From Cellular to Microcellular Foam

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The concept or the technology of microcellular thermoplastic foam appears to be an interesting extension of the cross-linked polyethylene foam. Nonetheless, its advantages and recent developments have spurred many commercial uses. Given the uniqueness of the technology, the breadth of application is continuing to grow and the future has practically no limits.

A Bit of History

Microcellular thermoplastic foam came to the public in the eighties from MIT1, unique in its cell size (100 - 101 microns) to differentiate from the conventional cellular products with cell size ranging from 102 to 104 microns. It employs inorganic physical blowing agent in its super critical state to create a swarm of bubble in the polymeric matrix. In the midst of ozone depletion concerns, it soon caught public's attention and support. In ten years, it moved from batch mode to continuous process. When Trexel is formed to bring this microcellular thermoplastic foam or Mucell technology to plastics industry, it was clearly focused on the material instead of the product. It turned out to be a clever approach in licensing the Mucell technology to equipment suppliers as well as foam producers, quite promising in bridging the gap between polymeric materials and polymeric foam products2.

The Advantages

The unique features of microcellular foam (MCF) are fine cell size, high cell density, inorganic blowing agent, and no nucleating agent. Since the cell is very fine, without careful attention, MCF may be taken as a plastic material rather than a cellular product.

When cell is reduced to micron range without using nucleating agent, decreased convection in the cell and less open cell make a uniform structured product with better insulation characteristics. Some mechanical properties, especially propagation related; such as: notch and fatigue, appeared superior to the parent plastic material. It was attributed to cell as propagation absorber. Conventional polymeric foam is known for its high performance/weight ratio, which increases as cell size decreases and cell integrity improves. This evidently enlarges property spectrum3.

Mechanisms

Foaming is a phase separation phenomenon governed by thermodynamic-driven kinetics. A common practice is to establish a positive super-heat, or supersaturation, that volatile phase tends to conglomerate into spherical gas bubbles. In general, saturate with gas, then apply vacuum or heat, or both, to induce thermodynamic instability. Bubbles appear. In the eighties, MIT tried carbon dioxide in the super critical state to polystyrene first, owing to its amorphous structure and favorable Tg4, then to various semicrystalline polymers to obtain the microcellular foam. In contrast, traditional cellular foam technology controls nucleation via nucleating agent5, whereas MCF by super critical carbon dioxide, which, namely, plays a dual role; blowing agent and nucleating agent6.

X-linked PE foam producers tempted compounding chemical blowing agent (CBA) into PE, and X-linking first to enhance polymeric strength, and then decompose the CBA to liberate nitrogen to form cellular structure. The less the expansion, the finer the cell. Fewer than ten times expansion, ten microns or under can be achieved. At thirty times expansion, the cell is in the hundred microns.

Cellular vs Microcellular

The conventional cellular foam (i.e. cell size in mm) is generally blown with non-volatile hydrocarbon blowing agent as opposed to microcellular foam with volatile carbon dioxide or nitrogen. The latter is characterized by aggressive, highly nucleated, and limited expansion in contrast to the former less aggressive, lowly nucleated, and large expansion. It was also noted that the cellular nucleation is heterogeneous in nature (i.e. adding nucleating agent), and microcellular homogeneous (i.e. without nucleating agent). Microcellular foam contains 108 cells/cm3, and cellular foam around 104 - 106 cells/cm3.

The aggressive expansion in microcellular makes the polymeric strength very critical in maintaining cell integrity, even more so in continuous extrusion, cell coalescence becomes otherwise inevitable. Thick cell wall is thus very necessary, and that lays the expansion limit to around ten times, whereas the cellular foaming can achieve over fifty times expansion. Saving materials can justify the material handling investment, therefore, cellular foam is still quite popular in the market.

However, when expansion reduces to 30 to 70% weight reduction, about two to three times expansion, quite a few polymers are qualified for processing and foaming. It became a great opportunity for engineered polymer, where material saving is rather substantial. Nylon, ABS, PC, and filled PP are good examples in MCF injection molding7. Publications in methods and technologies can be found in references6,7.

From Pilot to Commercialization

Pilot extrusion results were presented in the nineties. Trexel was formed to take over commercialization. However, consistence in commercial-scale polystyrene MCF extrusion became a concern. In the late nineties, efforts were then shifted to low expansion injection molding with special SCF injection design to render fine cell possible. Excellent cell integrity made unique features over gas-assisted injection molding technology. Other benefits were quite substantial: less tonnage, less cooling time, less residual stress, less warpage, less shrinkage…etc. Combining the processing and material saving benefits, licensing agreements soon expanded into international mode8. In December 2003, some interesting papers were presented in the Polymer-Supercritical Fluid Systems and Foams conference held in Japan9. More recently, plastics machinery manufacturer of Japan (Kawata Mfg. Co., Ltd., Osaka) developed a microcellular foam (MCF) extrusion process for biodegradable polylactic acid (PLA) resin. Kawata's MCF process is claimed to provide controllable expansion of up to 40 times.

Current Trends

Trexel has been working in quite a few fronts to advance this technology, especially in injection molding license, hoping to establish a solid material technology. Institute of Plastics Processing (IKV, Aachen, Germany) is committed to make specially designed injection unit for MCF injection molding10.

Lately, Univ. of Toronto formed a consortium for Cellular and Microcellular Plastics, focusing on extrusion, injection molding, and fundamental concepts. Univ. of Wisconsin and Ohio State Univ. are sponsored by National Science Foundation (NSF) to explore the application possibilities for nano particle induced MCF. Other institutes, such as: Kyoto Univ. in Japan, Washington Univ..… are trying to expand the MCF application spectrum.

Predictions or Future Realities

When nano-particle becomes a great topic in enhancing polymer's mechanical property, it is a natural combination into microcellular foam. Nano particle could be an ideal nucleating agent, and even dispersion can generate interfacial volume as nucleus for microcellular morphology. This nano-microcellular polymer could be a great product with an impressive performance/weight ratio; excellent physical, mechanical and thermal properties.

The other challenge is to explore the finest cell size, highest cell density, and MCF density. Is nano-cellular possible? It will then be a pure material development. Let's keep our eyes and ears open.

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