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ORIGINAL PAPER

Open-celled microcellular foaming and the formation of cellular structure by a theoretical pattern in polystyrene

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Abstract An open-celled structure was produced using polystyrene and supercritical carbon dioxide in a novel batch process. The required processing conditions to achieve open-celled structures were predicted by a theoretical model and confirmed by the experimental data. The theoretical model predicts that at least a saturation pressure of 130 bar and a foaming time between 9 and 58 s are required for this system to produce an open-celled structure. The foaming temperature range has been selected to be higher than the polymer glass transition temperature yet not higher than a temperature limit where the gas starts leaving the system. The experimental results in the batch foaming process verified the model substantially. The SEM pictures showed the presence of pores between the cells, and the mercury porosimetry test results verified the overall open-celled structure. Experimental results also showed that by increasing the saturation pressure and the foaming temperature, there was a drop in the time required for open-celled structure formation. At saturation pressure of 130 bar, foaming temperature of 150 °C and a foaming time of 60 s, open-celled microcellular polystyrene foams were obtained using supercritical CO_2 in the batch process. Based on the results, a schematic diagram, depicting the process of foam structure formation from nucleation to bubble coalescence and gas escape from polymer, was proposed. Theoretical calculations showed that by increasing foaming time, cell size was increased and cell density was reduced and the experimental results verified this prediction.

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Introduction

Polymeric foam is a composite of polymer and gas bubbles or cells [1]. An open-celled structure is defined as a structure in which cells are inter-connected throughout its bulk [1]. In open-celled foam processing, it is desirable to produce opened cell structures in such a way that the cells maintain their distinctive overall cellular shape without coalescence (Fig. 1). In this way, the mechanical properties of the open-celled foams are maintained. By maintaining the cell shapes, each cell must be interconnected to the adjacent cells through cell wall openings or pores. Microcellular foams, as initially described by Suh et al. [2–4], displayed superior mechanical properties as compared to foams produced by other traditional foaming methods. The term "microcellular foams" are mainly used for foams that have a uniform cell size in the order of 10 μm and bubble densities higher than 10^9 cells/cm^3 [4]. This definition is still being debated because it is difficult to relate the properties of polymer foams directly to the cell size and cell density. In general, a microcellular foam is defined by a cell size between 1 and 300 μm with its cell density higher than 10^8 cells/cm^3 [5–8].

Open-celled polymeric foams, due to interconnections between their cells or bubbles, have the ability to allow fluids pass through their structure. So, these foams can be used as membranes and/or filters in separation processes. Traditional open-celled foams are structurally weak due to their opened cell walls. Their mechanical strength is improved significantly by microcellular foaming due to