Microcellular HDPE Foam for Extruded Pipe and Tubing Applications

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Abstract

Thermoplastic HDPE has found widespread use in pipe and tubing applications due to its low cost, good physical characteristics, and ease of manufacturing. In particular it is used in applications for electrical conduit, chemical transport as well as potable water, irrigation and sprinkler systems. As with many plastics materials, cost and environmental concerns have put pressure on producers to reduce material usage through foaming, but HDPE has been difficult to foam using conventional processes and materials. Trexel has developed a microcellular foam process that is capable of foaming standard grades of HDPE while retaining excellent physical properties and surface quality. This unique process provides a means by which pipes and tubing can be made with weight reductions up to 30% while maintaining the necessary stiffness and high quality surface required for most applications.

Market

Advances in technology have allowed plastics to displace steel, copper, concrete and other non-polymeric materials in the pipe, conduit, and tubing industry. The plastic pipe market is currently valued at $5 billion and is projected to grow to about 33% of the total US pipe and conduit market by 2003. The global market demand for plastic pipe and conduit is projected to grow to about 39% by 2003. Developing countries in Asia, Central America and South America will generate much of this growth. In the developed nations, additional demand will come primarily from the use of plastic conduit in the telecommunications and electrical markets. HDPE is a critical material in these applications.

Background

One approach employed to meet the demand for reduced part weight is the application of foam technology.

Conventional foam processes can utilize either chemical or physical blowing agents to create the cellular structure. Both of these conventional foaming techniques however, have typically produced unsatisfactory results in HDPE with the primary difficulty being large cell size and insufficient control of foam uniformity. This has resulted in poor mechanical properties, poor surfaces and processing issues. In many respects, HDPE is considered non-foamable.

Microcellular foam technology overcomes the difficulties experienced with conventional foam approaches. Microcellular foams (licensed by Trexel under the registered trademark MuCell®) have a substantially smaller and more uniform cell structure than conventional foams. With cell sizes typically less than 50 microns, microcellular foams offer excellent mechanical properties and surface appearance. MuCell foams are made using supercritical fluids (SCF) of atmospheric gases such as either CO_2 or N_2 and standard grades of polymer resins, requiring no special or costly additives or polymer modification. They are easily recycled.

MuCell microcellular foams were invented in the Polymer Processing Laboratories of the Massachusetts Institute of Technology (MIT) under the direction of Dr. Nam Suh in response to the challenge of reducing the amount of material used in plastics products without sacrificing the physical properties. Dr. Suh's concept was to create a foam material with very small cell size in order to achieve better physical properties at reduced product weight.

Experimental Set-up

There are four basic steps in the extrusion of microcellular products. The first step is to feed, melt and meter the polymer in the extruder. In step 2, a supercritical fluid (SCF) blowing agent is introduced into the polymer melt and thoroughly mixed into the molten polymer to form a single phase solution.   The SCF is introduced through the barrel of the extruder utilizing specially designed injector ports to insure complete and uniform mixing. The third step is to cool the polymer/SCF solution to an appropriate extrusion temperature in the last stage of the extruder and just prior to the extrusion die. The final step is to extrude the mixture through a die which has been designed with a flow path that causes a rapid pressure drop in the melt, creating a large number of cells to nucleate in the extrudate and forming a microcellular foam.

To convert a typical extrusion line from solid operation to microcellular foam requires a screw designed to carry out steps one through three, a barrel modified with holes and the specialized injectors and die tooling designed to provide the required pressure drop rate for microcellular formation. In addition, an SCF pump and metering system is required to deliver specific and controlled amounts of SCF through the injectors.

Single, tandem and twin-screw extruders have all been successfully retrofit and utilized for microcellular extrusion processes. This work has been done on several different single screw extruders, ranging from 2 ½ inch to 4 ½ inch diameter, with typical L/D ratios of 34:1. The lines were outfitted with a Trexel designed screw and injection system for the introduction and mixing of the SCF.

The heads used for these trials were standard annular tube heads employing a spider design distribution system. The flow path through the head was designed to the rules required to create microcellular foam structures.

Materials used in these trials have all been commercial grade HDPE's. Fractional melt index wire and cable, extrusion, film and blow molding grades with melt flow indices ranging from 0.14 to 0.70 gm/10 min. and specific gravity's from 0.952 to 0.960 gm/cc have all been used successfully. Both supercritical CO_2 and N_2 have been used as blowing agents.

Results

The microcellular foaming process has been successfully used to foam standard HDPE material grades. Microcellular HDPE foam tubes and pipes with diameters ranging from 1.0 to 2.5 inches at wall thickness up to 0.150 inches have been extruded. Outputs up to 400 pounds/hour have been achieved. The average cell sizes of the foams have ranged as low as 15 microns. Density reductions of up to 50% have been achieved.

Figure 1 shows a photograph of a 2 inch OD x 0.050 inch wall HDPE tube foamed to a 43% density reduction using the MuCell microcellular foam process. The pipe was produced using standard vacuum sizing equipment at an output of approximately 275 lb/hr. The SCF blowing agent was CO_2. This pipe is free of pinholes and has excellent surface appearance

Figure 2 is a photomicrograph of the microcellular tube shown in Figure 1. The cells are uniform across the sample and have little interconnectivity. The density of this sample is 0.54 gm/cc, a density reduction of 43% from the original HDPE polymer.

Foam density in the tubes is uniform through out the thickness of the tube and can be controlled to different levels, depending on application need, by controlling the extrusion process parameters. Figure 4 shows how foam density varies with blowing agent level.

HDPE tubes made by this process have shown excellent retention of physical properties. Figure 3 shows the ring stiffness of tubes as a function of the linear weight of the tube. Ring stiffness was measured by cutting a 1 ½ inch wide ring from the 2 inch diameter tube and compressing them between parallel plates in an Instron test system. A crosshead speed of 0.50 in/min. was used.

The line labeled “solid” shows the measured weight and stiffness of HDPE tubes that were not foamed. The line labeled “linear 43%” is the calculated stiffness versus weight of a tube made from HDPE foamed to a density reduction of 43%. To do this calculation, it was assumed that the modulus of the foamed HDPE material is 0.57 times the modulus of solid HDPE, or a “linear” reduction of modulus due to foaming. The dashed line labeled “quadratic” is the calculated stiffness based on an assumption that the foamed modulus is 0.325 times the solid modulus, or a “quadratic” assumption. For both of the calculated lines, the formula for stiffness was:

$K = f E t^3$ where K = stiffness
E = modulus of the foamed material
t = thickness of the tube

It is common for conventional foams to exhibit a quadratic reduction in modulus with foam density.

The circles represent data from HDPE pipes made with a density reduction of 43%. It is apparent from the data that these microcellular foams exhibit a linear modulus relationship with foam density, and not the quadratic of conventional foams. At a stiffness of 1.25 lb/in the MuCell microcellular foams show a reduction in linear weight of 26% over the solid with the same stiffness.

This dramatic decrease in tube weight while maintaining stiffness equal to the solid has a tremendous economic impact on the cost of materials. For example, at a production rate of 350 lb/hr for a 7 day per week operation, material savings can be as high as 600,000 pounds. This translates to a yearly savings of more than $335,000 for HDPE at $0.50 per pound.

Conclusions

The microcellular extrusion process is able to foam standard grade HDPE in a high production rate process. Tubes and pipes can be made in a variety of diameters and thickness' using common HDPE grades. Foam density is uniform and can be controlled through control of the blowing agent. Foam densities as low as 0.52 gm/cc or a density reduction of 44% from solid HDPE have been achieved.

The reduction of modulus in these foams has been demonstrated to be linear with density reduction and is significantly better than normally achieved with conventional foaming processes. As a result of the excellent property retention of these microcellular foams, the density reduction can be translated to substantial weight savings while maintaining critical stiffness and appearance properties of the extrusions. A 43% foamed density reduction translates to a weight savings of 26% at stiffness equivalent to the solid tube.

The microcellular process can be applied to the production of HDPE tubes and pipes to save substantially on the cost of materials while maintaining critical physical properties. Potential applications of this technology include electrical and fiber optic conduit, thin walled tubes and profiles, and drainage pipes.

Figure 1. Extruded Tubes

Figure 2. Photomicrograph

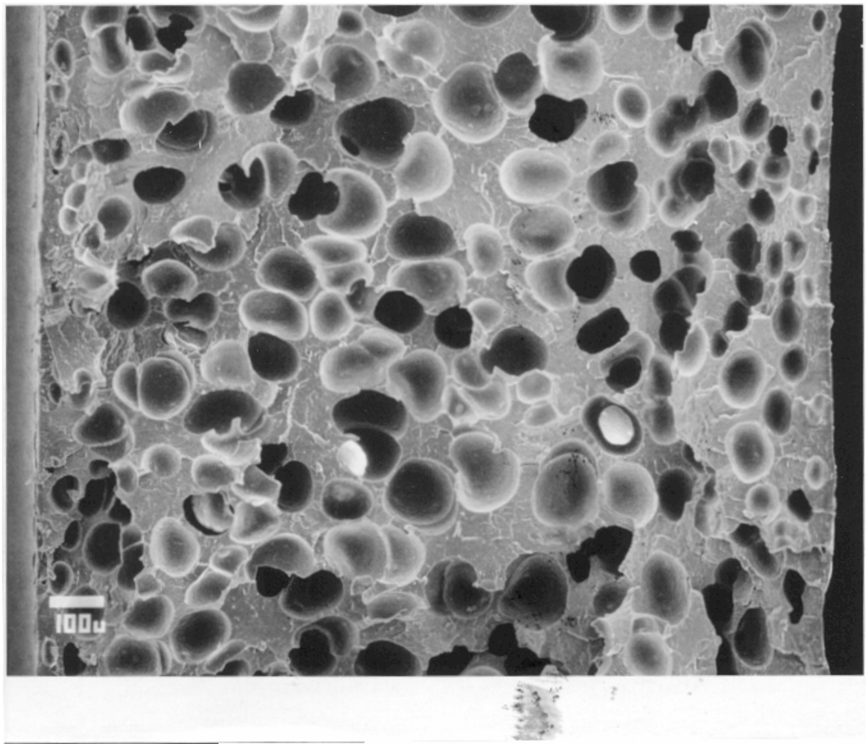

Fig. 3 - Ring Stiffness vs. Pipe Weight

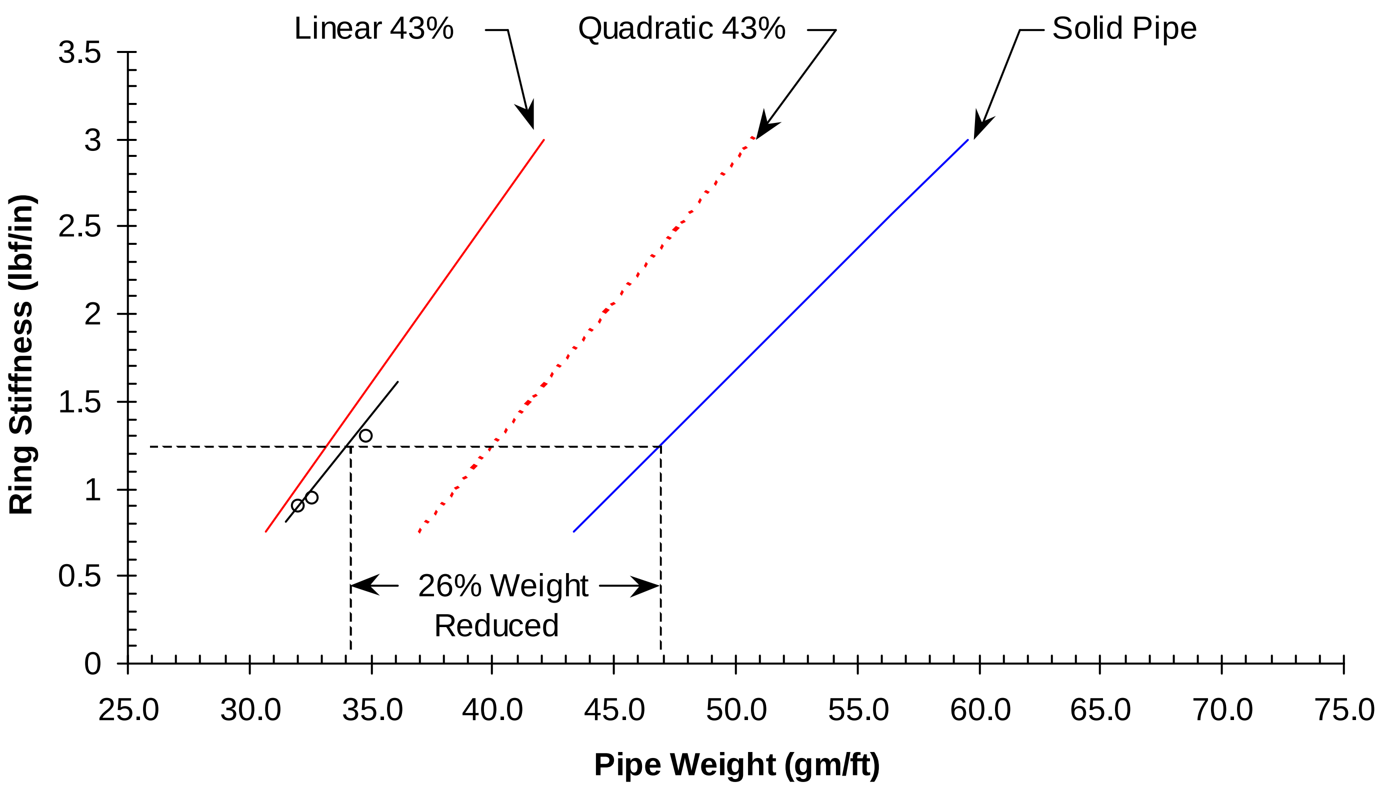

Fig. 4 - Foam Density vs. SCF Concentration