Using poly(vinyl chloride) copolymer latex for flame retardation in nonwoven substrates

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The application of a latex polymer to textiles and nonwovens is often required to achieve physical performance; in some cases, the latex binder itself can impart a significantly increased degree of flame retardation to the final product.

The application of latex to a textile or nonwoven fabric is often required to enhance the physical performance of the fabric, for example, its dimensional stability. In many applications, the end use stipulates that the fabricated product must possess a certain degree of flame retardancy. Although every feature of the final product will contribute to its overall flammability performance, the latex has great potential for dramatically influencing those properties. Latex frequently serves as a convenient vehicle for a flame-retardant additive, but through proper selection, the latex itself may provide a significant degree of flame retardation.

Using a sample of needlepunched nonwoven polypropylene carpeting, we determined the flammability performance of four different types of latex backcoatings. We studied the latexes without filler or flame-retardant additives to assess their influence on flammability. The results reported here substantiate the view that selecting the proper latex can lead to major improvements in flame retardance and, logically, to better cost and performance of the finished product.

To assess flammability, we used two industry flammability test methods: the Federal Motor Vehicle Safety Standard No. 302 and the American Society of Testing Materials (ASTM) E648 Critical Radiant Flux of Floor-covering Systems Using a Radiant Heat Energy Source. Both are widely used as important tests for carpeting. The limitations of these tests are that they measure a single property of the carpet such as flame spread rate or critical radiant flux. They do not yield information on what, if any, flame retarding mechanism is operating. Hence, a second objective of this project was to further establish the overall flammability performance characteristics of these backcoated carpets by evaluating their performance in another flammability test. The test that was chosen is the National Bureau of Standards cone calorimeter rate-of-heat-release apparatus. Material performance characteristics of particular interest include the rate of heat release, time-to-ignition, and the specific extinction area, which is a measure of the light-obscuring capacity of smoke following complete burning of the sample.

In extensive studies of the burning behavior of upholstered furniture at the National Bureau of Standards, they found that the size of an upholstered furniture fire is directly related to the peak rate of heat release of the fabric-covered cushion assembly from the furniture item measured in the cone calorimeter (*1-3*). Assemblies of the fabric-covered cushion material from furniture items that burn slowly have low-peak rate-of-heat-release values, and items that burn fast have values that are high. Studies of the flame spread characteristics of electrical cable systems at Factory Mutual Research Corp. have shown that the flame spread rate of the cables is related to a function of the rate of heat release and the time-to-ignition of the cables as tested in another small-scale laboratory rate-of-heat-release test (*4*). Thus, our third objective was to determine which of these fundamental fire performance features of the latex itself carries over and contributes to good fire performance of backcoated carpets in the MVSS 302 and other carpet flammability tests.

Experimental

The cone calorimeter has been fully described in several reference sources (*5, 6*). The sample, which is 100 × 100 mm (4 × 4 in.), is held on a weighing cell underneath a conically shaped heater unit of adjustable intensity. A continuously operated electrical spark serves to promote initiation of flaming combustion of the sample. Ignitability is measured by the time in seconds from the start of the experiment until the entire face of the specimen is completely in flames. Combustion products are drawn into an air-flow stream of controlled flow rate. Rate of heat release (RHR, measured in kW/m^2) is measured on the basis of the principle that, for a wide variety of fuels, a fixed amount of oxygen is consumed for every unit of heat

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I. List of latex polymers evaluated

Latex polymer	Description	Glass transition temperature, °C
Acrylic	Acrylic	-11
SBR	Styrene-butadiene	-27
EVCl	Vinyl chloride-ethylene	+30
PVC copolymer A	Vinyl chloride-acrylic	+38
PVC copolymer B	Vinyl chloride-acrylic	+55
PVC homopolymer	Vinyl chloride	+83

II. Latex backcoating compound for carpets

Ingredients	Dry parts
Latex (see Table I)	100
Sodium lauryl sulfate	1.5
Polyacrylate thickener	to 7000-7500 cp*
Ammonium hydroxide	to pH 9.0-9.2

*Brookfield RVF viscometer, No. 5 spindle, 20 rpm

III. Performance of uncompounded latex resin in the cone calorimeter

Latex polymer	Time to ignition, s	Peak mass loss rate, g/s	Peak rate of heat release, kW/m²	Total heat, MJ/m²	5 min avg. specific extinction area, m²/kg	Comments
Acrylic	114	0.10	260	190	340	Rate of heat release is constant.[b] Burns for at least 10 min with complete consumption.
SBR	78	0.17	580	220	970	Rate of heat release is constant.[b] Burns for at least 5 min with complete consumption.
EVCl	67	0.19	240	120	1250	Rate of heat release is constant.[b] Burns for at least 7 min with complete consumption.
PVC copolymer A	73	0.13	150	14	430	Charring with flame extinction after about 1 min.
PVC copolymer B	47	0.20	230	80	830	Rate of heat release decreases due to effects of char formation.
PVC homopolymer	500	0.10	70	60	680	
Polyethylene[a]	...	...	1330	...	340	

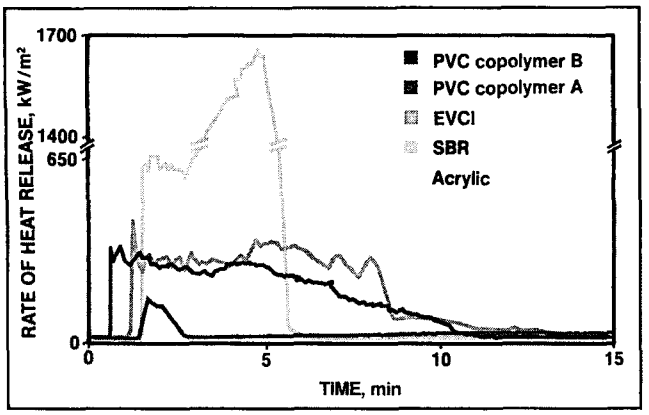
[a]Data from Ref. 10.

[b]Later in the experiment the sample curls and burns on the rear face giving a spuriously high result for this phase.

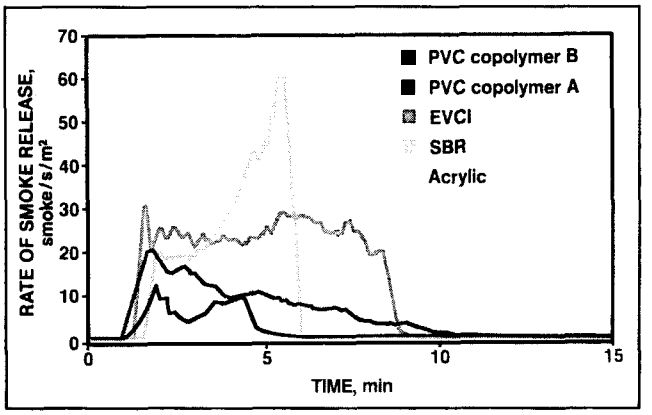
or energy that is released. Total heat is calculated by integrating the rate-of-heat-release data over the time interval from the start of the experiment until 15 min. The units of measure are MJ/m². Total heat results are useful for estimating the extent of char formation. Smoke obscuration, the decrease of transmitted light caused by smoke, measurements are also made using a laser light source and light intensity detector system, which views across the air stream which contains the smoke. The results of these measurements are expressed in terms of the specific extinction area and are measured in m²/kg. The output of the smoke detector system can also be used to calculate an expression for the rate of smoke release (RSR), which is equivalent to the expression of smoke results from the ASTM E906 Heat and Visible Smoke Release Rates for Materials and Products test. The results are expressed in smoke units/s/m² of sample surface area.

The test procedure for the flooring radiant panel test is described in ASTM E648. The specimen, 20 × 100 cm (8 × 40 in.), is mounted in the horizontal position. A radiant heater is mounted above the specimen at a 30° angle, producing a heat flux gradient along the length of the specimen. The extremes of the heat flux gradient in the test are approximately 0.1 and 1.1 W/cm². A gas pilot flame ignites the end of the specimen closest to the radiant heater. Time and maximum distance of specimen burning are recorded. The results are expressed in terms of the effective heat flux required for sustained burning at the position of maximum extent of burning. One difficulty with this test as currently configured is that samples often register the maximum critical radiant flux even though retests indicate the true value is considerably lower. This can be caused by problems with igniting the samples, which are glued on all sides to a backerboard. Because of these limitations, only the worst-case critical radiant flux value was used for further analysis in the "discussion"

1. Rate of heat release of uncompounded latex resin. Cone calorimeter/ irradiance at 30 kW/m².



2. Rate of smoke release of uncompounded latex resin. Cone calorimeter/ irradiance at 30 kW/m².



section (for example, when relating E648 data to other flammability parameters: cone calorimeter RHR). However, all E648 data are listed in the "results" section.

The Federal Motor Vehicles Safety Standard No. 302 (MVSS 302) is a horizontal burn test where flame spread rate is determined. Lower flame spread rate indicates better flame retardancy.

Latex polymers chosen for this work are listed in **Table I**. Samples of those materials suitable for testing in the cone calorimeter were prepared by drying the latex in thin sheets at room temperature. The dried material was pressed into solid, homogeneous plaques measuring 100 × 100 × 6 mm (4 × 4 × 0.25 in.) at 105–115°C and 10,000 psi. For carpet backcoating experiments, the latexes were evaluated in the compound shown in **Table II**. Thickener and base are used to adjust the batch to pH ≅ 9.0–9.2 and viscosity 7000–7500 cp using a Brookfield RVF viscometer, No. 5 spindle and 20 rpm.

Compounds were knife coated as-is onto 475-g/m² (14 oz./yd.²) polypropylene needlepunched nonwoven to achieve coating weights of 373 g/m² (11 oz./yd.²). This coating weight was used for all experiments. In some cases, lower coating weights were studied in the MVSS 302 test; here the compounds were frothed on a Hobart mixer (No. 2 setting) prior to coating. Drying for all samples was done in an air circulating oven at 120°C until dry to the touch, plus an additional 2 min (typically, about 7 min total drying time). Carpet samples were evaluated in the cone calorimeter, the MVSS 302, and the flooring radiant panel tests.

In the cone calorimeter, one of the key properties studied is peak rate of heat release. With some of the compression molded plaques, rate of heat release showed anomalous behavior due to sample distortion during testing. In particular, among samples which do not char while burning, one would expect the rate of heat release to remain constant as a function of time. Unfortunately, due to changes in sample shape or configuration in response to the applied heat flux, the irradiance was effectively increased in the experiments involving the acrylic and styrene butadiene rubber latex (SBR) samples, causing a rise in RHR with respect to time. As a result, the latter portions of their RHR curves are probably spuriously high. Therefore, for purposes of this analysis, peak RHR for the acrylic and SBR samples was taken as the RHR value during the period of steady-state burning prior to sample distortion. With the ethylene vinyl chloride (EVCl) sample, a strong RHR "spike" registered initially, then constant RHR followed. The RHR in the plateau period was considered to be the peak RHR for this analysis. Polyvinyl chloride (PVC) copolymers A and B showed charring behavior, meaning that RHR decreased with time. Therefore, the actual peak RHR value was used for analysis. These problems were not encountered with the coated carpets, which burned quickly and retained a flat shape. For the carpet experiments, the actual peak RHR was used for the analysis in all cases.

Results

Flammability characteristics of uncompounded latex in the cone calorimeter

Table III lists key results for the five cone calorimeter experiments involving plaques of uncompounded latex polymers. A radiant heat flux of 30 kW/m² was used. The various latexes perform as follows.

Acrylic. The acrylic latex has the longest time-to-ignition (except for PVC homopolymer) and burns relatively slowly with high total heat output and low smoke generation. This process does not involve char formation. The rate of heat release reaches a peak of ≅ 260 kW/m², not especially high since the length of time to burn is so great.

SBR. The SBR latex has the next longest time-to-ignition and burns very fast with high total heat output, high rate of heat release, high smoke production, and no char development. As with the acrylic, an increase in the rate of heat release with respect to time was observed.

EVCl. Time-to-ignition with the EVCl latex is shorter than the acrylic and SBR. The EVCl burns with a constant rate of heat release without char formation. Total heat is approximately half that of the SBR and ≅ 60% that of the acrylic. Smoke production is the greatest among the samples tested.

PVC copolymer B. PVC copolymer B has a time-to-ignition similar to the EVCl. It reaches peak rate of heat release (lower than the acrylic, SBR, and EVCl) immediately following ignition, then begins to decline. Accompanying this is the formation of a black char. As the char builds, the sample burns more slowly. This is seen in **Figs.**

1 and 2, which show decreasing rates of heat and smoke release as the experiment proceeds. In addition, the char can easily be seen.

PVC copolymer A. This latex shows similar effects to PVC copolymer B, only exaggerated. The peak rate of heat release is the lowest among all samples tested (except for PVC homopolymer). Char formation begins immediately following ignition, and the sample self-extinguishes after only 1 min of burning. Due to the self-extinguishing and charring nature of this material, a relatively low amount of fuel vapor is released into and consumed by the flame zone. Consequently, the peak RHR is low, and the total heat output is very small compared to the other samples tested (14 MJ/m²). In terms of smoke, the (initial) peak RSR is comparable to the acrylic, although this declines as char buildup takes effect.

Latex backcoated carpets tested in the cone calorimeter

Carpets backcoated with the acrylic, SBR, EVCl, and PVC copolymer A latexes were evaluated in the cone calorimeter at 30 kW/m² radiant flux. The results are listed in **Table IV**. The samples showed little differentiation in time-to-ignition. The carpet samples, which consist of ≅ 56% polypropylene fiber and ≅ 44% latex, all burned very quickly (within 2 min). Unlike the 100% latex sample, the combustion of the PVC copolymer A carpet sample was not dominated by char formation when burned in the cone calorimeter.

Latex backcoated carpets tested in the MVSS 302

The same latex backcoated carpets were subjected to the MVSS 302 horizontal burn test. Results are listed in **Table V** for different coating weights.

Latex backcoated carpets tested in the flooring radiant panel test

The flooring radiant panel test was run on carpets backcoated with acrylic, EVCl, and PVC copolymer A latexes. The data show that the critical radiant flux for the PVC copolymer A sample is over 20% higher than that for the EVCl and 130% higher than that for the acrylic (**Table VI**).

IV. Performance of latex backcoated carpets in the cone calorimeter

Backcoating latex	*Time to ignition, s*	*Peak mass loss rate, g/s*	*Peak rate of heat release kW/m²*	*Total heat, MJ/m²*	*5 min avg. specific extinction area, m²/kg*
Acrylic	28	0.18	710	37	36
SBR	33	0.18	830	43	62
EVCl	36	0.14	500	32	59
PVC copolymer A	29	0.11	380	26	48

V. Performance of latex backcoated carpets in the MVSS 302 test

	Flame spread rate, in./min	
	Coating weight, g/m²	
Backcoating latex	*240 ± 30*	*370 ± 30*
Acrylic	2.2	NR
SBR	2.2	2.5
EVCl	SE	1.2
PVC copolymer A	SE	SE

NR = not run. SE = self-extinguishing.

VI. Peformance of latex backcoated carpets in the flooring radiant panel test

	Critical radiant flux, W/cm²		
	Trial no.		
Backcoating latex	*1*	*2*	*3*
Acrylic	0.47+	1.08+	1.08+
SBR	NR	NR	NR
EVCl	0.89	1.08+	1.08+
PVC copolymer A	1.08+	1.08+	1.08+

NR = not run.

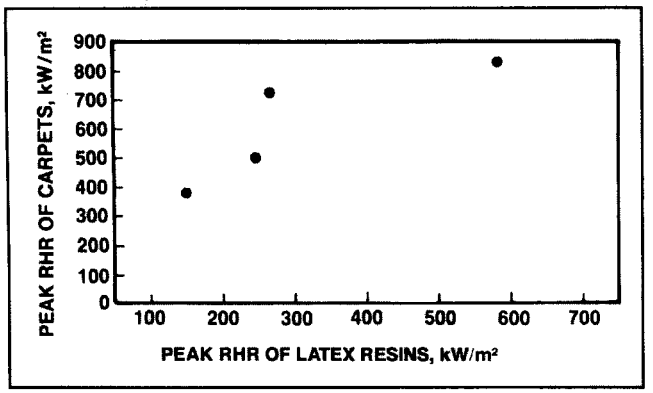
The value 1.08+ indicates the critical radiant flux exceeds 1.08, the maximum measurable value.

Discussion

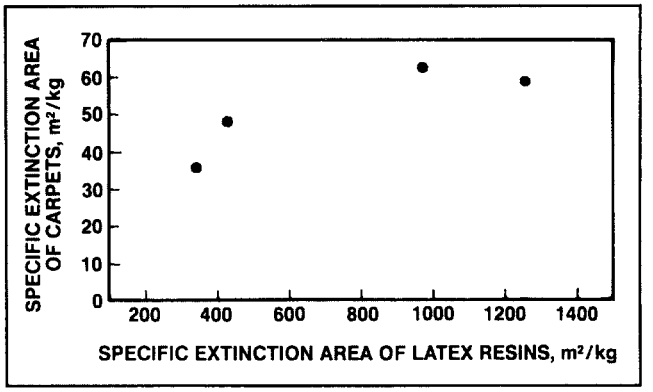
Performance of uncompounded latex resin in the cone calorimeter

The performance of all of the latex resins is evaluated on the basis of a comparison with the SBR and acrylic latexes. The SBR yields a slightly higher peak rate of heat release and total heat release than the acrylic but both are much higher than is seen for the vinyl chloride copolymers. The SBR yields considerably more smoke than the acrylic or the vinyl chloride copolymers (except the EVCl). These effects are due to the chemical composition of the latex materials. The acrylic materials contain a high proportion of oxygen, while the vinyl chloride copolymers contain high proportions of chlorine. In a burning process, these elements do not react with oxygen to release heat. A material such as an acrylic or a vinyl chloride copolymer, which contains a high proportion of oxygen or chlorine, correspondingly contains a proportionately lower fraction of carbon and hydrogen, elements which do react with oxygen in the burning process to release heat. Consequently, the total heat released upon combustion is greatly reduced compared to SBR. The rate of heat release is controlled by the rate of specimen mass loss, which is the rate of fuel generation, and the potential heat content of the fuel vapor. Since all of the materials have roughly the same rate of mass loss, the rate of heat release is determined by the fuel's heat of combustion value. The high proportion of unsaturation in the SBR is responsible for the high level of light-obscuring smoke produced by

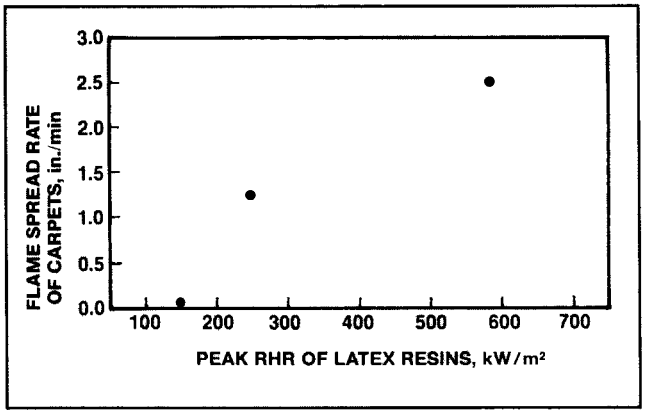
3. Comparison of peak RHR for uncompounded latex resins vs. latex backcoated carpets



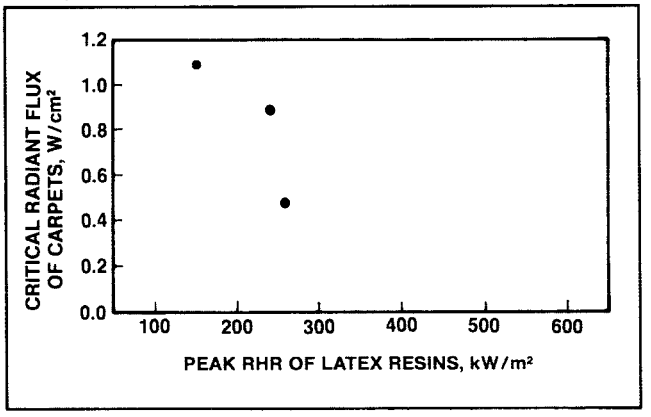
4. Comparison of specific extinction area for uncompounded latex resins vs. latex backcoated carpets



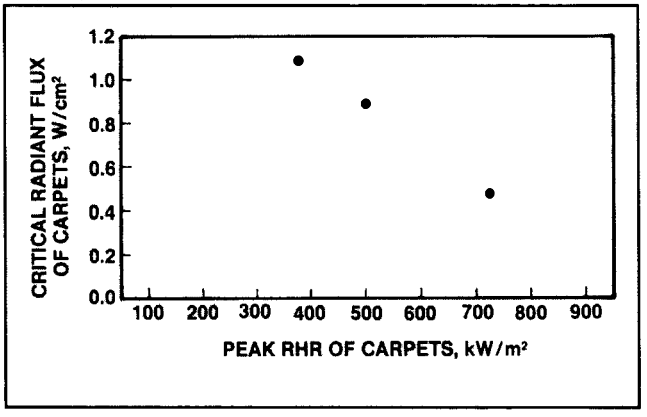
5. MVSS 302 flame spread rate vs. peak RHR of uncompounded latex resins



6. ASTM E648 critical radiant flux vs. peak RHR of uncompounded latex resins (worst-case data)



7. ASTM E648 critical radiant flux vs. peak RHR of latex backcoated carpets (worst-case data)



this material.

In the case of the EVCl, the RHR is intermediate between polyethylene and poly(vinyl chloride), as expected from its composition. In terms of smoke obscuration, the EVCl latex exhibits a considerably higher tendency to smoke during combustion than expected based on its composition. Both polyethylene and PVC produce less smoke than the EVCl (Table III). Smoke obscuration from chlorinated polymers depends quite strongly on the chlorine content of the polymer and the distribution of chlorine along the polymer chain (*7*, *8*). In the first stage of thermal degradation, dehydrochlorination, the cross-linking of the polymer chains that occurs establishes the type and amount of hydrocarbon pyrolysate that will be released in the second thermal decomposition stage. A high yield of aromatic hydrocarbons contributes to high smoke obscuration levels. In the vapor phase, the hydrogen chloride can further catalyze smoke generation by quenching the flame. Another characteristic of homopolymer poly(vinyl chloride) is char development. In the case of the EVCl copolymer, char formation does not occur. The high flammability of polyethylene appears to dominate over char formation.

PVC copolymer A exhibits low RHR comparable to homopolymer PVC. The peak RHR is 150 kW/m² vs. 240 kW/m² for the EVCl, with the major difference being the use of an acrylic comonomer rather than ethylene. As seen from the data given in Table III, poly(acrylates) typically produce considerably lower RHR values than polyethylene. Thus, the RHR properties of these two vinyl chloride copolymers are consistent with and are explained by the properties of the acrylic and ethylene monomers. The initial peak RHR of PVC copolymer A is 35% lower than the EVCl's, which is evidence that the vapor-phase hydrogen chloride flame quenching effect is operating to a greater degree. Considering the data in Table III for acrylic and PVC homopolymer, the low specific extinction area value for PVC copolymer A is reasonable. PVC

copolymer A exhibits char formation, an inherent feature of PVC homopolymer, in spite of the presence of the plasticizing acrylic comonomer. Char development commences immediately following ignition, and char builds as the sample burns, providing a second pathway to flame retarding activity. Attendant decreases in RHR, RSR, and mass loss rate are observed as charring proceeds. The role played by this char-forming process in actual end-use applications will depend on the concentration of latex in the system, geometric effects, the substrate, and the external fire conditions. Nevertheless, in many applications, char formation is known to be a reliable pathway to reduced ignitability, fire growth, and flame spread. In applications where charring is not favored, PVC copolymer A retains the key advantage of lower peak RHR vs. the EVCl (≅ 35% lower) as well as vs. the nonhalogenated polymers.

Comparison of the performance of uncompounded latex resin and latex backcoated carpets in the cone calorimeter

A comparison of the results of the cone calorimeter studies of uncompounded polymers and the corresponding backcoated carpets shows the existence of an important relationship. The established parameter for predicting flammability performance is RHR since it is most representative of the instantaneous conditions encountered at the flame front in a dynamic fire. The relationship of the RHR of the backcoated carpets with the RHR of the corresponding latexes is shown in **Fig. 3**. Figure 3 shows that the ranking of the latex RHR values predicts the ranking of the RHR values of the latex backcoated carpets reasonably well. Thus, the RHR performance characteristics of the backcoated carpets as measured in the cone calorimeter are determined by the performance characteristics of the latexes themselves. Of the latexes investigated, the best performance is noted for PVC copolymer A in the form of compression molded plaques as well as backcoated carpets.

The data in **Fig. 4** indicate that the specific extinction area values for the plaques also give a reasonable indication of the specific extinction area values for the corresponding backcoated carpets. However, in the case of EVCl, the specific extinction area for the carpet is better than expected based on results with uncompounded polymer. This is due to the presence of polypropylene fuel, which diminishes the catalytic effects of chlorine on smoke production as described above for the EVCl latex. Still, the EVCl releases over 20% more smoke than PVC copolymer A in the cone calorimeter carpet test, based on specific extinction area. In addition, the EVCl produces 60% more smoke than PVC copolymer A based on calculations of the smoke parameter:

$$\text{Smoke Parameter} = \text{RHR} \times \text{specific extinction area}/10^5$$

which considers a material's flammability as well as its smoke-producing properties (*9, 10*). Accounting for the effects of both of these factors provides a better estimate of smoke in a real fire situation.

Performance of latex backcoated carpets in the MVSS 302 test

Carpets backcoated with PVC copolymer A and burned in the horizontal mode exhibit char development and self-extinguish even at reduced coating weights. This property is unique among the samples tested and was predicted by the cone studies of the uncompounded polymers, where char formation and self-extinguishment were observed for PVC copolymer A.

Another factor contributing to the good performance of this carpet is the very low RHR performance characteristics of PVC copolymer A, which is the backcoating material. This is reinforced by the data in **Fig. 5**, which show that the RHR values for the carpets give a rough indication of the performance of the carpet in the MVSS 302 test. The effectiveness of PVC copolymer A as a flame retardant backcoating is a result of these flame retarding mechanisms, which act to slow, then extinguish, the flame.

The EVCl exhibits a lower flame spread rate than the acrylic and SBR polymers. However, there is no char formation and no self-extinguishment, except at the highest coating weight. For the EVCl to self-extinguish at the lower coating weight, flame retarding compounding additives would presumably be needed.

Performance of latex backcoated carpets in the flooring radiant panel test

The performance ranking in the radiant panel test is analogous to that in the MVSS 302 test. PVC copolymer A proved to have the highest critical radiant flux, as expected from its very good performance in the cone calorimeter experiments. **Figures 6 and 7** show that for the latexes and backcoated carpets investigated, the peak RHR values for the uncompounded latexes (Fig. 6) as well as the backcoated carpets (Fig. 7) give a rough indication of the critical radiant flux of the backcoated carpets. This indicates that a good relationship exists between cone calorimeter peak RHR data for the uncompounded latexes and performance of backcoated carpets in two very different usage tests. Furthermore, in both of these usage tests, carpet backcoated with PVC copolymer A gave superior performance.

The relationship between time-to-ignition as measured in the International Standards Organization (ISO) ignitability test for building products (ISO 5657) and the critical radiant flux as measured in the ASTM E648 flooring radiant panel test has recently been investigated (*11*). An inverse correlation was found between these two performance parameters. The materials with the best time-to-ignition performance had the worst performance in the flooring radiant panel test and vice versa. On the basis of these results, it was concluded that time-to-ignition as measured in the ISO 5657 test should not be used to determine the burning behavior of carpets. The results of the experiments on carpets reported here for time-to-ignition and critical radiant flux are consistent with those reported by Benisek (*11*) in that the best carpets in the flooring radiant panel test had the worst time-to-ignition values in the cone calorimeter. However, the results reported here indicate that the rate-of-heat-release values for the carpets measured in the cone calorimeter give a good indication of the performance of the carpets in the flooring radiant panel test. This is consistent with the

results of others where the relationship between flame spread rate and peak rate of heat release has been established for electrical cables (*4*). However, in the work with electrical cables it also was shown that time-to-ignition plays a role in determining the flame spread rate. Thus, it seems reasonable to expect that time-to-ignition plays some role in carpet performance in the flooring radiant panel test. But on the basis of the results reported here, it does appear that carpet flooring radiant panel test performance is dominated by the carpet peak rate of heat release and the role of time-to-ignition is minor.

Conclusions

We came to the following conclusions:

1. The cone calorimeter peak rate-of-heat-release value for carpets and backcoatings has been shown to relate to performance in carpet flammability tests. Specifically, the data gathered here indicate that lower peak RHR relates to lower flame spread rate and higher critical radiant flux.
2. PVC copolymer A exhibits lower peak RHR than EVCl, SBR, and acrylic latexes. We believe this is due to its high chlorine content and unique charring behavior.
3. Carpet backcoated with PVC copolymer A exhibits lower peak RHR, lower flame spread rate, and higher critical radiant flux vs. EVCl, SBR, and acrylic backcoated carpets under these test conditions.
4. In terms of its tendency to produce smoke during combustion, PVC copolymer A is generally comparable to the acrylic. The EVCl and SBR latexes produce 3–4 times the level of smoke of the acrylic as tested in the cone calorimeter.□

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