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Specific properties and fracture toughness of syntactic foam: Effect of foam microstructures

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Abstract

Studies were performed on the specific strength, moduli and fracture toughness of varied microstructures of syntactic foam. The different microstructures were created by using three different types of microspheres, namely 3M Scotchlite™ K15 and K46 glass bubbles, and Phenoset BJO-093 hollow phenolic microspheres, and by changing the volume fractions of microspheres from 0 to 50 vol%. Tension, compression, flexural and fracture tests were performed. Results showed that the tensile and flexural strengths decreased with increasing filler content. The behavior of the tensile and flexural strength was not affected by the component microspheres. Interestingly, the tensile and flexural moduli showed different trends for each type of microspheres with increasing filler content. Results of the compression tests revealed superior behavior of the high density microspheres. The specific fracture toughness data yielded maximum values at 30 vol% for each type of microspheres investigated. Scanning electron microscope studies were performed to determine the failure mode for each loading condition.

Keywords: Syntactic foam; Mechanical properties; Fracture toughness

1. Introduction

Syntactic foam is a ternary material system made in a mechanical way by mixing hollow particles (the filler) with a resin system (the binder). The hollow particles may be made of polymer, ceramic, carbon, or metal. Most often thermoset resins are used as the binder. Dispersion of the hollow particles creates a porous material with closed cells. By changing the amount of hollow filler particles, different densities and thus microstructures of syntactic foam can be created. Syntactic foams are known to possess low density, high stiffness, excellent compressive and hydrostatic strength, and good impact behavior [1–6]. Unlike most other foams, syntactic foam is a material whose density before curing is the same as that after curing. Such predictability is advantageous in the manufacturing process in aerospace structures.

Using hollow particles, having a lower density compared to the binder material, allows for the manufacturing of light-weight materials with the increase of the filler content. This type of syntactic foam with a filler density that is lower compared to the binder can be considered as a special type of particulate-filled polymer composite (PFPC). Generally, the weight of a PFPC increases with increasing filler content as solid filler particles are most often used. The mechanical and fracture behaviors of the PFPC were studied extensively [7]. The moduli and fracture properties often improve with increased solid filler content, given an intrinsically brittle matrix system and good interfacial bonding between the filler and the matrix.

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Most studies on the mechanical and fracture properties of syntactic foams are based on the maximum filler content of microspheres as this elicits the lowest possible weight of the composites [1–3]. This study investigates the influence of different compositions of syntactic foam on its specific mechanical and fracture properties. A comprehensive understanding of the structure–property relationship is lacking. Different compositions will be created by varying the type and volume fraction of microspheres. This route is different from that reported by Gupta et al. [4] whereby different microstructures were created by using different types of microspheres with similar size distributions. However, only the volume fraction of microspheres was kept constant for each type of microspheres. Bunn and Mottram [5] also reported on the effect of the volume fraction on phenolic microspheres on the compressive properties. The present paper compares the results derived from phenolic microspheres to those made of glass shells. It is expected the interfacial adhesion between phenolic microspheres and polymers could be stronger.

It is essential that specific properties be discussed in this paper because the density of syntactic foam changes with the amount of microspheres introduced. Specific properties allow for the comparison of the performance of syntactic foams to other potential foam materials in sandwich composites such as PU, PVC and aluminum foams. Furthermore, specific properties aid the comparison between the different microspheres used in this study. By normalizing mechanical and fracture properties against the density, it is believed the results would be fruitful for guiding future design for syntactic foams based on specific properties. Results from tension, compression, flexure and fracture tests will be discussed in relation to their microstructures.

2. Experimental work

2.1. Materials and equipment

The syntactic foams for this research were produced by mechanical dispersion of hollow microspheres in epoxy resin. Three different types of hollow microspheres, namely 3M Scotchlite™ Glass Bubbles K15 and K46 and Phenoset BJO-093 phenolic microspheres were used for the filler. Properties of the different types of microspheres are listed in Table 1. The values for the mean diameter were obtained with a Fritsch particle size analyzer. The values presented are an average of three measurements. The values for the average wall thickness were calculated based on the true density of the microsphere, the density of the microsphere wall material and the mean sphere diameter. The two types of hollow glass microspheres were chosen to study the possible differences in mechanical behavior between low and high density hollow glass microspheres with an increasing volume fraction. The phenolic microspheres were also investigated to examine any effects arising from the different nature and interfacial adhesion between filler and binder. Although the microspheres exhibit different material parameters, it is reasonable to examine the specific properties, which can be quantified and compared readily. In this paper, we address other material parameters, which form complex interactions with the mechanisms of failure and fracture, qualitatively.

For all the specimens Epicote 1006 epoxy resin was used as the binder. Epicote 1006 is a combination of liquid bisphenol-A, epichlorohydrin epoxide resin, amine and polymeric additives. The microspheres were added to the epoxy while slowly stirring the mixture to minimize gas bubbles in the resin. The microspheres were added in multiple steps to the epoxy resin to avoid agglomeration. Due to the low density of the microspheres compared to the binder, the microspheres showed a tendency to float to the top surface. This effect was minimized by stirring the mixtures close to the gel time of the resin, which was about 60 min for the epoxy. Scanning electron microscope (SEM) photomicrographs confirmed the homogeneity of the syntactic foam. After dispersion, the syntactic foam was compression molded using an aluminum mold coated with a silicone release agent. The syntactic foam was left under the press at a pressure of 1.6 MPa for 18–22 h to cure at room temperature. By adding different amounts of microspheres to the matrix, syntactic foams with various densities were thus created. Fig. 1 illustrates the general microstructure of syntactic foam.

Fig. 2 shows the measured densities of syntactic foams with increasing hollow microsphere content. The measured densities presented in Fig. 2 are an average of about 30 samples. The density was measured by

Table 1
Physical properties of the studied microspheres

Type of microsphere	True density (g/cc)	Static pressure (MPa)	Mean diameter (μm)	Average wall thickness (μm)	Thickness-to-radius ratio
BJO-093	0.25	3.44	71.5	1.84[b]	0.052
K15	0.15	2.07	70[a]	0.70	0.02
K46	0.46	41.37	43.6	1.37	0.063

[a] From [17].
[b] From SEM measurement.