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Plastic Foams

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Foams are relatively new forms of polymer-based materials. They are light in weight and versatile, and are employed increasingly in a variety of applications that include thermal and acoustic insulation, core materials for sandwich panels, fabrication of furniture and flotation materials. This Digest will discuss the nature, terminology and general properties of plastic foams; subsequent Digests will deal with the major types that are commercially available.

General Nature

A plastic foam material consists of a gas phase dispersed in a solid plastic phase and derives its properties from both. The solid plastic component forms the matrix. The gas phase is contained in voids or cells and is often referred to as the blowing or foaming agent. It should be noted, however, that the blowing agent used in the production of foams is not always gaseous and chemically identical with the gas component. Some blowing agents are solids, some are liquids. The term cellular plastic, a synonym for plastic foam, is derived from the structure of the material.

Foams are classified as open-cell or closed-cell. In closed-cell foams each cell (more or less spherical in shape) is completely enclosed by a thin wall or membrane of plastic (Figure 1 and Figure 2), whereas in open-cell foams the individual cells are interconnected (Figure 3). The terms plastic foam, foamed plastic and cellular plastic are used interchangeably; they refer to foamed plastics regardless of cell structure (open or closed). Expanded plastic refers to closed-cell materials; "sponge" is sometimes used for open-cell foams (e .g., sponge rubber).

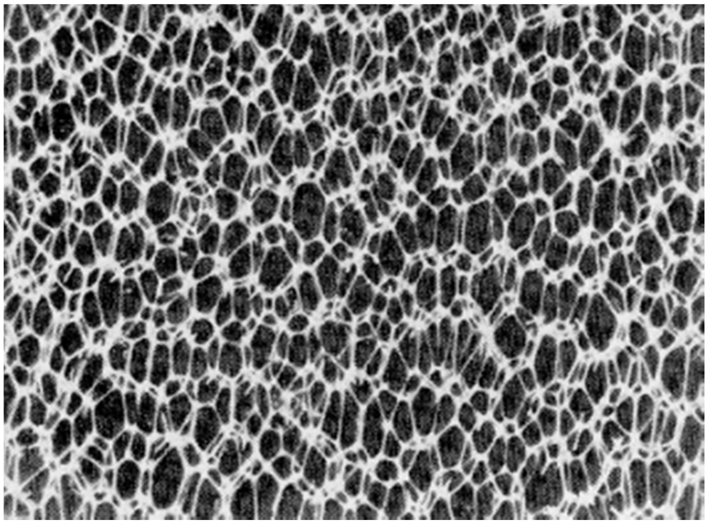

Figure 1. Photomicrograph of cross-section of rigid polyurethane foam (closed cell), 10X.*

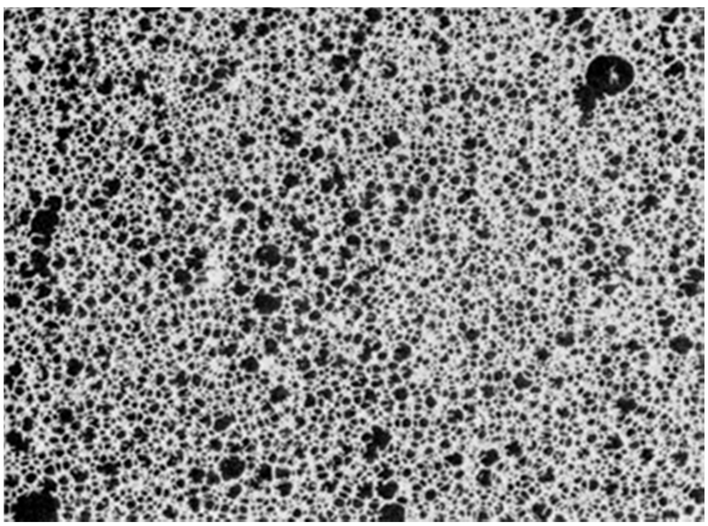

Figure 2. Photomicrograph of cross-section of rigid phenol-formaldehyde (closed cell), 10X.*

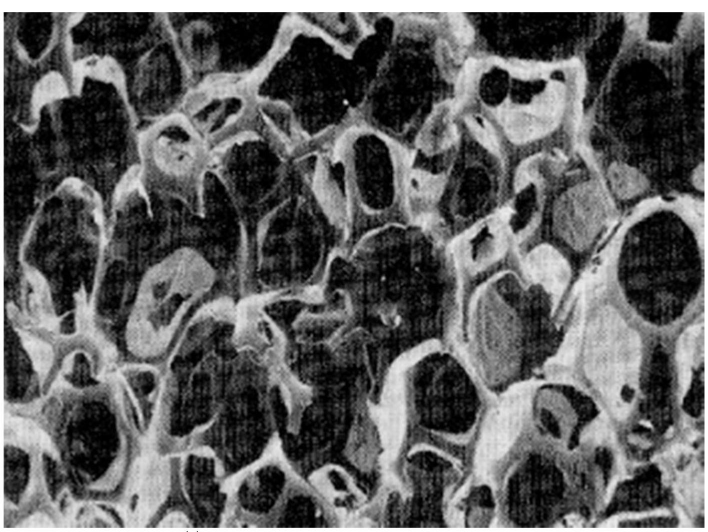

*Figure 3. SEM** micrograph of cross-section of flexible polyurethane foam (open cell), 20X.*

Plastic foams may be flexible, semi-flexible (or semi-rigid) and rigid, depending on chemical composition and the rigidity of the resin used as a matrix. Flexible foams have a glass transition (Tg) below room temperature, whereas rigid foams have one above room temperature.

Plastic Matrix

The matrix is made up of the base resin and other compounding ingredients that may include plasticizers, stabilizers, surfactants, dyes and pigments, fire retardants and fillers. The composition of the plastic matrix plays an important role in determining foam properties such as chemical resistance, thermal stability, flammability, specific heat, transition temperature and rigidity.

With respect to the base resin of the matrix, plastic foams may be either thermoplastic or thermosetting. Thermoplastic foams are based on linear polymers (CBD's **154**, **158**) exhibiting a definite melting range normally associated with the base resin in the matrix. In contrast, thermosetting foams based on cross-linked polymers (**CBD 159**) do not normally exhibit a definite melting range, although they may show some limited plastic flow at elevated temperature. Typical thermoplastic foams are polystyrene, poly(vinyl chloride) (PVC), the polyolefins (polyethylene and polypropylene) and ABS foams. Common thermoset foams include polyurethane (also called urethane), phenol-formaldehyde (phenolic), urea-formaldehyde and epoxy foams.

Gas Phase and Blowing Agents

Whereas the chemical and physical nature of the matrix is the principal factor in determining most foam properties, the composition of the gaseous phase has an important effect on selected properties such as thermal resistance. The blowing or foaming agents used to produce cellular structure during the foaming operation fall into two classes: physical blowing agents and chemical blowing agents. Physical blowing agents undergo only physical change. The most common are low-boiling organic liquids such as hydrocarbons and halogenated hydrocarbons, which develop cells within the plastic material by changing from liquid to gas during foaming under the influence of heat. Gases (e.g. nitrogen gas) constitute another group of substances belonging to this class. When physical blowing agents are used in foaming, therefore, the gas phase of the foam is chemically identical with the blowing agent.

Chemical blowing agents are materials that are stable at normal storage temperature and under specific processing conditions, but undergo decomposition with controllable gas evolution at reasonably well defined temperatures (or reaction conditions). When they are used in foaming, the gas phase of the resulting foam is different from the blowing agent (usually a solid substance). Popular blowing agents of this class are organic nitrogen compounds (e.g., azodicarbonamide); they produce, mainly, nitrogen gas along with smaller proportions of other gases.

Water is a well known blowing agent still used in the production of some polyurethane foams. It reacts with the isocyanate component of the foam mixture to generate carbon dioxide (CO_2), which produces the cellular structure. The gas phase (carbon dioxide) of the resulting foam is different from the substance used as blowing agent. Thus water may be considered a sort of chemical blowing agent.

Although the gas generated during foaming is originally present in closed-cell foams, it may diffuse slowly in service and gradually be replaced by air, water vapour and $CO_2$from the atmosphere.

Cell Structure

Cell structure determines certain properties, thereby influencing the type of application of the foamed plastic. Open-cell foams offer little resistance to the passage of liquids and gases through them. A general principle is that flexible foams have open-cell structure and rigid foams closed cells. The cell structure depends on the process used for the production of the foamed plastic; in some cases both flexible and rigid foams may be produced with either open or closed cells (e.g., PVC). Generally, no foam has entirely one type of cell structure (open- or closed-cell structure implies that the number of cells in the foam is predominantly open or closed, respectively). For example, most rigid polyurethane foams have high closed-cell contents, usually 85 to 95 per cent for a 2-lb/ft^3 foam.

In an open-cell foam the gas phase is inevitably air. Open-cell foams have sound absorbing properties and, when flexible, cushioning characteristics. This makes them suitable for use as sound absorbing materials and in cushioning applications (e.g.. flexible urethane foam).

In a closed-cell foam the resin membrane, which forms the cell walls, acts as a barrier to gases and liquids, although gases may pass through the membrane by the slow process of diffusion. Closed-cell foams, therefore, have lower water absorption and lower water vapour permeability than open-cell foams. If the gas phase has low thermal conductivity and is captive, closed-cell foams can usually provide higher thermal resistance than open-cell foams that are air filled (**CBD 149**). The cell size also influences thermal resistance.

How Plastic Foams Are Made

The cellular structure in plastics may be produced by physical, chemical or mechanical means. In all the methods the material to be foamed is in a liquid or plastic state during part of the operation.

Popular physical methods include expansion of a gas dissolved in a molten resin mix by reducing the pressure (e.g. extrusion of polyethylene foam using nitrogen gas); and volatilization of low-boiling liquid within the polymer mass either by application of external heat or under the influence of the heat of reaction (e.g., foaming of polyurethane with a fluorocarbon).

In chemical foaming, the gas producing the cellular structure results from chemical decomposition of a blowing agent; for example, in the production of some types of foamed PVC the decomposition of an organic nitrogen compound liberates nitrogen gas.

The third method of producing a cellular structure employs mechanical whipping (frothing) of gases into a polymeric material (melt, suspension or solution). As the material hardens it entraps gas bubbles in a matrix, thus yielding a cellular structure.

Common techniques used in the production of foam products include foaming-in-place, spraying, extrusion, injection moulding, and continuous slab stock production by pouring.

Density

The ratio of gas to the solid plastic component determines density and greatly affects other physical properties of foam. In fact, many important properties including thermal resistance, mechanical strength and heat capacity are specifically related to density. This being so, density measurements are a routing part of any testing, permitting identification, in general terms, of the characteristics of foams.

The density of cellular plastics may vary from 0.1 to 60 lb/ft^3 or more, with most commercial foams having densities between 1.5 and 2.5 lb/ft^3. Generally, low-density (less than 4 lb/ft^3), rigid foams are used for thermal insulation, flotation, and protective packaging; high-density materials for structural applications including fabrication of furniture.

Thermal Resistance of Rigid Foams

The insulation value of a specimen of rigid foam is represented by its R-factor or thermal resistance. It is customary to compare specimens of various foams on the basis of thermal resistance for 1 inch of thickness. This value can be calculated from 1/k where k is the thermal conductivity of a 1-inch specimen, also called k factor (for 1 inch thickness). For specimens of other thicknesses it is often necessary to measure the actual R-factor since thermal resistance per inch thickness and k-factor can depend on specimen thickness (**CBD 149**).

The thermal resistance of a specimen of insulation is usually measured by either of two methods, ASTM C177 (guarded hot plate) or ASTM C518 (heat flow meter). A third method, ASTM D-2326 (probe), is used only for quality control tests. The thermal resistance depends on moisture content, density, cell structure and size, composition of the cellular gas, and temperature at which the foam is used. Generally, thermal resistance decreases with moisture content of the foam. It is a complex function of density and cell size. Specimens of foam in which the gas phase is air or CO_2 have lower thermal resistance than similar specimens foamed with halogenated hydrocarbons. For example, a typical rigid plastic foam containing air has a stable thermal resistance of about 3.5 to 5 units (°F/Btu/hr ft²) for 1 inch of thickness. The initial thermal resistance of a typical 1- inch thick specimen of rigid foam containing fluorocarbon-11 (fluorotrichloromethane) is 6 to 9 units. Air and water vapour diffuse into, and the captive gas out of, the cells as the foams age. The thermal resistance decreases relatively quickly at first, and then more slowly over the long term (**CBD 149**).

Fire Behaviour

Because cellular plastics have a relatively large surface area, the problem of flammability is more acute than with bulk plastics. Thermoplastic foams, like polystyrene, usually melt during a fire and may produce drops of burning molten plastic that increase the fire hazard. Attempts to reduce the flammability of plastic foams are similar to those applied to bulk plastics. Most of the commercial foams can be modified to improve their fire behaviour. The products of combustion of plastics should also be considered in their application (**CBD 144**).

Buoyancy

Closed-cell, rigid, low-density foams have good buoyancy characteristics and are therefore used extensively in flotation applications. In such materials each cell behaves as an individual float. The initial buoyancy factor of a foam is equal to the density of the liquid on which it floats less the density of the foam. For example, 1 cubic foot of plastic foam having a density of 2 lb/ft³ will support a load of 60.5 lb/ft³ [62.5 lb/ft³ (density of water) — 2.0 lb/ft³]; as the foam absorbs water the factor decreases.

Durability of Plastic Foams

The successful performance of any material in a construction application depends on its appropriateness to the function it must fulfil. It is generally good practice to follow the instructions of foam manufacturers (or suppliers) for correct applications and installation.

The weathering resistance of foamed plastics is usually comparable to that of the plastics used to make the foam. Exposure to solar radiation for long periods induces degradation of the base resin and results in deterioration of its structure and therefore of its performance. Plastic foams should be protected from exposure to direct sunlight or high intensity ultraviolet light. In most instances this can be accomplished by applying a coating that is opaque to ultraviolet radiation.

Because they are inert most plastic foams resist attack by bacteria and fungus. Many, however, contain a minimum of additives such as plasticizers, stabilizers, lubricants and colorants, and these may be susceptible to microbiological attack.

Forms Available

To be adaptable to a wide range of installation techniques, plastic foams have been made available in a variety of forms: rigid closed-cell, rigid open-cell, flexible open-cell, flexible closed-cell materials, or combinations of these, and in blocks, slabs, boards, sheets and numerous moulded shapes. In addition, some liquid prefoam mixtures (e.g., thermoset foaming compounds) are supplied as two- or three-part systems that can be foamed-in-place, poured-in-place, froth poured-in-place, sprayed-in-place or used for potting and encapsulating.

Plastic Foams versus Conventional Materials

Compared with traditional materials such as wood, glass, metal and concrete, plastic foams are light in weight and have generally high strength-to-weight ratios. Many are very good electrical insulators. Lower density, closed-cell rigid foams are buoyant and provide varying degrees of thermal insulation.

Dimensional stability can be a problem with all foams; some shrink, some expand. Generally, dimensional stability is affected by high temperature and high humidity or both. Designers should therefore be aware of the characteristics of the foam to be used. Plastic foam products are easily fabricated with woodworking tools.

Summary

Foamed or cellular plastics are made up of a mass of fine gas bubbles (gas phase) dispersed in a solid plastic phase (matrix). According to the type of plastic used in the matrix, they are either thermoplastic or thermosetting. Plastic foams may be classified as open-cell or closed-cell foams, depending on which type of cell predominates. According to the degree of rigidity, plastic foams may be flexible, semi-flexible (or semi-rigid) and rigid. Rigid closed-cell foams can have good thermal insulation properties and buoyancy characteristics. Open-cell foams can have good cushioning characteristics (e.g., flexible) and sound absorbing properties.