Nucleation and Growth Mechanisms Underlying the Microstructure of Polymer Foams Produced by Dynamic Decompression and Cooling

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Abstract

The control of the microstructures of lightweight polymers, polymer blends, polymer-metal composites, and amorphous metals depends in large part on the procedures by which these materials are created and on an understanding of the nucleation and growth mechanisms underlying these procedures. We are further developing a novel approach for producing lightweight, foam structures — Dynamic Decompression and Cooling (DDC) — and using this approach for systematically providing data to new models for the underlying nucleation and growth mechanisms.

DDC involves heating and mixing polymer (and/or other source) materials under pressure in the presence of a volatile phase. Non condensable gas super-pressurizes the mixture. The rapid decompression of this mixture results in the boiling of the volatile phase (aided by the supersaturation of the non-condensable gas), and the cooling of the melt due to latent heat of vaporization of the volatile phase. The result is a solid, open-foam structure of low density possessing microstructures that differ greatly from those commonly found in polyethylene and polypropylene foams commercially available. The reasons for the difference stem from the greatly different nucleation and growth mechanisms as compared to extruded foams.

These mechanisms are shrouded in the complexity of the process. In particular, there are several nucleation and growth mechanisms occurring in a short period of time. Upon decompression, there is supersaturation of the non-condensable gas and superheating of the volatile phase. Bubble nucleation and growth follow, controlled by evaporation of the volatile phase and diffusion of the non-condensable phase. Supercooling of the melt occurs as the volatile phase takes its latent heat of vaporization from the melt. Growth is dependent on transport properties including the temperature-dependent viscosity and heat conductivity. Solidification may or may not involve a latent heat of fusion depending on whether crystallization occurs or an amorphous phase is formed.

In order to understand these nucleation and growth mechanisms, we must be able to vary the operating parameters over a wide range, and we must be able to follow the transient process in detail. Therefore, we shall use high speed video to record the process, which occurs in a fraction of a second, and to instrument the cell to record the time-dependent temperature and pressure in the mixture as it is decompressed. This data will provide input to the theoretical formalism, and will complement post-analysis data ranging from mechanical testing to electron micrographs and x-ray diffraction. We shall document the conditions at which the structure of foams changes from closed cell to open cell, and we shall correlate microstructure with nucleation and growth mechanisms.

The microgravity environment may aid in providing idealized conditions for such tests. In particular, phase separation, and layering and stratification effects are minimized so that

uniform initial states can be achieved prior to decompression. Also, non-uniform heating produces convective effects that are absent in zero-g, allowing for the study of transient processes and the resulting foams, which should be isotropic. These considerations are especially important when considering polymer blends and polymer-metal composites intended for high temperature applications (e.g., significantly above 200 °C) because of phase separation and density stratification effects. Ground-based studies will provide a baseline for future microgravity work.

Examples of the polymer foam structures produced by DDC and tentative models for rationalizing the observations will be presented at the conference.