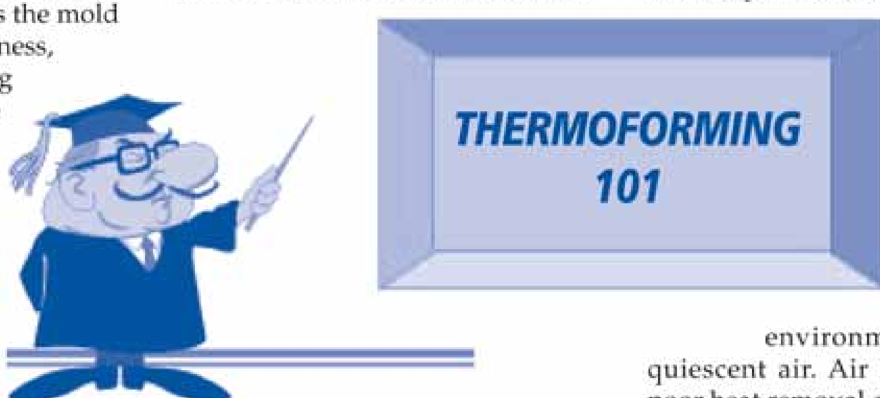
COOLING THE FORMED PART

So far, we have heated the sheet and stretched it. The sheet is now against the cooler mold surface. This part considers how the sheet cools.

Sheet Characteristics on the Mold

As discussed earlier, the sheet stretches differentially against the mold surface. That is, the sheet that touches the mold first yields the thickest portion of the formed part. The sheet that touches the mold last is usually the thinnest portion of the formed part. Further, the sheet that touches the mold first is cooled longer than the sheet that touches the mold last. The difference in thickness, cooling rate, and cooling time across the part surface may lead to different thermal stresses in the final part. And these different thermal stresses, together with the different degrees of stretching in the part during forming, can lead to part problems such as warping, uneven shrinkage, and part distortion. These problems are not restricted to general part size or initial sheet thickness or nature of the polymer, but can occur in thin-gauge and heavy-gauge parts.



Energy From the Sheet to the Mold

We discussed mold materials in an earlier tutorial. Here we discuss how the mold removes heat from the sheet. First, not all molds are actively cooled. Prototype tooling usually has no cooling channels. As a result, the heat extracted from the sheet by the cooler mold simply goes to heat the mold. As more and more parts are produced, the mold simply continues to heat, albeit at a slower and slower rate, since some heat is always lost to the room. This means that parts produced at the beginning of the run will have different levels of stress than parts produced at the end of the run. With "hand samples" or "show-and-tell" parts, this is rarely a problem.

Production molds are almost always actively cooled. For most commercially thermoformed polymers, water is the cooling medium. The cooling water is circulated through water channels drilled into or added to the back of the mold. The cooling water is either recirculated through a chiller and back into the mold or is exhausted to the drains. As we will see later in our discussions on process control, incoming and outgoing water temperature should be monitored to maintain uniform mold temperature across the entire mold. By the way, there are certain thin-gauge applications where chilled or refrigerated water is used as the cooling medium. And certain high-temperature applications where either steam or heated oil is used.

The energy is removed from the thermoformed sheet through the surface in contact with the mold surface by conduction. That energy is then conducted through the mold metal to the cooling channel, where it is removed from the mold by convection. Conduction depends on the thermal conductivity and the thickness of the mold material. Convection depends on the rate of flow and the chemical nature of the coolant through the cooling channel. The greater the distance between the plastic surface and the cooling channel is, the longer it takes to cool the plastic. Low thermal conductivity mold materials, such as stainless steel, will conduct heat slower than higher thermal conductivity mold materials, such as aluminum. The farther the coolant channel is from the mold surface, the slower the part will cool. The greater the coolant flow rate, the more rapidly the part will cool. And water is a more effective cooling medium than oil, and steam is much more effective than water.

Energy From the Sheet to the Air

For all but matched die forming, the free part surface, or the part surface away from the mold surface, is exposed to ambient mold conditions. For thin-gauge parts that are pressure formed, the free surface environment is static or quiescent air. Air has notoriously poor heat removal characteristics, so the free surface cools primarily by conduction through the side of the sheet that is in contact with the mold surface. For heavy-gauge parts, fans are usually used to remove heat from the free surface. The more rapidly the air is circulated against the free surface, the more rapidly the part will cool. In certain applications, humidified air or air containing water microdroplets is used to further enhance the rate of cooling from the free surface. The technical reason for trying to quickly cool the free surface is that, if both sides of the sheet are cooled equally, the sheet cools four times faster than if only one side is cooled.

Keywords: coolant channel, active cooling, conduction, convection, free surface

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