

Assessment of Relative Flammability and Thermochemical  
Properties of Some Thermoplastic Materials

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## ABSTRACT

### "Assessment of Relative Flammability and Thermochemical Properties of Some Thermoplastic Materials"

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The thermochemical and flammability characteristics of some typical thermoplastic materials currently in use and others being considered for use in aircraft interiors are described. The properties studied included (a) thermal mechanical properties such as glass transition and melt temperature, (b) changes in polymer enthalpy by differential scanning calorimetry, (c) thermogravimetric analysis in an anaerobic and oxidative environment, (d) oxygen index, (e) smoke evolution, (f) relative toxicity of the volatile products of pyrolysis, and (g) selected physical properties. The generic polymers which were evaluated included: acrylonitrile butadiene styrene, bisphenol A polycarbonate, bisphenol fluorenone carbonate-dimethylsiloxane block polymer, phenolphthalein-bisphenol A polycarbonate, phenolphthalein polycarbonate, polyether sulfone, polyphenylene oxide, polyphenylene sulfide, polyaryl sulfone, chlorinated polyvinyl chloride homopolymer, polyvinyl fluoride, and polyvinylidene fluoride. Processing parameters including molding characteristics of some of the advanced polymers are described. Test results and relative rankings of some of the flammability, smoke and toxicity properties are presented. Under these test conditions, some of the advanced polymers

evaluated were significantly less flammable and toxic or equivalent to polymers in current use. A relationship of the anaerobic char yield of the polymers to their relative flammability properties is shown.

## INTRODUCTION

Thermoplastic materials are used in aircraft interiors as decorative films, compression- and injection-molded parts, and thermoformed parts. Typical components include: passenger service units, luminaries, seat side panels, trays and shrouds, flight station and lavatory parts, and panel finish in the form of film. Even though currently used materials meet regulatory requirements (1) there is considerable effort both by industry, aircraft manufacturers, and government to study and define materials that would offer improved fire resistance and, upon combustion, produce less smoke, irritating fumes, and toxic gases (2-4).

This study assessed the relative thermal stability, flammability, and other related thermochemical properties of some typical state-of-the-art and candidate experimental thermoplastic materials and assessed their potential use as moldings, thermoformed parts, and decorative films in aircraft interiors. State-of-the-art materials that were evaluated included: acrylonitrile butadiene styrene (ABS), bisphenol A polycarbonate (BPAPC), polyphenylene oxide (PPO), and polyvinyl fluoride (PVF).

Advanced thermoplastic materials evaluated included: 9,9 bis (4-hydroxyphenyl) fluorene polycarbonate-poly (dimethylsiloxane) block polymer (BPFC-DMS), chlorinated polyvinyl chloride homopolymer (CPVC), phenolphthalein bisphenol A polycarbonate (PH-BPAPC), phenolphthalein polycarbonate (PHPC), polyethersulfone (PES), polyphenylene sulfide (PPS), polyaryl sulfone (PAS), and polyvinylidene fluoride (PVF<sub>2</sub>).

## EXPERIMENTAL

### Description of Polymers

A total of 12 polymers and 23 samples were utilized for this study. The polymers were either commercially obtained or were experimental polymers being developed by various laboratories. The chemical structure of the polymers is shown in Table 1. Polymers were available as molding pellets, extruded or solvent cast film, extruded or molded sheet, and molding powders or pellets. The description for each polymer is also shown in Table 1. A brief description of polymers follows: acrylonitrile butadiene styrene, sample 18, was commercially obtained in sheet form. Bisphenol A polycarbonate was available in two types: bisphenol A polycarbonate with no fire retardants (sample 14) and one with fire retardants (sample 19). 9,9-bis (4-hydroxyphenyl)-fluorene polycarbonate-poly (dimethylsiloxane) block polymer was evaluated as a clear film (sample 21), as an uncured and cured molding powder (samples 27 and 28) and as injection-molded clear discs (sample 23). The poly (dimethylsiloxane) varied in the samples from 15 to 22 percent. The chemistry and synthesis of this polymer have been described previously (5). The phenolphthalein-bisphenol A polycarbonate copolymers (samples 30, 31, and 55) were available in bulk polymer. Polyether sulfone was evaluated as molding pellets (samples 12 and 13) and extruded film (sample 22). Polyphenylene oxide was available in molded sheet (sample 16). Polyphenylene sulfide was evaluated as molding pellets (sample 11) and molded sheet (samples 20 and 24). Polyaryl sulfone was evaluated as molding pellets (sample 10) and molded sheet (sample 15). Chlorinated polyvinyl chloride homopolymer was evaluated as molded sheets (samples 17 and 25). Polyvinyl fluoride and polyvinylidene fluoride were evaluated as films (samples 32 and 58).

## Processing of Polymers

Processing studies were conducted to determine the feasibility of processing the advanced polymers. The purpose was to evaluate processing parameters for molding and to optimize the parameters for molding specimens with optimum thermophysical properties. Processing studies were conducted on 9,9 bis (4-hydroxyphenyl) fluorene polycarbonate-poly (dimethylsiloxane), polyether sulfone, polyphenylene sulfide, and polyaryl sulfone.

9,9 bis (4-hydroxyphenyl) fluorene polycarbonate-poly (dimethylsiloxane) block polymer was injection-molded using a Battenfeld 78.4 g reciprocating screw injection-molding machine. The granules of the polymer were dried prior to molding under vacuum at 130°C until no further weight loss was noted.

The following molding process parameters were utilized: the barrel temperature profile was set at the rear nozzle at 298°C, in the middle nozzle at 321°C, and at the front nozzle at 315°C. The mold temperature was 121°C; the mold surface temperature was 107°C. The injection pressure was 89635 kN/m<sup>2</sup>, the injection speed 1 sec, the injection pressure hold-time 10 sec, the feed time 25 sec, the screw rpm was 160, and the pressure in the runner feeding disk was 7998 kN/m<sup>2</sup>. Disks with good optical clarity (sample 23) were produced using the above molding procedure.

Molding of the other materials (polyether sulfone, polyphenylene sulfide, and polyaryl sulfone) was accomplished in a conventionally heated molding press using conventional compression molding techniques. Molding tests were made of polyether sulfone and polyphenylene sulfide to establish a workable temperature and pressure cycle that would form flat panels in a thickness range of 0.254 to 0.635 cm.

Polyether sulfone appears to have satisfactory molding characteristics for producing sheet stock. Initial trials were not successful because the pellets were not dried. Once the 148°C drying process was employed, satisfactory specimens could be provided over a molding temperature range of 213-316°C, molding pressure of 3.4 to 27.5 MN/m<sup>2</sup> and molding time of 3 to 7 min. Polyphenylene sulfide was slightly more difficult to mold into satisfactory specimens than polyether sulfone. The polyphenylene sulfide has a somewhat higher melting point than polyether sulfone (approximately 267°C). However, it becomes liquid at the molding temperature, and even low pressures force it out of the mold completely. Yet, at slightly lower temperatures, the material does not consolidate completely under very high pressures, i.e., 27.58 MN/m<sup>2</sup>. Optimum molding conditions and satisfactorily molded specimens were obtained with a molding pressure of 6.8 MN/m<sup>2</sup>, molding temperature of 238° to 289°C with a molding time of 3 to 8 min. Polyaryl sulfone was molded satisfactorily at a molding temperature of 310° to 370°C, molding pressure of 7.5 to 13.5 MN/m<sup>2</sup> and molding time of 2 to 10 min.

## RESULTS AND DISCUSSION

### Thermochemical Characterization

The polymers were characterized for the following chemical properties: thermomechanical properties such as glass transition temperature (T<sub>g</sub>), melt temperature (T<sub>m</sub>), and char yield in anaerobic and oxidative environments.

Thermomechanical Properties - The glass transition (T<sub>g</sub>) and melt (T<sub>m</sub>) temperatures were determined by the DuPont thermal mechanical analyzer (TMA), Model 441, with the DuPont thermal analyzer, Model 900. Measurements were made in the penetration or compression mode, using a hemispherical tip probe.

The materials that were studied included phenolphthalein-bisphenol A polycarbonate copolymer, polyether sulfone, polyphenylene sulfide, polyaryl sulfone, and polyvinylidene fluoride. The Tg and Tm data for these polymers are presented in Table 2 together with data of the other polymers.

In addition to studies conducted on the TMA, differential scanning calorimetry (DSC) studies were conducted with a DuPont Model 900 DSC on polyphenylene sulfide, polyaryl sulfone, and polyether sulfone. The Tg and Tm data for these polymers are shown in Table 2.

The thermal properties of polyphenylene sulfide were studied in detail using the DSC. Two endotherms and one exotherm were observed. The DSC thermogram shows an endotherm at 90°C. This temperature corresponds to the glass transition temperature (Tg = 89°C) determined by TMA. The transition at 89°C must be due to melting, which is a first-order transition. This is confirmed by the dilatometer measurements. The data indicate that polyphenylene sulfide is highly crystalline. Previous studies (6) have shown a glass transition temperature of 85°C. An exotherm was observed at 119°C which is due to crosslinking of polyphenylene sulfide. According to previous studies (6), crosslinking with recrystallization occurs in the presence of air. Polyphenylene sulfide again forms a glass on crosslinking.

A second glass temperature was detected at 250°C. The endotherm, at 250°C, is attributed to melting of the second glass state.

In summary, polyphenylene sulfide is thermally very stable. It undergoes interesting and unusual transitions in physical state when heated, which accounts for its good high-temperature mechanical properties. The extruded pellets of polyphenylene sulfide are highly crystalline, with a melting point



of 89°C. Crosslinking with the formation of an amorphous glass occurs at 119°C. The glass temperature of the second glass region is 250° to 271°C.

In the case of polyvinylidene fluoride, the glass transition temperature is at about 40°C. The glassy state is transformed with increasing temperature into a rubbery or elastomeric state. The material melts at about 145°C.

Thermogravimetric Analyses - Thermal analyses of the polymers were conducted on a DuPont 950 thermogravimetric analyzer (TGA) using both nitrogen and air atmospheres with a sample size of 10 mg and a heating rate of 40°C/min. The char yield (Yc) of these polymers at 800°C in air and nitrogen is shown in Table 3.

The pyrolysis of the samples in air and nitrogen atmospheres was conducted to determine the pyrolysis temperature of the samples in order that similar temperatures be utilized in the furnace used to pyrolyze samples for assessing their relative toxicity as described later in the text. Pyrolysis in an air atmosphere is intended to approximate the environment in the pyrolysis tube at the start of the toxicity test; pyrolysis in a nitrogen atmosphere is intended to approximate the environment in the pyrolysis tube during the test after the original air has been displaced by pyrolysis effluent. The degradation products are continuously removed from the sample during thermogravimetric analysis, and in the relative toxicity test apparatus described later they are conveyed only by normal thermal flow. The TGA data in the nitrogen atmosphere are considered more relevant, because in the toxicity apparatus the pyrolysis effluents that evolved at lower temperature have essentially displaced the original air by the time the temperature has reached 800°C.

All thermoplastics underwent thermooxidative decomposition in two major steps, which is characteristic of polymeric materials. The test materials

contained 1 to 3 percent moisture, which was lost between 200° to 280°C. This weight loss was not as evident in the fast heating rate (40°C/min) as it was in the lower heating rate (10°C/min).

9,9 bis (4-hydroxyphenyl) fluorene polycarbonate-poly (dimethylsiloxane) block polymer (samples 21, 23, 27, and 28) is the most stable transparent thermoplastic polymer and gives the highest char yield in nitrogen and air. Polyphenylene sulfide (samples 11, 20, and 24) is the most stable polymer tested in both the anaerobic and oxidative environments. According to previous studies (6), thermooxidative degradation of polyphenylene sulfide occurs rapidly above 520°C. This is in excellent agreement with the present studies, during which degradation occurred at approximately 500°C.

#### Physical Properties

Some of the physical properties of the polymers are shown in Table 4. Properties that were evaluated included specific gravity, tensile strength, ultimate elongation, heat deflection temperature, flexural strength, flexural modulus, impact strength, and compressive strength. Phenolphthalein-bisphenol A polycarbonate copolymer was not available in sufficient quantity to permit mechanical testing. The physical properties of the advanced polymers are within the range of the desired properties of thermoplastic materials for aircraft interior components.

#### Flammability Properties

Oxygen Index - The oxygen index (OI =  $O_2/O_2 + N_2$ ) of the polymers was determined per ASTM D-2863 and is shown in Table 5. Polyphenylene sulfide and 9,9 bis (4-hydroxyphenyl) fluorene polycarbonate-poly (dimethylsiloxane) block polymer had the highest oxygen index of the polymers tested.

Smoke Evolution - Smoke evolution from the polymers was determined using the NBS-Aminco smoke density chamber. The  $D_s$  specific optical smoke density ( $D_s = 132 \log_{10}(100/D)$ ) and the uncorrected maximum specific optical density ( $D_m$ ) values are obtained from individual test data and then averaged. The test results obtained are presented in Table 5. Tests were conducted at a heat flux of  $2.5 \text{ W/cm}^2$  under flaming conditions. Of the state-of-the-art materials, polyvinyl fluoride has an extremely low smoke evolution. Of the advanced materials, polyvinylidene fluoride has the lowest smoke evolution. The low smoke evolution of PVF was caused by the thin film utilized in this test. The film was consumed very rapidly upon application of the pilot flame. 9,9 bis (4-hydroxyphenyl) fluorene polycarbonate-poly (dimethylsiloxane) block polymer also exhibited low smoke evolution. Phenolphthalein-bisphenol A polycarbonate copolymer and phenolphthalein polycarbonate were not available in sufficient quantity to permit determination of the smoke evolution. In addition to the  $D_m$  values indicated in Table 5, the  $D_s$  values were determined at 1.5 and 4.0 min intervals during the test. The percent light transmittance ( $D = 100/10^{(D_s/132)}$ ) for these polymers is indicated in Table 6.

Relative Toxicity - The relative toxicity of the pyrolysis effluents of the thermoplastic materials was determined. The methodology and apparatus utilized for assessing the relative toxicity of the pyrolysis effluents has been described previously (7). A summary of the procedure follows.

Four swiss albino mice are placed in an animal exposure chamber (4.2 liter vol.) and given a minimum of 5 min to adjust to their surroundings. With both sample and animals in place, the entire system is sealed and all joints checked for proper sealing. The animal exposure chamber is the last part sealed, to minimize oxygen consumption before the actual start of test. The polymer

sample is placed in a quartz tube in the furnace. The furnace is preheated to 200°C and, at the start of the test, is turned on at the predetermined heating rate of 40°C/min. When the upper temperature limit of 800°C is approached or reached, this temperature is maintained by either automatic or manual control until the end of the test. The test period is normally 30 min; if 100 percent mortality occurs in less than 30 min, the test is terminated upon the death of the last surviving animal. It is difficult to choose time to death or time to incapacitation as the criterion of toxicity, because some materials produce incapacitation more rapidly than other materials. In these tests, 1.0 g of polymer was placed in the furnace for pyrolysis. The test results in terms of time to first sign of incapacitation (Ti) and time to death (Td) are shown in Table 5. Parameters which were measured during the test and the minimum or maximum values during the test were as follows: concentration of oxygen in animal exposure chamber, 13.2 percent by volume (minimum); temperature in animal exposure chamber, 29.5°C (maximum); temperature of pyrolysis furnace, 590-800°C; time to incapacitation (Ti) of the first animal observed and time to death (Td). The times indicated are the mean average times and the standard deviation between experiments for groups of replica experiments. The relative percent survival time at incapacitation ( $\text{percent Ti} = (100)(\text{Ti})/30$ ) and the relative percent survival time at death ( $\text{percent Td} = (100)(\text{Td})/30$ ) is indicated in Table 6. Test results are indicated in Table 5.

Chlorinated polyvinyl chloride homopolymer (samples 17 and 25) and polyphenylene oxide (sample 16) appeared to be among the least toxic on the basis of time to death, and among the most toxic on the basis of time to first sign of incapacitation. The choice of time to death or time to incapacitation as the criterion of toxicity evidently affects rankings of relative toxicity.

Bisphenol A polycarbonate (sample 14) appeared to be the least toxic on the basis of time to death. Lower times (Ti and Td) would probably be obtained for polyvinyl fluoride (sample 32) and polyvinylidene fluoride (sample 58) should the samples be pyrolyzed in a tube which would not react with the hydrogen fluoride evolved from the samples during pyrolysis. The quartz tube is slightly etched during the heating cycle in the furnace.

Effect of Char Yield on Oxygen Index - Previous studies (8) have shown a correlation between the flammability properties of some polymers and their char yield. Figure 1 compares the oxygen index of the polymers evaluated with their relative anaerobic char yield. It can be seen that, in general, polymers with high char yield exhibit a high oxygen index. Chlorinated polyvinyl chloride homopolymer (samples 17 and 25) exhibits a high oxygen index and a relatively low char yield. Previous studies (9) have shown that the principal combustion product of this polymer from ambient to 350°C are hydrogen chloride and benzene. The mole ratio of hydrogen chloride to benzene was 2.5:1 during the initial weight loss (approximately 63 percent weight loss from ambient to 350°C). This is equivalent to 0.539 g of HCl per 1.0 g of initial sample of polymer combusted. It is known (9) that HCl is a flame inhibitor and the high oxygen index is attributed to the quenching effect of the HCl during the test.

#### CONCLUSION

The flammability properties of the polymers evaluated are summarized in Table 5. The relative flammability characteristics of these polymers are indicated in Table 6. For comparative purposes, the values of the material properties are indicated in terms of percent, 100 percent indicating the most desirable fire-safe material properties. The problem of evaluation of materials in terms of fire safety is complex. To rank materials, it would be

desirable to develop a "fire safety equation" that would assign weight to specific measurements of each variable, i.e., oxygen index, smoke evolution, toxicity of the oxidative pyrolysates, and thermal stability (char yield) of each polymer. Development of such an equation is dependent on: identification of the variables (OI, D, percent Ti, percent Td, Yc), determination of the importance of each variable to the real aircraft fire situation, selection of measurement techniques for each variable and determination of the weight to be assigned to the measurement of each specific variable to reflect the real fire situation. It is beyond the scope of this study to define such an equation, but some general conclusions may be drawn based on the data presented in Table 6. Assuming equal weight assignment to each flammability parameter and averaging the percent values indicated, the polymers and their relative percent values could be rated as follows, in order of increased fire safety: polyphenylene oxide (sample 16) 28 percent; acrylonitrile butadiene styrene (sample 18) 30.1 percent; bisphenol A polycarbonate (sample 19) 32.5 percent; chlorinated polyvinyl chloride homopolymer (sample 17) 35.5 percent; bisphenol A polycarbonate (sample 14) 37.7 percent; polyaryl sulfone (sample 15) 42.4 percent; polyvinylidene fluoride (sample 58) 47.4 percent; polyvinyl fluoride (sample 32) 51.1 percent; polyether sulfone (sample 12) 51.3 percent; 9,9 bis(4-hydroxyphenol) fluorene polycarbonate-poly (dimethylsiloxane) block polymer (sample 23) 52.1 percent; and polyphenylene sulfide (sample 20) 53.0 percent. Based on these values, the relative ranking of the materials evaluated is indicated in Table 7. The polyvinyl fluoride film (sample 32) would have normally shown lower in the scale of fire-resistant polymers, except that low Ds numbers were obtained during the smoke tests, since the film was consumed early in the tests. In the toxicity tests, the relatively high Td times

obtained for polyvinyl fluoride (sample 32) and polyvinylidene fluoride (sample 58) and possibly attributed to the reaction of hydrogen fluoride evolved during the pyrolysis with the quartz tube in the furnace.

#### ACKNOWLEDGMENT

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Table 1. Typical Chemical Structures of Polymers

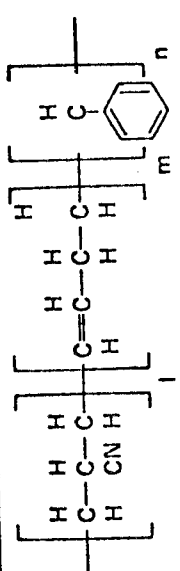
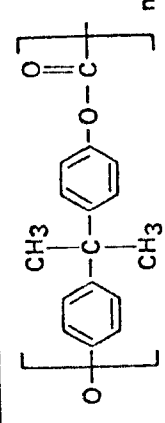
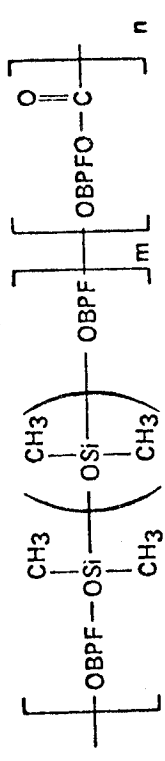
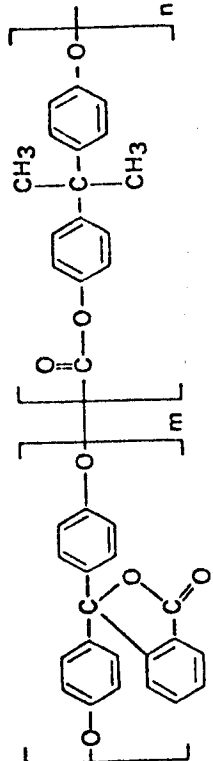
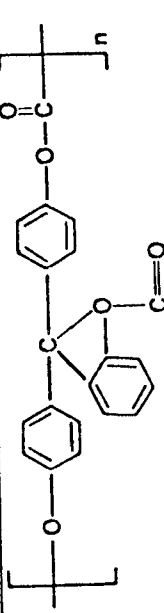
SAMPLE NUMBER	SAMPLE DESCRIPTION	POLYMER	POLYMER STRUCTURE
18	SHEET	ACRYLONITRILE BUTADIENE-STYRENE (ABS)	
14	SHEET	BISPHENOL A POLY-CARBONATE (BPAPC)	
19	FIRE RETARDANT; SHEET		
21	FILM; SOLVENT CAST FROM CHLOROFORM, 21% DMS	9,9 BIS (4-HYDROXYPHENYL) FLUORENE POLYCARBONATE-POLY (DIMETHYLSILOXANE) BLOCK POLYMER (BPFC-DMS)	
23	INJECTION MOLDED DISCS, 10.16 cm. DIA. by 0.3175 cm, 15% DMS		
27	UNCURED, MOLDING POWDER		
28	MOLDING POWDER, CURED AT 315.56°C		
30	80% MOLE PHENOLPHTHALEIN, FILM	PHENOLPHTHALEIN-BISPHENOL A POLYCARBONATE COPOLYMER (PH-BPAPC)	
31	70% MOLE PHENOLPHTHALEIN, FILM		
55	FILLED WITH 10% Al2O3, 5% TiO2; FILM		

Table 1. Concluded

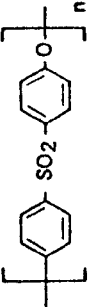
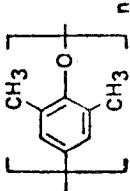
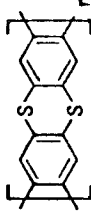
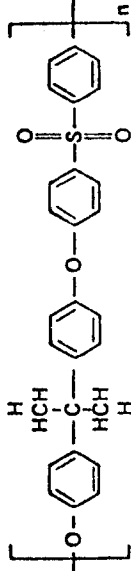
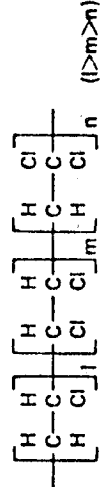
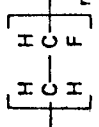
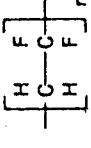
SAMPLE NUMBER	SAMPLE DESCRIPTION	POLYMER	POLYMER STRUCTURE
12 13 22	MOLDING PELLETS MOLDING PELLETS 0.0127 cm FILM	POLYETHER SULFONE (PES)	
16	MODIFIED; SHEET	POLYPHENYLENE OXIDE (PPO) (POLY-2,6-DIMETHYL-PHENYLENE OXIDE)	
11 20 24	MOLDING PELLETS MOLDED PART SECTION, 0.3175 cm THICK 0.3175 cm SHEET	POLYPHENYLENE SULFIDE (PPS)	
10 15	MOLDING PELLETS MODIFIED; SHEET	POLYARYLSULFONE (PAS)	
17 25	SHEET SHEET	CHLORINATED POLYVINYL CHLORIDE HOMOPOLYMER (CPVC)	
32	0.0051 cm FILM	POLYVINYL FLUORIDE (PVF)	
58	0.0127 cm FILM	POLYVINYLIDENE FLUORIDE (PVF2)	

Table 2. Glass Transition Temperature (T<sub>g</sub>) and Melting Temperature (T<sub>m</sub>) of Thermoplastics

SAMPLE NUMBER	POLYMER	RUN NUMBER	HEATING RATE (°C/min.)	T <sub>g</sub> (°C)	T <sub>m</sub> (°C)
18	ACRYLONITRILE BUTADIENE (ABS)	---	---	~ 80 (14)	---
14	BISPHEINOL A POLYCARBONATE (BPAPC)	---	---	150 (19)	263 (19)
19	9,9 BIS (4-HYDROXYPHENYL) FLUORENE POLYCARBONATE-POLY (DIMETHYLSILOXANE) BLOCK POLYMER (BPFC-DMS)	---	---	150 (19)	263 (19)
21		---	---	~240	~360
23		---	---	~215	~360-370
27		---	---	~215	~360-370
28		---	---	---	---
30	PHENOLPHTHALEIN-BISPHEINOL A POLYCARBONATE COPOLYMER (PH-BPAPC)			~255	~278
31				~250	~260
55	PHENOLPHTHALEIN POLY-CARBONATE (PHPC)	---	---	278 (19)	295 (19)
12	POLYETHER SULFONE (PES)	1	5	218	228
		2	15	220	228
		3	15	225	---
13	POLYETHER SULFONE (PES)	1	25	---	208
		---	---	---	---
22		---	---	---	---

Table 2. Concluded

SAMPLE NUMBER	POLYMER	RUN NUMBER	HEATING RATE (°C/min.)	T <sub>g</sub> (°C)	T <sub>m</sub> (°C)
16	POLYPHENYLENE OXIDE (PPO)	---	---	~210 (21)	~257 (21)
11		1	15	89	271
		2	2	88	250
20		---	---	---	---
24	POLYPHENYLENE SULFIDE (PPS)	1	15	89	271
		2	15	92	275
		3	15	86	270
		4	15	82	260
		5	30	88	267
10	POLYARYL SULFONE (PAS)	1	15	283	310
		2	15	282	303
15		---	---	---	---
17	CHLORINATED POLYVINYL CHLORIDE HOMOPOLYMER (CPVC)	---	---	---	~195 (29)
25		---	---	---	~195 (29)
32	POLYVINYL FLUORIDE (PVF)	---	---	70 (30)	210 (31)
58	POLYVINYLIDENE FLUORIDE (PVF <sub>2</sub> )	1	25	32	138
		2		50	148

Table 3. Char Yield of Thermoplastics in Nitrogen and Air

SAMPLE NO.	POLYMER	$\gamma_c$ , 800°C, N <sub>2</sub>	$\gamma_c$ , 800°C, AIR
18	ABS	18	5
14	BPAPC	30	3
19	BPAPC	27	5
21	BPFC-DMS	58	*
23	BPFC-DMS	61	19
27	BPFC-DMS	58	19
30	PH-BPAPC	47	2
31	PH-BPAPC	43	2
55	PHPC	50	*
12	PES	44	10
13	PES	43	10
22	PES	9	0
16	PPO	17	17
11	PPS	66	42
20	PPS	68	47
24	PPS	72	47
10	PAS	50	5
15	PAS	42	10
17	CPVC	29	5
25	CPVC	28	5
32	PVF	8	3
58	PVF <sub>2</sub>	30	5

\*NOT DETERMINED

Table 4. Physical Properties of Thermoplastics

SAMPLE NUMBER	POLYMER	PROPERTIES									
		SPECIFIC GRAVITY ASTM D792 (g/cm <sup>3</sup> )	TENSILE STRENGTH @ 23°C ASTM D1708 (MN/m <sup>2</sup> )	ULTIMATE ELONGATION @ 23°C ASTM D1708 (%)	HEAT DEFLECTION TEMPERATURE @ 182 KN/m <sup>2</sup> ASTM D648 (°C)	FLEXURAL STRENGTH @ 23°C ASTM D790 (MN/m <sup>2</sup> )	FLEXURAL MODULUS @ 23°C ASTM D790 (GN/m <sup>2</sup> )	IMPACT STRENGTH (NOTCHED Izod) @ 23°C ASTM D256 (J/m)	COMPRESSIVE STRENGTH @ 23°C ASTM D1621-64 (GN/m <sup>2</sup> )		
18	ACRYLONITRILE BUTADIENE STYRENE (ABS)	--	37.92	2	110.0	1.72-3.10	80.1	--			
14	BISPHENOL A POLYCARBONATE (BPAPC)	1.2	63.00	--	140.0	1.80	70.0	--			
19		58.61	50	132.0	2.06	408.5	82.74	82.74			
21	9,9 BIS (4-HYDROXYPHENYL) FLUORENE POLYCARBONATE-POLY (DIMETHYLSILOXANE) BLOCK POLYMER (BPFC-DMS)	--	57.20-82.74	20-48	--	--	--	--			
23		1.17	46.89-51.23	20-48	200-210	1.66-2.14	101.43-138.80	--			
27		1.17	46.89-51.23	20-48	200-210	1.66-2.14	101.43-138.80	--			
28		1.17	46.89-51.23	20-48	200-210	1.66-2.14	101.43-138.80	--			
30	PHENOLPHTHALEIN-BISPHENOL A POLYCARBONATE COPOLYMER (PH-BPAPC)	--	--	--	--	--	--	--			
31		--	--	--	--	--	--	--			
55	PHENOLPHTHALEIN POLYCARBONATE (PHPC)	1.27 (33)	91.7 (33)	--	250.0 (33)	--	80.0 (33)	--			
12		1.26	75.85	70	199.0	2.41	85.4	82.74			
13		1.37	84.12	40-80	202.8	2.55	85.4	--			
22		1.27	75.85	70	199.0	2.41	85.4	82.7			
16	POLYPHENYLENE OXIDE (PPO)	1.21	99.98	4-6	145.0	5.10	85.4	12.14			
11		--	--	--	--	--	--	--			
20	POLYPHENYLENE SULFIDE (PPS)	1.36	74.47	3	136.7	4.4	16.2	--			
24		1.36	74.47	3	136.7	4.4	16.2	--			

Table 4. Concluded

SAMPLE NUMBER	POLYMER	PROPERTIES							
		SPECIFIC GRAVITY ASTM D792 (g/cm <sup>3</sup> )	TENSILE STRENGTH @ 23°C ASTM D1708 (MN/m <sup>2</sup> )	ULTIMATE ELONGATION @ 23°C ASTM D1708 (%)	HEAT DEFLECTION TEMPERATURE @ 182 KN/m <sup>2</sup> ASTM D648 (°C)	FLEXURAL STRENGTH @ 23°C ASTM D790 (MN/m <sup>2</sup> )	FLEXURAL MODULUS @ 23°C ASTM D790 (GN/m <sup>2</sup> )	IMPACT STRENGTH (NOTCHED I <sub>zod</sub> ) @ 23°C ASTM D256 (J/m)	COMPRESSIVE STRENGTH @ 23°C ASTM D1621-64 (GN/m <sup>2</sup> )
10	POLYARYL SULFONE (PAS)	1.25	68.95	40	166.0	103.43	2.34	69.4	93.08
15		1.37	41.37	20	93.0	65.50	1.72	266.9	---
17	CHLORINATED POLYVINYL CHLORIDE HOMO. POLYMER (CPVC)	1.60	34.48	30	82.2	65.50	1.72	266.9	---
25		1.60	34.48	30	82.2	65.50	1.72	266.9	---
32	POLYVINYL FLUORIDE (PVF)	1.38-1.57	48.27-68.95	115-225	<107.0	---	---	---	---
58	POLYVINYLIDENE FLUORIDE (PVF2)	1.75-1.80	42.06-58.61	50-100	141-168	---	1.38	138.8-202.9	68.95



Table 5. Summary of Flammability Properties of Polymers

SAMPLE NUMBER	POLYMER	Y <sub>c</sub> 800°C, N <sub>2</sub>	OI	D <sub>m</sub>	T <sub>i</sub>	T <sub>d</sub>
18	ACRYLONITRILE BUTADIENE STYRENE (ABS)	14	34.5	843.07	11.35	19.30
14	BISPHENOL A POLYCARBONATE (BPAPC)	26	32.0	362.72	16.02	23.04
19		21	33.5	187.17	12.82	16.08
21	9,9 BIS (4-HYDROXYPHENOL) FLUORENE POLYCARBONATE-POLY (DIMETHYL-SILOXANE) BLOCK COPOLYMER (BPFC-DMS)	--	30.5	--	--	--
23		60	47.5	210.58	16.77	20.52
27		67	--	--	--	--
28		--	--	--	--	--
30	PHENOLPHTHALEIN-BISPHENOL A POLYCARBONATE COPOLYMER (PH-BPAPC)	46	38.0	--	--	--
31		41	26.8	--	14.15	16.92
55	PHENOLPHTHALEIN POLYCARBONATE (PHPC)	--	32.0	--	--	--
12	POLYETHER SULFONE (PES)	42	40.5	56.10	10.72	12.22
13		40	40.0	--	13.39	14.42
22		7	30.0	--	9.63	10.28
16	POLYPHENYLENE OXIDE (PPO)	13	32.0	775.35	8.65	19.96
11	POLYPHENYLENE SULFIDE (PPS)	64	48.0	--	9.59	10.57
20		68	48.0	124.88	10.22	11.07
24		62	50.0	--	10.84	12.40
10		47	36.0	--	10.01	11.23
15	POLYARYL SULFONE (PAS)	39	30.0	241.03	10.61	15.72
17	CHLORINATED POLYVINYL CHLORIDE (CPVC)	26	55.0	355.22	6.29	21.76
25		24	55.0	--	9.00	22.74
32	POLYVINYL FLUORIDE (PVF)	7	18.0	2.32	16.94	20.50
58	POLYVINYLIDENE FLUORIDE (PVF <sub>2</sub> )	30	43.4	18.83	9.19	17.34

Table 6. Relative Flammability Characteristics of Thermoplastics

