IARJSET

ISSN (Online) 2393-8021
ISSN (Print) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

CETCME-2017

"Cutting Edge Technological Challenges in Mechanical Engineering"

Noida Institute of Engineering & Technology (NIET), Greater Noida

Vol. 4, Special Issue 3, February 2017

Processing of Syntactic Foams: A Review

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Abstract: For structural application different types of lighter material with higher specific strength are being developed now days like honeycomb, metal foam, sandwich panels, syntactic foam etc. In this review paper the syntactic foam is discussed among all these lighter material. Syntactic foams are the materials in which micro spheres are incorporated in a matrix. In syntactic foams, the matrix is reinforced with hollow spherical particles which have a controlled systematic arrangement in the matrix. Hollow microspheres give the syntactic foam its low density, high specific strength, and low moisture absorption. Microspheres may comprise glass, polymer, carbon and ceramic or even metal. The strength of syntactic foams can be nearly equal to that of the matrix. The plateau and yield stress can be tailored over a wide range by selecting appropriate volume fraction and particle type. Metal matrix syntactic foams are expected to have better properties compared to open or closed-cell metallic foams since the former have controlled size and geometry of porosity and the ceramic shells contribute to stiffness and strength. Several preparation methods are used for preparing syntactic foam and various applications are discussed, depending on the types of matrix and reinforcement used.

Keywords: Microspheres, Metal foam, Composite, Mold.

I. INTRODUCTION

A. Syntactic Foam s: Definition

Lightweight materials with high specific strength are essential in aerospace, marine and other structural applications. The commonest method to produce such a material is by introducing a lightweight material in a matrix. This concept forms the basis of syntactic foams: hollow microspheres are incorporated into a matrix. As per the definition from the American Society for Testing and Materials (ASTM), syntactic foam is a 'material consisting of hollow sphere fillers in a resin matrix'. The term 'syntactic foam' was introduced in the 1960s. 'Syntactic' is derived from the Greek word 'Syntaktikos', means 'to arrange together. The term 'foam' is used because of the cellular nature of the material. Syntactic foams are also known as 'foam composites' because the hollow microspheres can be viewed as reinforcements in a matrix. This type of material was previously used in the marine industry, providing buoyancy for subsea apparatus such as submersible vehicles and oceanographic equipment. Nowadays, syntactic foams find many applications ranging from tea cups to the limits of space travel [1].

In syntactic foams, the matrix is reinforced with hollow spherical particles which have a controlled systematic arrangement in the matrix. Incorporating hollow particles having a lower density compared with binder material allows for the manufacture of lightweight materials with the increase of filler content. Thus, syntactic foam with a filler density that is lower compared with the binder can be considered to be a special type of particulate-filled polymer composite [2]. Syntactic foams are categorized as physical foams because the matrix is not foamed chemically but instead the gas-containing particles are filled mechanically into the matrix. They have the real advantage of being fabricated over a large density range and possess useful properties that can be tailored for specific applications.

B. Matrices used in Syntactic Foams

The matrices used in syntactic foam include polymers, metals or ceramics. Thermoplastic and thermosetting polymers have been employed to process syntactic foams. The important thermosetting resins used are epoxies, phenolics, cyanate esters, bismaleimides, unsaturated polyesters, and polyurethanes. Examples of the thermoplastic resin matrices used include polyethylene, polypropylene, polystyrene, and nylons. Mainly aluminum, titanium, iron are used to process metal syntactic foam , while ceramics syntactic foam are made from silicon carbide, carbon, zirconium carbide, zirconia, alumina, and silicon nitride.

C. Microspheres in Syntactic Foams

Hollow microspheres give the syntactic foam its low density, high specific strength, and low moisture absorption. Microspheres may comprise glass, polymer, carbon, ceramic, or even metal [3]. The microspheres have a burst pressure sufficient to withstand the forces imposed upon them during the formulation, mixing and dispensing processes. The main processing advantage of microspheres is that the viscosity of the systems with spherical fillers is always less than that of systems with fillers of any other shape. Properties such as high temperature resistance, good strength-to-weight ratios, clean surface chemistry, low thermal conductivity, low dielectric constant, and low dissipation factor make microballoons an important reinforcing material in these composites. Microspheres are characterized by their particle size, wall thickness and density. In general, microspheres used in syntactic foams have a diameter of 1–50 μm, wall thickness of 1–4 μm, bulk density of 70–500 kg/m3, and apparent density of 50–500 kg/m3. Hollow macrospheres (diameter, 1–100 mm) are also used as fillers in syntactic foams [4].

The most commonly used microspheres in syntactic foam are glass microspheres due to their high specific strength, regularity of the surface, good wetting characteristics, and low viscosity of the resin microballoon mixture, as well as energy absorption properties, low cost and ease of fabrication [5]. Also, hollow glass particles have very low densities as compared with corresponding hollow metallic and ceramic particles.

Polymeric microballoons are commonly made up of epoxy resin, unsaturated polyester resin, silicone resin, phenolics, melamine formaldehyde, polyvinyl chloride, polypropylene, or polystyrene. microspheres are produced by spraying low-viscosity solutions and melts. Among the various polymeric microballoons, phenolics microballoons have been widely used for processing syntactic foams. The main advantage of phenolics microspheres over those of glass is their lower density. Organic microspheres are also used in syntactic foams. They suffer from many limitations and their use is limited. Some organic microspheres can be converted into carbon microspheres. Usually, these spheres are derived from phenolics microspheres or carbon pitch spheres.

II. GENERAL METHODS FOR PREPARATION OF SYNTACTIC FOAMS

The general methods for the preparation of conventional polymer foams require the use of at least two chemical constituents: one to decompose into a gas to form the bubbles, and one to form the cell walls.

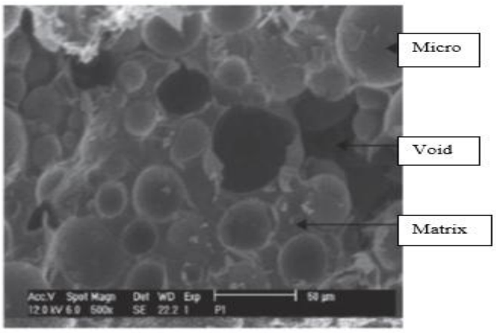


Fig. 1 SEM image of syntactic foam [4].

Various manufacturing techniques are available for processing syntactic foams. The microballoon concentration and matrix composition was found to be crucial for the ease of manufacturing syntactic foams [6]. The choice of process parameters (temperature, mixing time, addition sequence) is also a main challenge in the processing of syntactic foams.

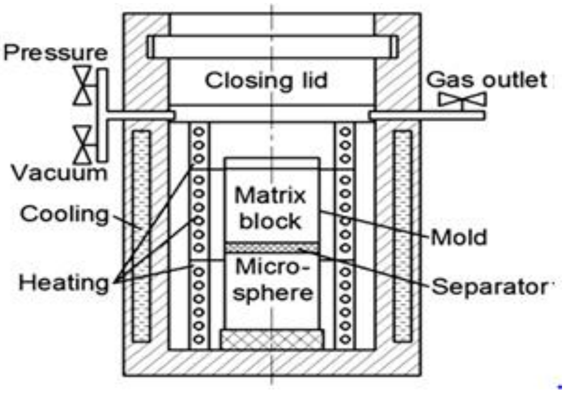
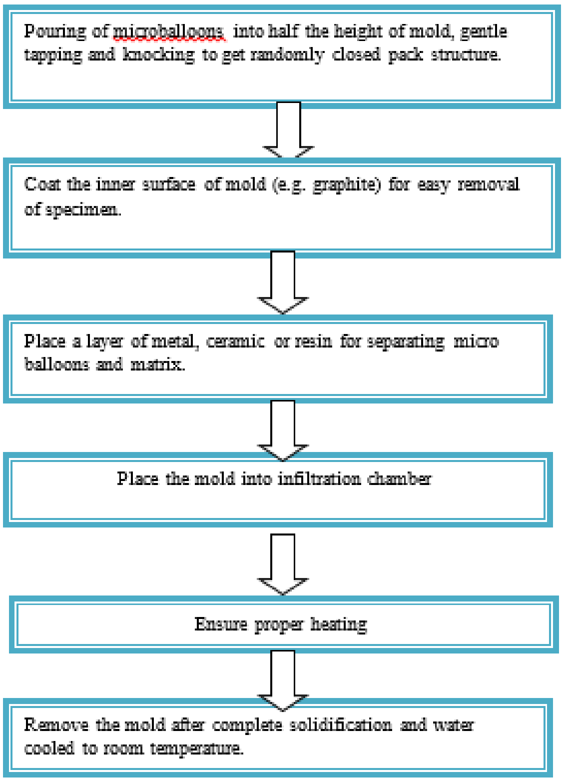


Fig. 2 Schematic sketch of the Infiltration chamber [7]

Following are the Steps followed in Infiltration process:



Pouring of microballoons into half the height of mold, gentle tapping and knocking to get randomly closed pack structure.

Coat the inner surface of mold (e.g. graphite) for easy removal of specimen.

Place a layer of metal, ceramic or resin for separating micro balloons and matrix.

Place the mold into infiltration chamber

Ensure proper heating

Remove the mold after complete solidification and water cooled to room temperature.

A common method for the preparation of syntactic foams is by impregnation of microspheres in a resin solution. This method ensures uniform coating of each sphere by the resin. Homogeneous dispersion of the resin among the microspheres is therefore achieved. The main difficulty of this method lies in the need to entirely remove the solvent before the final curing. Another method is to fill a mold with an appropriate amount of microspheres and then a pre-measured amount of resin solution is poured over it.

The solution penetrates into the intersphere voids due to gravity, capillary forces and sometimes with the aid of vacuum or positive pressure. Final curing is done after solvent removal. Easily removable, environmentally safe and low-density syntactic foams are prepared by mixing insoluble microballoons with a solution of water and/or alcohol-soluble polymer to produce pourable slurry. Vacuum-filtering the slurry in varying degrees removes unwanted solvent and solute polymer. Finally, drying removes the residual solvent. The method is used when the solute polymers are non-toxic and soluble in environmentally safe solvents such as water or low-molecular-weight alcohols. The syntactic foams produced by this method are particularly useful in those applications where ease of removability is beneficial, and could find application in: packaging of recoverable electronic components; drilling and mining applications; art works; the entertainment industry for special effects; manufacturing as temporary fixtures.

III. COMPARISON WITH CONVENTIONAL FOAMS

Blown and self-expanding foams develop a fairly random distribution of gas pockets of widely varying sizes and shapes. The porosity of syntactic foams can be much more closely controlled by careful selection and mixing of the microballoons with the matrix. The voids in syntactic foams are due to the cellular structure of the microsphere, so it is easier to predetermine and control the size and size distribution of the voids within syntactic foam. Ordinary foams are visibly porous, but syntactic foams have cells so small that the material looks like a homogeneous solid [8]. In conventional foams, cells are partially or fully connected whereas, in syntactic foams, the voids are enclosed within the walls of the microspheres and are therefore isolated from each other. The porosity of syntactic foams is typically at the microscopic level.

IV. PROPERTIES OF SYNTACTIC FOAMS

The application of syntactic foams has centered on their ability to: reduce weight; increase stiffness; exhibit buoyancy; provide good nailability and screwability; reduce cost. Syntactic foams are mechanically superior due to the rigidity of the microballoons. Hence, syntactic foams stand in-between conventional reinforced polymeric materials and foams with very high specific strengths.

Several other foamed materials offer better thermal insulation properties but none offer simultaneous high-strength properties. They have excellent compressive and hydrostatic strength, good impact behavior and damage tolerance compared with other closed-cell structured materials, which makes them very attractive for structural applications. They are found to be highly strain rate-sensitive, in contrast with metallic foams [9].

A. Mechanical Properties

Syntactic foams have excellent mechanical properties. They can absorb a considerable amount of energy under compressive loading. The high specific compressive strength of syntactic foams derives from the resistance of microspheres to compressive loads. The compressive properties of syntactic foams primarily depend on the properties of the microballoons, whereas the tensile properties depend on the matrix material used [10]. Microspheres have an extremely strong structure and hence can withstand stresses very well. In the case of two-phase syntactic foams, properties are a function of the properties of the resin and the microballoon and their proportions. In the case of three-phase syntactic foams, the shape and content of voids play an important part. At lower resin concentration, failure is mainly that of structure collapse, whereas at higher resin concentration polymer properties become more important and more spheres break before the structure collapse [11].

B. Moisture Absorption

The most significant property of syntactic foams is their low moisture absorption. Syntactic foams have completely closed cells and therefore absorb water to a lesser degree compared with foamed plastics in which the cells are open [12]. It is reported that for microballoon concentration <67 vol. %, the water absorption in syntactic foam is independent of density, but above such concentration absorptivities increase rapidly due to loss in binder integrity and the appearance of cavities. Syntactic foams absorb considerable amounts of water only at hydrostatic pressures above 100MPa; they absorb very little between 20 and 100MPa. They are stable in cyclic hydrostatic tests also. They can withstand up to 1000 cycles of alternating between 60MPa and atmospheric pressure. Even under hydrostatic pressures up to 75% of the collapsing pressure, syntactic foams do not absorb large amounts of water [13].

C. Thermal Properties

In general, the thermal properties of syntactic foams are dominated by the matrix characteristics. Filler type also has some effect on the thermal properties of syntactic foams. For example, the replacement of glass microspheres by phenolic microspheres improves the thermal oxidation stability of epoxy foams, especially at 100–150 °C. Syntactic foams are less combustible than their chemically foamed counterparts for the same reason [14].

V. APPLICATIONS OF SYNTACTIC FOAMS

A. Syntactic Foams in Buoyancy Applications

The most important application of syntactic foams is in deep submergence buoyancy where compressive and low moisture absorption properties are of prime importance [15]. They have been used as the principal source of supplementary buoyancy in recently developed deep submergence vehicles. Glass micro balloon-based syntactic foams are particularly useful for this application due to their high compressive strength [16].

B. Syntactic Foam as Thermal Insulation Material

Syntactic foams have been used as thermal insulating material for deep water sub-sea equipments and pipelines. The hollow spherical particles in syntactic foams encapsulate the insulating gas protecting the insulation from collapse due to the high pressures encountered in the subsea environment [17]. Components that are typically insulated include wet trees and valves, jumpers, sleds and pipe lined manifolds, risers and flowlines [18].

C. Syntactic Foams in the Aerospace Industry

There is an increasing demand for syntactic foams in the aerospace industry. Depending on the resin system used, syntactic foam has the potential for an improved transition temperature and a low dielectric constant, making it ideal for use in aerospace applications. Syntactic foams are good potting compounds, and have been used in the aerospace industry as fillers for finishing holes and edges in honeycomb structures. For thin panels, they may be specified for entire sandwich cores [19]. Epoxy- and phenolic-based syntactic foams have been successfully used for thermal protection of atmospheric re-entry space vehicles and to prevent structures from the extreme heat flux of rocket exhaust plumes. Phenolic syntactic foams have low thermal diffusivity and high char-forming properties which are desirable for a good ablative. Moreover, syntactic foams are sufficiently strong to encounter the aerodynamic shear and have adequate mass-saving advantage.

D. Syntactic Foams for Furniture Applications

The materials used in the construction of modern articles are undergoing a radical change. Therefore, attention has been focused by material scientists to develop polymer-based materials to substitute wood for various applications. The use of cast thermoset resins to make furniture parts is growing rapidly despite the problems of high density and brittleness. Syntactic foams are examined as ways to solve these problems without loss of the inherent advantages of cast thermosets, i.e., short initiation time from master to production parts, low equipment costs, low mould cost, high-quality detail reproduction, easy finishing, low part cost, and fast cycle times.

PVDC-based synthetic wood has been used in boat and other marine applications owing to its exceptional water-resistance, durability and mechanical strength; these characteristics are better than natural wood in many respects. They allow sandwich core hulls and decks with the same weight as a solid laminate but with stiffness 3–8 times greater and impact resistance up to 7–8 times greater[20].

E. Syntactic Foams in Underwater Sound Transducers

Underwater sound transducers are often employed under high hydro pressure. To realize a transducer with the desired directivity in the deep sea, a new transducer construction has been devised in which syntactic foam is attached to a sensitive cylindrical element. Syntech Materials, Inc., USA, combine syntactic foam technology with advanced acoustics theory to develop a novel class of underwater sound attenuators. These materials, known as the syntactic acoustic damping material (SADM) and syntactic acoustic transducer baffle (SATB) families of syntactic foams, have repeatedly shown high levels of echo reduction and insertion loss over the 10–100 kHz range at ambient pressure and at operating depth. Two types of materials are available: the –1 series for broadband attenuation and –0.5 series for improved performance at higher frequencies (>30 kHz). These materials have been found to be extremely effective in several underwater acoustic applications. SADM has been used extensively as an anechoic acoustic test tank lining. SATB is designed for use as a transducer isolation mounting material [21].

F. Syntactic Foams in the Sports Industry

New applications are emerging in the sports industry based on syntactic foams (e.g., snow skis, Adidas soccer balls are some of the examples). Bayer and Adidas produced high-tech soccer balls for the EUFA EURO 2004 Championship. The new official ball, called the Fevernova, is highly resistant to abrasion and has very low water-absorption properties. Figure 22 shows the schematic of Fevernova. The surface material of the ball is a high-solid polyurethane coating. Beneath the surface is an elastic layer of Impanel (syntactic polyurethane foam with low-temperature flexibility). The foam consists of equal-sized, highly elastic, exceptionally resistant gas-filled microcells. This composite ensures particularly good 'feel' and good damping properties of the ball.

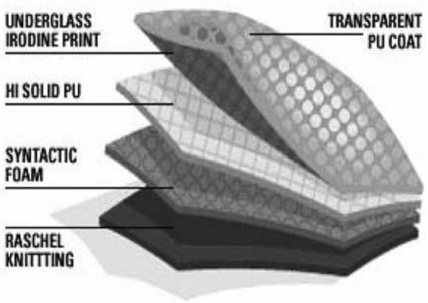


Fig. 3 Different layers present in 'Fevernova' [22]

VI. CONCLUSIONS

Most studies show substantially low modulus of syntactic foams compared to the matrix alloy. The strength of syntactic foams can be nearly equal to that of the matrix.

The plateau and yield stress can be tailored over a wide range by selecting appropriate volume fraction and particle type. Metal matrix syntactic foams are expected to have better properties compared to open or closed-cell metallic foams since the former have controlled size and geometry of porosity and the ceramic shells contribute to stiffness and strength. Some of the barriers to widespread use of metal matrix syntactic foams can be overcome by the availability of:

1. Low-cost defect-free hollow microspheres in narrow size ranges, including Nano size ranges.
2. Mechanical and physical property data for hollow microspheres.
3. Mechanical and physical property data for metal matrix syntactic foams, especially under high strain rates.
4. Processing methods enabling manufacture of large near-net shaped parts of syntactic foams.
5. Understanding of mechanisms of deformation and fracture, and energy absorption to develop quantitative relationships between structure-processing-property and predictive capability to design microstructures.
6. Understanding of solidification structure formation in the matrix in the presence of microballoons, and the influence of microballoons on grain size, dendrite size, micro, and macro segregation, and porosity in the matrix.
7. Understanding the reactions between the surfaces of microballoons and molten alloys and developing strategies of preventing undesirable reactions.

REFERENCES

[1] B. John, C.P.R. Nair and K.N. Ninan, Polymers and Polymer Composites, 2008, 16, 431.
[2] C.S. Karthikeyan, S. Sankaran and Kishore, Polymer International, 2000, 49, 2, 158.
[3] C.S Karthikeyan, S. Sankaran and Kishore, Macromolecular Materials and Engineering, 2005, 290, 1, 60.
[4] C.S. Karthikeyan, S. Sankaran and Kishore, Materials Letters, 2004, 58, 6, 995.]
[5] B. John, C.P.R. Nair and K.N. Ninan, Polymers and Polymer Composites, 2008, 16, 431.
[6] E.M. Wouterson, F.Y.C. Boey, X. Hu and S-C. Wong, Polymer, 2007, 48, 11, 3183.
[7] C.S. Karthikeyan and S. Sankaran, Journal of Reinforced Plastics and Composites, 2000, 19, 9, 732. , 20, 11, 982.
[8] R. Maharsia and H.D. Jerro, Materials Science and Engineering A, 2007, 454–455, 416.
[9] K.S.S. Kumar, C.P.R. Nair and K.N. Ninan, Journal of Applied Polymer Science, 2008, 107, 2, 1091.
[10] C.S. Karthikeyan, S. Sankaran, M.N.J. Kumar and Kishore, Journal of Applied Polymer Science, 2001, 81, 2, 405.
[11] C.S. Karthikeyan and S. Sankaran, Journal of Reinforced Plastics and Composites, 2001
[12] E.M. Wouterson, F.Y.C. Boey, S-C. Wong, L. Chen and X. Hu, Composites Science and Technology, 2007, 67, 14, 2924.
[13] Y-J. Huang, L. Vaikhanski and S.R. Nutt, Composites Part A: Applied Science and Manufacturing, 2006, 37, 3, 488.
[14] R. Maharsia, N. Gupta and H.D. Jerro, Materials Science and Engineering A, 2006, 417, 1–2, 249.
[15] E.M. Wouterson, F.Y.C. Boey, X. Hu and S-C. Wong, Polymer, 2007, 48, 11, 3183
[16] B. John, C.P.R. Nair and K.N. Ninan in Proceedings of Recent Advances in Polymeric Materials, MACRO 2009, IIT, Chennai, India, 2009.
[17] Dung D. Luong , Oliver M. Strbik , Vincent H. Hammond, Nikhil Gupta , Kyu Cho “Development of high performance lightweight aluminum alloy/SiC hollow sphere syntactic foams and compressive characterization at quasi-static and high strain rates” Journal of Alloys and Compounds 550 (2013) 412–422.
[18] L.C. Zou , Q. Zhang , B.J. Pang , G.H. Wua, L.T. Jiang , H. Sua “Dynamic compressive behavior of aluminum matrix syntactic foam and its multilayer structure” Materials and Design 45 (2013) 555–560.
[19] Imre Norbert Orbulov “Metal matrix syntactic foams produced by pressure infiltration—The effect of infiltration parameters” MaterialsScience&EngineeringA583 (2013)11–19.
[20] Michele Colloca, Nikhil Gupta, Maurizio Porfiri” Tensile properties of carbon nanofiber reinforced multiscale syntactic foams” Composites: Part B 44 (2013) 584–591.
[21] Imre Norbert Orbulov, Kornél Májlinger “Description of the compressive response of metal matrix syntactic foams” Materials and Design 49 (2013) 1–9.
[22] Players Bawl over Ball, BBC Sport, London, UK, 2002. http://news.bbc.co.uk/sport3/worldcup2002/hi/other_news/ewsid_2001000/2001924.stm