The Forming Temperature

Is the sheet ready to be formed?" This is the most difficult question in all of thermoforming. Part of the difficulty lies in the broad spectrum of polymers and part designs. And part lies in the difficulty in determining what measurable physical property in the polymer best characterizes the polymer formability. As discussed in an earlier lesson, thermoforming is best described as a rubbery sheet stretching process. As a result, the elastic character of the polymer, reflected in its temperature-dependent tensile strength and modulus, should give a strong clue. Methods of measuring and interpreting the elastic character are discussed in another lesson.

The Calibrated Eyeball

But first, what about other methods of determining formability? As noted in an earlier lesson, sheet sag is a manifestation of lowering tensile strength. And sag is used by the experienced operator to gauge when a sheet is hot enough to be formed. All things equal, the sheet should sag the same amount at the same temperature, time in and time out. Sheet "thumping" or the manual manipulation of the sheet during the later heating stages is also a gauge. A screwdriver or key thrust into the corner of the sheet will also yield a "calibrated eyeball" assessment of formability. Other indicators are the change in gloss of the sheet surface and the nature of the "smoke"[1] being evolved from the sheet. Of course, the trained observer must then correlate these experiential judgments with the extrinsic nature of the part that is being formed. In other words, deeply drawn parts probably require hotter sheet, which is then translated by the operator into greater sag or more loss in gloss, and so on.

Upper and Lower Forming Temperatures

Most references list upper and lower forming temperatures for generic polymers. Polystyrene, for example, has a lower forming temperature of 260°F and an upper forming temperature of 360°F. Compare this with polystyrene glass transition temperature of 210°F and its normal injection molding temperature of 425°F. Is it really true that PS has a 100°F thermo-forming window? No. In normal practice, the thermoforming window for PS being stretched into a specific mold shape may be 10°F or less. The practical forming window for PP may be one or two degrees, at best. Some polymers, such as many nylons, have no practical forming windows.

So, why list these temperatures? The lower forming temperature represents the very lowest temperature at which the plastic can be bent or twisted from its flat sheet shape. Mechanical forming and certain very thin-gauge shallow-draw package forming can take place at or slightly above this temperature. The upper forming temperature represents the very highest temperature at which the plastic remains a sheet. Above this temperature, the sheet will probably drip into the heater, smoke vigorously, ignite, and/or turn to charcoal. Don't go there!

Normal Forming Temperature

Many references also list normal forming temperatures for many generic plastic types. This temperature, too, is a guide to good forming, for it represents a reasonable starting temperature target. For example, polystyrene has a 300°F normal forming temperature. Keep in mind, though, that only the surface of the sheet is measured with infrared thermometers. The centerline temperatures of very thick sheets may be substantially below surface temperatures. For very thin sheets, infrared thermometers that measure at 3.5 microns must be used to prevent also measuring heater temperatures on the other sides of the sheets. More about temperature measuring in a later article.

THERMOFORMING 101

How to Establish An Initial Temperature Protocol

First, sheet temperature, not heater temperature, is the key to successful forming. Then, an initially uniform surface temperature across the sheet should be obtained, through adjustment of individual heaters. The normal forming temperature for the plastic should be the initial sheet surface temperature target. And finally, individual heaters should be adjusted to achieve pattern or zonal heating, where certain locations on the sheet are deliberately made hotter or colder than the rest of the sheet.

Keywords: forming temperature, normal forming temperature, upper forming temperature, lower forming temperature, sheet temperature protocol

[1]In truth, the "smoke" is probably not polymer decomposition products being evolved but volatile additives such as internal or external lubricants or processing aids.

[This is one in a series of articles introducing general concepts in thermoforming.]