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WHITE PAPER

Reticulated foams expand the boundaries of cellular solids

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Picture a structure formed by fibers or ligaments that frames open cells. Such a structure would be lightweight, permeable, and shock-resistant while retaining the properties of the parent material. Polymer foams, used for insulation, cushions, and packaging materials, were perhaps the first man-made material to take advantage of the unique characteristics of cellular solids. Today, another type of foam, reticulated foam, made of either a ceramic (typically alumina, silicon carbide, or vitreous carbon) or a metal (typically aluminum, copper, nickel, stainless steel, or zinc), provides an extraordinarily versatile material that can be engineered for particular properties and tailored for specific applications.[1]

Reticulated foams have a number of features that benefit research and design engineers across many industries. The interconnected lattice of continuous ligaments within the cellular structure provides greater strength than shorter fibers and also ensures uniform material characteristics throughout the structure (**Figure 1a**). Other characteristics that offer further benefits include:

High strength-to-weight ratio: Reticulated foam is particularly useful within cores of structural sandwich panels.[2] The isotropic properties of the foam allow for a uniform response to impact, regardless of impact angle. These foams also add strength and structure when used as part of a three-dimensional (3D) network of reinforcing fibers in composites.

High surface area-to-volume ratio: Deposition of a high-cost catalyst such as platinum or silver onto the ligament surfaces of a reticulated foam allows contact of a gas or liquid with the catalyst over a vast surface area.[3] This technique is cost-effective and proves to be particularly valuable in the development of fuel cells. In addition, reticulated foam offers an exceptionally large surface area in a compact and lightweight structure for use as a scaffold for biological growth in pollution control and other devices.

Conductive or insulating: Depending on the material, a reticulated foam can provide very low bulk thermal or electrical conductivity as well as insulation against high temperatures. In particular, vitreous carbon and silicon carbide reticulated foams are, like the solid material, structurally stable at extreme temperatures but at a fraction of the weight. These characteristics lend themselves for use in aerospace applications, in heat exchangers, porous electrodes, and wherever an exceptionally efficient, lightweight conductor or insulator is required.

Low flow resistance: The open, uniform cell structure and rigid geometry of reticulated ceramic or metal foam contribute to a low pressure drop, or little resistance to the flow of liquid or gas for fluid flow. This is useful for applications such as filters, demisters, gas diffusers and mixers, and liquid and gas separators.

Resistance to fracture and thermal shock: Because the properties of the parent material extend throughout the foam in three dimensions, a reticulated foam provides enhanced resistance to fracture and thermal shock. The continuous ligaments of the material deter crack propagation, since a crack encountering a continuous ligament (as opposed to a short fiber) is stopped from progressing through the structure.

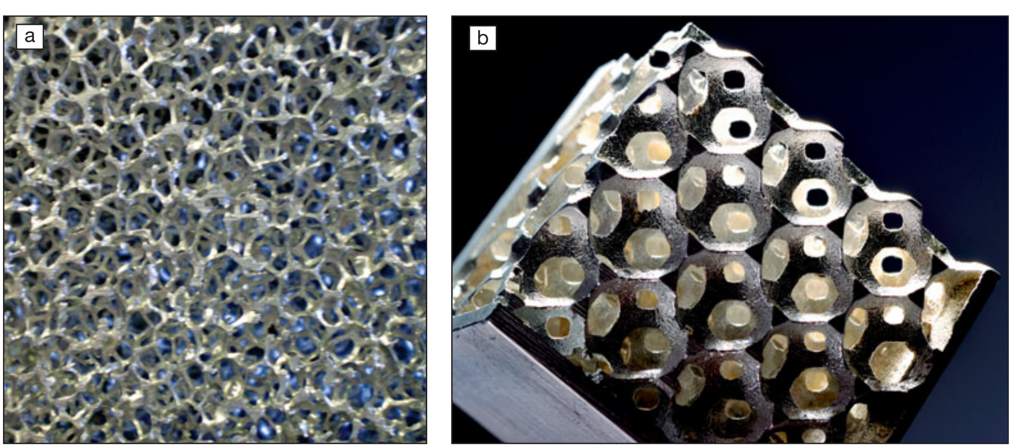

Figure 1. (a) Reticulated foams are low-density, permeable structures of open cells and continuous ligaments. Microscopically, they are like a three-dimensional mesh. It is the continuous nature of the ligaments that make the foam “reticulated.” (b) “Regular” aluminum foam with a solid base on three sides, magnified to show 85% porosity and regular tetrakaidecahedron cells.

Tailoring attributes for specific uses

Standard reticulated foams of ceramic materials or metals are suitable

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for many high-tech applications, including porous electrodes, high-temperature insulation, acoustic control, filters, storage batteries, scaffolds for biological growth, heat exchangers, and cores in structural sandwich panels. Such variety is achievable because it is possible to tailor properties for a specific application by adjusting the material composition, pore size, density, ligament structure, and even the shape of the component. In fact, the most exciting aspect of working with reticulated foams may be the opportunity to explore and exploit their properties for use in any number of new as well as established applications.

Significant advances in the production of reticulated foam and reticulated foam components include the lost carbonate sintering (LCS) process, sand casting, and 3D printing.

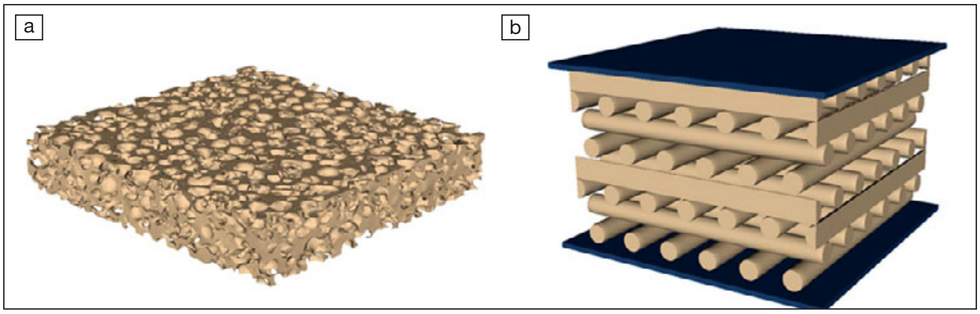

Figure 2. Schematic drawings showing the nonuniform microstructure of (a) open-cell stochastic foam and (b) the uniform microstructure of 3D-printed foam.

Lost carbonate sintering

Sintering a compact of copper powder and carbonate powder has proven to be a cost-effective means of producing copper foam with controlled cell shape, cell size, and porosity.[4] The particle size of the carbonate powder can be selected to match the desired cell size of the final foam. The compaction/sintering process yields a matrix of copper ligaments, in between which is the carbonate powder. After cooling, the carbonate is dissolved away or decomposed using heat. The resulting structure is regular and uniform throughout, giving a rigid, highly porous, and permeable structure with a controlled density of metal per unit volume.

This microporous copper foam structure is, not surprisingly, of particular interest to design engineers working in fields requiring heat exchange, where applications include, but are not limited to, liquid cooling, air cooling, heat exchangers, board-level electronics cooling, power electronics, and electromagnetic interference shielding. In addition to copper, the LCS process has successfully produced foams of other metals.

Sand-casting method

A recent development in the area of foam structures is a cost-effective "regular" aluminum foam with evenly spaced, open pores.[5] It is made up of cells defined as regular tetrakaidecahedrons (polygons with 14 faces—8 hexagonal and 6 square) (**Figure 1b**). The foam is manufactured using a sand-casting method, resulting in each manufactured piece being identical to and having exactly the same behavior as other pieces from the same casting process.

For impact absorption, this regular, reproducible aluminum foam product can be designed with the end use in mind, making it possible to optimize the exact structure necessary to absorb the energy from an impact based on a specific application. This metal foam potentially has the greatest advantages in heat exchange. Its high porosity (80–90%) and high relative surface area of up to 500 m^2/m^3 facilitate the movement of fluids and the recovery of heat, even at low speeds.

3D printing

Three-dimensional printing appears to be the next frontier in the creation of cellular solids. Materials scientists at Lawrence Livermore National Laboratory have developed a 3D-printed polymeric foam that they report to be superior in almost every way to stochastic foam of the same material.[6] The 3D-printed foam has a uniform structure with well-defined cellular shapes and dimensions down to the microscale level (**Figure 2**). This structure is associated with longer-term stability and superior mechanical performance compared to the stochastic foam.

Coating for enhanced performance

Coating the underlying structure of a foam is an economical way to enhance the performance of the structure for a particular application. Once the coating fills approximately 5% of the original pore space, the entire foam takes on the mechanical, thermal, and electrical properties of the coating. Typical coatings include pyrolytic carbon or graphite, refractory metals, ceramic compounds, and certain precious metals, with coating methods ranging from dipping to chemical vapor deposition.[7]

Summary

Reticulated foams are an increasingly important material class for researchers and innovative engineers seeking to achieve high performance with minimal weight. Continuing to creatively exploit the versatility that this structural form affords will result in new and exciting applications in the future.

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