Sharing The Knowledge
Module 9

Cooling and Freezing Polymers

M-PLA-0117-STK-MOD 9-12/89-00-1

STK 901

GE Plastics

Module 9

Cooling and Freezing Polymers

- Removing Heat
- Predicting Polymer Cooling
- Establishing Cooling Parameters

9

Participant's Notes:

STK 902

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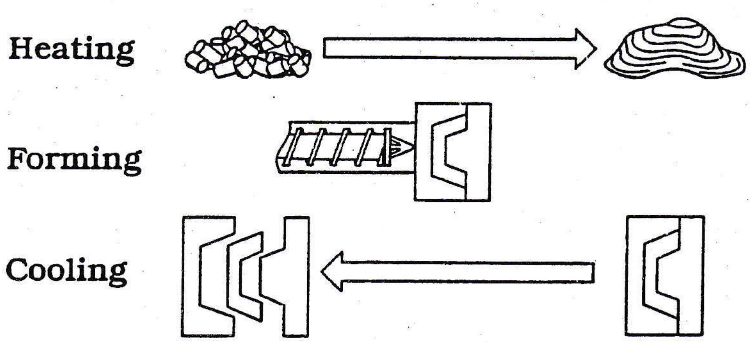
Thermoplastics Processing



Thermoplastic parts are produced by heating the resin, flowing and forming the melt, and then cooling the finished part.

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Participant's Notes:

Introduction

Cooling & Freezing Polymers

The process of cooling and freezing polymers is critical to the molding process, affecting everything from manufacturing productivity to material performance. Cost effective, high quality part production depends on the ability of the converter to understand polymer cooling performance so he can process each material according to its own specific cooling requirements. **STK 901**

Objectives:

At the end of this module, participant should be able to:

- Describe how a thermoplastic part is cooled.
- Describe how amorphous polymers and crystalline polymers respond differently during cooling.
- Describe the variables within each of the following factors when establishing cooling parameters for crystalline and amorphous resins: mold temperature, thermal conductivity and shrinkage.
- Describe the cooling parameters for a resin you are currently working with.

Thermoplastics Processing

Thermoplastics are processed by heating the resin, flowing and forming the melt, and then cooling the finished part.

The ability of thermoplastics to soften upon heating, form into a shape upon molding, and solidify into a part upon cooling is what makes them so unique. We talked about the heating, softening, and melting of polymers in Module 7 and we discussed flowing and forming in Module 8. This module examines the cooling and freezing of the polymer, discussing the phenomenon from both scientific and practical points of view. **STK 902**

STK 903

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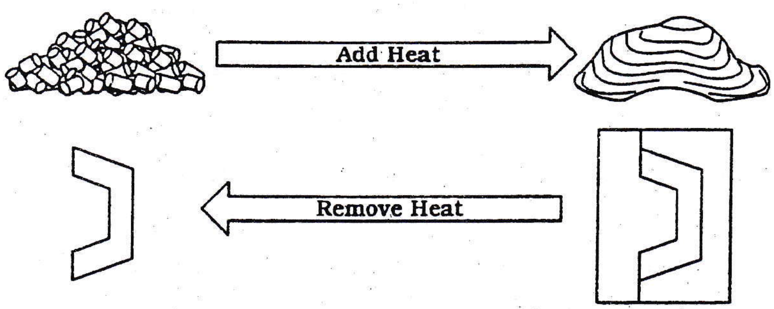
Heating & Cooling

Heat is applied to the plastic to soften and melt it.



Heat is removed from the plastic to cool and freeze it.

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Participant's Notes:

STK 904

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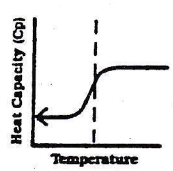
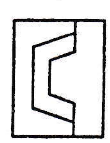
Cooling & Freezing Polymers

- Removing Heat
- Predicting Cooling Performance



- Establishing Cooling Parameters



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Participant's Notes:

Heat is removed from the plastic to cool and freeze it.

Heating & Cooling

Heat energy is added to a polymer to cause it to soften or melt. So long as this heat energy is present in the melt, the polymer is able to flow. In order to cool and freeze the melt, the heat energy that was put into the polymer must be removed. **STK 903**

Removing Heat

There are three elements covered in this module.

Cooling & Freezing Polymers

This module examines polymer cooling performance and makes suggestions for establishing cooling parameters. But first let's discuss the cooling process, or the removal of heat from the polymer melt. **STK 904**

STK 905

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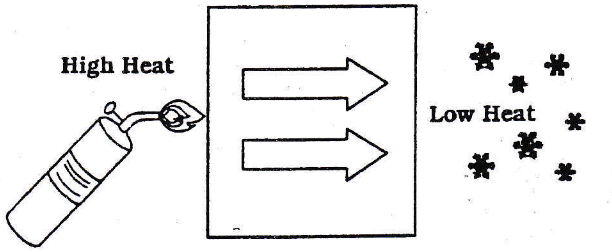
Heat Transfer

Heat Flow



Heat flows from an area of higher temperature to one of lower temperature.

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Participant's Notes:

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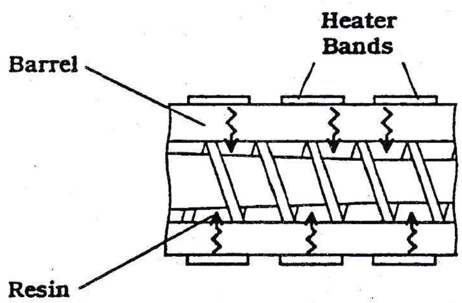
Heating



Polymer heating results from the transfer of heat from the higher temperature bands, to the barrel, to the lower temperature resin.

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Participant's Notes:

Heat flows from higher temperature areas to lower temperature areas.

Heat Transfer

Heat flows from the body of a higher temperature to the body of a lower temperature. It is the temperature difference between the two bodies that determines the flow of heat: the greater the difference in temperature between the two bodies, the greater the rate of heat flow between them. **STK 905**

Heat transfers from the heater bands to the resin.

Heating

In the conversion process, when the temperature of the heater bands is raised, the resulting heat flows from the bands into the lower temperature barrel, and eventually into the lower temperature resin. **STK 906**

STK 907

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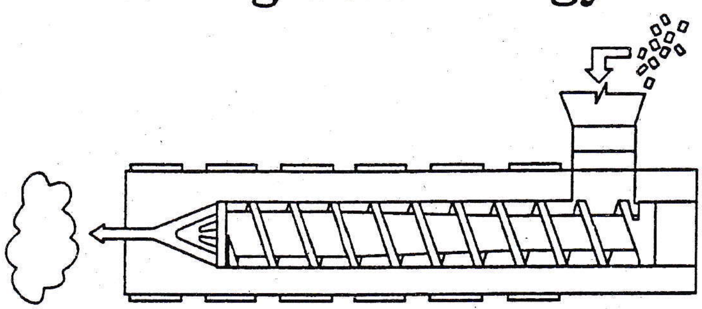
Adding Heat Energy



Temperature of the polymer increases as it moves through the barrel.

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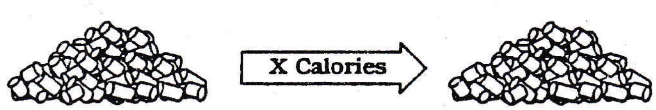
Heat Capacity

50°C

51°C



1 Gram

1 Gram

1 Cal / Gram / °C = 1 BTU / Lb. / °F

Heat Capacity (C_p) is the energy required to heat (in calories) one gram of material one degree centigrade.

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Participant's Notes:

Temperature of the polymer increases as it moves through the barrel.

Adding Heat Energy

Electricity provides a constant source of energy so that heat continues to flow into the barrel to raise the temperature of the resin. The temperature of the resin increases from the back of the screw to the front of the screw due to the addition of electrical and mechanical heat energy. **STK 907**

The heat capacity trace defines the energy required to raise the temperature of the polymer.

Heat Capacity

Heat capacity refers to the energy required to heat the material. It measures the number of calories it takes to raise one gram of material one degree centigrade. Units of heat capacity are measured in cals/gram/°C, or BTUs/lb/°F. A material's heat capacity is derived from information found in that material's heat capacity trace. **STK 908**

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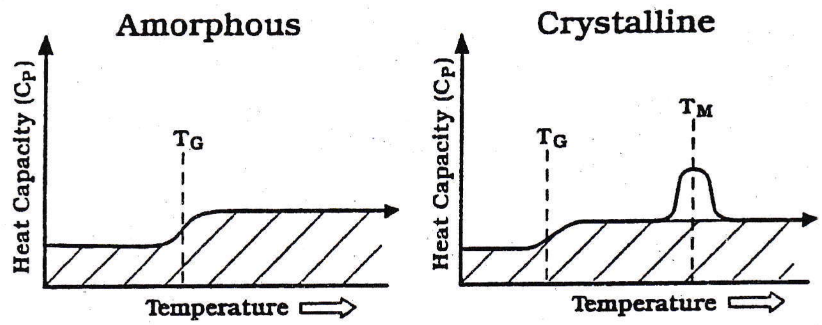
The Heat Capacity Trace (On Heating)



The heat capacity trace on heating indicates how a polymer responds (takes in heat) as it is heated.

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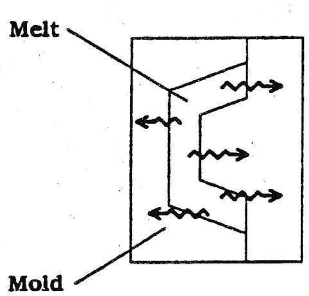
Cooling



Cooling results from the flow of heat from the higher temperature melt to the lower temperature mold.

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Participant's Notes:

The heat capacity trace (on heating) indicates how a polymer responds when heat is added.

The Heat Capacity Trace (On Heating)

The heat capacity trace on heating describes how a material responds as heat energy is applied, indicating the material's important physical transitions. As heat is applied the amorphous polymer goes through a glass transition and becomes soft and eventually flows. When a crystalline polymer is heated beyond its melt temperature it also flows.
STK 909

In cooling, heat flows from the higher temperature melt to the lower temperature mold.

Cooling

While the polymer is in its melt state, pressure is applied to form it into a part. In order to get the polymer to remain in this new form, the material must be cooled. Cooling results when the "hot" polymer melt, enters the "cold" mold. Hot and cold are relative terms. The material is considered hot because it is hotter than the mold. And the mold is considered cold because it is cooler than the material. But actually the mold temperature can be as high as 350°F. Still, it is lower in temperature than the melt. So the heat from the higher temperature material flows into the lower temperature mold. **STK 910**

STK 911

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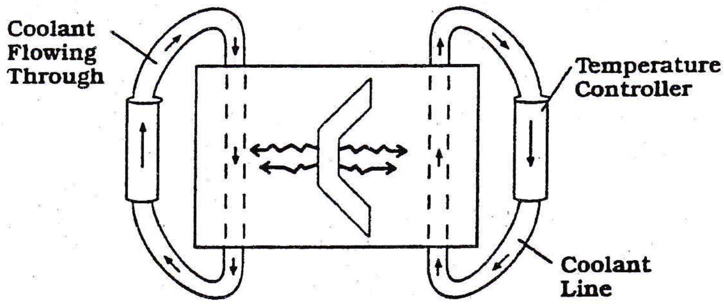
Removing Heat



Heat flows from the melt into the mold and is carried away by the coolant.

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Participant's Notes:

STK 912

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Mold Temperature Control

The temperature control lines maintain the temperature of the mold as it absorbs heat energy from the melt.

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Participant's Notes:

Removing Heat

Heat must be removed from the tool.

The heat energy that leaves the melt and enters the mold is then carried away by the coolant flowing through the temperature control lines. If it weren't for the constant flow of coolant, the mold would retain the absorbed heat, its temperature would rise, and the rate of heat transfer would slow down. The coolant serves to carry the heat out of the tool, thus maintaining its lower temperature, and encouraging faster cooling. **STK 911**

Mold Temperature Control

The temperature control lines maintain the temperature of the mold.

The mold temperature control lines maintain the temperature of the mold as it absorbs heat energy from the melt. Water or synthetic oil moved by a pump through the circulating passages in the mold carry away or introduce heat for maintaining the desired mold temperature. **STK 912**

STK 913

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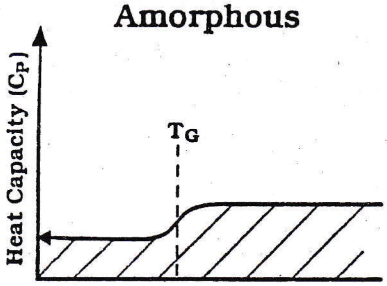
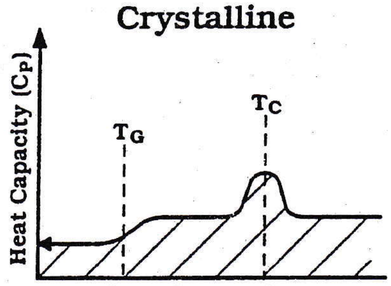
Heat Capacity Trace (On Cooling)

Amorphous



Crystalline



The heat capacity trace on cooling indicates how a polymer responds (gives off heat) as it is cooled.

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Participant's Notes: ____________________

STK 914

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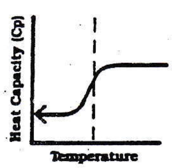
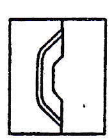
Cooling & Freezing Polymers

- Removing Heat

- Predicting Polymer Cooling



- Establishing Cooling Parameters



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Participant's Notes: ____________________

The heat capacity trace (on cooling) indicates how a polymer responds as heat is removed.

Heat Capacity Trace (On Cooling)

Just as the heat capacity trace on heating describes how a polymer responds as heat energy is applied, the heat capacity trace on cooling describes how a polymer responds as heat energy is removed. The heat capacity trace on cooling provides a blue print for polymer cooling and freezing. **STK 913**

Predicting Cooling Performance

Cooling & Freezing Polymers

The heat capacity trace on cooling provides important information on polymer cooling. It points out the important physical transitions the material goes through upon cooling, and it quantifies the amount of energy that must be removed before the material will go through these transitions and solidify into a part. **STK 914**

STK 915

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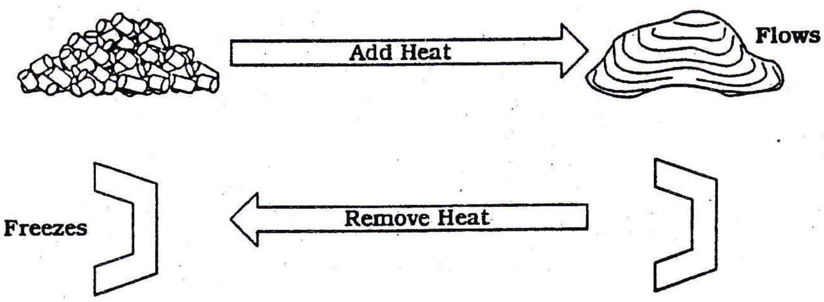
Polymer Cooling



The way a polymer responds upon cooling depends upon its structure and composition.

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Participant's Notes:

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Polymer Structure

Amorphous and crystalline polymers respond differently upon cooling:

- Amorphous polymers go through a glass transition.
- Crystalline polymers go through a crystallization process first, and then a glass transition.

9

Participant's Notes:

Each polymer responds differently on cooling.

Polymer Cooling

Just as polymers respond differently to **heating** depending on their composition and structure, they also respond differently to **cooling** depending on their chemical composition and molecular structure.

STK 915

Amorphous and crystalline polymers respond differently on cooling.

Polymer Structure

Polymers are comprised of many long chain-like molecules of repeating structural units. The way these molecular chains align themselves determines the structure of the polymer and ultimately has a great impact on the way the material responds to cooling. Because amorphous and crystalline polymers have very different structures, they also respond very differently to cooling: amorphous polymers go through a glass transition, while crystalline polymers go through a crystallization process first, then a glass transition. **STK 916**

STK 917

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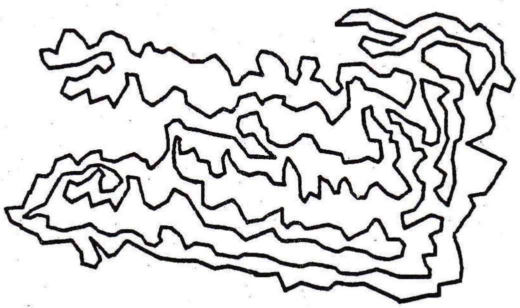
Amorphous Model



Amorphous polymers are comprised of a random entanglement of polymer chains.

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STK 918

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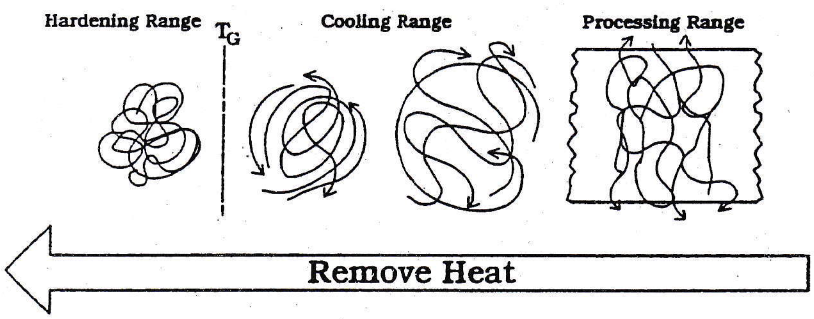
Cooling of Amorphous Resins



As heat is removed from an amorphous polymer, the molecular chains move closer together until the resin solidifies at its $\boxed{\text{Glass Transition Temperature } (T_G).}$

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Participant's Notes: ____

Amorphous polymers consist of a random entanglement of polymer chains.

Amorphous Model

To be "amorphous" means literally, to be without structure. Amorphous polymers are characterized by the randomness of their entangled polymer chains. This drawing is a simple model depicting amorphous structure. **STK 917**

In an amorphous resin the glass transition temperature is the key transition on cooling.

Cooling of Amorphous Resins

Above its glass transition temperature, the molecular chains that make up the amorphous polymer are loosely tangled and sliding back and forth making the polymer flow. As heat energy is removed from the polymer, these chains begin to slowly stop sliding back and forth, and instead start twisting, tangling, and collapsing in on themselves and their neighbors to form a tight structural "knot." It is below the glass transition temperature (T_G) that the material stops flowing and solidifies. **STK 918**

STK 919

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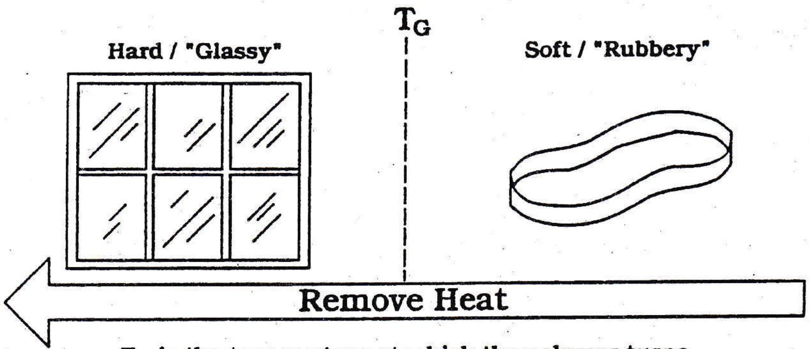
Glass Transition Temperature (T_G)



T_G is the temperature at which the polymer turns rubbery upon heating and glassy upon cooling.

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Participant's Notes: ____________________

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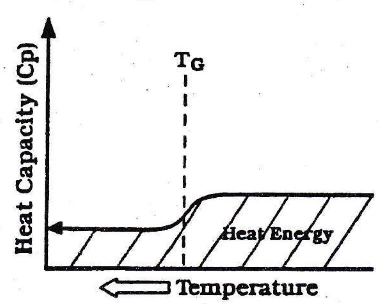
Heat Capacity Trace (On Cooling): Amorphous Resin



The heat capacity trace quantifies the amount of heat that must be removed on cooling.

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Participant's Notes: ____________________

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Glass Transition Temperature (T_G)

At T_G the polymer turns rubbery upon heating and glassy upon cooling.

Every polymer has a glass transition temperature (T_G). It is the temperature at which a material turns rubbery upon heating and glassy upon cooling. Above T_G, an amorphous material is soft, rubbery, and pliable. Below T_G, an amorphous polymer becomes hard, like glass, and structurally sound. The terms "rubbery" and "glassy" are actually referring to rubber and glass. Rubber has a very low glass transition temperature - below 0°F - so it is most often above its T_G and therefore rubbery and soft. Glass, on the other hand, has very high glass transition temperature - over 1000°F - so it is most often below its T_G and therefore glassy and rigid. **STK 919**

Heat Capacity Trace (On Cooling)/Amorphous Resin

The heat capacity trace (on cooling) quantifies the amount of heat removed on cooling.

The shape of the heat capacity trace on cooling is the same for all amorphous polymers; however the actual coordinates change with each individual resin and resin grade. The trace quantifies how much heat energy must be removed to decrease the temperature of the polymer below its T_G. Notice that the curve is constant, then drops dramatically, then levels off again. This dramatic drop indicates the additional heat energy given off by the polymer to allow it to freeze. The material's T_G falls on that slope, where sufficient heat energy has been given off for the material to begin to solidify. **STK 920**

STK 921

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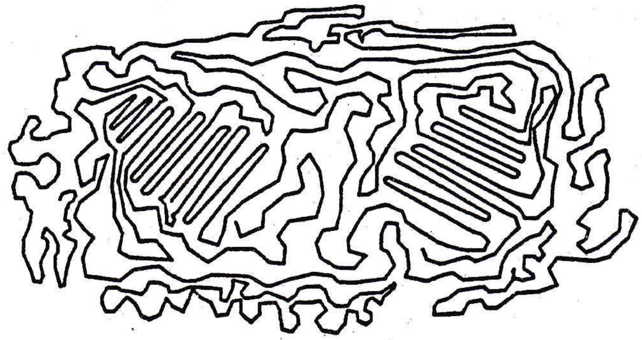
Crystalline Model



Crystalline Polymers are comprised of a random entanglement of polymer chains with areas of order.

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Participant's Notes:

STK 922

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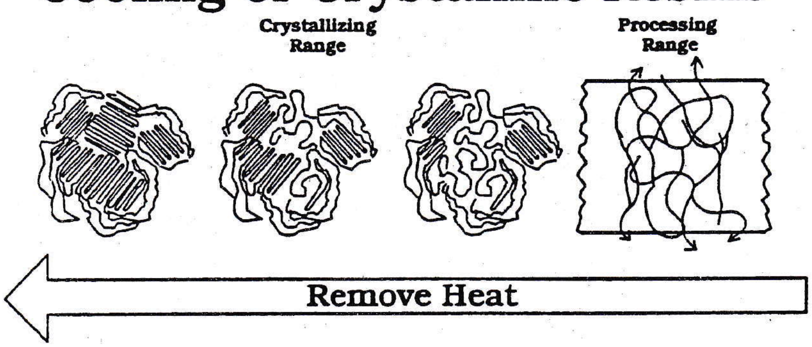
Cooling of Crystalline Resins



As heat is removed from a crystalline polymer, the molecular chains move closer together, align themselves, and begin to form crystals.

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Participant's Notes:

Crystalline Model

Crystalline polymers consist of random entanglement of polymer chains with areas of order called crystal regions.

Crystalline polymers respond differently than amorphous polymers to cooling due to their structural difference. Whereas amorphous polymers are comprised of a random mass of molecular chains, crystalline polymers contain areas of order in which their chains lie side-by-side in a regular fashion. These regions of order where the chains line up and lie closely together are referred to as crystallinity. This drawing is a simple model depicting crystalline structure.

STK 921

Cooling of Crystalline Resins

As heat is removed from a crystalline polymer, the molecular chains move closer together, align themselves, and begin to form crystals.

In the melt state, a crystalline polymer is above its melting temperature and actually amorphous. Its molecular chains are flowing in a random fashion. As heat is removed, the polymer chains begin to slow down and move closer together until there is no longer sufficient heat energy to keep them in motion. As the chains move closer together, they begin realigning themselves into tight, orderly crystals.

STK 922

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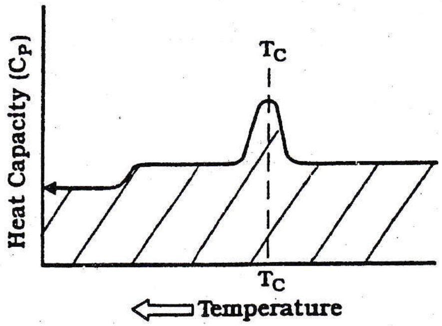
Crystallization Temperature



The Crystallization Temperature (T_C) indicates the temperature at which the polymer starts building crystallinity.

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Participant's Notes:____

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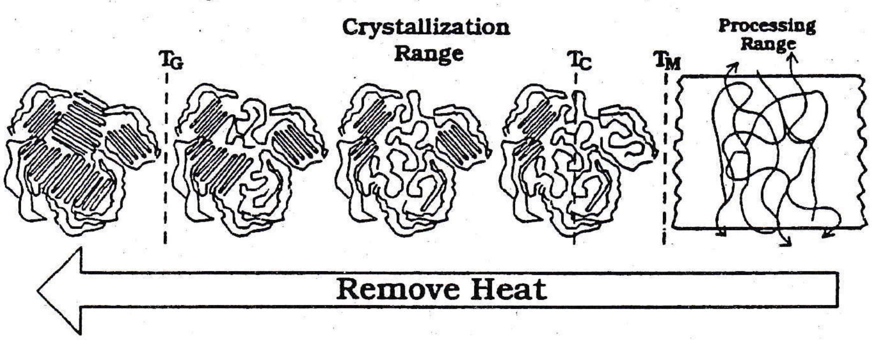
Crystallization Process



A polymer will build crystallinity below T_M and above T_G and is most rapid at T_C.

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Participant's Notes:____

Crystalline polymers build crystallinity at the crystallization temperature.

Crystallization Temperature

The crystallization temperature is the temperature at which rapid crystallization occurs on cooling. Crystallization temperature (T_C) is higher than glass transition temperature yet lower than melting temperature. At T_C, there is not enough heat energy to keep the crystalline material flowing, but there is enough heat energy available to allow the resin's molecular chains to begin lining up in an orderly fashion. Below T_G, however, there is insufficient heat in the polymer to allow the molecular chains to move. Below T_G the polymer is frozen.

STK 923

Crystalline polymers will build crystallinity between T_M and T_G.

Crystallization Process

A crystalline material will build crystallinity rapidly at T_C and continue to crystallize until it cools below T_G. Crystallinity is rate dependent: the more slowly the polymer cools, the greater the degree of crystallinity; the more quickly the polymer cools, the lesser the degree of crystallinity. This is why cycle time is so crucial when molding crystalline resins. From T_M to T_G is the polymer's crystallization range. Each crystalline polymer has its own crystallization range; some materials crystallize more quickly than others.

STK 924

STK 925

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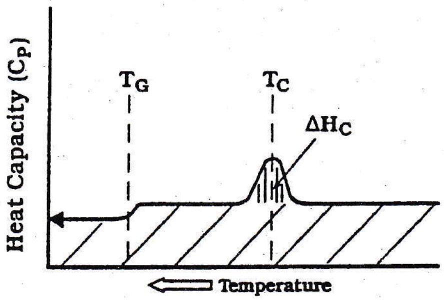
Heat Capacity Trace (On Cooling):

Crystalline Resin



The Heat Capacity Trace (On Cooling) for a Crystalline resin also indicates the $\boxed{\text{Heat of Crystallization } (\Delta H_C).}$

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Participant's Notes:

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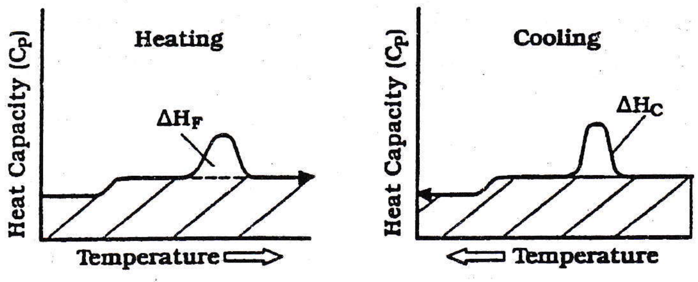
Heat of Crystallization (ΔH_C)



The Heat of Crystallization (ΔH_C) is the amount of energy that is given off as the polymer builds crystallinity on cooling.

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Participant's Notes:

The heat capacity trace (on cooling) for a crystalline resin indicates the heat of crystallization.

Heat Capacity Trace (On Cooling)/Crystalline Resin

The heat capacity trace (on cooling) for a crystalline resin indicates how much cooling is needed to lower the temperature of the polymer. The heat of crystallization (ΔH_c) indicates the amount of heat that is given off as crystals form. **STK 925**

The heat of crystallinity is the amount of energy that is given off as the polymer builds crystallinity.

Heat of Crystallization (ΔHc)

The polymer's heat capacity trace on cooling quantifies the amount of energy that must be given off for crystallization. You may recall it takes additional energy, the heat of fusion (ΔH_f), before the crystals in the crystalline polymer will melt. During cooling, all that additional energy must be released for the polymer to build crystallinity. This additional energy is the polymer's heat of crystallization (ΔH_c). It is the amount of energy that is given off as the polymer builds crystallinity. **STK 926**

STK 927

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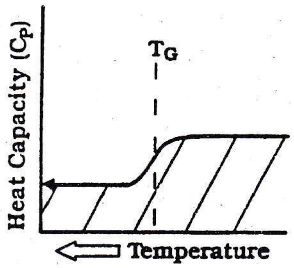
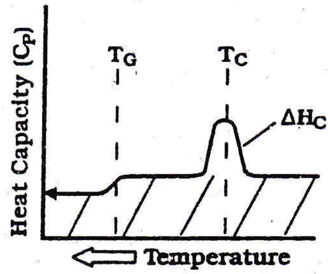
Polymer Cooling Requirements

Amorphous



Crystalline



Specific cooling requirements are established from values derived from each polymer's own heat capacity trace (on cooling).

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Participant's Notes:

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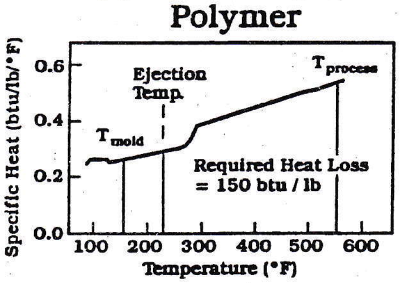
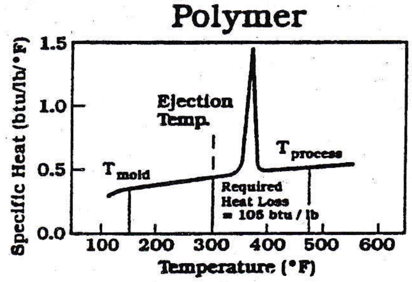
Cooling Requirements

Typical Amorphous Polymer



Typical Crystalline Polymer



The total energy that must be removed before ejection can be calculated from the polymer's heat capacity trace (on cooling).

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Participant's Notes:

Summary

Consult the heat capacity trace to determine a material's cooling requirements.

Polymer Cooling Requirements

General cooling characteristics are determined by the structure of the material: amorphous or crystalline. But each resin has its own specific cooling behavior due to its own particular structure and composition. Specific cooling requirements are determined by values derived from each polymer's heat capacity trace on cooling. Certain amorphous polymers cool more quickly than others. This information can be determined by comparing each polymer's heat capacity trace. And certain crystalline resins take longer to crystallize than others. Again, this information can be determined by comparing each polymer's heat of crystallization found on its heat capacity trace. **STK 927**

The actual heat and cooling requirements are calculated from the heat capacity trace.

Cooling Requirements

A material's heat capacity trace on cooling allows you to calculate the total energy that must be removed before ejecting the part. To calculate the cooling requirement for an amorphous polymer, you need to identify the processing and ejection temperatures, then calculate the area under the trace between those two temperatures. For example, this typical amorphous polymer has a processing temperature of 560°F and an ejection temperature of 225°F. This change in temperature can be multiplied by the polymer's heat capacity to determine the total amount of heat energy that must be removed from the polymer before ejection. The amount of energy that must be removed from the polymer for it to drop from 560°F to 225°F is 150 BTUs/lb.

To calculate the cooling requirement for a crystalline polymer you must take into account the heat of crystallization. As with the amorphous polymer, you must first identify the material's processing and ejection temperatures and calculate the area under the trace between these two temperatures. Then you must add the polymer's heat of crystallization to get the total cooling requirement. For example, this typical crystalline polymer has a processing temperature of 480°F and an ejection temperature of 300°F. The amount of energy that must be removed from the polymer for it to drop from 480°F to 300°F is 92 BTUs/lb. But the material must also give off an additional 13 BTUs/lb for maximum crystallinity. So the total cooling requirement is 105 BTUs/lb. **STK 928**

STK 929

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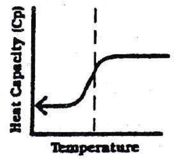
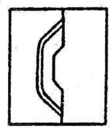
Cooling & Freezing Polymers

- Removing Heat
- Predicting Cooling Performance



- Establishing Cooling Parameters



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Participant's Notes:________________________________

STK 930

GE Plastics

Cooling Parameters

- Mold Temperature
- Thermal Conductivity

9

Participant's Notes:________________________________

Cooling Parameters

Establishing cooling parameters.

Cooling & Freezing Polymers

Having understood how to predict cooling performance from the heat capacity trace (on cooling) we can now use this information to establish cooling parameters.

STK 929

Two cooling parameters.

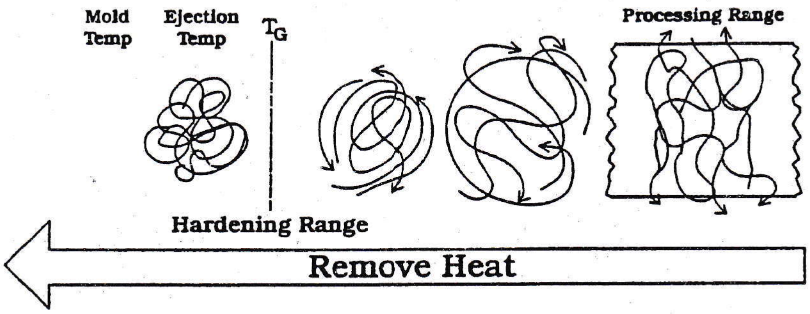
Cooling Parameters

The two important parameters in cooling are the temperature of the mold and the thermal conductivity of the melt and the mold.

STK 930

GE Plastics

Cooling Range: Amorphous Resin



- The mold temperature must be below T_G to solidify the part.

9

Participant's Notes: ______________________________

GE Plastics

Cold Molds

- Difficult Fill
- Higher Injection Pressure
- Higher Melt Temperature
- Difficult Ejection (Ejection Stress)
- Higher Molded-in Stress
- Tendency for Voids in Thicker Sections

Heated Molds

- Easier Fill
- Lower Injection Pressure
- Lower Melt Temperature
- Easier Ejection (Lower Ejection Stress)
- Lower Molded-in Stress
- Tendency for Sinks in Thicker Sections
- Improved Surface Finish

9

Participant's Notes: ______________________________

Cooling Range: Amorphous Resin

The mold temperature must be below T_G to solidify the part.

Amorphous polymers go through a glass transition upon cooling, becoming solid below T_G. Above T_G, the polymer is still flowing. Therefore the temperature of the mold must be below T_G to allow the part to solidify. From the heat capacity trace on cooling, the converter can determine how much heat must be removed to drop the temperature below T_G. The polymer's ejection temperature is set just below T_G to allow for sufficient cooling and minimum cycle time.

STK 931

Cold Molds/Heated Molds

Cold molds mean faster cooling and therefore faster cycle time, but cold molds present certain disadvantages to the converter. Cold molds are more difficult to fill and therefore require higher injection pressure and melt temperature. It is more difficult to eject from cold molds, because the part tends to shrink tightly to a cold mold upon cooling. This causes ejection stress. Cold molds can also cause higher molded-in stress and a tendency for voids in thick sections of the part.

Heated molds provide for easier processing than cold molds.

Heated molds, on the other hand, are easier to fill. They require lower injection pressure and melt temperature. Ejection is easier thus minimizing ejection stress. Parts tend to have lower molded-in stress. Still, heated molds can tend to cause sinks in thicker sections. But the part itself, has an improved surface finish. Ultimately, a heated mold is preferable to a cold mold. But cycle time is the overriding consideration when determining mold temperature.

STK 932

STK 933

GE Plastics

Thermal Conductivity

- Thermal Conductivity indicates the rate at which heat will be transferred through the resin.
- Plastics with higher Thermal Conductivity lose heat faster.

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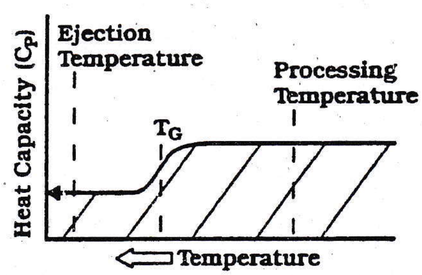
Participant's Notes:

STK 934

GE Plastics

Part Cooling: Amorphous Resin



- The cooling time depends on the amount of heat that must be removed and the rate at which it can be removed.
- The temperature of the polymer must be reduced from its processing temperature to its ejection temperature.

9

Participant's Notes:

Plastics with higher thermal conductivity lose heat faster.

Thermal Conductivity

It is the thermal conductivity of the material that determines the rate at which the heat can be removed. It is a measure of the ability of the resin to transfer heat. Plastics with higher thermal conductivity lose heat faster and therefore cool more quickly. Plastics with lower thermal conductivity lose heat more slowly, and therefore cool more slowly. **STK 933**

Amorphous resins must be below T_G.

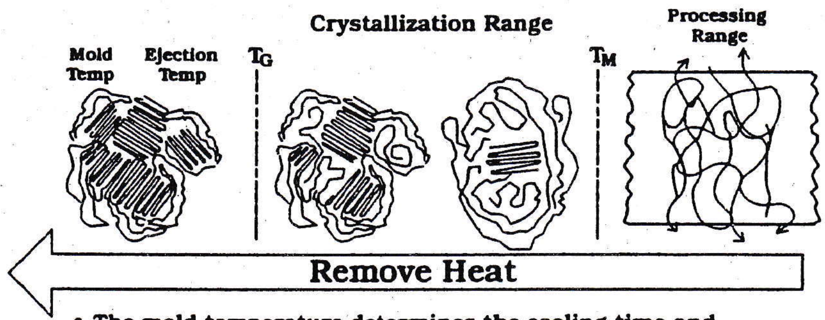
Part Cooling: Amorphous Resin

After entering the mold, the material must be reduced from its processing temperature to its ejection temperature. The amount of time it takes to reach its ejection temperature depends on the amount of heat that must be removed and the rate at which it can be removed. Just as the amount of energy that must be removed depends on the resin, so does the rate of removal depend on the resin being molded. **STK 934**

STK 935

GE Plastics

Crystallization Cooling Range



- The mold temperature determines the cooling time and therefore the degree of crystallinity.
- Cooling through the crystallization range too quickly will result in reduced crystallinity (quenching).

9

Participant's Notes:

STK 936

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Degree of Crystallinity

- The colder the mold - the faster the cooling - the lesser the degree of crystallinity.
- The hotter the mold - the slower the cooling - the greater the degree of crystallinity.

9

Participant's Notes:

Degree of crystallinity is determined by rate of cooling.

Crystallization Cooling Range

Crystalline cooling is more difficult to predict than amorphous cooling due to the process of crystallization. As with the amorphous resin, the rate at which the polymer will cool depends on its thermal conductivity. But with crystalline polymers, the need to allow the polymer to crystallize presents its own problems. If cooled too quickly, the crystalline polymer may cool through its crystallization range without building crystallinity. This is called quenching the polymer. Cold molds can cause quenching and insufficient polymer crystallinity, while heated molds tend to allow more crystallinity and a reduced chance of quenching. **STK 935**

The degree of crystallinity is related to the mold temperature.

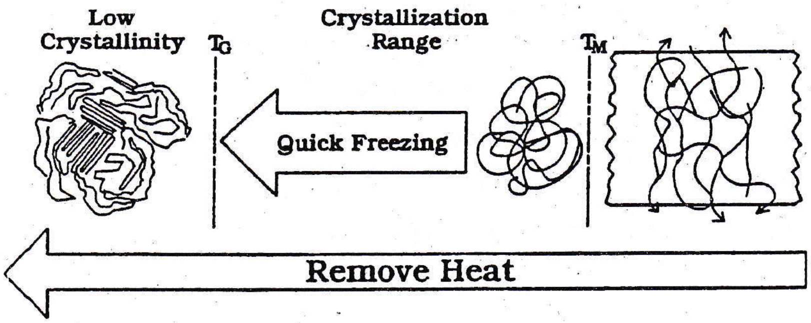
Degree of Crystallinity

As stated earlier, crystallinity is rate dependent: so the colder the mold, the more quickly the crystalline polymer cools, and the lesser the degree of crystallinity. The hotter the mold, the more slowly the crystalline polymer cools, and the greater the degree of crystallinity. **STK 936**

STK 937

GE Plastics

Cold Mold ➡ Lower Crystallinity



A cold mold freezes the polymer quickly not giving it a chance to fully crystallize. (Quenching)

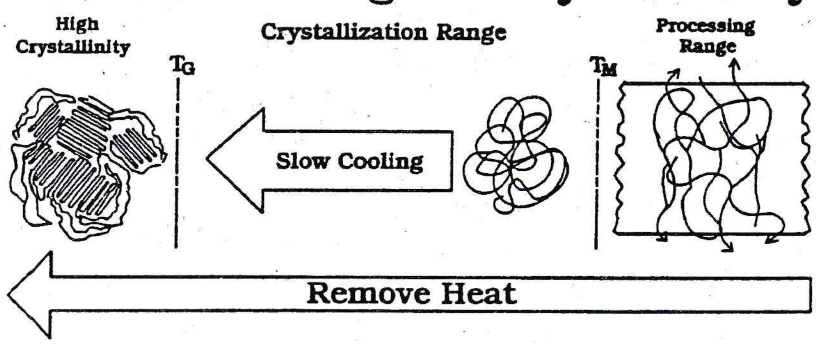
9

Participant's Notes: ____________________

STK 938

GE Plastics

Hot Mold ➡ Higher Crystallinity



A hotter mold cools the polymer more slowly, resulting in more crystallinity.

9

Participant's Notes: ____________________

Cold Mold/Lower Crystallinity

A cold mold doesn't allow the crystalline polymer to fully crystallize (quenching).

Heat flows from the body of a higher temperature to the body of a lower temperature. The rate of heat flow depends on the difference in the temperatures of the two bodies: the greater the difference, the faster the flow of heat. So it follows that a cold mold will cause the polymer to cool more quickly. But if the mold is too cold, it could cause the crystalline polymer to cool too quickly, freezing it before it has a chance to fully crystallize. **STK 937**

Hot Mold/Higher Crystallinity

A hotter mold cools the polymer more slowly allowing it to build more crystallinity.

If the mold is heated, the polymer cools more slowly and the crystalline polymer has time to build more crystallinity.

STK 938

STK 939

GE Plastics

Optimum Crystallinity

Optimum Crystallinity provides greater predictability in terms of:

- Chemical Resistance
- Dimensional Stability
- Heat Deflection Temperature (HDT)
- In-mold Shrinkage

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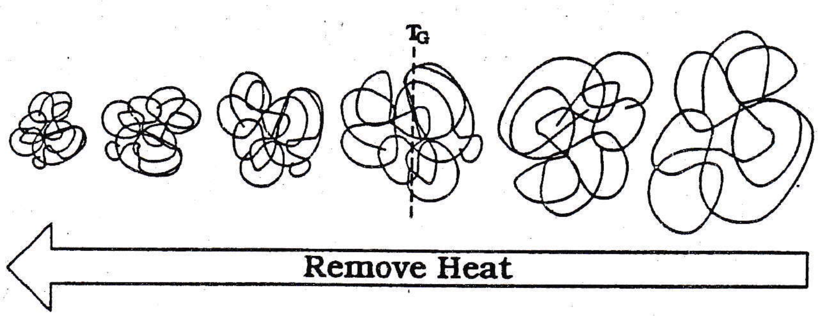
Participant's Notes:

STK 940

GE Plastics

Shrinkage



Shrinkage is the volume reduction caused by the decrease in the amount of space between polymer chains upon cooling.

9

Participant's Notes:

Optimum crystallinity provides optimum part performance.

Optimum Crystallinity

Crystalline polymers are often chosen for performance characteristics, such as chemical resistance, that are directly related to their crystallinity. Optimizing crystallinity will optimize part performance. In addition, optimum crystallinity provides greater dimensional stability due to the reduced chance of post-mold shrinkage. Higher crystallinity results in higher in-mold shrinkage. There is less chance for shrinkage in application, providing for greater dimensional stability and a higher heat deflection temperature (HDT). **STK 939**

Shrinkage is the volume reduction caused by the decrease in the amount of space between polymer chains upon cooling.

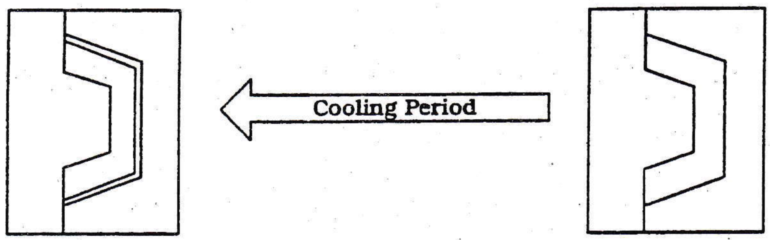
Shrinkage

Cooling a polymer melt causes a volume reduction referred to as shrinkage. During processing, heat is added to a polymer creating enough space between the molecular chains to allow them to slide past each other and flow. This space causes an increase in the volume of the material in its melt state. Upon cooling, the molecular chains slow down and move back together again, causing a reduction in the space between the molecules and therefore a reduction in the volume of the material. This kind of shrinkage occurs in both amorphous and crystalline polymers. **STK 940**

STK 941

GE Plastics

Shrinkage/Unfilled Amorphous Resin



Unfilled amorphous polymers tend to exhibit isotropic shrinkage.

9

Participant's Notes:

STK 942

GE Plastics

Resin Shrinkage Values

Each polymer has its own shrinkage values that must be accomodated for when designing the tool.

These values can be affected by:

- Resin Type
- Direction of Flow
- Part Wall Thickness
- Flow Length
- Cavity Pressure
- Fillers
- Melt Temperature

9

Participant's Notes:

Amorphous polymers tend to shrink evenly in all directions.

Shrinkage/Unfilled Amorphous Resin

Shrinkage in an amorphous polymer is normally consistent and therefore easier to predict and accommodate for in tooling. Unfilled amorphous materials tend to shrink the same in all directions. This type of even shrinkage is called isotropic shrinkage.

STK 941

Each polymer has its own shrinkage value that must be accomodated for when designing the tool.

Resin Shrinkage Values

Each polymer has its own shrinkage values that are reported on the material data sheet. These values can be affected by such factors as the particular grade of resin being processed, whether it contains fillers, or the direction of flow. Filled materials, for example, shrink more in the cross flow and less in the flow direction. This kind of uneven shrinkage is called anisotropic shrinkage. Consequently, the tool must be designed to accommodate for shrinkage when molding a reinforced polymer. Resin shrinkage values can also be affected by factors that affect the rate of cooling such as the part wall thickness, the flow length, the cavity pressure, or the temperature of the melt.

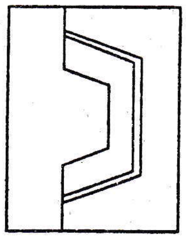
STK 942

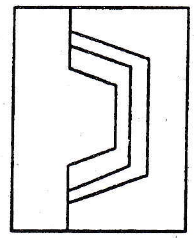
STK 943

GE Plastics

Shrinkage Comparison

Amorphous | **Crystalline**





Crystalline polymers shrink more than amorphous polymers due to the additional volume reduction caused by crystallization.

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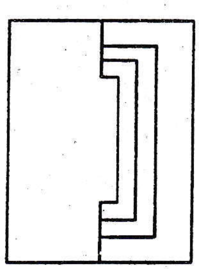
Participant's Notes:

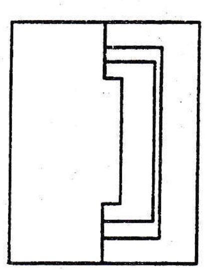
STK 944

GE Plastics

Wall Thickness

Thicker wall sections take longer to cool, and therefore shrink more.





Wall thickness affects the amount of shrinkage in amorphous and crystalline resins.

9

Participant's Notes:

Shrinkage Comparison

Crystalline polymers shrink more than amorphous polymers.

Crystalline materials tend to shrink more than amorphous materials due to the presence of crystallinity. In the crystalline regions, the molecules lie very close together in an orderly fashion. The polymer chains are packed more tightly together in these regions than the chains in an amorphous structure. Consequently there is less space between the molecules causing an additional reduction in volume when the material cools from a fluid state to a solid. If molding the same part, the tool cavity for a crystalline material will be slightly larger than the cavity for an amorphous material. Also, shrinkage in a crystalline polymer often has a greater range making it more difficult to accurately predict. **STK 943**

Wall Thickness

Shrinkage is affected by wall thickness.

The thickness of the part wall also affects the rate of cooling and therefore the amount of shrinkage: the thicker the wall section, the longer it takes to cool, and the higher the amount of shrinkage. This is true in both amorphous and crystalline resins. When processing crystalline polymers, thicker wall sections take longer to cool, creating more crystallinity and therefore more shrinkage. When processing amorphous polymers, thicker wall sections result in more shrinkage as the molecules have more time to move closer together. Maximizing in-mold shrinkage minimizes the chance of post-mold distortion. **STK 944**

STK 945

GE Plastics

Non-uniform Walls

- Non-uniform wall sections cause uneven cooling resulting in uneven shrinkage.
- Uneven shrinkage can result in high molded-in stress, warpage, voids, and sink marks.

9

Participant's Notes:

STK 946

GE Plastics

Understanding Cooling and Freezing Polymers

9

Participant's Notes:

Uniform wall thickness is important to avoid problems.

Non-uniform Walls

When a part contains varying wall thickness, thinner sections will cool more quickly than thicker sections. Once the thinner section has cooled, it freezes solid thus hindering the adjacent thicker section, which is still cooling, from shrinking freely. The result is a high degree of molded-in stress where the thin and thick sections meet. It is the stress at the juncture of high and low shrinkage areas that may cause a part to warp.

Uneven shrinkage does not always result in high stress. It may instead result in a void. When the already cooled section will not yield to the still cooling thicker section, the shrinking action may create a void.

Or the shrinking action in the still cooling thick section may compensate by creating a sink mark on the surface of the part. A sink mark is nothing more than a void on the surface.

Uniform wall thickness promotes even cooling and even shrinkage thus reducing such potential defects as molded-in stress, warpage, voids, or sink marks. **STK 945**

Summary and Performance Feedback

Understanding Cooling & Freezing

The cooling and freezing of the polymer is as complicated as the heating, softening, melting, flowing, and forming of the material. And it is just as important that it be understood completely and carried out correctly. By using the heat capacity trace on cooling as a blue print, the toolmaker and the converter can be certain that they are manufacturing the best possible parts in terms of such things as crystallinity, stress, and surface appearance. And they can be certain they are processing parts efficiently in terms of expended energy, part defects, and cycle time. **STK 946**

STK 947

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How is a thermoplastic part cooled?

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Participant's Notes:

STK 948

GE Plastics

How do amorphous and crystalline polymers respond differently upon cooling?

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Participant's Notes:

STK 949

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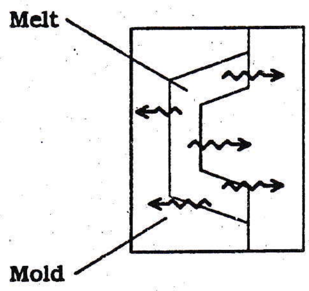
Cooling



Cooling results from the flow of heat from the higher temperature melt to the lower temperature mold.

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Participant's Notes:

STK 950

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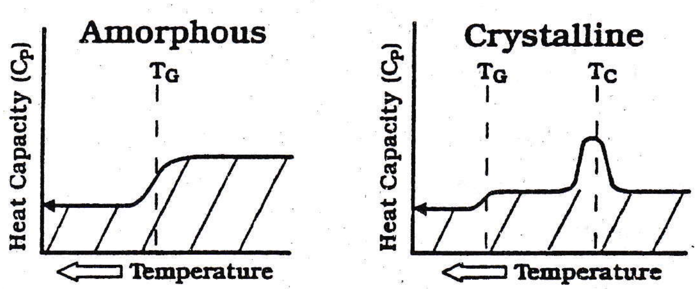
Polymer Cooling Requirements



Amorphous polymers go through a glass transition while crystalline polymers go through a crystallization process, then a glass transition.

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Participant's Notes:

STK 951

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How does mold temperature and rate of cooling affect a crystalline polymer?

9

Participant's Notes:

STK 952

GE Plastics

Degree of Crystallinity

- The colder the mold - the faster the cooling - the lesser the degree of crystallinity.
- The hotter the mold - the slower the cooling - the greater the degree of crystallinity.

9

Participant's Notes:

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Module 10

Design & Performance

- Processing
- Design
- Materials

9

Participant's Notes:

Module 9

Performance Feedback

1. Describe how a thermoplastic part is cooled.
2. Describe how amorphous polymers and crystalline polymers respond differently during cooling.
3. Describe the variables within each of the following factors when establishing cooling parameters for crystalline and amorphous resins: mold temerature, cooling period and shrinkage.
4. Describe the cooling parameters for a resin you are currently working with.