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Flash-Fire Propensity and Heat-Release Rate Studies of Improved Fire Resistant Materials

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FLASH-FIRE PROPENSITY AND HEAT-RELEASE RATE STUDIES OF IMPROVED FIRE RESISTANT MATERIALS

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ABSTRACT: Twenty-six improved fire resistant materials were tested for flash-fire propensity and heat-release rate properties. The tests were conducted to obtain a descriptive index based on the production of ignitable gases during the thermal degradation process and on the response of the materials under a specific heat load.

INTRODUCTION

The ascertainment of the thermal characteristics of nonmetallic materials used in commercial passenger aircraft has grown in importance in recent years due to increased passenger loads. Because of the increased utilization of polymeric materials on wide-body jets, the fire safety (thermal response) of each material used in an aircraft's interior must be established. The aircraft passenger seat represents the largest source of potentially combustible materials. When considering the quantity of nonmetallic materials being used in occupied areas of aircraft, heat-release rate, flash-fire propensity measurements, and toxicity must be taken into consideration.

The flash-fire phenomenon involves several processes of gas-phase combustion reactions of the volatile products of polymer degradation and air. A flash-fire will occur if combustible vapors produced by polymeric materials mix with air during thermal decomposition of the material and the mixture is then ignited. The propagation of the flame in the chamber is dependent on the composition of the combustibles and their ratio to air. The early work of Coward et al. [1] established the flammability limits for a wide range of gases based on their concentrations in air. Flame propagation is concentration-limited [2]; in order for the mixture to ignite and support combustion, it must be between the lower concentration limit (too fuel lean) and the upper concentration limit (fuel rich). Other factors such as heating rate, type of heating, heat release, ignition source, and the chemical nature of the polymeric material affect the rate and type of combustibles generated, and thus the material's flash-fire propensity.

Heat release rate (HRR) values are dependent on the mode of ignition and sample thickness. Two modes of ignition of the specimen exist: unpiloted and piloted. Unpiloted ignition is a process of auto-ignition of the pyrolysis gases; piloted ignition is achieved by the direct impingement or placement of the pilot flame so as to affect the ignition of the pyrolysis gases of the sample. Heat release rate measurements start the moment the sample is injected into the heat release rate calorimeter's sample chamber which has a constant flow of air. The samples were exposed individually to external heat fluxes ranging from 2.5 to 5.0 kW/cm^2. The temperature differential due to gases leaving the chamber were monitored with time, thus giving the heat release rate of the sample material. As the sample starts to burn, the flame spreads horizontally across the surface of the sample from the point of flame impingement, and the rate of heat release increases until the entire surface of the sample is involved.

Release rates for a sample are dependent on exposure or thermal flux. There is no one absolute value of release rate or flame-travel characteristic for a given material because materials do not respond thermally in the same manner. Each heat-release rate is specific for the given test parameters, any one of which, if varied, will considerably alter the results. Therefore, one test is not sufficient to adequately compare the performance of a material in a real fire. The predictive approach described in this study enables one to determine the basic thermal behavior or characteristics such as: (1) heat and smoke release rate as a function of time, and (2) rate of flame involvement at specific external heat fluxes.

The heat release rate is an indicative descriptive index of a material's thermal response to specific conditions of fire exposure. Heat-release rates will also differ for samples of the same material but of different thicknesses; if the sample forms a thick char, intumesces, or undergoes a dimensional surface change, the heat-release rate will vary due to the lack of steady state conditions.

The flash-fire propensity and heat-release rate data from these tests will enable the materials engineer or fire safety officer to accurately ascertain the thermal characteristics of these improved fire resistant materials; the data will also provide a quantitative description, in well-defined terms, of the combustibility of the material.

MATERIALS

The materials selected for this study were 14 fabric samples, 4 fabric batting, and 4 foam samples (see Table 1).

TEST APPARATUS AND PROCEDURE

Flash-Fire Propensity

The NBS flash fire cell was modified by adding a small electrically powered pyrolysis tube furnace attached to the demountable side arm of the apparatus (Figure 1). This design modification allows for faster, more reproducible heating regimes than can be accomplished by the NBS external heater approach [3].

The thermocouple junction was inserted through the septum (H in Figure 1) which is near the center of the main vertical tube. The thermocouple positioned at H (Figure 1) and the thermocouple probe, which is inserted in the sample, are recorded simultaneously on the same chart, as shown in Figures 2-13; the latter thermocouple will detect a fire front traveling vertically upward during a test run.

A cycle control and timer with a counter connected to the 10-kV transformer spark generator was set to cycle the 1-cm spark gap in the base of the cell for approximately 0.5 sec with a repetition rate of 6/min. The heat generated by the spark inside the main tube was detected on the thermocouple record as a short upscale pulse each time the ignition source spark was cycled. Power for the pyrolysis combustion tube heating coil was supplied by a variac transformer (20 A) which was adjusted manually to a preselected power level.

This pyrolysis permits the selection of a wide range of heating profiles (maximum 600°C/min) by adjustment of the voltage. Thermal fluxes to the sample are uniform over the internal surface of the pyrolysis tube because of the uniform output of the coil wire. Heating fluxes ranged from 0.1 to 4 W/cm^2. The test procedure was as follows. First, a 0.5-g sample was inserted in a pre-weighed heating coil/pyrolysis tube assembly, installed in the side tube (Figure 1), and connected to the variac power source. Second, the pyrolysis zone thermocouple probe was then inserted through the entrance tube in cap/joint D (Figure 1) and plugged into the ice point electronic reference; the recorder range for this output was set at 50 mV full scale. Third, the cycle timer was set for a 0.05-sec spark at 10-sec cycle intervals, the counter set to zero, and the dual pen recorder chart speed was set at 6.25 mm/min. Fourth, the start of each experimental run was initiated by switching on the pyrolysis coil power, the spark cycle timer, and depressing the hand-held record event marker switch to mark zero time on the recorder chart; the power to the pyrolysis tube was adjusted to 5.5 A. Fifth, the outlet at the internal end of the pyrolysis tube was observed and the event marker switch was depressed to mark the recorder chart at the time of the first appearance of smoke. The appearance and quantity of smoke and the relative intensity (light, sound, flame front travel, and force) of the flash-fire combustion were qualitatively assessed.

Heat Release Rate

The apparatus used to test materials in this study was a modified version of the Ohio State University heat-release-rate calorimeter [4] (Figure 14). In this study, sample specimens were exposed to external heat fluxes of from 2.5 to 5.0 W/cm^2. The heat released from the 15 × 15 cm square samples was measured and evaluated; the test samples received no prior treatment or conditioning. Quantitative measures of heat released, in terms of kilowatts or Btu's per minute were calculated per square meter of the surface area exposed, as a function of time. The test parameters, operational modes, and physical characteristics of the samples are listed in Table 2. A modified lightweight, stainless steel sample holder with a refractory backing of low thermal conductance was utilized in order to reduce heat absorption by the holder after the injection of the mounted sample into the heat release rate chamber.

The start of the test procedure begins by adjusting the electrically powered radiant panel thermal source to the required thermal flux using a hycal radiometer-calorimeter and allowing the system to equilibrate to a constant level with a continuous airflow through the chamber. The baseline temperature variations were recorded differentially between the air input temperature and the temperature of the exit stack of the provides the fuel for the initiation of the combustion process. Three samples exhibited multiple flashes (Table 3). The urethane elastomer coated on nylon (sample No. 6) produced a strong flash response in the flash fire cell at 450°C which could be described as an explosion. The fire-retardant treated nylon gave a strong flash response (100 and 85 tpu) at much higher sample pyrolysis temperatures (570° and 910°C, respectively). The wool/nylon blend (sample No. 4) gave low intensity multiple flashes (Table 3 and Figure 2) and a heavy, gray smoke. Wool, which is inherently flame resistant, has a high ignition temperature and low heat of combustion; when wool does burn or smoulder in excess air, it has been known to produce carbon monoxide in concentrations of 200 to 400 ppm and 30 to 70 ppm hydrogen cyanide [5,6]. Novoloid and novoloid/aramid blends in this study (Table 1) showed a high level of fire resistivity and generated smoke at higher temperatures. These novoloid and novoloid-aramid blends had longer times and higher temperatures at which flash-fire combustion occurred (Table 3), and had low heat-release rates (Table 4). Novoloid samples flashed at higher sample pyrolysis temperature (average 945°C) than novoloid/aramid blends (Table 3).

Novoloid/aramid blend undergoes flash-fire combustion at an average sample pyrolysis temperature of 830°C while aramid by itself does not give a flash response. In some manner, the aramid in the novoloid/aramid blend affects the flash-fire propensity values by altering either the chemical species of the volatile product or its rate of production. A determination or critical analysis of the results is difficult to make without a detailed gas analysis of the decomposition gases [1,11]. Aramid samples (Table 3 and Figure 3) gave off a heavy, yellow smoke and did not give a flash-fire response. The amide-imide/wool blend (Figure 1) did not flash; its low flammability is attributed to the fire resistant properties of wool [5] in the blend which dilutes the combustibles generated by the amide-imide material. Amide-imide material (Figure 9) when tested in the flash-fire cell gave a strong thermal response (100 tpu) at a sample pyrolysis temperature of 910°C (Table 3). Aramid chlorinated aramid, polychloroprene, silicone foam, glass fiber block foam, and polyphosphazene foam gave no flash-fire response in the flash-fire cell.

Results of heat-release-rate measurements (Table 4) showed the glass fiber block foam (sample No. 19) had the lowest heat-release rate of all materials tested. In general, materials that did not give a flash-fire response had lower heat-release rates than those which gave a flash-fire response.

Nine of the 26 samples tested for flash-fire propensity and heat-release rate passed the test criteria in this study. Of the nine samples that met these rigorous requirements, only one gave a flash-fire response and that occurred at a very high sample pyrolysis temperature (1040°C). The remainder of the samples gave no flash-fire response and had low heat-release rates. Aramid samples type A and B, novoloid on polyester, polychloroprene on cotton scrim, polychloroprene (K type), chlorinated aramid (both types), and glass fiber foam (Table 3, sample Nos. 3, 10, 13, 14-16, 18, 19, and 26) are classified as materials of high fire resistivity properties based on a previous study [3] and on flash-fire propensity and heat release rate generated by the ma materials.

CONCLUSION

Flash-fire propensity and heat-release-rate calorimetry proved to be of considerable value in determining the thermal characteristics of the materials evaluated in this study. These thermal test methods enabled the establishment of the flammability characteristics of the volatile products of decomposition of the materials in this study and the characteristics of their thermal response to specific heat fluxes.

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Table 1. Materials Tested for Flash Fire and Heat Release Rate

Sample No.	Density	Generic name*
1	389 g/m^2	Nylon
2	290 g/m^2	Amide-imide/wool
3	311 g/m^2	Aramid (Type A)
4	457 g/m^2	Wool/nylon
5	319 g/m^2	Phenolic/aramid (Type A)
6	385 g/m^2	Urethane/Nylon
7	244 g/m^2	Phenolic
8	200 g/m^2	Phenolic/aramid (Type B)
9	159 g/m^2	Phenolic/aramid (Type C)
10	213 g/m^2	Phenolic
11	273 g/m^2	Imidazole (Type A)
12	118 g/m^2	Imidazole (Type B)
13	425 g/cm^3	Polychloroprene (Type A)
14	945 g/cm^3	Polychloroprene (Type B)
15	322 g/m^2m	Chlorinated aramid (Type A)
16	214 g/m^2	Aramid (Type B)
17	250 g/m^2	Amide-imide
18	---	Chlorinated aramid (Type B)
19	0.03 - 0.06 g/cm^3	Glass fiber block
20	0.14 g/cm^3	Phosphazene
21	0.15 g/cm^3	Silicone (Type A)
22	0.19 g/cm^3	Silicone (Type B)
23	0.21 g/cm^3	Silicone (Type C)
24	0.03 g/cm^3	Fire retardant treated polyurethane foam
25	0.12 g/cm^3	Polychloroprene (HL type)
26	0.14 g/cm^3	Polychloroprene (K type)

*Contact the author for the disclosure of trade names of materials tested.

Table 2. Parameters for Heat Release Rate Calorimetry.

Parameter:	Unit of Measure
Airflow (constant)	60 $feet^3/min$
Thermal flux	2.5, 3.5, 5.0 W/cm^2
Exposure time	5-15 min
Time to ignition	seconds
Flame travel rate	millimeters/second
Point pilot flame (position)	10 cm from sample bottom center
Heat Release	$kilowatt/meter^2$ (kW/m^2) at second
Heat of Combustion	total heat/area at minute
Smoke release rate (SRR)	percent reduction in transmission per meter path length

Table 3. Flash Fire Propensity Test Data.

No.	Material I.D.	Time to first smoke, min	Sample pyrolysis temperature at 1st smoke, °C	Flash response No.	Flash response min	Flash response thermal pulse height, divisions	Sample pyrolysis temp., °C	Observations
1	Nylon (fire re-tardant treated)	0.8	380	1st	1.2	100	570	Medium light and sound
				2nd	3.3	85	910	Low light and sound
				3rd	4.5-4.8	8-12	1000	Very low
2	52.5% amide-imide 47.5% wool	0.4	290	No flash				Heavy yellow smoke
3	aramid (Type A)	0.7	378	No flash				Heavy yellow smoke
4	90% wool/10% Nylon	0.3	230	1st	1.6	17	275	Low noise and light
				2nd	1.7	15	264	Heavy gray smoke
				3rd	1.8	9	175	
5	50% Novoloid/ 50% aramid	0.5	319	1st	3.3	95	810	Medium sound and low light, dense light yellow smoke
6	Urethane elastomer coated on nylon	0.5	184	1st	1.4	100	450	Multiple explosions with low light and sound
				2nd	1.9	5	550	
				3rd	3.1	14	700	
7	Novoloid	0.6	350	1st	1.6	100	850	Fast detonation wave with medium sound and light
8	70% Novoloid/ 30% aramid (Type A) 200 g/m	0.8	480	1st	1.7	100	750	Fast detonation with low level sound and light
9	70% Novoloid/30% 159 g/m aramid (Type B)	0.7	463	1st	3.1	100	940	Rapid flash front and low light, sound

Table 3. Flash Fire Propensity Test Data (continued).

No.	Material I.D.	Time to first smoke, min	Sample pyrolysis temperature at 1st smoke, °C	Flash response: No.	Flash response: min	Flash response: thermal pulse height, divisions	Sample pyrolysis temp., °C	Observations
10	Novoloid on polyester	1.1	600	1st	3.6	100	1040	Low light and sound
11	Polybenzimidazole	1.0	510	1st	4.2	83	940	Very low light and sound, rapid flame front travel
12	Polybenzimidazole 118 g/m (Type B)	0.2	150	1st	3.1	100	960	Light white smoke, rapid flame front and medium light sound
13	0.156 cm thick polychloroprene (Type A) on cotton scrim	0.5	263	No flash				Light smoke
14	0.475 cm thick polychloroprene (Type B) on cotton scrim	0.5	580	No flash				Light smoke
15	Chlorinated aramid (Type A)	0.7	331	No flash				Medium quantity of brown smoke
16	Aramid (Type B)	0.3	319	No flash				Yellow smoke
17	Amide-imide	0.3	233	1st	2.9	100	910	Rapid flash, low light and sound
18	Chlorinated aramid (Type B) batting	0.4	343	No flash				Medium quantity of brown smoke
19	Glass Fiber Block Foam batting	0.8	485	No flash				Trace amount of smoke

Table 3. Flash Fire Propensity Test Data (concluded).

No.	Material I.D.	Time to first smoke, min	Sample pyrolysis temperature at 1st smoke, °C	Flash response: No.	Flash response: min	Flash response: thermal pulse height, divisions	Sample pyrolysis temp., °C	Observations
20	Polyphosphazene	0.2	295	No flash				High amount of white smoke
21	Silicone rubber sponge (Type A)	0.5	391	1st	3.0	12	825	Large quantity of white smoke
22	Silicone sponge (Type B)	1.2	520	No flash				
23	Silicone sponge (Type C)	0.8	555	1st	3.0	100	930	Low sound and white smoke
24	F.R. treated polyurethane foam	1.0	425	1st	1.6	100	600	Strong flash and sound
25	Polychloroprene (HL type)	0.6	380	1st	1.8	58	715	Medium smoke and flash, low sound
26	Polychloroprene (K type)	0.8	395	No flash				Very high amount of smoke

Table 4. Heat Release Data.

ΔP ≧ 2; Flux as shown Material No. and heat flux, W/cm^2	Time to ignition, sec.	Flame travel rate, mm/sec	Heat release, total, kW/m^2	Sample weight and char yield	Remarks
No. 1 Fire retardant treated Nylon					
2.5	Flashes 22	2.7	199 7.5 min	9.27 g <2 %	Burns completely Melts, flaming Drips - drips extinguish
3.5	Flashes 5	10	180 10 min	9.00 g <2 %	Flameout - 155 sec Melted drips burn in catch pan
5.0	Flashes 5	N.D. melting	181	9.41 g <1 %	Flameout - 103 sec Burns in drip pan
No. 2 52.5% amide-imide/ 47.5% wool					
2.5	Flashes 5	12	>65.2	6.82 g 36.7 %	Burns rapidly Shrinkage - 56% Char cracks
3.5	Flashes 5	7	>49 10 min	6.70 g 23.1 %	Burst into flame 70% shrinkage Flameout - 33 sec
5.0	Flashes 5	9	130 7 min	6.76 g 40.8 %	Flameout - 53 sec 5 surface flashes 66% shrinkage

Table 4. Heat Release Data (continued).

ΔP ≅ 2; Flux as shown Material No. and heat flux, W/cm^2	Time to ignition, sec	Flame travel rate, mm/sec	Heat release, total, kW/m^2	Sample weight and char yield	Remarks
No. 3 Aramid					
2.5	Flashes None	None	22.8	7 g 67.6 %	No flame Shrinkage 66% Blue flame surface flashes
3.5	Flashes 5	>6	49.3	7.2 g 23.6 %	Spalls off Flashes Shrinkage 70%
5.0	Flashes <6	>6	52.7	6.9 g 26 %	Spalls off as white powder 77% shrinkage
5.0	Flashes <6	>6	64.2	-	Spalls off as white powder 77% shrinkage
No. 4 90% Wool/10% Nylon					
2.5	Flashes <5	3	163	10.63 g <1 %	Burns rapidly 50% shrinkage Smolders and spalls off
3.5	Flashes <5	>6	159	10.40 g <1 %	Flameout - 80 sec
5.0	Flashes <5	6.7	160	10.63 g <1 %	Flameout - 78 sec 50% shrinkage Smolders to fine white ash

Table 4. Heat Release Data (continued).

ΔP ≥ 2; Flux as shown Material No. and heat flux, W/cm^2	Time to ignition, sec	Flame travel rate, mm/sec	Heat release, total, kW/m^2	Sample weight and char yield	Remarks
No. 5 50% Novoloid/50% Aramid					
2.5	Flashes 10	3.8	101.9	7.2 g –	Flashes occasionally Smolders for 15 min
3.5	Flashes <5	5.5	76.7	7.5 g 6 %	Flameout - 49.6 sec Smolders
5.0	Flashes <5	3	86.5 8.3 min	7.18 g <1 %	Flameout - 38 sec and Smolders to 7.5 min 20% shrinkage
No. 6 Urethane coated nylon					
2.5	Flashes <5	>6	107.2 and 103.7	6.6 g <1 %	Flameout - 100 sec Melts and drips
3.5	Flashes <5	>6	>90.1 3 min	6.88 g <1 %	Flameout - 77 sec melts and drips 95% shrinkage
5.0	Flashes <5	>6	>83.2 3 min	6.80 g <1 %	Flameout - 95 sec Melts and drips

Table 4. Heat Release Data (continued).

$\Delta P \cong 2$; Flux as shown Material No. and heat flux, W/cm^2	Time to ignition, sec	Flame travel rate, mm/sec	Heat release, total, kW/m^2	Sample weight and char yield	Remarks
No. 7 Novoloid					
2.5	Flashes None	None	43.6	3.8 g 15.3 %	Sporadic flashes Near 300 sec
3.5	Flashes <5	8.6	34.8	3.9 g <5 %	Sporadic flashes Flashes Smolders
5.0	Flashes <2	>6	57.7	3.6 g <1 %	Shrinks and cracks Thin flickering flame Following smoky flame
No. 8 70% Novoloid/30% aramid (Type B)					
2.5	Flashes 25 sec	3.6	74.7	4.8 g <2 %	Flameout - 34 sec Flashing sporadically w/smoldering over 6 min
3.5	Flashes <5	7	47.9	3.8 g <1%	Flashes Smoldering 10% shrinkage
5.0	Flashes <1	8.6	65.5	5.0 g <1 %	Flickering blue-white flames over surface Smoldering - burns out sample to ash in 6 min 25 sec

Table 4. Heat Release Data (continued).

ΔP ≅ 2; Flux as shown Material No. and heat flux, W/cm^2	Time to ignition, sec	Flame travel rate, mm/sec	Heat release, total, kW/m^2	Sample weight and char yield	Remarks
No. 9 70% Novoloid/30% Aramid (Type C)					
2.5	Flashes None	None	43.6	3.8 g 15.3 %	Sporadic flashes Near 300 sec
3.5	Flashes <5	8.6	34.8	3.9 g <5%	Sporadic flashes Flashes Smolders
5.0	Flashes <2	>6	57.7	3.6 g <1 %	Shrinks and cracks Thin flickering flame Following smoky flame
No. 10 Novoloid on polyester					
2.5	Flashes 25 sec	3.6	74.7	4.8 g <2 %	Flameout - 34 sec Flashing sporadically w/smoldering over 6 min
3.5	Flashes <5	7	47.9	3.8 g <1 %	Flashes Smoldering 10% shrinkage
5.0	Flashes <1	8.6	65.5	5.0 g <1 %	Flickering blue-white flames over surface Smoldering - burns out sample to ash in 6 min 25 sec

Table 4. Heat Release Data (continued).

$\Delta P \cong 2$; Flux as shown Material No. and heat flux, W/cm^2	Time to ignition, sec	Flame travel rate, mm/sec	Heat release, total, kW/m^2	Sample weight and char yield	Remarks
No. 11 Polybenzimidazole (PBI) (Type A)					
2.5	Flashes None	None	31.6 10 min	4.0 g 74 %	No flame 55% shrinkage Char flexible
3.5	Flashes None	None	43.1 10 min	3.9 g 25.6 %	Smoldering with flickering flames
5.0	Flashes None	None	95.7 13 min	4.0 g <1 %	Smolder w/flickering flames at 60 sec 50% shrinkage (initial)
No. 12 Polybenzimidazole (PBI) (Type B)					
2.5	Flashes None	None	13.9	2.28 g 74 %	No flames
3.5	Flashes None	None	7.4	2.2 g 77 %	No flames 80% shrinkage
5.0	Flashes None	None	12.9	1.9 g <1 %	Shrank away from pilot Blue flickering flames Smoldering ends in 9 min 89% shrinkage (initial)

Table 4. Heat Release Data (continued).

$\Delta P \cong 2$; Flux as shown Material No. and heat flux, W/cm^2	Time to ignition, sec	Flame travel rate, mm/sec	Heat release, total, kW/m^2	Sample weight and char yield	Remarks
No. 13 Polychloroprene (Type A)					
2.5	Flashes <10 slight	None	58.9	10.4 g <5 %	Flames briefly around pilot - some smoldering Shrinkage - 30% Spalls off
3.5	Flashes <10	Flash vert.	51.4 8 min	10.6 g <5 %	Flashed across top edge Smoldering - spalling
5.0	Flashes <6	Flash vert.	17.2	10.3 g <5%	Flameout - 68 sec Spalls off - 92 sec
No. 14 Polychloroprene (Type B)					
2.5	Flashes None	None	82.7	22.7 g <5 %	Friable char No smoldering Shrinks 16.6% Spalls off
3.5	Flashes <7	0.6	76.7	21.0 g <5 %	Flameout 96 sec Spalls off
5.0	Flashes <7	0.9	74.8	23.5 g <5 %	Flameout in 100 sec Sporadic flashes Spalls off

Table 4. Heat Release Data (continued).

ΔP ≅ 2; Flux as shown Material No. and heat flux, W/cm^2	Time to ignition, sec	Flame travel rate, mm/sec	Heat release, total, kW/m^2	Sample weight and char yield	Remarks
No. 15 Chlorinated Aramid (Type A)					
2.5	Flashes None	None	70.7	7.8 g 44.6 %	No flame propagation 95% shrinkage
3.5	Flashes None	None	44.4	7.8 g N.D.	No flame propagation 95% shrinkage
5.0	Flashes <5	4	-	7.5 g N.D.	HRR values high due to baseline shift Strong smoldering
No. 16 Aramid (Type B)					
2.0	-	-	>10.3		
2.5	Flashes <5	>6	>21.3	5.8 g 57 %	Flameout 33 sec Shrinkage - 10% No smoldering
3.5	Flashes <5	>6	71.6	6.25 g 4 %	Flameout - 45 sec Shrinkage - 95%
5.0	Flashes <2	>6	73.3 7.6 min	6.1 g <2 %	Flameout at 62 sec and smoldering begins 75 sec Shrinkage - 50%

Table 4. Heat Release Data (continued).

$\Delta P \cong 2$; Flux as shown Material No. and heat flux, W/cm^2	Time to ignition, sec	Flame travel rate, mm/sec	Heat release, total, kW/m^2	Sample weight and char yield	Remarks
No. 17 Amide-imide					
2.5	Flashes 17	4	>60.2	6.2 g 29%	Shrinkage - 50% Burns irregularly
3.5	Flashes 8	>6	>60.6	6.15 g 25.2 %	Charred to white residue Flameout 45 sec, Shrinkage 95%
5.0	Flashes 3	>6	>66.95	6.2 g <1 %	Totally charred out - white residue Flameout at 46 sec Shrinkage 95%
No. 18 Chlorinated aramid (Type B)					
2.5	Flashes None	None	71.7	8.8 g N.D.	33% shrinkage
3.5	Flashes None	None	36.9	7.8 g N.D.	50% shrinkage After 5 min - flash flames
5.0	Flash at 40 sec	None	77.4 9 min	7.8 g N.D.	3 blue flashes at upper center of specimen Smolders - 40 sec - 6 min 28 sec 10% shrinkage

Table 4. Heat Release Data (continued).

$\Delta P \cong 2$; Flux as shown Material No. and heat flux, W/cm^2	Time to ignition, sec	Flame travel rate, mm/sec	Heat release, total, kW/m^2	Sample weight and char yield	Remarks
No. 19 Glass fiber block					
2.5	Flashes None	None	35.1	24.4 g 83.2 %	Adhesive side exposed No flame Charred 50% through
3.5	Flashes None	None	24.6	17.84 g 85.2 %	No flame
5.0					
No. 20 Polyphosphazene foam					
2.5	Flashes 10	1.4	226	63.4 g 58.3 %	
3.5	Flashes <5	3	492.9 at 14.5 min	N.D.	Flameout 370 sec Burns steadily No shrinkage
5.0	Flashes <5	5	412 at 13.5 min	65 g 52 %	Flameout - 512 sec Burns steadily 5 min Swells - white char