OPTIMIZATION OF AIRCRAFT INTERIOR PANELS

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16. Abstract

Eight different graphite composite panels were fabricated using four different resin matrices. The resin matrices included Hercules 71775, a blend of vinylpolystyrpyridine and bismaleimide, H795, a bismaleimide, Cycom 6162, a phenolic, and PSP 6022M, a polystyrylpyridine. Graphite panels were fabricated using fabric or unidirectional tape. This report describes the processes for preparing these panels and some of their mechanical, thermal and flammability properties. Panel properties are compared with state-of-the-art epoxy fiberglass composite panels.

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

LIST OF TABLES

EXECUTIVE SUMMARY

Previous testing conducted on composite panels using small- and large-scale tests (ref. 1) have demonstrated that composite panels fabricated with a polyimide resin exhibited low heat-release rates, and low smoke-evolution rates. However, these composite panels are fairly expensive to fabricate, requiring multiple bonding steps and curing at temperatures of 250°C (482°F) or higher. Because of this high-temperature cure, these panels also require the use of a polyimide-coated Nomex (E.I. DuPont de Nemours and Co.) honeycomb which is more expensive than the phenolic-coated Nomex honeycomb currently used in composite panels.

The approach taken in the present study was to develop a composite panel which a) uses a resin system which cures at 177°C (350°F); b) does not require a secondary bond or extra adhesive to bond the face sheets to the honeycomb, and c) possesses optimum fire-resistant, thermal, and mechanical properties.

This panel is composed of unidirectional graphite tape impregnated with a resin consisting of a blend of bismaleimide (H795) (Technochemie GMBH) and vinylpolystyrlpyridine (XU71775) (Dow Chemical Co.). The properties of this panel are described and compared with panels made from three other different resins and a baseline panel consisting of epoxy-fiberglass.

INTRODUCTION

Objective.

The objective of this study was to develop and fabricate a composite panel with optimum thermophysical properties while maintaining processing parameters compatible with state-of-the-art panels composed of phenolic resins. In addition, panels constructed from other advanced materials were made and their flammability and mechanical properties were determined.

Background.

When structural interior composite panels for aircraft are subjected to intense heat or fire, release of heat and smoke into the aircraft cabin occurs (ref. 2). Experimental composite panels were developed and tested that offered improved fire resistance and smoke reduction in aircraft fires. In this program eight different types of experimental composite panels were evaluated in terms of their flammability and mechanical properties.

The composite panels used by most airframe manufacturers as interior paneling are sandwich panels that vary slightly in configuration, component composition, thickness, and density, depending on the type of aircraft in which they are used and the specific application. The baseline panel used in this study consists of a clear polyvinyl fluoride film bonded to a polyvinyl fluoride decorative film bonded to a fiberglass-resin laminate. The complete laminate is bonded to an aromatic polyamide-honeycomb core either when the prepreg is uncured or with a suitable adhesive film. The other side of the panel is similar, except for the absence of the decorative film. The complete description of this panel is given in Table 1.

DISCUSSION

Descriptions of Composite Panels.

Eight types of composite panels were evaluated in addition to the baseline panel. Four types of resin systems were used in the fabrication of the laminates used in these composites: a) H795/XU 71775, b) H795, c) Phenolic (Cycom 6162, American Cynamid Co.), and d) Polystyrylpyridine (PSP-6022, Society Nationale des Poudres et Explosifs).

These resins were used to fabricate the eight types of composite panels using two types of reinforcements: a) Graphite Fabric (A-193) and b) Unidirectional Tape (AS-4, Hercules, Inc.) graphite fiber. All panels were fabricated using both of Nomex HR-10 honeycomb, and all panels were decorated using a polyetheretherketone (PEEK, Imperial Chemical Industries, Ltd.) film attached with a silicone adhesive on the one side of the panel.

The components and composition of the panels are given in Table 1. The thickness of the panels varied slightly depending on the number of plies in each panel. Panels constructed with the A-193 graphite fabric had one ply on each side and panels fabricated with the AS-4 graphite unidirectional tape had three plies on each side placed at 0°, 90°, and 0° orientation for maximum strength.

The processing of the baseline panel has been described previously in detail (Ref. 3). Panels Type A, B, E, and F were cocured with the honeycomb core without the use of an additional adhesive. Panels Type C, D, G, and H used an adhesive film to bond the face sheets to the honeycomb (Table 1). Details of the prepreg development and preparation are shown in Appendix A. The fabrication procedure for the composite panels is described in Appendix B.

TEST RESULTS AND ANALYSIS

Thermochemical Characterization of Resins.

All of the resins used for the fabrication of the composite panels were obtained commercially with the exception of the resin for Panels A and B. The resin for panels A and B was formulated specifically for these panels and was characterized to obtain the optimum processing and curing conditions.

Differential-Scanning Calorimetry (DSC). The DSC of the H795/XU71775 resin was measured at 10°C/min (18°F/min) in nitrogen as shown in Figure 1. The endothermic peak at 60-140°C (140-284°F) is probably due to the evaporation of trace amounts of volatiles. The exothermic cure temperature is at 160-240°C, with the cure peak at 211°C (411°F). The resin can be cured at 177°C (350°F) for a longer time. The resin after heating at 177°C (350°F) for 3 hr showed no residue cure peak. The exothermic peak at 300-360°C (572-680°F) is probably related to the decomposition of the resin.

Thermogravimetric Analysis (TGA). The TGA curve of the 177°C- cured (350°F) pure resin in nitrogen at 10°C/min (18°F/min) is shown in Figure 2. The resin starts to decompose at about 320°C (608°F). The char yield at 800°C

(1472°F) is 52.5%. Additional thermal characterization details for the resins used in the preparation of Panels A, B, C, and D are shown in Appendix A.

Panel Evaluation.

Thermogravimetric Analyses. Thermal analyses of the baseline and type-B panels were conducted on a DuPont 1090 TGA using both nitrogen and air atmospheres with a sample size of 10 mg. The TGA analyses data of 10°C/min (18°F/min) heating rate in nitrogen and air is given in Table 2. It can be seen that under both the nitrogen and air environment, Panel B had a higher char yield than did the baseline epoxy panel.

Mass-Loss Comparison. The mass loss of the composite panels was determined using the modified National Bureau of Standards (NBS) Smoke Chamber (ref. 4). For these studies, the heater was calibrated using a water-cooled copper calorimeter at the approximate position where the samples were to be placed. The calibration curve for this calorimeter is shown in Figure 3. The samples were cut into 7.62-cm (3- by 3-in.) squares. They were put into the sample holder as shown in Figure 4. A heat shield was positioned directly in front of the heater. The sample and holder were placed in position in front of the heater, but behind the shield, as shown in Figure 4. the heat shield was removed and the testing equipment was turned on simultaneously. At the end of the allotted testing time period for each sample, usually 3 min, the heat shield was replaced, and the sample was removed and allowed to cool.

At least three specimens were tested from each of the eight panel configurations at a radiant heat flux of 3.5 W/cm^2 (3.08 $Btu/ft^2 \cdot sec$). The percent mass loss as a function of time is shown in Figure 5.

The percent mass loss is governed by this equation:

$$\% \text{ Mass Loss} = \frac{(\text{Mass loss at any time interval})}{\text{Original Mass}} \times 100$$

It can be seen in Figure 5 that the panels fabricated with the PSP 6022 resin had the lowest weight loss of all the specimen tested. The second lowest was Panel B fabricated with the H795/XU71775 resin using the graphite unidirectional tape. The panel with the highest weight loss was the baseline epoxy-fiberglass panel. Weight loss of the composite panels is an important parameter since it corresponds directly to the amount of visible smoke and other toxic gases produced during the pyrolysis of the sample. The lower rate of weight loss corresponds a lower rate of pyrolysis products produced.

Surface Flammability. The composite panels with the PEEK film were tested in accordance with the procedures specified in ASTM E-162-83 (Ref. 5). Specimens were predried for 24 hr at 60°C (140°F) and then conditioned to equilibrium at a temperature of 23°C (75°F) and a relative humidity of 50% ± 5%. The specimens were supported with a 2.5-cm (1-in.) hexagonal wire mesh in accordance with para- graph 5.9.2 of the test method. The panels were tested with the film side facing the radiant heat source.

The test results are given in Table 3. The following observations were made during the testing of these panels.

Baseline Panel: There was considerable charring, bubbling, and cracking on the specimen surface. The panel core maintained good structural integrity, and there was slight smoke evolution.

Panel A: There was considerable melting, bubbling, and shrinking of the film facing. The panel core maintained good structural integrity with moderate charring on the surface, and there was slight smoke evolution.

Panel B: There was considerable melting and shrinking away of the film facing. The panel core maintained good structural integrity, and there was very light smoke evolution. (A disparity among the flame-spread indices (Table 3) is indicative of a much greater heat rise in the case of specimens 3 and 4 and in the case of specimen 2, a flame front advance which did not extend to the first data point at 7.5 cm (3 in.).)

Panel C: There was considerable melting, shrinking, and bubbling of the film facing. The panel core maintained good structural integrity with moderate charring and slight flaking, and there was slight smoke evolution.

Panel E: There was considerable melting, bubbling, and shrinking away of the film facing. The panel core maintained good structural integrity with slight charring and swelling, and there was slight smoke evolution. (The higher flame-spread indices (Table 3) for specimens 3 and 4 were due to a greater heat rise in both cases and, additionally, a flame-spread advance which extended to the 15-cm (6-in.) data point on specimen 4.)

Panel F: There was considerable melting and shrinking away of the film facing. The panel core maintained good structural integrity, with moderate charring, swelling, and blistering, and there was moderate smoke evolution.

Panel G: There was considerable bubbling of the film facing noted shortly after radiant heat exposure. Surface flaming was confined to the facing material. The panel core maintained good structural integrity. (A higher flame spread index for specimen 1 was due to a greater heat rise.)

Heat Release. The heat release of the panels was determined using the Ohio State Heat Release Calorimeter. The procedure followed was that described in Ref. 1 (Revision of Ref. b). Total-heat release and peak-heat release rates were evaluated for each composite panel at a heat-flux exposure of 3.5 W/cm^2 (3.08 $Btu/ft^2 \cdot sec$). The heat release was determined using the calorimetric method. The test results are shown in Table 4. According to these test results, of the nine panels tested only Panel Type B-XU771775/H795 Tape/PEEK met the criteria indicated in Ref. 1. These results included a maximum total-heat release of 62 $kW \cdot min/m^2$ at 2 min and a peak-heat release rate of 51 kW/m^2.

Smoke-Emission Test. The smoke-emmision characteristics of the panels were determined using the technique of smoke accumulation in an enclosure and were measured using the NBS smoke chamber (Ref. 7).

The values for the smoke generation of the materials in this report were obtained in strict accordance with this standard procedure. They shall be used solely to define the properties of the described materials when exposed to heat and flames in controlled laboratory conditions. The results shall not

be used as measures of smoke hazard under actual fire conditions or for toxicological assessment.

The method defines smoke generation under flaming and nonflaming modes, which are reported as average maximum specific optical density. The method is intended for use only in research and development and not as a basis for regulatory purposes. Test samples are conditioned at 60°C (140°F) for 24 hr followed by stabilization at 21°C (70°F) and 50% relative humidity. This method employs 76.2- by 76.2-mm (3- by 3-in.) specimens mounted in a peripherally flanged, vertical steel holder at a distance of 38.1 mm (2.5 in.) from an electrically heated radiant-energy source putting out 2.5 W/cm^2 (2.2 $Btu/ft^2 \cdot sec$) for a period up to 20 min. The film side of each panel is exposed to the radiant heat source. The temperature on the center surface of the back wall is maintained at 35 ± 2°C (95 ± 4°F). The smoke evolved is measured through a light path of 91 cm (36 in.) in the sealed chamber using a light source and photomultiplier tube arrangement. A minimum of three specimens are exposed to the identical heat source with a row of six small flamelets across the lower edge of the exposed sample. Millivolt output from the photomultiplier tube is recorded until a minimum value is recorded or for 20 min maximum. The dimensionless value is expressed as specific optical density (D_s).

The percentage change in the light transmission is converted to an optical density value by means of the following equations:

$$D_s = (V/AL) \log a_{10}(100/Plt)$$

where: V is chamber volume, 0.51 m^3 (18 ft^3); L is light path length, 0.91 m (3 ft); A is exposed-test-specimen surface area, 42.35 cm^2 (6.56 $in.^2$); and Plt is percent light transmission. The smaller the D_s value is, the less smoke is evolved from the material. The smoke-test data are included in Tables 5 and 6.

Gas Analyses. In addition to D_s, the panels tested were sampled for carbon monoxide, nitrogen oxide, hydroden fluoride and hydrogen cyanide. These gases are measured as approximate parts per million (ppm) produced during the burning process in the flaming mode only. The samples were exposed for 20 min in the NBS smoke chamber described previously in this paper.

During the flaming mode, test gases were drawn through colorimetric tubes manufactured by Kitagawa. The length of stain produced for each of the gases was measured and was related to the number of pump strokes. From these measurements an approximate concentration in ppm can be determined.

The test results are given in Table 7.

Oxygen Index. The composite panels were tested in accordance with the American Society for Testing Materials (ASTM) D-2863-77 (Ref. 8). The oxygen index is defined as the minimum concentration of oxygen, in a mixture of oxygen and nitrogen that will just support combustion of a material under conditions of this method. The intent of this test method is to determine the relative flammability of plastics by measuring the minimum concentration of

oxygen in a slowly rising mixture of oxygen and nitrogen that will just support combustion. This method is limited to the use of physically self-supporting plastic test specimen(s). Specimens 6.5 mm (0.25 in.) wide and 70 to 150 mm (2.5 to 5.9 in.) long are tested in an as-received condition. The test column is a heat-resistant glass tube that is 75 mm in diameter and is at least 450 mm long. The tube is mounted on a base of noncombustible material with a mixing chamber. The top of the specimen is ignited with the flame (natural gas or propane) adjusted so that the specimen is well ignited and the entire top is burning. The igniting flame is removed and the oxygen/nitrogen ratio is adjusted so that the specimen burns 3 min or longer, or the specimen burns to a depth of 50 mm. A minimum of seven specimens are tested.

Seven 152.4- × 6.35-mm (6- × 2.5-in.) samples were cut from the panels. These were tested with the added step of equilibration at approximately 50% R.H. and 23°C (75°F). The test results are shown in Table 8.

Panel B-XU71775/H795 Tape/PEEK had the highest oxygen index of all the panels tested following by Panel A-XU71775/H795 Fabric/PEEK. The Baseline-Epoxy-Glass Fabric/PVF had the lowest oxygen index.

Ignition Resistance. The composite panels were tested in accordance with Federal Aviation Regulation (FAR) 25.853 (Ref. 9). This method is intended for use in determining the resistance of material to flame and glow propagation and tendency to char. It is designated primarily for cellulosic fabrics treated with a flame retardant, but may be used in other applications such as laminates, as specified in applicable procurement documents.

The material undergoing test was evaluated for after-flame time, afterglow time, and char length on each specimen. The specimens were conditioned in accordance with the ASTM standard. Each specimen tested was exposed to the test flame within 20 sec after removal from the standard atmosphere. Each specimen was inserted into the cabinet and the 3.81-mm (1 1/2-in.) Bunsen burner flame was applied vertically at approximately 899°CF (1659°F) to the middle of the lower edge of the specimen for 60 sec.

The after-flame time and afterglow time of the specimen were recorded to the nearest 0.2 sec and the char length to the nearest 2.5 mm (0.1 in.). The test criteria for this test are:

Char length:	Maximum average, 15.2 cm (6 in.).
After-flame:	Maximum average, 15 sec
Drip burn:	Maximum average, 3 sec

Each specimen was 7.0 by 30.5 cm (2 3/4 by 12 in.). Seven specimens were tested for the base panel and four each for other panels. The test results are shown in Table 9.

The panels, except for the A-XU71775/H795 Fabric/PEEK, are considered to have passed FAR 25.853A 60-Sec Vertical Test and Federal Test Standard 191 Method 5903, with respect to drip, after-flame, and afterglow. Panel A failed because its char length extended beyond 15.2 cm (6 in.).

Mechanical Properties. The flexural strength and modulus, peel, and tensile strength, and density of the composite panels were determined using the Military Standard, MIL-STD-401 (Ref. 10). The properties of the baseline epoxy-glass fabric panel in 2.54 cm (1 in.) thickness have been reported previously in (Ref. 11). The present panels tested were approximately 0.67 cm (0.26 in.) thick.

Flexular Strength and Modulus. The flexural strength and modulus of the composites was measured using the sandwich-beam flexure apparatus. The bottom span was 55 cm (22 in.) and the top span was 20 cm (4 in.). The test results are given in Table 10. Panels type B and D showed the highest compressive stress. Panels constructed with the unidirectional tape showed the highest flexural strength. Panel type B at 0.72 cm (0.28 in.) thick had a compressive stress of 91.1 kg/cm (510 lb/in.) compared to a baseline epoxy-glass fabric panel at 2.54 cm (1 in.) thick with a compressive stress of 70.2 kg/cm (393 lb/in.).

Peel Strength. The peel strength of each composite was determined using the climbing-drum peel apparatus. The rate of test was 2.5 cm/min (1.0 in./min), the drum radius was 5.0 cm (2 in.), the flange radius was 6.3 cm (2.5 in.) and the torque arm was 1.2 cm long (0.5 in.). The test results are given in Table 11. Panel type F had the highest peel strength. The baseline panel has a peel strength of 1.3 cm-Kg/cm width (Ref. 11).

Flatwise-Tensile Strength. The flatwise tensile strength of the panels is given in Table 12. As a comparison, the flatwise tensile strength of the baseline panel is 19.0 kg/cm^2 (270 $lb/in.^2$) (Ref. 11).

Density. The density of the panels is given in Table 13. Panel type B has approximately equivalent density to the baseline panel. All of the graphite fabric panels have a lower density than the baseline panel.

SUMMARY OF RESULTS

Eight graphite composite panels were fabricated and tested in addition to a baseline epoxy-glass fabric panel. The thermal and flammability tests conducted included: DSC, TGA, mass loss, surface flammability, heat release, smoke emission, gas analyses, oxygen index, and ignition resistance. The mechanical tests conducted included flexural strength and modulus, peel strength, and flatwise-tensile strength and density. The following is a summary of the major results:

1. The Baseline panel had the highest heat-release rates, total-heat release rate, smoke evolution, mass loss, and CO evolution, and the lowest oxygen index.

2. Panel Type A had the lowest flame-spread index. However, it failed the ignition resistance test.

3. Panel Type B had the lowest heat-release rates and total-heat release, and highest oxygen index.

4. Panel Type C exhibited low flame spread in the surface flammability test.

5. Panel Type D exhibited low smoke evolution.

6. Panel Type E had average smoke evolution and heat-release rate.

7. Panel Type F had the highest peel strength.

8. Panel Type G had the lowest smoke evolution.

9. Panel Type H had the lowest mass loss. The results are also summarized in Table 14, which gives the relative ranking of the panels based on the flammability tests.

CONCLUSIONS

Three conclusions can be drawn from our results:

1. Graphite panels consisting of XU 71775/H795 tape/PEEK exhibited the lowest heat-release rates of all the panels tested. This panel meets the proposed regulatory requirements stated in Reference 6 and as revised in Reference 1. This panel also exhibited the highest oxygen index of all the panels tested.

2. At approximately equivalent densities, the PEEK panel has much higher flexural strength and equivalent and tensile strength than the baseline epoxy-fiberglass panel.

3. The baseline panel exhibited the highest heat release rates and smoke evolution of all the panels tested.

APPENDIX A

PREPREG DEVELOPMENT AND PREPARATION

Prepregs for Panels A and B.

Prepregs were formulated in the following manner:

1. Gel Times: 5 min at 177°C (350°F)
   18 min, 40 sec at 140°C (300°F)
   less than 1 hr, 15 min at 121°C (250°F)

2. Exotherm Tests: Exothermed in 10 hr at 80°C (176°F); in 3 hr at 100°C (212°F)

3. Solubilities: Soluble in tetrahydrofuran and dimenthylformamide, dispersible in methyl ethyl ketone.

An attempt was made to make 7.6-cm (3-in.) prepreg tape of this formulation on AS4W-12W without roll-milling. Prepregging was very difficult because of the large particle size of the 71775. Roll-milling of the hot resin solved this problem and good tape was produced.

A 15-ply, 7.6- by 25-cm (3- by 10-in.) panel was cured for 2 hr at 177°C (350°F). Samples measuring 1.3 cm by 6.4 cm (0.5 in by 2.5 in.) were cut and given various postcures. The samples were then tested to determine the glass transition temperature (TΔG'). From this study and from results of testing by Ames Research Center, the following cure/postcure schedule was developed:

1. Precure = 20 min at 130°C (266°F)
2. Cure = 6 hr at 177°C (350°F)
3. Postcure = 18 hr at 177°C (350°F)

The precure step was found by Ames Research Center to aid in flow control on fabric prepreg. A TΔG' of 193°C (380°F) was ultimately reached. Higher-temperature postcures (up to 232°C, 450°F) produced the same TΔG'.

Sixteen kilograms of the formulation were mixed. This mix was roll-milled in four batches for hot-melt prepregging onto A193P fabric using Hercules production equipment - 107-cm-wide (42-in.-) prepreg was produced. The resin ran very well in the prepregger.

Prepregs for Panels C and D.

The H795 is a brittle, glassy solid which becomes tacky and flexible above 50°C (122°F). To obtain a room-temperature flexible and tacky prepreg, the resin requires formulation with some liquid diluent--preferable a reactive diluent to avoid losing mechanical properties at elevated temperatures. Thus, H795 was mixed at various percentages with several reactive, unsaturated, and fairly high-boiling-liquid monomers. The mixtures were tested for flexibility and tackiness at room temperature by pressing with a wooden spatula. In this way a H795 formulation possessing suitable tack and flexible properties was

found. Several tests showed it to be fairly reactive (i.e., a DSC, gel time at 177°C (350°F), gel curve). However, exotherm tests indicated it to be resistant to runaway exotherming at prepregging temperatures.

This formulation was soluble to at least 70% by weight in methyl ethyl ketone. Hand-made fabric prepregs (A193P) from this solvent were successfully made. Resin contents were determined to be 68% and 56%. The prepreg lost its tackiness on standing at room temperature, probably because of increased reactivity of the reactive diluents.

In spite of these indications of reactivity, and in view of the reassuring exotherm tests, 7.6-cm (3-in.) tape prepregging was attempted. The first 4000-g batch gelled in the hopper after 60 m (200 ft) of tape had been made, and the second batch gelled during mixing. Neither batch exothermed.

Fabric prepregging of this formulation using the solvent coater (methyl ethyl ketone as solvent) was also unsuccessful. The machine malfunctioned and only 12 m (40 ft) of prepreg were produced.

It was decided to test free-radical inhibitors to reduce the reactivity of this formualtion. Thus, a selection of inhibitors were added to the formulation at several levels. The resulting formulation possessed physical and reactivity properties which were suitable for hot-melt and solvent-based prepregging, as shown in the following list:

1. Differential Scanning Calorimetry: small exotherm (4 J/g) at 105° - 155°C (221 - 311°F) with major exotherm (220-250 J/g) at 214°C (417°F)

2. Thermogravimetric Analysis: about 5% weight loss in volatiles up to 160°C (320°F) with major decomposition occuring at 415°C (779°F); char yield of 55% at 520°C (968°F)

3. Gel Curve: viscosity at 78°C (172°F) of 1200 poise, with a minimum viscosity of 4.2 poise at 130°C (266°F)

4. Gel Time at 177°C (350°F): time of 8 to 9 min

5. Exotherm Test: exotherm started at about 10 hr at 100°C (212°F)

6. Solubilities: soluble in acetone, methyl ethyl ketone, methylene chloride; insoluble in 1,1,1-trichloroethane

This inhibited forumulation was successfully hot-melt prepregged to yield 7.6-cm (3-in.) tape. This prepreg was used for Panel Type D. A 15-ply 7.6-cm. × 25-cm. (3 in. × 10 in.) panel was given a cure of 2 hr at 177°C (350°F). Pieces of cured panel, 1.3 cm × 6.4 cm (0.5 in × 2.5 in.), were cut and given various post cures. The TΔG' (the temperature at which the composite modulus drastically drops) was, over 300°C (572°F) with an autoclave cure of 2 hr at 177°C (350°F) and a post cure of 1 hr at 204°C (400°F) and 4 hr at 232°C (450°F).

Fabric prepreg on A193P was then successfully made using a solvent coater with the resin dissolved at 65% w/w in aceone. This prepreg was used for Panel Type C.

APPENDIX B

FABRICATION PROCEDURES FOR COMPOSITE PANELS

SCOPE: This process document covers materials and procedures for the fabrication of Ames Research Center Panel Types A, B, C, D, E, F, G, and H shown in Table 1.

APPLICABLE DOCUMENTS: MIL-STD-401--Sandwich constructions and core materials; general test methods

REQUIREMENTS: This process document establishes the fabrication techniques for manufacture of Ames Research Center panel types A, B, C, D, E, F, G, and H for fire-resistant-aircraft interior paneling. Included are materials, tooling, equipment, and fabrication procedures.

MATERIALS.

PRODUCTIVE MATERIALS: Productive materials are those materials incorporated into the product during fabrication and shall be limited to those described in Table B1:

TABLE B1.- PRODUCTIVE MATERIALS

	DESCRIPTION	SOURCE
ALL	NOMEX HONEYCOMB TYPE HRH-10-1/8-3.0 6.35 mm (0.25 in.) THICK	HEXCEL CORP. LONG BEACH, CA
A	XU71775/H795/A193P GRAPHITE PREPREG	HERCULES, INC. MAGNA, UT
B	XU71775/H795/AS4 GRAPHITE PREPREG	HERCULES, INC. MAGNA, UT
C	H795/A193P GRAPHITE PREPREG	HERCULES, INC. MAGNA, UT
D	H795/AS4 GRAPHITE PREPREG	HERCULES, INC. MAGNA, UT
E	Cycom 6162/A193P GRAPHITE PREPREG	AMERICAN CYANAMID CHARLOTTE, NC
F	Cycom 6162/AS4 GRAPHITE PREPREG	AMERICAN CYANAMID CHARLOTTE, NC
G.	PSP 6022M/A193P GRAPHITE PREPREG	COMPOSITES HORIZONS, INC. COVINA, CA
H.	PSP 6022M/AS4 GRAPHITE PREPREG	COMPOSITES HORIZONS, INC. COVINA, CA
I.	FM 34-B-32 ADHESIVE FILM	AMERICAN CYANAMID HAVRE DEGRACE, MD
J.	X3-5815 ADHESIVE	DOW CORNING MIDLAND, MI
K.	PEEK FILM	WEST PLASTICS LENNI, PA

NONPRODUCTIVE MATERIALS: Nonproductive materials (Table B2) are those materials not incorporated into the product, but are typical of those used and consumed during the fabrication process.

TABLE B2.- NONPRODUCTIVE MATERIALS

DESCRIPTION	SOURCE
RELEASE FILMS	
TX 1040 1 MIL TEFLON FILM	COMMERCIAL* DUPONT
BLEEDERS AND BREATHERS	
AIRWEAVE N10	AIRTECH, INC. CARSON CITY, CA
MOCHBURG GLASS CLOTH, STYLE 120	OWENS CORNING
VACUUM BAGGING MATERIALS	
VAC-PAC HS-8171	RICHMOND REDLANDS, CA
KAPTON (HIGH-PERFORMANCE BAG) SM 5126-2 VACUUM SEALANT	SCHNEE-MORIHEAD, INC. SANTA FE SPRINGS, CA
MISCELLANEOUS MATERIALS	
SILICON DAMING	COMMERCIAL
HIGH-TEMPERATURE TAPE	COMMERCIAL
METHYLENE CHLORIDE	COMMERCIAL
0.64-CM (0.25-IN.) ALUMINUM CAUL PLATE	COMMERICAL

*COMMERCIAL REFERS TO AN OFF-THE-SHELF PRODUCT.

EQUIPMENT AND FACILITIES.

OVEN: A circulating-air-batch oven capable of controlling temperatures up to 522 K (480°F, 249°C) is required for processing the honeycomb core, postcuring the skins, postcuring sandwiches, and curing adhesive for bonding of the decorative PEEK film. the oven must be equipped with a suction fan to vent the exhaust gases to the outside atmosphere.

AUTOCLAVE: An autoclave capable of the following minimum temperatures and pressures are required for cure of graphite sandwiches and/or graphite skins (Table B3).

TABLE B3.- MINIMUM TEMPERATURE AND PRESSURES

PANEL TYPE	TEMPERATURE, K (°F, °C)	PRESSURE, KPA(PSI)
A,B	450 (350, 177)	172 (25)
C,D	450 (350, 177)	690 (100)
E,F	405 (270, 132)	172 (25)
G,H	478 (400, 204)	1034 (150)

MATERIALS STORAGE AND HANDLING: All graphite prepreg and FM 34B film adhesive shall be stored at or below 255 K (0°F, -18°C). Those materials shall be allowed to warm at room temperature in their sealed containers prior to removal to prevent moisture condensation. Honeycomb shall be stored flat in its original shipping container. The X3-5815 adhesive will be stored in a nonflammable cabinet when not in use.

FABRICATION OF PRECURED GRAPHITE SKINS: The panel types C, D, G, and H are fabricated by the following steps:

1. Allow graphite prepreg to warm to room temperature prior to unspooling.

2. Cut patterns for the following and lay up on an aluminum or graphite platen.

Panel Types C and D

a. 1-mil Teflon film
b. TX 1040
c. 1-ply Type-c graphite prepreg or 3-ply Type-D graphite prepreg
d. Tx 1040
e. 1 mil Teflon film
f. 0.25 in. aluminum caul plate
g. Airweave N10

Panel Types G and H

a. 1 mil Teflon film
b. TX 1040
c. 1-ply Type-G graphite prepreg or 3-ply Type-H graphite prepreg
d. TX 1040
e. glass cloth, style 120
f. 1 mil Teflon film
g. 0.25 in. aluminum caul plate
h. airweave N10

3. Bag lay up for autoclave cure. For Panel Types C and D use Vac-Pac HS-8171 film and vacuum sealant. For Panel Types G and H use kapton film and vacuum sealant.

4. Autoclave cure as follows:

Panel Types C and D

a. Apply vacuum 584-mm (23-in.) Mercury
b. Raise pressure to 690 kPa (100 psi) and temperature to 450°K (350°F, 177°C) at a rate of 1.5 K/min (3°F/min, 1.5°C/min).
c. Hold temperature, pressure, and vacuum for 2 hr.
d. Cool to 339 K (150°F, 66°C) under pressure and vacuum.

Panel Types G and H

a. Raise temperature to 450 K (350°F, 177°C) at a rate of 1.5 K/min (3°F/min, 1.5°C/min).
b. Hold 450 K (350°F, 177°C) for 1 hr.
c. Raise temperature to 478 K (400°F, 204°C) at a rate of 1.5 K/min (3°F/min, 1.5°C/min) dwell 15 min.
d. Apply vacuum, 584 mm Mercury (23 in. Mercury), dwell 10 min.
e. Apply 1034 kPa (150 psi) at a rate of 69 kPa/min (10 psi/min).
f. Vent vacuum at 139 kPa (20 psi).
g. Hold 478 K (400°F, 204°C) and 1034 kPa (150 psi) for 9 hr.
h. Cool to 339 K (150°F, 66°C) under pressure.

5. Debag cured skin stock. Place skin stock (stacking same size skins) on aluminum or graphite platen and cover skin stock with 0.64 cm (0.25 in.) aluminum caul plate. Place platen in a circulating air oven and post cure as follows:

Panel Types C and D

a. Raise temperature rapidly to 477 K (400°F, 204°C).
b. Hold 477 K (400°F, 204°C) for 1 hr.
c. Raise temperature to 505 K (450°F, 232°C) at 1.5 K/min (3°F/min, 1.5°C/min).
d. Hold 505 K (450°F, 232°C) for 4 hr.
e. Cool to 339 K (150°F, 66°C).

a. Raise temperature to 522 K (480°F, 249°C).
b. Hold 522 K (480°F, 249°C) for 2 hr.
c. Cool to 339 K (150°F, 66°C).

6. Store precured skin stock flat until ready for use in the sandwich-bonding operations.

FABRICATION OF CORE STOCK: Fabrication of the core stock is done by the following steps:

1. Cut the 6.3-mm-(0.25-in.-) thick Nomex core into the required sizes (same size as graphite skins).

2. Place the Nomex in an air-circulating oven and bake as follows:

a. Raise temperature to 394 K (250°F, 121°C).
b. Hold 394 K (250°F, 121°C) for 1/2 hr.
c. Cool to 339°D (150°F, 66°C).

BONDING OF SANDWICH STOCK: Bonding of the sandwich stock is done by the following steps:

1. Tape corners of teflon film to platen with high performance tape. Teflon should be 25.4 mm (1 in.) larger, on all sides, than graphite skin.

2. Lay precured graphite skin on top of teflon film (leave TX 1040 on bottom side only).

3. Position a ply of FM-34B adhesive film onto the precured skin. If joints are required, they are to be butt joints.

4. Position the trimmed Nomex core as per engineering drawing requirements.

5. Position a ply of FM-34B adhesive film on to the Nomex core. If joints are required, they are to be butt joints.

6. Position a precured graphite skin on top of the FM-34B adhesive (leave TX 1040 on top side of graphite only).

7. Apply a piece of mochburg over the TX 1040.

8. Apply 0.64-cm (0.25-in.) aluminum caul plate (same size as graphite skin) on tope of the mochburg.

9. Surround the lay up with silicon-edge dam 63 mm × 25.4 mm (0.25 in. × 1 in). Stack damming until it is flush with or higher than the aluminum caul plate.

10. Cover entire lay up with airweave N10 leaving at least 25.4 mm (1 in.) overhang around the perimeter.

11. Apply a Vac-Pac HS-8171 bag over the lay up with vacuum sealant and draw a minimum vacuum of 584 mm Hg (23 in.). Be sure all bridging is eliminated, and the bag is free of leaks.

12. Autoclave cure as follows:

    a. Apply a vacuum of 584 mm (23 in.) Hg. and pressure of 173 kPa (25 psi).
    b. Raise temperature at 1.5 K/min (3°F/min, 1.5°C/min) to 394 K (250°F, 121°C).
    c. Hold 394 K (250°F, 121°C) for 30 min.
    d. Raise at 1.5 K/min (3°F/min, 1.5°C/min) to 450 K (350°F, 177°C).
    e. Hold at 450 K (350°F, 177°C) for 4 hr.
    f. Cool to 339 K (150°F, 66°C).
    g. Release pressure.

13. Debag the lay up and clean up as required.

FABRICATION OF COCURED PANEL TYPES A, B, E, AND F
FABRICATION OF CORE STOCK (SEE STEP 7.1)
FABRICATION OF PANELS: Fabrication of the panel are done by the following steps:

1. Allow graphite prepreg to warm to room temperature prior to unspooling.

2. Tape corners of teflon film to platen with high-temperature tape.

3. Lay uncured graphite prepreg (with TX 1040 on bottom side) on teflon film. One-ply graphite prepreg, Type A or E, or 3-plies graphite prepreg, Type B or F.

4. Position honeycomb core on prepreg.

5. Lay uncured graphite prepreg (with TX 1040 on top side) on honeycomb core. One-ply graphite prepreg, Type A or E, or 3-plies graphite prepreg, Type B or F.

6. Lay a piece of teflon film over TX 1040.

7. Apply high-temperature tape from the teflon to platen on all edges.

8. Position a 0.64-cm (0.25-in.) aluminum caul plate over the teflon.

9. Surround the lay up with silicon-edge dam 6.3 mm × 25.4 mm (0.25 in. × 1 in.). Stack damming until it is flush with or higher than the aluminum caul plate.

10. Cover entire lay up with airweave N10 leaving at least 25.4 mm (1 in.) overhang around the perimeter.

11. Apply a Vac-Pac HS-8171 bag over the lay up with vacuum sealant and draw a minimum vacuum of 584 mm Hg (23 in.). Be sure all bridging is eliminated and the bag is free of leaks.

12. Autoclave cure as follows:

Panel Types A and B

a. Apply vacuum of 584 mm Hg (23 in.) and pressure of 173 kPa (25 psi).
b. Raise temperature at 1.5 K/min (1.5°C/min) to 403 K (266°F, 130°C).
c. Hold at 403 K (266°F, 130°C) for 20 min.
d. Raise temperature at 1.5 K/min (3°F/min, 1.5°C/min) to 450 K (350°F, 177°C).
e. Hold at 450 K (350°F, 177°C) for 6 hr.
f. Cool to 339 K (150°F, 66°C).
g. Release pressure.

Panel Types E and F

a. Apply vacuum of 584 mm Hg. (23 in.) and pressure of 173 kPa (25 psi).
b. Raise temperature at 1.5 K/min (3°F/min, 1.5°C/min) to 405 K (270°F, 132°C).
c. Hold at 405 K (270°F, 132°C) for 1 hr.
d. Cool to 339 K (150°F, 66°C).
e. Release pressure.

14. Debag the lay up and clean as required.

15. Post cure Panel Types A and B only as follows:

a. Place panels on aluminum or graphite platen and cover with 0.64-cm (0.25-in.) alumimum caul plate.
b. Place platen in circulating air oven and post cure 18 hr at 450 K (350°F, 177°C).
c. Cool to 339 K (150°F, 66°C).

APPLICATION OF PEEK FILM: The PEEK film is applied by the following steps;

1. Clean panel skin with MeCl. Air dry.

2. Prepare xylene and benzoyl peroxide catalyst solution as follows:

xylene -	4.70 g
benzoyl peroxide -	0.52 g
	5.22 g

Mix solution with 350 g of X3-5815 adhesive. Several batches of catalized adhesive may be required depending on the number of panels to be processed.

3. Apply a 0.0025 cm (0.001 in.) coating of the prepared adhesive to the finished panel.

4. Dry the adhesive at the following temperatures:

   a. 343 K (158°F, 70°C) for 15 min or more
   b. 423 K (302°F, 150°C) for 5 min

5. Apply PEEK film to the panel and place under vacuum 584 mm Hg. (23 in.) for 1 hr.

6. Trim PEEK film to edge of panel.

7. Cut panels to the desired size.

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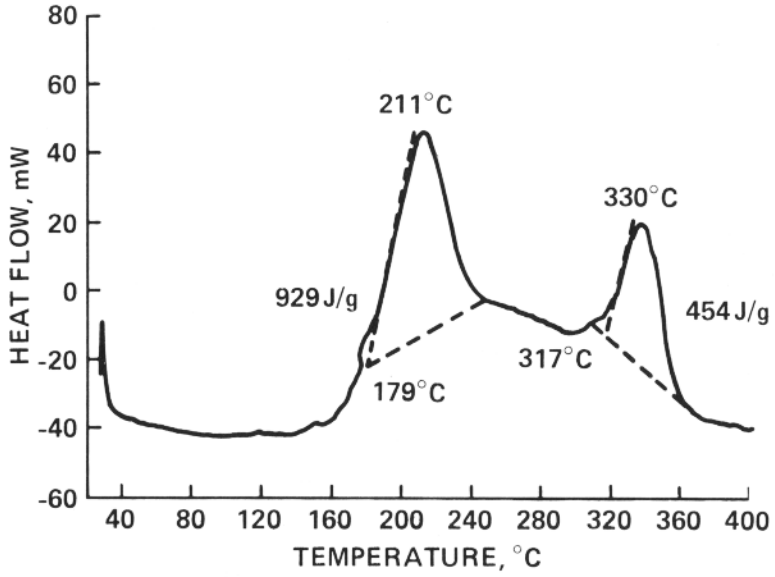

FIGURE 1. DIFFERENTIAL SCANNING CALORIMETRY OF XU-71775/H795 RESIN.

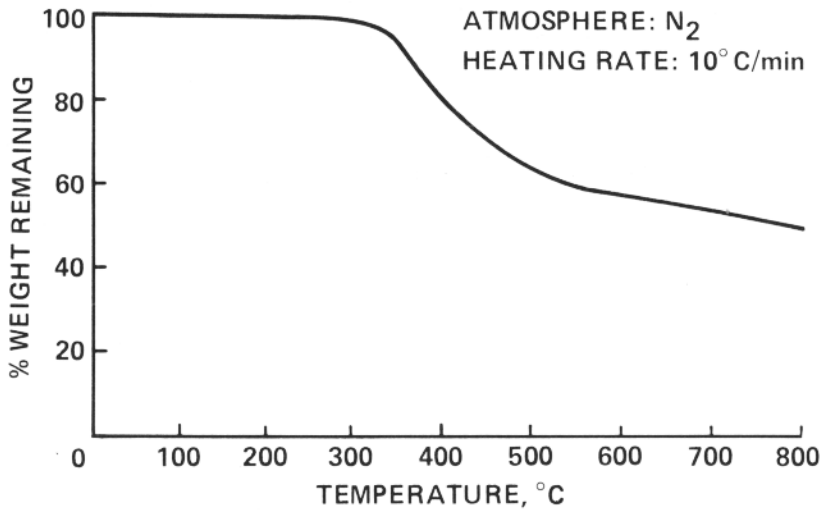

FIGURE 2. THERMOGRAVIMETRIC ANALYSIS OF XU-71775/H795 RESIN.

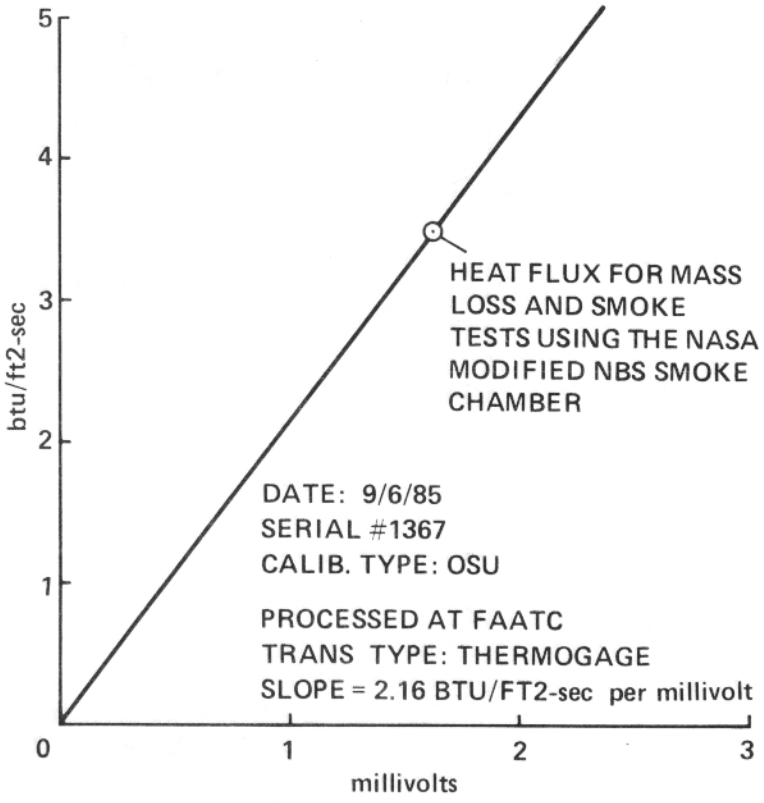

FIGURE 3. CALIBRATION CURVE FOR CALORIMETER.

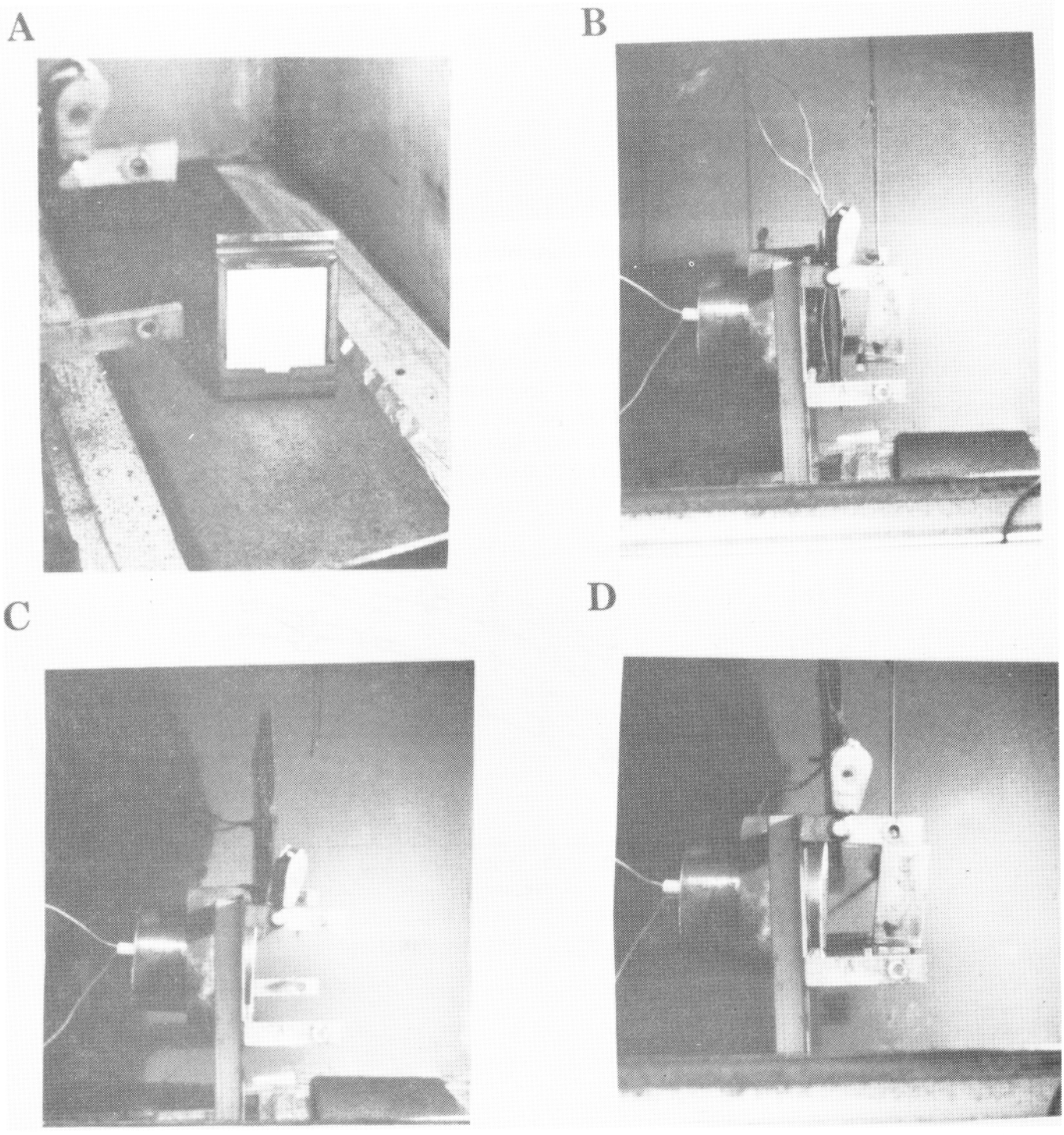

FIGURE 4. MASS-LOSS SAMPLE HOLDER.

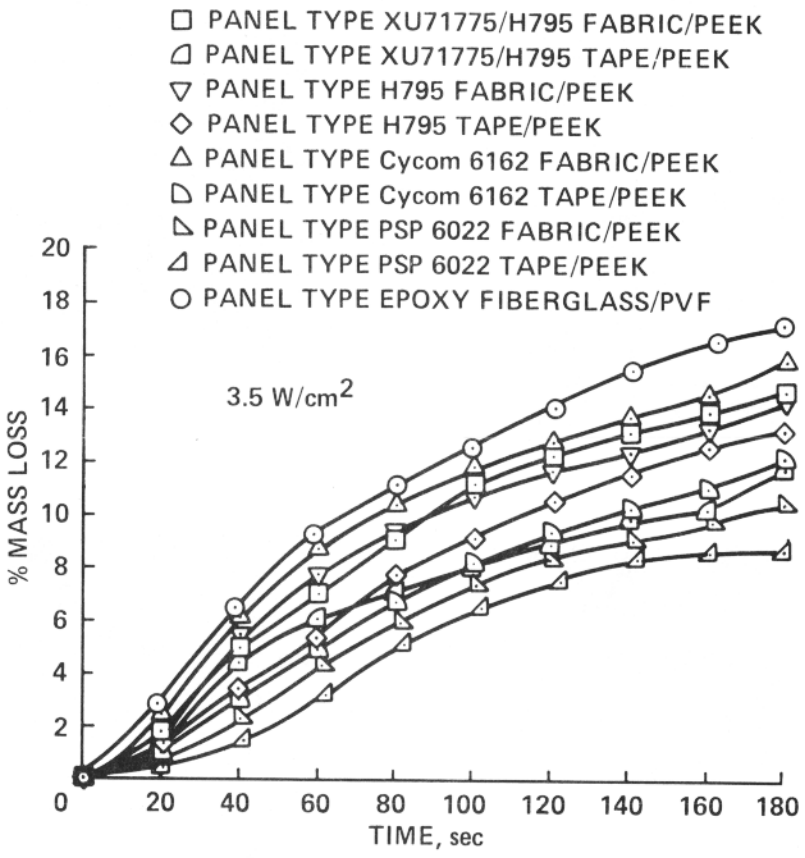

FIGURE 5. MASS LOSS OF PANELS.

TABLE 1.- DESCRIPTION OF TEST PANELS

PANEL TYPE	DESCRIPTION
BASELINE EPOXY GLASS FABRIC/PVF	GLASS FABRIC FACINGS, FACE 1 PLY 7781 STYLE WOVEN FIBERGLASS IMPREGNATED WITH EPOXY RESIN, BACK 1 PLY 120 GLASS AND CO-CURED TO HONEYCOMB, USING 1 PLY 120 FIBERGLASS EPOXY PREGREG. ONE SURFACE COVERED WITH PVF.
A: XU71775/H795 FABRIC/ PEEK	GRAPHITE FABRIC FACINGS, FACE AND BACK 1 PLY GRAPHITE FABRIC IMPREGNATED WITH XU71775/H795 AND CO-CURED TO HONEYCOMB. ONE SURFACE COVERED WITH PEEK.
B: XU71775/H795 TAPE/ PEEK	GRAPHITE TAPE FACINGS, FACE AND BACK 3 PLIES TAPE 0°, 90°, 0° IMPREGNATED WITH XU71775/H795 AND CO-CURED TO HONEYCOMB. ONE SURFACE COVERED WITH PEEK.
C: H795 FABRIC/ PEEK	GRAPHITE FABRIC FACINGS, FACE AND BACK 1 PLY GRAPHITE FABRIC IMPREGNATED WITH H795 BISMALEIMIDE RESIN AND BONDED TO HONEYCOMB USING ADHESIVE. ONE SURFACE COVERED WITH PEEK.
D: H795 TAPE/PEEK	GRAPHITE TAPE FACINGS FACE AND BACK, 3 PLIES TAPE 0°, 90°, 0° IMPREGNATED WITH H795 BISMALEIMIDE RESIN AND BONDED TO HONEYCOMB USING ADHESIVE. ONE SURFACE COVERED WITH PEEK.
E: CYCOM 6162 FABRIC/ PEEK	GRAPHITE FABRIC FACINGS, FACE AND BACK, 1 PLY GRAPHITE FABRIC IMPREGNATED WITH CYCOM 6162 PHENOLIC RESIN AND CO-CURED TO HONEYCOMB. ONE SURFACE COVERED WITH PEEK.
F: CYCOM 6162 TAPE/PEEK	GRAPHITE TAPE FACINGS, FACE AND BACK, 3 PLIES TAPE 0°, 90°, 0° IMPREGNATED WITH CYCOM 6162 PHENOLIC RESIN AND CO-CURED TO HONEYCOMB. ONE SURFACE COVERED WITH PEEK.
G: PSP 6022 FABRIC/PEEK	GRAPHITE FABRIC FACINGS, FACE AND BACK, 1 PLY GRAPHITE FABRIC IMPREGNATED WITH PSP 6022 POLYSTYRYLPYRIDINE RESIN AND BONDED TO HONEYCOMB USING AN ADHESIVE. ONE SURFACE COVERED WITH PEEK.
H: PSP 6022 TAPE/PEEK	GRAPHITE TAPE FACINGS, FACE AND BACK 3 PLIES 0°, 90°, 0° IMPREGNATED WITH PSP 6022 POLYSTYRYLPYRIDINE RESIN AND BONDED TO HONEYCOMB USING AN ADHESIVE. ONE SURFACE COVERED WITH PEEK.

TABLE 2.- THERMOGRAVIMETRIC ANALYSIS OF PANELS TYPE BASELINE AND B

SAMPLE TEMPERATURE, °C	PANEL TYPE		PANEL TYPE	
	XU71775/ H795 TAPE/ PEEK	BASELINE EPOXY GLASS FABRIC/PVF	XU71775/ H795 TAPE/ PEEK	BASELINE EPOXY GLASS FABRIC/PVF
	CHAR YIELD, % (in N_2)		CHAR YIELD, % (in air)	
100	100	98	98	99
200	97	98	97	98
300	97	97	96	92
400	97	90	95	88
500	89	78	87	80
600	70	64	67	66
700	62	51	45	45
800	56	41	40	32
900	52	34	38	32

TABLE 3.- SURFACE FLAMMABILITY OF COMPOSITE PANELS

PANEL TYPE	SPECIMEN NUMBER	FLAME SPREAD FACTOR, F_s	HEAT EVOLUTION FACTOR, Q	FLAME SPREAD INDEX, I_s
BASELINE:	1	2.02	3.56	7.19
EPOXY GLASS	2	2.08	2.29	4.76
FABRIC/PVF	3	2.28	2.80	6.38
	4	2.02	2.29	5.04
AVERAGE		2.15	2.74	5.84
STD. DEVIATION		0.12	0.60	1.14
A	1	1.91	2.80	5.35
XU71775/H795	2	2.14	2.04	4.37
FABRIC/PEEK	3	2.33	1.53	3.56
	4	2.49	2.04	5.08
AVERAGE		2.04	2.10	4.59
STD. DEVIATION		0.58	0.52	0.80
B	1	2.00	2.80	5.60
XU71775/H795	2	1.00	2.80	2.80
TAPE/PEEK	3	4.28	4.33	18.53
	4	4.74	5.09	24.13
AVERAGE		3.00	3.76	12.77
STD. DEVIATION		1.79	1.15	10.21
C	1	2.92	2.04	5.96
H795 FABRIC/	2	1.93	1.53	2.95
PEEK	3	2.14	2.80	5.99
	4	3.00	2.04	6.12
AVERAGE		2.50	2.10	5.26
STD. DEVIATION		0.54	0.52	1.54
E	1	3.00	3.56	10.68
CYCOM 6162	2	2.47	3.56	8.79
FABRIC/PEEL	3	2.75	5.09	14.00
	4	3.96	5.09	20.16
AVERAGE		3.04	4.33	13.41
STD. DEVIATION		0.65	0.88	4.99
F	1	2.30	2.29	5.27
CYCOM 6162	2	3.92	1.53	6.00
TAPE/PEEK	3	4.03	2.80	11.28
	4	2.30	5.09	11.71
AVERAGE		3.14	2.93	8.57
STD. DEVIATION		0.97	1.53	3.40
G	1	3.80	6.87	26.11
PSP 6022M	2	3.22	4.83	15.55
FABRIC/PEEK	3	3.33	4.83	16.08
	4	3.95	3.31	13.07
AVERAGE		3.58	4.96	17.70
STD. DEVIATION		0.35	1.46	5.76

TABLE 4.- HEAT RELEASE OF PANELS

PANEL TYPE	SPECIMEN NUMBER	TOTAL HEAT RELEASE, kW-min/m^2					PEAK HEAT RELEASE RATE, kW/m^2	
		TIME, sec					DQ/Dt	T, sec
		30	60	120	180	300		
BASELINE	1	14	35	81	93	88	84	26
EPOXY GLASS	2	15	39	90	102	102	80	24
FABRIC/PVF	3	18	41	97	118	124	83	22
AVERAGE		16	39	89	104	105	82	24
STD. DEVIATION		1.7	3.1	8.0	12.7	18.1	2.1	2.0
A	1	8	27	64	69	78	47	87
XU71775/H795	2	10	35	70	77	91	72	59
FABRIC/PEEK	3	8	32	65	72	77	52	59
AVERAGE		9	31	66	73	82	57	68
STD. DEVIATION		1.2	4.0	3.2	4.0	7.8	13.2	16.2
B	1	5	22	53	71	78	44	45
XU71775/H795	2	6	23	54	73	94	48	89
TAPE/PEEK	3	5	29	78	96	107	61	91
AVERAGE		6	25	62	80	93	51	75
STD. DEVIATION		0.6	3.8	14	14	14.5	8.9	26
C	1	12	47	85	100	113	87	45
H795	2	7	43	76	84	94	93	35
FABRIC/PEEK	3	6	33	57	71	91	71	34
AVERAGE		8	41	72	85	99	84	38
STD. DEVIATION		3.2	7.2	14.3	14.5	11.9	11.4	6.1
D	1	3	36	62	87	113	94	51
H795	2	4	37	72	109	140	85	44
TAPE/PEEK	3	3	38	71	100	131	94	52
AVERAGE		3	37	69	99	128	91	49
STD. DEVIATION		0.6	1.0	5.5	11.1	13.7	5.2	4.4

TABLE 4.- CONCLUDED

PANEL TYPE	SPECIMEN NUMBER	TOTAL HEAT RELEASE, kW-min/m^2					PEAK HEAT RELEASE RATE, kW/m^2	
		TIME, sec					DQ/Dt	T, sec
		30	60	120	180	300		
E	1	10	41	73	74	76	74	45
CYCOM 6162	2	17	54	91	97	104	85	44
FABRIC/PEEK	3	16	53	87	88	92	81	34
AVERAGE		15	49	83	86	91	80	41
STD. DEVIATION		3.8	7.2	9.5	11.6	14	5.6	6.1
F	1	8	46	83	109	128	86	41
CYCOM 6162	2	9	46	93	141	162	87	53
TAPE/PEEK	3	12	48	97	138	163	77	42
AVERAGE		10	46	91	130	151	83	45
STD. DEVIATION		2.1	1.2	7.2	17.7	19.9	5.5	6.7
G	1	14	63	124	147	166	110	41
PSP 6022	2	14	59	106	117	129	97	44
FABRIC/PEEK	3	11	49	85	89	96	91	39
AVERAGE		13	57	105	118	130	99	41
STD. DEVIATION		1.7	7.2	19.5	29	35	9.7	2.5
H	1	1	22	65	83	99	64	74
PSP 6022	2	2	29	65	76	98	80	61
TAPE/PEEK	3	2	25	48	65	91	57	42
AVERAGE		2	25	59	75	96	67	59
STD. DEVIATION		0.6	3.5	9.8	9.1	4.4	11.8	16.1

TABLE 5.- SPECIFIC OPTICAL DENSITY OF COMPOSITE PANELS

TEST PARAMETER	PANEL TYPE							
	BASELINE	A	B	C	D	E	F	G
D_s [a] AT 1.5 min								
FLAMING	87.0	20.0	24.0	21.0	5.5	14.0	15.0	9.6
NONFLAMING	2.1	1.9	0.4	0.0	0.0	6.0	1.2	0.3
D_s AT 4.0 min								
FLAMING	89.7	32.0	38.0	45.0	9.5	28.0	35.0	17.6
NONFLAMING	12.1	4.2	8.5	0.9	3.9	8.9	6.0	1.1
TIME TO REACH D_s 16, min								
FLAMING	0:33	0:46	3:15	2:00	3:15	1:40	1:00	4:44
NONFLAMING	4:50	—	12:53	—	—	9:30	10:06	—
TIME TO REACH $D_{MAX.}$ [b], min								
FLAMING	8:10	13:48	14:02	10:00	16:28	11:40	15:40	15:47
NONFLAMING	18:1	19:40	12:53	19:56	18:43	13:49	18:36	18:22

[a] D_s = Specific optical density.

[b] $D_{MAX.}$ = Maximum optical density.

TABLE 6.- MAXIMUM SPECIFIC OPTICAL DENSITY OF COMPOSITE PANELS

TEST PARAMETER	PANEL TYPE							
DATA	BASELINE	A	B	C	D	E	F	G
$D_{MAX.}$ [a] UNCORRECTED								
FLAMING	119.2	49.5	55.4	45.9	26.2	44.1	54.7	25.8
NONFLAMING	24.0	10.9	15.7	5.2	12.8	15.2	18.9	2.9
OVERALL AVERAGE	71.6	30.2	35.6	25.5	19.5	29.6	36.8	14.35
$D_{MAX.}$ CORRECTED								
FLAMING	115.3	44.3	53.3	42.0	23.2	41.0	48.7	24.2
NONFLAMING	22.7	9.7	15.3	4.1	12.5	15.2	18.6	1.7
OVERALL AVERAGE	69.0	27.0	34.3	23.0	17.8	28.1	33.6	13.0

[a] $D_{MAX.}$ = Maximum specific optical density.

TABLE 7.- GAS ANALYSIS FROM THE FLAMING COMBUSTION OF COMPOSITE PANELS

GAS CONCENTRATION, ppm [a]	PANEL TYPE							
	BASELINE	A	B	C	D	E	F	G
CO	200-700	75-300	50-400	100-400	100-400	100-325	50-300	100-300
NO_x	5-20	5-20	2-15	5-20	15-20	TRACE-5	15-20	0-10
HF	0	0	0	0	0	0	0	0
HCN	2-10	5-10	5-10	2-10	3-15	5	2-13	2-5

[a] NOTE: Values given are the high and low values obtained on three samples.

TABLE 8.- OXYGEN INDEX OF COMPOSITE PANELS

PANEL TYPE	OXYGEN INDEX
BASELINE EPOXY GLASS FABRIC/PVF	34.6
A-XU71775/H795 FABRIC/PEEK	44.3
B-XU71775/H795 TAPE/PEEK	45.6
C-H795/FABRIC/PEEK	35.7
D-H795 TAPE/PEEK	45.0
E-CYCOM 6162/FABRIC/PEEK	38.8
F-CYCOM 6162/TAPE/PEEK	36.9
G-PSP 6022M/FABRIC/PEEK	40.3

TABLE 9.- IGNITION RESISTANCE OF COMPOSITE PANELS

TEST PARAMETER	PANEL TYPE						
	BASELINE	A	B	C	E	F	G
AVERAGE CHAR LENGTH, cm (in.)	12.55 (4.94)	15.72 (6.19)	14.94 (5.88)	13.82 (5.44)	12.55 (4.94)	11.43 (4.5)	6.05 (2.38)
AFTERFLAME, sec	10.5	0.0	0.0	0.0	0.0	0.0	0.0

[a] There was no drip burn or afterglow.

TABLE 10.- FLEXULAR STRENGTH AND MODULUS OF COMPOSITE PANELS

TEST PARAMETER	PANEL TYPE						
	A	B	C	D	E	F	G
TOTAL SAND. THICKNESS, cm:	0.69	0.72	0.68	0.71	0.69	0.71	0.67
STD. DEVIATION:	0.00	0.003	0.002	0.01	0.002	0.001	0.003
(in.):	(0.27)	(0.28)	(0.27)	(0.29)	(0.27)	(0.28)	(0.26)
WIDTH, cm:	7.67	7.63	7.66	7.65	7.67	7.67	7.65
STD. DEVIATION:	0.02	0.01	0.02	0.11	0.00	0.00	0.02
(in.):	(3.01)	(3.01)	(3.02)	(3.01)	(3.02)	(3.02)	(3.01)
MAX. LOAD, kg:	16.7	40.4	21.2	45.9	20.8	36.7	18.9
STD. DEVIATION:	0.63	1.1	2.4	4.8	0.43	1.3	0.6
(lb):	(36.8)	(89.2)	(46.8)	(101.1)	(45.8)	(80.9)	(41.8)
TYPE OF FAILURE:	A	A	A	B	C	C	C
COMPRESSIVE STRESS, kg/cm:	37.5	91.1	47.9	104	46.7	82.3	42.6
STD. DEVIATION:	1.34	2.5	5.5	10.7	0.95	2.8	1.26
(lb/in.):	(210)	(510)	(262)	(518)	(262)	(462)	(238)
MODULUS, $kg/m^2 \times 10^9$:	3.99	7.90	4.4	8.90	4.30	6.50	4.22
STD. DEVIATION:	0.19	0.24	0.1	0.14	0.05	0.06	0.14
(psi $\times 10^6$):	(5.7)	(11.3)	(6.2)	(12.6)	(6.2)	(9.2)	(6.0)

A = Core tensile.
B = Core-tensile failure, shear failure in adhesive bond of tensile face.
C = Compressive face.

TABLE 11.- CLIMBING-DRUM PEEL STRENGTH OF COMPOSITE PANELS

TEST PARAMETER	PANEL TYPE						
	A	B	C	D	E	F	G
WIDTH, cm:	7.64	7.65	7.67	7.51	7.66	7.68	7.68
STD. DEVIATION:	0.008	0.03	0.0	0.04	0.01	0.01	0.01
(in.):	(3.01)	(3.01)	(3.02)	(2.96)	(3.02)	(3.02)	(3.02)
AVERAGE LOAD, kg:	9.6	11.5	15.4	21.1	15.3	34.4	9.20
STD. DEVIATION:	0.39	1.4	0.73	0.62	0.44	1.98	0.19
(lb):	(21.1)	(25.4)	(34.0)	(46.5)	(33.7)	(75.7)	(20.4)
TYPE OF FAILURE:	A	A	A	A	A	A	B
PEEL STRENGTH,							
cm-kg/cm WIDTH:	0.77	0.59	1.77	1.77	1.79	4.52	0.72
STD. DEVIATION:	0.12	0.14	0.13	0.27	0.06	0.34	0.06
(in.-lb/in. OF WIDTH):	(1.9)	(1.3)	(3.9)	(3.9)	(4.0)	(10.0)	(1.6)

A = Cohesive failure within adhesive.
B = Adhesive failure to core.

TABLE 12.- FLATWISE TENSILE STRENGTH OF COMPOSITE PANELS

TEST PARAMETER	PANEL TYPE						
	A	B	C	D	E	F	G
NOMINAL WIDTH, cm:	5.08	5.08	5.08	5.08	5.08	5.08	5.15
STD. DEVIATION:	0.00	0.00	0.00	0.00	0.00	0.00	0.03
(in.):	(2.00)	(2.00)	(2.00)	(2.00)	(2.00)	(2.00)	(2.02)
NOMINAL LENGTH, cm:	5.08	5.08	5.08	5.08	5.08	5.08	5.15
STD. DEVIATION:	0.00	0.00	0.00	0.00	0.00	0.00	0.02
(in.):	(2.00)	(2.00)	(2.00)	(2.00)	(2.00)	(2.00)	(2.02)
MAX. LOAD, kg:	466	508	205	129	557	562	333
STD. DEVIATION:	89.0	114	91.0	28.0	42.0	22.0	50.9
(lb):	(1028)	(1119)	(451)	(285)	(1229)	(1238)	(732)
TYPE OF FAILURE:	A	B	A	C	D	D	D
FLATWISE TENSILE STRENGTH, kg/cm^2:	18.0	19.7	8.0	4.2	21.6	21.8	126
STD. DEVIATION:	3.5	4.4	3.5	1.8	1.6	0.9	19.0
(psi):	(257)	(280)	(113)	(68)	(308)	(310)	(179)

A = Cohesive failure within adhesive.
B = Core-tensile failure and interlaminar failure of facing.
C = Adhesive failure to core.
D = Core-tensile failure.

TABLE 13.- DENSITY OF PANELS

PANEL TYPE	WEIGHT, g	WIDTH, cm (in.)	LENGTH, cm (in.)	THICKNESS, cm (in.)	VOLUME, cm^3 ($in.^3$)	DENSITY, g/cm^3 ($g/in.^3$)	DENSITY, kg/m^3 (lb/ft^3)	UNIT WT., kg/m^2 (lb/ft^2)
BASE-LINE	602.00	55.000 (21.81)	61.00 (24.0)	0.635 (0.250)	2130 (130.9)	0.283 (4.599)	282.6 (17.696)	1.790 (0.365)
A	3.211	5.118 (2.015)	5.118 (2.015)	0.686 (0.270)	17.96 (1.096)	0.196 (2.930)	178.8 (11.162)	1.226 (0.250)
B	4.540	5.080 (2.000)	5.131 (2.020)	0.709 (0.279)	18.47 (1.127)	0.277 (4.028)	245.8 (15.345)	1.742 (0.357)
C	3.649	5.100 (2.008)	5.113 (2.013)	0.709 (0.279)	18.49 (1.128)	0.222 (3.235)	197.4 (12.324)	1.399 (0.287)
D	11.776	5.138 (2.023)	10.231 (4.028)	0.739 (0.291)	38.86 (2.371)	0.718 (4.967)	303.1 (18.922)	2.240 (0.459)
E	3.002	5.095 (2.006)	5.133 (2.021)	0.693 (0.273)	18.14 (1.107)	0.183 (2.712)	165.5 (10.332)	1.148 (0.235)
F	5.158	5.103 (2.009)	5.110 (2.012)	0.701 (0.276)	18.29 (1.116)	0.315 (4.622)	282.1 (17.608)	1.978 (0.405
G	7.491	7.554 (2.974)	7.691 (3.028)	0.665 (0.262)	38.66 (2.359)	52.03 (3.175)	29.435 (12.095)	1.289 (0.264)

TABLE 14.- RELATIVE RANKING OF COMPOSITES

OHIO STATE CALORIMETER TEST			ASTM E-162
RANKING	HEAT RELEASE	SMOKE DENSITY (DS)	FLAME SPREAD
1 (BEST)	A, B, C, E, H	B, D, H	A, B, C, BASELINE
2	D	C, A	F
3	F, G, BASELINE	E, F	E
4	—	G	G
6 (WORST)		BASELINE	