PMMA Syntactic Bimodal Foams with CO_2-Philic Octatrimethylsiloxy POSS Cell Nucleators

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Bimodal PMMA foams are produced with a new method combining syntactic foam production and supercritical CO_2 ($scCO_2$) foaming. Bimodal pore structure offers several potential advantages to foam properties, such as reduced mass density and excellent thermal and sound insulation properties. To produce the foams, first PMMA composites are produced with hollow glass microspheres (HGMs) and octatrimethlysiloxy POSS nanoparticles using a twin-screw extruder. The composite syntactic foams are then processed with $scCO_2$ to form bimodal pore structured PMMA-HGM-POSS composite foams. Highly CO_2-philic POSS nanoparticles contribute to $scCO_2$ foaming as cell nucleators enhancing the foaming performance and pore density of the syntactic composites, while the large pores growing from the voids between the matrix and HGM surfaces lead to formation of the bimodal foam matrix. The effects of process pressure (11 MPa, 22MPa), time (2 h, 24 h), and concentration of HGMs (5%, 15%) and POSS nanoparticles (0%, 5%) on the foam morphology are studied, while the temperature and the venting rate are kept at 35 °C and 0.28 MPa/s, which provided the smallest average pore diameter (D_{avg}) and highest pore density in the $scCO_2$-processed PMMA-POSS composites in previous studies.

The syntactic foams processed with $scCO_2$ at the lower pressure (11MPa) have only large pores with D_{avg} of 15 µm. Incorporation of POSS nanoparticles leads to formation of smaller pores with D_{avg} range of 0.1-1 µm. Among all the produced foams, the specimens with the smallest average pore diameter of 0.1 µm and highest pore density of 6.14 x 10^{13} cm^{-3} are obtained by processing the PMMA-HGM-POSS composites with 5wt% HGM and 5wt% POSS at 11 MPa. The foam densities were about 50% lower than those of the bulk composites. HGMs contribute to foaming with two opposite effects; one of them is their barrier effect and the other is associated with the voids between the HGMs and the polymer matrix. The dominance of their contribution is highly influenced by the process pressure. Increasing the concentration of HGMs in PMMA-POSS matrix at 11 MPa increases the average pore diameter and decreases the density of the smaller pores indicating that their barrier effect is dominant at this pressure, which hinders the rapid diffusion and escape of CO_2 from the polymer, leading to the coalescence of the pores. At 22 MPa, on the other hand, the enhanced transport of CO_2 due to the voids between HGMs and the matrix dominates the foaming performance. At this pressure, which corresponds to a higher concentration of CO_2 solubilized in the matrix, increasing the concentration of the HGMs allows the rapid transport of the gas during depressurization due to the increased number the voids between the HGMs and the matrix. This suppresses the pore coalescence and decreases the average pore diameter. These results show that the indirect relationships between the morphology of the PMMA-POSS-HGM composite foams and certain parameters such as the processing pressure and concentrations of POSS and HGM allow the control of the composite foam morphology.

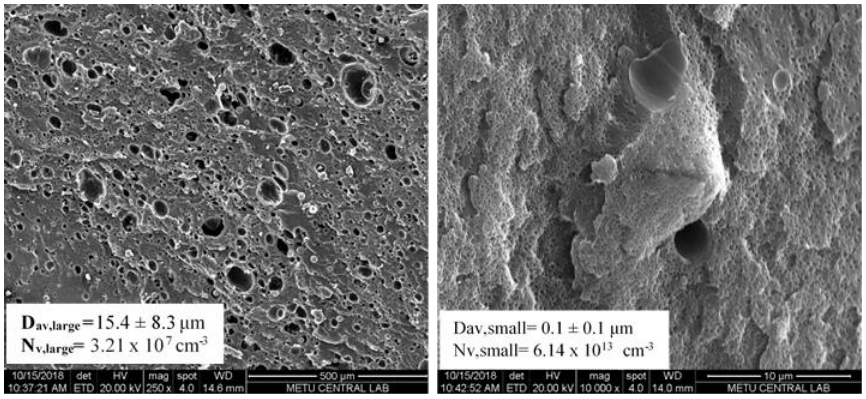

Figure 1. SEM images of the PMMA-5%HGM-5%POSS composite processed at 35 °C, 11 MPa for 24 h, and depressurized at 0.28 MPa/s.