

Square One – Polymer Selection-Orientation^{1,2}

In the last TF101, we discussed some of the aspects of extrusion that are of importance to the thermoformer. We began by summarizing the extrusion process, then focused on polymer characteristics that influence the extrusion process. In this lesson, we continue our investigation of the extrusion process.

Orientation

Orientation is by definition, frozen-in stretching or elongation of the polymer molecules. If the sheet is extruded, this stretching occurs during the polymer journey from the extrusion die to the windup or cutoff area of the extrusion process. Unless carefully controlled, extrusion can induce substantial orientation in both the machine direction (MD) and cross-machine direction (TD). Orientation is usually less in calendered sheet and there is rarely any orientation in cast sheet. Although there is no general rule, polymers that have extensive side branches or bulky side branches along the polymer backbone tend to be more susceptible to frozen-in elongation than polymers that have little side chains. Polymers that are quite rubbery or elastic tend to be less susceptible to frozen-in orientation than polymers that have little elasticity.

If the polymer crystallizes, the desired crystalline state shows ball-like crystallites called spherulites. Polymers that crystallize quickly, like high-density polyethylene, tend to have higher levels of spherulites and thus lower levels of orientation than polymers that crystallize slowly, like polypropylene. In a word, the slowly crystallizing polymer is frozen into an oriented pattern before it can fully crystallize into the spheru-

litic state. The crystallites are then in an "extended chain" state. When the polymer is reheated in the thermoforming oven, the crystallites reform into the sphere-like state. This causes the sheet to distort and shrink, with the results ranging from uneven part wall thickness to sheet pulling from the clamping grips.

Testing for Orientation



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Although many tests have been devised to determine orientation in sheet, the so-called Chrysler test is still preferred by both practitioners and researchers, alike. There are many variations of this test. In one version, 1-in. x 10-in. strips are cut from a test sheet. It is always recommended that several sections be cut with some having the length in the machine direction and others in the cross direction. For wide thin-gauge sheet, it is also recommended that strips be cut at the edges and the middle of the sheet, to determine local orientation. These strips are then placed in an oven at about the normal thermoforming temperature for the polymer. After an appropriate length of time, dictated by the thickness of the sheet, the strips are again measured. The greater the difference in the "before" and "after" lengths, the greater the orientation. In some extreme instances, strips may actually curl, indicating extensive orientation.

In certain instances, for transparent polymers such as polystyrene, acrylic, polyethylene terephthalate, and in some polyvinyl chlorides, orientation can be observed by passing the sheet between polarized film. Orientation will appear as rainbow patterns across the sheet. The narrower the color bands become, the greater will be the local orientation.

Orientation in Thermoforming

When we stretch a plastic in the forming press, we orient the molecules.

When the plastic is pressed against the cool mold, we freeze this orientation. Simply put, our plastic part is now oriented. The level of orientation is a function of the extent of stretching needed to push the part into the various corners of the part³. Importantly here is that the nature of the orientation of a polymer is affected by the rate of cooling of the plastic against the mold surface. This is particularly true for slowly crystallizing polymers such as polyethylene terephthalate and polypropylene. The levels of orientation can be reduced by reducing the cooling rate even for amorphous polymers such as polystyrene and ABS. This is sometimes called "annealing."

Orientation v. Shrinkage

As a thermoformed part is cooled in the mold, it appears to "shrink" away from female portions and onto male portions of the mold. This dimensional change is codified according to whether the polymer is amorphous or crystalline. Amorphous polymers always show lower dimensional changes than crystalline ones. However, we must distinguish between dimensional change that is due to relaxation of orientation and dimensional change that is inherent in density increase due to cooling. Technically, "shrinkage" is temperature-dependent volume change. When polystyrene, for example, is slowly cooled from 300°F to room temperature, its density changes from 0.99 spgr⁴ to 1.05 spgr. In other words, it shrinks 6% volumetrically. On the other hand, the density of PP changes from 0.77 spgr at 330°F to 0.92 spgr at room temperature. This is a 19% volumetric change. Cooling the part too quickly will prevent the polymer from reaching its final density. Reheating the part sometime later will allow the plastic to continue its densifying. This may result in warpage and distortion.

So, to get the true "mold shrinkage," as commonly used, we need to add the effect of relaxation of orientation, as measured by the Chrysler test or some other test, to the natural polymer dimensional change values. ■

Keywords: orientation, Chrysler test, shrinkage, spherulite

¹ *Thermoforming 101* is designed to be a tutorial on the basic building blocks of the thermoforming industry. The first series of lessons concluded in TFQ 21:3, 2002. This is the third in the second series of lessons that have as their objective to fill in the gaps from the first series of lessons.

² Readers should note that C. Rauwendaal's book, *Polymer Extrusion*, is reviewed in this issue.

³ In a future lesson on part design, we will deal with orientation and shrinkage and their influence on part performance.

⁴ Spgr is specific gravity, in grams per cubic centimeter. Multiply by 62.4 to get lbs. per cu. ft.