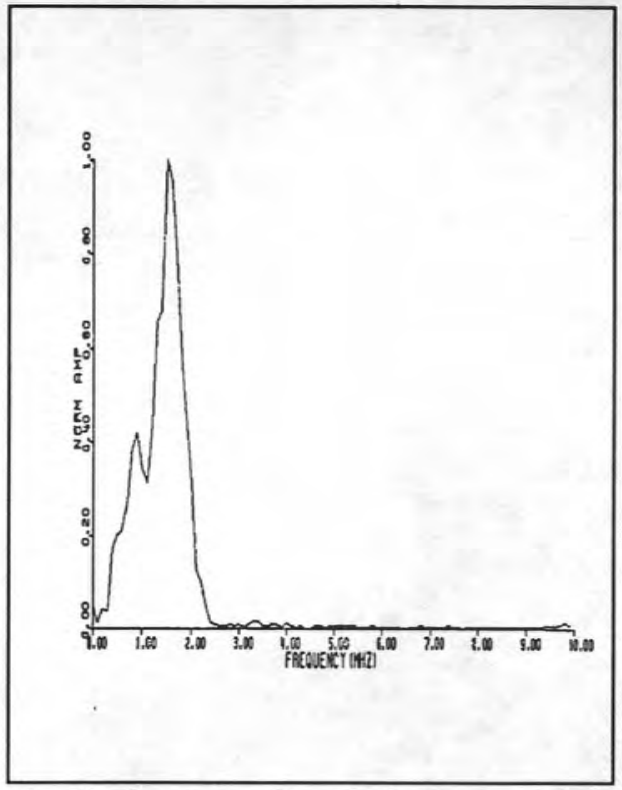


Fig. 24. Spectrum of one leaky Lamb mode in carbon/epoxy.

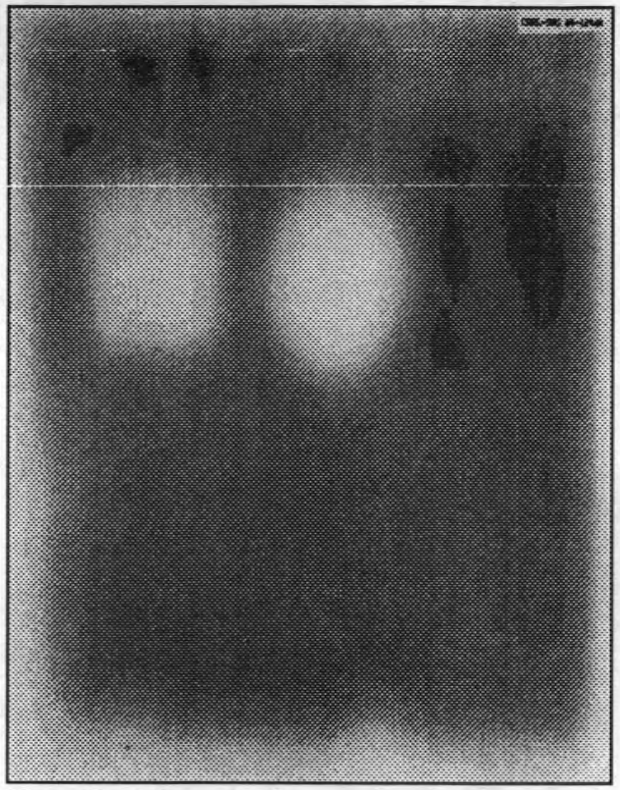


Fig. 25. Image of a carbon/epoxy sample showing detection of two "defects" by leaky Lamb wave.

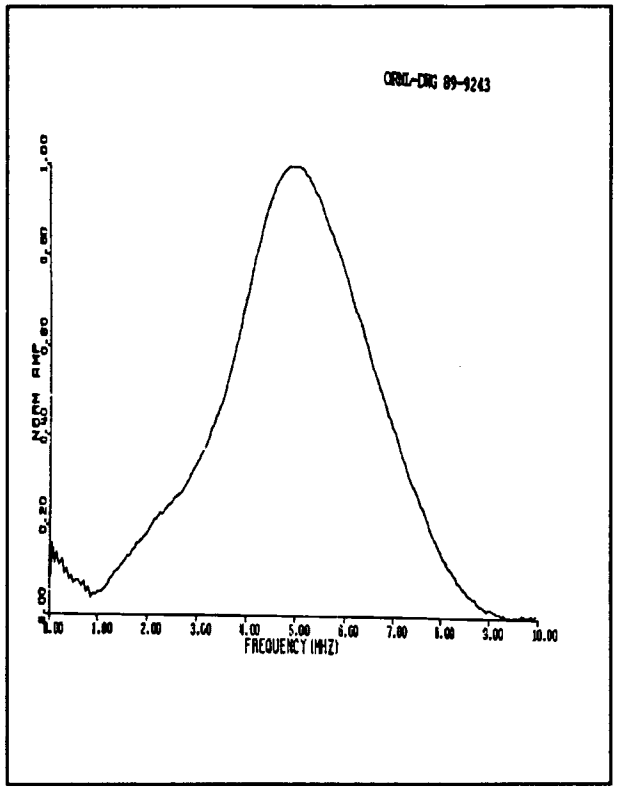


Fig. 26. Spectrum of the transducer used to study Lamb waves.

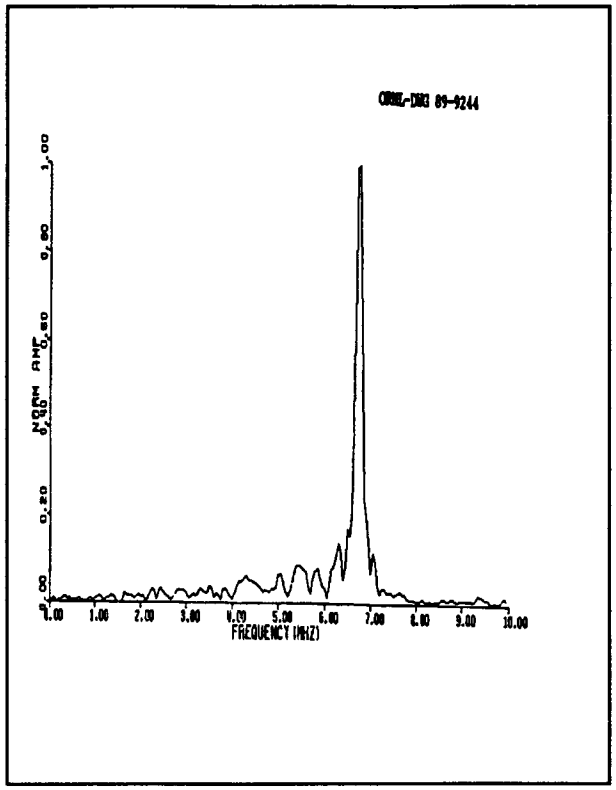


Fig. 27. Spectrum of the backscattered energy along fiber direction of the 0° ply.

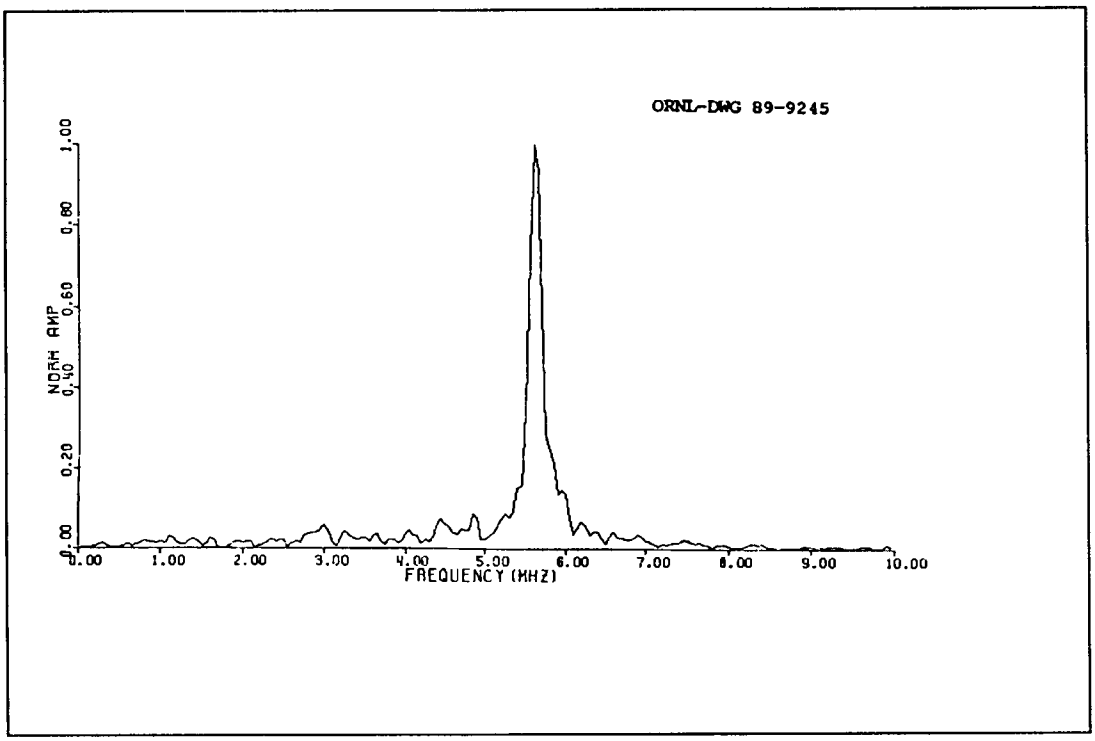


Fig. 28. Spectrum of the backscattered energy at right angles to the fiber direction of the 0° ply.

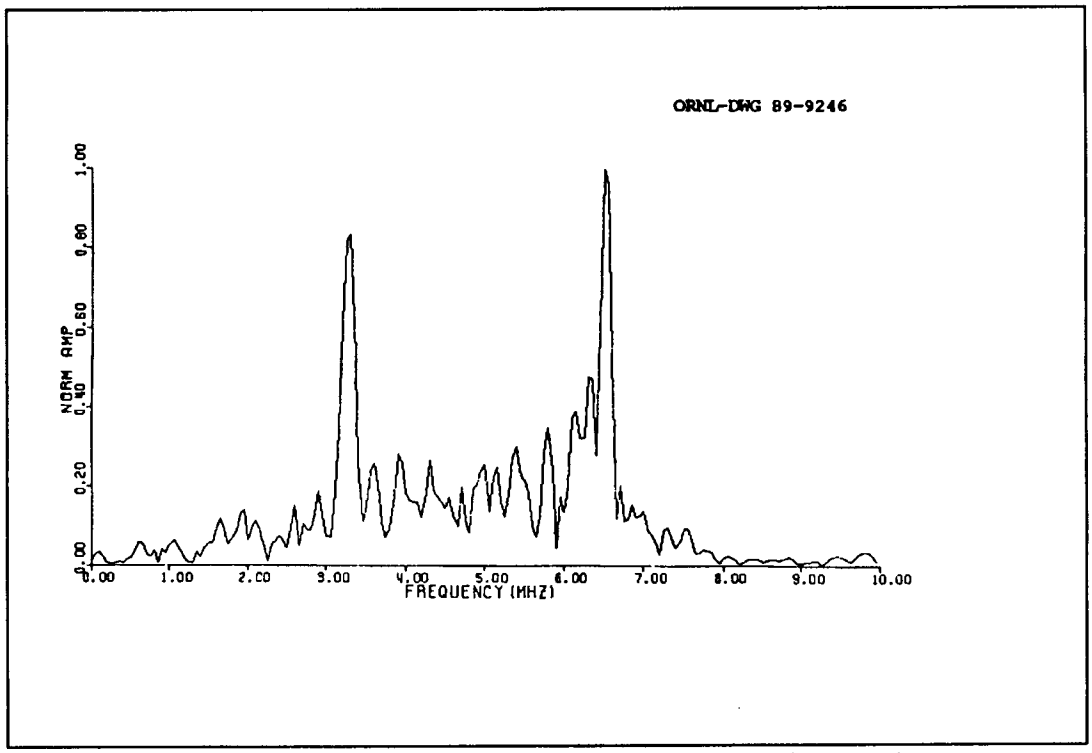


Fig. 29. Backscattering spectrum at a region on the composite showing appearance of a half-frequency mode.

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Appendix A

ZERO-DEGREE COMPRESSIVE PROPERTIES ACCORDING TO ASTM D-3410

IM6/3501-6
0 DEGREE COMPRESSIVE PROPERTIES PER ASTM D-3410

SUMMARY OF TEST DATA

EXPOSURE TEMP.	EXPOSURE TIME	"DRY" PRECON. COMPRESSION STRENGTH	"DRY" PRECON. STRENGTH RETENTION	"WET" PRECON. COMPRESSION STRENGTH	"WET" PRECON. STRENGTH RETENTION
(DEG. F)	(MIN.)	(PSI)	%	(PSI)	%
73		44,761	97.0	43,663	100.0
350	60	46,167	100.0	42,947	98.4
450	60	41,346	89.6	39,923	91.4
550	5	43,757	94.8	39,283	90.0
550	30	40,756	88.3	38,425	88.0
550	60	32,138	69.6	26,574	60.9
650	5	40,981	88.8	33,756	77.3
650	30	18,735	40.6	20,554	47.1
650	60	4,458	9.7	3,710	8.5
750	5	18,785	40.7	22,122	50.7
750	10	12,084	26.2	10,697	24.5
750	30	4,097	8.9	2,805	6.4

COMPRESSION DATA FOR :

ROOM TEMPERATURE

SPECIMEN NUMBER	COMPRESSIVE STRENGTH	COMPRESSIVE LOAD	STRESS AREA	MAT'L PRE-CON
#	PSI	LBS	IN^2	
11-6	45,640	5,580	0.1223	DRY
13-6	44,147	5,340	0.1210	DRY
14-6	39,824	4,850	0.1218	DRY
16-6	47,403	5,710	0.1205	DRY
17-1	46,790	5,610	0.1199	DRY
AVERAGE	44,761	5,418		
STD. DEV.	3,026	345		
% COEF. VAR	6.76	6.37		

ROOM TEMPERATURE

SPECIMEN NUMBER	COMPRESSIVE STRENGTH	COMPRESSIVE LOAD	STRESS AREA	MAT'L PRE-CON
#	PSI	LBS	IN^2	
11-23	41,183	5,030	0.1221	WET
13-23	42,318	5,100	0.1205	WET
14-23	42,867	5,250	0.1225	WET
16-19	48,056	5,840	0.1215	WET
17-10	43,893	5,380	0.1226	WET
AVERAGE	43,663	5,320		
STD. DEV.	2,643	321		
% COEF. VAR	6.05	6.03		

COMPRESSION DATA FOR :

350 F FOR 60 MINUTES

SPECIMEN NUMBER	COMPRESSIVE STRENGTH	COMPRESSIVE LOAD	STRESS AREA	MAT'L PRE-CON
#	PSI	LBS	IN^2	
11-7	47,891	5,760	0.1203	DRY
13-7	41,501	5,020	0.1210	DRY
14-7	47,702	5,770	0.1210	DRY
16-7	51,657	6,290	0.1218	DRY
17-2	42,086	5,190	0.1233	DRY
AVERAGE	46,167	5,606		
STD. DEV.	4,298	509		
% COEF. VAR	9.31	9.07		

350 F FOR 60 MINUTES

SPECIMEN NUMBER	COMPRESSIVE STRENGTH	COMPRESSIVE LOAD	STRESS AREA	MAT'L PRE-CON
#	PSI	LBS	IN^2	
11-24	44,731	5,380	0.1203	WET
13-24	41,631	5,180	0.1244	WET
14-24	39,643	4,920	0.1241	WET
16-20	44,719	5,400	0.1208	WET
17-11	44,012	5,400	0.1227	WET
AVERAGE	42,947	5,256		
STD. DEV.	2,242	209		
% COEF. VAR	5.22	3.99		

COMPRESSION DATA FOR :

450 F FOR 60 MINUTES

SPECIMEN NUMBER	COMPRESSIVE STRENGTH	COMPRESSIVE LOAD	STRESS AREA	MAT'L PRE-CON
#	PSI	LBS	IN^2	
11-8	43,650	5,250	0.1203	DRY
13-8	39,305	4,950	0.1259	DRY
14-8	41,343	5,030	0.1217	DRY
16-8	44,075	5,300	0.1202	DRY
17-3	38,356	4,730	0.1233	DRY
AVERAGE	41,346	5,052		
STD. DEV.	2,543	232		
% COEF. VAR	6.15	4.59		

450 F FOR 60 MINUTES

SPECIMEN NUMBER	COMPRESSIVE STRENGTH	COMPRESSIVE LOAD	STRESS AREA	MAT'L PRE-CON
#	PSI	LBS	IN^2	
11-25	40,198	4,790	0.1192	WET
13-25	41,712	5,090	0.1220	WET
14-25	40,049	4,900	0.1224	WET
16-21	40,218	4,860	0.1208	WET
17-12	37,437	4,570	0.1221	WET
AVERAGE	39,923	4,842		
STD. DEV.	1,546	188		
% COEF. VAR	3.87	3.89		

COMPRESSION DATA FOR :

550 F FOR 5 MINUTES

SPECIMEN NUMBER	COMPRESSIVE STRENGTH	COMPRESSIVE LOAD	STRESS AREA	MAT'L PRE-CON
#	PSI	LBS	IN^2	
11-9	41,593	5,000	0.1202	DRY
13-9	42,836	5,400	0.1261	DRY
14-9	44,436	5,470	0.1231	DRY
16-9	42,976	5,220	0.1215	DRY
17-4	46,945	5,670	0.1208	DRY
AVERAGE	43,757	5,352		
STD. DEV.	2,047	254		
% COEF. VAR	4.68	4.75		

550 F FOR 5 MINUTES

SPECIMEN NUMBER	COMPRESSIVE STRENGTH	COMPRESSIVE LOAD	STRESS AREA	MAT'L PRE-CON
#	PSI	LBS	IN^2	
11-26	40,262	4,920	0.1222	WET
13-26	34,288	4,180	0.1219	WET
14-26	39,235	4,810	0.1226	WET
16-22	40,758	4,860	0.1192	WET
17-13	41,872	5,200	0.1242	WET
AVERAGE	39,283	4,794		
STD. DEV.	2,949	375		
% COEF. VAR	7.51	7.82		

COMPRESSION DATA FOR :

550 F FOR 30 MINUTES

SPECIMEN NUMBER	COMPRESSIVE STRENGTH	COMPRESSIVE LOAD	STRESS AREA	MAT'L PRE-CON
#	PSI	LBS	IN^2	
11-10	38,700	4,770	0.1233	DRY
13-10	40,695	5,020	0.1234	DRY
14-10	36,423	4,530	0.1244	DRY
16-10	41,419	5,020	0.1212	DRY
17-5	46,545	5,760	0.1238	DRY
AVERAGE	40,756	5,020		
STD. DEV.	3,773	461		
% COEF. VAR	9.26	9.18		

550 F FOR 30 MINUTES

SPECIMEN NUMBER	COMPRESSIVE STRENGTH	COMPRESSIVE LOAD	STRESS AREA	MAT'L PRE-CON
#	PSI	LBS	IN^2	
11-27	41,322	4,970	0.1203	WET
13-27	35,688	4,490	0.1258	WET
14-27	35,175	4,330	0.1231	WET
16-23	38,681	4,610	0.1192	WET
17-14	41,260	5,060	0.1226	WET
AVERAGE	38,425	4,692		
STD. DEV.	2,939	313		
% COEF. VAR	7.65	6.67		

COMPRESSION DATA FOR :

550 F FOR 60 MINUTES

SPECIMEN NUMBER	COMPRESSIVE STRENGTH	COMPRESSIVE LOAD	STRESS AREA	MAT'L PRE-CON
#	PSI	LBS	IN^2	
11-11	30,037	3,775	0.1257	DRY
13-11	30,869	3,765	0.1220	DRY
14-11	25,419	3,110	0.1224	DRY
16-11	34,972	4,170	0.1192	DRY
17-6	39,394	4,880	0.1239	DRY
AVERAGE	32,138	3,940		
STD. DEV.	5,288	649		
% COEF. VAR	16.45	16.46		

550 F FOR 60 MINUTES

SPECIMEN NUMBER	COMPRESSIVE STRENGTH	COMPRESSIVE LOAD	STRESS AREA	MAT'L PRE-CON
#	PSI	LBS	IN^2	
11-28	25,987	3,095	0.1191	WET
13-28	25,098	3,050	0.1215	WET
14-28	24,746	3,090	0.1249	WET
16-24	28,946	3,510	0.1213	WET
17-15	28,091	3,410	0.1214	WET
AVERAGE	26,574	3,231		
STD. DEV.	1,857	213		
% COEF. VAR	6.99	6.58		

COMPRESSION DATA FOR :

650 F FOR 5 MINUTES

SPECIMEN NUMBER	COMPRESSIVE STRENGTH	COMPRESSIVE LOAD	STRESS AREA	MAT'L PRE-CON
#	PSI	LBS	IN^2	
11-12	42,196	5,180	0.1228	DRY
13-12	43,115	5,370	0.1245	DRY
14-12	35,632	4,310	0.1210	DRY
16-12	40,470	4,780	0.1181	DRY
17-7	43,493	5,350	0.1230	DRY
AVERAGE	40,981	4,998		
STD. DEV.	3,210	452		
% COEF. VAR	7.83	9.04		

650 F FOR 5 MINUTES

SPECIMEN NUMBER	COMPRESSIVE STRENGTH	COMPRESSIVE LOAD	STRESS AREA	MAT'L PRE-CON
#	PSI	LBS	IN^2	
11-29	33,513	4,010	0.1197	WET
13-29	35,079	4,420	0.1260	WET
14-29	29,545	3,600	0.1218	WET
16-25	32,410	3,930	0.1213	WET
17-16	38,234	4,670	0.1221	WET
AVERAGE	33,756	4,126		
STD. DEV.	3,217	422		
% COEF. VAR	9.53	10.22		

COMPRESSION DATA FOR :

650 F FOR 30 MINUTES

SPECIMEN NUMBER	COMPRESSIVE STRENGTH	COMPRESSIVE LOAD	STRESS AREA	MAT'L PRE-CON
#	PSI	LBS	IN^2	
11-13	23,528	2,900	0.1233	DRY
13-13	16,575	2,030	0.1225	DRY
14-13	15,451	1,910	0.1236	DRY
16-13	12,995	1,575	0.1212	DRY
17-8	25,126	3,100	0.1234	DRY
AVERAGE	18,735	2,303		
STD. DEV.	5,296	662		
% COEF. VAR	28.27	28.73		

650 F FOR 30 MINUTES

SPECIMEN NUMBER	COMPRESSIVE STRENGTH	COMPRESSIVE LOAD	STRESS AREA	MAT'L PRE-CON
#	PSI	LBS	IN^2	
11-30	16,762	2,040	0.1217	WET
13-30	24,541	2,970	0.1210	WET
14-30	24,609	3,000	0.1219	WET
16-26	17,879	2,150	0.1202	WET
17-17	18,978	2,280	0.1201	WET
AVERAGE	20,554	2,488		
STD. DEV.	3,754	462		
% COEF. VAR	18.26	18.56		

COMPRESSION DATA FOR :

650 F FOR 60 MINUTES

SPECIMEN NUMBER	COMPRESSIVE STRENGTH	COMPRESSIVE LOAD	STRESS AREA	MAT'L PRE-CON
#	PSI	LBS	IN^2	
11-14	3,201	388	0.1212	DRY
13-14	4,427	540	0.1220	DRY
14-14	7,211	890	0.1234	DRY
16-1	2,661	324	0.1218	DRY
17-9	4,790	588	0.1228	DRY
AVERAGE	4,458	546		
STD. DEV.	1,768	220		
% COEF. VAR	39.65	40.37		

650 F FOR 60 MINUTES

SPECIMEN NUMBER	COMPRESSIVE STRENGTH	COMPRESSIVE LOAD	STRESS AREA	MAT'L PRE-CON
#	PSI	LBS	IN^2	
11-31	4,957	603	0.1216	WET
13-31	4,049	490	0.1210	WET
14-31	3,287	408	0.1241	WET
16-14	3,688	447	0.1212	WET
17-18	2,566	315	0.1228	WET
AVERAGE	3,710	453		
STD. DEV.	889	106		
% COEF. VAR	23.95	23.43		

COMPRESSION DATA FOR :

750 F FOR 5 MINUTES

SPECIMEN NUMBER	COMPRESSIVE STRENGTH	COMPRESSIVE LOAD	STRESS AREA	MAT'L PRE-CON
#	PSI	LBS	IN^2	
11-15	14,037	1,720	0.1225	DRY
13-1	18,103	2,200	0.1215	DRY
13-15	15,175	1,890	0.1245	DRY
14-15	26,850	3,290	0.1225	DRY
16-2	19,761	2,425	0.1227	DRY
AVERAGE	18,785	2,305		
STD. DEV.	5,051	614		
% COEF. VAR	26.89	26.66		

750 F FOR 5 MINUTES

SPECIMEN NUMBER	COMPRESSIVE STRENGTH	COMPRESSIVE LOAD	STRESS AREA	MAT'L PRE-CON
#	PSI	LBS	IN^2	
11-18	17,399	2,165	0.1244	WET
11-32	24,393	2,940	0.1205	WET
13-32	22,971	2,780	0.1210	WET
14-32	26,877	3,295	0.1226	WET
16-15	18,968	2,300	0.1213	WET
AVERAGE	22,122	2,696		
STD. DEV.	3,897	465		
% COEF. VAR	17.62	17.24		

COMPRESSION DATA FOR :

750 F FOR 10 MINUTES

SPECIMEN NUMBER	COMPRESSIVE STRENGTH	COMPRESSIVE LOAD	STRESS AREA	MAT'L PRE-CON
#	PSI	LBS	IN^2	
11-16	7,605	952	0.1252	DRY
13-2	15,540	1,912	0.1230	DRY
13-16	12,384	1,498	0.1210	DRY
14-16	7,470	914	0.1224	DRY
16-3	17,422	2,050	0.1177	DRY
AVERAGE	12,084	1,465		
STD. DEV.	4,524	527		
% COEF. VAR	37.44	35.95		

750 F FOR 10 MINUTES

SPECIMEN NUMBER	COMPRESSIVE STRENGTH	COMPRESSIVE LOAD	STRESS AREA	MAT'L PRE-CON
#	PSI	LBS	IN^2	
11-19	14,450	1,738	0.1203	WET
11-33	15,370	1,862	0.1211	WET
13-33	6,761	828	0.1225	WET
14-18	8,627	1,056	0.1224	WET
16-16	8,280	1,004	0.1213	WET
AVERAGE	10,697	1,298		
STD. DEV.	3,923	468		
% COEF. VAR	36.67	36.10		

COMPRESSION DATA FOR :

750 F FOR 30 MINUTES

SPECIMEN NUMBER	COMPRESSIVE STRENGTH	COMPRESSIVE LOAD	STRESS AREA	MAT'L PRE-CON
#	PSI	LBS	IN^2	
11-17	3,965	488	0.1231	DRY
13-3	2,807	341	0.1215	DRY
13-17	5,548	699	0.1260	DRY
14-17	2,603	325	0.1249	DRY
16-4	5,562	658	0.1183	DRY
AVERAGE	4,097	502		
STD. DEV.	1,429	174		
% COEF. VAR	34.87	34.57		

750 F FOR 30 MINUTES

SPECIMEN NUMBER	COMPRESSIVE STRENGTH	COMPRESSIVE LOAD	STRESS AREA	MAT'L PRE-CON
#	PSI	LBS	IN^2	
11-20	3,088	385	0.1247	WET
11-34	1,819	217	0.1193	WET
13-34	1,968	240	0.1220	WET
14-19	2,425	303	0.1249	WET
16-17	4,723	555	0.1175	WET
AVERAGE	2,805	340		
STD. DEV.	1,181	137		
% COEF. VAR	42.10	40.21		

Appendix B

ZERO-DEGREE SHORT-BEAM-SHEAR PROPERTIES ACCORDING TO ASTM D-2344

IM6/3501-6
0 DEGREE SHORT BEAM SHEAR PROPERTIES PER ASTM D-2344

SUMMARY OF TEST DATA

EXPOSURE TEMP.	EXPOSURE TIME	"DRY" PRECON. SHEAR STRENGTH	"DRY" PRECON. STRENGTH RETENTION	"WET" PRECON. SHEAR STRENGTH	"WET" PRECON. STRENGTH RETENTION
(DEG. F)	(MIN.)	(PSI)	%	(PSI)	%
73		6,044	100.00	6,230	100.00
350	60	6,042	99.97	5,917	94.99
450	60	5,672	93.85	5,784	92.85
550	5	5,474	90.57	4,781	76.74
550	30	4,067	67.30	3,256	52.26
550	60	3,197	52.90	2,097	33.66
650	5	1,530	25.31	1,117	17.93
650	30	314	5.19	275	4.41
650	60	279	4.62	295	4.73

% WEIGHT GAIN AFTER PRECONDITIONING = 0.94 %

SPECIMEN NUMBER	SHEAR STRENGTH	BREAKING LOAD	EXPOSURE TEMP.	EXPOSURE TIME	MAT'L PRE-CON
#	PSI	LBS	DEG F.	MINUTES	WET DRY
10-34	6,376	256.0	73	N/A	WET
10-35	6,403	260.5	73	N/A	WET
10-36	6,183	255.0	73	N/A	WET
22-43	6,367	246.5	73	N/A	WET
22-44	6,288	247.0	73	N/A	WET
22-45	6,289	246.5	73	N/A	WET
22-79	6,135	238.5	73	N/A	WET
23-41	5,830	228.0	73	N/A	WET
23-42	6,220	249.0	73	N/A	WET
23-43	6,205	250.0	73	N/A	WET
AVERAGE	6,230	248			
STD. DEV.	166	9			
% COEF.VAR.	2.67	3.73			

% WEIGHT LOSS AFTER PRECONDITIONING = 0.15 %

SPECIMEN NUMBER	SHEAR STRENGTH	BREAKING LOAD	EXPOSURE TEMP.	EXPOSURE TIME	MAT'L PRE-CON
#	PSI	LBS	DEG F.	MINUTES	WET DRY
10-1	5,952	247.0	73	N/A	DRY
10-2	6,292	263.0	73	N/A	DRY
10-3	5,567	222.5	73	N/A	DRY
22-1	5,873	227.5	73	N/A	DRY
22-2	6,106	241.5	73	N/A	DRY
22-3	6,057	239.5	73	N/A	DRY
22-37	5,925	231.5	73	N/A	DRY
23-1	6,206	251.0	73	N/A	DRY
23-2	6,263	253.5	73	N/A	DRY
23-3	6,194	249.5	73	N/A	DRY
AVERAGE	6,044	243			
STD. DEV.	222	13			
% COEF.VAR.	3.67	5.21			

% WEIGHT GAIN AFTER PRECONDITIONING = 0.94 %

SPECIMEN NUMBER	SHEAR STRENGTH	BREAKING LOAD	EXPOSURE TEMP.	EXPOSURE TIME	MAT'L PRE-CON
#	PSI	LBS	DEG F.	MINUTES	WET DRY
10-37	6,357	264.5	350	60	WET
10-38	5,824	236.5	350	60	WET
10-39	5,934	240.5	350	60	WET
22-46	5,566	215.5	350	60	WET
22-47	5,560	217.5	350	60	WET
22-48	5,817	227.5	350	60	WET
22-80	6,149	239.0	350	60	WET
23-44	5,940	241.0	350	60	WET
23-45	6,075	242.5	350	60	WET
23-46	5,953	243.5	350	60	WET
AVERAGE	5,917	237			
STD. DEV.	246	14			
% COEF.VAR.	4.15	5.96			

% WEIGHT LOSS AFTER PRECONDITIONING = 0.15 %

SPECIMEN NUMBER	SHEAR STRENGTH	BREAKING LOAD	EXPOSURE TEMP.	EXPOSURE TIME	MAT'L PRE-CON
#	PSI	LBS	DEG F.	MINUTES	WET DRY
10-4	5,881	233.0	350	60	DRY
10-5	6,471	264.5	350	60	DRY
10-6	6,248	254.0	350	60	DRY
22-4	5,865	228.0	350	60	DRY
22-5	6,041	237.0	350	60	DRY
22-6	5,817	227.0	350	60	DRY
22-38	5,692	225.5	350	60	DRY
23-4	6,155	244.0	350	60	DRY
23-5	5,975	243.0	350	60	DRY
23-6	6,275	255.5	350	60	DRY
AVERAGE	6,042	241			
STD. DEV.	242	13			
% COEF.VAR.	4.01	5.58			

% WEIGHT GAIN AFTER PRECONDITIONING = 0.94 %

SPECIMEN NUMBER	SHEAR STRENGTH	BREAKING LOAD	EXPOSURE TEMP.	EXPOSURE TIME	MAT'L PRE-CON
#	PSI	LBS	DEG F.	MINUTES	WET DRY
10-40	5,679	233.0	450	60	WET
10-41	5,918	241.5	450	60	WET
10-42	5,710	231.0	450	60	WET
22-49	5,636	220.0	450	60	WET
22-50	5,830	229.0	450	60	WET
22-51	5,607	217.5	450	60	WET
22-81	5,766	226.0	450	60	WET
23-47	5,956	236.0	450	60	WET
23-48	5,794	234.5	450	60	WET
23-49	5,943	238.5	450	60	WET
AVERAGE	5,784	231			
STD. DEV.	127	8			
% COEF.VAR.	2.19	3.35			

% WEIGHT LOSS AFTER PRECONDITIONING = 0.15 %

SPECIMEN NUMBER	SHEAR STRENGTH	BREAKING LOAD	EXPOSURE TEMP.	EXPOSURE TIME	MAT'L PRE-CON
#	PSI	LBS	DEG F.	MINUTES	WET DRY
10-7	5,661	227.0	450	60	DRY
10-8	6,191	252.0	450	60	DRY
10-9	5,788	231.5	450	60	DRY
22-7	5,591	218.5	450	60	DRY
22-8	5,334	206.5	450	60	DRY
22-9	5,403	210.5	450	60	DRY
22-39	5,557	216.0	450	60	DRY
23-7	5,776	235.0	450	60	DRY
23-8	5,527	221.0	450	60	DRY
23-9	5,893	233.5	450	60	DRY
AVERAGE	5,672	225			
STD. DEV.	252	13			
% COEF.VAR.	4.44	5.99			

% WEIGHT GAIN AFTER PRECONDITIONING = 0.94 %

SPECIMEN NUMBER	SHEAR STRENGTH	BREAKING LOAD	EXPOSURE TEMP.	EXPOSURE TIME	MAT'L PRE-CON
#	PSI	LBS	DEG F.	MINUTES	WET DRY
10-43	4,172	169.0	550	5	WET
10-44	4,149	172.5	550	5	WET
10-45	5,253	214.5	550	5	WET
22-52	5,258	206.5	550	5	WET
22-53	4,384	171.5	550	5	WET
22-54	5,492	213.5	550	5	WET
22-82	4,499	177.0	550	5	WET
23-50	4,549	186.5	550	5	WET
23-51	4,389	177.0	550	5	WET
23-52	5,660	228.5	550	5	WET
AVERAGE	4,781	192			
STD. DEV.	572	22			
% COEF.VAR.	11.96	11.43			

% WEIGHT LOSS AFTER PRECONDITIONING = 0.15 %

SPECIMEN NUMBER	SHEAR STRENGTH	BREAKING LOAD	EXPOSURE TEMP.	EXPOSURE TIME	MAT'L PRE-CON
#	PSI	LBS	DEG F.	MINUTES	WET DRY
10-10	5,480	225.5	550	5	DRY
10-11	5,528	224.0	550	5	DRY
10-12	5,367	224.5	550	5	DRY
22-10	5,033	198.5	550	5	DRY
22-11	5,226	204.0	550	5	DRY
22-12	5,205	201.5	550	5	DRY
22-40	4,998	196.5	550	5	DRY
23-10	5,906	232.5	550	5	DRY
23-11	6,294	256.5	550	5	DRY
23-12	5,700	229.5	550	5	DRY
AVERAGE	5,474	219			
STD. DEV.	405	19			
% COEF.VAR.	7.41	8.67			

% WEIGHT GAIN AFTER PRECONDITIONING = 0.94 %

SPECIMEN NUMBER	SHEAR STRENGTH	BREAKING LOAD	EXPOSURE TEMP.	EXPOSURE TIME	MAT'L PRE-CON
#	PSI	LBS	DEG F.	MINUTES	WET DRY
10-46	3,015	125.0	550	30	WET
10-47	3,032	122.5	550	30	WET
10-48	3,832	160.0	550	30	WET
22-55	3,482	136.5	550	30	WET
22-56	2,539	97.5	550	30	WET
22-57	4,053	157.5	550	30	WET
22-83	2,545	98.5	550	30	WET
23-53	4,177	169.0	550	30	WET
23-54	2,384	95.0	550	30	WET
23-55	3,496	136.5	550	30	WET
AVERAGE	3,256	130			
STD. DEV.	651	27			
% COEF.VAR.	19.99	20.89			

% WEIGHT LOSS AFTER PRECONDITIONING = 0.15 %

SPECIMEN NUMBER	SHEAR STRENGTH	BREAKING LOAD	EXPOSURE TEMP.	EXPOSURE TIME	MAT'L PRE-CON
#	PSI	LBS	DEG F.	MINUTES	WET DRY
10-13	4,784	195.6	550	30	DRY
10-14	4,780	199.0	550	30	DRY
10-15	4,071	170.0	550	30	DRY
22-13	3,395	131.5	550	30	DRY
22-14	3,367	132.5	550	30	DRY
22-15	4,903	191.5	550	30	DRY
22-41	4,688	184.5	550	30	DRY
23-13	3,562	141.5	550	30	DRY
23-14	3,741	153.0	550	30	DRY
23-15	3,382	136.0	550	30	DRY
AVERAGE	4,067	164			
STD. DEV.	656	28			
% COEF.VAR.	16.14	16.93			

% WEIGHT GAIN AFTER PRECONDITIONING = 0.94 %

SPECIMEN NUMBER	SHEAR STRENGTH	BREAKING LOAD	EXPOSURE TEMP.	EXPOSURE TIME	MAT'L PRE-CON
#	PSI	LBS	DEG F.	MINUTES	WET DRY
10-49	2,866	116.8	550	60	WET
10-50	3,505	146.0	550	60	WET
10-51	1,564	63.2	550	60	WET
22-58	1,826	72.0	550	60	WET
22-59	2,266	89.0	550	60	WET
22-60	2,219	86.8	550	60	WET
22-84	1,622	63.2	550	60	WET
23-56	1,687	69.6	550	60	WET
23-57	1,678	66.6	550	60	WET
23-58	1,735	70.8	550	60	WET
AVERAGE	2,097	84			
STD. DEV.	639	27			
% COEF.VAR.	30.47	32.19			

% WEIGHT LOSS DURING PRECONDITIONING = 0.15 %

SPECIMEN NUMBER	SHEAR STRENGTH	BREAKING LOAD	EXPOSURE TEMP.	EXPOSURE TIME	MAT'L PRE-CON
#	PSI	LBS	DEG F.	MINUTES	WET DRY
10-16	3,961	163.0	550	60	DRY
10-17	3,903	159.0	550	60	DRY
10-18	3,392	143.6	550	60	DRY
22-16	2,700	105.2	550	60	DRY
22-17	4,304	169.4	550	60	DRY
22-18	2,218	84.8	550	60	DRY
22-42	2,869	112.0	550	60	DRY
23-16	3,132	126.2	550	60	DRY
23-17	3,195	128.0	550	60	DRY
23-18	2,298	88.0	550	60	DRY
AVERAGE	3,197	128			
STD. DEV.	705	31			
% COEF.VAR.	22.04	23.87			

% WEIGHT GAIN AFTER PRECONDITIONING = 0.94 %

SPECIMEN NUMBER	SHEAR STRENGTH	BREAKING LOAD	EXPOSURE TEMP.	EXPOSURE TIME	MAT'L PRE-CON
#	PSI	LBS	DEG F.	MINUTES	WET DRY
10-52	BROKE WHILE HANDLING		650	5	WET
10-53	1,635	66.6	650	5	WET
10-54	551	23.6	650	5	WET
22-61	773	29.8	650	5	WET
22-62	582	23.0	650	5	WET
22-63	3,643	142.2	650	5	WET
22-85	582	22.8	650	5	WET
23-59	733	29.2	650	5	WET
23-60	570	23.2	650	5	WET
23-61	982	38.8	650	5	WET
AVERAGE	1,117	44			
STD. DEV.	1,008	39			
% COEF.VAR.	90.23	88.54			

% WEIGHT LOSS AFTER PRECONDITIONING = 0.15 %

SPECIMEN NUMBER	SHEAR STRENGTH	BREAKING LOAD	EXPOSURE TEMP.	EXPOSURE TIME	MAT'L PRE-CON
#	PSI	LBS	DEG F.	MINUTES	WET DRY
10-19	1,187	49.3	650	5	DRY
10-20	782	31.7	650	5	DRY
10-21	1,417	57.5	650	5	DRY
22-19	744	29.0	650	5	DRY
22-20	4,784	184.8	650	5	DRY
22-21	2,791	108.8	650	5	DRY
23-19	1,057	42.8	650	5	DRY
23-20	914	36.8	650	5	DRY
23-21	744	30.2	650	5	DRY
23-37	875	35.0	650	5	DRY
AVERAGE	1,530	61			
STD. DEV.	1,297	50			
% COEF.VAR.	84.79	81.93			

% WEIGHT GAIN DURING PRECONDITIONING = 0.94 %

SPECIMEN NUMBER	SHEAR STRENGTH	BREAKING LOAD	EXPOSURE TEMP.	EXPOSURE TIME	MAT'L PRE-CON
#	PSI	LBS	DEG F.	MINUTES	WET DRY
10-55	260	11.0	650	30	WET
10-56	290	12.2	650	30	WET
10-57	313	13.0	650	30	WET
22-64	323	12.6	650	30	WET
22-65	243	9.5	650	30	WET
22-66	202	7.8	650	30	WET
23-62	256	10.5	650	30	WET
23-63	310	12.5	650	30	WET
23-64	252	10.2	650	30	WET
23-77	286	11.3	650	30	WET
AVERAGE	275	11			
STD. DEV.	38	2			
% COEF.VAR.	13.77	14.61			

% WEIGHT LOSS AFTER PRECONDITIONING = 0.15 %

SPECIMEN NUMBER	SHEAR STRENGTH	BREAKING LOAD	EXPOSURE TEMP.	EXPOSURE TIME	MAT'L PRE-CON
#	PSI	LBS	DEG F.	MINUTES	WET DRY
10-22	233	9.4	650	30	DRY
10-23	229	9.7	650	30	DRY
10-24	245	9.9	650	30	DRY
22-22	306	12.0	650	30	DRY
22-23	321	12.6	650	30	DRY
22-24	269	10.6	650	30	DRY
23-22	568	22.9	650	30	DRY
23-23	326	13.1	650	30	DRY
23-24	322	13.0	650	30	DRY
23-38	317	12.4	650	30	DRY
AVERAGE	314	13			
STD. DEV.	97	4			
% COEF.VAR.	31.06	31.10			

% WEIGHT GAIN AFTER PRECONDITIONING = 0.94 %

SPECIMEN NUMBER	SHEAR STRENGTH	BREAKING LOAD	EXPOSURE TEMP.	EXPOSURE TIME	MAT'L PRE-CON
#	PSI	LBS	DEG F.	MINUTES	WET DRY
10-58	255	10.5	650	60	WET
10-59	308	13.0	650	60	WET
10-60	277	11.5	650	60	WET
22-67	303	12.0	650	60	WET
22-68	296	11.6	650	60	WET
22-69	309	12.2	650	60	WET
23-65	232	9.3	650	60	WET
23-66	338	13.3	650	60	WET
23-67	278	11.3	650	60	WET
23-78	309	12.5	650	60	WET
AVERAGE	295	12			
STD. DEV.	31	1			
% COEF.VAR.	10.38	9.93			

% WEIGHT LOSS AFTER PRECONDITIONING = 0.15 %

SPECIMEN NUMBER	SHEAR STRENGTH	BREAKING LOAD	EXPOSURE TEMP.	EXPOSURE TIME	MAT'L PRE-CON
#	PSI	LBS	DEG F.	MINUTES	WET DRY
10-25	305	12.4	650	60	DRY
10-26	316	13.0	650	60	DRY
10-27	258	10.6	650	60	DRY
22-25	288	11.3	650	60	DRY
22-26	321	12.6	650	60	DRY
22-27	199	7.8	650	60	DRY
23-25	248	10.0	650	60	DRY
23-26	193	7.8	650	60	DRY
23-27	310	12.8	650	60	DRY
23-39	355	14.2	650	60	DRY
AVERAGE	279	11			
STD. DEV.	54	2			
% COEF.VAR.	19.21	19.46			

Appendix C

NINETY-DEGREE SHORT-BEAM-SHEAR PROPERTIES ACCORDING TO ASTM D-2344

IM6/3501-6
90 DEGREE SHORT BEAM SHEAR PROPERTIES PER ASTM D-2344

SUMMARY OF TEST DATA

EXPOSURE TEMP.	EXPOSURE TIME	"DRY" PRECON. SHEAR STRENGTH	"DRY" PRECON. STRENGTH RETENTION	"WET" PRECON. SHEAR STRENGTH	"WET" PRECON. STRENGTH RETENTION
(DEG. F)	(MIN.)	(PSI)	%	(PSI)	%
73		8,691	91.99	9,983	100.00
350	60	9,448	100.00	8,918	89.34
450	60	8,846	93.63	7,374	73.86
550	5	8,880	93.99	6,535	65.46
550	30	4,561	48.28	4,270	42.78
550	60	2,085	22.06	2,402	24.07
650	5	2,492	26.38	3,396	34.02

% WEIGHT GAIN AFTER PRECONDITIONING = 0.85 %

SPECIMEN NUMBER	SHEAR STRENGTH	BREAKING LOAD	EXPOSURE TEMP.	EXPOSURE TIME	MAT'L PRE-CON
#	PSI	LBS	DEG F.	MINUTES	WET DRY
17-14	9,736	396.0	73	N/A	WET
17-17	9,951	408.0	73	N/A	WET
16-77	9,869	403.0	73	N/A	WET
16-89	8,248	345.0	73	N/A	WET
16-101	11,144	456.0	73	N/A	WET
16-113	10,325	425.0	73	N/A	WET
16-125	10,499	427.0	73	N/A	WET
16-204	10,077	414.0	73	N/A	WET
16-216	9,094	372.0	73	N/A	WET
16-228	10,884	440.0	73	N/A	WET
AVERAGE	9,983	409			
STD. DEV.	845	32			
% COEF. VAR	8.47	7.93			

% WEIGHT LOSS AFTER PRECONDITIONING = 0.27 %

SPECIMEN NUMBER	SHEAR STRENGTH	BREAKING LOAD	EXPOSURE TEMP.	EXPOSURE TIME	MAT'L PRE-CON
#	PSI	LBS	DEG F.	MINUTES	WET DRY
17-2	7,619	303.0	73	N/A	DRY
16-6	8,586	349.0	73	N/A	DRY
16-18	9,468	385.0	73	N/A	DRY
16-30	8,410	342.0	73	N/A	DRY
16-42	9,124	368.0	73	N/A	DRY
16-54	9,868	398.0	73	N/A	DRY
16-143	8,408	353.0	73	N/A	DRY
16-155	9,503	384.0	73	N/A	DRY
16-167	7,866	325.0	73	N/A	DRY
16-179	8,059	327.0	73	N/A	DRY
AVERAGE	8,691	353			
STD. DEV.	763	30			
% COEF. VAR	8.78	8.61			

% WEIGHT GAIN AFTER PRECONDITIONING = 0.85 %

SPECIMEN NUMBER	SHEAR STRENGTH	BREAKING LOAD	EXPOSURE TEMP.	EXPOSURE TIME	MAT'L PRE-CON
#	PSI	LBS	DEG F.	MINUTES	WET DRY
16-78	9,551	394.0	350	60	WET
16-90	9,891	387.5	350	60	WET
16-102	7,814	319.0	350	60	WET
16-114	9,223	382.5	350	60	WET
16-126	8,000	326.0	350	60	WET
16-205	9,918	405.0	350	60	WET
16-217	8,338	331.5	350	60	WET
16-229	8,395	340.0	350	60	WET
17-15	10,100	405.0	350	60	WET
17-18	7,954	317.0	350	60	WET
AVERAGE	8,918	361			
STD. DEV.	909	37			
% COEF. VAR	10.19	10.27			

% WEIGHT LOSS AFTER PRECONDITIONING = 0.27 %

SPECIMEN NUMBER	SHEAR STRENGTH	BREAKING LOAD	EXPOSURE TEMP.	EXPOSURE TIME	MAT'L PRE-CON
#	PSI	LBS	DEG F.	MINUTES	WET DRY
16-7	8,885	342.5	350	60	DRY
16-19	8,698	353.0	350	60	DRY
16-31	9,185	375.0	350	60	DRY
16-43	9,575	396.5	350	60	DRY
16-55	8,556	353.5	350	60	DRY
16-144	10,710	428.5	350	60	DRY
16-156	9,005	356.5	350	60	DRY
16-166	12,960	526.0	350	60	DRY
16-180	8,401	350.0	350	60	DRY
17-3	8,502	346.5	350	60	DRY
AVERAGE	9,448	383			
STD. DEV.	1,409	57			
% COEF. VAR	14.92	14.91			

% WEIGHT GAIN AFTER PRECONDITIONING = 0.85 %

SPECIMEN NUMBER	SHEAR STRENGTH	BREAKING LOAD	EXPOSURE TEMP.	EXPOSURE TIME	MAT'L PRE-CON
#	PSI	LBS	DEG F.	MINUTES	WET DRY
16-79	7,712	320.0	450	60	WET
16-91	7,097	285.0	450	60	WET
16-103	7,604	308.0	450	60	WET
16-115	7,202	297.0	450	60	WET
16-127	6,994	278.0	450	60	WET
16-206	7,215	297.5	450	60	WET
16-218	7,813	317.0	450	60	WET
16-230	6,681	279.5	450	60	WET
17-16	7,729	308.0	450	60	WET
17-19	7,688	307.0	450	60	WET
AVERAGE	7,374	300			
STD. DEV.	386	15			
% COEF. VAR	5.23	4.99			

% WEIGHT LOSS AFTER PRECONDITIONING = 0.27 %

SPECIMEN NUMBER	SHEAR STRENGTH	BREAKING LOAD	EXPOSURE TEMP.	EXPOSURE TIME	MAT'L PRE-CON
#	PSI	LBS	DEG F.	MINUTES	WET DRY
16-4	9,111	366.0	450	60	DRY
16-8	11,352	457.0	450	60	DRY
16-20	8,166	324.5	450	60	DRY
16-32	7,942	329.5	450	60	DRY
16-44	10,117	390.0	450	60	DRY
16-56	8,484	345.0	450	60	DRY
16-145	7,893	327.5	450	60	DRY
16-157	7,731	317.0	450	60	DRY
16-169	8,685	346.0	450	60	DRY
16-181	8,974	365.0	450	60	DRY
AVERAGE	8,846	357			
STD. DEV.	1,134	42			
% COEF. VAR	12.82	11.74			

% WEIGHT GAIN AFTER PRECONDITIONING = 0.85 %

SPECIMEN NUMBER	SHEAR STRENGTH	BREAKING LOAD	EXPOSURE TEMP.	EXPOSURE TIME	MAT'L PRE-CON
#	PSI	LBS	DEG F.	MINUTES	WET DRY
16-80	6,123	252.0	550	5	WET
16-92	6,650	267.0	550	5	WET
16-104	6,451	260.5	550	5	WET
16-116	6,816	280.5	550	5	WET
16-128	7,161	289.5	550	5	WET
16-140	6,271	259.5	550	5	WET
16-207	6,723	276.0	550	5	WET
16-219	5,715	230.5	550	5	WET
16-231	6,484	262.0	550	5	WET
17-20	6,951	272.5	550	5	WET
AVERAGE	6,535	265			
STD. DEV.	424	16			
% COEF. VAR	6.48	6.21			

% WEIGHT LOSS AFTER PRECONDITIONING = 0.27 %

SPECIMEN NUMBER	SHEAR STRENGTH	BREAKING LOAD	EXPOSURE TEMP.	EXPOSURE TIME	MAT'L PRE-CON
#	PSI	LBS	DEG F.	MINUTES	WET DRY
16-9	9,926	395.5	550	5	DRY
16-21	8,902	356.0	550	5	DRY
16-33	8,573	357.0	550	5	DRY
16-45	8,565	352.5	550	5	DRY
16-57	8,865	362.0	550	5	DRY
16-146	8,486	350.5	550	5	DRY
16-158	7,367	302.0	550	5	DRY
16-178	8,286	331.5	550	5	DRY
16-182	10,760	435.0	550	5	DRY
17-5	9,066	365.0	550	5	DRY
AVERAGE	8,880	361			
STD. DEV.	922	35			
% COEF. VAR	10.39	9.80			

% WEIGHT GAIN AFTER PRECONDITIONING = 0.85 %

SPECIMEN NUMBER	SHEAR STRENGTH	BREAKING LOAD	EXPOSURE TEMP.	EXPOSURE TIME	MAT'L PRE-CON
#	PSI	LBS	DEG F.	MINUTES	WET DRY
16-81	4,978	202.0	550	30	WET
16-93	5,229	210.0	550	30	WET
16-105	3,619	141.5	550	30	WET
16-117	3,886	162.5	550	30	WET
16-129	3,541	144.0	550	30	WET
16-141	4,200	175.0	550	30	WET
16-208	5,066	206.0	550	30	WET
16-220	3,623	148.5	550	30	WET
16-232	3,542	147.0	550	30	WET
17-21	5,019	202.5	550	30	WET
AVERAGE	4,270	174			
STD. DEV.	720	29			
% COEF. VAR	16.87	16.47			

% WEIGHT LOSS AFTER PRECONDITIONING = 0.27 %

SPECIMEN NUMBER	SHEAR STRENGTH	BREAKING LOAD	EXPOSURE TEMP.	EXPOSURE TIME	MAT'L PRE-CON
#	PSI	LBS	DEG F.	MINUTES	WET DRY
16-13	3,858	155.0	550	30	DRY
16-25	3,501	140.0	550	30	DRY
16-37	4,322	170.0	550	30	DRY
16-49	4,925	199.0	550	30	DRY
16-61	5,504	222.0	550	30	DRY
16-150	5,026	206.5	550	30	DRY
16-162	4,071	166.5	550	30	DRY
16-171	5,038	209.5	550	30	DRY
16-186	5,366	216.5	550	30	DRY
17-6	4,000	163.0	550	30	DRY
AVERAGE	4,561	185			
STD. DEV.	695	29			
% COEF. VAR	15.23	15.72			

% WEIGHT GAIN AFTER PRECONDITIONING = 0.85 %

SPECIMEN NUMBER	SHEAR STRENGTH	BREAKING LOAD	EXPOSURE TEMP.	EXPOSURE TIME	MAT'L PRE-CON
#	PSI	LBS	DEG F.	MINUTES	WET DRY
16-82	2,646	107.6	550	60	WET
16-94	2,006	81.6	550	60	WET
16-106	3,205	129.4	550	60	WET
16-118	1,840	75.2	550	60	WET
16-130	2,410	98.8	550	60	WET
16-209	2,012	80.2	550	60	WET
16-221	2,065	80.6	550	60	WET
16-233	2,419	99.0	550	60	WET
17-22	3,019	122.8	550	60	WET
AVERAGE	2,402	97			
STD. DEV.	477	20			
% COEF. VAR	19.87	20.24			

% WEIGHT LOSS AFTER PRECONDITIONING = 0.27 %

SPECIMEN NUMBER	SHEAR STRENGTH	BREAKING LOAD	EXPOSURE TEMP.	EXPOSURE TIME	MAT'L PRE-CON
#	PSI	LBS	DEG F.	MINUTES	WET DRY
16-35	1,641	67.2	550	60	DRY
16-47	2,792	114.0	550	60	DRY
16-59	1,900	75.2	550	60	DRY
16-67	2,084	83.4	550	60	DRY
16-148	1,711	70.0	550	60	DRY
16-172	2,242	88.8	550	60	DRY
16-184	2,046	81.2	550	60	DRY
17-7	2,260	88.0	550	60	DRY
AVERAGE	2,085	83			
STD. DEV.	364	15			
% COEF. VAR	17.47	17.54			

% WEIGHT GAIN AFTER PRECONDITIONING = 0.85 %

SPECIMEN NUMBER	SHEAR STRENGTH	BREAKING LOAD	EXPOSURE TEMP.	EXPOSURE TIME	MAT'L PRE-CON
#	PSI	LBS	DEG F.	MINUTES	WET DRY
16-83	3,855	154.8	650	5	WET
16-95	3,608	145.8	650	5	WET
16-107	3,691	150.6	650	5	WET
16-119	3,526	137.2	650	5	WET
16-131	2,599	105.4	650	5	WET
16-137	5,214	212.0	650	5	WET
16-210	2,429	100.0	650	5	WET
16-222	2,697	110.0	650	5	WET
16-234	3,661	149.8	650	5	WET
17-23	2,683	107.6	650	5	WET
AVERAGE	3,396	137			
STD. DEV.	837	34			
% COEF. VAR	24.64	24.67			

% WEIGHT LOSS AFTER PRECONDITIONING = 0.27 %

SPECIMEN NUMBER	SHEAR STRENGTH	BREAKING LOAD	EXPOSURE TEMP.	EXPOSURE TIME	MAT'L PRE-CON
#	PSI	LBS	DEG F.	MINUTES	WET DRY
16-12	2,197	89.0	650	5	DRY
16-24	1,796	69.6	650	5	DRY
16-36	2,469	99.2	650	5	DRY
16-48	2,974	118.2	650	5	DRY
16-60	3,113	124.8	650	5	DRY
16-149	2,831	115.6	650	5	DRY
16-161	2,206	92.6	650	5	DRY
16-173	1,621	64.6	650	5	DRY
16-185	1,528	62.4	650	5	DRY
17-8	4,185	169.2	650	5	DRY
AVERAGE	2,492	101			
STD. DEV.	812	33			
% COEF. VAR	32.60	32.73			

Appendix D

PERCENT WEIGHT-LOSS DATA FOR ZERO-DEGREE SHORT-BEAM-SHEAR SPECIMENS

IM6/3501-6
% WEIGHT LOSS DATA FOR 0 DEGREE SHORT BEAM SHEAR SPECIMENS

EXPOSURE TEMP.	EXPOSURE TIME	"DRY" PRECONDITIONING % WEIGHT LOSS	"DRY" PRECONDITIONING SHEAR STRENGTH	"WET" PRECONDITIONING % WEIGHT LOSS	"WET" PRECONDITIONING SHEAR STRENGTH
(DEG. F)	(MIN.)	%	(PSI)	%	(PSI)
350	60	0.28	6,042	0.89	5,917
450	60	0.32	5,672	1.37	5,784
550	5	0.45	5,474	1.63	4,781
550	30	1.65	4,067	3.38	3,256
550	60	2.30	3,197	4.21	2,097
650	5	4.51	1,530	6.36	1,117
650	30	7.01	314	9.74	275
650	60	9.65	279	11.58	295

EXPOSURE TEMP 350 DEGREES FARENHEIT
EXPOSURE TIME 60 MINUTES % WEIGHT GAIN AFTER PRECOND.= .94

SPECIMEN #	PRE-HEAT WEIGHT	POST-HEAT WEIGHT	% WEIGHT LOSS	SHEAR STRENGTH	MAT'L COND.
	GRAMS	GRAMS		PSI	
23-46	0.5628	0.5585	0.76	5953	WET
22-46	0.5332	0.5285	0.88	5566	WET
10-39	0.5602	0.5543	1.05	5934	WET
22-47	0.5413	0.5364	0.91	5560	WET
23-45	0.5479	0.5433	0.84	6075	WET
10-37	0.5719	0.5659	1.05	6357	WET
22-48	0.5468	0.5421	0.86	5817	WET
23-44	0.5537	0.5489	0.87	5940	WET
10-38	0.5589	0.5535	0.97	5824	WET
22-80	0.5385	0.5344	0.76	6149	WET
AVERAGE	0.5515	0.5466	0.89	5917	
STD. DEV.	0.0121	0.0117	0.10	246	
% COEF. VAR.	2.20	2.15	11.44	3.94	

EXPOSURE TEMP 350 DEGREES FARENHEIT
EXPOSURE TIME 60 MINUTES % WEIGHT LOSS AFTER PRECOND.= .15

SPECIMEN #	PRE-HEAT WEIGHT	POST-HEAT WEIGHT	% WEIGHT LOSS	SHEAR STRENGTH	MAT'L COND.
	GRAMS	GRAMS		PSI	
22-4	0.5323	0.5314	0.17	5865	DRY
22-5	0.5387	0.5382	0.09	6041	DRY
10-5	0.5563	0.5561	0.04	6471	DRY
10-6	0.5574	0.5552	0.39	6248	DRY
22-6	0.5367	0.5350	0.32	5817	DRY
23-5	0.5475	0.5461	0.26	5975	DRY
23-6	0.5553	0.5537	0.29	6275	DRY
22-38	0.5382	0.5355	0.50	5692	DRY
23-4	0.5408	0.5394	0.26	6155	DRY
10-4	0.5412	0.5387	0.46	5881	DRY
AVERAGE	0.5444	0.5429	0.28	6042	
STD. DEV.	0.0091	0.0092	0.15	242	
% COEF. VAR.	1.66	1.69	54.33	3.80	

EXPOSURE TEMP 450 DEGREES FARENHEIT
EXPOSURE TIME 60 MINUTES % WEIGHT GAIN AFTER PRECON.=.94 %

SPECIMEN #	PRE-HEAT WEIGHT	POST-HEAT WEIGHT	% WEIGHT LOSS	SHEAR STRENGTH	MAT'L COND.
	GRAMS	GRAMS		PSI	
23-48	0.5555	0.5491	1.15	5794	WET
22-81	0.5380	0.5301	1.47	5766	WET
10-40	0.5654	0.5574	1.41	5679	WET
23-47	0.5500	0.5430	1.27	5956	WET
10-42	0.5581	0.5496	1.52	5710	WET
23-49	0.5513	0.5434	1.43	5943	WET
22-50	0.5446	0.5369	1.41	5830	WET
22-49	0.5436	0.5366	1.29	5636	WET
22-51	0.5448	0.5381	1.23	5607	WET
10-41	0.5578	0.5496	1.47	5918	WET
AVERAGE	0.5509	0.5434	1.37	5784	
STD. DEV.	0.0084	0.0082	0.12	127	
% COEF. VAR.	1.52	1.50	8.94	2.20	

EXPOSURE TEMP 450 DEGREES FARENHEIT
EXPOSURE TIME 60 MINUTES % WEIGHT LOSS AFTER PRECON.=.15 %

SPECIMEN #	PRE-HEAT WEIGHT	POST-HEAT WEIGHT	% WEIGHT LOSS	SHEAR STRENGTH	MAT'L COND.
	GRAMS	GRAMS		PSI	
10-7	0.5396	0.5380	0.30	5661	DRY
10-9	0.5423	0.5409	0.26	5788	DRY
23-7	0.5536	0.5516	0.36	5776	DRY
23-8	0.5436	0.5423	0.24	5527	DRY
22-8	0.5273	0.5256	0.32	5334	DRY
10-8	0.5530	0.5497	0.60	6191	DRY
22-7	0.5373	0.5359	0.26	5591	DRY
22-9	0.5283	0.5263	0.38	5403	DRY
22-39	0.5353	0.5339	0.26	5557	DRY
23-9	0.5418	0.5406	0.22	5893	DRY
AVERAGE	0.5402	0.5385	0.32	5672	
STD. DEV.	0.0088	0.0086	0.11	252	
% COEF. VAR.	1.64	1.60	34.48	4.44	

EXPOSURE TEMP 550 DEGREES FARENHEIT
EXPOSURE TIME 5 MINUTES % WEIGHT GAIN AFTER PRECON.=.94 %

SPECIMEN #	PRE-HEAT WEIGHT	POST-HEAT WEIGHT	% WEIGHT LOSS	SHEAR STRENGTH	MAT'L COND.
	GRAMS	GRAMS		PSI	
23-52	0.5554	0.5491	1.13	5660	WET
22-52	0.5446	0.5384	1.14	5258	WET
22-54	0.5386	0.5319	1.24	5492	WET
10-45	0.5548	0.5449	1.78	5253	WET
23-50	0.5577	0.5467	1.97	4549	WET
22-53	0.5431	0.5320	2.04	4384	WET
10-44	0.5730	0.5585	2.53	4149	WET
10-43	0.5618	0.5484	2.39	4172	WET
23-51	0.5492	0.5474	0.33	4389	WET
22-82	0.5399	0.5307	1.70	4499	WET
AVERAGE	0.5518	0.5428	1.63	4781	
STD. DEV.	0.0108	0.0092	0.67	572	
% COEF. VAR.	1.96	1.69	41.15	11.34	

EXPOSURE TEMP 550 DEGREES FARENHEIT
EXPOSURE TIME 5 MINUTES % WEIGHT LOSS AFTER PRECON.=.15 %

SPECIMEN #	PRE-HEAT WEIGHT	POST-HEAT WEIGHT	% WEIGHT LOSS	SHEAR STRENGTH	MAT'L COND.
	GRAMS	GRAMS		PSI	
23-11	0.5540	0.5529	0.20	6294	DRY
23-10	0.5414	0.5409	0.09	5906	DRY
23-12	0.5436	0.5422	0.26	5700	DRY
22-12	0.5373	0.5343	0.56	5205	DRY
22-11	0.5389	0.5370	0.35	5226	DRY
10-10	0.5609	0.5576	0.59	5480	DRY
22-10	0.5435	0.5407	0.52	5033	DRY
22-40	0.5411	0.5361	0.92	4998	DRY
10-12	0.5667	0.5636	0.55	5367	DRY
10-11	0.5536	0.5508	0.51	5528	DRY
AVERAGE	0.5481	0.5456	0.45	5474	
STD. DEV.	0.0101	0.0100	0.24	405	
% COEF. VAR.	1.84	1.83	52.43	7.41	

EXPOSURE TEMP 550 DEGREES FARENHEIT
EXPOSURE TIME 30 MINUTES % WEIGHT GAIN AFTER PRECON.=.94 %

SPECIMEN #	PRE-HEAT WEIGHT	POST-HEAT WEIGHT	% WEIGHT LOSS	SHEAR STRENGTH	MAT'L COND.
	GRAMS	GRAMS		PSI	
23-53	0.5497	0.5366	2.38	4177	WET
22-57	0.5408	0.5256	2.81	4053	WET
23-55	0.5433	0.5271	2.98	3496	WET
22-55	0.5434	0.5234	3.68	3482	WET
22-56	0.5358	0.5152	3.84	2539	WET
22-83	0.5359	0.5154	3.83	2545	WET
23-54	0.5520	0.5318	3.66	2384	WET
10-46	0.5680	0.5466	3.77	3015	WET
10-47	0.5558	0.5361	3.54	3032	WET
10-48	0.5758	0.5565	3.35	3832	WET
AVERAGE	0.5501	0.5314	3.38	3256	
STD. DEV.	0.0133	0.0131	0.50	651	
% COEF. VAR.	2.42	2.47	14.73	19.99	

EXPOSURE TEMP 550 DEGREES FARENHEIT
EXPOSURE TIME 30 MINUTES % WEIGHT LOSS AFTER PRECON.=.15 %

SPECIMEN #	PRE-HEAT WEIGHT	POST-HEAT WEIGHT	% WEIGHT LOSS	SHEAR STRENGTH	MAT'L COND.
	GRAMS	GRAMS		PSI	
22-15	0.5270	0.5227	0.82	4903	DRY
22-41	0.5397	0.5338	1.09	4688	DRY
10-14	0.5650	0.5558	1.63	4780	DRY
23-13	0.5353	0.5262	1.70	3562	DRY
23-14	0.5465	0.5364	1.85	3741	DRY
23-15	0.5437	0.5316	2.23	3382	DRY
22-14	0.5347	0.5242	1.96	3367	DRY
22-13	0.5330	0.5224	1.99	3395	DRY
10-15	0.5679	0.5580	1.74	4071	DRY
10-13	0.5522	0.5439	1.50	4784	DRY
AVERAGE	0.5445	0.5355	1.65	4067	
STD. DEV.	0.0136	0.0132	0.42	657	
% COEF. VAR.	2.50	2.46	25.72	16.14	

EXPOSURE TEMP 550 DEGREES FARENHEIT
EXPOSURE TIME 60 MINUTES % WEIGHT GAIN AFTER PRECON.=.94 %

SPECIMEN #	PRE-HEAT WEIGHT	POST-HEAT WEIGHT	% WEIGHT LOSS	SHEAR STRENGTH	MAT'L COND.
	GRAMS	GRAMS		PSI	
10-50	0.5746	0.5545	3.50	3505	WET
22-59	0.5415	0.5217	3.66	2266	WET
23-58	0.5549	0.5322	4.09	1735	WET
22-84	0.5415	0.5193	4.10	1622	WET
10-51	0.5618	0.5359	4.61	1564	WET
23-57	0.5452	0.5201	4.60	1678	WET
23-56	0.5544	0.5276	4.83	1687	WET
22-58	0.5436	0.5197	4.40	1826	WET
22-60	0.5340	0.5112	4.27	2219	WET
10-49	0.5645	0.5419	4.00	2866	WET
AVERAGE	0.5516	0.5284	4.21	2097	
STD. DEV.	0.0126	0.0129	0.42	639	
% COEF. VAR.	2.29	2.45	10.10	30.48	

EXPOSURE TEMP 550 DEGREES FARENHEIT
EXPOSURE TIME 60 MINUTES % WEIGHT LOSS AFTER PRECON.=.15 %

SPECIMEN #	PRE-HEAT WEIGHT	POST-HEAT WEIGHT	% WEIGHT LOSS	SHEAR STRENGTH	MAT'L COND.
	GRAMS	GRAMS		PSI	
22-17	0.5359	0.5270	1.66	4304	DRY
10-17	0.5515	0.5388	2.30	3903	DRY
23-17	0.5438	0.5311	2.34	3195	DRY
22-42	0.5384	0.5256	2.38	2869	DRY
22-16	0.5330	0.5199	2.46	2700	DRY
22-18	0.5003	0.4863	2.80	2218	DRY
23-18	0.5294	0.5162	2.49	2298	DRY
23-16	0.5499	0.5372	2.31	3132	DRY
10-18	0.5736	0.5604	2.30	3392	DRY
10-16	0.5554	0.5447	1.93	3961	DRY
AVERAGE	0.5411	0.5287	2.30	3197	
STD. DEV.	0.0193	0.0197	0.31	705	
% COEF. VAR.	3.57	3.72	13.51	22.05	

EXPOSURE TEMP 650 DEGREES FARENHEIT
EXPOSURE TIME 5 MINUTES % WEIGHT GAIN AFTER PRECON.=.94 %

SPECIMEN #	PRE-HEAT WEIGHT	POST-HEAT WEIGHT	% WEIGHT LOSS	SHEAR STRENGTH	MAT'L COND.
	GRAMS	GRAMS		PSI	
22-63	0.5448	0.5301	2.70	3643	WET
10-53	0.5517	0.5261	4.64	1635	WET
23-61	0.5490	0.5196	5.36	982	WET
22-61	0.5369	0.5055	5.85	773	WET
22-62	0.5510	0.5136	6.79	582	WET
23-60	0.5587	0.5176	7.36	570	WET
10-54	0.5869	0.5423	7.60	551	WET
22-85	0.5444	0.5022	7.75	582	WET
10-52	0.5554	0.5087	8.41	spec.broke	WET
23-59	0.5490	0.5098	7.14	733	WET
AVERAGE	0.5528	0.5176	6.36	1117	
STD. DEV.	0.0134	0.0124	1.73	1014	
% COEF. VAR.	2.43	2.39	27.29	85.07	

EXPOSURE TEMP 650 DEGREES FARENHEIT
EXPOSURE TIME 5 MINUTES % WEIGHT LOSS AFTER PRECON.=.15 %

SPECIMEN #	PRE-HEAT WEIGHT	POST-HEAT WEIGHT	% WEIGHT LOSS	SHEAR STRENGTH	MAT'L COND.
	GRAMS	GRAMS		PSI	
22-20	0.5349	0.5213	2.54	4784	DRY
22-21	0.5365	0.5245	2.24	2791	DRY
10-21	0.5554	0.5354	3.60	1417	DRY
10-19	0.5640	0.5398	4.29	1187	DRY
23-20	0.5449	0.5184	4.86	914	DRY
10-20	0.5575	0.5261	5.63	782	DRY
22-19	0.5385	0.5106	5.18	744	DRY
23-21	0.5546	0.5221	5.86	744	DRY
23-37	0.5477	0.5181	5.40	875	DRY
23-19	0.5483	0.5183	5.47	1057	DRY
AVERAGE	0.5482	0.5235	4.51	1530	
STD. DEV.	0.0097	0.0086	1.30	1297	
% COEF. VAR.	1.77	1.65	28.92	84.79	

EXPOSURE TEMP 650 DEGREES FARENHEIT
EXPOSURE TIME 30 MINUTES % WEIGHT GAIN AFTER PRECON.=.94 %

SPECIMEN #	PRE-HEAT WEIGHT	POST-HEAT WEIGHT	% WEIGHT LOSS	SHEAR STRENGTH	MAT'L COND.
	GRAMS	GRAMS		PSI	
22-64	0.5373	0.5006	6.83	323	WET
10-55	0.5497	0.5003	8.99	260	WET
10-56	0.5769	0.5235	9.26	290	WET
23-77	0.5560	0.4967	10.67	286	WET
23-62	0.5475	0.4908	10.36	256	WET
23-66	0.5365	0.4786	10.79	202	WET
22-65	0.5457	0.4887	10.45	243	WET
23-64	0.5613	0.5020	10.56	252	WET
10-57	0.5723	0.5170	9.66	313	WET
23-63	0.5556	0.5008	9.86	310	WET
AVERAGE	0.5539	0.4999	9.74	275	
STD. DEV.	0.0135	0.0130	1.19	38	
% COEF. VAR.	2.43	2.61	12.25	13.66	

EXPOSURE TEMP 650 DEGREES FARENHEIT
EXPOSURE TIME 30 MINUTES % WEIGHT LOSS AFTER PRECON.=.15 %

SPECIMEN #	PRE-HEAT WEIGHT	POST-HEAT WEIGHT	% WEIGHT LOSS	SHEAR STRENGTH	MAT'L COND.
	GRAMS	GRAMS		PSI	
23-22	0.5455	0.5211	4.47	568	DRY
23-23	0.5434	0.5111	5.94	326	DRY
22-22	0.5324	0.4992	6.24	306	DRY
23-38	0.5376	0.4983	7.31	317	DRY
22-24	0.5422	0.5002	7.75	269	DRY
10-24	0.5487	0.5033	8.27	245	DRY
10-22	0.5527	0.5110	7.54	233	DRY
10-23	0.5629	0.5165	8.24	229	DRY
22-23	0.5398	0.5007	7.24	321	DRY
23-24	0.5444	0.5061	7.04	322	DRY
AVERAGE	0.5450	0.5068	7.01	314	
STD. DEV.	0.0085	0.0079	1.17	97	
% COEF. VAR.	1.55	1.55	16.66	29.46	

EXPOSURE TEMP 650 DEGREES FARENHEIT
EXPOSURE TIME 60 MINUTES % WEIGHT GAIN AFTER PRECON.=.94 %

SPECIMEN #	PRE-HEAT WEIGHT	POST-HEAT WEIGHT	% WEIGHT LOSS	SHEAR STRENGTH	MAT'L COND.
	GRAMS	GRAMS		PSI	
23-67	0.5570	0.4959	10.97	278	WET
23-65	0.5487	0.4922	10.30	232	WET
22-69	0.5420	0.4889	9.80	309	WET
10-60	0.5715	0.4963	13.16	277	WET
22-68	0.5409	0.4803	11.20	296	WET
22-67	0.5463	0.4798	12.17	303	WET
10-58	0.5645	0.4950	12.31	255	WET
23-78	0.5473	0.4818	11.97	309	WET
10-59	0.5791	0.5086	12.17	308	WET
23-66	0.5507	0.4862	11.71	338	WET
AVERAGE	0.5548	0.4905	11.58	295	
STD. DEV.	0.0129	0.0090	1.01	31	
% COEF. VAR.	2.33	1.83	8.75	9.50	

EXPOSURE TEMP 650 DEGREES FARENHEIT
EXPOSURE TIME 60 MINUTES % WEIGHT LOSS AFTER PRECON.=.15 %

SPECIMEN #	PRE-HEAT WEIGHT	POST-HEAT WEIGHT	% WEIGHT LOSS	SHEAR STRENGTH	MAT'L COND.
	GRAMS	GRAMS		PSI	
10-26	0.5546	0.5119	7.70	316	DRY
22-25	0.5394	0.4981	7.66	288	DRY
23-25	0.5483	0.4915	10.36	248	DRY
23-26	0.5498	0.4939	10.17	193	DRY
22-27	0.5381	0.4885	9.22	199	DRY
10-27	0.5600	0.4998	10.75	258	DRY
10-25	0.5637	0.5056	10.31	305	DRY
23-27	0.5440	0.4882	10.26	310	DRY
22-26	0.5369	0.4856	9.55	321	DRY
23-39	0.5429	0.4859	10.50	355	DRY
AVERAGE	0.5478	0.4949	9.65	279	
STD. DEV.	0.0093	0.0088	1.13	54	
% COEF. VAR.	1.69	1.79	11.71	18.22	

Appendix E

ZERO-DEGREE FLEXURAL PROPERTIES ACCORDING TO ASTM D-790

IM6/3501-6
0 DEGREE FLEXURAL PROPERTIES PER ASTM D-790

SUMMARY OF TEST DATA

EXPOSURE TEMP.	EXPOSURE TIME	"DRY" PRECON. FLEXURAL STRENGTH	"DRY" PRECON. STRENGTH RETENTION	"WET" PRECON. FLEXURAL STRENGTH	"WET" PRECON. STRENGTH RETENTION
(DEG. F)	(MIN.)	(PSI)	%	(PSI)	%
73		51,660	97.92	53,297	100.00
350	60	52,759	100.00	50,797	95.31
450	60	47,400	89.84	46,010	86.33
550	5	42,642	80.82	42,805	80.31
550	30	30,822	58.42	31,726	59.53
550	60	19,873	37.67	23,076	43.30
650	5	10,975	20.80	6,045	11.34
650	30	3,355	6.36	2,350	4.41
650	60	2,729	5.17	2,465	4.62
750	5	3,046	5.77	2,953	5.54
750	10	2,935	5.56	3,101	5.82
750	30	2,117	4.01	3,880	7.28

FLEXURAL DATA FOR : ROOM TEMPERATURE

% WEIGHT LOSS AFTER PRECONDITIONING = 0.24 %

SPECIMEN NUMBER	FLEXURAL STRENGTH	FLEXURAL LOAD	FIBER STRAIN	DEFLECTION	FLEXURAL MODULUS	MAT'L PRE-CON
			AT MAXIMUM LOAD			WET
#	PSI	LBS	IN/IN	INCHES	PSI	DRY
2-18	52,672	370.0	0.026	0.190	3.57E+06	DRY
5-18	51,850	379.0	0.018	0.128	3.35E+06	DRY
2-6	50,692	369.0	0.018	0.126	3.43E+06	DRY
3-6	49,255	364.0	0.017	0.117	3.33E+06	DRY
5-1	53,504	390.0	0.019	0.132	3.53E+06	DRY
5-6	51,158	376.0	0.018	0.124	3.31E+06	DRY
8-6	52,141	396.0	0.018	0.123	3.39E+06	DRY
2-3	53,617	384.0	0.018	0.132	3.33E+06	DRY
3-3	50,048	389.0	0.017	0.119	3.20E+06	DRY
AVERAGE	51,660	380	0.019	0.132	3.38E+06	
STD. DEV.	1,504	11	0.003	0.022	114,262	
% C.V.	2.91	2.86			3.38	

FLEXURAL DATA FOR : ROOM TEMPERATURE

% WEIGHT GAIN AFTER PRECONDITIONING = 1.05 %

3-50	54,264	395.0	0.017	0.119	3.37E+06	WET
5-58	54,504	394.0	0.031	0.220	3.45E+06	WET
8-53	50,886	390.0	0.020	0.140	3.38E+06	WET
2-38	58,283	408.0	0.034	0.232	3.56E+06	WET
3-38	49,503	391.0	0.021	0.149	3.30E+06	WET
5-46	52,655	387.0	0.021	0.140	3.45E+06	WET
5-70	54,004	420.0	0.018	0.127	3.37E+06	WET
8-41	52,276	394.0	0.033	0.227	3.66E+06	WET
AVERAGE	53,297	397	0.024	0.169	3.44E+06	
STD. DEV.	2,657	11	0.007	0.048	115,756	
% C.V.	4.99	2.78			3.36	

FLEXURAL DATA FOR : 350 F. FOR 60 MINUTES.

% WEIGHT LOSS AFTER PRECONDITIONING = 0.24 %

SPECIMEN NUMBER	FLEXURAL STRENGTH	FLEXURAL LOAD	FIBER STRAIN	DEFLECTION	FLEXURAL MODULUS	MAT'L PRE-CON
			AT MAXIMUM LOAD			WET
#	PSI	LBS	IN/IN	INCHES	PSI	DRY
2-7	53,855	405.0	0.017	0.119	3.49E+06	DRY
3-7	51,595	388.0	0.025	0.175	3.43E+06	DRY
5-7	53,328	403.0	0.019	0.129	3.39E+06	DRY
5-31	53,816	405.0	0.018	0.127	3.47E+06	DRY
8-7	51,200	402.0	0.017	0.119	3.45E+06	DRY
AVERAGE	52,759	401	0.019	0.134	3.45E+06	
STD. DEV.	1,268	7	0.003	0.024	37,817	
% C.V.	2.40	1.79			1.10	

FLEXURAL DATA FOR : 350 F. FOR 60 MINUTES.

% WEIGHT GAIN AFTER PRECONDITIONING = 0.87 %

2-39	50,588	365.0	0.016	0.113	3.68E+06	WET
2-62	51,559	372.0	0.024	0.174	3.60E+06	WET
3-39	50,493	367.0	0.026	0.187	3.61E+06	WET
5-47	49,557	376.0	0.018	0.123	3.33E+06	WET
5-71	51,525	369.0	0.018	0.128	3.54E+06	WET
8-42	51,062	388.0	0.017	0.118	3.46E+06	WET
AVERAGE	50,797	373	0.020	0.140	3.54E+06	
STD. DEV.	756	8	0.004	0.032	123,644	
% C.V.	1.49	2.25			3.50	

FLEXURAL DATA FOR : 450 F. FOR 60 MINUTES.

% WEIGHT LOSS AFTER PRECONDITIONING = 0.24 %

SPECIMEN NUMBER	FLEXURAL STRENGTH	FLEXURAL LOAD	FIBER STRAIN	DEFLECTION	FLEXURAL MODULUS	MAT'L PRE-CON
			AT MAXIMUM LOAD			
#	PSI	LBS	IN/IN	INCHES	PSI	WET DRY
5-20	42,664	328.0	0.020	0.135	2.94E+06	DRY
2-8	52,825	372.0	0.017	0.125	3.48E+06	DRY
2-31	48,589	342.0	0.017	0.124	3.39E+06	DRY
3-8	47,727	365.0	0.018	0.126	3.16E+06	DRY
5-8	45,103	337.0	0.027	0.189	3.30E+06	DRY
5-32	47,372	348.0	0.026	0.181	3.38E+06	DRY
8-8	47,523	367.0	0.017	0.118	3.14E+06	DRY
AVERAGE	47,400	351	0.020	0.143	3.25E+06	
STD. DEV.	3,127	17	0.004	0.029	186,293	
% C.V.	6.60	4.80			5.72	

FLEXURAL DATA FOR : 450 F. FOR 60 MINUTES.

% WEIGHT GAIN AFTER PRECONDITIONING = 0.87 %

2-52	45,884	334.0	0.018	0.127	2.95E+06	WET
3-52	43,317	315.0	0.017	0.119	2.97E+06	WET
5-60	47,601	351.0	0.019	0.130	2.95E+06	WET
8-55	44,134	341.0	0.028	0.190	2.67E+06	WET
8-66	40,367	323.0	0.032	0.217	2.58E+06	WET
2-40	48,082	350.0	0.015	0.110	3.64E+06	WET
2-63	48,624	351.0	0.024	0.174	3.33E+06	WET
3-40	46,379	332.0	0.016	0.113	3.37E+06	WET
5-48	46,216	339.0	0.016	0.111	3.29E+06	WET
5-72	47,611	344.0	0.017	0.118	3.60E+06	WET
8-43	47,889	376.0	0.016	0.111	3.17E+06	WET
AVERAGE	46,010	341	0.020	0.138	3.14E+06	
STD. DEV.	2,501	16	0.006	0.037	347,585	
% C.V.	5.44	4.76			11.07	

FLEXURAL DATA FOR : 550 F. FOR 5 MINUTES.

% WEIGHT LOSS AFTER PRECONDITIONING = 0.24 %

SPECIMEN NUMBER	FLEXURAL STRENGTH	FLEXURAL LOAD	FIBER STRAIN	DEFLECTION	FLEXURAL MODULUS	MAT'L PRE-CON
			AT MAXIMUM LOAD			
#	PSI	LBS	IN/IN	INCHES	PSI	WET DRY
2-21	34,124	257.0	0.016	0.109	2.62E+06	DRY
3-21	40,026	301.0	0.017	0.120	2.72E+06	DRY
5-21	37,520	282.5	0.023	0.160	3.36E+06	DRY
8-21	43,494	330.0	0.024	0.164	3.40E+06	DRY
8-33	41,708	319.5	0.017	0.115	3.33E+06	DRY
2-9	45,792	333.0	0.016	0.117	3.27E+06	DRY
2-32	46,659	334.0	0.024	0.173	3.21E+06	DRY
3-9	45,827	339.0	0.031	0.220	3.08E+06	DRY
5-9	46,708	366.0	0.027	0.185	3.01E+06	DRY
5-33	41,101	312.0	0.018	0.123	2.92E+06	DRY
8-9	46,098	356.0	0.017	0.119	2.97E+06	DRY
AVERAGE	42,642	321	0.021	0.146	3.08E+06	
STD. DEV.	4,175	32	0.005	0.037	260,584	
% C.V.	9.79	9.87			8.46	

FLEXURAL DATA FOR : 550 F. FOR 5 MINUTES.

% WEIGHT GAIN AFTER PRECONDITIONING = 0.87 %

2-41	42,664	313.0	0.017	0.121	3.61E+06	WET
3-41	41,963	326.0	0.023	0.158	3.26E+06	WET
3-62	42,735	332.0	0.022	0.152	3.50E+06	WET
5-49	43,268	322.0	0.034	0.235	3.43E+06	WET
5-73	42,596	301.0	0.015	0.105	3.47E+06	WET
8-44	43,602	342.0	0.025	0.170	3.25E+06	WET
AVERAGE	42,805	323	0.023	0.157	3.42E+06	
STD. DEV.	570	14	0.007	0.045	141,921	
% C.V.	1.33	4.46			4.15	

FLEXURAL DATA FOR : 550 F. FOR 30 MINUTES.

% WEIGHT LOSS AFTER PRECONDITIONING = 0.24 %

SPECIMEN NUMBER	FLEXURAL STRENGTH	FLEXURAL LOAD	FIBER STRAIN	DEFLECTION	FLEXURAL MODULUS	MAT'L PRE-CON
			AT MAXIMUM LOAD			
#	PSI	LBS	IN/IN	INCHES	PSI	WET DRY
2-22	24,345	180.0	0.013	0.094	3.08E+06	DRY
3-22	31,295	231.5	0.023	0.164	3.24E+06	DRY
5-22	31,142	227.0	0.017	0.123	3.19E+06	DRY
8-22	36,849	280.0	0.023	0.162	3.05E+06	DRY
8-34	33,449	262.5	0.014	0.098	2.98E+06	DRY
2-10	33,272	246.0	0.018	0.130	3.04E+06	DRY
3-10	30,056	233.5	0.023	0.156	2.95E+06	DRY
3-30	28,454	217.5	0.021	0.145	3.05E+06	DRY
5-10	34,627	246.5	0.013	0.094	3.03E+06	DRY
5-34	29,500	209.5	0.010	0.075	3.28E+06	DRY
8-10	26,056	199.5	0.017	0.115	2.94E+06	DRY
AVERAGE	30,822	230	0.018	0.123	3.07E+06	
STD. DEV.	3,697	28	0.005	0.031	113,409	
% C.V.	11.99	12.37			3.69	

FLEXURAL DATA FOR : 550 F. FOR 30 MINUTES.

% WEIGHT GAIN AFTER PRECONDITIONING = 0.87 %

2-54	23,379	168.5	0.016	0.115	3.29E+06	WET
3-54	26,975	206.5	0.013	0.092	3.23E+06	WET
5-62	36,839	257.5	0.014	0.102	3.02E+06	WET
8-57	26,417	207.0	0.010	0.071	2.86E+06	WET
8-68	45,020	347.5	0.024	0.165	3.43E+06	WET
AVERAGE	31,726	237	0.016	0.109	3.17E+06	
STD. DEV.	8,990	69	0.005	0.035	226,014	
% C.V.	28.34	29.15			7.14	

FLEXURAL DATA FOR : 550 F. FOR 60 MINUTES.

% WEIGHT LOSS AFTER PRECONDITIONING = 0.24 %

SPECIMEN NUMBER	FLEXURAL STRENGTH	FLEXURAL LOAD	FIBER STRAIN	DEFLECTION	FLEXURAL MODULUS	MAT'L PRE-CON
			AT MAXIMUM LOAD			WET
#	PSI	LBS	IN/IN	INCHES	PSI	DRY
2-23	16,948	123.0	0.012	0.084	2.72E+06	DRY
3-23	20,688	155.5	0.016	0.113	3.16E+06	DRY
5-23	22,389	159.0	0.015	0.110	3.13E+06	DRY
8-23	15,337	118.5	0.011	0.075	2.71E+06	DRY
8-35	16,887	128.0	0.011	0.078	3.00E+06	DRY
2-11	18,519	132.5	0.009	0.065	3.34E+06	DRY
3-11	14,587	111.5	0.012	0.084	2.86E+06	DRY
3-31	21,444	164.0	0.022	0.154	3.01E+06	DRY
5-11	32,154	230.5	0.030	0.211	3.34E+06	DRY
5-35	17,725	127.0	0.014	0.097	3.10E+06	DRY
8-11	21,927	169.5	0.016	0.109	3.02E+06	DRY
AVERAGE	19,873	147	0.015	0.107	3.04E+06	
STD. DEV.	4,868	34	0.006	0.042	213,297	
% C.V.	24.49	23.14			7.03	

FLEXURAL DATA FOR : 550 F. FOR 60 MINUTES.

% WEIGHT GAIN AFTER PRECONDITIONING = 0.87 %

2-55	25,564	189.2	0.014	0.097	3.18E+06	WET
3-55	33,098	253.0	0.020	0.141	3.11E+06	WET
5-63	39,165	278.0	0.030	0.213	3.33E+06	WET
8-58	30,042	232.0	0.021	0.148	2.96E+06	WET
8-69	27,181	211.5	0.021	0.141	2.90E+06	WET
2-43	24,090	171.0	0.015	0.110	3.23E+06	WET
3-43	10,404	77.0	0.006	0.045	2.84E+06	WET
3-64	16,915	125.0	0.015	0.108	3.05E+06	WET
5-51	13,204	103.0	0.009	0.061	2.94E+06	WET
5-75	13,317	99.5	0.007	0.051	2.84E+06	WET
8-46	20,859	158.5	0.013	0.087	3.00E+06	WET
AVERAGE	23,076	173	0.016	0.109	3.04E+06	
STD. DEV.	9,100	67	0.007	0.050	160,621	
% C.V.	39.43	38.75	45.05	45.64	5.29	

FLEXURAL DATA FOR : 650 F. FOR 5 MINUTES.

% WEIGHT LOSS AFTER PRECONDITIONING = 0.24 %

SPECIMEN NUMBER	FLEXURAL STRENGTH	FLEXURAL LOAD	FIBER STRAIN	DEFLECTION	FLEXURAL MODULUS	MAT'L PRE-CON
			AT MAXIMUM LOAD			WET
#	PSI	LBS	IN/IN	INCHES	PSI	DRY
2-24	4,217	30.2	0.005	0.038	3.08E+06	DRY
3-24	5,633	44.4	0.006	0.039	2.94E+06	DRY
5-24	10,128	72.0	0.007	0.052	3.10E+06	DRY
8-24	8,140	62.8	0.006	0.043	2.31E+06	DRY
2-12	12,529	91.2	0.006	0.042	3.26E+06	DRY
3-12	20,505	154.2	0.011	0.074	2.98E+06	DRY
5-12	13,862	107.0	0.010	0.069	3.38E+06	DRY
5-36	12,789	94.0	0.009	0.064	2.97E+06	DRY
AVERAGE	10,975	82	0.007	0.052	3.00E+06	
STD. DEV.	5,180	39	0.002	0.014	317,440	
% C.V.	47.20	47.54	28.05	27.67	10.57	

FLEXURAL DATA FOR : 650 F. FOR 5 MINUTES.

% WEIGHT GAIN AFTER PRECONDITIONING = 0.87 %

2-56	4,007	29.4	0.003	0.022	1.53E+06	WET
3-56	7,504	56.4	0.005	0.033	2.44E+06	WET
5-64	4,927	35.6	0.006	0.043	1.17E+06	WET
8-59	7,447	58.5	0.005	0.033	2.14E+06	WET
2-44	7,161	53.0	0.006	0.041	2.08E+06	WET
3-65	4,529	35.2	0.005	0.034	1.17E+06	WET
5-52	4,870	38.2	0.004	0.030	1.62E+06	WET
5-76	9,833	73.4	0.007	0.050	1.48E+06	WET
8-47	4,126	31.8	0.004	0.030	1.19E+06	WET
AVERAGE	6,045	46	0.005	0.035	1.65E+06	
STD. DEV.	2,014	15	0.001	0.008	470,974	
% C.V.	33.32	33.05	23.61	24.21	28.60	

FLEXURAL DATA FOR : 650 F. FOR 30 MINUTES.

% WEIGHT LOSS AFTER PRECONDITIONING = 0.24 %

SPECIMEN NUMBER	FLEXURAL STRENGTH	FLEXURAL LOAD	FIBER STRAIN	DEFLECTION	FLEXURAL MODULUS	MAT'L PRE-CON
			AT MAXIMUM LOAD			WET
#	PSI	LBS	IN/IN	INCHES	PSI	DRY
2-25	2,749	20.0	0.002	0.015	1.28E+06	DRY
3-25	3,040	22.5	0.003	0.018	1.88E+06	DRY
5-25	3,563	27.5	0.003	0.019	1.95E+06	DRY
8-25	3,532	27.3	0.003	0.019	1.49E+06	DRY
2-13	2,875	20.4	0.002	0.017	3.07E+06	DRY
3-13	2,576	19.7	0.003	0.020	2.08E+06	DRY
5-13	5,179	40.3	0.004	0.026	2.63E+06	DRY
5-37	3,161	24.4	0.003	0.017	2.02E+06	DRY
8-13	3,521	27.4	0.004	0.025	1.63E+06	DRY
AVERAGE	3,355	26	0.003	0.019	2.00E+06	
STD. DEV.	772	6	0.001	0.003	557,712	
% C.V.	23.02	25.19	19.42	18.04	27.85	

FLEXURAL DATA FOR : 650 F. FOR 30 MINUTES.

% WEIGHT GAIN AFTER PRECONDITIONING = 0.87 %

2-57	3,058	21.5	0.002	0.014	1.95E+06	WET
3-57	2,482	18.4	0.002	0.014	2.76E+06	WET
5-65	2,724	20.0	0.001	0.010	2.70E+06	WET
8-60	2,345	17.8	0.002	0.014	1.96E+06	WET
2-45	1,921	14.0	0.003	0.020	1.20E+06	WET
3-45	1,840	13.9	0.002	0.017	1.22E+06	WET
5-53	1,974	14.2	0.002	0.017	1.20E+06	WET
5-77	2,505	18.1	0.003	0.019	1.08E+06	WET
8-48	2,299	17.6	0.003	0.018	1.48E+06	WET
AVERAGE	2,350	17	0.002	0.016	1.73E+06	
STD. DEV.	398	3	0.000	0.003	653,909	
% C.V.	16.96	15.83	19.82	19.78	37.87	

FLEXURAL DATA FOR : 650 F. FOR 60 MINUTES.

% WEIGHT LOSS AFTER PRECONDITIONING = 0.24 %

SPECIMEN NUMBER	FLEXURAL STRENGTH	FLEXURAL LOAD	FIBER STRAIN	DEFLECTION	FLEXURAL MODULUS	MAT'L PRE-CON
			AT MAXIMUM LOAD			
#	PSI	LBS	IN/IN	INCHES	PSI	WET DRY
2-26	2,546	18.2	0.003	0.018	1.37E+06	DRY
3-26	3,256	24.8	0.003	0.020	2.29E+06	DRY
5-26	2,570	20.0	0.002	0.014	1.88E+06	DRY
8-26	3,230	25.5	0.004	0.026	1.46E+06	DRY
2-14	3,046	22.2	0.002	0.015	2.19E+06	DRY
3-14	2,710	21.1	0.002	0.013	1.82E+06	DRY
5-14	2,382	17.8	0.002	0.013	1.74E+06	DRY
5-38	2,462	18.7	0.002	0.011	2.90E+06	DRY
8-14	2,358	17.9	0.001	0.009	2.37E+06	DRY
AVERAGE	2,729	21	0.002	0.015	2.00E+06	
STD. DEV.	357	3	0.001	0.005	483,190	
% C.V.	13.06	14.25	33.83	33.14	24.13	

FLEXURAL DATA FOR : 650 F. FOR 60 MINUTES.

% WEIGHT GAIN AFTER PRECONDITIONING = 0.87 %

2-58	2,388	16.7	0.002	0.014	1.97E+06	WET
3-58	1,975	14.9	0.003	0.018	1.16E+06	WET
5-66	2,470	19.1	0.003	0.022	1.46E+06	WET
8-61	2,851	21.7	0.002	0.015	1.87E+06	WET
2-46	2,912	21.2	0.002	0.015	1.60E+06	WET
3-46	2,355	17.7	0.003	0.020	1.02E+06	WET
5-54	2,960	22.9	0.002	0.014	1.76E+06	WET
5-78	2,074	15.3	0.002	0.014	1.62E+06	WET
8-49	2,196	17.0	0.003	0.023	1.63E+06	WET
AVERAGE	2,465	18	0.002	0.017	1.57E+06	
STD. DEV.	367	3	0.001	0.004	312,025	
% C.V.	14.89	15.61	22.47	21.41	19.94	

FLEXURAL DATA FOR : 750 F. FOR 5 MINUTES.

% WEIGHT LOSS AFTER PRECONDITIONING = 0.24 %

SPECIMEN NUMBER	FLEXURAL STRENGTH	FLEXURAL LOAD	FIBER STRAIN	DEFLECTION	FLEXURAL MODULUS	MAT'L PRE-CON
			AT MAXIMUM LOAD			WET
#	PSI	LBS	IN/IN	INCHES	PSI	DRY
2-27	2,499	17.9	0.004	0.028	1.17E+06	DRY
3-27	5,640	40.4	0.006	0.043	1.59E+06	DRY
5-27	4,456	32.8	0.003	0.025	1.82E+06	DRY
8-27	3,662	28.8	0.003	0.022	1.50E+06	DRY
2-15	1,649	12.0	0.002	0.013	1.03E+06	DRY
3-15	1,913	14.9	0.003	0.024	6.32E+05	DRY
5-15	2,044	14.9	0.002	0.017	1.02E+06	DRY
5-39	3,142	22.5	0.004	0.030	1.04E+06	DRY
8-15	2,405	18.6	0.005	0.034	8.26E+05	DRY
AVERAGE	3,046	23	0.004	0.026	1.18E+06	
STD. DEV.	1,325	10	0.001	0.009	382,176	
% C.V.	43.51	42.31	33.10	33.60	32.33	

FLEXURAL DATA FOR : 750 F. FOR 5 MINUTES.

% WEIGHT GAIN AFTER PRECONDITIONING = 0.87 %

2-59	1,328	9.5	0.002	0.014	1.19E+06	WET
3-59	3,477	26.2	0.005	0.033	1.33E+06	WET
5-67	3,975	30.9	0.003	0.017	3.10E+06	WET
8-62	3,033	23.2	0.002	0.013	2.47E+06	WET
AVERAGE	2,953	22	0.003	0.020	2.02E+06	
STD. DEV.	1,150	9	0.001	0.009	919,992	
% C.V.	38.93	40.96	47.07	47.14	45.51	

FLEXURAL DATA FOR : 750 F. FOR 10 MINUTES.

% WEIGHT LOSS AFTER PRECONDITIONING = 0.24 %

SPECIMEN NUMBER	FLEXURAL STRENGTH	FLEXURAL LOAD	FIBER STRAIN	DEFLECTION	FLEXURAL MODULUS	MAT'L PRE-CON
			AT MAXIMUM LOAD			
#	PSI	LBS	IN/IN	INCHES	PSI	WET DRY
2-4	2,299	17.3	0.001	0.007	2.77E+06	DRY
3-4	3,446	25.1	0.002	0.016	2.14E+06	DRY
5-4	2,966	22.2	0.005	0.033	1.12E+06	DRY
8-4	3,505	27.5	0.004	0.025	1.32E+06	DRY
2-5	3,220	23.2	0.002	0.012	2.64E+06	DRY
3-5	2,890	22.1	0.003	0.020	1.49E+06	DRY
5-5	3,178	23.6	0.003	0.019	1.70E+06	DRY
8-5	1,975	15.0	0.006	0.040	1.52E+06	DRY
AVERAGE	2,935	22	0.003	0.021	1.84E+06	
STD. DEV.	542	4	0.002	0.011	611,804	
% C.V.	18.46	18.38	51.84	51.27	33.30	

FLEXURAL DATA FOR : 750 F. FOR 10 MINUTES.

% WEIGHT GAIN AFTER PRECONDITIONING = 0.87 %

2-36	2,591	19.0	0.002	0.015	1.51E+06	WET
3-36	2,951	21.1	0.004	0.031	1.39E+06	WET
5-44	3,019	23.3	0.002	0.015	1.63E+06	WET
8-39	3,017	23.3	0.006	0.042	1.66E+06	WET
2-37	3,155	22.0	0.003	0.020	1.37E+06	WET
3-37	3,583	25.7	0.003	0.020	1.70E+06	WET
5-45	3,757	26.6	0.004	0.029	1.58E+06	WET
8-40	2,736	21.1	0.002	0.013	1.76E+06	WET
AVERAGE	3,101	23	0.003	0.023	1.57E+06	
STD. DEV.	396	3	0.001	0.010	141,148	
% C.V.	12.75	11.01	43.68	42.99	8.97	

FLEXURAL DATA FOR : 750 F. FOR 30 MINUTES.

% WEIGHT LOSS AFTER PRECONDITIONING = 0.24 %

SPECIMEN NUMBER	FLEXURAL STRENGTH	FLEXURAL LOAD	FIBER STRAIN	DEFLECTION	FLEXURAL MODULUS	MAT'L PRE-CON
			AT MAXIMUM LOAD			WET
#	PSI	LBS	IN/IN	INCHES	PSI	DRY
2-28	1,561	11.6	0.001	0.010	1.51E+06	DRY
3-28	2,242	16.9	0.002	0.013	1.73E+06	DRY
5-28	1,904	14.7	0.002	0.015	1.10E+06	DRY
8-28	1,785	13.6	0.003	0.020	9.00E+05	DRY
2-16	2,117	14.7	0.002	0.017	1.15E+06	DRY
3-16	2,172	16.3	0.004	0.026	1.31E+06	DRY
5-16	2,487	19.2	0.003	0.022	1.76E+06	DRY
5-40	2,762	20.3	0.003	0.021	1.18E+06	DRY
8-16	2,027	15.7	0.004	0.030	9.23E+05	DRY
AVERAGE	2,117	16	0.003	0.019	1.28E+06	
STD. DEV.	361	3	0.001	0.006	318,664	
% C.V.	17.06	17.12	33.83	33.11	24.80	

FLEXURAL DATA FOR : 750 F. FOR 30 MINUTES.

% WEIGHT GAIN AFTER PRECONDITIONING = 0.87 %

2-60	4,299	31.0	0.004	0.025	1.57E+06	WET
3-60	3,794	28.5	0.004	0.030	1.22E+06	WET
5-68	4,298	32.1	0.004	0.025	1.42E+06	WET
8-63	4,861	36.3	0.005	0.037	1.15E+06	WET
2-48	2,505	17.6	0.002	0.017	1.10E+06	WET
3-48	4,342	33.8	0.010	0.068	7.78E+05	WET
5-56	3,945	29.5	0.003	0.020	1.46E+06	WET
5-58	2,717	20.0	0.003	0.020	1.14E+06	WET
8-51	4,160	32.6	0.007	0.045	1.19E+06	WET
AVERAGE	3,880	29	0.005	0.032	1.23E+06	
STD. DEV.	779	6	0.002	0.016	235,529	
% C.V.	20.08	21.61	52.04	50.55	19.20	

Appendix F

NINETY-DEGREE FLEXURAL PROPERTIES ACCORDING TO ASTM D-790

IM6/3501-6
90 DEGREE FLEXURAL PROPERTIES PER ASTM D-790

SUMMARY OF TEST DATA

EXPOSURE TEMP.	EXPOSURE TIME	"DRY" PRECON. FLEXURAL STRENGTH	"DRY" PRECON. STRENGTH RETENTION	"WET" PRECON. FLEXURAL STRENGTH	"WET" PRECON. STRENGTH RETENTION
(DEG. F)	(MIN.)	(PSI)	%	(PSI)	%
73		87,046	92.96	89,749	100.00
350	60	93,638	100.00	87,300	97.27
450	60	79,554	84.96	71,921	80.14
550	5	57,628	61.54	58,355	65.02
550	30	28,715	30.67	34,919	38.91
550	60	17,478	18.67	21,247	23.67
650	5	7,832	8.36	10,054	11.20
650	30	3,094	3.30	3,068	3.42
650	60	2,246	2.40	2,531	2.82
750	5	1,921	2.05	1,884	2.10
750	10	2,195	2.34	2,440	2.72
750	30	3,732	3.99	4,246	4.73

FLEXURAL DATA FOR : ROOM TEMPERATURE

% WEIGHT LOSS AFTER PRECONDITIONING = 0.07 %

SPECIMEN NUMBER	FLEXURAL STRENGTH	FLEXURAL LOAD	FIBER STRAIN	DEFLECTION	FLEXURAL MODULUS	MAT'L PRE-CON
			AT MAXIMUM LOAD			WET
#	PSI	LBS	IN/IN	INCHES	PSI	DRY
18-18	77,489	534.0	0.011	0.078	7.34E+06	DRY
19-18	86,494	716.0	0.014	0.090	6.37E+06	DRY
20-18	93,948	586.0	0.013	0.104	6.89E+06	DRY
21-18	88,384	628.0	0.013	0.092	6.93E+06	DRY
18-31	82,451	601.0	0.014	0.100	6.48E+06	DRY
18-6	88,679	602.0	0.013	0.098	6.73E+06	DRY
19-6	78,579	630.0	0.013	0.088	5.98E+06	DRY
20-6	102,204	621.0	0.014	0.113	6.99E+06	DRY
20-30	98,141	590.0	0.014	0.111	6.84E+06	DRY
21-6	74,090	528.0	0.013	0.097	6.12E+06	DRY
AVERAGE	87,046	604	0.013	0.097	6.67E+06	
STD. DEV.	9,173	53	0.001	0.011	422,398	
% C.V.	10.54	8.78			6.33	

FLEXURAL DATA FOR : ROOM TEMPERATURE

% WEIGHT GAIN AFTER PRECONDITIONING = 0.89 %

18-57	92,328	622.0	0.013	0.097	7.01E+06	WET
19-57	84,899	717.0	0.013	0.097	5.95E+06	WET
20-57	97,152	596.0	0.017	0.110	7.28E+06	WET
21-57	90,933	634.0	0.016	0.120	6.68E+06	WET
18-45	81,418	556.0	0.017	0.125	6.35E+06	WET
19-45	81,599	663.0	0.013	0.097	5.92E+06	WET
20-45	91,048	558.0	0.015	0.101	6.59E+06	WET
20-69	97,152	596.0	0.014	0.112	6.80E+06	WET
21-45	91,213	651.0	0.016	0.121	6.09E+06	WET
AVERAGE	89,749	621	0.015	0.109	6.52E+06	
STD. DEV.	5,925	52	0.002	0.011	477,261	
% C.V.	6.60	8.34			7.32	

FLEXURAL DATA FOR : 350 F. FOR 60 MINUTES.

% WEIGHT LOSS AFTER PRECONDITIONING = 0.07 %

SPECIMEN NUMBER	FLEXURAL STRENGTH	FLEXURAL LOAD	FIBER STRAIN	DEFLECTION	FLEXURAL MODULUS	MAT'L PRE-CON
			AT MAXIMUM LOAD			WET
#	PSI	LBS	IN/IN	INCHES	PSI	DRY
18-7	87,359	606.0	0.013	0.095	6.72E+06	DRY
19-7	85,165	674.0	0.013	0.090	6.46E+06	DRY
20-7	103,091	615.0	0.015	0.117	7.44E+06	DRY
21-7	98,937	695.0	0.015	0.109	6.80E+06	DRY
AVERAGE	93,638	648	0.014	0.103	6.85E+06	
STD. DEV.	8,731	44	0.001	0.012	415,528	
% C.V.	9.32	6.75			6.06	

FLEXURAL DATA FOR : 350 F. FOR 60 MINUTES.

% WEIGHT GAIN AFTER PRECONDITIONING = 0.76 %

SPECIMEN NUMBER	FLEXURAL STRENGTH	FLEXURAL LOAD	FIBER STRAIN	DEFLECTION	FLEXURAL MODULUS	MAT'L PRE-CON
			AT MAXIMUM LOAD			WET
#	PSI	LBS	IN/IN	INCHES	PSI	DRY
18-46	86,950	585.0	0.014	0.104	6.50E+06	WET
19-46	84,408	663.0	0.014	0.098	6.14E+06	WET
20-46	89,011	521.0	0.013	0.100	7.03E+06	WET
21-46	88,830	624.0	0.015	0.111	6.14E+06	WET
AVERAGE	87,300	598	0.014	0.103	6.45E+06	
STD. DEV.	2,141	61	0.001	0.006	419,847	
% C.V.	2.45	10.12			6.51	

FLEXURAL DATA FOR : 450 F. FOR 60 MINUTES.

% WEIGHT LOSS AFTER PRECONDITIONING = 0.07 %

SPECIMEN NUMBER	FLEXURAL STRENGTH	FLEXURAL LOAD	FIBER STRAIN	DEFLECTION	FLEXURAL MODULUS	MAT'L PRE-CON
			AT MAXIMUM LOAD			WET
#	PSI	LBS	IN/IN	INCHES	PSI	DRY
18-20	79,343	532.0	0.012	0.092	6.81E+06	DRY
18-33	80,895	555.0	0.013	0.093	6.49E+06	DRY
19-20	72,865	583.0	0.013	0.091	6.02E+06	DRY
20-20	76,482	473.0	0.012	0.090	6.98E+06	DRY
21-20	75,670	553.0	0.013	0.091	6.39E+06	DRY
18-8	85,896	586.0	0.014	0.105	6.19E+06	DRY
19-8	75,262	604.0	0.013	0.088	5.83E+06	DRY
20-8	88,362	532.0	0.012	0.094	7.42E+06	DRY
21-8	81,208	569.0	0.012	0.090	6.67E+06	DRY
AVERAGE	79,554	554	0.013	0.092	6.53E+06	
STD. DEV.	5,124	39	0.001	0.005	498,340	
% C.V.	6.44	7.02			7.63	

FLEXURAL DATA FOR : 450 F. FOR 60 MINUTES.

% WEIGHT GAIN AFTER PRECONDITIONING = 0.76 %

18-59	81,139	553.0	0.013	0.094	6.70E+06	WET
18-70	79,498	537.0	0.013	0.092	6.70E+06	WET
19-59	56,408	446.0	0.019	0.128	5.74E+06	WET
20-59	63,312	478.0	0.012	0.084	5.36E+06	WET
21-59	78,695	565.0	0.013	0.094	6.24E+06	WET
18-47	73,879	513.0	0.011	0.082	6.80E+06	WET
19-47	61,437	495.0	0.011	0.073	5.79E+06	WET
20-47	78,784	487.0	0.012	0.090	7.13E+06	WET
21-47	74,135	532.0	0.012	0.084	6.39E+06	WET
AVERAGE	71,921	512	0.013	0.091	6.32E+06	
STD. DEV.	9,143	39	0.002	0.015	583,584	
% C.V.	12.71	7.55			9.24	

FLEXURAL DATA FOR : 550 F. FOR 5 MINUTES.

% WEIGHT LOSS AFTER PRECONDITIONING = 0.07 %

SPECIMEN NUMBER	FLEXURAL STRENGTH	FLEXURAL LOAD	FIBER STRAIN	DEFLECTION	FLEXURAL MODULUS	MAT'L PRE-CON
			AT MAXIMUM LOAD			WET
#	PSI	LBS	IN/IN	INCHES	PSI	DRY
18-34	69,084	473.5	0.012	0.090	6.45E+06	DRY
18-21	61,077	417.5	0.011	0.080	6.97E+06	DRY
19-21	42,318	344.0	0.015	0.099	5.46E+06	DRY
20-21	69,137	428.0	0.014	0.112	6.64E+06	DRY
21-21	50,578	356.0	0.012	0.090	5.70E+06	DRY
18-9	63,438	433.0	0.012	0.092	6.05E+06	DRY
19-9	52,605	427.0	0.012	0.078	5.45E+06	DRY
20-9	55,933	334.0	0.011	0.090	7.52E+06	DRY
21-9	54,487	386.0	0.012	0.089	5.61E+06	DRY
AVERAGE	57,628	400	0.013	0.091	6.20E+06	
STD. DEV.	8,884	47	0.001	0.010	734,177	
% C.V.	15.42	11.84			11.83	

FLEXURAL DATA FOR : 550 F. FOR 5 MINUTES.

% WEIGHT GAIN AFTER PRECONDITIONING = 0.76 %

18-60	56,647	382.0	0.011	0.081	6.25E+06	WET
18-71	51,101	340.0	0.015	0.114	6.60E+06	WET
19-60	60,021	480.0	0.013	0.086	5.58E+06	WET
20-60	51,930	327.0	0.009	0.070	6.48E+06	WET
21-60	52,562	372.0	0.009	0.067	6.14E+06	WET
18-48	49,748	326.0	0.011	0.080	6.60E+06	WET
19-48	55,826	471.0	0.013	0.084	5.51E+06	WET
20-48	83,596	517.0	0.013	0.101	6.83E+06	WET
21-48	63,766	466.0	0.012	0.082	5.91E+06	WET
AVERAGE	58,355	409	0.012	0.085	6.21E+06	
STD. DEV.	10,488	74	0.002	0.015	466,200	
% C.V.	17.97	18.19			7.50	

FLEXURAL DATA FOR : 550 F. FOR 30 MINUTES.

% WEIGHT LOSS AFTER PRECONDITIONING = 0.07 %

SPECIMEN NUMBER	FLEXURAL STRENGTH	FLEXURAL LOAD	FIBER STRAIN	DEFLECTION	FLEXURAL MODULUS	MAT'L PRE-CON
			AT MAXIMUM LOAD			WET
#	PSI	LBS	IN/IN	INCHES	PSI	DRY
18-22	29,706	203.0	0.005	0.040	5.93E+06	DRY
18-35	24,730	169.5	0.006	0.041	5.54E+06	DRY
19-22	46,225	378.0	0.012	0.078	5.39E+06	DRY
20-22	39,327	241.5	0.008	0.062	6.07E+06	DRY
21-22	25,196	175.5	0.005	0.040	5.43E+06	DRY
18-10	25,444	173.5	0.006	0.048	4.94E+06	DRY
19-10	21,101	174.0	0.005	0.033	4.49E+06	DRY
20-10	20,297	128.0	0.005	0.035	4.68E+06	DRY
21-10	26,412	190.0	0.006	0.045	4.96E+06	DRY
AVERAGE	28,715	204	0.006	0.047	5.27E+06	
STD. DEV.	8,612	72	0.002	0.014	540,756	
% C.V.	29.99	35.36			10.26	

FLEXURAL DATA FOR : 550 F. FOR 30 MINUTES.

% WEIGHT GAIN AFTER PRECONDITIONING = 0.76 %

18-61	29,023	198.0	0.006	0.047	5.42E+06	WET
18-72	37,195	254.0	0.007	0.052	5.49E+06	WET
19-61	29,936	237.5	0.009	0.064	4.84E+06	WET
20-61	39,122	240.0	0.014	0.110	5.63E+06	WET
21-61	39,985	287.5	0.020	0.141	4.86E+06	WET
18-49	28,127	184.5	0.005	0.040	5.16E+06	WET
19-49	38,548	297.5	0.009	0.063	5.37E+06	WET
20-49	26,071	164.5	0.005	0.040	5.21E+06	WET
21-49	46,266	325.0	0.012	0.088	4.80E+06	WET
AVERAGE	34,919	243	0.010	0.072	5.20E+06	
STD. DEV.	6,841	54	0.005	0.035	307,282	
% C.V.	19.59	22.26			5.91	

FLEXURAL DATA FOR : 550 F. FOR 60 MINUTES.

% WEIGHT LOSS AFTER PRECONDITIONING = 0.07 %

SPECIMEN NUMBER	FLEXURAL STRENGTH	FLEXURAL LOAD	FIBER STRAIN	DEFLECTION	FLEXURAL MODULUS	MAT'L PRE-CON
			AT MAXIMUM LOAD			WET
#	PSI	LBS	IN/IN	INCHES	PSI	DRY
18-23	27,774	183.0	0.005	0.037	5.98E+06	DRY
18-36	15,310	104.5	0.004	0.027	5.96E+06	DRY
19-23	18,599	154.5	0.005	0.032	5.23E+06	DRY
20-23	10,064	63.5	0.002	0.013	5.82E+06	DRY
21-23	17,091	120.0	0.003	0.024	6.22E+06	DRY
18-11	15,274	105.0	0.008	0.056	4.37E+06	DRY
19-11	20,880	171.0	0.005	0.031	4.95E+06	DRY
20-11	15,726	92.0	0.004	0.029	5.50E+06	DRY
21-11	16,587	116.0	0.004	0.030	4.73E+06	DRY
AVERAGE	17,478	123	0.004	0.031	5.42E+06	
STD. DEV.	4,840	39	0.002	0.011	636,289	
% C.V.	27.69	31.57			11.74	

FLEXURAL DATA FOR : 550 F. FOR 60 MINUTES.

% WEIGHT GAIN AFTER PRECONDITIONING = 0.76 %

18-62	12,817	222.5	0.003	0.020	5.30E+06	WET
18-73	19,723	333.5	0.004	0.026	6.42E+06	WET
19-62	15,766	311.0	0.005	0.031	5.68E+06	WET
20-62	25,487	384.0	0.007	0.052	6.39E+06	WET
21-62	24,299	431.0	0.006	0.043	5.55E+06	WET
18-50	25,059	174.0	0.005	0.040	6.01E+06	WET
19-50	18,391	147.0	0.005	0.034	4.98E+06	WET
20-50	31,888	197.5	0.006	0.050	6.17E+06	WET
21-50	17,794	125.0	0.004	0.029	5.04E+06	WET
AVERAGE	21,247	258	0.005	0.036	5.73E+06	
STD. DEV.	5,901	110	0.001	0.011	551,623	
% C.V.	27.77	42.46			9.63	

FLEXURAL DATA FOR : 650 F. FOR 5 MINUTES.

% WEIGHT LOSS AFTER PRECONDITIONING = 0.07 %

SPECIMEN NUMBER	FLEXURAL STRENGTH	FLEXURAL LOAD	FIBER STRAIN	DEFLECTION	FLEXURAL MODULUS	MAT'L PRE-CON
			AT MAXIMUM LOAD			WET
#	PSI	LBS	IN/IN	INCHES	PSI	DRY
18-24	8,944	60.0	0.003	0.021	4.49E+06	DRY
18-37	6,904	46.6	0.003	0.019	3.99E+06	DRY
19-24	7,506	60.0	0.003	0.022	3.04E+06	DRY
20-24	6,191	37.6	0.005	0.039	2.81E+06	DRY
21-24	4,350	30.6	0.005	0.033	2.14E+06	DRY
18-12	7,053	47.8	0.003	0.025	3.16E+06	DRY
19-12	6,524	53.4	0.003	0.020	2.81E+06	DRY
20-12	9,733	58.6	0.003	0.026	3.63E+06	DRY
21-12	13,284	90.0	0.003	0.022	5.34E+06	DRY
AVERAGE	7,832	54	0.003	0.025	3.49E+06	
STD. DEV.	2,566	17	0.001	0.007	985,142	
% C.V.	32.76	31.48			28.22	

FLEXURAL DATA FOR : 650 F. FOR 5 MINUTES.

% WEIGHT GAIN AFTER PRECONDITIONING = 0.76 %

18-63	12,178	82.0	0.004	0.031	4.91E+06	WET
18-74	9,685	65.6	0.003	0.020	3.90E+06	WET
19-63	10,630	86.8	0.003	0.023	4.26E+06	WET
20-63	13,160	80.0	0.004	0.028	5.61E+06	WET
21-63	6,924	49.0	0.003	0.020	3.28E+06	WET
18-51	7,390	49.6	0.003	0.024	3.15E+06	WET
19-51	18,950	151.4	0.005	0.032	5.08E+06	WET
20-51	4,954	29.8	0.004	0.034	3.85E+06	WET
21-51	6,613	46.8	0.002	0.014	4.71E+06	WET
AVERAGE	10,054	71	0.003	0.025	4.31E+06	
STD. DEV.	4,309	36	0.001	0.007	833,686	
% C.V.	42.86	50.06			19.35	

FLEXURAL DATA FOR : 650 F. FOR 30 MINUTES.

% WEIGHT LOSS AFTER PRECONDITIONING = 0.07 %

SPECIMEN NUMBER	FLEXURAL STRENGTH	FLEXURAL LOAD	FIBER STRAIN	DEFLECTION	FLEXURAL MODULUS	MAT'L PRE-CON
			AT MAXIMUM LOAD			WET
#	PSI	LBS	IN/IN	INCHES	PSI	DRY
18-25	3,276	22.0	0.002	0.015	2.98E+06	DRY
18-38	4,028	27.3	0.001	0.011	3.07E+06	DRY
19-25	3,367	27.8	0.002	0.015	1.70E+06	DRY
20-25	3,576	21.2	0.001	0.010	2.99E+06	DRY
21-25	3,469	25.3	0.001	0.010	3.43E+06	DRY
18-13	2,312	15.6	0.002	0.014	1.72E+06	DRY
19-13	3,118	25.5	0.002	0.011	2.57E+06	DRY
20-13	2,042	12.3	0.002	0.013	1.54E+06	DRY
21-13	2,658	19.1	0.002	0.017	1.68E+06	DRY
AVERAGE	3,094	22	0.002	0.013	2.41E+06	
STD. DEV.	639	5	0.000	0.003	744,185	
% C.V.	20.64	24.49			30.89	

FLEXURAL DATA FOR : 650 F. FOR 30 MINUTES.

% WEIGHT GAIN AFTER PRECONDITIONING = 0.76 %

18-64	3,088	20.8	0.001	0.009	4.33E+06	WET
18-75	3,401	23.4	0.006	0.044	2.33E+06	WET
19-64	2,990	23.9	0.003	0.019	1.67E+06	WET
20-64	3,786	23.7	0.002	0.014	2.82E+06	WET
21-64	3,410	24.0	0.002	0.011	3.15E+06	WET
19-52	2,690	21.5	0.001	0.010	3.35E+06	WET
20-52	2,285	13.7	0.002	0.014	1.85E+06	WET
21-52	2,892	20.9	0.001	0.008	2.78E+06	WET
AVERAGE	3,068	21	0.002	0.016	2.79E+06	
STD. DEV.	469	3	0.002	0.012	857,967	
% C.V.	15.27	16.04			30.80	

FLEXURAL DATA FOR : 650 F. FOR 60 MINUTES.

% WEIGHT LOSS AFTER PRECONDITIONING = 0.07 %

SPECIMEN NUMBER	FLEXURAL STRENGTH	FLEXURAL LOAD	FIBER STRAIN	DEFLECTION	FLEXURAL MODULUS	MAT'L PRE-CON
			AT MAXIMUM LOAD			WET
#	PSI	LBS	IN/IN	INCHES	PSI	DRY
18-26	2,125	14.5	0.002	0.017	2.79E+06	DRY
18-39	1,817	12.4	0.002	0.017	2.22E+06	DRY
19-26	2,840	22.5	0.002	0.017	1.27E+06	DRY
20-26	2,042	12.3	0.001	0.010	1.64E+06	DRY
21-26	2,270	16.3	0.002	0.014	1.59E+06	DRY
18-14	2,511	17.2	0.001	0.008	2.87E+06	DRY
19-14	2,588	20.9	0.001	0.008	2.76E+06	DRY
20-14	1,785	11.2	0.001	0.011	2.58E+06	DRY
21-14	2,235	15.5	0.002	0.012	1.53E+06	DRY
AVERAGE	2,246	16	0.002	0.013	2.14E+06	
STD. DEV.	352	4	0.001	0.004	635,383	
% C.V.	15.69	24.46			29.73	

FLEXURAL DATA FOR : 650 F. FOR 60 MINUTES.

% WEIGHT GAIN AFTER PRECONDITIONING = 0.76 %

18-65	2,549	17.3	0.001	0.010	2.99E+06	WET
18-76	2,997	20.3	0.001	0.010	2.76E+06	WET
19-65	2,127	18.1	0.001	0.007	2.72E+06	WET
20-65	1,518	9.2	0.001	0.010	1.88E+06	WET
21-65	2,953	20.0	0.001	0.010	3.07E+06	WET
18-53	2,250	14.7	0.003	0.020	1.49E+06	WET
19-53	4,338	36.4	0.002	0.016	2.17E+06	WET
20-53	1,607	10.0	0.001	0.010	1.66E+06	WET
21-53	2,445	17.5	0.002	0.017	1.68E+06	WET
AVERAGE	2,531	18	0.002	0.012	2.27E+06	
STD. DEV.	851	8	0.001	0.004	621,475	
% C.V.	33.60	43.65			27.41	

FLEXURAL DATA FOR : 750 F. FOR 5 MINUTES.

% WEIGHT LOSS AFTER PRECONDITIONING = 0.07 %

SPECIMEN NUMBER	FLEXURAL STRENGTH	FLEXURAL LOAD	FIBER STRAIN	DEFLECTION	FLEXURAL MODULUS	MAT'L PRE-CON
			AT MAXIMUM LOAD			WET
#	PSI	LBS	IN/IN	INCHES	PSI	DRY
18-27	1,691	11.2	0.001	0.009	2.03E+06	DRY
19-27	1,347	10.9	0.001	0.008	2.30E+06	DRY
19-30	1,676	13.5	0.002	0.016	1.31E+06	DRY
20-27	1,514	9.5	0.002	0.013	1.87E+06	DRY
21-27	1,763	12.3	0.002	0.012	1.25E+06	DRY
18-15	2,233	15.3	0.002	0.013	2.08E+06	DRY
19-15	2,882	24.0	0.002	0.013	1.72E+06	DRY
20-15	1,998	12.7	0.002	0.014	2.11E+06	DRY
21-15	2,190	15.4	0.001	0.010	1.87E+06	DRY
AVERAGE	1,921	14	0.002	0.012	1.84E+06	
STD. DEV.	465	4	0.000	0.003	357,851	
% C.V.	24.22	30.77			19.48	

FLEXURAL DATA FOR : 750 F. FOR 5 MINUTES.

% WEIGHT GAIN AFTER PRECONDITIONING = 0.76 %

18-66	2,399	16.3	0.001	0.008	2.39E+06	WET
19-66	1,389	11.5	0.002	0.012	2.42E+06	WET
19-69	1,731	14.3	0.002	0.013	1.67E+06	WET
20-66	1,842	11.5	0.003	0.020	1.92E+06	WET
21-66	1,472	10.2	0.002	0.017	2.57E+06	WET
18-54	1,893	12.8	0.002	0.017	1.65E+06	WET
19-54	2,277	18.2	0.003	0.017	1.95E+06	WET
20-54	1,901	11.3	0.003	0.024	1.51E+06	WET
21-54	2,051	14.7	0.002	0.017	1.73E+06	WET
AVERAGE	1,884	13	0.002	0.016	1.98E+06	
STD. DEV.	333	3	0.001	0.005	386,569	
% C.V.	17.69	19.77			19.53	

FLEXURAL DATA FOR : 750 F. FOR 10 MINUTES.

% WEIGHT LOSS AFTER PRECONDITIONING = 0.07 %

SPECIMEN NUMBER	FLEXURAL STRENGTH	FLEXURAL LOAD	FIBER STRAIN	DEFLECTION	FLEXURAL MODULUS	MAT'L PRE-CON
			AT MAXIMUM LOAD			
#	PSI	LBS	IN/IN	INCHES	PSI	WET DRY
18-29	1,861	12.9	0.002	0.011	1.72E+06	DRY
19-29	1,705	14.0	0.002	0.015	1.11E+06	DRY
19-32	2,802	21.7	0.002	0.013	1.76E+06	DRY
20-29	2,210	13.3	0.002	0.014	1.89E+06	DRY
21-29	2,072	14.5	0.002	0.017	1.69E+06	DRY
18-16	1,952	13.6	0.002	0.016	1.48E+06	DRY
19-16	1,918	15.1	0.002	0.016	1.31E+06	DRY
20-16	2,708	15.3	0.003	0.022	1.86E+06	DRY
21-16	2,527	17.9	0.003	0.022	1.37E+06	DRY
AVERAGE	2,195	15	0.002	0.016	1.58E+06	
STD. DEV.	394	3	0.000	0.004	270,270	
% C.V.	17.97	18.21			17.14	

FLEXURAL DATA FOR : 750 F. FOR 10 MINUTES.

% WEIGHT GAIN AFTER PRECONDITIONING = 0.76 %

18-68	2,408	16.3	0.002	0.014	1.41E+06	WET
19-68	2,273	17.7	0.002	0.014	9.25E+05	WET
19-71	2,484	20.0	0.002	0.014	2.30E+06	WET
20-68	2,561	15.0	0.003	0.027	1.43E+06	WET
21-68	2,785	20.4	0.002	0.012	2.74E+06	WET
18-55	2,003	13.7	0.002	0.013	1.52E+06	WET
19-55	2,609	20.7	0.003	0.023	1.46E+06	WET
20-55	2,531	15.2	0.002	0.015	1.58E+06	WET
21-55	2,304	16.2	0.002	0.013	1.67E+06	WET
AVERAGE	2,440	17	0.002	0.016	1.67E+06	
STD. DEV.	227	3	0.001	0.005	534,534	
% C.V.	9.29	14.96			31.98	

FLEXURAL DATA FOR : 750 F. FOR 30 MINUTES.

% WEIGHT LOSS AFTER PRECONDITIONING = 0.07 %

SPECIMEN NUMBER	FLEXURAL STRENGTH	FLEXURAL LOAD	FIBER STRAIN	DEFLECTION	FLEXURAL MODULUS	MAT'L PRE-CON
			AT MAXIMUM LOAD			
#	PSI	LBS	IN/IN	INCHES	PSI	WET DRY
18-28	3,705	25.3	0.003	0.020	2.21E+06	DRY
19-28	3,660	29.7	0.004	0.024	1.37E+06	DRY
19-31	3,049	23.8	0.003	0.020	1.39E+06	DRY
20-38	4,486	27.1	0.004	0.028	2.66E+06	DRY
21-38	3,672	26.0	0.004	0.030	2.09E+06	DRY
18-17	4,561	31.7	0.003	0.023	2.30E+06	DRY
19-17	4,109	34.7	0.004	0.025	1.54E+06	DRY
20-17	3,686	23.0	0.003	0.022	3.57E+06	DRY
21-17	2,658	18.8	0.003	0.023	1.44E+06	DRY
AVERAGE	3,732	27	0.003	0.024	2.06E+06	
STD. DEV.	615	5	0.000	0.003	733,159	
% C.V.	16.49	18.03			35.55	

FLEXURAL DATA FOR : 750 F. FOR 30 MINUTES.

% WEIGHT GAIN AFTER PRECONDITIONING = 0.76 %

18-67	3,891	25.7	0.003	0.025	1.45E+06	WET
19-67	2,938	23.5	0.003	0.021	1.23E+06	WET
19-70	3,390	28.8	0.004	0.028	9.65E+05	WET
20-67	4,457	26.9	0.004	0.029	1.75E+06	WET
21-67	3,849	28.1	0.003	0.022	1.68E+06	WET
18-56	4,783	32.6	0.003	0.022	2.12E+06	WET
19-56	6,268	50.5	0.003	0.022	2.96E+06	WET
20-56	3,936	24.1	0.008	0.059	2.08E+06	WET
21-56	4,705	32.1	0.004	0.031	2.26E+06	WET
AVERAGE	4,246	30	0.004	0.029	1.83E+06	
STD. DEV.	965	8	0.001	0.012	599,378	
% C.V.	22.73	27.22			32.69	

Appendix G

SHORE-D HARDNESS VALUES ACCORDING TO ASTM D-2240

IM6/3501-6
SHORE D HARDNESS VALUES PER ASTM D-2240

SUMMARY OF TEST DATA

EXPOSURE TEMP.	EXPOSURE TIME	"DRY" PRECONDITIONING AVERAGE HARDNESS	C.V.	NO.	STR. RETENT.	"WET" PRECONDITIONING AVERAGE HARDNESS	C.V.	NO.	STR. RETENT
(DEG. F)	(MIN.)	SHORE D	%	#	%	SHORE D	%	#	%
73		93.5	1.2	10	99.4	93.5	0.9	10	98.9
350	60	94.1	2.2	9	100.0	94.5	1.3	10	100.0
450	60	92.1	2.7	10	97.9	92.5	3.0	10	97.9
550	5	92.6	2.0	10	98.4	94.4	1.0	10	99.8
550	30	89.9	1.3	10	95.6	92.9	0.8	4	98.3
550	60	89.5	2.0	10	95.1	89.1	3.3	10	94.2
650	5	73.4	20.4	9	78.1	60.1	20.3	10	63.6
650	30	54.3	14.4	9	57.8	47.4	8.2	9	50.1
650	60	52.7	7.2	9	56.0	48.2	9.2	9	51.0
750	5	42.6	13.1	9	45.3	44.5	9.7	9	47.0
750	10	45.4	5.9	8	48.3	47.4	8.5	9	50.1
750	30	41.8	17.9	9	44.5	44.3	9.9	9	46.9

Appendix H

MICROMETER MEASUREMENTS AT MAXIMUM SPECIMEN THICKNESS

IM6/3501-6
MICROMETER MEASUREMENTS AT MAXIMUM THICKNESS

SUMMARY OF TEST DATA

EXPOSURE TEMP.	EXPOSURE TIME	"DRY" PRECONDITIONING AVERAGE THICKNESS	COEFF. VAR.	NO. OF SPEC.	WET" PRECONDITIONING AVERAGE THICKNESS	COEFF. VAR.	NO. OF SPEC.
(DEG. F)	(MIN.)	(MILS)	%	#	(MILS)	%	#
73		120	3	13	121	3	13
350	60	123	3	15	122	4	14
450	60	123	4	15	123	3	15
550	5	125	3	15	125	3	15
550	30	125	3	15	123	3	9
550	60	124	2	15	124	3	15
650	5	158	14	13	166	13	15
650	30	189	15	13	206	11	14
650	60	196	17	13	219	10	14
750	5	232	15	13	271	10	9
750	10	254	10	12	247	9	12
750	30	267	7	13	274	6	13

Appendix I

T-TEST SUMMARY OF MECHANICAL PROPERTY RESULTS OF IM6/3501-6 SPECIMENS

T-TEST SUMMARY OF MECHANICAL PROPERTY RESULTS
OF IM6/3501-6 SPECIMENS

ARE THE MEANS OF THE "WET" AND "DRY" DATA STATISTICALLY SIGNIFICANTLY DIFFERENT AT THE 95% CONFIDENCE LEVEL AT A SPECIFIC TEMPERATURE/TIME ? YES OR NO

EXPOSURE TEMP.	EXPOSURE TIME	90 DEG. S.B.S.	0 DEG. S.B.S.	0 DEG. COMP.	0 DEG. FLEX.	90 DEG. FLEX.	SHORE D
73		YES	YES	NO	NO	NO	NO
350	60	NO	NO	NO	YES	NO	NO
450	60	YES	NO	NO	NO	YES	NO
550	5	YES	YES	YES	NO	NO	YES
550	30	NO	YES	NO	NO	NO	YES
550	60	NO	YES	NO	NO	NO	NO
650	5	YES	NO	YES	YES	NO	YES
650	30		NO	NO	YES	NO	YES
650	60		NO	NO	NO	NO	YES
750	5			NO	NO	NO	NO
750	10			NO	NO	NO	NO
750	30			NO	YES	NO	NO

EQUATIONS AND TABLES USED FOR THE T-TEST

$$SDIFF = \sqrt{\left(\frac{N1 + N2}{N1N2}\right)\left(\frac{(N1 - 1)S1^2 + (N2 - 1)S2^2}{N1 + N2 - 2}\right)}$$

N1 AND N2 ARE THE SAMPLE SIZES FOR THE FIRST AND SECOND SAMPLES, RESPECTIVELY.

S1 AND S2 ARE THE SAMPLE STANDARD DEVIATIONS FOR THE FIRST AND SECOND SAMPLES, RESPECTIVELY.

$$T\ EXPERIMENTAL\ (EXP.) = \frac{\bar{X}1 - \bar{X}2}{SDIFF}$$

$\bar{X}1$ AND $\bar{X}2$ ARE THE SAMPLE MEANS FOR THE FIRST AND SECOND SAMPLES, RESPECTIVELY.

DEGREES OF FREEDOM (DF) = N1 + N2 - 2

TABLE OF T CRITICAL (CRT.) VALUES (AT THE 95% CONFIDENCE LEVEL) FOR SELECTED DEGREES OF FREEDOM.

DF	T(CRT.)	DF	T(CRT.)	DF	T(CRT.)
6	2.45	14	2.15	20	2.09
8	2.31	15	2.13		
9	2.26	16	2.12		
11	2.20	17	2.11		
12	2.18	18	2.10		

WHEN T(EXP.) IS LARGER THAN T(CRT.) IN ABSOLUTE VALUE THEN THERE IS A STATISTICALLY SIGNIFICANT DIFFERENCE (AT THE 95% CONFIDENCE LEVEL) BETWEEN THE TWO MEANS OF THE "WET" AND "DRY" GROUPS AT A SPECIFIC TEMPERATURE/TIME.

90 DEGREE SHORT BEAM SHEAR

TEMP.-TIME	MEAN	STD.DEV	NO.	SDIFF	T(EXP.)	DF	T(CRT.)	IS T(EXP.)>T(CRT.)?
RT	9983	845	10	360	3.59	18	2.10	YES
	8691	763	10					
350-60	8918	909	10	530	-1.00	18	2.10	NO
	9448	1409	10					
450-60	7374	386	10	379	-3.89	18	2.10	YES
	8846	1134	10					
550-5	6535	424	10	321	-7.31	18	2.10	YES
	8880	922	10					
550-30	4270	720	10	316	-0.92	18	2.10	NO
	4561	695	10					
550-60	2402	477	9	208	1.52	15	2.13	NO
	2085	364	8					
650-5	3396	837	10	369	2.45	18	2.10	YES
	2492	812	10					

0 DEGREE SHORT BEAM SHEAR

TEMP.-TIME	MEAN	STD.DEV	NO.	SDIFF	T(EXP.)	DF	T(CRT.)	IS T(EXP.)>T(CRT.)?
RT	6230	166	10	88	2.12	18	2.10	YES
	6044	222	10					
350-60	5917	246	10	109	-1.15	18	2.10	NO
	6042	242	10					
450-60	5784	127	10	89	1.26	18	2.10	NO
	5672	252	10					
550-5	4781	572	10	222	-3.13	18	2.10	YES
	5474	405	10					
550-30	3256	651	10	292	-2.77	18	2.10	YES
	4067	656	10					
550-60	2097	639	10	301	-3.66	18	2.10	YES
	3197	705	10					
650-5	1117	1008	9	538	-0.77	17	2.11	NO
	1530	1297	10					
650-30	275	38	10	33	-1.18	18	2.10	NO
	314	97	10					
650-60	295	31	10	20	0.81	18	2.10	NO
	279	54	10					

0 DEGREE COMPRESSION

TEMP.-TIME	MEAN	STD.DEV	NO.	SDIFF	T(EXP.)	DF	T(CRT.)	IS T(EXP.)>T(CRT.)?
RT	44761	3026	5	1797	0.61	8	2.31	NO
	43663	2643	5					
350-60	46167	4298	5	2168	1.49	8	2.31	NO
	42947	2242	5					
450-60	41346	2543	5	1331	1.07	8	2.31	NO
	39923	1546	5					
550-5	43757	2047	5	1605	2.79	8	2.31	YES
	39283	2949	5					
550-30	40756	3773	5	2139	1.09	8	2.31	NO
	38425	2939	5					
550-60	32138	5288	5	2506	2.22	8	2.31	NO
	26574	1857	5					
650-5	40981	3210	5	2032	3.55	8	2.31	YES
	33756	3217	5					
650-30	18735	5296	5	2903	-0.63	8	2.31	NO
	20554	3754	5					
650-60	4458	1768	5	885	0.85	8	2.31	NO
	3710	889	5					
750-5	18785	5051	5	2853	-1.17	8	2.31	NO
	22122	3897	5					
750-10	12084	4524	5	2678	0.52	8	2.31	NO
	10697	3923	5					
750-30	4097	1429	5	829	1.56	8	2.31	NO
	2805	1181	5					

0 DEGREE FLEXURAL

TEMP.-TIME	MEAN	STD.DEV	NO.	SDIFF	T(EXP.)	DF	T(CRT.)	IS T(EXP.)>T(CRT.)?
RT	51660	1504	9	1031	-1.59	15	2.13	NO
	53297	2657	8					
350-60	52759	1268	5	615	3.19	9	2.26	YES
	50797	756	6					
450-60	47400	3127	7	1331	1.04	16	2.12	NO
	46010	2501	11					
550-5	42642	4175	11	1738	-0.09	15	2.13	NO
	42805	570	6					
550-30	30822	3697	11	3092	-0.29	14	2.15	NO
	31726	8990	5					
550-60	19873	4868	11	3112	-1.03	20	2.09	NO
	23076	9100	11					
650-5	10975	5180	8	1862	2.65	15	2.13	YES
	6045	2014	9					
650-30	3355	772	9	290	3.47	16	2.12	YES
	2350	398	9					
650-60	2729	357	9	171	1.55	16	2.12	NO
	2465	367	9					
750-5	3046	1325	9	769	0.12	11	2.20	NO
	2953	1150	4					
750-10	2935	542	8	237	-0.70	14	2.15	NO
	3101	396	8					
750-30	2117	361	9	286	-6.16	16	2.12	YES
	3880	779	9					

90 DEGREE FLEXURAL

TEMP.-TIME	MEAN	STD.DEV	NO.	SDIFF	T(EXP.)	DF	T(CRT.)	IS T(EXP.)>T(CRT.)?
RT	87046	9173	10	3591	-0.75	17	2.11	NO
	89749	5925	9					
350-60	93638	8731	4	4495	1.41	6	2.45	NO
	87300	2141	4					
450-60	79554	5124	9	3494	2.18	16	2.12	YES
	71921	9143	9					
550-5	57628	8884	9	4582	-0.16	16	2.12	NO
	58355	10488	9					
550-30	28715	8612	9	3666	-1.69	16	2.12	NO
	34919	6841	9					
550-60	17478	4840	9	2544	-1.48	16	2.12	NO
	21247	5901	9					
650-5	7832	2566	9	1672	-1.33	16	2.12	NO
	10054	4309	9					
650-30	3094	639	9	275	0.09	15	2.13	NO
	3068	469	8					
650-60	2246	352	9	307	-0.93	16	2.12	NO
	2531	851	9					
750-5	1921	465	9	191	0.19	16	2.12	NO
	1884	333	9					
750-10	2195	394	9	152	-1.62	16	2.12	NO
	2440	227	9					
750-30	3732	615	9	381	-1.35	16	2.12	NO
	4246	965	9					

SHORE D

TEMP.-TIME	MEAN	STD.DEV	NO.	SDIFF	T(EXP.)	DF	T(CRT.)	IS T(EXP.)>T(CRT.)?
RT	93.5	1.1	10	0	0.00	18	2.10	NO
	93.5	0.8	10					
350-60	94.1	2.1	9	1	-0.51	17	2.11	NO
	94.5	1.3	10					
450-60	92.1	2.5	10	1	-0.34	18	2.10	NO
	92.5	2.8	10					
550-5	92.6	1.9	10	1	-2.65	18	2.10	YES
	94.4	1	10					
550-30	89.9	1.2	10	1	-4.55	12	2.18	YES
	92.9	0.8	4					
550-60	89.5	1.8	10	1	0.36	18	2.10	NO
	89.1	3	10					
650-5	73.4	15	9	6	2.13	17	2.11	YES
	60.1	12.2	10					
650-30	54.3	7.8	9	3	2.37	16	2.12	YES
	47.4	3.9	9					
650-60	52.7	3.8	9	2	2.29	16	2.12	YES
	48.2	4.5	9					
750-5	42.6	5.6	9	2	-0.81	16	2.12	NO
	44.5	4.3	9					
750-10	45.4	2.7	8	2	-1.19	15	2.13	NO
	47.4	4	9					
750-30	41.8	7.5	9	3	-0.86	16	2.12	NO
	44.3	4.4	9					

Appendix J

NINETY-DEGREE FLEXURAL PROPERTIES ACCORDING TO ASTM D-790 AFTER EXTENDED PRECONDITIONING FOR 82 DAYS

IM6/3501-6
90 DEGREE FLEXURAL PROPERTIES PER ASTM D-790
AFTER EXTENDED PRECONDITIONING FOR 82 DAYS.

SUMMARY OF TEST DATA

EXPOSURE TEMP.	EXPOSURE TIME	"DRY" FLEXURAL STRENGTH	"WET" FLEXURAL STRENGTH
(DEG. F)	(MIN.)	(PSI)	(PSI)
550	5	37,560	45,649
550	30	19,597	26,314
550	42	20,354	17,816
550	60	14,575	24,004

90 DEGREE FLEXURAL DATA : 550 F. FOR 5 MINUTES

% WEIGHT LOSS AFTER PRECONDITIONING = .10%

SPECIMEN NUMBER & TIME EXPOSED #	FLEXURAL STRENGTH PSI	FLEXURAL LOAD LBS	FIBER STRAIN AT MAXIMUM LOAD IN/IN	DEFLECTI AT MAXIMUM LOAD INCHES	FLEXURAL MODULUS PSI	MAT'L PRE-CON WET DRY
5 MIN.						
19-35	39,554	313.5	0.010	0.069	5.30E+06	DRY
21-35	32,939	231.5	0.013	0.094	5.82E+06	DRY
21-36	40,187	283.0	0.008	0.056	5.74E+06	DRY

AVERAGE 37560
STD. DEV. 4015
% C.V. 10.69

90 DEGREE FLEXURAL DATA : 550 F. FOR 5 MINUTES

% WEIGHT GAIN AFTER PRECONDITIONING = 1.05%

SPECIMEN NUMBER & TIME EXPOSED #	FLEXURAL STRENGTH PSI	FLEXURAL LOAD LBS	FIBER STRAIN AT MAXIMUM LOAD IN/IN	DEFLECTI AT MAXIMUM LOAD INCHES	FLEXURAL MODULUS PSI	MAT'L PRE-CON WET DRY
5 MIN.						
20-72	44,447	268.0	0.010	0.077	6.20E+06	WET
21-77	46,046	327.5	0.020	0.144	5.83E+06	WET
21-78	46,454	326.0	0.017	0.121	5.45E+06	WET

AVERAGE 45649
STD. DEV. 1061
% C.V. 2.32

90 DEGREE FLEXURAL DATA : 550 F. FOR 30 MINUTES

% WEIGHT LOSS AFTER PRECONDITIONING = .10%

SPECIMEN NUMBER & TIME EXPOSED #	FLEXURAL STRENGTH PSI	FLEXURAL LOAD LBS	FIBER STRAIN AT MAXIMUM LOAD IN/IN	DEFLECTI AT MAXIMUM LOAD INCHES	FLEXURAL MODULUS PSI	MAT'L PRE-CON WET DRY
30 MIN.						
20-36	17,272	108.0	0.005	0.035	7.66E+06	DRY
21-33	21,042	151.0	0.005	0.037	4.62E+06	DRY
21-34	20,476	146.5	0.005	0.034	5.19E+06	DRY

AVERAGE 19597
STD. DEV. 2033
% C.V. 10.37

90 DEGREE FLEXURAL DATA : 550 F. FOR 30 MINUTES

% WEIGHT GAIN AFTER PRECONDITIONING = 1.05%

SPECIMEN NUMBER & TIME EXPOSED #	FLEXURAL STRENGTH PSI	FLEXURAL LOAD LBS	FIBER STRAIN AT MAXIMUM LOAD IN/IN	DEFLECTI AT MAXIMUM LOAD INCHES	FLEXURAL MODULUS PSI	MAT'L PRE-CON WET DRY
30 MIN.						
20-73	23,491	141.5	0.005	0.040	5.82E+06	WET
21-75	21,915	157.5	0.005	0.039	5.06E+06	WET
21-76	33,537	239.0	0.009	0.063	5.35E+06	WET

AVERAGE 26314
STD. DEV. 6304
% C.V. 23.96

90 DEGREE FLEXURAL DATA : 550 F. FOR 42 MINUTES

% WEIGHT LOSS AFTER PRECONDITIONING = .10%

SPECIMEN NUMBER & TIME EXPOSED #	FLEXURAL STRENGTH PSI	FLEXURAL LOAD LBS	FIBER STRAIN AT MAXIMUM LOAD IN/IN	DEFLECTI AT MAXIMUM LOAD INCHES	FLEXURAL MODULUS PSI	MAT'L PRE-CON WET DRY
42 MIN.						
19-39	11,977	101.0	0.004	0.027	4.60E+06	DRY
20-37	35,173	208.0	0.006	0.047	7.60E+06	DRY
21-32	13,911	98.5	0.003	0.022	5.69E+06	DRY

AVERAGE 20354
STD. DEV. 12870
% C.V. 63.23

90 DEGREE FLEXURAL DATA : 550 F. FOR 42 MINUTES

% WEIGHT GAIN AFTER PRECONDITIONING = 1.05%

SPECIMEN NUMBER & TIME EXPOSED #	FLEXURAL STRENGTH PSI	FLEXURAL LOAD LBS	FIBER STRAIN AT MAXIMUM LOAD IN/IN	DEFLECTI AT MAXIMUM LOAD INCHES	FLEXURAL MODULUS PSI	MAT'L PRE-CON WET DRY
42 MIN.						
19-76	24,197	191.5	0.005	0.036	5.86E+06	WET
20-75	11,457	71.5	0.003	0.025	6.12E+06	WET
21-74	17,794	125.0	0.004	0.029	5.42E+06	WET

AVERAGE 17816
STD. DEV. 6370
% C.V. 35.75

90 DEGREE FLEXURAL DATA : 550 F. FOR 60 MINUTES

% WEIGHT LOSS AFTER PRECONDITIONING = .10%

SPECIMEN NUMBER & TIME EXPOSED #	FLEXURAL STRENGTH PSI	FLEXURAL LOAD LBS	FIBER STRAIN AT MAXIMUM LOAD IN/IN	DEFLECTI AT MAXIMUM LOAD INCHES	FLEXURAL MODULUS PSI	MAT'L PRE-CON WET DRY
60 MIN.						
19-36	11,756	91.0	0.003	0.020	4.88E+06	DRY
20-35	17,775	108.0	0.004	0.028	5.87E+06	DRY
21-31	14,194	100.2	0.003	0.022	5.38E+06	DRY

AVERAGE 14575
STD. DEV. 3027
% C.V. 20.77

90 DEGREE FLEXURAL DATA : 550 F. FOR 60 MINUTES

% WEIGHT GAIN AFTER PRECONDITIONING = 1.05%

SPECIMEN NUMBER & TIME EXPOSED #	FLEXURAL STRENGTH PSI	FLEXURAL LOAD LBS	FIBER STRAIN AT MAXIMUM LOAD IN/IN	DEFLECTI AT MAXIMUM LOAD INCHES	FLEXURAL MODULUS PSI	MAT'L PRE-CON WET DRY
60 MIN.						
19-75	30,710	251.5	0.007	0.046	5.08E+06	WET
20-74	19,805	121.5	0.004	0.034	6.29E+06	WET
21-73	21,497	153.5	0.005	0.033	5.52E+06	WET

AVERAGE 24004
STD. DEV. 5869
% C.V. 24.45

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