IV. Plastic Morphology

- **Types of Plastics**
- **Mechanical Properties**
- **Common Materials and their Characteristics**
- **Some Experiments**

Types of Plastics

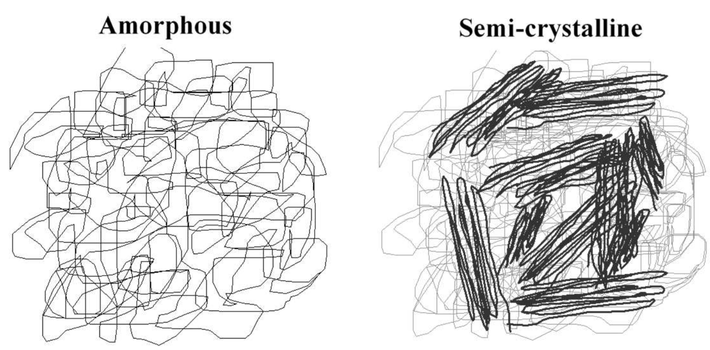
Basically, there exists two types of plastics: thermosets and thermoplastics.

Thermoset materials are those materials that can be molded only once. The injection molding of thermosets is somewhat different than the molding of thermoplastics; therefore, ***Universal Molding***^{TM} for thermosets such as liquid silicon, bulk molding compounds (BMC), epoxy, rubber, melamine, etc., will not be discussed in this text.

Thermoplastic polymers are those materials that can be melted repeatedly, and consequently can be reground and molded multiple times. Their molecular organization falls into two types, amorphous and semi-crystalline.

Amorphous materials are thermoplastics that do not offer any type of molecular organization; in other words, their molecules have a totally random organization, like spaghetti.

Semi-crystalline materials are a combination of organized segments (crystals) surrounded by disorganized (amorphous) segments.

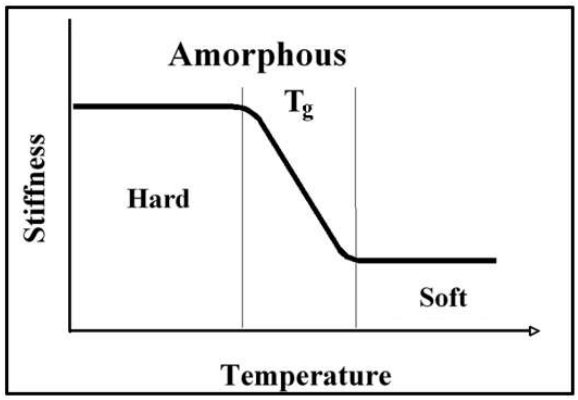


IV-1. Illustration representing amorphous and semi-crystalline molecular organization

The molecular structure of semi-crystalline material includes organized groups with some type of orientation, known as crystals. These crystals are surrounded by disorganized amorphous molecules. This partially organized mix of amorphous and crystalline material is known as semi-crystalline.

Mechanical Properties

A material's molecular orientation brings mechanical properties which can affect the injection molding process. The mechanical characteristic of these materials can be illustrated with a graph of stiffness versus temperature. Look at the graph below.

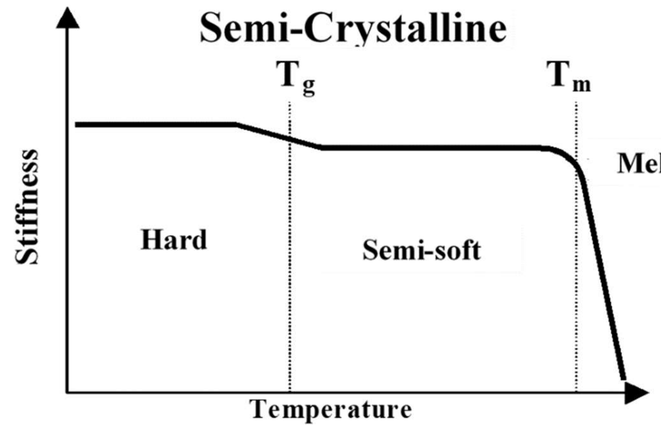


IV 2. Graph illustrating stiffness versus temperature in amorphous materials

The vertical axis indicates the stiffness, in which the origin represents soft or melted material and any increase represents a rise in stiffness. The horizontal axis indicates the material's temperature, in which the origin represents a material at room temperature and any increase represents a rise in temperature.

The profile graph of amorphous polymers illustrates that, at certain low temperatures, the material will stay in a solid state. With an increase in temperature the material will reach a glass transition temperature T_g. After this glass transition temperature is reached, the material enters a transition zone that is known as the glass transition zone, where it will gradually lose its stiffness. If the temperature continues to increase, you will obtain a totally soft material. Think of it as an elastic or putty-like melt that is not liquid. It is in this softened state that amorphous materials are injected.

The graph of a semi-crystalline material offers a distinct picture.



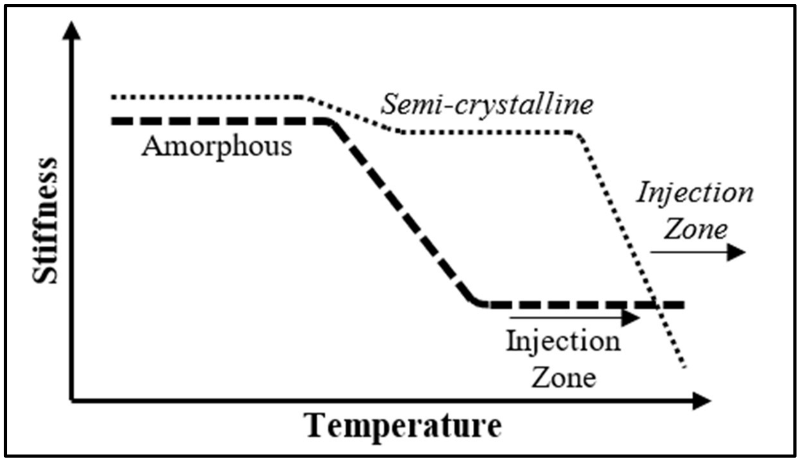
IV-3. Graph illustrating stiffness versus temperature in semi-crystalline materials

The graph profile of a semi-crystalline material shows that, just like amorphous polymers, the material will remain in a solid state at lower temperatures and reaches a glass transition zone at temperature T_g when the temperature is increased. With semi-crystallines, the glass zone corresponds to the amorphous part of the material and is so insignificant that the term T_g is rarely used.

If the temperature continues to increase beyond the glass transition zone, the material will lose some stiffness. Even then, it will remain in a solid state.

If the temperature keeps increasing, melt temperature T_m will be reached. At temperatures greater than T_m semi-crystalline materials will melt. After T_m the material becomes liquid; for this reason, it is said that semi-crystallines melt and do not soften like amorphous materials. It is after temperature T_m that semi-crystallines are molded.

Note that semi-crystalline materials do not have the advantage of as large an injection zone as amorphous materials, making them harder to melt. Semi-crystalline materials change from melted to solid more quickly than amorphous materials do.



IV-4. Overlaid graphs of stiffness versus temperature of semi-crystalline and amorphous materials

Once the material has been identified, determine the injection molding process settings, taking into consideration that amorphous materials soften and semi-crystalline materials melt

Common Materials and their Characteristics

Amorphous	Semi-crystalline
ABS	PA (nylon)
Polystyrene	Acetate
Acrylic	Polyethylene
PVC	Polyester
Polycarbonate	Polypropylene

IV-5. Common amorphous amd semi-crystalline materials

Semi-crystallines are only opaque in their solid state, since in their melted state the crystals become disorganized like an amorphous material and permit the passage of light. If you ever have the opportunity to observe a purge of a semi-crystalline melt, for example, polyethylene with no additives, you can appreciate how the material changes from translucent to opaque as it cools and solidifies.

Not all melted materials have amorphous morphology; there are some that form crystals in their liquid state. These materials are called *liquid crystal polymers*.

The formation of crystals in semi-crystalline materials can be controlled by adjusting the molding process. In other words, as a molder, you can control the quantity of crystals formed during the cooling stage. Being able to control the formation of crystals with adjustments in the molding process is an opportunity. For example:

- With the objective of maximizing clarity in the fabrication of PET preforms, which will later be stretched and blown to form bottles, crystal formation needs to be reduced as much as possible. If you ever look at PET pellets you will notice that they are white and opaque, the PET having been crystallized to its maximum. Remember that crystals block the passage of light. That is why during cooling a thermal shock is given, using a super cold mold, with the objective of halting the formation of crystals.
- The ultrasonic assembly of thermoplastics can be dampened by the material's crystalline structure. This is another reason some molders control the formation of crystals.
- When it is necessary to control mechanical properties such as flexibility and toughness in molded products made from semi-crystalline resins, such as nylon ties for cable bundling (Tie wraps), it is important to consider the material's crystalline structure. This crystalline structure tends to make the material more rigid and inflexible. For this reason, some molders implement strategies to control crystal formation during the molding process.

Know the type of material you are using before trying to mold a product and identify the mechanical properties that most affect your product.

Remember that hold pressure and cooling temperature combine to affect the final dimensions of a molded product. The cooling temperature affects the thermal dimensions, and the hold pressure affects the mass dimensions. In addition, the temperature and pressure could create a combined effect;

this is when the temperature and the pressure combine within a certain range, creating a particular effect on the dimensions. Although the combined contribution is difficult to visualize, it does exist. For example, the time it takes to solidify the gates corresponds the hold stage and could be affected by the mold temperature, a cooling stage parameter.

Amorphous	Semi-crystallines
Soften When you inject an amorphous melt, it has a putty or gummy consistency. A purge of this type of melt will clump like a paste with little intention to flow.	*Melt* When you inject a semi-crystalline melt, it has a liquid consistency. In other words, a purge of this type of melt will run like a liquid.
Less resistant to chemical attacks When amorphous materials are exposed to a chemical like a solvent, they could decompose. Even though polycarbonate is used for bulletproof glass, a polycarbonate container will decompose if filled with gasoline.	*More resistant to chemical attacks* Semi-crystallines have a better resistance to solvents. For example, an HDPE container can store gasoline.
Transparent Melted or solid amorphous materials without additives are translucent or clear. Note: Do not confuse the "material clarity" property with the term "crystalline morphology".	*Opaque* Semi-crystallines in their solid state have organized segments (crystals), which divert the passage of light and thus are opaque.
Low shrinkage Amorphous materials shrink less since the disorganized molecules occupy more space. Note: It is said that mass dimensions are more significant with amorphous materials.	*High shrinkage* The crystals in semi-crystallines are groups of organized molecules that tend to take up less space. This is why they shrink more during cooling and crystal formation. Note: Thermal dimensions are said to be more significant with semi-crystalline materials.

IV-6. List of mechanical characteristics of amorphous and semi-crystalline materials

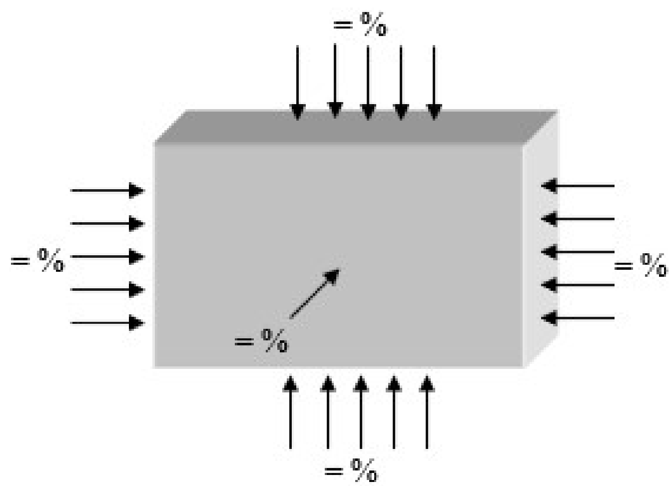
The contribution to the dimension of each of these characteristics will depend upon the type of material being used. Because of this you should understand your material before trying to correct dimensions or any attribute.

Amorphous	Semi-crystalline
Problems of overpacking due to low shrinkage.	Problems with incomplete packing due to too much shrinkage.
Problems with flash due to overpacking.	Parts with sink marks due to high shrinkage.
Parts breaking during ejection since little shrinkage causes parts to stick to the cavity walls.	Easy part ejection since high shrinkage helps separate parts from the cavity walls.

IV-7. List of process characteristics of amorphous and semi-crystalline materials

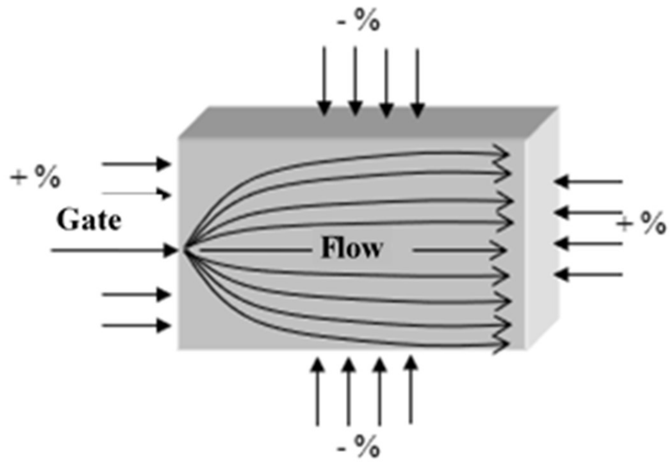
Shrinkage

Amorphous materials, for practical purposes, shrink proportionally in all directions.



IV-8. Amorphous material shrinkage

Semi-crystalline materials shrink more in the direction of injection flow rather than in the direction perpendicular to the injection flow.



IV-9. Semi-crystalline material shrinkage

During injection, the polymeric chains orient themselves to the direction of flow and are forced to maintain some orientation, crystals included, as they solidify. During shrinkage, these molecules seek to conform into a less uncomfortable position; because of this, the shrinkage will be greater in the direction of the flow.

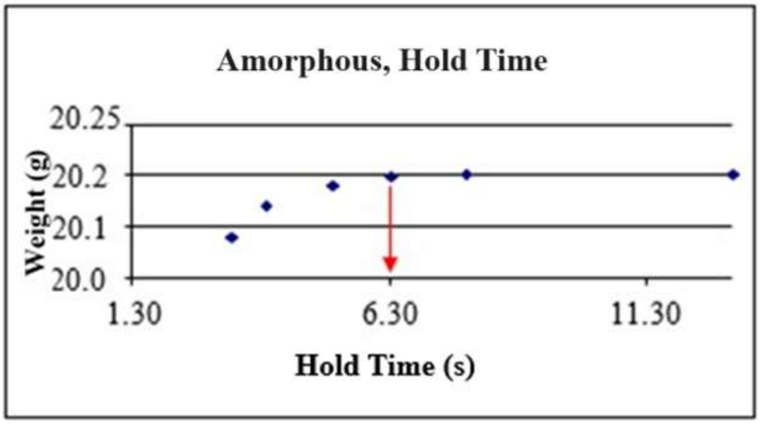
When a semi-crystalline is reinforced with fiberglass its shrinkage becomes inverse, less in the direction of injection flow and greater in the perpendicular flow direction. This is because the glass fibers orient themselves to the direction of injection flow and, during shrinkage, they act like steel bars inside concrete, resisting shrinkage in the direction of their orientation.

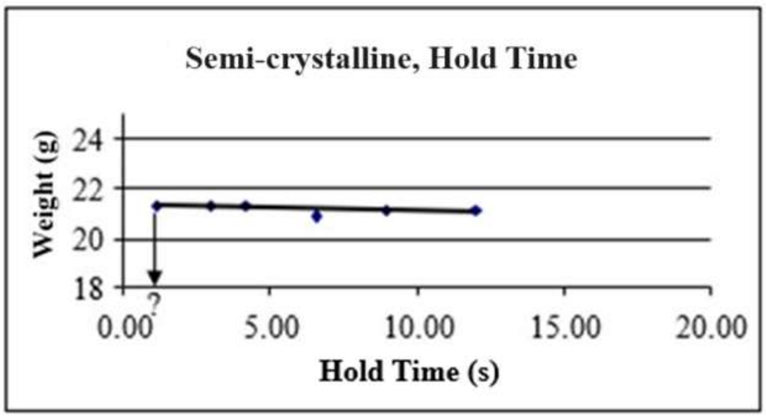
Some Experiments

Let us review some experiments performed by ***Universal Molding™*** students.

Experiment #1:

Using the same mold, injection molding machine and auxiliary equipment, the effect of hold time upon gate freeze was tested using two materials, one amorphous (polystyrene) and the other semi-crystalline (nylon).





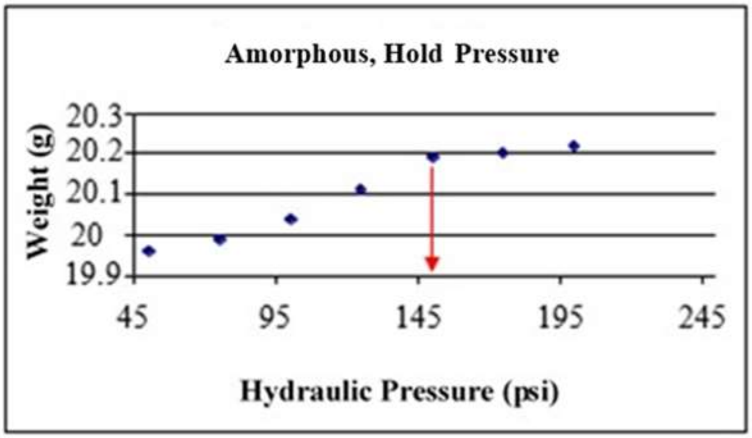
IV-10. The effect of hold time on the part weight in amorphous and semi-crystralline materials

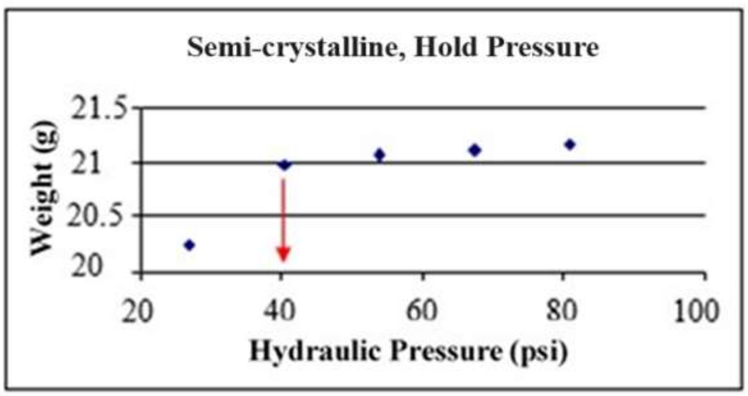
The graphs of part weight versus hold time reveal that the amorphous material solidified in the gates in close to 6 seconds, which consequently caused the weight of the part to stop increasing. With the semi-crystalline material, the students stopped the experiment after one second of packing with the gates solidifying, showing that the gate freeze occurs in less time than with the amorphous material.

This is expected since the semi-crystallines change from solid to liquid and vice versa quickly, unlike amorphous materials that remain in a pasty state during a large temperature range.

Experiment #2:

Using the same mold, injection molding machine and auxiliary equipment, the effect of the hold pressure upon the weight of the parts was tested using two materials, an amorphous (polystyrene) and a semi-crystalline (nylon).





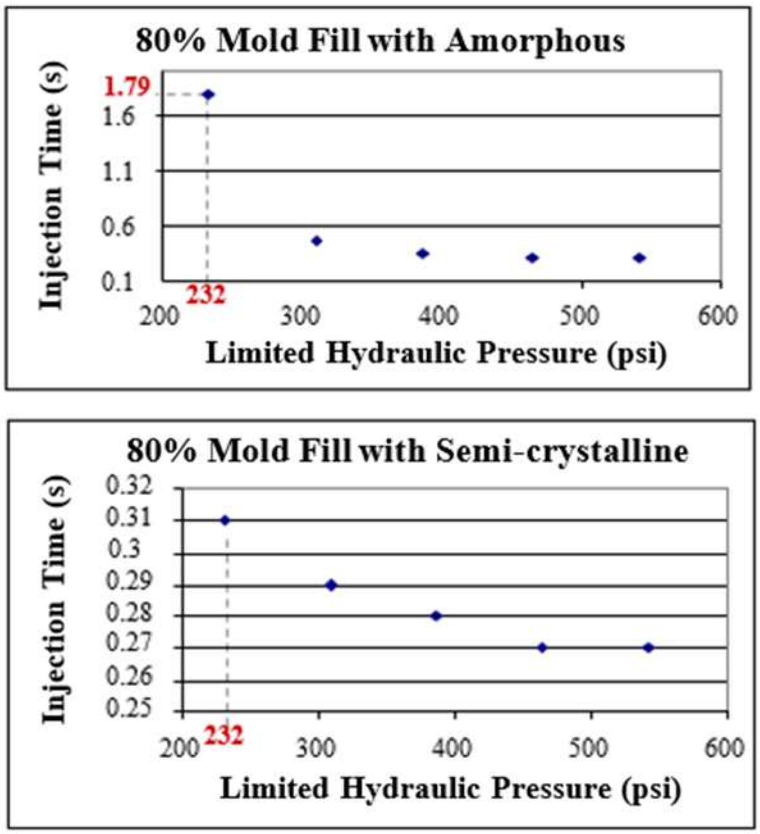
IV-11. The effect of hold pressure on the part weight of amorphous and semi-crystralline materials

The amorphous part's weight stopped increasing significantly at a hold pressure close to 150 psi, while the semi-crystalline part's weight stopped increasing significantly at a hold pressure close to 40 psi.

This holding pressure differential could be attributed to the fact that the amorphous melt is pasty and not liquid like the semi-crystalline, or that a rapid gate freeze occurs when using a semi-crystalline material.

Experiment #3

Using the same mold, injection molding machine and auxiliary equipment, the effect of fill pressure on fill time on a mold filled to 80% was tested with two materials, an amorphous (polystyrene) and a semi-crystalline (nylon).



IV-12. The effect of injection pressure on injection time with amorphous and semi-crystralline materials

The semi-crystalline material, being more liquid, required less pressure. For example, at a pressure limit of 232 psi, the fill time with the semi-crystalline was 0.31 seconds compared to 1.79 seconds with the amorphous material.

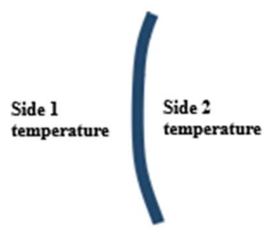
Questions

1) How many times can you melt an already molded thermoset?
   a. One time, since it was already molded once.
   b. None, since it was already molded once.
   c. Four to seven times.
   d. It depends on the type of thermoset.

2) In the recovery stage
   a. amorphous material melts.
   b. semi-crystalline material softens.
   c. semi-crystalline material melts and amorphous material softens.

3) To reduce the formation of crystals in semi-crystalline parts that will be ultrasonically welded
   a. heat the mold to reduce the crystals.
   b. cool the mold to increase the crystals.
   c. freeze the molecules as quickly as possible, to minimize the formation of crystals.

4) A part warps after being ejected. We know that we can eliminate that warpage by using distinct temperatures on the faces of the mold.



   The solution is
   a. make side 1's temperature greater than side 2's temperature.
   b. make side 2's temperature greater than side 1's temperature.
   c. make both temperatures equal.

5) We control amorphous material shrinkage by
   a. increasing the mold temperature to get parts with thicker walls.
   b. heating the mold to halt part shrinkage.
   c. using hot molds to get more shrinkage and cold molds to get less shrinkage.
   d. none of the above. Amorphous materials do not shrink.

6) The shrinkage of semi-crystalline materials is
    a. equal in all directions.
    b. less in the direction of injection flow.
    c. greater in the direction of injection flow unless the material is reinforced with fiberglass.

7) Since amorphous shrinkage is less than semi-crystalline,
    a. amorphous parts have more sinkage problems.
    b. semi-crystallines have more problems with part ejection.
    c. semi-crystalline parts have more sinkage problems than amorphous parts.