THERMOCHEMICAL CHARACTERIZATION OF

AIRCRAFT INTERIOR PANEL MATERIALS

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ABSTRACT: On-board fires in wide body jet aircraft represent a serious threat to life and have resulted in considerable economic losses to the airline and aircraft industry. Since there is considerable interest in the reduction of the flammability and smoking of polymeric materials used in aircraft interiors, it has been the objective of this study to characterize the thermochemical properties of some of these materials and to seek methods and approaches in the development and formulation of advanced polymers and composites which would offer improved fire resistance over the state-of-the-art materials and could eventually be utilized in the fabrication of aircraft interior panels. This paper discusses the thermochemical characterization of the state-of-the-art aircraft interior materials and, specifically, polyvinyl fluoride used currently as a decorative surface in aircraft interiors. Characterization includes (1) polymer characterization, (2) thermochemical studies to measure the effect of environment upon polymer decomposition, and (3) quantitative analysis of the volatile products from pyrolysis, oxidative degradation, and flaming combustion of the polymer.

In addition this paper describes the processing and evaluation of composite sidewall panels fabricated from currently used and advanced fire-resistant materials. Laboratory test methodology used to qualify candidate composite materials

includes thermochemical characterization of the polymeric

compounds and evaluation of the completed panel assemblies

for flammability, fire endurance, and smoke evolution. The

use of these test methods will be discussed in comparing ad-

vanced composites consisting of phenolphthalein polycarbonate,

bismaleimide-glass, polyamide, and polyquinoxaline, with

conventional baseline materials consisting of polyvinyl

fluoride, epoxy-glass, and polyamide. Particular attention

is given to the development of assessment criteria such as

fire endurance, or fire containment capability, and smoke

produced when these composites are subjected to a fire envi-

ronment.

INTRODUCTION

Improvements in aircraft interior materials are being sought in

order to enhance human survivability in aircraft fires. The primary

goal of the NASA-Ames Research Center program is to achieve a level of

improvement in fire safety through the development and efficient imple-

mentation of materials having improved fire resistant characteristics.

Improvements are being directed toward reduced ignition susceptibility,

fuel contribution, and smoke and toxic fume emission. Suitable interior

panel materials are being developed which could offer improved fire

resistance and smoke reduction in aircraft fires.[1-5] These advanced

fire resistant composite structures could offer enhanced survivability

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and reduce property losses in ramp fires, in-flight fires, and survivable post-crash fires.

The ramp fire occurs with parked aircraft that may be attended or unattended. Personnel aboard could include flight crew, passengers, ground maintenance personnel, or combinations thereof. The aircraft location could be a passenger loading ramp, a ground maintenance position, or include partially completed aircraft at factory locations. Ramp fires occur from a number of causes which vary between commercial air carriers and military aircraft. Electrical and oxygen system malfunctions account for the majority of known causes of ramp fires in world wide U.S. air carriers, while fueling procedures and engine fires account for the major number of military aircraft ramp fires.

The in-flight fire occurs during aircraft climb-out, cruise, or letdown flight phases. A number of in-flight fires have been passenger initiated with the prime location in lavatory areas. Exclusive of engine fires, most in-flight fires among U.S. commercial air carriers are due to electrical origin and cigarettes, while engine and fuel sources remain the major causes of in-flight fires aboard military aircraft.

Advanced materials described in this paper could also offer increased survivability in post-crash fires where there is no major damage to the aircraft fuselage. These materials could offer fire hardening against fuel-fed external fires.

A summary of aircraft accidents involving fires in U.S. commercial aircraft in the period from 1963-1973 is shown in Table 1. Approximately

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139 fire-involved accidents for turbine- and piston-powered aircraft have

occurred during this period; this includes engine, wheel, and brake fire

accidents.[6] The table is arranged by flight purpose and gives the

number of accidents, the number of accidents with fatalities, and the

number of fatalities (caused by trauma or fire). This indicates that

two-thirds of the 139 fire accidents were passenger flights. Also, two-

thirds occurred "after impact." Forty-five percent (62 of 139) of the

fire accidents had fatalities (57 of those, 92%, were after-impact fires),

63% (37 of 57) were passenger carriers with fires after impact; 41%

(57 of 139) of all fire accidents were after-impact fires with fatalities,

and approximately 4% (5 of 139) were in-flight fatal fire accidents.

EXPERIMENTAL PROCEDURE AND RESULTS

A.   State-of-the-art Interior Panels

A typical wide body aircraft interior is shown in Figure 1. A

typical composite used by the aircraft manufacturers in aircraft interiors

is shown in Figure 2. The state-of-the-art system utilized by most air-

frame manufacturers as interior paneling is a sandwich panel which varies

slightly in configuration, component composition, thickness, and density

depending on the type of aircraft used and the specific application. In

general, the panel consists of a decorative surface bonded to a laminate

and a honeycomb core. The process for producing the decorative surface

consists of silkscreening the required decor on a 0.005-cm polyvinyl

fluoride film by a continuous web process. After drying, a 0.0025-cm

transparent polyvinyl fluoride film, coated on one side with polymethyl

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methacrylate, is bonded to the decorative film to provide protection for the printed surface. This laminate is then bonded to one ply of epoxy-preimpregnated 181 E glass which may have a canvas or other texture applied during this bonding operation. Time, temperature, and pressure vary depending on the texture applied. The current core material for sandwich paneling is a polyamide, hexagonal-cell honeycomb structure. The cell size varies 0.312 cm, 0.625 cm, or 0.937 cm depending upon strength and application requirements. The current method of bonding the skins to the core consists of using an epoxy resin-preimpregnated bond ply over which is applied the pre-prepared 181 E glass/polyvinyl fluoride decorative laminate. The resin in the bond ply provides the adhesive to bond the skin to the honeycomb and the decorative laminate to the bond ply. Curing is accomplished at 110°C with 50 cm Hg minimum vacuum bag pressure. For panels requiring decorative laminates on one side only, the bond ply provides the backside skin. Edge close-outs consist of either polyurethane foam or a phenolic microballoon-filled epoxy potting compound.

PANEL COMPONENT CHARACTERIZATION.—Typical thermochemical properties of the polymers currently used in the fabrication of interior panels are shown in Table 2. The approximate quantity of these polymers in the passenger compartment of a typical wide body aircraft is shown in Table 3. Polyvinyl fluoride was selected for a detailed analytical and thermo-chemical study since it is extensively used on the front surface of the aircraft interior and would be involved in the initial phases of the combustion process.

ANALYTICAL METHODOLOGY.—The general analytical scheme that was used in the analysis of this polymer is shown in Figure 3. As indicated in Figure 3, the three aspects covered in this study were (1) polymer characterization, (2) thermal characteristics as a function of heating rate and environment, and (3) thermal degradation in an inert and an oxidative environment.

Polymer characterization has been limited to the determination of the elemental analysis and the infrared spectrum of the polymer. The elemental analysis of the polymer was performed utilizing an F & M Model 185 Carbon, Hydrogen, Nitrogen Analyzer. Infrared spectra were obtained using the KBr pellet technique on a Perkin-Elmer Model 237 Grating Infrared Spectrometer. All thermoanalytical studies were performed using a Mettler Thermoanalyzer 1 equipped with a corrosive gas inlet.

Prior to analysis, all samples for the studies using the Mettler Thermoanalyzer were dried at 60°C at 10^{-6} torr for several days. All gases used were checked for purity using a gas chromatograph (GC). Studies conducted in an air environment employed laboratory air that was dried by passing it through a calcium sulfate trap. The studies to determine the effect of heating rate or environment used a 10 ± 0.1 mg sample size and a carrier gas flow rate of 160 ± 10 ml/minute. In order to obtain sufficient quantites of the gaseous species resulting from either pyrolysis or oxidative degradation, larger sample sizes were used in the studies conducted on the Mettler Thermoanalyzer employing trapping techniques. Samples were subjected to temperature-programming from ambient

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to 1000°C at dynamic heating rates of 10, 25, or 100°C/minute. All experiments were performed in triplicate using aluminum oxide as the reference material.

The sub-classification of Thermal Degradation Studies (Figure 3) includes pyrolysis, thermal oxidative degradation, and flaming combustion. The procedure used to identify the products of degradation that eluted from the polymeric material is illustrated in Figure 4.

The analytical system used to identify the products of polymer degradation is shown in Figure 5. The system consists of a thermobalance, appropriate gas sampling devices, and a gas chromatograph and is capable of performing simultaneous differential thermal analysis, thermogravi-metric analysis, differential thermal gravimetry, and effluent gas analysis.

The detailed apparatus for gas sampling is shown in Figures 6 and 7. In Figure 6 gases are sampled directly from the quartz furnace on the thermoanalyzer Ⓐ, which allows the temperature, the TGA, the DTG, and the DTA to be monitored continuously during the degradation of the sample. Particulate matter generated during pyrolysis or oxidative degradation is removed in the glass or Teflon wool plug Ⓑ, and the volatile products are collected in trap Ⓔ which is packed with porous polymer. An option-al trap at Ⓒ may be used to absorb water from the effluent to simplify the subsequent analysis. The carrier gas is finally bubbled through aqueous and nonaqueous solvent traps at Ⓖ to insure that no products escape into the room. A heated aluminum block Ⓓ contains two multiport

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high conductance valves that direct the carrier gas from the Mettler Thermoanalyzer and the GC through the trap. The three possible orientations of the valves are shown in Figure 7. Three modes of operation include (1) the GC and thermoanalyzer operate independently of one another, (2) the thermoanalyzer vents through the trap, and (3) the GC carrier gas flows through the trap and sweeps the trapped components into the injection port on the GC. In practice, products of polymer decomposition produced at any temperature flow through the trap which is held at subambient temperatures. After the gases are trapped, the interface valves are turned to direct the GC carrier gas through the trap. By applying heat, all volatile components can be desorbed from the porous polymer packing in the trap in less than one minute and injected into the GC.

The apparatus used to generate the products from flaming combustion of the polymer is shown in Figure 8. The nichrome heating element is used as an ignition source and as a means of sustaining the combustion process until the samples cease to flame. The sample size (0.2 gm) is determined by the availability of oxygen content in the bulb, using a stoichiometric balance between carbon, hydrogen, nitrogen, and the oxygen needed to insure complete combustion. The walls of the combustion bulb are maintained at 150°C with a heating mantle to reduce condensation of high molecular weight species. In addition, a balloon is attached to the bulb as an expansion reservoir to prevent explosions.

After the combustion process is completed, the bulb is evacuated by opening the lower valve in Figure 8 and drawing the combustion products

through the trapping arrangement with a peristaltic pump. Trap number 1, filled with Tenax porous polymer, is held at room temperature and effectively traps components containing 4 or more carbon atoms. The effluent then passes through a drying agent to remove a major portion of water, and finally through trap number 2, consisting of Porapak Q porous polymer cooled to -110°C. This final trap effectively collects all lighter effluents, excluding carbon monoxide and methane. The reaction vessel is flushed with nitrogen to allow the inside of the bulb to react to atmospheric pressure and then the bulb is re-evacuated with the peristaltic pump. This procedure is repeated 6 times over a 1-hour period to desorb materials with low vapor pressure from the walls of the reaction vessel. Once the desorption step is completed, both traps are connected to the sampling loop system and run in the usual manner for GC and mass spectrometric (MS) identification.

THERMOCHEMICAL CHARACTERIZATION OF POLYVINYL FLUORIDE.—The sample used in these studies was laboratory sample #M-62, obtained from Boeing Aircraft Company, a clear film 0.005 cm thick. Results of the elemental analysis of the sample are shown in Table 4.

The effect of environment upon polymer weight loss is shown in Figure 9. The maximum weight loss in the TGA trace at 450°C corresponds to the same weight loss the polymer would undergo in the quantitative loss of hydrogen fluoride (HF) from the monomeric unit. According to Madorsky [7] the possible mechanism for thermal degradation of polyvinyl fluoride is:

$$\left[CH_2CHF \right]_n \rightarrow \left[CH = CH \right]_n + nHF$$
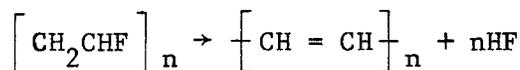
The volatile products produced from the pyrolysis of polyvinyl fluoride were identified. Using the Mettler Thermoanalyzer and the procedures outlined previously, samples of the polymer were pyrolyzed in a nitrogen atmosphere at 450°C. In this series of experiments, the polymer specimens were temperature-programmed from ambient to 450°C at a heating rate of 100°C/minute. The effluents from the thermoanalyzer were trapped for a subsequent analysis beginning at 250°C. This is the temperature which is just prior to the onset of the major weight loss. The initial sampling of effluents continued for a period of 4 minutes after a temperature of 450°C was attained.

The volatile products resulting from the pyrolysis were collected using the trapping system, desorbed from the porous polymer trap, and analyzed using the computerized GC/MS system. Five pyrolysis runs were conducted for identification and quantitation of the volatile products described herein.

The quantity of each compound was calculated from the corresponding peak numbers of the flame ionization detector traces, the trapping efficiencies, and the response factors. The results were obtained using a stainless steel column containing Chromosorb 101 stationary phase that was temperature-programmed from -20 to 240°C at a rate of 10°C/minute. The average weight percents determined from the mass of all elements in the polymer and the identified compounds are recorded in Table 5. HF was determined by gravimetric techniques using the calcium sulfate method:

$$2HF + Ca^{++} \rightarrow CaF_2(S) + 2H^+$$
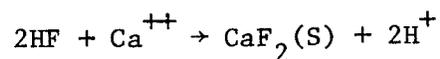
Samples of the polyvinyl fluoride were degraded in the presence of
air isothermally at 450°C following a dynamic heating rate at 100°C/
minute from ambient to 450°C. Detailed analysis of the volatiles was
conducted using the methodology described in the previous pyrolysis
studies. The average weight percents determined from the masses of all
elements and volatile products are also recorded in Table 5. As noted,
thermal degradation results in the quantitative loss of HF in excess of
17%. Previous studies [8] have shown a 27.5% loss of HF as indicated
in Table 6.

The products from the degradation of polyvinyl fluoride, under
conditions of flaming combustion, were studied using the apparatus that
was described pregiously (Figure 8). A 0.2- g sample of the polymer was
ignited, and the flaming mode was sustained by using the nichrome wire
heat source. Samples were ignited, and the products were trapped and then
desorbed from the porous polymer trapping system for subsequent GC/MS
analysis. Table 7 is a summary of the volatile products that have been
identified from these flaming combustion studies.

Table 8 shows calculated values for volatile concentration in a
typical wide body aircraft, assuming no venting to the exterior of the
aircraft. Calculations are based on 100% thermal degradation of the
polyvinyl fluoride present in the aircraft. This is estimated to be
approximately 101,000 g polyvinyl fluoride degraded in 840 m^3 (120 g/m^3).
Column 4 is calculated from the formula:

$$PPM = \frac{(mg/m^3)(24.3)}{\text{Molecular Weight of Compound}}$$

Column 5 is the threshold limit value allowable for 8-hours-per-day exposures as adapted by the American Conference of Governmental Industrial Hygeinists. In column 6, a TLV factor of 1 is the safe limit to which personnel may be exposed during an 8-hour work day (The TLV factor is obtained by dividing the concentration in air of the compound (mg/m^3) evolved by the threshold limit value of the particular compound (mg/m^3).) TLV factors of less than 1 are not indicated.

B. Advanced Interior Panels

PANEL PROCESSING AND FABRICATION.—A typical advanced composite panel is shown in Figure 2. It consists of a phenolphthalein polycarbonate film adhered with chlorendic anhydride-epoxy adhesive to one or more plies of bismaleimide-glass laminate. The laminate is adhered to the polyamide honeycomb containing polyquinoxaline foam with a polyimide adhesive. An additional laminate is bonded on the opposite side.

Processing of the panel is as follows: The polyamide honeycomb is coated with an intumescent coating [9] of the formulation shown in Table 9. The amount (dry weight) of intumescent paint used is approximately 0.20-0.23 g/cm^2 (honeycomb face area) for a honeycomb structure with a 0.312-cm cell size. After application, the paint is dried at 100°C for 1 hour. The coated honeycomb is heated at a temperature range of 316-371°C to form the carbonaceous char (polyquinoxaline foam); and any excess amount is removed from the faces of the honeycomb. The bismaleimide used in the fabrication of the face sheets is a hot-melt, addition type polyimide [10]. Prepregs are prepared from this resin and 1 to 4 pieces of

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181 E-glass cloth to form flat laminates. Softening of the resin occurs

at 70°C, and complete melting occurs at 130°C. The prepreg is stiff at

room temperature and becomes tacky at 50°C. Laminates are prepared by

placing them in a bag for autoclave cure at a heating rate of 1-2°C/

minute to 180°C under vacuum and 690 KN/m^2 pressure. Laminates are

cured for 1 hour at 180°C. Laminates are adhered to the polyquinoxaline-

filled honeycomb structure with a polyimide resin [11] using contact

pressure in a heated press at 170°C for 2 hours. After fabrication of

the composite panel, the phenolphthalein polycarbonate film is adhered

to the panel surface with a chlorendic anhydride-epoxy adhesive and bonded

by applying contact pressure in a mold at 150°C.

PANEL COMPONENT CHARACTERIZATION.—Typical thermochemical properties

of the polymers used in the fabrication of the advanced interior panels

are shown in Table 10. Selection criteria for including materials in the

panel fabrication include polymers which (1) during thermal degradation

produce the least amount of toxic volatile products, (2) produce the least

amount of smoke ($D_s < 20$) when exposed to a heating or fire environment,

(3) exhibit a high weight fraction (char yield) remaining after the polymer

has been subjected to a dynamic thermogravimetric analysis in nitrogen and

air environments, (4) exhibit a high temperature of decomposition when they

have been subjected to the thermogravimetric conditions mentioned above,

(5) have a high limiting oxygen index (> 35) when tested in accordance with

the oxygen index test, ASTM D-2863, and (6) are easily processable or

could eventually be developed to be comparable to the state-of-the-art

materials. Generally, higher processing temperatures are required for

these advanced materials.

The thermochemistry and thermophysical properties of the phenolphthalein polymer are detailed by Parker et al. [12]. The thermal degradation products of this polymer are currently being determined. The thermophysical properties of various types of addition type bismaleimide resins have been investigated previously [13,14]. The thermochemistry and the thermal degradation products of the bismaleimide resin used in these composites were studied in accordance with the analytical procedures outlined previously. The thermal degradation products resulting from the pyrolysis of the polymer at 600°C and 1000°C are shown in Table 11.

COMPOSITE PANEL PROPERTIES.—Typical flammability and smoke properties of the state-of-the-art and prototype advanced interior panels are shown in Table 12. It is shown that at equivalent density the fire containment or fire endurance capability of the advanced panel has been improved by a factor of five. This improvement is believed to be due to the thermal protection efficiency of the high-char-yield foam filling the honeycomb structure. It may also be seen in Table 12 that these panel modifications have resulted in a significant reduction in the specific optical smoke density when panels are tested in the NBS smoke chamber [15]. Examination of the smoke density values for the constituent components of these composites clearly shows that the principle contributor to smoke is the epoxy-resin laminating resin in the state-of-the-art panel. The bismaleimide resin replacing the epoxy effectively reduces the total smoke produced from the composite panel. As shown, the specific optical density is an additive property of the individual component values.

Figure 10 compares the fire endurance or containment capability of the state-of-the-art and advanced panels under conditions of the NASA-Ames T-3 test [16]. In this figure, the backface temperature rise is plotted as a function of the time in minutes under the impact of front face heat flux of 11×10^4 w/m^2, which is a reasonable simulation of a full-scale fuel fire. It can be seen that the backface temperature of the conventional composite reaches 200°C in 2 minutes whereas it takes as long as 9 minutes to reach a comparable backface temperature in the advanced composite. Similar fire containment capability and smoke reduction can be expected in full-scale component testing of interior panels fabricated from these high-temperature-resistant polymers. In addition, the advanced composite panel exhibited less distortion and better structural integrity after the test than the state-of-the-art materials as shown in Figure 11. A comparison of the smoke density of these panels is shown in Figure 12. In this figure smoke density is plotted against percent transmission through 0.9 meters. The advanced composite panels permit 15% transmission when exposed to a flaming combustion of 2.5 w/cm^2.

CONCLUSIONS

Polymeric components of aircraft interior panels such as polyvinyl fluoride have been characterized thermochemically. Analytical procedures have been refined to permit the detailed thermochemical characterization of polymeric constituents in aircraft interior composites. These characterization studies are essential in the selection of polymers with optimum thermochemical properties for use in composite structures

possessing improved fire resistant characteristics. Polymers possessing high char yield and high temperature of decomposition have been selected and utilized in the fabrication of advanced composites. Flammability parameters of individual polymers relate to the fire containment and smoke evolution properties of the composites. Advanced composites have been shown to possess increased fire resistance to a sustained fire environment and produce less smoke. Additional efforts must be expended to evaluate these composites under full-scale component test conditions in aircraft structural configuration.

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J. A. Parker

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List of Figures

| FLIGHT PURPOSE | PHASE OF FLIGHT | | | | | | | | TOTALS | | |
| | IN-FLIGHT | | | GROUND OR RAMP | | POST-CRASH | | | | | |
	NO.	NO. FATAL	FATALITIES	NO.	NO. FATAL	NO.	NO. FATAL	FATALITIES	ACCIDENTS	FATAL ACCIDENTS	FATALITIES
PASSENGER	14	4	194	21	0	57	39	1506	92	43	1700
CARGO	3	1	3	1	0	27	13	46	31	14	49
TRAINING/FERRY	4	0	0	2	0	10	5	31	16	5	31
TOTAL	21	5	197	24	0	94	57	1583	139	62	1780

* INCLUDES TURBINE AND PISTON-POWERED ENGINES; INCLUDES ENGINE, WHEEL AND BRAKE FIRES.

Table 1

MATERIAL	WEIGHT, %	CHAR YIELD Y_c, N_2, 700°C, %	POLYMER DECOMPOSITION TEMP. Td °C N_2	LIMITING OXYGEN INDEX $\dfrac{O_2}{N_2 + O_2}$, ASTMD-2863
POLYVINYL FLUORIDE $\left[CH_2CHF\right]_n$	7.6	10	400	20
GLASS: SiO_2	41.9	100	—	>70
EPOXY: 4,4'-ISOPROPYLIDENEDIPHENOL (BISPHENOL A)	30.0	23	180	21
POLYAMIDE: POLY (M-PHENYLENE ISOPHTHALAMIDE)	20.5	48	420	48
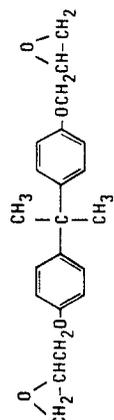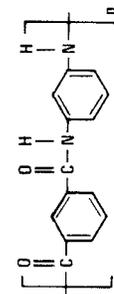
Table 2

FUSELAGE (PASSENGER SECTION) LENGTH:	5638 cm
FUSELAGE DIAMETER	650 cm
PLENUM HEIGHT	152 cm
CABIN HEIGHT	254 cm
CARGO HEIGHT	243 cm
VOLUME OF FUSELAGE	$2156 m^3$
VOLUME OF OCCUPIED PASSENGER COMPARTMENT	$840 m^3$
AREA OF CEILING/WALL PANELS	$1021 m^3$
WEIGHT OF CEILING/WALL PANELS — $0.155 g/cm^2$	1,594,000g
WEIGHT OF POLYVINYL FLUORIDE — $1.3 g/cm^3$, $0.0097 g/cm^2/0.0076 cm$	101,000g
WEIGHT OF POLYAMIDE HONEYCOMB STRUCTURE	326,770g
WEIGHT OF EPOXY-GLASS	1,166,230g

Table 3

ELEMENT	COMPOSITION, %			
	ANALYSIS[1]	ANALYSIS[2]	THEORETICAL[3]	REFERENCE[7]
CARBON	53.2	52.5	52.2	51.80
FLUORINE	39.9	41.0	41.3	41.22
HYDROGEN	6.9	6.50	6.5	6.98

(1) ANALYSIS BY UNIVERSITY OF UTAH

(2) ANALYSIS BY SCHWARTZKOPF MICROANALYTICAL LABORATORIES

Table 4

COMPOUND	WEIGHT, %	
	NITROGEN	AIR
METHANE	0.18	1.02
CARBON DIOXIDE	0.0	1.03
ETHYLENE	0.17	0.17
ACETYLENE	0.006	0.003
ETHANE	0.13	0.06
VINYL FLUORIDE	0.13	0.08
PROPENE	0.18	0.13
ALLYL FLUORIDE	0.05	0.04
BUTANE	0.03	0.04
1,2-BUTADIENE	0.10	0.07
FLUOROBUTADIENE	0.03	0.02
1,3-BUTADIENE	0.35	0.02
CYCLOPENTADIENE	0.02	0.02

COMPOUND	WEIGHT, %	
	NITROGEN	AIR
BENZENE	2.79	1.39
FLUOROBENZENE	~0.1	~0.1
TOLUENE	0.76	0.56
FLUOROTOLUENE	~0.05	~0.05
o-XYLENE	0.25	0.19
ETHYLBENZENE		
STYRENE	0.47	0.38
n-PROPYLBENZENE	0.18	0.14
ISOPROPYLBENZENE	0.26	0.08
PROPENYLBENZENE	0.13	0.09
INDENE	0.14	?
NAPTHALENE	0.40	0.34
HYDROGEN FLUORIDE	>17%	>17%
TOTAL	23.9	23.0
CHAR RESIDUE	30.0	28.0
UNIDENTIFIED COMPOUNDS	46.1	49.0
TOTAL	100.0	100.00

Table 5

RESIDUE	13.9
V_{pyr}	49.2
V_{hf}	27.5
V_{25}	9.0
V_{-190}	0.4
TOTAL	100.0

PYROLYSIS CONDITIONS: 26g ORIGINAL POLYMER, HELIUM ATMOSPHERE ($40 \, cm^3/min$), HEATING RATE TO 455°C, 6°C/min, HELD AT 455°C FOR 30 min

R — RESIDUE OR CHAR

V_{pyr} — MATERIALS THAT CONDENSE AT ROOM TEMPERATURE

V_{hf} — HYDROGEN FLUORIDE (HF)

V_{25} — MATERIALS THAT VOLATILIZE AT 25°C AND REMAIN GASEOUS AT HIGHER TEMPERATURE; HOWEVER, THEY CONDENSE AT -190°C

V_{-190} — MATERIALS THAT DO NOT CONDENSE AT -190°C

Table 6

COMPOUND	WEIGHT,%[1]
ETHYLENE	0.78
ACETYLINE	0.33
ETHANE	0.31
VINYL FLUORIDE	0.26
PROPENE	0.33
ALLYL FLUORIDE	0.30
BENZENE	2.97
TOLUENE	0.25
O-XYLENE	0.03
STYRENE	0.02
HYDROGEN FLUORIDE	>17.0
UNIDENTIFIED COMPOUNDS, RESIDUE	77.42
TOTAL	100.00

(1) WEIGHT % DETERMINED FROM THE MASS OF ALL ELEMENTS IN
POLYMER AND PRODUCT.

Table 7

COMPOUND	WEIGHT, %	CONC. IN AIR (mg/840m³)	CONC. IN AIR (mg/m³)	PPM	TLV (mg/m³)	TLV FACTOR
HYDROGEN FLUORIDE	>17.0	>17,170,000	>20,400	>24,786	2	>10,200
METHANE	1.0				9000	
CARBON DIOXIDE	1.0				1000	
ACETYLENE	0.003				1100	
ETHYLENE	0.17				1200	
ETHANE	0.06					
VINYL FLUORIDE	0.12	121,200	144	76	1.6	90
PROPENE	0.13				1800	
ALLYL FLUORIDE	0.06	60,600	72	29	0.6	120
BUTANE	0.4					
1,2 BUTADIENE	0.07				2000	
FLUOROBUTADENE	0.022					
1,3 BUTADIENE	0.021				2000	
CYCLOPENTADIENE	0.015				200	
BENZENE	1.2	1,212,000	1,442	449	80	18
FLUOROBENZENE	0.09					
TOLUENE	0.51				375	
FLUOROTOLUENE	0.05					
ETHYL BENZENE	0.19				435	
M OR P-XYLENE	0.19				435	
STYRENE	0.19				420	
N-PROPYL BENZENE	0.14					
ISOPROPYL BENZENE	0.08					
PROPENYL BENZENE	0.09					
INDENE	0.11					
FLUORONAPHTHALENE	0.09					
NAPHTHALENE	0.34	34,340	408	77	50	8
TOTAL	22.95					

CHAR RESIDUE	28.13
UNIDENTIFIED COMPOUNDS	48.92
TOTAL	100.00

Table 8

COMPOSITION

INGREDIENTS	WEIGHT, %
METHYL ETHYL KETONE	32.8
NITROCELLULOSE	6.9
p-NITROANILINE	27.5
ETHYL ALCOHOL	13.1
SULFURIC ACID	19.7

PAINT PROPERTIES

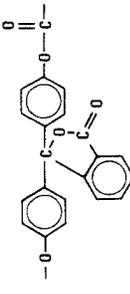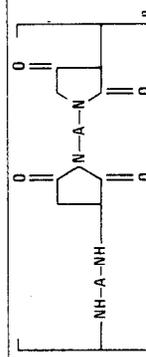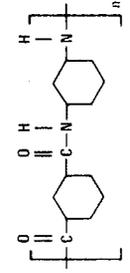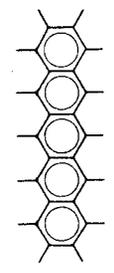|	
NON-VOLATILE, wt %	54
DENSITY, g/cc	1.09
VISCOSITY, BROOKFIELD, 25°C cps	1300
FINENESS OF GRIND, HEGEMAN SCALE	4 +
PIGMENT/BINDER RATIO, wt	6.9
P-NA/ACID RATIO, wt	1.4

Table 9

MATERIAL	WEIGHT, %	CHAR YIELD, Y_c, N_2, 700°C, %	POLYMER DECOMPOSITION TEMP. T_d, °C, N_2	LIMITING OXYGEN INDEX $\frac{O_2}{N_2+O_2}$, ASTMD-2863
PHENOLPHTHALEIN POLYCARBONATE	5.0	58	425	38
GLASS: SiO_2;	30.0	100	—	>70
BIS-MALEIMIDE	30.0	45	430	46
POLYAMIDE: POLY (M-PHENYLENE ISOPHTHALAMIDE)	20.5	48	420	44
POLYQUINOXOLINE (CARBONACEOUS CHAR)	14.5	90	530	48

Table 10

PRODUCT	600°C WEIGHT, %[1]	1000°C WEIGHT,%[1]
CARBON MONOXIDE	1.05	4.13
CARBON DIOXIDE	1.65	10.50
METHANE	— —	1.71
WATER	27.30	7.70
ETHYLENE	— —	0.98
PROPENE	— —	1.36
PROPANE	— —	1.33
BENZENE	— —	2.94
TOLUENE	— —	3.99
XYLENE	— —	0.24
BENZONITRILE	— —	0.12
CHAR RESIDUE	45.0	40.0
UNIDENTIFIED COMPOUNDS	25.0	25.0
	100.0	100.0

(1) WEIGHT % DETERMINED FROM THE MASS OF ALL ELEMENTS IN POLYMER AND PRODUCT.

Table 11

COMPOSITE PROPERTIES	PVF, EPOXY-GLASS POLYAMIDE HONEYCOMB, EPOXY-GLASS	PHENOL-POLYCARBONATE, BASMALEIMIDE-GLASS, POLYAMIDE HONEYCOMB FILLED WITH POLYQUINOXALINE FOAM, BISMALEIMIDE-GLASS
DENSITY (ASTM D 71)	96 kg/m^3	96 kg/m^3
FLATWISE TENSILE STRENGTH (ASTM C307), 24°C	0.02-0.05 N/m^2	–
FIRE ENDURANCE, NASA AMES T-3 THERMAL TEST FACILITY, TIME (min) TO REACH BACK-FACE TEMPERATURE OF 204°C, FRONT FACE HEAT FLUX 11 × 10^4 W/m^2	2	10
SMOKE DENSITY (NBS), Ds 4 min. SPECIFIC OPTICAL DENSITY	87	16
FAR 25.853, VERTICAL TEST METHOD STAND. 191, METHOD 5903	PASSES	PASSES

COMPONENT SMOKE DENSITY MAXIMUM SPECIFIC OPTICAL DENSITY (NBS SMOKE CHAMBER)		
	POLIVINYL FLUORIDE 7	PHENOL-POLYCARBONATE 5
	POLYAMIDE PHENOLIC PAPER 2	NOMEX PHENOLIC PAPER 2
	EPOXY RESIN 90	BISMALEIMIDE RESIN 9
	GLASS –	–

COMPOSITE MATERIAL BALANCE % BY WEIGHT		
	POLYVINYL FLUORIDE 7.6	PHENOL POLYCARBONATE 5.0
	POLYAMIDE PHENOLIC PAPER 20.5	POLYAMIDE PHENOLIC PAPER 20.5
	181, 120 GLASS 41.9	181 GLASS 30.0
	EPOXY RESIN 30.0	BISMALEIMIDE RESIN 30.0
		POLYQUINOXALINE 14.5

Table 12