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Application of Polyurethane Foam for Impact Absorption and Thermal Insulation for Radioactive Materials Packagings.

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Abstract

Polyurethane foam has been widely used as an impact absorbing and thermal insulating material for large radioactive materials packages, since the 1980's. With the adoption of the regulatory crush test requirement, for smaller packages, polyurethane foam has been adopted as a replacement for cane fiberboard, because of its ability to withstand the crush test. Polyurethane foam is an engineered material whose composition is much more closely controlled than that of cane fiberboard. In addition, the properties of the foam can be controlled by controlling the density of the foam. The conditions under which the foam is formed, whether confined or unconfined have an affect on foam properties. The study reported here reviewed the application of polyurethane foam in RAM packagings and compared property values reported in the literature with published property values and test results for foam specimens taken from a prototype 9977 packaging. The study confirmed that, polyurethane foam behaves in a predictable and consistent manner and fully satisfies the functional requirements for impact absorption and thermal insulation.

Introduction

Polyurethane foam has been used as the overpack impact absorbing and thermal insulating material for over twenty years. The polyurethane is typically foamed in place. That is, it is injected as a two-component liquid and reacts, rising and hardening to form a rigid foam structure. Alternatively, foam components can be produced separately and assembled into the package overpack. Applications have included both Type A and Type B packages of all sizes. Among the packages which employ polyurethane foam are:

TRUPACT I
TRUPACT II
T-3
Patriot (fresh fuel package)
BUSS Cask
AT-400
RH-TRU 72
MH-1A
HIFR

The packages listed vary in size from very large packages, such as the TRUPACTs to small, drum-size packages. Most are Type B packages, but the Patriot is a Type A fresh fuel package.

Review of Published Data
A review of Safety Analysis Reports for Packagings and other literature yielded data on the properties reported for past applications of polyurethane foam. The crush stress and thermal conductivity are the principal properties of importance for radioactive materials packaging overpack performance.

Crush Strength
In order to evaluate the consistency of urethane foam properties from batch to batch, the published values from the various references can be compared with the properties tabulated by General Plastics for the various densities of Last-A-Foam FR-3700. Where possible, values for the density of foam employed in the 9977 were considered. However, the degree of consistency between the General Plastics data and that from other sources is indicative of the ability to obtain consistent, predictable properties, even though it is for other densities.

When foam materials are crushed, the initial response is elastic, with crushing beginning typically at about 10% strain, and the stress remaining nearly constant up to over 50%. Above 50% to 60% strain, the slope of the stress-strain curve increases rapidly. For purposes of comparison of the information from the various sources, the stress for 10% and 20% strain is tabulated below.

Table 1 shows that, for given density, crush properties are highly consistent for materials from a wide range of sources and are generally consistent with current published information.

For the recent 9977 General Purpose Fissile Package development, General Plastics prepared specimens from material taken from the drum sidewall and from the bottom of a prototype package, Figures 1 and 2. The structural specimens were nominally 2 in. square and 1 in. thick and enabled testing for both parallel-to-rise and perpendicular-to-rise orientations. Tests were performed in accordance with ASTM D1621-94.

Table 1. Comparison of Published Data with Last-A-Foam Reference Data

		10% Strain,		20% Strain	
Application	Density lbm/ft3	Package Foam Crush Stress, psi	General Plastics Last –A- Foam Stress, psi	Package Foam Crush Stress, psi	General Plastics Last –A- Foam Stress, psi
9977	16		776 (766 perp)		802
Sandia CRETE	16.23	767	776	767	802
Sandia CRETE	29	2320	2249		
Seo, et al	29	2030	2249	2300	2469
TRUPACT-II	8.25	235	228 (for 8 lbm/ft3)	235	221
Sandia BUSS	18	1000	958	1250	1002
AT-400	30	2500	2390		
RH-TRU 72-B	11.5	376	430	376	430
MH-1A ('87 last-a-foam data)	4	88	96		
MH-1A ('87 data)	15	700	691	750	710
HIFR ('87)	17	960	865	1000 -	900

Table 2. Summary and Comparison of Crush Test Results for SN-6

Specimen Sample Location	Test orientation relative to foam rise	In-situ sample			Batch Sample "free rise"		
		Density	Stress at 10% strain,	Nominal stress at 10% strain*	Density	Stress at 10% strain	Nominal stress at 10% strain**
		(lbm/ft^3)	(psi)	(psi)	(lbm/ft^3)	(psi)	(psi)
Sidewall	Parallel	16.73	726.4	841	15.46	651.3	730
Sidewall	Perpendicular	17.83	816.8	952	16.29	692.5	795
Bottom	Parallel	16.8	732.8	847	16.27	706.8	800

* Nominal stress corresponds to interpolated data from GP handbook at measured density of SN-6 sample.

** Nominal stress corresponds to interpolated data from GP handbook at measured density of batch sample.

Figure 1. A 9977 package was sectioned to obtain in-situ specimens for material property tests.

Figure 2. Thermal conductivity specimens were taken from the section of the side wall shown in Figure 1.

Thermal Conductivity

Polyurethane foam is an excellent thermal insulator. This characteristic is beneficial for minimizing the thermal challenge for containment systems under fire conditions. For packages whose contents generate significant heat, the package must permit dissipation of the internal heat generated to the environment. A higher thermal conductivity is important for this purpose. The foam specified must have a high enough thermal conductivity to maintain acceptable interior temperatures, but still provide adequate thermal protection during a fire.

The General Plastics data shows a linear relationship between density and thermal conductivity. This dependence on density is supported by the data from other sources. Thermal conductivity values reported in several sources were compared with the published GP Last-A-Foam property data.

Table 3. Comparison of Published Thermal Conductivity Data with Last-A-Foam Reference Data

Application	Density lbm/ft3	k, Btu/hr ft F, @ ca. 75F	k, General Plastics Last–A-Foam (2007)
TRUPACT II (1989)	8.25	0.0193	0.0217
72-B (2001)	11.5	0.0188	0.025
MH-1A ('87)	15	0.0194	0.0273
Piping Tech. & Prods data	16	0.022	0.0281
9977*	18.48	0.02844	0.0283

*Side wall perpendicular to rise.

The table shows that there is variation in the reported values of thermal conductivity from source to source and batch to batch. For example, the material employed in the TRUPACT-II is General Plastics Last-A-Foam, but the reported value of thermal conductivity differs from the General Plastics published data by 11%. Variations in material composition among manufacturers will result in differences in thermal conductivity for material from the different sources. The changes associated with elimination of Freon as the blowing agent (i.e., the bubble producing agent) may account for some of the difference between older applications and present data. As the data in Table 2 shows, the installed density is typically greater than the free-rise density, for a given installation. Since thermal conductivity is directly related to density, the thermal conductivity of the foam installed in the package will be greater that that of the free-rise sample by a corresponding amount.

It is recognized that the thermal conductivities for polyurethane foam of the densities considered here are quite low, so that all are very good thermal insulators. Studies of the effects of thermal properties on thermal response of packages have shown that differences in thermal conductivity on the order of those shown here have little effect on the performance of the package in a fire event, References 12 and 13. Accordingly, the thermal response of the packages will not be greatly affected by the variations from batch to batch or for differences in parallel-to-rise or perpendicular-to-rise values.

Conclusions

Polyurethane foams can be produced in a wide range of densities. The properties of the foam are largely dependent on the density, so that control of the density permits control of structural and thermal properties.

For structural properties, the material is well characterized, with consistent and predictable properties. As a result, for a given density, the properties from differing lots are closely comparable. For the structural properties, this is observed over a range of materials from various sources.

For thermal conductivity, material behaves consistently, with thermal conductivity varying with density. However, samples from different sources exhibit much greater variability than for the structural properties. Accordingly, thermal conductivity measurements for the "as installed" material are recommended for new package designs.

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