AMMRC TR 81-36

LOW-COST FORMING INFLUENCE ON REINFORCED THERMOPLASTIC MECHANICAL PROPERTIES

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Prepared for

ARMY MATERIALS AND MECHANICS RESEARCH CENTER
Watertown, Massachusetts 02172
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This report describes a study of the influence of low-cost forming methods on the mechanical properties of reinforced thermoplastics. Two tasks comprise the main body of the study; one establishes a relationship between processing parameters (time/pressure/temp-variables) and selected material properties (modulus, flex strength, inter-laminar shear strength); the other determines the effects (measured by the change in material flexural properties) of simulated RGM solvent attack on...
Block No. 20

Painted and unpainted laminates. Two secondary tasks complete the study: a review of the available literature on industrial and government-sponsored reinforced thermoplastic materials, material properties, and fabrication methods. The other task required the manufacture of four, 16" x 20", five ply Kevlar 49 style 285 fabric, polysulfone, laminated panels for AMMRC testing. Test data (with respect to processing parameters) indicates a decrease in flexural strength as thermoforming temperature increases with highest strength readings coming at the 450°F thermoforming temperature. Modulus values are highest in the 500°F - 550°F thermoforming temperature range. Interlaminar shear strength values also tend to decrease as thermoforming temperature increases. Regarding solvent attack, test data indicates generally higher flexural strength with polyphenylsulfone than with polysulfone sandwich beams. Conversely higher "EI" values occurred in the polysulfone than in the polyphenylsulfone sandwich beams. Data also suggests no degradation in material flexural properties when specimens are exposed to acetone and methyl-ethyl-ketone solvents.
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</tr>
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</tr>
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</table>
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FOREWORD

This final technical report concludes the study of low-cost forming influence on reinforced thermoplastic mechanical properties contract for the Army Materials & Mechanics Research Center (AMMRC), Watertown, Massachusetts, by the Boeing Vertol Company under Contract DAAG46-79-C-0092.

Mr. Peter Dehmer was the Army Contracting Officer's Technical Representative. The program was conducted at the Boeing Vertol Company under the technical direction of Mr. Thomas W. Griffith, Program Manager. Principal contributors were Donald J. Hoffstedt, Project Engineer; Donald J. Toto; Lawrence C. Ritter; and Erwin Durchlaub.
SUMMARY

The following is a general summary of results for each of the tasks comprising this study program.

1. Task I — Literature Review and Oral Presentation

Development of hot melt preimpregnation has shown encouraging results with Udel polysulfone P-1700 and CM-1 polyarylsulfone.

Emergence of hot roll continuous impregnation from film and continuous fiber materials make highly solvent resistant polymers candidates for further development.

Hot melt development is recommended with candidates offered by suppliers in film form.

2. Task II — Establish Relationship Between Processing Parameters and Selected Material Properties

Time/Temperature/Pressure Variables — Utilizing a polysulfone matrix and Kevlar 49 aramid fabric, specimens were fabricated to determine the experimental relationship between preconsolidated laminate flexure strength versus postformed laminate flexure strength when exposed to the forming parameters in Table 1. This relationship is described by:

(a) Flexural strength
(b) Modulus
(c) Interlaminar shear strength

Flexural Strength — Only those specimens postformed at the 450°F thermoforming temperature had increased flexural strength readings (up 5%) over the nonpostformed control group. The group having the highest flexural strength readings below those of the control (10% under control) were postformed at 500°F. All other higher temperature postformed groups (550°F, 600°F, 650°F) had flexural strength readings a minimum of 28% under the nonpostformed control group. (NOTE: All percentage differences are based on “group average” values.)

Generally, the test data indicated a definite decrease in flexural strength as thermoforming (postforming) temperatures increase. This trend was unaffected by variations in post forming pressure (vacuum only or vacuum plus light die pressure).

Modulus — Specimens postformed at the 500°F postforming temperatures had the highest percentage increase (+23%) over the control group modulus values. Two other groups had higher modulus values than the control group: 450°F postforming (+6.5%), 550°F postforming (+15.5%). The two remaining postformed specimen groups had modulus values lower than those of the nonpostformed control group: Postformed at 600°F (−1.8%), postformed at 650°F (−21.4%). (NOTE: All percentage differences were based on “group average” values.)
### TABLE 1. THERMOFORMING PROCESSING CONDITIONS

<table>
<thead>
<tr>
<th>SPECIMEN GROUP</th>
<th>MATERIAL (POLYSULFONE P-1700 RESIN)</th>
<th>POST-FORMING TEMPERATURE (°F)</th>
<th>PRESSURE DURING HEAT CYCLE (PSI)</th>
<th>POST-FORMING PRESSURE (PSI)</th>
<th>VAC ONLY</th>
<th>VLOP *</th>
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<tbody>
<tr>
<td>CONTROL (NO POST-FORMING)</td>
<td>5-PLY KEVLAR 285</td>
<td></td>
<td></td>
<td></td>
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<td></td>
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<tr>
<td>1</td>
<td>5-PLY KEVLAR 285</td>
<td>X</td>
<td>0</td>
<td></td>
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<tr>
<td>2</td>
<td>5-PLY KEVLAR 285</td>
<td>X</td>
<td>0</td>
<td></td>
<td></td>
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<tr>
<td>3</td>
<td>5-PLY KEVLAR 285</td>
<td>X</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4</td>
<td>5-PLY KEVLAR 285</td>
<td>X</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>5</td>
<td>5-PLY KEVLAR 285</td>
<td>X</td>
<td>0</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>6</td>
<td>5-PLY KEVLAR 285</td>
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<td>0</td>
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<tr>
<td>7</td>
<td>5-PLY KEVLAR 285</td>
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<td>5-PLY KEVLAR 285</td>
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<td></td>
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<td>9</td>
<td>5-PLY KEVLAR 285</td>
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<tr>
<td>10</td>
<td>5-PLY KEVLAR 285</td>
<td>X</td>
<td>0</td>
<td></td>
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</tr>
</tbody>
</table>

* VLOP = VACUUM PLUS LIGHT DIE PRESSURE

**VAC ONLY = VACUUM ONLY**
Interlaminar Shear Strength — Those specimens postformed at 450°F and using vacuum only as the postforming pressure comprised the only group to attain higher interlaminar shear strength readings than that of the nonpostformed control group. All other specimen groups had shear strength readings a minimum of 15% under that of the control group. Although 9 out of the 10 specimen groups had shear strength readings less than those of the control group, a trend of decreasing interlaminar shear strength with increasing thermoforming temperature, regardless of postforming pressure, became evident in the data compilation.

3. Task III — Determination of Simulated Repair and Maintenance (R&M) Solvent Effects on Protected and Unprotected Laminates

Composite honeycomb sandwich test specimens were fabricated from thermoformed 2 ply Kevlar 49 style 285 fabric/polysulfone and 2 ply Kevlar 49 type 285 fabric/polyphenylsulfone using 1/2-inch thick Nomex honeycomb as the core material as outlined in Table 2. These specimens were used to determine the solvent resistance of painted and unpainted laminates as described by the effects on their flexure properties (flexural strength and stiffness “El”).

Four-point flex testing of Udel (Polysulfone) and Radel (Polyphenylsulfone) sandwich beams indicates higher overall flexure strength readings with Radel beams than Udel beams by some 14-15% regardless of paint and solvent effects. Conversely, stiffness “El” values are 25-30% higher in the Udel beams than the Radel beams, again ignoring paint and solvent effects.

Realistic exposure (application of a solvent soaked rag for two hours or until dry) had no degrading effects on specimen flexural properties.

4. Task IV — Panel Fabrication

Six (6) 17.75” x 18.0” panels of 5 ply Kevlar 49 style 285 fabric (preimpregnated with P1700 polysulfone using methylene chloride solvent dispersal) were fabricated for testing by AMMRC. One of the six panels is to be used as a control specimen, therefore, it had no postforming operation. Each of the remaining five panels were thermoformed (postformed) at different temperatures (450°F, 500°F, 550°F, 600°F, 650°F), but with the same postforming pressure (Vacuum Plus Light Die Pressure).
**TABLE 2. SOLVENT TESTING MATRIX**

<table>
<thead>
<tr>
<th>COMPOSITE MATERIAL</th>
<th>* CONTROL</th>
<th>MEK</th>
<th>ACETONE</th>
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<tr>
<td></td>
<td>SPECIMEN QTY.</td>
<td>SPECIMEN QTY.</td>
<td>SPECIMEN QTY.</td>
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<tr>
<td>KEVLAR/POLYSULFONE</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>PAINTED</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>UNPAINTED</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>KEVLAR/POLYPHENYL SULFONE</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>PAINTED</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
<tr>
<td>UNPAINTED</td>
<td>3</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

*CONTROL - NO SOLVENT EXPOSURE*
INTRODUCTION

Lightweight composite structure research and development for U.S. Army helicopter applications has centered largely around fiber-reinforced epoxy structures. The raw materials are more expensive than current metallic raw materials and cost parity can only be achieved through reduction in manufacturing costs of the details and assemblies. One promising approach for helicopter structures is the use of reinforced thermoplastics rather than reinforced epoxy, since investigations to date indicate that reduction in fabrication cost may be achieved with little loss in mechanical properties.

This program attempts to define and evaluate the most suitable materials for application of low elongation fiber reinforced thermoplastic laminates to helicopter secondary structures, (adapting low cost commercial techniques currently used for unreinforced, chopped-fiber-reinforced, and high elongation continuous fiber reinforced thermoplastics such as polyesters, acrylics and polycarbonates) by determining the correlation between the mechanical properties of selected fiber-reinforced thermoplastics and processing parameters in variants of vacuum-forming.

This program studies only the mechanical properties aspects of continuous fiber reinforced thermoplastics and not the suitability of the material for thermoforming shapes other than two dimensional forms.
TASK I
LITERATURE REVIEW AND ORAL PRESENTATION

This literature review is organized in the order of: definition of the areas of consideration, general review of base polymer characteristics, review of existing data on low elongation continuous fiber reinforced thermoplastic R&D, and recommendations for current and future material utilization and development.

1. MATERIAL AND FABRICATION CONSIDERATIONS

The areas of interest to this technology include matrix thermoplastic candidate systems, fibrous reinforcements of interest, the processability of component systems into a total material system, and the resulting physical and mechanical properties.

Some of the major attributes sought include low cost of base materials, good chemical resistance to solvents encountered in military helicopter environment and depot maintenance actions, low flammability smoke and toxicity hazard, low energy consumption in laminate consolidation, adaptability to low cost postforming methods, and ability to reprocess formed parts if unsatisfactory. Mechanical properties would be required to compare well with epoxy matrix reinforced with similar fibers.

Matrix Materials

Specific task assignment is the review of matrix resin systems to include those listed below.

- Polysulfone
- Polyphenylsulfone
- PKXA
- Nylon
- Polybutylene Terephthalate

Fibrous Reinforcements

The continuous fiber reinforcements listed below are of specific interest in this technology:

- Kevlar 49 Tape
- Kevlar 49 Fabric
- E-Glass Fabric
- E-Glass Tape
- AS Graphite Tape
- HMS Graphite Tape
- HTS Graphite Tape
- T300 Graphite Tape
- T300 Graphite Fabric
Fabrication Cycle

The fabrication stages outlined below are of specific interest in this fabrication technology:

Preimpregnation Method
Dispersion Coating
Solution Coating
   N-Methyl Pyrrolidone
   Dimethyl Formamide
   Methylene Chloride
   Other
Hot Melt (Film)

Solvent Dispersal/Drying
Cycle Time
Temperature

Consolidation Methods
Temperature Range
Pressure Range
Dwell Time

Thermoforming
Vacuum Forming
Vacuum and Plug
Vacuum and Matched Dies

Material System Properties

The material properties desired after prepregging, consolidating and postforming the reinforced laminates are listed below:

Physical Properties
   Fiber Volume
   Density
   Coefficient of Linear Thermal Expansion
   Heat Distortion Temperature @ 264 psi

Mechanical Properties
   Tensile Strength
   Tensile Modulus
   Compressive Strength
2. GENERAL SCREENING, BASE POLYMERS

Basic polymers and their specific products have been reviewed in a general sense and the advantages and disadvantages of each are noted in Table 3.

3. SPECIFIC DATA SOURCE REVIEW

Previous investigators have selected one or more thermoplastic resin system and reinforced them with one or more continuous fiber reinforcement system and performed processing trials, measured mechanical properties and evaluated the effects of environmental exposure on the mechanical properties. Most of the work has been performed using high pressure post-forming methods.

Matrix Material Evaluations

Materials were reviewed and compared by prior investigators in selecting best candidates for process evaluation and engineering property measurement when reinforced with low elongation continuous fibers. Resins evaluated and systems selected are shown in Table 4, with reasons for rejection, when known.

Matrix/Fiber System Evaluations

The selected candidate matrices have been used in preimpregnation, processing, postforming and mechanical properties evaluation. Material system evaluation results are presented in Table 5.
<table>
<thead>
<tr>
<th>BASE POLYMER</th>
<th>MATERIAL TYPE OR DESIGNATION</th>
<th>PRO</th>
<th>CON</th>
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<tr>
<td>&quot;Styrenics&quot;</td>
<td>ABS</td>
<td>Good Processability</td>
<td>Low Softening Point</td>
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<tr>
<td></td>
<td></td>
<td>Low Cost</td>
<td>Low Strength</td>
</tr>
<tr>
<td></td>
<td>Styrene-Acrylonitrile</td>
<td>Good Processability</td>
<td>Low Softening Point</td>
</tr>
<tr>
<td>Fluorocarbon Polymers</td>
<td>Ethylene-Tetrafluoroethylene</td>
<td>Exceptional Chemical</td>
<td>High Cost (?)</td>
</tr>
<tr>
<td></td>
<td>Copolymer Tefzel 200</td>
<td>Resistance</td>
<td>Creep</td>
</tr>
<tr>
<td>Polyvinylchloride</td>
<td>Rigid PVC</td>
<td>Nonflammable</td>
<td>Low Softening Temperature</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Relatively Low Cost</td>
<td>Solvent Attack by Ketones, Some Chlorinated &amp; Aromatic Compounds, Esters</td>
</tr>
<tr>
<td>Sulfones</td>
<td>Polysulfone Udel</td>
<td>Good Engineering</td>
<td>Attacked by Ketones, Chlorinated and Aromatic Hydrocarbons</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Properties Low Creep</td>
<td>&quot; (Improved)</td>
</tr>
<tr>
<td></td>
<td>Polyphenylsulfone Radel</td>
<td>Good Engineering</td>
<td>Attacked by Ketones, Some Halogenated &amp; Aromatic Hydrocarbons</td>
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<tr>
<td></td>
<td></td>
<td>Properties Low Creep</td>
<td></td>
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<tr>
<td></td>
<td>Polyethersulfone Viltrex</td>
<td>Good Engineering</td>
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<td></td>
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<td>Properties Low Creep</td>
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<tr>
<td></td>
<td>Polyarylsulfone HC3601</td>
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### TABLE 3. GENERAL SCREENING OF BASE POLYMERS – Continued

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<th>Material Type or Designation</th>
<th>Pro</th>
<th>Con</th>
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<tr>
<td>Polyphenylene Sulfide</td>
<td>PPS Ryton</td>
<td>Good Wetting</td>
<td>High Consolidation</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Good Chemical Resistance</td>
<td>Temp (&gt;700°F)</td>
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<tr>
<td></td>
<td></td>
<td>Nonflammable</td>
<td>Difficult to Process</td>
</tr>
<tr>
<td>Polyphenylene Oxide</td>
<td>PPO Noryl</td>
<td>Toughened Polystyrene</td>
<td>Attacked by Chlorinated Hydrocarbon Solvents and Ketones</td>
</tr>
<tr>
<td>Polyamide</td>
<td>Nylon 6/6</td>
<td>Good Chemical Resistance</td>
<td>Reduced High Temperature Properties</td>
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<td></td>
<td>Nylon 6</td>
<td></td>
<td>High Water Absorption</td>
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<td>Nylon 6/10</td>
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<td>Rate and Plasticization</td>
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<td>Nylon 11</td>
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<td>Nylon 12</td>
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<td>Acetal Polymers &amp; Co-Polymers</td>
<td>Acetal Co-Polymer</td>
<td>Good Chemical Resistance</td>
<td>Fiber-Matrix Adhesion Problems</td>
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<td>Celcon M90</td>
<td>Good Mechanical Properties</td>
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<td>Polyolefins</td>
<td>Polyethylene Hostalen</td>
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<td>GRAPHITE</td>
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<td></td>
<td>5-77</td>
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<tr>
<td>REF.</td>
<td>PROJECT CONTRACT</td>
<td>RESIN</td>
<td>FIBER</td>
</tr>
<tr>
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<td>-----------------</td>
<td>-------</td>
<td>-------</td>
</tr>
<tr>
<td>8</td>
<td>AFRTP IND. REVIEW F33615-76-C-3048 7-79</td>
<td>P-1700</td>
<td>&quot;AS&quot; GRAPHITE TAPE 3&quot;, 6&quot;</td>
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<tr>
<td>9</td>
<td>NO0019-77-C-0561 MAY, 1979</td>
<td>POLYPHENYL SULFON PKXA.41 PKXA.517 POLYETHER SULFONE</td>
<td>T300 GRAPHITE FABRIC</td>
</tr>
</tbody>
</table>

**TABLE 5. FIBER/MATRIX SYSTEMS – THERMOPLASTIC INVESTIGATIONS – Continued**
TASK II
ESTABLISH RELATIONSHIP BETWEEN PROCESSING
PARAMETERS AND SELECTED MATERIAL PROPERTIES

Work performed by Boeing Aerospace¹ has identified a strength reduction associated with heating preconsolidated laminates to forming temperatures and forming with vacuum/air assist. Table 1 establishes a test matrix to determine whether a correlation exists between postforming temperature and pressure on consolidated blanks during heat-up and postforming pressure with respect to flexural strength of the resulting laminate. Figure 1 is a photograph showing the attachment of a thermocouple to a 5-ply laminate. Figure 2 is a photograph showing a consolidated blank during the thermoforming process.

Flexural testing was performed in accordance with ASTM D790-71 (reapproved 1978), "Standard Test Methods for Flexural Properties of Plastics and Electrical Insulating Materials", except that four specimens were tested from each laminate for this screening program.

For the required short-beam shear testing, specimens were built up by (250°F cure) film adhesive bonding of three thicknesses (see Appendix "A") and tested in horizontal shear by the standard test method ASTM D2344-76, "Apparent Interlaminar Shear Strength of Parallel Fiber Composites by Short-Beam Method", except that the laminates were prepared for test using the processed postformed material, not ring-type specimens. This approach has been used by previous investigators since NOL rings are not representative of the process.

Four Point Flexural Tests

Flexural testing was accomplished under the standard test procedure stated above in accordance with Method II — a four point loading system utilizing two load points equally spaced from their adjacent support points, with a distance between load points of one third of the support span (Figure 3). All specimens had commonality in these values:

- Fiber orientation: $0^\circ$, $90^\circ$
- Specimen length: 2.0 in. (Nom)
- Specimen width: 0.50 in. ± 0.02
- Support Span: 1.00 in.
- Load Span: 0.33 in.
- Rate of cross lead motion: 0.05 in./Min
- Hexcel Prepreg 5 ply laminate consolidation conditions: 600°F, 100 Psig — for 30 minutes

Results of four point flex testing on 5 ply Kevlar 49 type 285 fabric/polysulfone (P1700) are summarized in Table 6. Individual specimen dimensions and test results are given in Table 7.

When a beam is loaded in flexure at two central points (1/3-span) and supported at two outer points, the maximum stress in the outer fibers occurs between the two central loading points that define the load span. This stress may be calculated for any point on the load-deflection curve for relatively small deflections by the following equation:
Figure 1. Kevlar 49/Polyethylene Consolidated Blank, With Thermocouple
Figure 3. Four-Point Loading System for Flexural Testing of 5-Ply Laminate
<table>
<thead>
<tr>
<th>Specimens Group I.D. Qty</th>
<th>Postforming Temp (^\circ)F</th>
<th>Postforming Pressure VAC (2)</th>
<th>Postforming Pressure VLDP (3)</th>
<th>Flexural Strength (psi) Group Avg (\sigma) (4)</th>
<th>Modulus (psi (\times 10^6)) Group Avg (\sigma) (4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>4</td>
<td>NO POSTFORMING</td>
<td></td>
<td>43453</td>
<td>2379</td>
</tr>
<tr>
<td>1</td>
<td>4</td>
<td>450</td>
<td>X</td>
<td>47402</td>
<td>728</td>
</tr>
<tr>
<td>2</td>
<td>4</td>
<td>500</td>
<td>X</td>
<td>38031</td>
<td>4391</td>
</tr>
<tr>
<td>3</td>
<td>4</td>
<td>550</td>
<td>X</td>
<td>32745</td>
<td>4768</td>
</tr>
<tr>
<td>4</td>
<td>4</td>
<td>600</td>
<td>X</td>
<td>30404</td>
<td>7467</td>
</tr>
<tr>
<td>5</td>
<td>4</td>
<td>650</td>
<td>X</td>
<td>26787</td>
<td>4563</td>
</tr>
<tr>
<td>6</td>
<td>4</td>
<td>450</td>
<td>X</td>
<td>43575</td>
<td>1270</td>
</tr>
<tr>
<td>7</td>
<td>4</td>
<td>500</td>
<td>X</td>
<td>39900</td>
<td>1919</td>
</tr>
<tr>
<td>8</td>
<td>4</td>
<td>550</td>
<td>X</td>
<td>29981</td>
<td>12891</td>
</tr>
<tr>
<td>9</td>
<td>6</td>
<td>600</td>
<td>X</td>
<td>28664</td>
<td>2590</td>
</tr>
<tr>
<td>10</td>
<td>4</td>
<td>650</td>
<td>X</td>
<td>29358</td>
<td>6585</td>
</tr>
</tbody>
</table>

(1) All testing was done at room temperature.
(2) VAC = Vacuum Pressure Only.
(3) VLDP = Vacuum Plus Light Die Pressure.
(4) \(\sigma\) = Standard Deviation (with N-1 weighting).
\[ S = \frac{PL}{bd^2} \]

where:
- \( S \) = stress in the outer fiber throughout load span (psi)
- \( P \) = load at a given point on the load-deflection curve (Lbf)
- \( L \) = support span (in.)
- \( b \) = width of beam (in.)
- \( d \) = depth of beam (in.)

The tangent modulus of elasticity is the ratio, within the elastic limit of stress to corresponding strain and will be expressed in pounds per square inch. It is calculated by drawing a tangent to the steepest initial straight-line portion of the load-deflection curve and using the following equation:

\[ E_b = 0.21L^3m/bd^3 \]

where:
- \( E_b \) = modulus of elasticity in bending (psi)
- \( L \) = support span (in.)
- \( b \) = width of beam (in.)
- \( d \) = depth of beam (in.)
- \( m \) = slope of the tangent to the initial straight-line portion of the load-deflection curve, lb/in. of deflection.

Shown in Figure 4 are photographs of thermoforming molds used in the postforming of consolidated Kevlar 49/Polysulfone blanks.

Figure 5 is a photograph showing the finished blank number 10 after the postforming process, with water-jet cutting lines marked on it. All testing in Task II for specimens processed under these postforming conditions (650°F and vacuum plus light die pressure) were cut from the blank shown in Figure 5.
Figure 6. Flexural Strength vs Thermoforming Temperature
Figure 7. Flexural Stiffness vs Thermoforming Temperature
### TABLE 7. FOUR POINT FLEX TEST – THERMOPLASTIC

**SPECIMEN BREAKDOWN**

Specimen Group — Control  
No Postforming Operation  
Tested per ASTM D790,

| Specimen Group — Control | Specimen Length = 2.0 in.  
| Support Span = 1.0 in.  
| Load Span = 0.33 in.  
| Rate of Cross Head Motion = 0.05 in./min  
| 5 Ply Laminated Kevlar 49  
| Style 285 Fabric/P1700 Polysulfone |

---

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>t (in.)</th>
<th>w (in.)</th>
<th>Max Deflection Before Load Dropoff (in.)</th>
<th>Max Load (lbs)</th>
<th>Strength (psi)</th>
<th>Modulus (psi x 10^6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-1</td>
<td>0.039</td>
<td>0.5110</td>
<td>0.15</td>
<td>32</td>
<td>41,172</td>
<td>3.05</td>
</tr>
<tr>
<td>C-2</td>
<td>0.039</td>
<td>0.5158</td>
<td>VOID</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>C-3</td>
<td>0.040</td>
<td>0.5158</td>
<td>0.125</td>
<td>36</td>
<td>43,622</td>
<td>3.56</td>
</tr>
<tr>
<td>C-4</td>
<td>0.039</td>
<td>0.5210</td>
<td>0.15</td>
<td>36</td>
<td>46,691</td>
<td>3.62</td>
</tr>
<tr>
<td>C-5</td>
<td>0.041</td>
<td>0.5200</td>
<td>0.125</td>
<td>37</td>
<td>42,328</td>
<td>3.91</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Avg</th>
<th></th>
<th></th>
<th>Average</th>
<th>43,453</th>
<th>3.54</th>
</tr>
</thead>
<tbody>
<tr>
<td>σ*</td>
<td></td>
<td></td>
<td>Standard Deviation (with N-1 weighting)</td>
<td>2,379</td>
<td>0.36</td>
</tr>
</tbody>
</table>

*σ* = Standard Deviation (with N-1 weighting)
<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>t (in.)</th>
<th>w (in.)</th>
<th>Max Deflection Before Load Dropoff (in.)</th>
<th>Max Load (lbs)</th>
<th>Strength (psi)</th>
<th>Modulus (psi x 10^6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-1</td>
<td>0.044</td>
<td>0.5178</td>
<td>0.1375</td>
<td>47</td>
<td>46,885</td>
<td>4.19</td>
</tr>
<tr>
<td>1-2</td>
<td>0.044</td>
<td>0.5202</td>
<td>0.125</td>
<td>47</td>
<td>46,668</td>
<td>4.17</td>
</tr>
<tr>
<td>1-3</td>
<td>0.043</td>
<td>0.5180</td>
<td>0.1375</td>
<td>46</td>
<td>48,028</td>
<td>N/A</td>
</tr>
<tr>
<td>1-4</td>
<td>0.043</td>
<td>0.5190</td>
<td>VOID</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1-5</td>
<td>0.043</td>
<td>0.5180</td>
<td>0.1375</td>
<td>46</td>
<td>48,028</td>
<td>4.08</td>
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<tr>
<td>Avg</td>
<td></td>
<td></td>
<td></td>
<td></td>
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<td>4.15</td>
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<tr>
<td>σ*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>728</td>
<td>0.06</td>
</tr>
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</table>

*σ = Standard Deviation (with N-1 weighting)
TABLE 7. FOUR POINT FLEX TEST – THERMOPLASTIC
SPECIMEN BREAKDOWN (Continued)

Specimen Group – No. 2
500°F, Vacuum Only
Specimen Length = 2.0 in.
Tested per ASTM D790,
Support Span = 1.0 in.
Rate of Cross Head Motion = 0.05 in./min
Load Span = 0.33 in.
5 Ply Laminated Kevlar 49
Style 285 Fabric/P1700 Polysulfone

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>t (in.)</th>
<th>w (in.)</th>
<th>Max Deflection Before Load Dropoff (in.)</th>
<th>Max Load (lbs)</th>
<th>Strength (psi)</th>
<th>Modulus (psi x 10^6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-1</td>
<td>0.043</td>
<td>0.5210</td>
<td>0.125</td>
<td>40</td>
<td>41,523</td>
<td>4.46</td>
</tr>
<tr>
<td>2-2</td>
<td>0.043</td>
<td>0.5242</td>
<td>0.150</td>
<td>38</td>
<td>38,206</td>
<td>4.84</td>
</tr>
<tr>
<td>2-3</td>
<td>0.043</td>
<td>0.5234</td>
<td>0.125</td>
<td>38.5</td>
<td>39,782</td>
<td>4.84</td>
</tr>
<tr>
<td>2-4</td>
<td>0.043</td>
<td>0.5218</td>
<td>0.175</td>
<td>30.5</td>
<td>31,613</td>
<td>4.45</td>
</tr>
</tbody>
</table>

Avg 38,031 4.65

\( \sigma^* \) = Standard Deviation (with N-1 weighting)
TABLE 7. FOUR POINT FLEX TEST — THERMOPLASTIC
SPECIMEN BREAKDOWN (Continued)

Specimen Group — No. 3
550°F, Vacuum Only
Tested per ASTM D790,

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>t (in.)</th>
<th>w (in.)</th>
<th>Max Deflection Before Load Dropoff (in.)</th>
<th>Max Load (lbs)</th>
<th>Strength (psi)</th>
<th>Modulus (psi x 10^6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-1</td>
<td>0.044</td>
<td>0.5078</td>
<td>0.100</td>
<td>26</td>
<td>26,447</td>
<td>3.73</td>
</tr>
<tr>
<td>3-2</td>
<td>0.043</td>
<td>0.5092</td>
<td>0.125</td>
<td>32</td>
<td>33,988</td>
<td>4.40</td>
</tr>
<tr>
<td>3-3</td>
<td>0.043</td>
<td>0.5132</td>
<td>0.125</td>
<td>36</td>
<td>37,938</td>
<td>4.94</td>
</tr>
<tr>
<td>3-4</td>
<td>0.043</td>
<td>0.5142</td>
<td>0.1125</td>
<td>31</td>
<td>32,606</td>
<td>4.93</td>
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</table>

<table>
<thead>
<tr>
<th></th>
<th>Avg</th>
<th>32,645</th>
<th>4.51</th>
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<tbody>
<tr>
<td>σ*</td>
<td>4,768</td>
<td>0.59</td>
<td></td>
</tr>
</tbody>
</table>

*σ = Standard Deviation (with N-1 weighting)
TABLE 7. FOUR POINT FLEX TEST — THERMOPLASTIC
SPECIMEN BREAKDOWN (Continued)

Specimen Group — No. 4
600°F, Vacuum Only
Tested per ASTM D790,

Specimen Length = 2.0 in.
Support Span = 1.0 in.
Load Span = 0.33 in.
Rate of Cross Head Motion = 0.05 in./min
5 Ply Laminated Kevlar 49
Style 285 Fabric/P1700 Polysulfone

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>t (in.)</th>
<th>w (in.)</th>
<th>Max Deflection Before Load Dropoff (in.)</th>
<th>Max Load (lbs)</th>
<th>Strength (psi)</th>
<th>Modulus (psi x 10^6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4–1</td>
<td>0.047</td>
<td>0.5180</td>
<td>0.100</td>
<td>22</td>
<td>19,226</td>
<td>3.44</td>
</tr>
<tr>
<td>4–2</td>
<td>0.046</td>
<td>0.5180</td>
<td>0.1125</td>
<td>38</td>
<td>34,669</td>
<td>3.33</td>
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<tr>
<td>4–3</td>
<td>0.047</td>
<td>0.5160</td>
<td>0.100</td>
<td>39</td>
<td>34,215</td>
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<tr>
<td>4–4</td>
<td>0.047</td>
<td>0.5202</td>
<td>0.125</td>
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<td>33,504</td>
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</tr>
<tr>
<td>Avg</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>30,404</td>
<td>3.3</td>
</tr>
<tr>
<td>σ*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>7,467</td>
<td>0.12</td>
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</tbody>
</table>

*σ* = Standard Deviation (with N-1 weighting)
TABLE 7. FOUR POINT FLEX TEST – THERMOPLASTIC
SPECIMEN BREAKDOWN (Continued)

Specimen Group — No. 5
650°F, Vacuum Only
Tested per ASTM D790,

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>t (in.)</th>
<th>w (in.)</th>
<th>Max Deflection Before Load Dropoff (in.)</th>
<th>Max Load (lbs)</th>
<th>Strength (psi)</th>
<th>Modulus (psi x 10^6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5–1</td>
<td>0.054</td>
<td>0.5098</td>
<td>0.100</td>
<td>49</td>
<td>32,962</td>
<td>2.02</td>
</tr>
<tr>
<td>5–2</td>
<td>0.052</td>
<td>0.5070</td>
<td>0.0875</td>
<td>31</td>
<td>22,612</td>
<td>2.22</td>
</tr>
<tr>
<td>5–3</td>
<td>0.052</td>
<td>0.5138</td>
<td>0.100</td>
<td>38</td>
<td>27,352</td>
<td>2.79</td>
</tr>
<tr>
<td>5–4</td>
<td>0.053</td>
<td>0.5144</td>
<td>0.100</td>
<td>35</td>
<td>24,222</td>
<td>2.11</td>
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</table>

Avg  26,787  2.29

\( \sigma^* \)  4,563  0.35

\( \sigma^* \) = Standard Deviation (with N-1 weighting)
<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>t (in.)</th>
<th>w (in.)</th>
<th>Max Deflection Before Load Dropoff (in.)</th>
<th>Max Load (lbs)</th>
<th>Strength (psi)</th>
<th>Modulus (psi x 10^6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6-1</td>
<td>0.051</td>
<td>0.5114</td>
<td>0.125</td>
<td>57</td>
<td>42,852</td>
<td>3.47</td>
</tr>
<tr>
<td>6-2</td>
<td>0.052</td>
<td>0.5120</td>
<td>0.100</td>
<td>58.5</td>
<td>42,255</td>
<td>3.41</td>
</tr>
<tr>
<td>6-3</td>
<td>0.054</td>
<td>0.5132</td>
<td>0.100</td>
<td>66</td>
<td>44,103</td>
<td>3.38</td>
</tr>
<tr>
<td>6-4</td>
<td>0.053</td>
<td>0.5132</td>
<td>0.100</td>
<td>65</td>
<td>45,090</td>
<td>3.30</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Avg</th>
<th>43,575</th>
<th>3.39</th>
</tr>
</thead>
<tbody>
<tr>
<td>σ*</td>
<td>1,270</td>
<td>0.07</td>
<td></td>
</tr>
</tbody>
</table>

*σ = Standard Deviation (with N-1 weighting)
TABLE 7. FOUR POINT FLEX TEST — THERMOPLASTIC
SPECIMEN BREAKDOWN (Continued)

Specimen Group — No. 7
500°F, Vacuum Plus Light Die Pressure
Tested per ASTM D790,

<table>
<thead>
<tr>
<th>Specimen Group</th>
<th>Specimen Length = 2.0 in.</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Support Span = 1.0 in.</td>
</tr>
<tr>
<td></td>
<td>Load Span = 0.33 in.</td>
</tr>
<tr>
<td></td>
<td>Rate of Cross Head Motion = 0.05 in./min</td>
</tr>
<tr>
<td></td>
<td>5 Ply Laminated Kevlar 49</td>
</tr>
<tr>
<td></td>
<td>Style 285 Fabric/P1700 Polysulfone</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Specimen</th>
<th>t (in.)</th>
<th>w (in.)</th>
<th>Max Deflection Before Load Dropoff (in.)</th>
<th>Max Load (lbs)</th>
<th>Strength (psi)</th>
<th>Modulus (psi x 10^6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7–1</td>
<td>0.043</td>
<td>0.5074</td>
<td>0.1375</td>
<td>39.5</td>
<td>42,103</td>
<td>4.16</td>
</tr>
<tr>
<td>7–2</td>
<td>0.043</td>
<td>0.5140</td>
<td>0.125</td>
<td>36.5</td>
<td>38,405</td>
<td>4.11</td>
</tr>
<tr>
<td>7–3</td>
<td>0.043</td>
<td>0.5156</td>
<td>0.1375</td>
<td>39</td>
<td>40,909</td>
<td>3.93</td>
</tr>
<tr>
<td>7–4</td>
<td>0.043</td>
<td>0.5170</td>
<td>0.100</td>
<td>36.5</td>
<td>38,183</td>
<td>N/A</td>
</tr>
</tbody>
</table>

Avg |

| 39,900 | 4.07 |

σ* | 1,919 | 0.12 |

*σ  = Standard Deviation (with N-1 weighting)
TABLE 7. FOUR POINT FLEX TEST — THERMOPLASTIC
SPECIMEN BREAKDOWN (Continued)

Specimen Group — No. 8
550°F, Vacuum Plus Light Die Pressure
Tested per ASTM D790,
Specimen Length = 2.0 in.
Support Span = 1.0 in.
Load Span = 0.33 in.
Rate of Cross Head Motion = 0.05 in./min
5 Ply Laminated Kevlar 49
Style 285 Fabric/P1700 Polysulfone

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>t (in.)</th>
<th>w (in.)</th>
<th>Max Deflection Before Load Dropoff (in.)</th>
<th>Max Load (lbs)</th>
<th>Strength (psi)</th>
<th>Modulus (psi x 10^6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8-1</td>
<td>0.040</td>
<td>0.5100</td>
<td>0.1375</td>
<td>39.5</td>
<td>48,407</td>
<td>3.69</td>
</tr>
<tr>
<td>8-2</td>
<td>0.042</td>
<td>0.5100</td>
<td>VOID</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>8-3</td>
<td>0.043</td>
<td>0.5156</td>
<td>0.100</td>
<td>28</td>
<td>28,370</td>
<td>4.10</td>
</tr>
<tr>
<td>8-4</td>
<td>0.045</td>
<td>0.5170</td>
<td>0.075</td>
<td>22</td>
<td>21,014</td>
<td>N/A</td>
</tr>
<tr>
<td>8-5</td>
<td>0.045</td>
<td>0.5164</td>
<td>0.100</td>
<td>22.1</td>
<td>21,134</td>
<td>3.21</td>
</tr>
</tbody>
</table>

|              | Avg     | 29,981  | 3.67                                   |
|              | σ*      | 12,891  | 0.63                                   |

*σ = Standard Deviation (with N-1 weighting)
TABLE 7.  FOUR POINT FLEX TEST – THERMOPLASTIC  
SPECIMEN BREAKDOWN (Continued)

Specimen Group — No. 9  
600°F, Vacuum Plus Light Die Pressure  
Tested per ASTM D790,  
Specimen Length = 2.0 in.  
Support Span = 1.0 in.  
Load Span = 0.33 in.  
Rate of Cross Head Motion = 0.05 in./min  
5 Ply Laminated Kevlar 49  
Style 285 Fabric/P1700 Polysulfone

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>t (in.)</th>
<th>w (in.)</th>
<th>Max Deflection Before Load Dropoff (in.)</th>
<th>Max Load (lbs)</th>
<th>Strength (psi)</th>
<th>Modulus (psi x 10^6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9-1</td>
<td>0.044</td>
<td>0.5100</td>
<td>0.100</td>
<td>32</td>
<td>32,410</td>
<td>3.79</td>
</tr>
<tr>
<td>9-2</td>
<td>0.044</td>
<td>0.5082</td>
<td>0.100</td>
<td>28</td>
<td>28,459</td>
<td>3.88</td>
</tr>
<tr>
<td>9-3</td>
<td>0.045</td>
<td>0.5086</td>
<td>0.125</td>
<td>30</td>
<td>29,129</td>
<td>3.62</td>
</tr>
<tr>
<td>9-4</td>
<td>0.047</td>
<td>0.5090</td>
<td>0.100</td>
<td>28</td>
<td>24,903</td>
<td>3.18</td>
</tr>
<tr>
<td>9-5</td>
<td>0.046</td>
<td>0.5086</td>
<td>0.070</td>
<td>29</td>
<td>26,947</td>
<td>3.39</td>
</tr>
<tr>
<td>9-6</td>
<td>0.045</td>
<td>0.5080</td>
<td>0.100</td>
<td>31</td>
<td>30,135</td>
<td>3.99</td>
</tr>
</tbody>
</table>

Avg          | 0.045   | 0.5083  | 0.100                                  | 28,664         | 3.64           |                      |

σ*           | 2,590   | 0.31    |                                        |                |                |                      |

*σ = Standard Deviation (with N-1 weighting)
TABLE 7. FOUR POINT FLEX TEST — THERMOPLASTIC
SPECIMEN BREAKDOWN (Continued)

<table>
<thead>
<tr>
<th>Specimen Group — No. 10</th>
<th>Specimen Length = 2.0 in.</th>
</tr>
</thead>
<tbody>
<tr>
<td>650°F, Vacuum Plug Light Die Pressure</td>
<td>Support Span = 1.0 in.</td>
</tr>
<tr>
<td>Tested per ASTM D790,</td>
<td>Load Span = 0.33 in.</td>
</tr>
<tr>
<td></td>
<td>Rate of Cross Head Motion = 0.05 in./min</td>
</tr>
<tr>
<td></td>
<td>5 Ply Laminated Kevlar 49</td>
</tr>
<tr>
<td></td>
<td>Style 285 Fabric/P1700 Polysulfone</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>t (in.)</th>
<th>w (in.)</th>
<th>Max Deflection Before Load Dropoff (in.)</th>
<th>Max Load (lbs)</th>
<th>Strength (psi)</th>
<th>Modulus (psi x 10^6)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10–1</td>
<td>0.040</td>
<td>0.5112</td>
<td>0.175</td>
<td>32</td>
<td>39,124</td>
<td>3.59</td>
</tr>
<tr>
<td>10–2</td>
<td>0.043</td>
<td>0.5114</td>
<td>0.0875</td>
<td>26</td>
<td>27,496</td>
<td>3.14</td>
</tr>
<tr>
<td>10–3</td>
<td>0.043</td>
<td>0.5118</td>
<td>0.100</td>
<td>24</td>
<td>25,361</td>
<td>3.14</td>
</tr>
<tr>
<td>10–4</td>
<td>0.043</td>
<td>0.5100</td>
<td>0.100</td>
<td>24</td>
<td>25,451</td>
<td>3.23</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Avg</th>
<th>29,358</th>
<th>3.3</th>
</tr>
</thead>
<tbody>
<tr>
<td>σ*</td>
<td>6,585</td>
<td>0.21</td>
</tr>
</tbody>
</table>

*σ = Standard Deviation (with N-1 weighting)
Horizontal Shear Tests

The horizontal shear test specimen is center-loaded as shown in Figure 8. The specimen ends rest on two supports which allow lateral motion, the load being applied by means of a loading nose directly centered on the midpoint of the test specimen. Although the apparent shear strength obtained by this method cannot be used as a design criteria, it can be utilized for comparative testing of composite materials. This apparent shear strength may be calculated by the following equation:

\[ S_H = 0.75 \frac{P_B}{bd} \]

where:
- \( S_H \) = shear strength (psi)
- \( P_B \) = breaking load (lbF)
- \( b \) = width of specimen (in.)
- \( d \) = thickness of specimen (in.)

The horizontal shear test specimens were fabricated utilizing 3M AF163 film adhesive (250°F cure) to “stack-up” three five-ply laminates of Kevlar 49, Style 285 fabric/P1700 polysulfone with the fiber orientation being in the 0°, 90° direction (see Appendix A). This three-laminate “stack-up” procedure was accomplished subsequent to the five-ply laminate thermoforming (postforming) operation. Other areas common to all specimens were:

- Specimen width: 0.250 ± 0.010
- Specimen length: 7 x thickness, as prescribed by (3)
- Support span: 5 x thickness, as prescribed by (3)
- Rate of crosshead motion: 0.05 in./Min
- Hexcel prepreg 5-ply laminate consolidation conditions: 600°F, 100 PSIG — for 30 minutes

Results of three point interlaminar shear tests are summarized in Table 8. Individual specimen dimensions, and test results are given in Table 9. NOTE: Not all specimens exhibited the classical midthickness horizontal shear failure mode; however, a comparison of the maximum load levels achieved by those that did fail in the classical manner with the maximum load levels achieved by those specimens that did not exhibit the classical failure mode, demonstrates values commensurate with each other. Therefore, it is assumed that all failures are valid interlaminar shear failures. Prior experience with Kevlar fabrics with epoxy and thermoplastic resins also has demonstrated similar nonclassical failure modes.
Figure 8. Three Point Loading System for Interlaminar Shear Testing
### TABLE 8. THREE POINT INTERLAMINAR SHEAR TEST (4) — SUMMARY

<table>
<thead>
<tr>
<th>Specimens Group I.D.</th>
<th>Qty</th>
<th>Postforming Temp (°F)</th>
<th>Postforming Pressure VAC (1)</th>
<th>VLDP (2)</th>
<th>Interlaminar Shear Strength (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Control</td>
<td>5</td>
<td>No Postforming</td>
<td></td>
<td></td>
<td>2217</td>
</tr>
<tr>
<td>1</td>
<td>5</td>
<td>450</td>
<td>X</td>
<td></td>
<td>2469</td>
</tr>
<tr>
<td>2</td>
<td>5</td>
<td>500</td>
<td>X</td>
<td></td>
<td>1719</td>
</tr>
<tr>
<td>3</td>
<td>5</td>
<td>550</td>
<td>X</td>
<td></td>
<td>1655</td>
</tr>
<tr>
<td>4</td>
<td>5</td>
<td>600</td>
<td>X</td>
<td></td>
<td>1357</td>
</tr>
<tr>
<td>5</td>
<td>5</td>
<td>650</td>
<td>X</td>
<td></td>
<td>1917</td>
</tr>
<tr>
<td>5A</td>
<td>5</td>
<td>650</td>
<td>X</td>
<td></td>
<td>1799</td>
</tr>
<tr>
<td>6</td>
<td>5</td>
<td>450</td>
<td>X</td>
<td></td>
<td>1725</td>
</tr>
<tr>
<td>6A</td>
<td>6</td>
<td>450</td>
<td>X</td>
<td></td>
<td>1835</td>
</tr>
<tr>
<td>7</td>
<td>5</td>
<td>500</td>
<td>X</td>
<td></td>
<td>1851</td>
</tr>
<tr>
<td>8</td>
<td>5</td>
<td>550</td>
<td>X</td>
<td></td>
<td>1547</td>
</tr>
<tr>
<td>9</td>
<td>5</td>
<td>600</td>
<td>X</td>
<td></td>
<td>1441</td>
</tr>
<tr>
<td>10</td>
<td>5</td>
<td>650</td>
<td>X</td>
<td></td>
<td>1438</td>
</tr>
</tbody>
</table>

(1) \( \text{VAC} = \text{Vacuum Pressure Only.} \)
(2) \( \text{VLDP} = \text{Vacuum Plus Light Die Pressure.} \)
(3) \( \sigma = \text{Standard Deviation (with N-1 weighting).} \)
(4) All testing was done at room temperature.

**NOTE** — Strength values exhibited herein are to be used for comparative purposes only and not as design criteria.
3-PT ILS TEST 5-PLY LAMINATE – 3 LAMINATE STACKUP (USING FM163 FILM ADHESIVE)
ASTM D2344-76 KEVLAR 49 STYLE 285 FABRIC
POLYSULFONE THERMOPLASTIC

![Graph](image)

**Figure 9.** Interlaminar Shear Strengths vs Thermoforming Temperature

**NOTE:** USE FOR COMPARATIVE PURPOSES ONLY, NOT DESIGN CRITERIA
TABLE 9. THREE POINT INTERLAMINAR SHEAR TEST
SPECIMEN BREAKDOWN

Specimen Group — CONTROL
(No Thermoforming)

Tested Per ASTM D2344-76:
Recommended Support Span = 5t
Recommended Specimen Length = 7t
Recommended Rate of Cross Head Motion = 0.05 in./min

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>t (in.)</th>
<th>w (in.)</th>
<th>Load (lbf)</th>
<th>Shear Strength (psi) (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-1</td>
<td>0.133</td>
<td>0.255</td>
<td>95</td>
<td>2101</td>
</tr>
<tr>
<td>C-2</td>
<td>0.132</td>
<td>0.256</td>
<td>101</td>
<td>2242</td>
</tr>
<tr>
<td>C-3</td>
<td>0.132</td>
<td>0.254</td>
<td>99</td>
<td>2215</td>
</tr>
<tr>
<td>C-4</td>
<td>0.132</td>
<td>0.257</td>
<td>100</td>
<td>2211</td>
</tr>
<tr>
<td>C-5</td>
<td>0.132</td>
<td>0.255</td>
<td>104</td>
<td>2317</td>
</tr>
</tbody>
</table>

Avg          | 2217    |
σ*           | 77.65   |

*σ = Standard Deviation (with N-1 weighting)

(1) NOTE: Use for comparative purposes only, not design criteria.
TABLE 9. THREE POINT INTERLAMINAR SHEAR TEST
SPECIMEN BREAKDOWN (Continued)

Specimen Group — NO. 1
450°F, Vacuum Pressure Only

Tested Per ASTM D2344-76:
Recommended Support Span = 5t
Recommended Specimen Length = 7t
Recommended Rate of Cross Head
Motion = 0.05 in./min

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>t (in.)</th>
<th>w (in.)</th>
<th>Load (lb)</th>
<th>Shear Strength (psi) (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-1</td>
<td>0.130</td>
<td>0.254</td>
<td>107</td>
<td>2430</td>
</tr>
<tr>
<td>1-2</td>
<td>0.130</td>
<td>0.254</td>
<td>108</td>
<td>2453</td>
</tr>
<tr>
<td>1-3</td>
<td>0.131</td>
<td>0.254</td>
<td>112</td>
<td>2524</td>
</tr>
<tr>
<td>1-4</td>
<td>0.131</td>
<td>0.249</td>
<td>108</td>
<td>2483</td>
</tr>
<tr>
<td>1-5</td>
<td>0.131</td>
<td>0.254</td>
<td>109</td>
<td>2457</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Avg</th>
<th></th>
<th></th>
<th></th>
<th>2469</th>
</tr>
</thead>
<tbody>
<tr>
<td>σ*</td>
<td></td>
<td></td>
<td></td>
<td>35.85</td>
</tr>
</tbody>
</table>

*σ = Standard Deviation (with N-1 weighting)

(1) NOTE: Use for comparative purposes only, not design criteria.
TABLE 9. THREE POINT INTERLAMINAR SHEAR TEST
SPECIMEN BREAKDOWN (Continued)

Specimen Group — NO. 2
500°F, Vacuum Pressure Only

Tested Per ASTM D2344-76:
Recommended Support Span = 5t
Recommended Specimen Length = 7t
Recommended Rate of Cross Head Motion = 0.05 in./min

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>t (in.)</th>
<th>w (in.)</th>
<th>Load (lbf)</th>
<th>Shear Strength (psi) (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-1</td>
<td>0.133</td>
<td>0.255</td>
<td>79</td>
<td>1747</td>
</tr>
<tr>
<td>2-2</td>
<td>0.134</td>
<td>0.255</td>
<td>78</td>
<td>1712</td>
</tr>
<tr>
<td>2-3</td>
<td>0.134</td>
<td>0.256</td>
<td>78</td>
<td>1705</td>
</tr>
<tr>
<td>2-4</td>
<td>0.134</td>
<td>0.254</td>
<td>76</td>
<td>1675</td>
</tr>
<tr>
<td>2-5</td>
<td>0.134</td>
<td>0.255</td>
<td>80</td>
<td>1756</td>
</tr>
</tbody>
</table>

Avg 1719  
σ* 32.92

σ = Standard Deviation (with N-1 weighting)

(1) NOTE: Use for comparative purposes only, not design criteria.
TABLE 9. THREE POINT INTERLAMINAR SHEAR TEST
SPECIMEN BREAKDOWN (Continued)

Specimen Group — NO. 3
550°F, Vacuum Pressure Only

Tested Per ASTM D2344-76:
Recommended Support Span = 5t
Recommended Specimen Length = 7t
Recommended Rate of Cross Head Motion = 0.05 in./min

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>t (in.)</th>
<th>w (in.)</th>
<th>Load (lbf)</th>
<th>Shear Strength (psi) (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3-1</td>
<td>0.133</td>
<td>0.254</td>
<td>75</td>
<td>1665</td>
</tr>
<tr>
<td>3-2</td>
<td>0.134</td>
<td>0.254</td>
<td>74</td>
<td>1631</td>
</tr>
<tr>
<td>3-3</td>
<td>0.134</td>
<td>0.249</td>
<td>74</td>
<td>1663</td>
</tr>
<tr>
<td>3-4</td>
<td>0.134</td>
<td>0.253</td>
<td>74</td>
<td>1637</td>
</tr>
<tr>
<td>3-5</td>
<td>0.136</td>
<td>0.253</td>
<td>77</td>
<td>1678</td>
</tr>
</tbody>
</table>

Avg                  | 1655
σ*                  | 19.96

*σ = Standard Deviation (with N-1 weighting)

(1) NOTE: Use for comparative purposes only, not design criteria.
### TABLE 9. THREE POINT INTERLAMINAR SHEAR TEST  
SPECIMEN BREAKDOWN (Continued)

Specimen Group — NO. 4  
600°F, Vacuum Pressure Only

Tested Per ASTM D2344-76:  
Recommended Support Span = 5t  
Recommended Specimen Length = 7t  
Recommended Rate of Cross Head Motion = 0.05 in./min

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>t (in.)</th>
<th>w (in.)</th>
<th>Load (lbf)</th>
<th>Shear Strength (psi) (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-1</td>
<td>0.141</td>
<td>0.255</td>
<td>61</td>
<td>1272</td>
</tr>
<tr>
<td>4-2</td>
<td>0.141</td>
<td>0.256</td>
<td>65</td>
<td>1351</td>
</tr>
<tr>
<td>4-3</td>
<td>0.141</td>
<td>0.256</td>
<td>67</td>
<td>1392</td>
</tr>
<tr>
<td>4-4</td>
<td>0.140</td>
<td>0.255</td>
<td>68</td>
<td>1429</td>
</tr>
<tr>
<td>4-5</td>
<td>0.140</td>
<td>0.256</td>
<td>64</td>
<td>1339</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Avg</th>
<th></th>
<th></th>
<th></th>
<th>1357</th>
</tr>
</thead>
<tbody>
<tr>
<td>σ*</td>
<td></td>
<td></td>
<td></td>
<td>59.15</td>
</tr>
</tbody>
</table>

*σ = Standard Deviation (with N-1 weighting)

(1) NOTE: Use for comparative purposes only, not design criteria.
### TABLE 9. THREE POINT INTERLAMINAR SHEAR TEST SPECIMEN BREAKDOWN (Continued)

Specimen Group — NO. 5  
650°F, Vacuum Pressure Only

Tested Per ASTM D2344-76:
Recommended Support Span = 5t  
Recommended Specimen Length = 7t  
Recommended Rate of Cross Head Motion = 0.05 in./min

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>t (in.)</th>
<th>w (in.)</th>
<th>Load (lbf)</th>
<th>Shear Strength (psi) (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5-1</td>
<td>0.164</td>
<td>0.257</td>
<td>104</td>
<td>1851</td>
</tr>
<tr>
<td>5-2</td>
<td>0.164</td>
<td>0.257</td>
<td>98</td>
<td>1744</td>
</tr>
<tr>
<td>5-3</td>
<td>0.165</td>
<td>0.254</td>
<td>118</td>
<td>2112</td>
</tr>
<tr>
<td>5-4</td>
<td>0.163</td>
<td>0.256</td>
<td>121</td>
<td>2175</td>
</tr>
<tr>
<td>5-5</td>
<td>0.163</td>
<td>0.257</td>
<td>95</td>
<td>1701</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Avg</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1917</td>
<td></td>
</tr>
</tbody>
</table>

$\sigma^*$ 215.37

$\sigma^*$ = Standard Deviation (with N-1 weighting)

(1) NOTE: Use for comparative purposes only, not design criteria.
Table 9. Three Point Interlaminar Shear Test
Specimen Breakdown (Continued)

Specimen Group — NO. 5A
650°F, Vacuum Pressure Only

Tested Per ASTM D2344-76:
Recommended Support Span = 5t
Recommended Specimen Length = 7t
Recommended Rate of Cross Head Motion = 0.05 in./min

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>t (in.)</th>
<th>w (in.)</th>
<th>Load (lbf)</th>
<th>Shear Strength (psi) (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5A–1</td>
<td>0.156</td>
<td>0.260</td>
<td>93</td>
<td>1720</td>
</tr>
<tr>
<td>5A–2</td>
<td>0.156</td>
<td>0.259</td>
<td>98</td>
<td>1819</td>
</tr>
<tr>
<td>5A–3</td>
<td>0.156</td>
<td>0.259</td>
<td>95</td>
<td>1763</td>
</tr>
<tr>
<td>5A–4</td>
<td>0.155</td>
<td>0.255</td>
<td>VOID</td>
<td></td>
</tr>
<tr>
<td>5A–5</td>
<td>0.156</td>
<td>0.258</td>
<td>97</td>
<td>1808</td>
</tr>
<tr>
<td>5A–6</td>
<td>0.157</td>
<td>0.256</td>
<td>101</td>
<td>1885</td>
</tr>
</tbody>
</table>

Avg                      1799
σ*                      62.0

*σ = Standard Deviation (with N-1 weighting)

(1) NOTE: Use for comparative purposes only, not design criteria.
TABLE 9. THREE POINT INTERLAMINAR SHEAR TEST
SPECIMEN BREAKDOWN (Continued)

Specimen Group — NO. 6
450°F, Vacuum Plus Light Die Pressure

Tested Per ASTM D2344-76:
Recommended Support Span = 5t
Recommended Specimen Length = 7t
Recommended Rate of Cross Head Motion = 0.05 in./min

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>t (in.)</th>
<th>w (in.)</th>
<th>Load (lbf)</th>
<th>Shear Strength (psi)</th>
<th>(1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6-1</td>
<td>0.154</td>
<td>0.259</td>
<td>87</td>
<td>1636</td>
<td></td>
</tr>
<tr>
<td>6-2</td>
<td>0.155</td>
<td>0.253</td>
<td>88</td>
<td>1683</td>
<td></td>
</tr>
<tr>
<td>6-3</td>
<td>0.155</td>
<td>0.257</td>
<td>95</td>
<td>1789</td>
<td></td>
</tr>
<tr>
<td>6-4</td>
<td>0.156</td>
<td>0.257</td>
<td>92</td>
<td>1721</td>
<td></td>
</tr>
<tr>
<td>6-5</td>
<td>0.156</td>
<td>0.257</td>
<td>96</td>
<td>1796</td>
<td></td>
</tr>
<tr>
<td><strong>Avg</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>1725</strong></td>
<td>(1)</td>
</tr>
<tr>
<td><strong>σ</strong></td>
<td></td>
<td></td>
<td></td>
<td><strong>68.63</strong></td>
<td></td>
</tr>
</tbody>
</table>

*σ = Standard Deviation (with N-1 weighting)

(1) NOTE: Use for comparative purposes only, not design criteria.
TABLE 9. THREE POINT INTERLAMINAR SHEAR TEST
SPECIMEN BREAKDOWN (Continued)

Specimen Group — NO. 6A
450°F, Vacuum Plus Light Die Pressure

Tested Per ASTM D2344-76:
Recommended Support Span = 5t
Recommended Specimen Length = 7t
Recommended Rate of Cross Head
Motion = 0.05 in./min

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>t (in.)</th>
<th>w (in.)</th>
<th>Load (lbf)</th>
<th>Shear Strength (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6A-1</td>
<td>0.157</td>
<td>0.255</td>
<td>96</td>
<td>1798</td>
</tr>
<tr>
<td>6A-2</td>
<td>0.157</td>
<td>0.257</td>
<td>98</td>
<td>1822</td>
</tr>
<tr>
<td>6A-3</td>
<td>0.156</td>
<td>0.259</td>
<td>93</td>
<td>1726</td>
</tr>
<tr>
<td>6A-4</td>
<td>0.153</td>
<td>0.258</td>
<td>101</td>
<td>1919</td>
</tr>
<tr>
<td>6A-5</td>
<td>0.157</td>
<td>0.259</td>
<td>94</td>
<td>1734</td>
</tr>
<tr>
<td>6A-6</td>
<td>0.155</td>
<td>0.260</td>
<td>108</td>
<td>2010</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>t (in.)</th>
<th>w (in.)</th>
<th>Load (lbf)</th>
<th>Shear Strength (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Avg</td>
<td></td>
<td></td>
<td></td>
<td>1835</td>
</tr>
<tr>
<td>σ*</td>
<td></td>
<td></td>
<td></td>
<td>110.66</td>
</tr>
</tbody>
</table>

*σ = Standard Deviation (with N-1 weighting)

(1) NOTE: Use for comparative purposes only, not design criteria.
TABLE 9. THREE POINT INTERLAMINAR SHEAR TEST
SPECIMEN BREAKDOWN (Continued)

Specimen Group — NO. 7
500°F, Vacuum Plus Light Die Pressure

Tested Per ASTM D2344-76:
Recommended Support Span = 5t
Recommended Specimen Length = 7t
Recommended Rate of Cross Head
Motion = 0.05 in./min

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>t (in.)</th>
<th>w (in.)</th>
<th>Load (lbf)</th>
<th>Shear Strength (psi) (1)</th>
</tr>
</thead>
<tbody>
<tr>
<td>7-1</td>
<td>0.132</td>
<td>0.257</td>
<td>84</td>
<td>1857</td>
</tr>
<tr>
<td>7-2</td>
<td>0.134</td>
<td>0.257</td>
<td>85</td>
<td>1851</td>
</tr>
<tr>
<td>7-3</td>
<td>0.134</td>
<td>0.259</td>
<td>88</td>
<td>1902</td>
</tr>
<tr>
<td>7-4</td>
<td>0.134</td>
<td>0.260</td>
<td>82</td>
<td>1765</td>
</tr>
<tr>
<td>7-5</td>
<td>0.135</td>
<td>0.260</td>
<td>88</td>
<td>1880</td>
</tr>
<tr>
<td>Avg</td>
<td></td>
<td></td>
<td></td>
<td>1851</td>
</tr>
<tr>
<td>σ*</td>
<td></td>
<td></td>
<td></td>
<td>52.14</td>
</tr>
</tbody>
</table>

*σ = Standard Deviation (with N-1 weighting)

(1) NOTE: Use for comparative purposes only, not design criteria.
### TABLE 9. THREE POINT INTERLAMINAR SHEAR TEST
SPECIMEN BREAKDOWN (Continued)

Specimen Group — NO. 8
550°F, Vacuum Plus Light Die Pressure

Tested Per ASTM D2344-76:
Recommended Support Span = 5t
Recommended Specimen Length = 7t
Recommended Rate of Cross Head Motion = 0.05 in./min

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>t (in.)</th>
<th>w (in.)</th>
<th>Load (lbf)</th>
<th>Shear Strength (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>8–1</td>
<td>0.132</td>
<td>0.255</td>
<td>66</td>
<td>1471</td>
</tr>
<tr>
<td>8–2</td>
<td>0.132</td>
<td>0.260</td>
<td>71</td>
<td>1552</td>
</tr>
<tr>
<td>8–3</td>
<td>0.132</td>
<td>0.259</td>
<td>70</td>
<td>1536</td>
</tr>
<tr>
<td>8–4</td>
<td>0.132</td>
<td>0.259</td>
<td>73</td>
<td>1601</td>
</tr>
<tr>
<td>8–5</td>
<td>0.134</td>
<td>0.256</td>
<td>72</td>
<td>1574</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Avg</th>
<th>1547</th>
</tr>
</thead>
<tbody>
<tr>
<td>σ*</td>
<td></td>
<td>48.90</td>
</tr>
</tbody>
</table>

*σ = Standard Deviation (with N-1 weighting)

(1) NOTE: Use for comparative purposes only, not design criteria.
TABLE 9. THREE POINT INTERLAMINAR SHEAR TEST
SPECIMEN BREAKDOWN (Continued)

Specimen Group — NO. 9
600°F, Vacuum Plus Light Die Pressure

Tested Per ASTM D2344-76:
Recommended Support Span = 5t
Recommended Specimen Length = 7t
Recommended Rate of Cross Head
Motion = 0.05 in./min

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>t (in.)</th>
<th>w (in.)</th>
<th>Load (lbf)</th>
<th>Shear Strength (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>9-1</td>
<td>0.136</td>
<td>0.256</td>
<td>65</td>
<td>1400</td>
</tr>
<tr>
<td>9-2</td>
<td>0.136</td>
<td>0.254</td>
<td>70</td>
<td>1520</td>
</tr>
<tr>
<td>9-3</td>
<td>0.137</td>
<td>0.255</td>
<td>66</td>
<td>1417</td>
</tr>
<tr>
<td>9-4</td>
<td>0.137</td>
<td>0.255</td>
<td>67</td>
<td>1438</td>
</tr>
<tr>
<td>9-5</td>
<td>0.138</td>
<td>0.255</td>
<td>67</td>
<td>1428</td>
</tr>
</tbody>
</table>

Avg 1441  
\[ \sigma^* = 46.57 \]

*\( \sigma \) = Standard Deviation (with N-1 weighting)

(1) NOTE: Use for comparative purposes only, not design criteria.
TABLE 9. THREE POINT INTERLAMINAR SHEAR TEST
SPECIMEN BREAKDOWN (Continued)

Specimen Group — NO. 10
650°F, Vacuum Plus Light Die Pressure

Tested Per ASTM D2344-76:
Recommended Support Span = 5t
Recommended Specimen Length = 7t
Recommended Rate of Cross Head
Motion = 0.05 in./min

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>t (in.)</th>
<th>w (in.)</th>
<th>Load (lbf)</th>
<th>Shear Strength (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>10–1</td>
<td>0.134</td>
<td>0.253</td>
<td>62</td>
<td>1438</td>
</tr>
<tr>
<td>10–2</td>
<td>0.134</td>
<td>0.254</td>
<td>65</td>
<td>1432</td>
</tr>
<tr>
<td>10–3</td>
<td>0.134</td>
<td>0.256</td>
<td>64</td>
<td>1399</td>
</tr>
<tr>
<td>10–4</td>
<td>0.134</td>
<td>0.256</td>
<td>66</td>
<td>1443</td>
</tr>
<tr>
<td>10–5</td>
<td>0.135</td>
<td>0.256</td>
<td>68</td>
<td>1476</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th></th>
<th>Avg</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Shear Strength (psi)</td>
<td>1438</td>
<td></td>
</tr>
</tbody>
</table>

\[ \sigma^* = 27.50 \]

\( \sigma = \text{Standard Deviation (with N-1 weighting)} \)

(1) NOTE: Use for comparative purposes only, not design criteria.
One of the unanswered questions with regard to polysulfone practicality in U.S. Army field operations is its susceptibility to attack by certain solvents. Methyl-ethyl-ketone and acetone are available to maintenance personnel and might be improperly used during repair operations, such as paint stripping or adhesive bonding preparation. Data are available on property reduction of reinforced polysulfone after twenty-four-hour immersion in solvent, but this is obviously an extreme and unrealistic criterion. Therefore, it was proposed that the degree of damage be assessed in the possible circumstance wherein a solvent soaked rag is rested upon a reinforced polysulfone laminate and remains for two-hours or until dry.

The effect of both MEK and acetone was examined on thin-skin two-ply laminates in both the painted and unpainted conditions. The Kevlar 49 style 285 fabric/polysulfone or polyphenylsulfone laminates prepared for this investigatory task were consolidated at 600°F and 100 psi for 30 minutes. To permit testing thin laminates, honeycomb sandwich panels were prepared by bonding the two-ply laminate skins to HRP-10 4.0 PCF honeycomb core with AF126 Grade 10 film adhesive and hot press curing at 30-50 psi at 250°F for 90 minutes.

For reasons of material availability and high material cost, we elected to use the two-ply (285 style Kevlar 49 fabric/polysulfone or polyphenylsulfone) laminate on only the compression face of the sandwich panel. Five available substitutes for use on the tension face of the sandwich panel were analyzed. One, two and three-ply laminates of readily available, in-house, material were checked in order to provide a minimum tensile strength of two times the Kevlar compression face strength and thus ensure a failure in the Kevlar 49/thermoplastic material. The chosen substitute was a precured three-ply fiberglass (1002 scotchply/epoxy) laminate, oriented at 0°/90°/0°.

Flexural testing was performed in accordance (per contractual requirement) with MIL-A-25463 — Military Specification — Adhesive, Metallic Structural Sandwich Construction; Section 4.6.7 — Normal Temperature Sandwich Flexure Test. Three exceptions to this test method were taken; three to five specimens per group were tested instead of six as recommended by MIL-A-25463, test set up and specimen size also differed from those prescribed in the military specification. Number of specimens and maximum size was dictated by the amount of the available material. Test set up and specimen size may be noted in Figure 10.

Utilizing the loading diagram and description of sectional areas shown in Figure 11, the maximum beam flexural strength was determined from the face sheet bending stress equation for the Kevlar 49/thermoplastic laminate as follows:

\[ f_{b1} = \frac{M}{hwt_{1}} \]

where:

- \( M \) = maximum bending moment = \( \frac{Pa}{2} \)
- \( h \) = distance between the upper and lower laminate centroidal axes =
  \[ 0.475 + \frac{(0.018)}{2} + (0.03) = 0.499 \]
Figure 10. Typical Test Set-Up and Specimen Size for 4 Point Sandwich Flex Test.
a = 4.5 IN.
L = 13.0 IN.

Figure 11. Sandwich Beam Sectional Area and Loading Diagram
w = specimen width  
t = thickness of K49/polyphenylsulfone or polysulfone laminate = 0.018

Introducing these values into the bending stress equation a simplified equation now develops for the sandwich beam bending stress:

\[ f_{b1} = \frac{P_{a}}{2wh_{t}} = \frac{P (4.5)}{2 (0.499) W (0.018)} \]

\[ f_{b1} = 250.5 \frac{P}{W} \]

Relative stiffness of the (nonhomogeneous material) sandwich beams may be obtained by the formula:

\[ EI = \frac{P/2a}{24 y} (3L^2 - 4a^2) \]

\[ EI = (P/y) \left( \frac{a}{48} \right) (3L^2 - 4a^2) \]

where:

P/y = slope of the tangent to the initial straight line portion of the load-deflection curve (lbs per inch of deflection)

a = 4.5 In. (See Figure 11)

L = 13.0 In. (See Figure 11)

Substituting these values into the above equation, a reduced equation is now obtained for the relative stiffness of the honeycomb sandwich beams:

\[ EI = (P/y) \left( \frac{4.5}{48} \right) [3 (13^2) - 4 (4.5^2)] \]

\[ EI = 39.9375 (P/y) \]

Results of four point flex testing on honeycomb sandwich beams painted and unpainted, with and without exposure to solvent soaked rags, are summarized in Table 10. Individual specimen dimensions and test results are given in Table 11.

Specimens were painted in accordance with MIL-F-18264D — “Finishes: Organic, Weapons System, Application and Control of” — 23 April 1971.

Two primer coats were applied in accordance with MIL-F-23377 — “Primer Coating, Epoxy — Polyamide, Chemical and Solvent Resistant, for Weapons Systems” — 7 August 1962.

Two top coats were applied per MIL-L-46159 — “Lacquer, Acrylic, Low Reflective, Olive Drab” — 15 January 1973.
## TABLE 10. SANDWICH BEAM FOUR POINT FLEX TEST SUMMARY

<table>
<thead>
<tr>
<th>Polysulfone (Udel)</th>
<th>Polyphenylsulfone (Radel)</th>
<th>Specimen Material and Treatment</th>
<th>Number of Specimens in Group</th>
<th>Strength (ksi) Avg</th>
<th>$\sigma^*$</th>
<th>Stiffness (EI) psi-in.$^4$ (x $10^4$) Avg</th>
<th>$\sigma^*$</th>
</tr>
</thead>
<tbody>
<tr>
<td>X</td>
<td>X</td>
<td>Control No Solvent Acetone MEK Painted Unpainted</td>
<td>3</td>
<td>14.536</td>
<td>0.239</td>
<td>2.872</td>
<td>0.257</td>
</tr>
<tr>
<td>X</td>
<td>X</td>
<td>Acetone MEK Painted Unpainted</td>
<td>3</td>
<td>12.783</td>
<td>0.399</td>
<td>2.493</td>
<td>0.168</td>
</tr>
<tr>
<td>X</td>
<td>X</td>
<td>X</td>
<td>3</td>
<td>16.028</td>
<td>0.576</td>
<td>2.546</td>
<td>0.144</td>
</tr>
<tr>
<td>X</td>
<td>X</td>
<td>X</td>
<td>3</td>
<td>15.154</td>
<td>0.313</td>
<td>2.556</td>
<td>0.277</td>
</tr>
<tr>
<td>X</td>
<td>X</td>
<td>X</td>
<td>3</td>
<td>13.870</td>
<td>0.237</td>
<td>2.547</td>
<td>0.101</td>
</tr>
<tr>
<td>X</td>
<td>X</td>
<td>X</td>
<td>3</td>
<td>14.317</td>
<td>0.119</td>
<td>2.641</td>
<td>0.081</td>
</tr>
<tr>
<td>X</td>
<td>X</td>
<td>Acetone MEK Painted Unpainted</td>
<td>4</td>
<td>16.271</td>
<td>1.896</td>
<td>1.916</td>
<td>0.108</td>
</tr>
<tr>
<td>X</td>
<td>X</td>
<td>X</td>
<td>4</td>
<td>16.616</td>
<td>1.718</td>
<td>1.825</td>
<td>0.192</td>
</tr>
<tr>
<td>X</td>
<td>X</td>
<td>X</td>
<td>5</td>
<td>18.420</td>
<td>1.451</td>
<td>2.084</td>
<td>0.153</td>
</tr>
<tr>
<td>X</td>
<td>X</td>
<td>X</td>
<td>5</td>
<td>15.351</td>
<td>0.917</td>
<td>1.943</td>
<td>0.137</td>
</tr>
<tr>
<td>X</td>
<td>X</td>
<td>X</td>
<td>3</td>
<td>16.717</td>
<td>0.870</td>
<td>2.480</td>
<td>0.272</td>
</tr>
<tr>
<td>X</td>
<td>X</td>
<td>X</td>
<td>3</td>
<td>16.526</td>
<td>0.667</td>
<td>2.269</td>
<td>0.204</td>
</tr>
</tbody>
</table>

* $\sigma^*$ = Standard Deviation (with N-1 weighting)
Figure 12. Flexural Strength vs Solvent Exposure
Figure 13. Flexural Stiffness vs Solvent Exposure
<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>w (in.)</th>
<th>t (in.)</th>
<th>Painted</th>
<th>Max Load (lbs)</th>
<th>Flex Strength (ksi)</th>
<th>Deflection at Max Load (in.)</th>
<th>P/Y</th>
<th>Stiffness EI psi ( \text{in.}^4 \times 10^4 )</th>
</tr>
</thead>
<tbody>
<tr>
<td>B4</td>
<td>2.178</td>
<td>0.539</td>
<td>Yes</td>
<td>124</td>
<td>14.262</td>
<td>0.250</td>
<td>162/0.25</td>
<td>2.588</td>
</tr>
<tr>
<td>B5</td>
<td>2.138</td>
<td>0.539</td>
<td>Yes</td>
<td>125</td>
<td>14.646</td>
<td>0.30</td>
<td>184/0.25</td>
<td>2.939</td>
</tr>
<tr>
<td>B6</td>
<td>2.130</td>
<td>0.538</td>
<td>Yes</td>
<td>125</td>
<td>14.701</td>
<td>0.30</td>
<td>174/0.225</td>
<td>3.088</td>
</tr>
<tr>
<td>Avg</td>
<td></td>
<td></td>
<td></td>
<td>14.536</td>
<td></td>
<td></td>
<td>2.872</td>
<td></td>
</tr>
<tr>
<td>( \sigma^* )</td>
<td></td>
<td></td>
<td></td>
<td>0.239</td>
<td></td>
<td></td>
<td>0.257</td>
<td></td>
</tr>
</tbody>
</table>

\( \sigma^* = \) Standard Deviation (with N-1 Weighting)
TABLE 11. SANDWICH BEAM SPECIMEN GROUP BREAKDOWN
FOUR POINT FLEX TEST RESULTS (Continued)

SPECIMEN MATERIAL
Thermoplastic Compression Laminate — 2 Ply Kevlar 49/Polysulfone
Style 285 Fabric — (0° — orientation)
Tension Laminate — 3 Ply 1002 Scotchply Fiberglass/Epoxy (0°/90° orientation)
Core — HRP-10, 4.0 PCF, 3/16 in. Cell, Nom. 1/2 in. THK
Adhesive (Core to Skin) — AF-126, GR-10 Film Adhesive Hot Press Cured for 90 Minutes
@ 250°F and 30-50 psi

SOLVENT EXPOSURE — NONE — CONTROL GROUP

TEST SPEED/TEST TEMPERATURE — Rate of Crosshead Motion = 0.02 in. per min/Room Temperature

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>w (in.)</th>
<th>t (in.)</th>
<th>Painted</th>
<th>Max Load (lbs)</th>
<th>Flex Strength (ksi)</th>
<th>Deflection at Max Load (in.)</th>
<th>P/Y</th>
<th>Stiffness El psi — in.4(x10^4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>B1</td>
<td>2.062</td>
<td>0.535</td>
<td>No</td>
<td>103</td>
<td>12.513</td>
<td>0.225</td>
<td>245/0.425</td>
<td>2.302</td>
</tr>
<tr>
<td>B2</td>
<td>2.148</td>
<td>0.535</td>
<td>No</td>
<td>108</td>
<td>12.595</td>
<td>0.275</td>
<td>160/0.25</td>
<td>2.556</td>
</tr>
<tr>
<td>B2</td>
<td>2.100</td>
<td>0.536</td>
<td>No</td>
<td>111</td>
<td>13.241</td>
<td>0.2675</td>
<td>164/0.25</td>
<td>2.620</td>
</tr>
</tbody>
</table>

Avg 12.783

σ* = Standard Deviation (with N-1 Weighting)
TABLE 11. SANDWICH BEAM SPECIMEN GROUP BREAKDOWN
FOUR POINT FLEX TEST RESULTS (Continued)

SPECIMEN MATERIAL
Thermoplastic Compression Laminate — 2 Ply Kevlar 49/Polysulfone
Style 285 Fabric - (0°) orientation
Tension Laminate — 3 Ply 1002 Scotchply Fiberglass/Epoxy (0°/90° orientation)
Core — HRP-10, 4.0 PCF, 3/16 in. Cell, Nom. 1/2 in. THK
Adhesive (Core to Skin) — AF-126, GR-10 Film Adhesive Hot Press Cured for 90 Minutes
@ 250°F and 30-50 psi

SOLVENT EXPOSURE — MEK

TEST SPEED/TEST TEMPERATURE — Rate of Crosshead Motion = 0.02 in. per min/Room Temperature

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>w (in.)</th>
<th>t (in.)</th>
<th>Painted</th>
<th>Max Load (lbs)</th>
<th>Flex Strength (ksi)</th>
<th>Deflection at Max Load (in.)</th>
<th>P/Y</th>
<th>Stiffness EI psi – in.^4 (x10^4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A1</td>
<td>2.090</td>
<td>0.539</td>
<td>Yes</td>
<td>118</td>
<td>14.143</td>
<td>0.225</td>
<td>150/0.225</td>
<td>2.663</td>
</tr>
<tr>
<td>A2</td>
<td>2.100</td>
<td>0.540</td>
<td>Yes</td>
<td>115</td>
<td>13.718</td>
<td>0.225</td>
<td>140/0.225</td>
<td>2.485</td>
</tr>
<tr>
<td>A3</td>
<td>2.150</td>
<td>0.540</td>
<td>Yes</td>
<td>118</td>
<td>13.748</td>
<td>0.35</td>
<td>156/0.25</td>
<td>2.492</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Avg</th>
<th>13.870</th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th>2.547</th>
</tr>
</thead>
</table>

σ* = 0.237

σ* = Standard Deviation (with N-1 Weighting)
### TABLE 11. SANDWICH BEAM SPECIMEN GROUP BREAKDOWN
#### FOUR POINT FLEX TEST RESULTS (Continued)

**SPECIMEN MATERIAL**

<table>
<thead>
<tr>
<th>Material Type</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermoplastic Compression Laminate</td>
<td>2 Ply Kevlar 49/Polysulfone Style 285 Fabric – (0° – orientation)</td>
</tr>
<tr>
<td>Tension Laminate</td>
<td>3 Ply 1002 Scotchply Fiberglass/Epoxy (0°/90° orientation)</td>
</tr>
<tr>
<td>Core</td>
<td>HRP-10, 4.0 PCF, 3/16 in. Cell, Nom. 1/2 in. THK</td>
</tr>
<tr>
<td>Adhesive (Core to Skin)</td>
<td>AF-126, GR-10 Film Adhesive Hot Press Cured for 90 Minutes @ 250°F and 30-50 psi</td>
</tr>
</tbody>
</table>

**SOLVENT EXPOSURE**

- MEK

**TEST SPEED/TEST TEMPERATURE**

- Rate of Crosshead Motion = 0.02 in. per min/Room Temperature

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>w (in.)</th>
<th>t (in.)</th>
<th>Painted</th>
<th>Max Load (lbs)</th>
<th>Flex Strength (ksi)</th>
<th>Deflection at Max Load (in.)</th>
<th>P/Y</th>
<th>Stiffness El psi – in.⁴(x10⁴)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A7</td>
<td>2.142</td>
<td>0.535</td>
<td>No</td>
<td>122</td>
<td>14.268</td>
<td>0.40</td>
<td>166/0.25</td>
<td>2.652</td>
</tr>
<tr>
<td>A8</td>
<td>2.132</td>
<td>0.535</td>
<td>No</td>
<td>123</td>
<td>14.452</td>
<td>0.3875</td>
<td>160/0.25</td>
<td>2.556</td>
</tr>
<tr>
<td>A9</td>
<td>2.130</td>
<td>0.539</td>
<td>No</td>
<td>121</td>
<td>14.230</td>
<td>0.35</td>
<td>170/0.25</td>
<td>2.716</td>
</tr>
</tbody>
</table>

| Avg          |         |         |         | 14.317        |                     |                             |        |                               |

| σ*           | 0.119   |         |         |               |                     |                             |        | 0.081                         |

σ* = Standard Deviation (with N-1 Weighting)
<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>w (in.)</th>
<th>t (in.)</th>
<th>Painted</th>
<th>Max Load (lbs)</th>
<th>Flex Strength (ksi)</th>
<th>Deflection at Max Load (in.)</th>
<th>P/Y</th>
<th>Stiffness EI psi - in.$^4$(x10$^4$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A4</td>
<td>2.112</td>
<td>0.541</td>
<td>Yes</td>
<td>137</td>
<td>16.249</td>
<td>0.35</td>
<td>160/0.25</td>
<td>2.556</td>
</tr>
<tr>
<td>A5</td>
<td>2.118</td>
<td>0.540</td>
<td>Yes</td>
<td>130</td>
<td>15.375</td>
<td>0.30</td>
<td>168/0.25</td>
<td>2.684</td>
</tr>
<tr>
<td>A6</td>
<td>2.100</td>
<td>0.539</td>
<td>Yes</td>
<td>138</td>
<td>16.461</td>
<td>0.40</td>
<td>150/0.25</td>
<td>2.396</td>
</tr>
</tbody>
</table>

Avg 16.028

$\sigma^* = \text{Standard Deviation (with N-1 Weighting)}$
## TABLE 11. SANDWICH BEAM SPECIMEN GROUP BREAKDOWN
### FOUR POINT FLEX TEST RESULTS (Continued)

### SPECIMEN MATERIAL
- Thermoplastic Compression Laminate: 2 Ply Kevlar 49/ Polysulfone Style 285 Fabric – (0° orientation)
- Tension Laminate: 3 Ply 1002 Scotchply Fiberglass/Epoxy (0°/90° orientation)
- Core: HRP-10, 4.0 PCF, 3/16 in. Cell, Nom. 1/2 in. THK
- Adhesive (Core to Skin): AF-126, GR-10 Film Adhesive Hot Press Cured for 90 Minutes @ 250°F and 30-50 psi

### SOLVENT EXPOSURE
- ACETONE

### TEST SPEED/TEST TEMPERATURE
- Rate of Crosshead Motion = 0.02 in. per min/Room Temperature

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>w (in.)</th>
<th>t (in.)</th>
<th>Painted</th>
<th>Max Load (lbs)</th>
<th>Flex Strength (ksi)</th>
<th>Deflection at Max Load (in.)</th>
<th>P/Y</th>
<th>Stiffness EI psi in.(^4)(x10(^4))</th>
</tr>
</thead>
<tbody>
<tr>
<td>A10</td>
<td>2.160</td>
<td>0.537</td>
<td>No</td>
<td>128</td>
<td>14.844</td>
<td>0.375</td>
<td>90/0.125</td>
<td>2.876</td>
</tr>
<tr>
<td>A11</td>
<td>2.100</td>
<td>0.539</td>
<td>No</td>
<td>127</td>
<td>15.149</td>
<td>0.425</td>
<td>120/0.2</td>
<td>2.396</td>
</tr>
<tr>
<td>A12</td>
<td>2.170</td>
<td>0.540</td>
<td>No</td>
<td>134</td>
<td>15.469</td>
<td>0.475</td>
<td>150/0.25</td>
<td>2.396</td>
</tr>
</tbody>
</table>

**Avg** 15.154

\[\sigma^* = 0.313\] 2.556

\[\sigma^* = \text{Standard Deviation (with N-1 Weighting)}\]
TABLE 11. SANDWICH BEAM SPECIMEN GROUP BREAKDOWN
FOUR POINT FLEX TEST RESULTS (Continued)

SPECIMEN MATERIAL
Thermoplastic Compression Laminate — 2 Ply Kevlar 49/Polyphenylsulfone
Style 285 Fabric — (0° — orientation)
Tension Laminate — 3 Ply 1002 Scotchply Fiberglass/Epoxy (0°/90° orientation)
Core — HRP-10, 4.0 PCF, 3/16 in. Cell, Nom. 1/2 in. THK
Adhesive (Core to Skin) — AF-126, GR-10 Film Adhesive Hot Press Cured for 90 Minutes
@ 250°F and 30-50 psi

SOLVENT EXPOSURE — NONE — CONTROL GROUP

TEST SPEED/TEST TEMPERATURE — Rate of Crosshead Motion = 0.02 in. per min/Rom Temperature

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>w (in.)</th>
<th>t (in.)</th>
<th>Painted</th>
<th>Max Load (lbs)</th>
<th>Flex Strength (ksi)</th>
<th>Deflection at Max Load (in.)</th>
<th>P/Y</th>
<th>Stiffness EI psi — in.⁴(×10⁴)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3—4</td>
<td>2.080</td>
<td>0.535</td>
<td>Yes</td>
<td>142</td>
<td>17.101</td>
<td>0.60</td>
<td>230/0.475</td>
<td>1.934</td>
</tr>
<tr>
<td>3—5</td>
<td>2.068</td>
<td>0.536</td>
<td>Yes</td>
<td>120</td>
<td>14.536</td>
<td>0.4625</td>
<td>260/0.575</td>
<td>1.806</td>
</tr>
<tr>
<td>3—6</td>
<td>2.018</td>
<td>0.537</td>
<td>Yes</td>
<td>120</td>
<td>14.896</td>
<td>0.450</td>
<td>175/0.375</td>
<td>1.864</td>
</tr>
<tr>
<td>1—2</td>
<td>2.012</td>
<td>0.538</td>
<td>Yes</td>
<td>149</td>
<td>18.551</td>
<td>0.625</td>
<td>335/0.65</td>
<td>2.058</td>
</tr>
</tbody>
</table>

Avg 16.271 1.916

σ* = Standard Deviation (with N-1 Weighting)
### TABLE 11. SANDWICH BEAM SPECIMEN GROUP BREAKDOWN
FOUR POINT FLEX TEST RESULTS (Continued)

**SPECIMEN MATERIAL**
- Thermoplastic Compression Laminate — 2 Ply Kevlar 49/Polyphenylsulfone
  Style 285 Fabric — (0° — orientation)
- Tension Laminate — 3 Ply 1002 Scotchply Fiberglass/Epoxy (0°/90° orientation)
- Core — HRP-10, 4.0 PCF, 3/16 in. Cell, Nom. 1/2 in. THK
- Adhesive (Core to Skin) — AF-126, GR-10 Film Adhesive Hot Press Cured for 90 Minutes @ 250°F and 30-50 psi

**SOLVENT EXPOSURE** — NONE — CONTROL GROUP

**TEST SPEED/TEST TEMPERATURE** — Rate of Crosshead Motion = 0.02 in. per min/Room Temperature

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>w (in.)</th>
<th>t (in.)</th>
<th>Painted</th>
<th>Max Load (lbs)</th>
<th>Flex Strength (ksi)</th>
<th>Deflection at Max Load (in.)</th>
<th>P/Y</th>
<th>Stiffness E1 psi – in.4(x104)</th>
</tr>
</thead>
<tbody>
<tr>
<td>3–1</td>
<td>1.830</td>
<td>0.535</td>
<td>No</td>
<td>135</td>
<td>18.480</td>
<td>0.65</td>
<td>315/0.775</td>
<td>1.623</td>
</tr>
<tr>
<td>3–2</td>
<td>1.982</td>
<td>0.536</td>
<td>No</td>
<td>133</td>
<td>16.809</td>
<td>0.675</td>
<td>245/0.575</td>
<td>1.702</td>
</tr>
<tr>
<td>3–3</td>
<td>2.152</td>
<td>0.537</td>
<td>No</td>
<td>123</td>
<td>14.318</td>
<td>0.50</td>
<td>245/0.5</td>
<td>1.951</td>
</tr>
<tr>
<td>1–5</td>
<td>2.006</td>
<td>0.541</td>
<td>No</td>
<td>135</td>
<td>16.858</td>
<td>0.575</td>
<td>240/0.475</td>
<td>2.018</td>
</tr>
</tbody>
</table>

**Avg** 16.616 1.825

| σ*          | 1.718  | 0.192 |

σ* = Standard Deviation (with N-1 Weighting)
TABLE 11. SANDWICH BEAM SPECIMEN GROUP BREAKDOWN
FOUR POINT FLEX TEST RESULTS (Continued)

SPECIMEN MATERIAL

<table>
<thead>
<tr>
<th>Material</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermoplastic Compression Laminate</td>
<td>2 Ply Kevlar 49/Polyphenylsulfone</td>
</tr>
<tr>
<td></td>
<td>Style 285 Fabric – (0^0 – orientation)</td>
</tr>
<tr>
<td>Tension Laminate</td>
<td>3 Ply 1002 Scotchply Fiberglass/Epoxy (0^0/90^0 orientation)</td>
</tr>
<tr>
<td>Core</td>
<td>HRP-10, 4.0 PCF, 3/16 in. Cell, Nom. 1/2 in. THK</td>
</tr>
<tr>
<td>Adhesive (Core to Skin)</td>
<td>AF-126, GR-10 Film Adhesive Hot Press Cured for 90 Minutes @ 250^0F and 30-50 psi</td>
</tr>
</tbody>
</table>

SOLVENT EXPOSURE

- MEK

TEST SPEED/TEST TEMPERATURE

- Rate of Crosshead Motion = 0.02 in. per min/Room Temperature

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>w (in.)</th>
<th>t (in.)</th>
<th>Painted</th>
<th>Max Load (lbs)</th>
<th>Flex Strength (ksi)</th>
<th>Deflection at Max Load (in.)</th>
<th>P/Y</th>
<th>Stiffness E1 psi – in.^4(x10^4)</th>
</tr>
</thead>
<tbody>
<tr>
<td>11-4</td>
<td>2.030</td>
<td>0.535</td>
<td>Yes</td>
<td>135</td>
<td>16.659</td>
<td>0.50</td>
<td>235/0.375</td>
<td>2.503</td>
</tr>
<tr>
<td>11-5</td>
<td>2.130</td>
<td>0.535</td>
<td>Yes</td>
<td>135</td>
<td>15.877</td>
<td>0.525</td>
<td>240/0.35</td>
<td>2.739</td>
</tr>
<tr>
<td>11-6</td>
<td>2.062</td>
<td>0.535</td>
<td>Yes</td>
<td>145</td>
<td>17.615</td>
<td>0.55</td>
<td>275/0.5</td>
<td>2.197</td>
</tr>
</tbody>
</table>

| Avg          |         |         |         | 16.717        |                     |                            |            | 2.480                        |

\( \sigma^* \) = Standard Deviation (with N-1 Weighting)
<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>w (in.)</th>
<th>t (in.)</th>
<th>Painted</th>
<th>Max Load (lbs)</th>
<th>Flex Strength (ksi)</th>
<th>Deflection at Max Load (in.)</th>
<th>P/Y</th>
<th>Stiffness EI psi – in.⁴(x10⁴)</th>
</tr>
</thead>
<tbody>
<tr>
<td>11–1</td>
<td>2.070</td>
<td>0.532</td>
<td>No</td>
<td>132</td>
<td>15.974</td>
<td>0.525</td>
<td>230/0.375</td>
<td>2.449</td>
</tr>
<tr>
<td>11–2</td>
<td>2.070</td>
<td>0.532</td>
<td>No</td>
<td>135</td>
<td>16.337</td>
<td>0.625</td>
<td>275/0.475</td>
<td>2.312</td>
</tr>
<tr>
<td>11–3</td>
<td>2.060</td>
<td>0.533</td>
<td>No</td>
<td>142</td>
<td>17.267</td>
<td>0.625</td>
<td>205/0.4</td>
<td>2.047</td>
</tr>
<tr>
<td>Avg</td>
<td></td>
<td></td>
<td></td>
<td>16.526</td>
<td></td>
<td></td>
<td></td>
<td>2.269</td>
</tr>
<tr>
<td>σ*</td>
<td></td>
<td></td>
<td></td>
<td>0.667</td>
<td></td>
<td></td>
<td></td>
<td>0.204</td>
</tr>
</tbody>
</table>

σ* = Standard Deviation (with N-1 Weighting)
TABLE 11. SANDWICH BEAM SPECIMEN GROUP BREAKDOWN
FOUR POINT FLEX TEST RESULTS (Continued)

SPECIMEN MATERIAL

<table>
<thead>
<tr>
<th>Material Type</th>
<th>Details</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermoplastic Compression Laminate</td>
<td>2 Ply Kevlar 49/Polyphenylsulfone</td>
</tr>
<tr>
<td></td>
<td>Style 285 Fabric – (0° orientation)</td>
</tr>
<tr>
<td>Tension Laminate</td>
<td>3 Ply 1002 Scotchply Fiberglass/Epoxy (0°/90° orientation)</td>
</tr>
<tr>
<td>Core</td>
<td>HRP-10, 4.0 PCF, 3/16 in. Cell, Nom. 1/2 in. THK</td>
</tr>
<tr>
<td>Adhesive (Core to Skin)</td>
<td>AF-126, GR-10 Film Adhesive Hot Press Cured for 90 Minutes @ 250°F and 30-50 psi</td>
</tr>
</tbody>
</table>

SOLVENT EXPOSURE

- ACETONE

TEST SPEED/TEST TEMPERATURE

- Rate of Crosshead Motion = 0.02 in. per min/Room Temperature

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>w (in.)</th>
<th>t (in.)</th>
<th>Painted</th>
<th>Max Load (lbs)</th>
<th>Flex Strength (ksi)</th>
<th>Deflection at Max Load (in.)</th>
<th>P/Y</th>
<th>Stiffness EI psi - in.⁴(x10⁴)</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-4</td>
<td>2.050</td>
<td>0.540</td>
<td>Yes</td>
<td>158</td>
<td>19.307</td>
<td>0.65</td>
<td>287/0.625</td>
<td>1.834</td>
</tr>
<tr>
<td>4-5</td>
<td>2.078</td>
<td>0.540</td>
<td>Yes</td>
<td>145</td>
<td>17.480</td>
<td>0.70</td>
<td>225/0.425</td>
<td>2.114</td>
</tr>
<tr>
<td>4-6</td>
<td>1.930</td>
<td>0.541</td>
<td>Yes</td>
<td>157</td>
<td>20.377</td>
<td>0.5625</td>
<td>280/0.5</td>
<td>2.237</td>
</tr>
<tr>
<td>1-1</td>
<td>2.022</td>
<td>0.539</td>
<td>Yes</td>
<td>147</td>
<td>18.211</td>
<td>0.625</td>
<td>400/0.7375</td>
<td>2.166</td>
</tr>
<tr>
<td>1-3</td>
<td>2.022</td>
<td>0.541</td>
<td>Yes</td>
<td>135</td>
<td>16.725</td>
<td>0.55</td>
<td>285/0.55</td>
<td>2.069</td>
</tr>
</tbody>
</table>

Avg | 18.420 | 2.084 |

σ* = Standard Deviation (with N-1 Weighting)
<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>w (in.)</th>
<th>t (in.)</th>
<th>Painted</th>
<th>Max Load (lbs)</th>
<th>Flex Strength (ksi)</th>
<th>Deflection at Max Load (in.)</th>
<th>P/Y</th>
<th>Stiffness EI (psi-in.(^4))</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-1</td>
<td>1.810</td>
<td>0.538</td>
<td>No</td>
<td>100</td>
<td>13.840</td>
<td>0.50</td>
<td>140/0.325</td>
<td>1.720</td>
</tr>
<tr>
<td>4-2</td>
<td>1.978</td>
<td>0.537</td>
<td>No</td>
<td>120</td>
<td>15.197</td>
<td>0.525</td>
<td>245/0.5</td>
<td>1.957</td>
</tr>
<tr>
<td>4-3</td>
<td>2.000</td>
<td>0.538</td>
<td>No</td>
<td>125</td>
<td>15.656</td>
<td>0.675</td>
<td>290/0.6</td>
<td>1.930</td>
</tr>
<tr>
<td>1-4</td>
<td>2.003</td>
<td>0.538</td>
<td>No</td>
<td>127</td>
<td>15.883</td>
<td>0.55</td>
<td>285/0.55</td>
<td>2.069</td>
</tr>
<tr>
<td>1-6</td>
<td>2.013</td>
<td>0.538</td>
<td>No</td>
<td>130</td>
<td>16.177</td>
<td>0.40</td>
<td>255/0.50</td>
<td>2.037</td>
</tr>
<tr>
<td>Avg</td>
<td></td>
<td></td>
<td></td>
<td>15.351</td>
<td></td>
<td></td>
<td></td>
<td>1.943</td>
</tr>
</tbody>
</table>

\(\sigma^*\) = Standard Deviation (with N-1 Weighting)
Six (6) panels of 5-ply Kevlar 49/polysulfone were fabricated for AMMRC testing. All panels were 17.75" x 18.0" x 0.040" in size. Five ply laminates of Kevlar 49 style 285 fabric, pre-impregnated with PI700 polysulfone using methylene chloride solvent dispersal, were consolidated at 600°F and 100 psig for 30 minutes. Postforming parameters for each specimen are contained in Table 12. Figure 4 shows the metal tools utilized in thermoforming the consolidated blanks for Task II, Task III, and Task IV.

**TABLE 12. POST FORMING PARAMETERS FOR AMMRC PANELS**

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>Max Part Temp During Postforming Operation</th>
<th>Postforming Pressure</th>
<th>Bottom: Die Travel Into Part</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>450</td>
<td>Vacuum Plus Light Die Pressure</td>
<td>3/4 In.</td>
</tr>
<tr>
<td>4</td>
<td>600</td>
<td>Vacuum Plus Light Die Pressure</td>
<td>3/4 In.</td>
</tr>
<tr>
<td>Control</td>
<td>— No Postforming Process —</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

6 Panels Total
### TASK I - RECOMMENDATIONS FOR CURRENT AND FUTURE APPLICATIONS

<table>
<thead>
<tr>
<th>Polybutylene Teraphthalate</th>
<th>Products</th>
<th>Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Tenite 6 PRO</td>
<td>Principally a molding compound available in unreinforced grades</td>
</tr>
<tr>
<td></td>
<td>Deroton Tap 10</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hostadur BVP 860</td>
<td>• Low deflection temperature unload</td>
</tr>
<tr>
<td></td>
<td>Celanex 2001</td>
<td>• Tensile strength &lt; Nylon 6.6 (8000 psi)</td>
</tr>
<tr>
<td></td>
<td>Valox 310</td>
<td>• Notch sensitive under impact — low temperature</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Affected by chlorinated hydro-carbon solvents (Methylene Chloride)</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Low water absorption</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Melts at 435°F</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Processes at 482°F</td>
</tr>
<tr>
<td></td>
<td></td>
<td>• Creeps at elevated temperature (120°F)</td>
</tr>
</tbody>
</table>

**Conclusions**

While this polymer processes in desirable temperature range and exhibits generally good chemical resistance, it is attacked by chlorinated hydrocarbon solvents, such as methylene chloride, and has poor elevated temperature creep properties, within service temperature range of −65°F to +165°F.

**Recommendation**

Does not appear to warrant development for continuous fiber reinforced composites for aircraft.

**Nylon 6.6**

Basic drawback is water absorption and creep, making long term environmental degradation likely.

Not recommended as the matrix in fiber reinforced composites for aircraft.

**Polysulfone (Udel) P-1700**

Recommended for continued use in manufacturing technology development because of large data base. Should be replaced with systems impervious to aromatic and chlorinated hydrocarbons, when available.
Polyphenylsulfone 5010 (Radel)

Processes similar to polysulfone — Superior in resistance to methylene chloride. Attacked by MIL-H-83306 Phosphate Ester type hydraulic fluid.

Should be considered for P-1700 replacement on military helicopters.

PKXA .41, .517 Silane End-Capped Polysulfone


Solvent resistance achieved through cross-linking which occurs at room temperature aging environment. Material not believed to be reformable as result of cross-linking. Not recommended for further development.

Polyether Sulfone 300P

Superior solvent resistance to methylene chloride over P-1700. Processes at 50°-100°F higher temperature than P-1700. Good properties through 350°F, fluid immersion in common aircraft fluids in stressed condition caused delamination.

Not recommended for further development.

KM-1 (600P)

Limited tests encouraging — continue evaluation.

Polyarylsulfone CM-1

Limited tests encouraging — continue evaluation.

General

Development of hot melt preimpregnation has shown encouraging results with Udel P-1700 and CM-1 polyarylsulfone.

Emergence of hot roll continuous impregnation from film and continuous fibers may make highly solvent resistant polymers candidates for further development.

Further hot melt development recommended with candidates offered by suppliers in film form.
 TASK II & III – CONCLUSIONS AND RECOMMENDATIONS

The experimental portion of this program has been performed to examine the effects of post-forming conditions on the mechanical properties of a polysulfone composite laminate and to determine the effects of solvent exposure on the strength of thin thermoplastic laminates.

The flexural mechanical properties of a laminate comprising woven Kevlar 49 fabric/Pi 700 polysulfone decrease with increasing thermoforming temperature. Postforming at 450°F shows no difference in flexural strength with respect to the non-postformed control laminate. The strength decreases with increasing postforming temperature (to 650°F) to a minimum of about 62% of the control. Visual examination of the specimens show no discernable difference in any of the specimens except that there is an increase in the specimen thickness with increasing postforming temperature. This swelling affects the calculated stresses but does not alter the general trend of decreasing strength with increasing temperature. The flexural modulus also shows the same trend but to a lesser degree.

The interlaminar, short beam shear specimens also showed a reduction in shear strength with increasing postforming temperature.

There appears to be no difference in either the flexural or short beam shear test results with respect to the postforming pressures; vacuum only or vacuum with light die pressure.

The reference (1) investigation originally identified the non-reversible swelling which occurs in a thermoforming cycle, in which a pre-consolidated flat laminate is heated to post-forming temperatures (450°–500°F) under ambient pressure. The effort in the current study was directed at determining the effect of this swelling on the matrix dominated post formed material properties.

Determination of the physical or chemical principles causing the swelling was not addressed within the scope of the contract. It is speculated however, that the unrestrained expansion of the polysulfone at temperatures above glass transition results in deconsolidation of the laminate; i.e., the polymer, which is not bound homogenously by elastic cross-linking expands from the mechanical molecular arrangement created in the 100 psi, 600°F consolidation cycle and the thermal contraction during cool-down produces insufficient force to regain the original thickness. This loss of densification must inevitably have an effect on shear strength and fiber stabilization in compression/flexure. Further investigation might be directed toward non-destructive test of the laminate, GPC or HPLC characterization, TGA or TMA analysis. Isothermal decomposition is not indicated at 250°F for up to 1000 hours exposure with Pi 700 and Kevlar 49, Reference 14, hence it is not immediately suspect at 450° to 600° for 1 minute aging.

The matrix degradation appears also to be time related (see Reference 1), the longer at elevated temperature, the greater the strength loss. Therefore, in the design and manufacturing of structural elements using thermoplastics, it should be planned to postform at the lowest possible temperature and shortest time consistent with forming requirements and to use design mechanical properties consistent with the material strength and stiffness after such a temperature-time exposure.
It has been determined from the Task III test results that when realistically exposed to acetone or MEK the two thermoplastic resins tested (polyphenylsulfone-polysulfone) evidenced no strength or stiffness loss. In fact, the test results indicate an improvement in strength for the (PI 700) polysulfone when painted and/or exposed to acetone. Although there were only 3 replicates per condition, and all the data may be considered to be within normal test scatter, the trend of strength improvement appears correct. Some loss in strength is indicated when unpainted polyphenylsulfone is exposed to acetone. The painting appears to protect the Polyphenylsulfone from the acetone for the kind of exposure used in this experiment. The polyphenylsulfone exposed to MEK, painted or unpainted, shows no strength difference with respect to the control specimens.

These results indicate that the two thermoplastic resins tested could be put into normal U.S. Army field operations without undue concern for exposure to available solvents. Normal cleaning and wiping operations would not degrade strength or stiffness. Immersion is detrimental and normal wiping is not. The question that arises is “what length of the time and severity of exposure is detrimental and what visual signs of degradation exist?” If an unnatural exposure went undetected during the event, “what visual signs would exist that would indicate that corrective action would be necessary?” Information from actual field service exposure is the subject of further U.S. Army investigation under separate contract.
LIST OF REFERENCES


18. Boeing Vertol/DuPont IR&D Thermoplastic Matrix Screening Discussions and Interlaminar Shear Tests, Hoffstedt, Dr. Funer, Dr. Juan.


INTRODUCTION

During the final in-house review of this report it was decided to research the limited published data available to date, and to wait for some current representative unpublished data from Seattle (BAC) obtained through the effort of an ongoing program. The comparison of data obtained under this contract with the published data was favorable (e.g., interlaminar shear value of 3,050 psi with 61% fiber volume). However, the data later obtained from Seattle (BAC) exhibited much higher interlaminar shear values. It was then decided, at no direct cost to the Government, to verify the Seattle (BAC) findings using their specimen configuration of 7-ply Kevlar 49 style 285/P1700 polysulfone. Results provided confirmation of Seattle's (BAC) latest unpublished data. It remained incumbent upon Boeing Vertol to verify the interlaminar shear data (obtained under this contract), at no direct cost to the Government, using an in-house consolidated laminate (homogeneous 15-ply Kevlar 49 style 285/P1700 polysulfone). These results were of similar magnitude to the unpublished Seattle (BAC) data, one order of magnitude greater than data obtained under this contract and earlier published data. It then remained to validate or invalidate the configuration of a bonded “stack-up” specimen used under this contract (3 laminates comprised of 5-plys of Kevlar 49 style 285/P1700 polysulfone each, bonded together at 250°F and 50 psi for 60 minutes utilizing AF 163 Grade 10 film adhesive). Laminates were consolidated in-house but otherwise constructed in an identical manner. Test data showed lower values than a 15-ply homogeneous laminate, but, 64% higher values than the subcontracted consolidated material used under this contract.
OBJECTIVES

In order to understand why portions of the test data, obtained under this contract, were directly comparable with existing data but relatively poor when compared to new data, it remained to logically and methodically retrace each step (including fabrication, testing, and final comparison) utilized to obtain the data in question and:

1) To validate BAC data (new, unpublished)

2) To evaluate the effect of secondary bonding upon interlaminar shear testing

3) To evaluate consolidation process

4) To study the effect of specimen geometry upon interlaminar shear testing
SPECIMEN FABRICATION

In an effort to verify the BAC (Seattle) unpublished interlaminar shear data, specimens were fabricated to the configuration used by BAC for their testing (see Figure A-1).

![Figure A-1. 7-Ply Homogeneous Specimen](image)

The 7-ply laminate was hot-press consolidated at 600°F with 100 PSIG for 30 minutes. After consolidation and cutting to size, ten of the twenty specimens were put into an oven for one minute at 550°F under no added pressure to simulate typical conditions of the thermoforming operation; the remaining ten specimens were to be control articles and therefore were not exposed to the aforementioned post-heating cycle. Subsequent interlaminar shear testing revealed values of the same order of magnitude as recorded in the BAC unpublished data.

Due to the above result, the interlaminar shear test specimens fabricated under this contract had then to be verified. Specimens were cut to the same dimensions as described in Task II of the report. The laminate fabricated for this auxiliary test was a 15-ply solid homogeneous Kevlar 49 style 285 fabric/P1700 polysulfone pre-preg (see Figure A-2), consolidated in-house (at 600°F with 100 PSIG for 30 minutes), as opposed to a 3 laminate “stack-up” of 5-ply each laminate, consolidated at a subcontractor. After the consolidation and cutting processes, ten of the twenty specimens were again put into an oven at 550°F with no added pressure for one minute to simulate typical conditions of the thermoforming operation. The remaining ten specimens became the control set. Interlaminar shear test results demonstrated values commensurate with the BAC unpublished data, but, one order of magnitude greater than the values obtained under this contract.

The bonded “stack-up” interlaminar shear specimen remained as the final configuration to undergo verification. Every procedure that was included in the initial fabrication process (for interlaminar shear test specimens reported on in Task II of the report) was repeated during this re-test activity with only one exception — the laminates were consolidated in-house as opposed to subcontractor consolidated. Three 5-ply Kevlar 49 style 285 fabric/P1700 polysulfone laminates were hot press consolidated at 600°F with 100 PSIG for 30 minutes. After laminate consolidation, these three laminates were bonded together utilizing AF163 Grade 10 film adhesive at 250°F with 50 PSIG for 60 minutes, resulting in a non-homogeneous 15-ply laminate (see Figure A-3). For the effect of bonding on laminate ILS see Test Results Section.
IN-HOUSE HOT-PRESS LAMINATE CONSOLIDATION AT 600°F WITH 100 PSIG FOR 30 MINUTES

RESULT – ONE SOLID HOMOGENEOUS 15-PLY LAMINATE
10 IN. X 10 IN. X 0.124 IN.

Figure A-2. 15-Ply Homogeneous Specimen

IN-HOUSE LAMINATE CONSOLIDATION AT 600°F WITH 100 PSIG FOR 30 MINUTES
(HEATED PRESS)

“STACK-UP” OPERATION WITH AF-163 GRADE 10 FILM ADHESIVE
AT 250°F WITH 50 PSIG FOR 60 MINUTES
(HEATED PRESS)

RESULT – NON-HOMOGENEOUS 15-PLY LAMINATE
10 IN. X 10 IN. X 0.136 IN.

Figure A-3. Bonded “Stack-Up” Specimen
TEST PROCEDURE

For these verification tests, the same methods for horizontal shear tests (described in Task II of the report) were utilized, with one exception: The procedure for interlaminar shear testing used by BAC (Seattle) recommended the use of a 1-inch long specimen on a four times the thickness support span. Only during the verification of the BAC data was their method of testing attempted.

TEST RESULTS

The BAC unpublished data was the first to undergo verification testing at Boeing Vertol. A close examination of the test procedure utilized by BAC revealed a 1-inch long specimen supported on a span length equal to 4.0 times the specimen thickness. During the test set-up operation at Boeing Vertol it was discovered that the test fixtures could not accept such a small support span as was represented by the 4.0 times the specimen thickness dimension. It was decided to test the material at support spans equal to 4.5, 5.0, 5.5 and 6.0 times the specimen thickness and through the use of linear regression methods, obtain the resultant value representative of a test performed at a support span of 4.0 times the specimen thickness. The results of this initial exercise demonstrated values of the same order of magnitude obtained by the BAC interlaminar shear tests (see Table A-1 and Figure A-4).

TABLE A-1. THREE POINT INTERLAMINAR SHEAR TEST SPECIMEN BREAKDOWN

<table>
<thead>
<tr>
<th>Specimen Group — 7 Ply</th>
<th>Tested Per BAC (Seattle) Procedure</th>
<th>Specimen Breakdown</th>
</tr>
</thead>
<tbody>
<tr>
<td>Homogeneous Laminate</td>
<td>Recommended Support Span = (A)</td>
<td>Control — No Post-Form (Heat)</td>
</tr>
<tr>
<td>Control — No Post-Form</td>
<td>Recommended Specimen Length = 1.0 in</td>
<td>Recommended Rate of Gross Head</td>
</tr>
<tr>
<td></td>
<td>Motion = 0.05 in./min</td>
<td>Motion = 0.05 in./min</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>t (in.)</th>
<th>w (in.)</th>
<th>Load (lbf)</th>
<th>Shear Strength (psi)</th>
<th>Support Span (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>C-1</td>
<td>0.062</td>
<td>0.262</td>
<td>107.0</td>
<td>4940</td>
<td>4.5t</td>
</tr>
<tr>
<td>C-2</td>
<td>0.062</td>
<td>0.260</td>
<td>104.0</td>
<td>4839</td>
<td>4.5t</td>
</tr>
<tr>
<td>C-3</td>
<td>0.063</td>
<td>0.258</td>
<td>103.0</td>
<td>4753</td>
<td>5.0t</td>
</tr>
<tr>
<td>C-4</td>
<td>0.062</td>
<td>0.248</td>
<td>98.3</td>
<td>4795</td>
<td>5.0t</td>
</tr>
<tr>
<td>C-5</td>
<td>0.062</td>
<td>0.257</td>
<td>100.0</td>
<td>4707</td>
<td>5.5t</td>
</tr>
<tr>
<td>C-6</td>
<td>0.062</td>
<td>0.248</td>
<td>96.0</td>
<td>4683</td>
<td>5.5t</td>
</tr>
<tr>
<td>C-7</td>
<td>0.062</td>
<td>0.253</td>
<td>94.2</td>
<td>4504</td>
<td>6.0t</td>
</tr>
<tr>
<td>C-8</td>
<td>0.061</td>
<td>0.250</td>
<td>87.8</td>
<td>4318</td>
<td></td>
</tr>
</tbody>
</table>

*σ = Standard Deviation (with N-1 weighting)

Avg 4692

σ* 197
TABLE A-1. THREE POINT INTERLAMINAR SHEAR TEST
SPECIMEN BREAKDOWN (Continued)

Specimen Group — 7 Ply
Homogeneous Laminate
Post-Heated 1 minute at 550°F

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>t (in.)</th>
<th>w (in.)</th>
<th>Load (lbf)</th>
<th>Shear Strength (psi)</th>
<th>Support Span (A)</th>
</tr>
</thead>
<tbody>
<tr>
<td>P-1</td>
<td>0.060</td>
<td>0.248</td>
<td>95.0</td>
<td>4788</td>
<td></td>
</tr>
<tr>
<td>P-2</td>
<td>0.061</td>
<td>0.254</td>
<td>96.5</td>
<td>4671</td>
<td>4730</td>
</tr>
<tr>
<td>P-3</td>
<td>0.061</td>
<td>0.246</td>
<td>87.4</td>
<td>4368</td>
<td>4580</td>
</tr>
<tr>
<td>P-4</td>
<td>0.062</td>
<td>0.245</td>
<td>97.0</td>
<td>4789</td>
<td>5.0t</td>
</tr>
<tr>
<td>P-5</td>
<td>0.062</td>
<td>0.252</td>
<td>95.5</td>
<td>4584</td>
<td>4621</td>
</tr>
<tr>
<td>P-6</td>
<td>0.062</td>
<td>0.248</td>
<td>95.5</td>
<td>4658</td>
<td>5.5t</td>
</tr>
<tr>
<td>P-7</td>
<td>0.061</td>
<td>0.243</td>
<td>80.0</td>
<td>4048</td>
<td>4270</td>
</tr>
<tr>
<td>P-8</td>
<td>0.062</td>
<td>0.254</td>
<td>94.3</td>
<td>4491</td>
<td>6.0t</td>
</tr>
</tbody>
</table>

*σ = Standard Deviation
(with N-1 weighting)

Having verified the unpublished data from BAC, logic demanded a recheck of the data obtained under this contract. For this, it was decided to:

(a) Evaluate the effect of a bonded "stack-up" specimen on interlaminar shear strength. This was accomplished by fabricating specimens having the same number of fabric plies, but, consolidating them as a single, homogeneous, 15-ply laminate.

(b) Evaluate the consolidation process as performed by the subcontractor. This was accomplished by fabricating specimens of the bonded "stack-up" configuration. With the exception of the consolidation process, the specimens were identical in all respects to those fabricated under this contract. Consolidation was accomplished by Boeing Vertol (using in-house heated presses) instead of by a subcontractor.

The results of interlaminar shear testing on the homogeneous 15-ply laminate again demonstrated values along the same order of magnitude as obtained under the representative BAC testing, one order of magnitude greater than data obtained under this contract. See Table A-2 for individual specimen dimensions and test results.
Figure A-4. 7-Ply Kevlar 49/285 Style/P1700 Polysulfone Homogeneous Laminate Control – No Postform (Sheet 1 of 2)
Figure A-4. 7-Ply Kevlar 49/285 Style/P1700 Polysulfone Homogeneous Laminate
Postformed 1 Minute at 550°F/No Added Pressure (Sheet 2 of 2)
TABLE A-2. THREE POINT INTERLAMINAR SHEAR TEST
SPECIMEN BREAKDOWN

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>t (in.)</th>
<th>w (in.)</th>
<th>Load (lbf)</th>
<th>Shear Strength (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>A-1</td>
<td>0.123</td>
<td>0.249</td>
<td>193</td>
<td>4726</td>
</tr>
<tr>
<td>A-2</td>
<td>0.123</td>
<td>0.269</td>
<td>206</td>
<td>4670</td>
</tr>
<tr>
<td>A-3</td>
<td>0.123</td>
<td>0.256</td>
<td>182</td>
<td>4335</td>
</tr>
<tr>
<td>A-4</td>
<td>0.123</td>
<td>0.266</td>
<td>225</td>
<td>5158</td>
</tr>
<tr>
<td>A-5</td>
<td>0.123</td>
<td>0.273</td>
<td>225</td>
<td>5025</td>
</tr>
<tr>
<td>A-6</td>
<td>0.123</td>
<td>0.259</td>
<td>217</td>
<td>5109</td>
</tr>
<tr>
<td>A-7</td>
<td>0.123</td>
<td>0.245</td>
<td>197</td>
<td>4903</td>
</tr>
<tr>
<td>A-8</td>
<td>0.123</td>
<td>0.252</td>
<td>202</td>
<td>4888</td>
</tr>
<tr>
<td>A-9</td>
<td>0.123</td>
<td>0.271</td>
<td>237</td>
<td>5333</td>
</tr>
<tr>
<td>A-10</td>
<td>0.123</td>
<td>0.251</td>
<td>212</td>
<td>5150</td>
</tr>
</tbody>
</table>

Avg                               4930
σ* = 292

*σ = Standard Deviation (with N-1 weighting)
TABLE A-2. THREE POINT INTERLAMINAR SHEAR TEST
SPECIMEN BREAKDOWN (Continued)

Specimen Group — 15-Ply
Homogeneous Laminate
Post-Heated at 550°F for 1 Minute

Tested Per ASTM D2344-76:
Recommended Support Span = 5t
Recommended Specimen Length = 7t
Recommended Rate of Cross Head
Motion = 0.05 in./min

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>t (in.)</th>
<th>w (in.)</th>
<th>Load (lbf)</th>
<th>Shear Strength (psi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>SP-1</td>
<td>0.123</td>
<td>0.258</td>
<td>195</td>
<td>4609</td>
</tr>
<tr>
<td>SP-2</td>
<td>0.123</td>
<td>0.264</td>
<td>208</td>
<td>4804</td>
</tr>
<tr>
<td>SP-3</td>
<td>0.124</td>
<td>0.250</td>
<td>200</td>
<td>4839</td>
</tr>
<tr>
<td>SP-4</td>
<td>0.123</td>
<td>0.250</td>
<td>186</td>
<td>4537</td>
</tr>
<tr>
<td>SP-5</td>
<td>0.123</td>
<td>0.268</td>
<td>216</td>
<td>4914</td>
</tr>
<tr>
<td>SP-6</td>
<td>0.123</td>
<td>0.256</td>
<td>198</td>
<td>4716</td>
</tr>
<tr>
<td>SP-7</td>
<td>0.124</td>
<td>0.261</td>
<td>212</td>
<td>4913</td>
</tr>
<tr>
<td>SP-8</td>
<td>0.124</td>
<td>0.242</td>
<td>180</td>
<td>4499</td>
</tr>
<tr>
<td>SP-9</td>
<td>0.123</td>
<td>0.268</td>
<td>215</td>
<td>4892</td>
</tr>
<tr>
<td>SP-10</td>
<td>0.123</td>
<td>0.250</td>
<td>171</td>
<td>4171</td>
</tr>
</tbody>
</table>

Avg 4689.4
σ* 238.6

*σ = Standard Deviation (with N-1 weighting)
The results of interlaminar shear testing on the bonded “stack-up” specimens demonstrated values lower than a 15-ply homogeneous laminate, but, 64% higher values than the subcon-tracted consolidated material used under this contract. See Table A-3 for individual specimen dimensions and test results.

TABLE A-3. THREE POINT INTERLAMINAR SHEAR TEST SPECIMEN BREAKDOWN

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>t (in.)</th>
<th>w (in.)</th>
<th>Load (lbf)</th>
<th>Shear Strength (psi)</th>
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<td>F-1</td>
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<td>0.252</td>
<td>163</td>
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<td>164</td>
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Avg: 3527

\[ \sigma^* = 92.1 \]

*\( \sigma \) = Standard Deviation (with N-1 weighting)
TABLE A-3. THREE POINT INTERLAMINAR SHEAR TEST
SPECIMEN BREAKDOWN (Continued)

Specimen Group — Bonded
"Stack-Up" Specimens (15 Ply Total)
Post-Formed 1 Minute @ 550°F
(with no added pressure)

Tested Per ASTM D2344-76:
Recommended Support Span = 5t
Recommended Specimen Length = 7t
Recommended Rate of Cross Head Motion = 0.05 in./min

<table>
<thead>
<tr>
<th>Specimen No.</th>
<th>t (in.)</th>
<th>w (in.)</th>
<th>Load (lbf)</th>
<th>Shear Strength (psi)</th>
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Avg 3205

\[ \sigma^* = 151.0 \]

*\( \sigma \) = Standard Deviation (with N-1 weighting)
CONCLUSIONS

It may be concluded that the subcontracted consolidation process of Boeing Vertol specimen material (utilized under this contract) had not achieved the optimum material strength characteristics. However, interlaminar shear and flexural strength test data should always be used for comparative purposes only, and not design criteria. Thus, the comparative nature of this program has not been degraded.

It is probable that the difference in coefficient of thermal expansion between polysulfone and epoxy ($14 \times 10^{-6}$ vs $42 \times 10^{-6}$ in./in./°F) causes residual strains normal to and within the plane of the laminate, contributing to reduced interlaminar shear strength. This is further affected by the reinforcement of the polysulfone with Kevlar 49, decreasing its apparent thermal expansion and increasing its apparent modulus significantly relative to the low modulus high expansion epoxy, thus forcing the epoxy to make the strain accommodation. The lower thermal coefficient of polysulfone with respect to epoxy may account for some of the improvement in impact damage reported with glass, graphite and Kevlar 49 laminates in this case due to reduced residual strain in the resin after processing.
LIST OF REFERENCES

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   Contract N00019-74-C-0226.
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