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L. L. Fewell, Fred Duskin, Howard Spieth,
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L. L. Fewell, Ames Research Center, Moffett Field, California
Fred Duskin
Howard Spieth
Ed Trabold, McDonnell-Douglas Aircraft Company, Long Beach, California
J. A. Parker, Ames Research Center, Moffett Field, California

NASA
National Aeronautics and
Space Administration

Ames Research Center
Moffett Field, California 94035

RELEASE-RATE CALORIMETRY OF MULTILAYERED MATERIALS FOR AIRCRAFT SEATS

Larry L. Fewell,* Fred Duskin,** Howard Spieth,**
Ed Trabold,**, and John A. Parker*

SUMMARY

Multilayered samples of contemporary and improved fire-resistant aircraft seat materials (foam cushion, decorative fabric, slip sheet, fire-blocking layer, and cushion-reinforcement layer) were evaluated for their rates of heat release and smoke generation. Top layers (decorative fabric, slip sheet, fire blocking, and cushion reinforcement) with glass-fiber block cushion were evaluated to determine which materials, based on their minimum contributions to the total heat release of the multilayered assembly, may be added or deleted. Top layers exhibiting desirable burning profiles were combined with foam cushion materials. The smoke and heat release rates of multilayered seat materials were then measured at heat fluxes of 1.5 and 3.5 W/cm^2. Choices of contact and silicone adhesives for bonding multilayered assemblies were based on flammability, burn and smoke generation, animal toxicity tests, and thermal gravimetric analysis.

Abrasion tests were conducted on the decorative fabric covering and slip sheet to ascertain service life and compatibility of layers.

INTRODUCTION

Increased utilization of polymeric materials on wide-body jets has led to an awareness of the fire potential of these materials and of the need for a critical evaluation of their thermal properties. Nonmetallic components of an aircraft passenger seat represent a large source of potentially combustible materials. The aircraft seat is a multicomponent system consisting of fabric, polymeric foam, thermo-formed plastics, and a tubular aluminum frame. Testing multilayered (ML) materials for heat release and smoke production is important because it realistically approximates the thermal response or aircraft seat materials.

Heat-release-rate (HRR) measurements, although they do not portray the actual full-scale burning characteristics of a material, provide a sufficient descriptive index (ref. 1) thermal response of a material to specific heat flux and test conditions. The HRR enables one to predict realistically the development rate of a fire in an enclosure in which the materials are used (table 1). The rate with which a fire proceeds in an enclosed area is a function of a number of related events such as the ignition source, ventilation

*Ames Research Center, NASA, Moffett Field, Calif.
**McDonnell-Douglas Aircraft Co., Long Beach, Calif.

rate, the construction aspects or geometrical configuration of the seat and the HRR properties of the material itself. The elements of the fire model (ref. 2) are the mass-removal rate during the burning process, rate of generation of combustible products, rate of heat release, and rate of oxygen depletion. The burning profile of a material is complex (ref. 2). The previously stated conditions or elements interact to varying degrees in the combustion process and are directly related to the HRR properties of a material. Tests on ML samples help establish the effect of functional layers on the HRR of improved fire-resistant materials for aircraft seat construction.

Multilayered samples were constructed of baseline and improved fire-resistant materials (table 1) as established in a previous study (ref. 3).

Candidate ML assemblies (fig. 1) were tested in a modified version of the Ohio State University HRR calorimeter (fig. 2, ref. 4). Multilayered samples were 25 cm × 25 cm and were positioned vertically in the HRR and exposed to a thermal flux of 3.5 W/cm^2.

Samples received no prior treatment. Quantitative measurements of heat release were made in terms of kW/min and calculated per square meter of the original sample surface area exposed as a function of time. The test procedure was started 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 HRR. The temperatures were within ±0.5 divisions on the chart which is equivalent to 1.0 kW/m^2 of heat release.

The reliability or accuracy of the temperature curve was ascertained by comparing calculated vs calibrated values obtained at the same airflow rate as the test materials and using natural gas of known heat content as a standard.

The selection of contact adhesives used in the assembly of ML test samples was based on their flammability and smoke generation tests (FAR 25.853), thermal gravimetric analysis (table 2, fig. 3), flash fire propensity (table 3) and animal toxicity tests (table 4).

The author wishes to thank Mrs. Renata Ibidapo from San Jose State University, San Jose, Calif., for technical services rendered during this study.

RESULTS AND DISCUSSION

Tests on ML samples consisted of two parts. The first dealt with construction of test samples which were of various upper layers having functions such as decorative fabric covering, slipcover, fire-blocking layer, and cushion backing. Glass fiber block backing was used to differentiate between layered materials and combinations of materials which may contribute significantly to the heat release of the ML assembly. The glass fiber block cushion, because of its low HRR (ref. 3), was also used to minimize any contribution to the total heat release value by the substrate (foam cushion material).

These tests were conducted to ascertain the thermal response characteristics of upper-seat layered materials which are initially exposed to the thermal flux from a fire. Multilayered samples in the first part of this test study were exposed to a heat flux of 3.5 W/cm^2. A higher heat flux (5.0 W/cm^2 or greater) would compress and obscure the thermal response processes of the layered materials, thus preventing the observation of any differences. A higher heat flux would also prevent differentiation of the additive or preferably the subtractive contributions of the layer to the overall fire resistivity of the materials utilized in seat constructions.

A representation of nine ML assemblies with glass fiber block-cushion backing (ML assemblies 1-9) is described in table 5. These ML samples consist of advanced materials of proven fire resistivity (ref. 3) and thermo-mechanical properties. The thermocouple readings from the front and back faces of the fire-blocking layer give an indication of its insulative effectiveness, which is its primary function (fig. 4, ref. 3). A temperature differential of 50° C after 5 min at a thermal flux of 3.5 W/cm^2 was considered minimum insulative effectiveness for a fire blocking-layered materials (Kynol, Vonar, and Durette) are compared in figure 4.

All ML samples of improved fire-resistant materials backed with glass fiber block cushion (ML assemblies 1-9) evidenced an initial short-term flaming condition. This was followed by a short period of extinguishment and then a second flaming which lasted for several minutes and involved deeper layers of material.

Variations that do exist in the HRR and smoke-release rates as evidenced in figures 5 and 6, respectively, are indicative of the type and quantity of adhesive utilized in the bonding of the ML assembly (table 2). Figure 5 indicates that the heat release of the upper layers (advanced materials) in the first 5 min was on the average below 300 kW/m^2. In figure 5 we also see the rather high HRR values of ML assemblies 3, 4, and 7, each with a reinforcement layer of silicone elastomer on glass fabric. The silicone elastomer layer contributed significantly to the total heat release value.

The second phase of HRR testing of ML assemblies having polymeric foam backing (table 6) was performed on ML assembly nos. 10-21. The baseline samples (nos. 10, 11, and 20) burned rapidly with complete involvement of the entire assembly in the first few minutes of testing. All specimens of improved fire-resistant materials gave a lower total heat release than the baseline sample (fig. 5) within the first 1.5 min (at a thermal flux of 3.5 W/cm^2 while the baseline samples gave over twice the heat release value of ML specimens Nos. 1 and 2 (fig. 5). Such a rapid HRR in a relatively short time indicates a potentially hazardous contribution to the propagation of the fire.

Evaluations of fire-blocking layer materials in combination with cushion-reinforcement layers based on their minimum contributions to the HRR of the

ML assembly are shown in figure 5. The Durette batting/Durette duck (ML assembly No. 9) fire-blocking layer/cushion reinforcement combination had the lowest heat release value of all the ML assemblies with fiberglass block backing in the HRR evaluations of upper layer materials (fig. 5). The significant contribution to the heat release of the ML assembly due to the silicone elastomer on glass fabric (fig. 5, ML assemblies Nos. 3, 4, and 7) is evidenced regardless of which fire-blocking layer (Kynol, Vonar, and Durette) it is in combination with in the ML assembly.

Smoke generation rates (SSU/m^2)[1] of ML assemblies shown in figure 6 indicate low amounts of smoke[2] generated during HRR testing within the first 5 min at a thermal flux of 3.5 W/cm^2. Multilayered assemblies with neoprene, polyimide, and fiberglass cushion materials contributed the minimum amount of smoke. Multilayered assemblies nos. 13 and 18 which contained silicone cushion materials produced high amounts of smoke (fig. 6). A comparison of the HRR of improved ML assemblies, fire-blocking layer, and polymeric foam cushion materials is shown in figure 7. The high HRR value of ML assembly no. 18 is apparently due to the silicone foam in the assembly. The high HRR and smoke generation values for silicone materials have necessitated that this material be dropped as a candidate material for aircraft seats. Improved fire-resistant materials with thermal stability inherent from their chemical structure, had lower HRR (fig. 8) and smoke generation values (the exception being silicone materials) than baseline materials. This confirms the findings of reference 3. The low smoke release rates and total HRR of ML constructions which utilized neoprene, polyimide, and fiberglass as cushioning materials are shown in figure 9. The individual contributions of upper-layer materials to the total heat release of the ML assembly is shown in figure 10. ML assemblies constructed from improved fire-resistant materials (ML assemblies nos. 16 and 21) are compared with contemporary materials at thermal fluxes of 1.5 and 3.5 W/cm^2, respectively (fig. 10). ML assembly no. 21 could not be ignited even though piloted ignition was utilized, while the baseline ML sample burned completely during HRR testing.

The thermal response of a material is dependent on the thermal load or flux as well as on the inherent thermal stability of the material which is determined by its chemical structure.

All ML samples tested in this study had total heat release values below 125 W/m^2 for the first 5 min of exposure, with the exception of the baseline materials (polyurethane foam cushion) and ML assemblies that had a silicone foam or silicone elastomer. These baseline materials had total HRR

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[1]SSU - standard smoke units.

[2]SMOKE - standard metric optical kinetic emission.

$$SMOKE = (D/LA) \times (Vo/T)$$

- D = optical density = log (100/T)
- L = light path (0.134 m)
- A = area of specimen (0.0645 m^2)
- T = time (min)
- V = flow rate (m^3/min)

above 300 kW/m^2. In this study the efficiency and functionality of the fire-blocking layer were ascertained (fig. 4) and selections made for use in aircraft seats. The results will be utilized in future designs of aircraft seats. The effects of various modifications of materials, e.g., mass effects from different weaves and weights, were not evaluated in this study. Modifications of materials do exhibit minor effects on the heat release values. These tests provide a descriptive profile of the levels of heat release to be expected in full-scale fire testing of aircraft passenger seats.

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TABLE 1.- MATERIALS UTILIZED IN THE CONSTRUCTION OF ML ASSEMBLIES

Sample No.	Sample Type	Generic name	Material description	Material density	Function in ML assembly
1	Fabric	Amide-imide wool	52.5% Kermel/47% wool	290 g/m^2	Decorative covering
2	Fabric	Wool/amide	90% Wool/10% nylon	457 g/m^2	Decorative covering
3	Fabric	Aramid	Nomex III	254 g/m^2	Slipcover cushion reinforcement
4	Batting	Chlorinated aramid	Durette	---	Fire-blocking
5	Foam	Polychloroprene with cotton scrim	0.475-cm thick polychloroprene Vonar no. 3	954 g/m^3	Fire-blocking
6	Duck	Chlorinated aramid	Durette	---	Cushion reinforcement
7	Fabric	Novoloid	Kynol	213 g/m^2	Fire blocking
8	Fabric	Silicone/glass	Silicone elastomer on glass fabric	---	Cushion reinforcement
9	Cement	Adhesive	R2332 NF	---	Cement
10	Cement	Silicone adhesive	RTV 133	---	Cement
11	Foam	Urethane	Polyurethane foam	0.20 g/cm^3	Cushion
12	Foam	Glass	Glass fiber block cushion	.03 g/cm^3	Cushion
13	Foam	Imide	Polyimide foam	.06 g/cm^3	Cushion
14	Elastomer	Silicone	Silicone rubber	.19 g/cm^3	Cushion
15	Foam	Polychloroprene	Low-smoke neoprene foam	.14 g/cm^3	Cushion
16	Fabric	Polybenzimidazole	PBI	274 g/m^2	Cushion reinforcement

TABLE 2.- DATA SUMMARY CHART, ADHESIVE SCREENING

Test and test method	Units	T685 N/F Columbia Cement	R1275 N/F Columbia Cement	R2332 N/F Columbia Cement	EC 1475 3 M Co.	RTV-133 General Electric
Burn test DMS 1511						
Burn time	sec	0	0	0	0	1
Burn length	cm	3.0	3.8	4.0	3.8	2.54
Drip		0	0	0	0	0
NBS smoke						
Nonflaming						
90 sec	sec	3	9	7	2	7
4 min		4	13	7	3	16
Flaming	sec					
90 sec		5	16	8	5	9
4 min		7	18	9	6	24
Limiting oxygen index ASTM D2863	%	>92	47	79	61	38
TGA temp, 650° C Maximum weight loss	%	8	15	7	15	8.5

TABLE 3.- FLASH-FIRE PROPENSITY TEST

Material	Time to first smoke, min	Sample pyrolysis temperature at first smoke, °C	Flash response				Observations
Identification and weight			Sequence number	Time, min	Thermal pulse height-division	Sample pyrolysis temperature, °C	
Adhesive R2332 N/F Columbia Cement #3 0.27 g	0.56	414	No flash				Yellowish dense smoke
Adhesive 685 0.28 g	0.72	355	first second	2.00 2.16	4 16	614 650	Yellowish dense smoke Very small flash No sound
Adhesive EC4715 (black) 0.26 g	0.72	367	first	1.04	80	497	White light smoke Flash from bottom to
Adhesive R1275 NF 0.26 g	0.32	367	No flash				Yellow/gray smoke Dense smoke

TABLE 4.- TOXICITY TESTS - ADHESIVES

Adhesive	T_i,[a] (average values, min)	Time to death, min
RTV-133 1.5 g	6.4 ± 0.2	2/6 lived 30 min; aging trend not noticed
R2332 0.25 g N/F Adhesive	5.0 ± 2.6	4/4 lived 30 min; aging effect noticeable
685 N/F 0.15 g Col. Cement	1.8 4.9 0	1 died, 30 min; 2/3 survived
EC 4715 0.5 g 3M Co.	5.1 ± 2.75	1/3 lived 30 min; aging effect noticeable
R1275 N/F 0.25 g Col. Cement	13.1 ± 3	1/3 lived 30 min; no aging effect noticeable

[a]Time to incapacitation T_i is the elapsed time from the start of the test (pyrolysis of sample) to the time when the test animal can no longer respond to the motor-driven exercise wheel (ref. 3).

TABLE 5.- MULTILAYERED MATERIALS WITH GLASS-FIBER-BLOCK BACKING

ML specimen no.[a]	Adhesive	Fire block	Reinforcement	Adhesive
1	R2332 N/F	Kynol	Nomex III	N2332 N/F
2	R2332 N/F	Kynol	Durette duck	N2332 N/F
3	R2332 N/F	Kynol	Glass fabric	RTV 133
4	R2332 N/F	Vonar no. 3	Glass fabric	RTV 133
5	R2332 N/F	Vonar no. 3	Nomex III	N2332 N/F
6	R2332 N/F	Vonar no. 3	Durette duck	N2332 N/F
7	R2332 N/F	Durette batting	Glass fabric	RTV 133
8	R2332 N/F	Durette batting	Nomex III	N2332 N/F
9	R2332 N/F	Durette batting	Durette duck	N2332 N/F

[a]All specimen contained 52.5% kermel/47.5% wool blend with Nomex III slipcover.

TABLE 6.- MULTILAYERED MATERIALS WITH POLYMERIC FOAM BACKING

ML specimen no.[a]	Adhesive	Fire block	Reinforcement	Adhesive	Cushion
10[b]	---	---	---	R2332 N/F	Urethane foam
11[c]	---	---	---	R2332 N/F	Urethane foam
12	R2332 N/F	Durette batting 400-11	Nomex III	Same	Polyimide foam
13	R2332 N/F	Durette batting 400-11	Nomex III	Same	Silicone foam
14	R2332 N/F	Durette batting 400-11	Nomex III	Same	LS-neoprene foam
15	R2332 N/F	Durette batting 400-11	Nomex III	Same	LS-neoprene foam cored
16	R2332 N/F	Durette batting	Nomex III	Same	LS-neoprene foam
17[d]	---	Vonar = 3	Nomex III	R2332 N/F	Polyimide foam
18[d]	---	Vonar = 3	Nomex III	R2332 N/F	Silicone foam
19[d]	---	Vonar = 3	Nomex III	R2332 N/F	LS-neoprene foam
20[e]	---	---	---	R2332 N/F	Urethane foam
21	R2332 N/F	Durette batting	PBI 40-9031-2	Same	LS-neoprene foam

[a]ML specimens consisted of 52.5% kermel/47.5% wool blend with Nomex III slipcover.

[b]ML specimens consisted of 90% wool/10% nylon blend with flame retarded cotton muslin slipcover.

[c]ML specimens consisted of 52.5% kermel/47.5% wool blend with flame retarded cotton muslin slipcover.

[d]ML specimens consisted of 52.5% kermel/47.5% wool blend with no slipcover.

[e]ML specimens consisted of flame retarded cotton muslin slipcover.

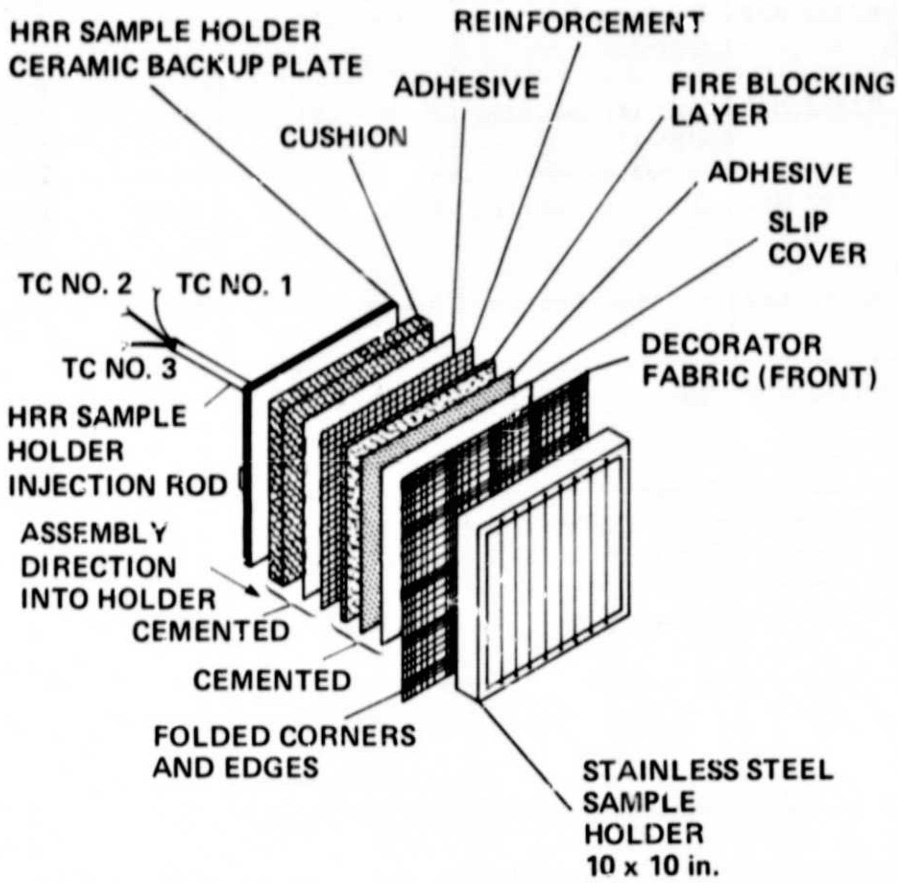


Figure 1.- Multilayered sample construction of test specimens.

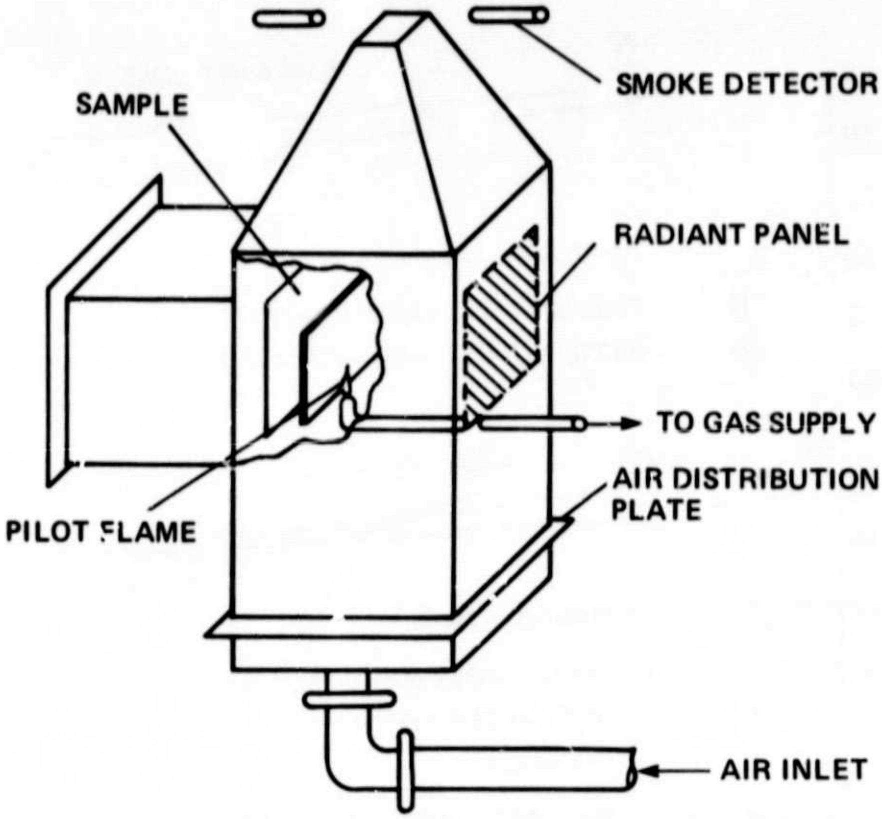


Figure 2.- Ohio State University heat-release apparatus.

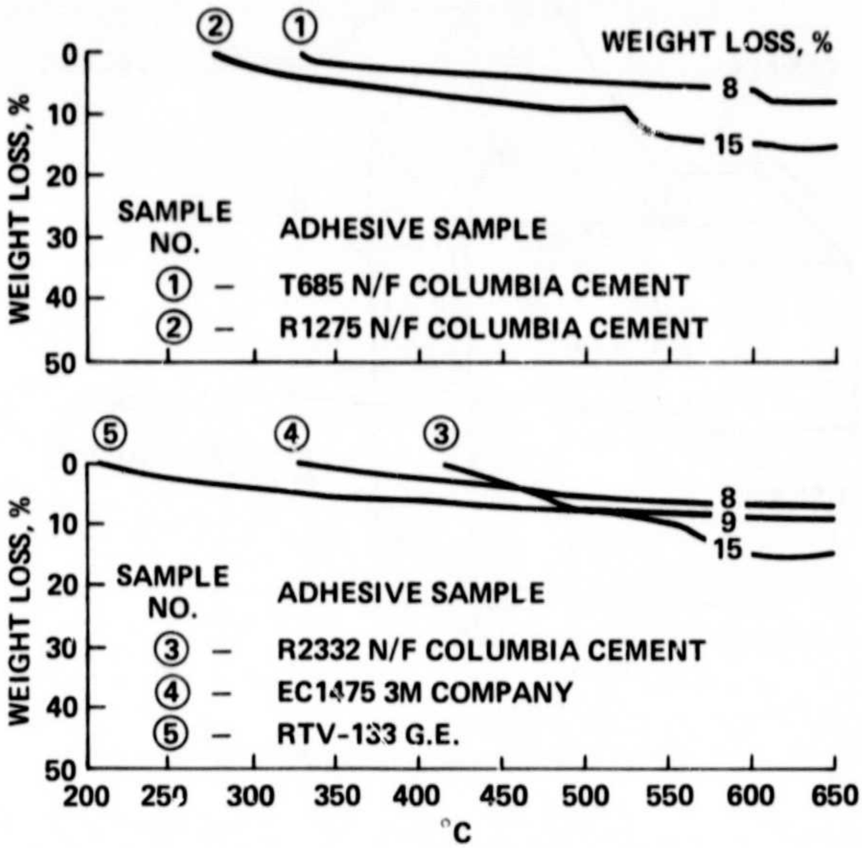
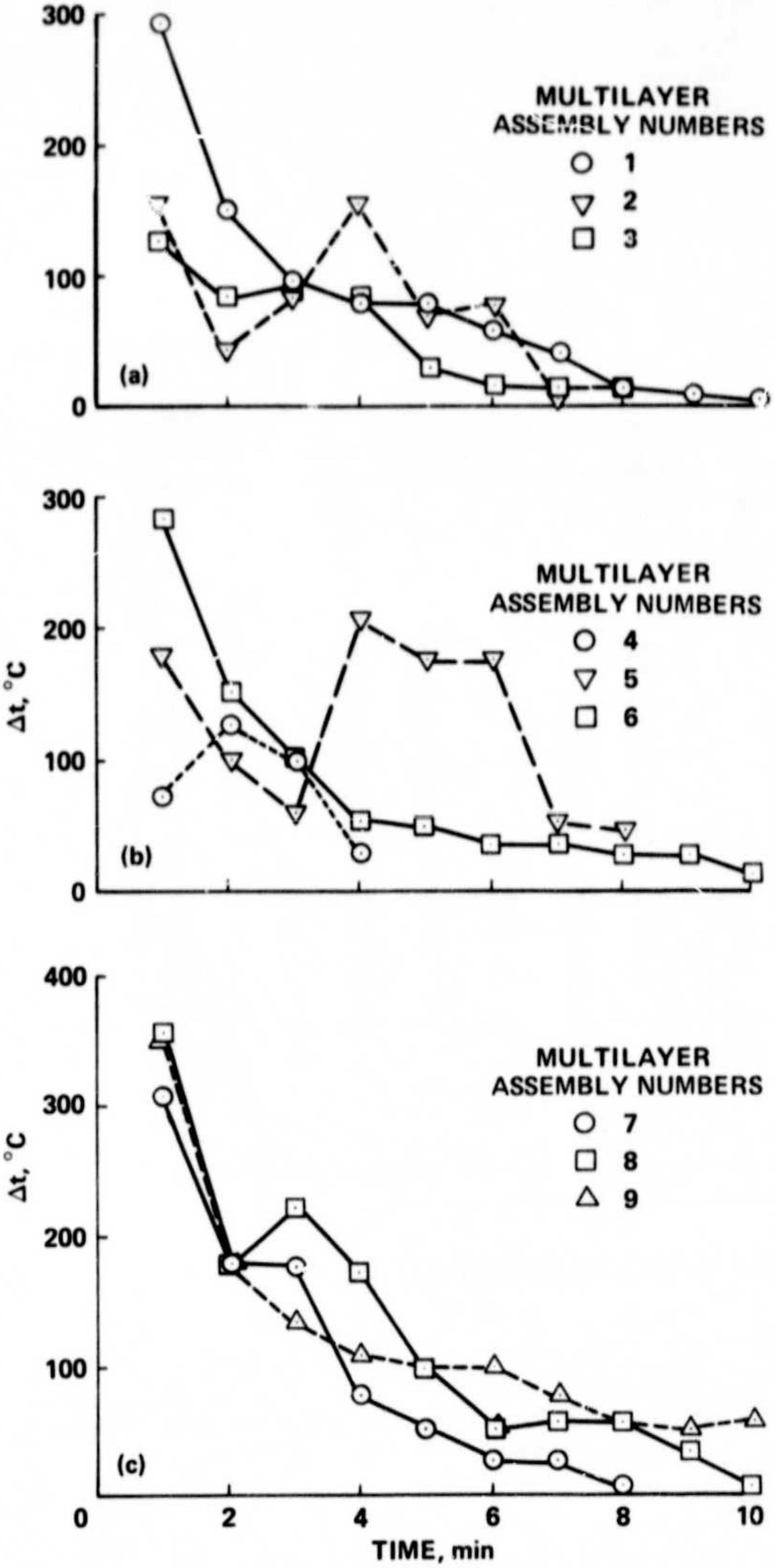


Figure 3.- Thermogravimetric analysis of adhesive samples screened and used in bonding upper layer materials.



THERMAL PROFILES OF FIRE BLOCKING LAYERS

Figure 4.- Thermal profiles of the fire-blocking-layer materials in the assembly.

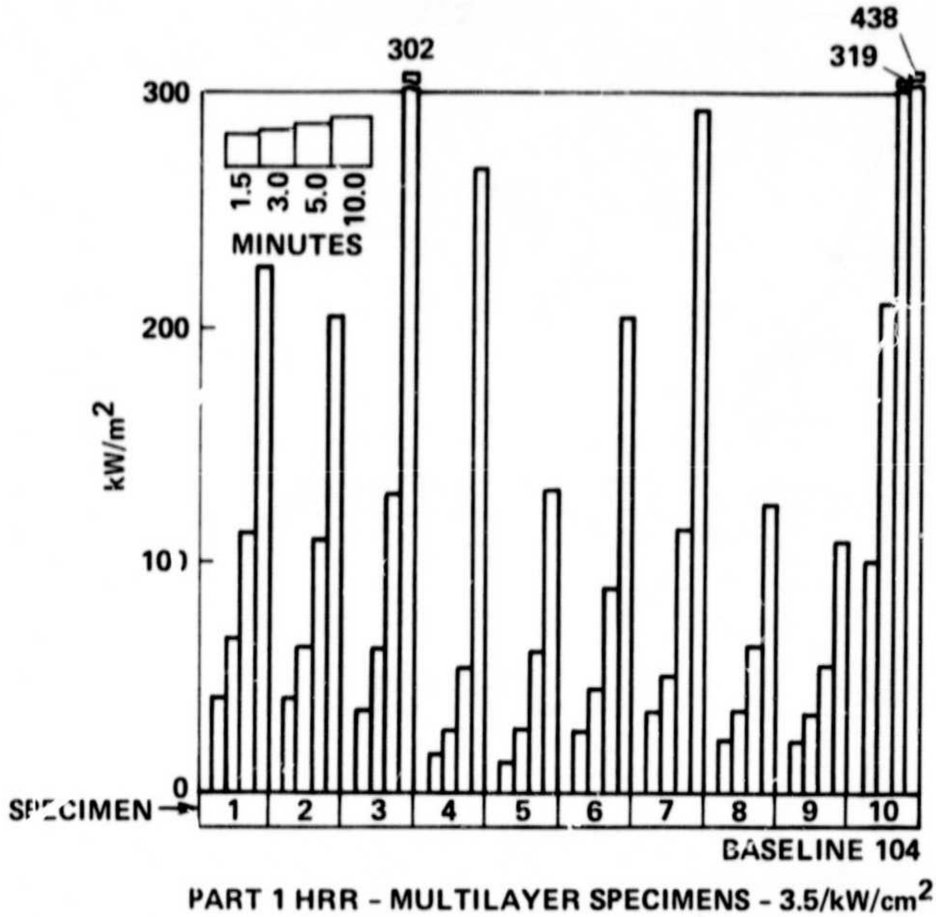


Figure 5.- Heat release rate of multilayered samples with fiberglass cushions.

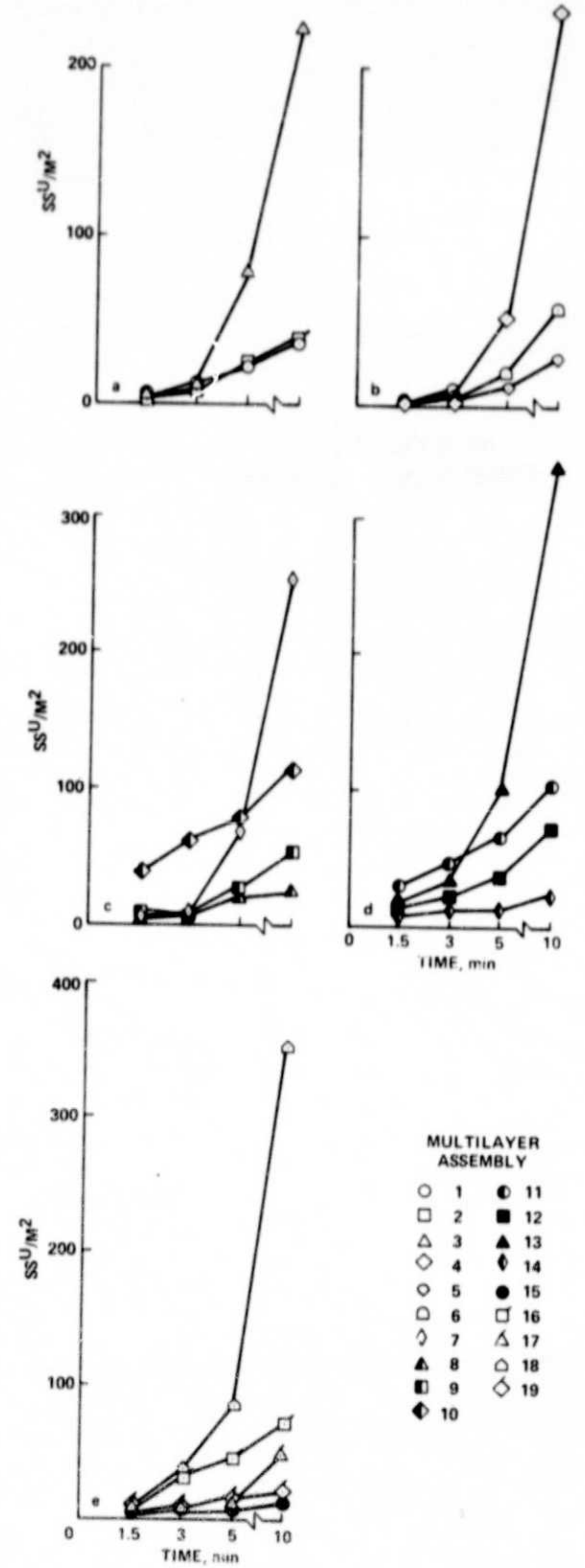


Figure 6.- Smoke generation rates for multilayered assemblies.

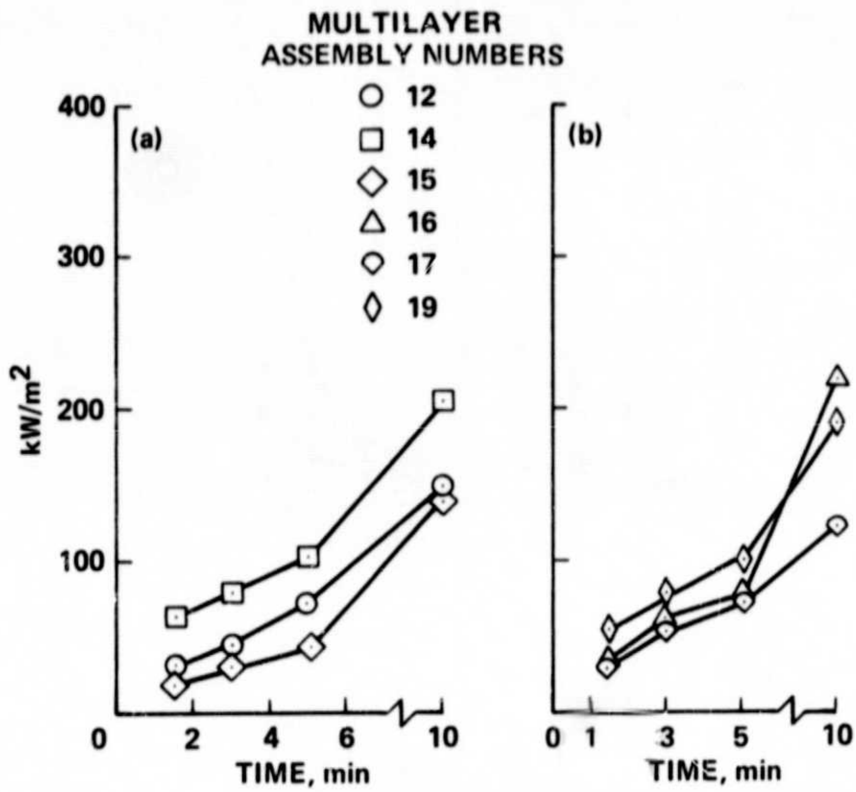


Figure 7.- Heat release rates of improved multilayered assemplies.

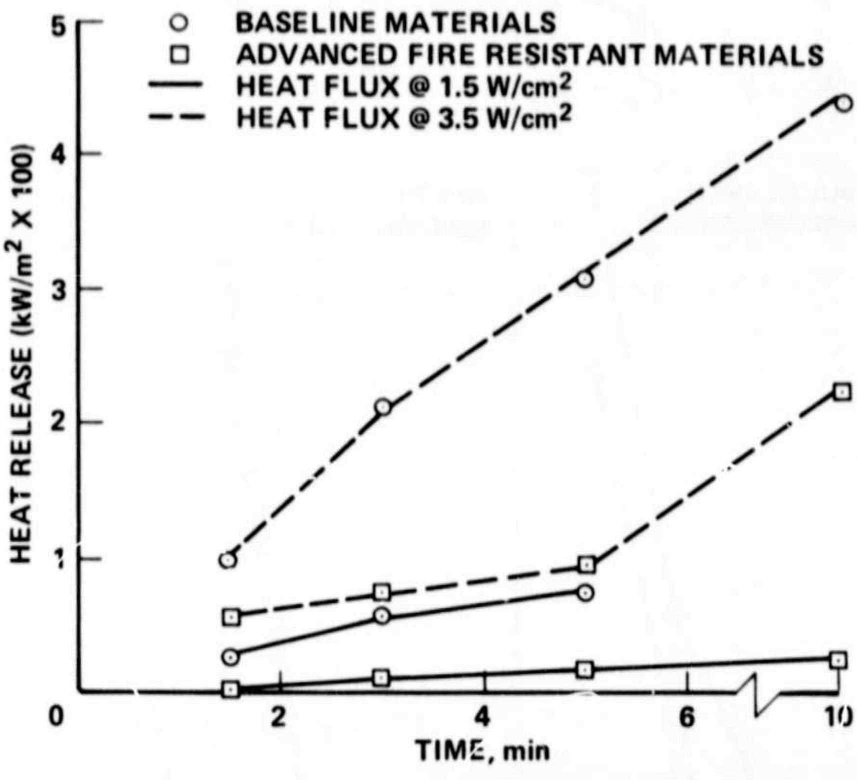


Figure 8.- Heat release rates of baseline and advanced materials.

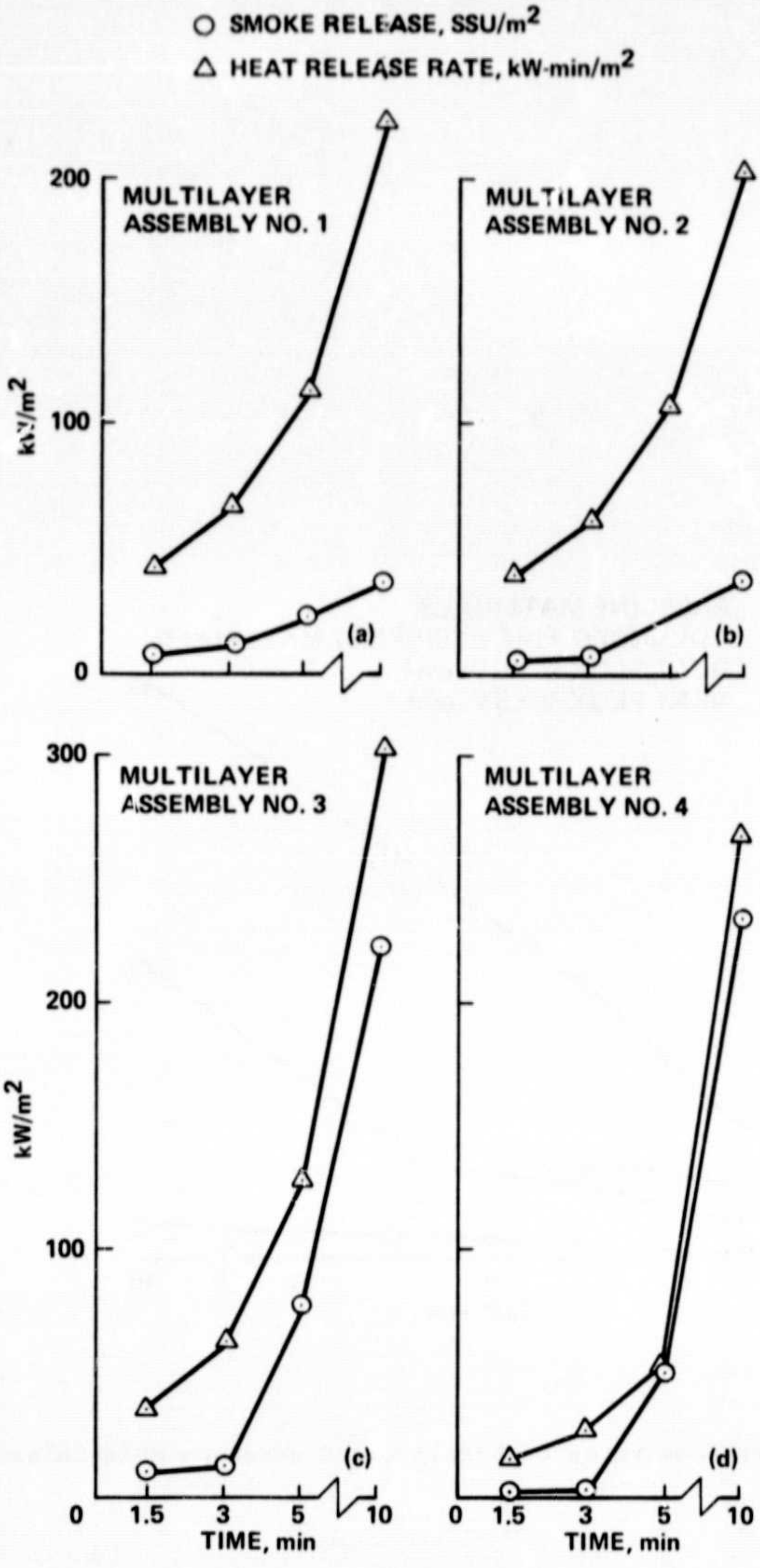


Figure 9.- Heat release and smoke release rates for assemblies backed with fiberglass block and neoprene.

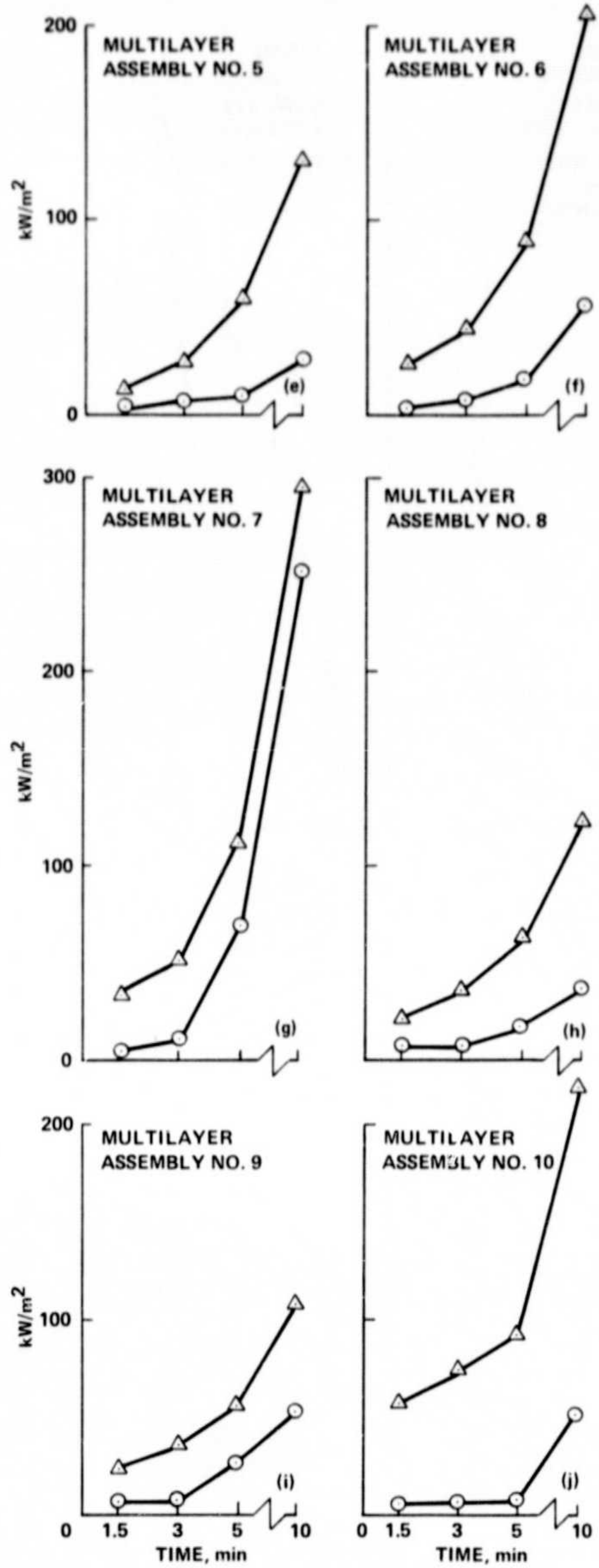


Figure 9.- Concluded.

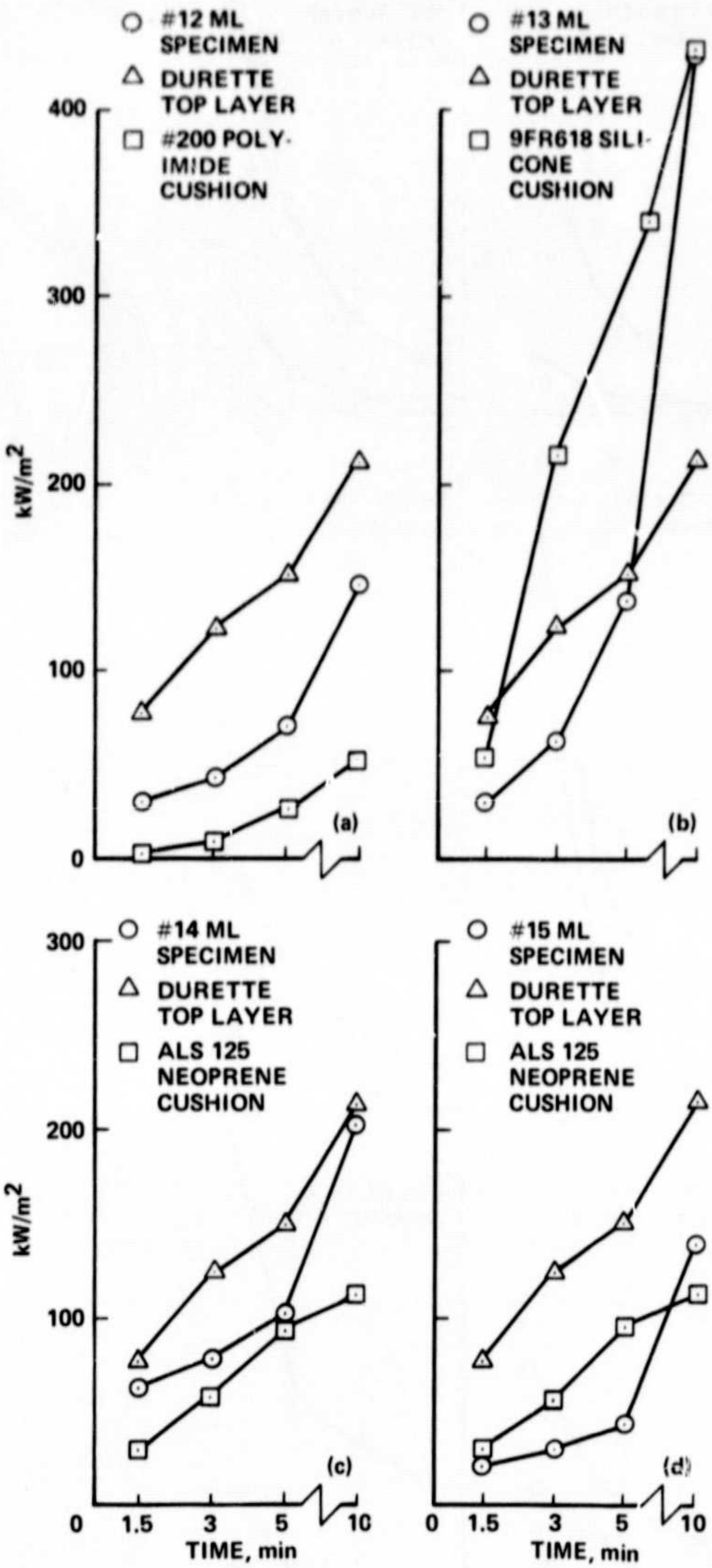


Figure 10.- Contributions of upper layer materials to the total heat release of various multilayered assemblies.

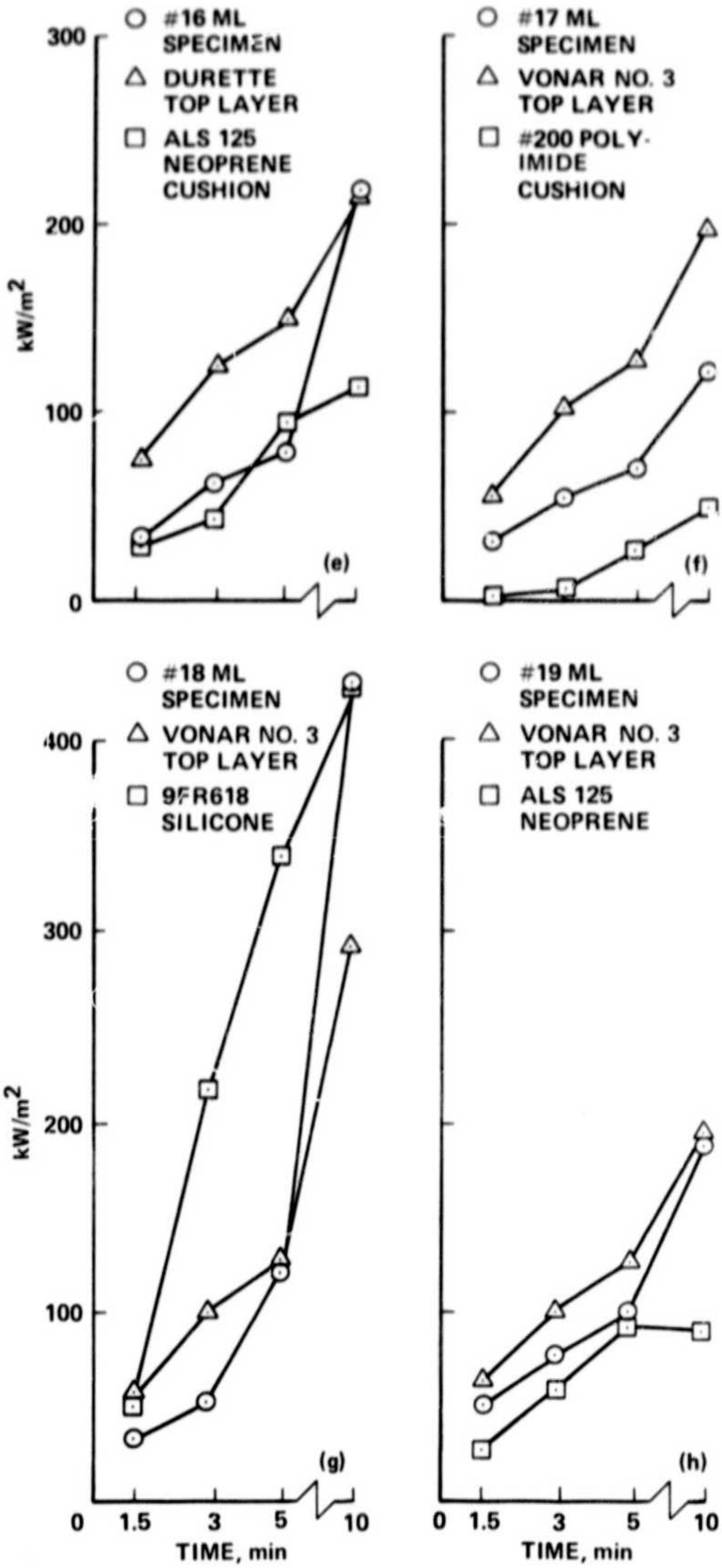


Figure 10.- Concluded.