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A novel foaming method for fabricating microcellular injection-molded parts

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Water vapor represents a new kind of physical blowing agent for the fabrication of foamed-polycarbonate parts with a smooth surface finish.

In the microcellular-injection-molding process, supercritical fluids (SCFs, usually nitrogen or carbon dioxide) are typically blended with polymer melts in the injection-molding machine barrel. The resultant single-phase polymer/gas solution subsequently foams during the injection-molding stage, leading to the production of lightweight microcellular injection-molded parts.[1,2] Compared to the development of solid parts, this fabrication process can be conducted at lower processing temperatures and pressures, leading to a reduction of the required clamp tonnage, cycle time, and energy consumption.[3,4] Additionally, cell growth throughout the entire part leads to uniform packing, thereby reducing the residual stress and improving the dimensional stability.[5,6]

The benefits of this technology do, however, come with some limitations. Notably among these, the equipment costs are higher, and the produced parts have rougher surfaces and lower mechanical properties compared with solid injection-molded parts. Microcellular injection-foamed parts tend to have surface finishes with swirl marks and silver streaks due to the stretching and collapsing of nucleated cells (bubbles) on the part surface. These features limit their application.[1–7]

We have developed a new microcellular injection-molding technique that employs water vapor (W) as the physical blowing agent.[6] This technique has the potential benefit of reducing equipment costs by eliminating the need for dedicated SCF generation and injection systems.

We used two kinds of nucleating agents—cubic sodium chloride (NaCl) and non-uniform active carbon (AC)—to produce vapor-foamed polycarbonate (PC) parts. The PC-NaCl-W parts were produced via a typical injection-molding machine, with the addition of a valve and meter mounted on top of the barrel hopper. These devices allow the water (or 2wt% water/salt solution) to be dispersed and enable control over the feed rate (0.5ml/min).[8] Because the AC cannot

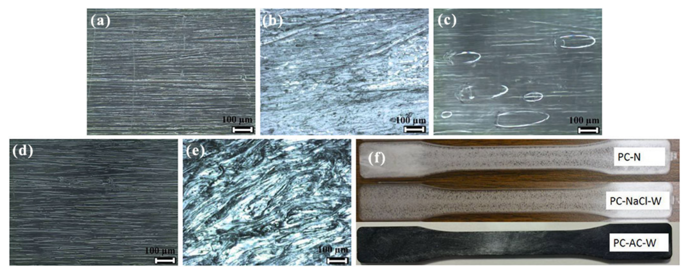

Figure 1. *3D surface images, obtained via scanning electron microscope (SEM), of polycarbonate (PC) injection-molded samples with active carbon (AC) and cubic sodium chloride (NaCl) used as nucleating agents. We fabricated solid parts (S) and foamed parts, in which nitrogen (N) or water (W) were used as blowing agents. (a) PC-S, (b) PC-AC-S, (c) PC-N, (d) PC-NaCl-W, and (e) PC-AC-W. (f) Picture of foamed parts. Scale bars: 100μm.*

be dissolved in water as a salt, we compounded solid batch pellets via a twin-screw extruder in the parts incorporating AC (PC-AC, 0.5wt%). Water, acting as the blowing agent, was carried by the AC instead of directly dispensed. To enhance the water-absorption capability of the PC-AC pellets, we immersed them in an ultrasonic tank of water and then dried them at ambient temperature prior to the injection-molding process.[7,8] Compared with their solid counterparts, the foamed parts have an average weight reduction of 6–16%. It has been reported that water could also be employed as a blowing agent during the extrusion foaming process.[9]

We achieved the most desirable surface finish in the water-foamed PC-NaCl-W parts, in which 0.5wt% NaCl was used as the nucleating agent. Their finish is better than that of typical foamed parts in which nitrogen is used as the blowing agent (see Figure 1). The rougher surface characteristics of PC-N parts occur mainly due to gas escaping from the PC-nitrogen solution, leading to bubbles that are trapped, collapsed, and stretched at the melt front. The PC-AC-S and PC-AC-W samples also have relatively rough surfaces due to the appearance of

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AC powders. However, unlike nitrogen, water does not emerge from the polymer melt quickly. This results in a slower cell-nucleation rate and thus a reduced number of cells at the melt front. Even when vapor cells are formed at the advancing melt front and subsequently come into contact with the mold wall (at 85°C), they condense at the mold interface, forming a lubricating layer that helps to reduce surface roughness. The phase change also induces a large volume contraction in the cells—in contrast to cells filled with nitrogen, which stay in gaseous form—thereby further minimizing any visible surface defects.

The fabricated foamed parts have varying cell structures (i.e., cell size and cell density). Vapor-foamed PC-AC-W parts possess smaller cells than the PC-N and PC-NaCl-W parts (see Figure 2). The smaller cell sizes are attributed to high amounts of low-density AC powder serving as a nucleating agent, even at the same weight concentration as NaCl. These tiny uniform cell structures help to maintain the foamed parts' mechanical properties. In general, the foamed parts have comparable tensile properties, whereas PC-AC-W foamed parts exhibit relatively higher strengths and Young's moduli.[6] Furthermore, high temperature and moisture levels during processing are potential causes of thermal or hydrolytic degradation of the PC. The reductions in the average molecular weight of PC-AC-W (7.2% reduction compared with solid injection-molded PC-S parts) are comparable to that caused by normal melt processing.

Using water vapor as a physical blowing agent offers a novel foaming method for fabricating microcellular injection-molded PC parts. The water foaming process can be achieved using typical injection molding setups, without the extra requirement of SCF units. In contrast to typical microcellular injection-molded parts, water-vapor-foamed PC-NaCl parts have a smooth surface, comparable to that of solid parts. On the other hand, foamed PC-AC has desirable specific mechanical properties as well as an attractive average weight reduction of 16.4wt%, but with a rougher surface. We were also able to improve the microcellular structure by using low-density and non-uniform AC particles as nucleating agents and reinforcements. In the next stage of our research, we will focus on fabricating injection-molded foamed parts using multi-functional nucleating agents, with the aim of achieving desirable microcellular structures, mechanical properties, and surface appearances.

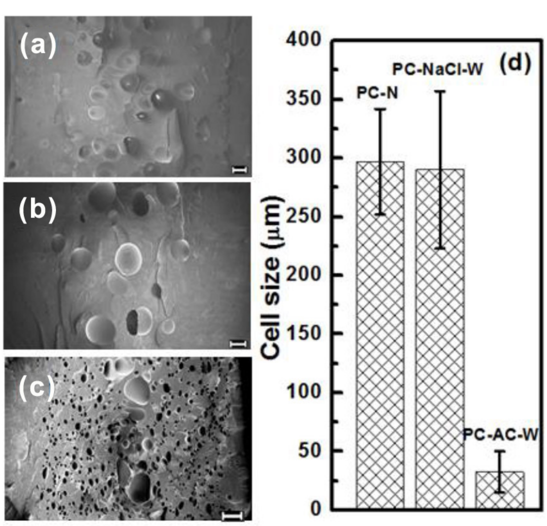

Figure 2. SEM images of the fractured surface: (a) PC-N, (b) PC-NaCl-W, (c) PC-AC-W, and (d) their cell sizes. Scale bars: 200μm.

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