Extrusion of thermoplastic foams

Applications of foamed plastics, include rigid profiles, pipe, food trays, dunnage material, and thermal insulation. Polystyrene (PS) finds the widest application in foamed products but appreciable quantities of Polyvinyl chloride (PVC) and Acrylonitrile-Butadiene-Styrene (ABS) are also produced. All of the common thermoplastics can be foamed using the techniques described below.

When blown to 50 to 60% of their solid densities, ABS, PS and PVC can be formed into rigid cellular profiles or pipe. The advantage here is that a foamed section has a higher section modulus than a solid section of equal weight. This allows foam profiles to compete with wood products such as decorative moldings and pipe products to be stiffened economically.

The most widely used techniques for making these products employs a chemical blowing agent, (CBA) azodicarbonamide, that decomposes at a specific temperature releasing nitrogen gas which inflates the cells. The CBA may be tumble blended with resin pellets but this approach may result in poor foam quality and plate-out on screen packs and die surfaces due to inadequate mixing and dispersion. A better technique is to employ a compound in which the CBA has been predispersed in a compounding extruder at a temperature below the decomposition point of the CBA. Another possibility is to use a CBA concentrate in the same manner as color concentrates are employed. Depending on the melt temperature reached in processing, it may or may not be necessary to use an activator which serves to reduce the temperature at which the CBA decomposes.

A conventional extruder can be used in this process but care must be taken to avoid premature decomposition of the CBA and subsequent loss of the nitrogen through the feedthroat. Best results are obtained by reaching the decomposition temperature in the metering section of the screw and allowing the nitrogen to go into solution in the polymer where it is retained by high pressure acting on the melt. It is necessary to design the die with a steep pressure gradient to maintain high pressure on the melt to prevent premature foaming within the die which results in tearing and rupture of the cell structure. Thin walled sections are easiest to handle and as section thickness is increased the extrusion rate must be increased to maintain the steep pressure gradient.

Foam density is affected by melt temperature through its effects on melt viscosity and gas pressure and by the concentration of blowing agent which is usually about 1%. The general procedure is to operate the extruder to provide a low melt temperature and to slowly increase the temperature until foam is observed forming outside the die. If the melt temperature gets out of control the foam point will move inside the die resulting in destruction of the cellular structure.

Two patented techniques of sizing and cooling the extrudate are employed. In the Gatto process, the part is extruded from an undersized die and allowed to foam outside the die as it enters a water cooled vacuum calibrator which determines the final shape. A skin of high density material can be formed by blowing air on the surface but care must be taken to avoid over-cooling since this will restrain the foaming.

The Ugine Kuhlman process employs a die with an internal mandrel to form a follow extrudate. The outer dimensions of the die orifice are essentially that of the final product and the outer skin is quickly frozen by a water cooled sizing die attached to the hot die. This technique can provide a thick, dense skin while allowing the foam to form in the inward direction filling the internal cavity.

When lower density products are desired, such as packaging and dunnage materials, techniques utilizing liquid blowing agents are employed. The most commonly used liquid blowing agents are pentane and the fluorocarbons Freon® R1 and R12. Pentane may be incorporated into PS in the’ polymerization reactor or in a pressure vessel. Adequate pressure and temperature is maintained to cause the pentane to diffuse into the pellets. The pellets than may be extruded on a conventional extruder to form a foamed product. Two disadvantages of this method are that various levels of pentane are required to manufacture products of different density and the pentane slowly diffuses out of the polymer resulting in limited storage life.

The disadvantages of pre-impregnation can be overcome by using the tandem extruder process. This process utilizes a plasticating extruder where PS along with about ½% of fine particle size talc to act as a nucleating agent is employed. Citric acid with sodium bicarbonate also makes an excellent nucleating system. The extruder is fitted with a port to allow injection of pentane or Freon® R1 or R12 blowing agents into the melt where it goes into solution due to the high pressure and temperature involved. It is necessary to employ intensive mixing to get the blowing agent distributed in the melt and this results in melt temperatures in the range of 425 to 450F. Since these liquid blowing agents have a strong plasticizing action we would find overblowing of the foam, cell rupture and collapse of the cell structure if we would attempt to extrude the foam through a die in this temperature range. A second extruder, one size larger than the plasticating extruder, is used to cool the melt to the range of 265 to 300F depending on the amount of blowing agent used. The melt is transferred under high pressure through piping connecting the two extruders. The second extruder functions primarily as a heat exchanger and its design can be optimized for this purpose since it is independently controlled. The first extruder must be designed to impart relatively high work input to assure good dispersion of the nucleating agent and distribution of the blowing agent. In contrast, the cooling extruder is designed to minimize work input and therefore to minimize the amount of heat which must be extracted through the barrel wall. This is achieved by using a large diameter resulting in reduced screw RPM and by optimizing the channel depth of the screw. As channel depth is increased work input is decreased but the thickness of the layer of polymer to be cooled increases causing poorer heat transfer. At a point determined by the thermal and viscous properties of the polymer, an optimum channel depth is reached. Barrel temperature also goes through an optimum generally in the range of 100 to 130F., since excessively low temperatures raise the melt viscosity increasing work input.

The tandem, direct-injection foam extrusion process is extremely versatile and can accommodate a wide range of polymers and can produce foams ranging in density from 2.5 to 60% of the polymer density.

- Leonard F. Sansone

See also:

- PVC testing
- Structural changes in PVC due to extrusion
- Volume reduction

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