Polymer Processing

Dipping

Earlier in the semester we talked about the structure and properties of polymers. Since the name of this course is Materials and Processes, today we’ll talk about processes used to make polymer products.

The oldest method is *dipping*. You can make candles by dipping string into molten beeswax. Pull the string out, let the wax cool and solidify, and repeat until you get a tapered candle…we call them *tapers*.

You can dip other polymers too. If you ever look carefully at a set of pliers, you’ll notice that the *vinyl plastisol* grips were made by dipping. There’s a little nub on each handle end where the plastisol dripped off. Plastic-coated coathangers are often coated by dipping.

This picture shows *dipped expanded metal*. This was a picnic table in Sleeping Bear Dunes National Lakeshore, where there’s a lot of sand blowing around. The entire picnic table was made of expanded metal, so sand doesn’t collect. The rubbery coating keeps the steel from rusting, and because it’s rubbery, it can’t be sandblasted very easily.

Casting

The second oldest method of forming polymers is *casting*. You pour molten polymer into a mold, solidify, remove. Paraffin wax is a type of polyethylene. Cylindrical candles are typically molded with paraffin wax. There’s no additional pressure applied…just heat…so these processes are done at atmospheric pressure.

Some cast polymers react in the mold, then cool. An example is 2-part epoxy. When the two components react, they give off heat as they cure.

Slush Casting

Another casting method done at atmospheric pressure is *slush casting*. Pour vinyl plastisol, neoprene, or other liquid polymer into a heated mold. A skin forms against the mold wall. Pour off the excess liquid for reuse, heat to fuse gelled skin, then remove the finished product.

![Fill the mold with liquid polymer.](image1)

![Heat the mold. Polymer touching the mold wall gels.](image2)

![Pour off remaining liquid.](image3)

![Heat the mold to fully cure the gel.](image4)

![Strip the part from the mold.](image5)

This is how galoshes and latex gloves are made. The exterior of a pair of galoshes is the molded side; the interior is the wet side.

Let’s look at how you might use slush casting to produce a copy of an existing product. Follow the sequence of photographs in the course handout.

1. First, we pour liquid silicone over the turtle. We pick a flexible, tear-resistant silicone that has poor adhesion properties, so it won’t actually stick to the turtle.
2. We cover the turtle with about ¼” to spare, then wait overnight.
3. Next, we pull the turtle out of the cured silicone. The silicone is a mold we can use to make a copy.
4. We pour a slush-casting polymer into the mold. It could be a rubber material such as neoprene, or some other plastic resin that hardens with time. We coat the entire surface of the mold, and pour off the excess.
5. Now we let the slush-casting resin cure.
6. Once it’s cured, we can remove it from the mold to make a hollow replica, or we can fill it with foam or some other
material to make a solid replica.

7. Once the foam is cured, we can remove the replica, and you see it here next to the original.

What we’re looking at is a series of different polymer processes. We’re using conventional casting to make the silicone mold. We’re using slush casting to make the skin of the replica. We’re using foam casting to make the foam filler inside the replica.

This process is not just for making ornaments and toys. When I worked in industry, silicone molds were used for making prototype cast parts out of hard epoxy. We spent a few hundred dollars on the tooling and supplies, instead of spending tens of thousands of dollars on injection molds. For prototyping, you don’t know what the dimensions are going to be when the design is finished…you want to try several different shapes and sizes, so this is faster and cheaper.

Compression Molding & Transfer Molding

The next oldest molding process is compression molding. It’s used mostly for thermosets like Bakelite (there are cheaper methods available for thermoplastics).

1. Pour pellets or powder (prepolymer) into mold.
2. Insert punch, apply PRESSURE & HEAT.
3. Ejector pin pops solid part out.

This method dates to 1860s, when it was used with shellac, straw, and wax (or pitch). Old-fashioned vinyl LP records were made by compression molding:

1. A “biscuit” is preheated to 150°C (300°F).
2. The biscuit is pressed between nickel molds at 150-170°C (300-340°F) at 12.4-13.8 MPa (1800-2000 psi).
3. The record is formed and cooled in 40 seconds.

Note the flash on the part in the cartoon…you need to plan for that in mold design and manufacturing operation. How do you remove the flash? You can tumble parts with liquid nitrogen (rubber parts are done this way) or with ceramic beads.

In compression molding, we melt and pressurize a prepolymer in the mold.

In transfer molding, we melt the prepolymer before molding. Many electrical connectors are made by molding plastic around delicate sheet metal or wire components. If we pressurize before the polymer is fully melted, the viscosity is so high that delicate inserts can deform.

Injection Molding

In compression molding, we don’t apply pressure until after the polymer is already in the mold. This limits the kinds of shapes we can make, and it also limits the cycle time.

In 1921, the first injection molding machine was built in Germany, and it revolutionized the plastics industry. It was basically a metal die-casting machine that was modified for use with plastics. With injection molding, we apply pressure to the polymer before it goes in the mold. The oldest injection-molding process is a single stage plunger.

1. Pour the prepolymer in a hopper. This polymer is in the form of pellets, flakes, or beads.
2. A reciprocating plunger pushes the prepolymer through a flow restriction and heat, and the polymer melts.
3. Liquid polymer is injected into the mold.
The next technological improvement in Injection Molding was the *two stage plunger*. We use a screw (like a meat grinder) to *plasticize* (soften) the feedstock.

1. Pour prepolymer in hopper.
2. The screw plasticizes the polymer, making it soft and pliable.
3. The plunger pushes the polymer into the heated zone to fully melt it.
4. The plunger pushes the liquid polymer into the mold.

The most common injection molding system today combines the plunger and the screw. The screw rotates constantly, plasticizing the prepolymer. The screw slides to the left to inject molten plastic into the mold, then it slides to the right.

The *single stage reciprocating plunger* is faster than other methods, and in injection molding, speed is everything. The machines and molds are really expensive, so you have to make parts fast in order to recover your capital costs.

Injection molding is mostly used for thermoplastics, because if the machine stops running with plastic in it, a thermoset would have to be chiseled out…a thermoset can be remelted in place by applying heat.

In injection molding, 3 to 6 shots per minute are common. Scrap is typically <10% (thermoplastic scrap can be reground and reused, mixed with virgin plastic).

**Hollow Parts**

**Stretch Blow Molding**

Injection molding is great for solid products, but it’s useless for making hollow products like pop bottles, because all plastic surfaces are formed by mold walls. How would you get the inner mold material out of a pop bottle? Instead, we use *stretch blow molding* for making hollow parts like pop bottles, detergent bottles, children’s toys, automotive fuel tanks, double wall power tool case, automotive arm rests, etc.

You start with a *parison*…extruded tubing. Blow air into the parison to make a *preform*, then blow air into the preform to make the product. Hot plastic cools when it contacts the mold walls.

Alternatively, you can make the parison by injection molding…then there’s only one step to make the final product from the parison.

Question for class: how can you tell which method was used to make a bottle? (look for parting lines…two sets on an injection-molded parison)

Dies cost 20 to 50% of the cost of injection mold dies…no runners, cores, gates, etc. Since you only need one mold surface, you only have to pay for half the tooling of an injection-molded part.

You can coextrude more than one polymer. ..ketchup bottles have several layers. The inner layer contains the odor and preserves the flavor, the middle layer can be for strength, and the outer layer can be printable or be a good surface for the label adhesive to stick to. Some bottles are made with as many as 7 coextruded layers.
Major drawbacks of blow molding:

- **Stiffness:** You cannot mold-in ribs, bosses, etc. for stiffness.
- **Wall Thickness:** The finished product has a nonuniform wall thickness. Wherever the polymer has to stretch the most (at the largest cross section), the walls will be thinnest. In a pop bottle, the walls are thickest at the two ends, and thinnest around the large diameter.

You can get around this issue by making a parison with changing wall thickness, so when it’s blown, the final product has a more uniform wall thickness. As the parison is extruded, the mandrel moves up and down to adjust wall thickness. This technology would be difficult to control mechanically, but it’s easy to control with computers.

This is a design issue…with a computer-programmed parison, you can reduce the wall thickness where the stresses are lowest, and increase the wall thickness where the stresses are highest. You can optimize the wall thickness, not just make it uniform. This is a way of saving money on raw materials.

### Rotational Molding

If you want to produce a tank with a uniform wall thickness, you can use a process called *rotational molding*. Place some polymer powder inside a closed mold with heated walls, then rotate the mold about 2 axes. As you tumble the powder, it fuses to the heated mold walls and forms the finished part. In the diagram, the blue dots represent powder particles.

### Shell Molding

Another way to produce a uniform wall thickness is with *shell molding* (not in the textbook). Shell molding can produce uniform wall thicknesses ±10%. The polymer powder is placed in a *fluidized bed*, and a voltage of about 80kV is imposed between the powder and the mold. The particles, which are negatively charged in this diagram, are attracted to the positively charged mold surface. The advantages of this method are:

- **No Pressure:** Since there is no applied pressure, the mold can be thinner than in injection molding and other pressure-based processing systems.
- **Stops When Done:** The reaction occurs only where surface is hot…so deposited polymer *insulates* & the reaction is *self-limiting*.

A fluidized bed is a bunch of solid particles suspended in a tank by gas flow…typically air. Example: hot air popcorn popper. It’s called *fluidized* because the particles behave like molecules of a liquid or gas…they move around, bump into each other, etc. They’re not stationary, like solid particles in a pile are. Hot air popcorn poppers from the 1980s are fluidized beds.

### Thermoforming

The major disadvantage of most molding processes is the cost of the mold. Injection molds are often 10s or 100s of thousands of dollars, depending on shape and size. Another disadvantage is the pressure required to fill the mold. Presses
can get very expensive. An alternative for large parts or low volume is *thermoforming*. Take a thermoplastic sheet, soften it, then place it over a mold. Draw a vacuum and the sheet sags, & fills the mold. The tool is the *inside shape* (non-cosmetic side). Cosmetic appearance comes from surface finish of the sheet (texture, color, etc.)

The largest vacuum thermoforming unit in USA can produce a 10' × 22' × 4 ' draw (Thermoform Plastics Co., 2004)...used for making boat hulls.

Mold materials: can be machined metal (aluminum), or even plywood covered in felt…really cheap.

A variant on this process is PRESSURE THERMOFORMING, where you apply air pressure to sheet, instead of sucking with a vacuum. Now the tool is the OUTSIDE SHAPE, and you can mold-in the final texture.

Thermoforming is used for making many kinds of products, including styrofoam egg containers, food packaging, greenhouse trays, plastic pallets (to replace wood pallets), truck bed liners, dumpster lids, and refrigerator liners.

We’ve discussed 8 processes for making plastic parts. There are another half-dozen processes described in the textbook, and many more still in industry (for polymer foams, polymer-based composites, etc.) This lecture gives you a flavor of the different kinds of processing methods that are available.

The process you pick to make a given part depends on economics…what can you afford, based on your annual volumes. If you know about other processes, then you can help your employer change from one process to a better one. A Fort Wayne swimming pool company used to build swimming pool steps by glueing parts together. Now the company uses thermoforming…it’s cheaper, it’s faster, and it’s much safer for the employees…no more glue fumes in the workplace.