**Technical Note 600-2**

# NOTES ON THE DESIGN AND CONSTRUCTION OF SYNTACTIC FOAM PRODUCTS

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## INTRODUCTION

Syntactic foam is an advanced composite material typically composed of plastic, glass, and other high strength ingredients. It offers low density combined with great strength along with a number of remarkable properties, and is widely used for deepsea buoyancy and marine thermal insulation. This paper is an introduction to the basic principles underlying the design and construction of syntactic foam. For more detailed information, see the bibliography on Page 3.

## HISTORY

The manufacture of syntactic foam began shortly after the commercial introduction of hollow glass microspheres in the 1950s. Among the first applications were buoyancy blocks for small deep diving ROVs for the United States Navy. Other military applications included buoyant void fillers for nuclear submarines and naval weapons systems. Large-volume manufacture of syntactic foam got under way in the late 1960s when floating oilrigs started using buoyancy modules to support their drilling risers. Since that time, syntactic foam has become an integral part of offshore operations, and all recent depth records have been set using some form of the material. Starting in the mid-1990s, syntactic foam found rapidly growing acceptance as deepsea thermal insulation, and this application has grown into a major use of the material.

## FOAMED PLASTICS

Ordinary foamed plastics use a blowing agent to create a lightweight structure of gas-filled bubbles or voids. Expanded polystyrene, for example, is the white plastic foam often used to mold coffee cups. Other familiar forms of foamed plastics include the soft, flexible polyurethane foam found in pillows and seat cushions, and the polypropylene or PVC foams used as insulation in the building trades. These materials are extremely light, but they are not very strong. Their strength is limited by the weakness of the individual cell walls and an inherently random and irregular cell structure. To create truly useful engineering products, a much stronger and more dependable material is required.

## SYNTACTIC FOAM

The term *syntactic foam* describes composite materials in which the cellular structure is formed by hollow spherical fillers reinforced by a binder holding them together. The word *syntactic* comes from the same ancient Greek stem as the grammatical term *syntax*, meaning “an orderly arrangement.” In other words, syntactic foam has a carefully designed *order* to its cellular structure that is lacking in ordinary “blown” foams. The order is established by the use of hollow spherical fillers, either very small microspheres and/or larger macrospheres. See the diagram in **Figure 1**. Glass microspheres typically average about 100 microns in diameter, with a wall thickness between 1.0 and 2.0 microns. A typical fiberglass macrosphere is made of epoxy and glass fiber in a nominal diameter of 10 mm with a wall thickness between 0.25 and 0.50 mm. These spherical fillers are engineered and pre-manufactured to specific densities and strengths.

## MICROSPHERES AND MACROSPHERES

Hydrospace grade microspheres are made from high purity borosilicate glass in a verti-cal furnace. The raw materials of the glass are fed as a fine powder into the flame at the bottom of the furnace. As the materials rise through the hottest part of the flame, they melt and fuse while nitrogenous additives gasify to blow tiny “bubbles” of glass. The furnace product is then sent through a number of refining operations that can include sorting by size and strength, washing, floating, and chemical treatment to arrive at glass microspheres with precisely controlled properties. Fiberglass macrospheres are made in large tumblers that apply successive coats of epoxy resin and reinforcing fibers to form hollow shells. By varying the type of fiber and wall thickness, macrospheres of a wide range of strengths and densities can be formed. After coating, the macrospheres are sorted by size and strength and given additional treatments to optimize their properties.

## CLOSE PACKING OF SPHERES

The theoretical limit for random close packing of uniformly sized spheres in a closed space is about 64%. Practical considerations reduce this packing fraction to somewhere around 50%. If two sizes of spheres are used, and the ratio of their diameters is greater than 1:7, then the total packing fraction can approach 75%. This is why macrosphere syntactic foam is usually lighter than “solid” (glass microspheres only) syntactic foam: the two kinds of spheres pack better, fill a larger fraction of the total volume, and reduce the density of the composite. The result is often a less expensive product, as well.

## SPHERICAL STRENGTH

The sphere is the best shape for resisting uniform hydrostatic pressure: in theory, pressure is converted into pure compressive stress in a perfectly spherical shell. Unfortunately, “real” hollow spheres have imperfect geometry, and therefore tend to collapse at pressures lower than predicted by theory. However, when bonded together and reinforced by a rigid binder, the spheres exhibit much greater strength. This “reinforcement factor” depends on the size and relative stiffness of the spheres. Glass microspheres, which are both very small and very stiff, easily survive pressures when encapsulated in rigid epoxy six times greater than if unsupported. 10 mm fiberglass macrospheres, being much larger, typically derive reinforcement equal to at least twice their unsupported strength. Spheres that are very large with respect to their surround-ings (imagine a 100 mm dia. sphere cast into a 100 mm plastic cube) may receive no effective reinforcement at all.

## THE MANUFACTURING AND TESTING PROCESS

Casting of a syntactic foam product typically employs the following procedure: (1) a mold is prepared of the proper shape, and its inner surfaces coated with a release agent; (2) the inner surface of the mold is covered with dry fiberglass mat or other reinforcement, as required; (3) if fiberglass macrospheres are to be used, they are poured into the mold cavity at this point; (4) a syntactic mixture is prepared of epoxy resin and hardener, plus glass microspheres, and injected into the mold under vacuum; (5) the filled mold is heated in an oven to cure the epoxy binder; (6) the mold is opened and the part removed; and (7) the product is finished, painted as required, tested, and prepared for shipment. **Figure 2** illustrates the results of a typical hydrostatic pressure test.

Suggested Readings:

Bardella, L. and Genna, F.: "On the Elastic Behavior of Syntactic Foams," International Journal of Solids and Structures, Pergamon, 2000.

Cuming Corporation Technical Notes:
600-1, "Thermal Insulating Properties of Syntactic Foam"
600-3, "Notes on the Mechanical Properties of Syntactic Foam"
600-4, "Notes on the Heat Transfer Behavior of Syntactic Foam"

DeRuntz, J. A.: "Micromechanics and Macromechanics of Syntactic Foam," Proceedings of the 1969 Southampton Conference.

Dudt, Phillip J.: "Prediction of Short-Term Critical Collapse of Syntactic Foam Under Hydrostatic Pressure," U.S.Navy R&D Report, 1969.

Mast, Beaubien, and Mulville: "Optimum Packing of Hollow Spheres in Buoyancy Materials," NRL Report 6904, June 30, 1969.

Watkins, Lou: "Syntactic Foam Buoyancy for Production Risers," Offshore Mechanics Conference Technical Paper, 1988.