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Rigid Thermosetting Plastic Foams

Originally published 1974

A. Blaga

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Improvements in foaming, production techniques and resulting properties of thermosetting foams have contributed to their recent prominence as materials for a wide range of applications. The matrix of these foams is based on cross-linked polymers so that, like the bulk plastics from which they are derived, they have generally good resistance to solvents and most chemicals. Although some show limited plastic flow at elevated temperatures, thermoset foams do not usually exhibit a melting range and can often be used at higher temperatures than thermoplastic foams (there are exceptions).

In the production of thermoset foams, foaming takes place at the same time as the polymer is built up by the reaction of liquid starting materials. The techniques used are therefore adaptable to on-site (in situ) foaming, an important consideration for some applications. The best known thermoset foams are polyurethane, phenol-formaldehyde, and urea-formaldehyde; less well known are epoxy and silicone foams. Some, such as phenol-formaldehyde and urea-formaldehyde, are produced with an inorganic acid catalyst and the acid residue can in some cases cause corrosion problems. Improved grades, however, have been reported having reduced corrosive properties or none at all.

Plastics in general, and most foams in particular (because of their large surface area), can present a degree of fire and smoke hazard in buildings. At the present time there is much concern about the potential hazards of exposed foams, and some authorities recommend that the more flammable and sprayed foams be placed behind a barrier of some material to provide a degree of fire protection.

This discussion will be confined to the rigid foams, usually closed-celled, which are used in construction and related fields. Of these, polyurethane is the most versatile and will be described in greatest detail. The general properties, characteristics and applications of four commercial rigid thermoset foams are presented in Tables I and II.

Table I. Typical Properties of Rigid Thermoset Plastic Foams (1)*

	Density	Thermal Resistance	Coeff Thermal	Water Vapour	Water Absorption	Compressive	Max Continuou
Plastic Foam	, lb/ft ³	1-in. Specimens,*	l Exp,	Transmission	n (short	Strength at 10%	s Service

	* °F/Btu/hr ft ² (ASTM C-177)	10 ⁻⁵ /°F (ASTM D-696)	perm-in. (ASTM C-355)	term), % by vol (ASTM D-2127)	Deflection, psi (ASTM D-1621)	Temp, °F	
Polyurethane*** *	1.5-3.0	6-9	3-8	0.9-3.0	<0.1-2.0	15-60	212
Phenol- formaldehyde (Foamed-in- place)	2.0-5.0	4-5	0.5	10-90	1.0-4.0 at 50% RH 13-51 at 100% RH	22-85	300
Urea- formaldehyde (Carbamide- formaldehyde)	0.8-1.2	5-6	-	30-100	Very high	5	120
Epoxy (Sprayed or foamed-in-place)	1.8-2.3	7-9	-	-	-	13-26	160-200

*Some of the data given have been obtained by testing commercial products at DBR/NRC laboratories

**Thermal resistance is for 70°F mean temperature.

***The values given are for the dry material; the values for wet foams are usually much lower.

****Foamed with halocarbon.

Table II. Characteristics And Applications of Rigid Thermoset Plastic Foams

Foam Material	Characteristics And Forms Available	Principal Application*
Polyurethane	Very high thermal resistance for given thickness; low water absorption and low water vapour permeability; good thermal stability; good adhesion. Available as blocks, boards, slabs, moulded shapes, liquid prefoam mixtures.**	Thermal insulation for roofs, cavity walls, perimeter; refrigeration, pipe lagging. Core material for sandwich panels; flotation; protective packaging; furniture.
Phenol- formaldehyde (Phenolic foam)	Relatively low resistance for given thickness. High strength and very good thermal stability. Available as blocks and sheets and liquid prefoam mixtures for foaming-in-place.	Insulation of flat roofs. Core material for sandwich panels.
Urea- formaldehyde	High thermal resistance for a given thickness but low mechanical strength. High water absorption and high water vapour permeability. Available as blocks, slabs	Cavity wall insulation.

	and shreds, liquid prefoam mixtures for foaming-in-place.	
Epoxy	Good insulation efficiency. High strength, good chemical and moisture resistance. Available as board stock, moulded shapes, liquid prefoam mixture for foaming-in-place and spraying.	Because of relatively high cost, use restricted to spray applications for storage tanks and vessels, and as core material for sandwich panels.

*Although some thermoset foams have very low water permeability, a vapour barrier should always be used.

**Formulations available as "one-shot," partial prepolymer two- and three-part systems for foaming-in-place, spray and froth foaming-in-place.

Polyurethane Foams

Polyurethane (urethane) foam is available in flexible and rigid form, closed and open cells, in prefabricated products or as liquid prefoam mixtures for foaming-in-place, spraying, etc. The rigid foam is a highly cross-linked product that does not recover when deformed. Properties of polyurethane foam depend on formulation plus foaming technique and the process used to produce it. To understand its nature and thus its performance better, foaming methods and production techniques will be considered very briefly.

Foaming

Basically, polyurethane foam is produced by the reaction of the two main ingredients (liquid) of a formulation, a polyol (bearing hydroxyl groups, OH) and a polyisocyanate (bearing isocyanate groups, -N=C=O) in the presence of a catalyst, a blowing (or foaming) agent and a surfactant (and other ingredients). The two main ingredients react exothermically (generating heat) to form the polymeric structure of the foam matrix. By varying the type and amount of compounding ingredients a wide variety of foams can be produced having densities ranging from less than one to over 60 lb/ft³.

The polyol may be either a polyether or a polyester, but currently polyether polyol is used most frequently. The polyisocyanates used most often in the production of rigid urethane foams are TDI (tolylene diisocyanate) and MDI (diphenylmethane diisocyanate). A polymeric form of MDI (crude MDI) is most generally used at present.

Compounding of the ingredients of a foam formulation is generally carried out in either of two ways: the "one-shot" or the "partial prepolymer" method. In the one-shot method all ingredients are mixed simultaneously at the time of foaming so that there is great flexibility in formulation and range of properties. In the partial prepolymer method all the isocyanate is reacted first with part of the polyol; this intermediate is referred to as the A component. The remainder of the polyol, containing the catalyst, blowing agent, and other ingredients, forms the B component. The two components are supplied in separate containers and constitute a two-part prefoam mixture system that requires good agitation for blending and foaming.

Techniques for Making Foams

Common techniques for producing rigid polyurethane foams include foaming-in-place (or pour-in-place), spraying, and continuous slabbing. Foaming-in-place requires that the liquid or froth be poured, after mixing, directly into a mould or cavity. It is a useful technique for filling irregular voids or cavities: for example, cavities within the walls of truck bodies or refrigerators, between the facings of building walls (cavity walls). Adhesion is good with most materials, but

it is best when the surface is warm and clean, oil-free, dry, and roughened. Most rigid foams produced by foaming-in-place are based on partial prepolymer formulation systems because of ease of processing and relatively low hazard. Use of froth prefoam mixtures is increasing for producing foams by the foaming-in-place technique. The froth foaming-in-place process can use either the one-shot method or partial prepolymer compounding method. This technique of foam production is specially suited to high-rise applications and gives good uniformity in density and foam structure.

In the spraying process, urethane chemicals are mixed and atomized with special guns and dispensed as a spray rather than as a stream. The process permits thin layers of rigid urethane foam to be built up on large surface areas without the need for special forming. Spray formulations are fast reacting (highly catalyzed) to prevent sagging of the foam; and additional layers can be applied almost immediately in consecutive passes.

In the slabbing process (carried out in a factory) the reactants are metered in a mixing head and deposited continuously on a moving conveyor belt. After cure, which takes place away from the production machine, the slab can be cut or formed by other mechanical means to specific thickness and shape. In one modification of this process a second top conveyor or belt is used for producing foam panels having facings on both sides (sandwich panels). The facing materials include metals such as aluminum and steel, and glass-fibre-reinforced polyester, plywood and perlite board.

Properties and Application

As thermosetting materials, rigid urethane foams have relatively good resistance to thermal decomposition up to about 390 to 480°F, Their maximum continuous service temperature is 212 to 275°F (100 to 135°C), whereas conventional polyolefins, polystyrene and styrene copolymer foams cannot be used above 160 to 175°F (71 to 79°C). General purpose foams are flammable, but with the addition of flame retardants they can be made with varying degrees of flammability for applications where specific fire requirements must be met.

Most low density (<4.0 lb/ft³), rigid foams are foamed with halocarbons. For example, fluorotrichloromethane (fluorocarbon-11) may be used alone or in conjunction with difluorodichloromethane (fluorocarbon-12). Some higher density (>4.0 lb/ft³) foams are expanded with carbon dioxide. In these, the gas is chemically released in situ by the reaction of water (purposely added) with polyisocyanate. New specimens of urethane foams expanded with halocarbons have considerably higher R factors (thermal resistance) than similar specimens foamed with CO₂. Typical values for 1-inch specimens are 9 to 7. These values represent the initial thermal resistances of the foam specimens; after 6 months to a year of aging the R factor decreases to 6 units (or less). Subsequently, the R factor of the halocarbon blown foam continues to fall, although more slowly, as a result of diffusion of air and water vapour into the cells and halocarbon out of them (**CBD 149**). The R factor will eventually decrease to 4 to 4.5 units for a 1-inch specimen.

Because of its poor weathering resistance, conventional low density urethane foam should be protected when exposed to the atmosphere. High density foams, particularly those produced to retain a skin have better weathering resistance. Generally, the common rigid urethane foams will neither support nor inhibit biological growth.

Owing to a combination of interesting properties, urethane foam is the most widely used of all thermoset foams. Its popularity is second only to that of polystyrene foam (a thermoplastic). Although more expensive than other insulating materials, urethane foam has a number of advantages: high thermal resistance for a given thickness, lightweight strength, relatively low water vapour permeability, and low water absorption. In addition, it is adaptable to on site applications such as filling complex cavities. Applications include use as thermal insulation, core material in sandwich panels, packaging and fabrication of furniture.

Rigid urethane foams, in particular those expanded with halocarbons, have been used as thermal insulation over a wide range of temperature (-127 to +260°F; -88 to +127°C).

Applications include use as perimeter insulation, wall and roof insulation in residential and industrial or public buildings, curtain wall panels, low-temperature insulation in freezers and refrigerated truck trailers, in refrigerated pipe, and insulation of industrial pipe and storage tanks. In roof deck insulation, foamed urethane has an additional advantage over polystyrene foam, its major competitor for this application, in that it can be hot mopped with bitumen without serious damage to the cellular structure.

Adhesion to many substrates, fabrication adaptability and lightweight strength make rigid urethane foam a good core material for the manufacture of factory-produced modular sandwich panels and other structural components.

Because of its closed-cell structure, which slows water absorption, low density, rigid foam retains its buoyancy characteristics for a relatively long time. Flotation applications include floating docks, buoys, buoyancy material in pleasure boats and deep-submergence vessels, floating ramps and foamed-in-situ buoyancy material in marine salvage operations. Its energy absorption property and adaptability for filling irregular cavities make urethane foams suitable for protective packaging, particularly for electronic equipment and military hardware.

Good mouldability characteristics and convenient one-step fabrication (simultaneous foaming and fabrication of finished products) by the pour-in-place technique have led to successful use of rigid foams in the production of furniture. Good mouldability even permits faithful reproduction of wood grain and other decorative patterns. The foams used for furniture are high density (up to 45 lb/ft³).

Polyisocyanurate Foams

Closely related to foamed polyurethane, the recently introduced polyisocyanurate foams have higher thermal stability and inherently lower flammability characteristics than polyurethane. Polyisocyanurate foams are generally produced from the same basic reactants as expanded polyurethane (using the same foaming methods); these reactants include polyisocyanate (usually MDI) and polyol (in reduced amount). The reaction conditions used, however, are different in that the polyisocyanate is induced to polymerize predominantly into polyisocyanurate rather than exclusively into polyurethane polymers.

Phenol-Formaldehyde Foams (Phenolic Foams)

Phenolic foams have good dimensional stability and high strength to weight ratio, and are less flammable than most plastic foams, but because of their high open-cell content they have relatively low thermal resistance, very high water absorption and water vapour permeability. Thermal insulation efficiency can be improved by the application of a skin, for example, a covering of felt or hot bitumen. Recently, phenolic foams have been developed with relatively high closed-cell content (up to 75 per cent) and these are even less flammable.

Phenolic foams are used as thermal insulation (e.g. insulation of flat roofs), as core material in sandwich panels, packaging, and as an art medium and handicraft material. They are generally used in densities between 2.5 and 4 lb/ft³ where high strength is required.

Urea-Formaldehyde Foams

Urea-formaldehyde foam, also referred to as carbamide formaldehyde foam (especially in the United Kingdom), is a low-cost material that can be made in very low densities (0.5 to 10 lb/ft³). It has high thermal resistance for a given thickness and good sound-absorbing qualities (when the cells are predominantly open). It has, however, several drawbacks such as low mechanical strength, high water absorption and high water vapour permeability, a tendency to undergo considerable shrinkage on drying, plus a relatively narrow range of service temperatures (-20 to +120°F; -29 to +50°C). Its main application is as thermal insulation in cavity walls where it is foamed in situ. Recently, many chemical modifications of urea-formaldehyde have been made to remedy certain weaknesses such as friability, lack of dimensional stability, and high water absorption.

Epoxy Foams

These foams have very good chemical and moisture resistance, and provide good thermal insulation. Because they are more expensive than the common foams, their use in the construction field is limited mainly to foamed-in-place low density core panel systems and some sprayed-in-place thermal insulation for walls, tanks, and vessels. Special grades of epoxy foams are available that extend their service temperature range to 250°F (120°C).

Reference

1. Guide to Plastics, by the Editors of Modern Plastics Encyclopedia, McGraw-Hill Inc., New York, 1970.