



Sharing The Knowledge

Module 2

Polymer Structure



Module 2

Polymer Structure

- Types of Structure
- Property Comparison
- Processing
- Tooling

2

Participant's Notes: _____



Properties of Polymers Depend Upon:

- **Chemical Composition of the Monomers**
- Shape and Length of the Polymer Chains
- Alignment of the Polymer Chains

2

Participant's Notes: _____

Introduction

Polymer Structure

As a group, thermoplastic materials have very distinct structural characteristics that make them different from other materials. But there are structural differences between certain thermoplastic materials as well. Module 2 explores the difference between amorphous and crystalline resins, and describes how this structural difference will affect processing and tooling. In discussing polymer structure, we'll also define glass transition temperature and melting temperature - two very important concepts.

STK 201

Objectives:

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

- Describe differences between amorphous and crystalline polymers.
- Compare the properties of amorphous and crystalline polymers.
- Define T_G and T_M .
- Describe the behavior of amorphous polymers vs temperature.
- Describe the behavior of crystalline polymers vs temperature.
- Describe the implications of structure on processing and tooling.
- Identify which resins you are working with that are crystalline and which are amorphous.
 - Identify T_G of the amorphous resins.
 - Identify T_G and T_M of the crystalline resins.

Factors That Affect Properties

The chemical composition of the polymer molecule determines the properties of the resin. Polyethylene, for example, has different properties than polypropylene. Polyethylene is made up of ethylene monomers, while polypropylene is made up of propylene monomers. The chemical composition of the monomers makes each unique.

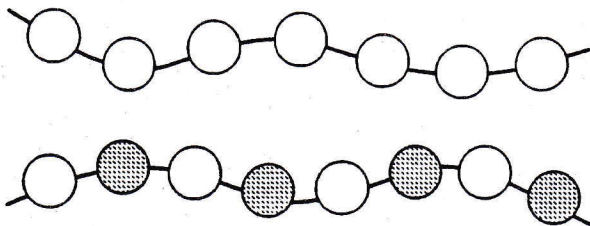
STK 202

**Chemical composition
affects properties.**



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Polymer



A Chemical Compound Formed by Many Monomers Linking to Form Larger Molecules That Contain Repeating Structural Units

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Participant's Notes: _____



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Properties of Polymers Depend Upon:

- Chemical Composition of the Monomers
- Shape and Length of the Polymer Chains
- Alignment of the Polymer Chains

2

Participant's Notes: _____

A polymer is formed by many monomers linking to form larger molecules.

Polymer

A polymer is a chemical compound formed by many small molecular units linking together to form a large, chain-like molecule. You can imagine the polymer molecule as a long strand of pearls and each pearl as a tiny structural unit referred to as a monomer. Each polymer molecule contains thousands of monomers.

STK 203

Shape of polymer chains affect polymer properties.

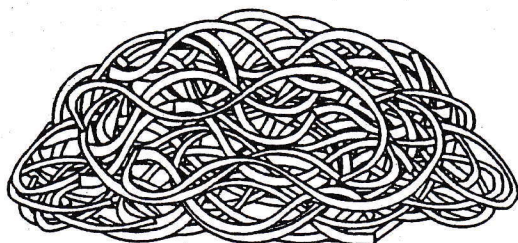
Properties of Polymers Depend upon:

In addition to chemical composition, polymer properties also depend upon the shape of the polymer chains. Polymers can be either linear or branched depending on the catalyst used. Branching affects the flow characteristics of the material. For example, high density polyethylene, a resin built of a linear polymer, flows very easily and is suitable for most injection molding applications. Low density polyethylene is built of branched polymers and consequently flows more stiffly, making it more suitable for blow molding and extrusion.

STK 204



Spaghetti-like Structure



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Participant's Notes: _____



Properties of Polymers Depend Upon:

- Chemical Composition of the Monomers
- Shape and Length of the Polymer Chains
- Alignment of the Polymer Chains

2

Participant's Notes: _____

Random alignment and entanglement of polymer chains.

Spaghetti-like Structure

Very long molecules create a structural mass of bending and twisting molecules that resembles cooked spaghetti - a random entanglement of polymer chains collapsing in on themselves and their neighbors.

STK 205

Alignment affects certain polymer properties.

Properties of Polymers Depend upon:

We have briefly reviewed how polymer properties are affected by the chemical composition and shape of the polymer chains. During this module, we will focus on learning how the alignment of the polymer chains determines certain polymer properties.

STK 206



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Polymer Morphology

Refers to the Structure
of the Polymer Material

- Amorphous
- Crystalline

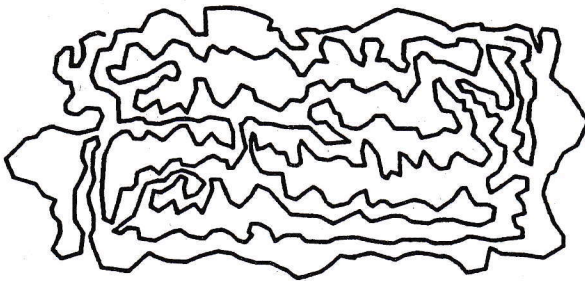
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Participant's Notes: _____



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Amorphous Model



A Random Entanglement
of Polymer Chains

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Participant's Notes: _____

Types of Structure

Polymer morphology defines physical structure.

Polymer Structure

Polymer morphology refers to the structure of the material. The way the molecular chains align themselves determines the structure of the polymer. Polymers can be either amorphous or crystalline.

STK 207

Amorphous structure has no order.

Amorphous Model

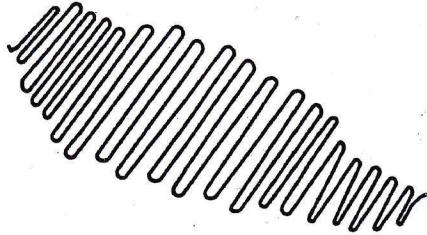
"Amorphous" literally means without structure. Amorphous polymers are characterized by the randomness of their entangled polymer chains. This simple model depicts an amorphous structure.

STK 208



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Crystalline Model



Areas of Order in which
Molecular Chains Lie Side by Side
in a Regular Fashion

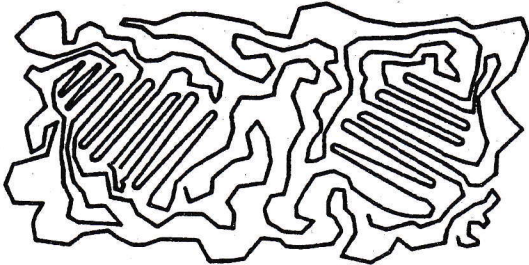
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Participant's Notes: _____



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Crystalline Polymers Are Actually Semi-Crystalline



Regions of Crystallinity in an
Otherwise Amorphous Mass

2

Participant's Notes: _____

Some polymers develop areas of order called crystals.

Crystalline Model

Crystalline polymers, on the other hand, contain areas of order in which the molecular chains lie side-by-side in a regular fashion. These regions of order where the molecular chains line up and lie tightly together are sometimes referred to as "crystals." The presence of these crystals is referred to as crystallinity. This simple model depicts the structure of a crystal.

STK 209

Semi-crystalline polymers actually contain amorphous and crystalline regions.

Crystalline Polymers Are Actually Semi-crystalline

Crystalline polymers are not crystalline throughout, but contain regions of crystallinity in an otherwise amorphous mass. Still, due to the presence of crystallinity, they are considered to be crystalline in structure as opposed to amorphous. This simple model depicts crystallinity in an amorphous mass.

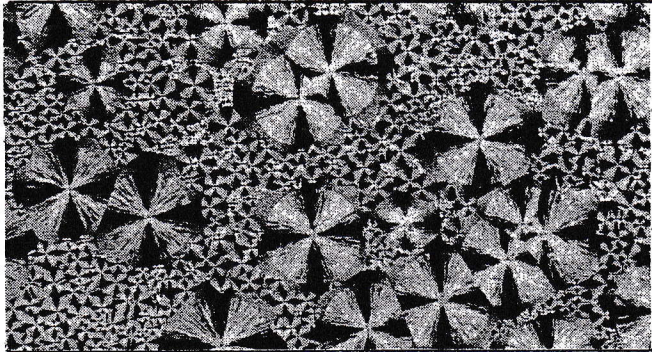
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STK 211

Actual Polymer Structure



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Participant's Notes: _____

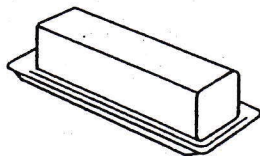


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STK 212

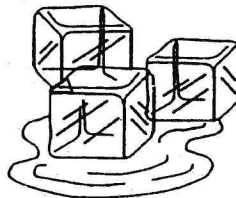
Property Comparison

Amorphous



**Broad
Softening Range**

Crystalline



**Sharp
Melting Point**

2

Participant's Notes: _____

Each of the round structures is comprised of crystals and contains both crystalline and amorphous material.

Actual Polymer Structure

Here is a cross section of an actual crystalline polymer, polyethylene. The material has been photographed using polarized light to reveal its crystalline structure. The crystalline regions resemble ribbons growing from a central core. A pattern arises from the presence of spherulites which are those regions where the chains have aggregated into spheres. The spheres vary in size and flatten out as they meet other spheres in the material. It is important to remember that we are using a two-dimensional photograph to depict three-dimensional polymer structure. The polymer is actually three-dimensional, as are its molecular chains and its crystal spheres. **STK 211**

Property Comparison

Crystalline and amorphous polymers melt differently.

Property Comparison

As we have seen and will continue to see, a polymer's structure can be defined either in terms of its molecular composition, or by the way its structure manifests itself in terms of material properties. For example, an amorphous material has a broad softening range while a crystalline material has a sharp melting point. An amorphous polymer will soften gradually over a wide temperature range the same way butter softens gradually. Crystalline polymers, however, melt quickly the same way ice remains solid below its freezing point then turns immediately to liquid when raised just above that temperature. **STK 212**



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STK 213

Amorphous Polymers

- Are Structural Below the Glass Transition Temperature (T_G) and Rubbery Above It
- Rely on Physical Entanglements of the Molecular Chains for Structural Properties Below T_G

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Participant's Notes: _____



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STK 214

Glass Transition Temperature (T_G)

That Temperature at Which
a Polymer Structure Turns
Rubbery upon Heating and
Glassy upon Cooling

2

Participant's Notes: _____

Property Comparison

Amorphous

Each amorphous polymer exhibits a unique temperature where properties change dramatically.

Amorphous Polymers

Amorphous polymers can be defined in terms of their physical structure and by the way that structure is manifested in terms of properties. An amorphous polymer is structural or rigid below its glass transition temperature and soft or rubbery above it. **STK 213**

The polymer changes from a glassy to rubbery state at the glass transition temperature.

Glass Transition Temperature (T_g) - Definition

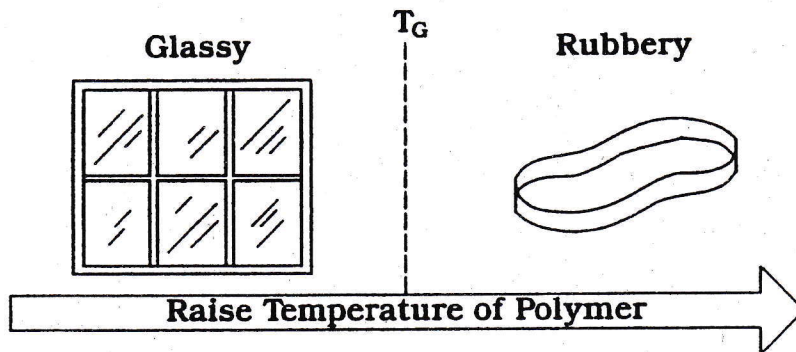
Every polymer has a glass transition temperature. It is the temperature at which the material turns rubbery upon heating and glassy upon cooling. **STK 214**



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STK 215

Glass Transition Temperature (T_G)



Both amorphous and crystalline polymers exhibit a glass transition temperature.

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Participant's Notes: _____



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STK 216

Amorphous Polymers

- Are Structural Below the Glass Transition Temperature (T_G) and Rubbery Above It
- Rely on Physical Entanglements of the Molecular Chains for Structural Properties Below T_G

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Participant's Notes: _____

Amorphous and crystalline polymers exhibit a glass transition temperature.

Amorphous polymers get their properties from the entanglement of amorphous chains.

Glass Transition Temperature (T_g) - Illustration

Below T_g , an amorphous polymer is hard, like glass, and structurally sound. Above T_g , an amorphous material begins to soften, becoming rubbery and increasingly pliable. The terms "glassy" and "rubbery" are actually referring to glass and rubber. Glass is an amorphous polymer, though not a plastic. It has an extremely high glass transition temperature - over 1000°F. So it is most often below its T_g and therefore "glassy" and rigid. Rubber is a polymer as well as a thermoset. It has a very low glass transition temperature - below 0°F. So it is most often above its T_g and therefore "rubbery" and soft.

Perhaps you've noticed the way a garden hose will "freeze" and become rigid when left outside in the winter months. That same hose will then soften in the spring, becoming increasingly rubbery as the summer days approach and the temperature begins to rise. During the winter, the hose was well below its glass transition temperature and therefore "glassy" and rigid. In the summer time, it was well above its glass transition temperature and therefore "rubbery" and soft. An amorphous material exhibits the same kind of behavior.

STK 215

Amorphous Polymers

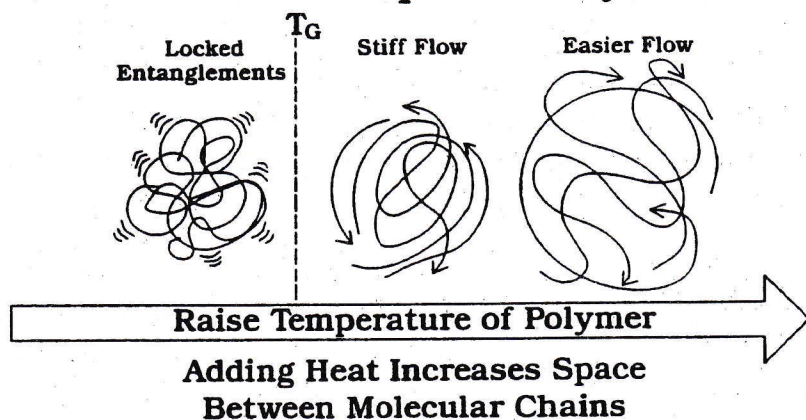
The way an amorphous polymer behaves above and below T_g is determined by the random entanglement of its molecular chains. Properties will be lost if the chain length is shortened (degraded).

STK 216



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Model of Amorphous Polymers



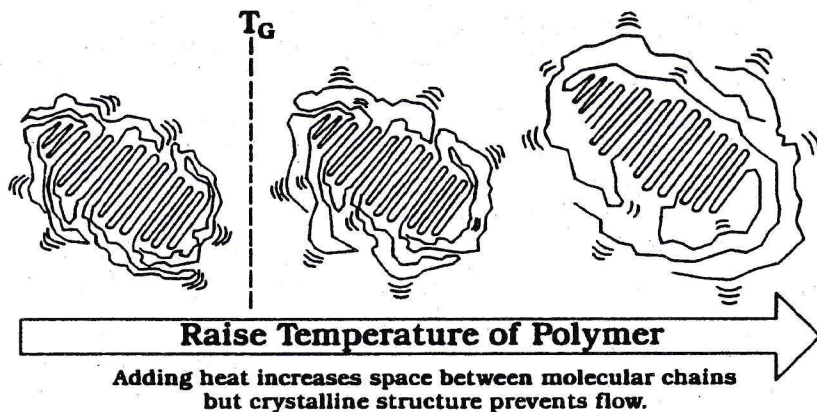
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Participant's Notes: _____



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Model of Crystalline Polymers



2

Participant's Notes: _____

Amorphous polymer chains are physically locked below T_g but are free to move above T_g .

Property Comparison

Crystalline

Crystalline polymers expand and become rubbery above T_g but are not free to flow because of the crystalline structure.

Model of Amorphous Polymers

All matter is in a state of motion. But the molecules in a solid material are moving more slowly than the molecules in a liquid. Applying energy to a material makes its molecules move faster. Heat is a form of energy. Heat energy is applied to a polymer to allow it to flow.

This simple model illustrates what happens structurally to an amorphous polymer upon heating. As the temperature approaches T_g , the locked entanglements vibrate more rapidly but the material remains "glassy" and rigid. As the temperature rises above T_g , the chains loosen and move far enough apart to actually slide past one another. The material starts to become soft and begins to flow. As the temperature rises well above T_g , the chains move farther and farther apart, sliding past one another more freely making the material flow more easily.

STK 217

Model of Crystalline Polymers

This simple model illustrates the different way a crystalline polymer responds to heating above its glass transition temperature. When heat energy is applied to a crystalline polymer, its molecular chains begin to vibrate. As the temperature approaches T_g , the molecules vibrate more rapidly but the material remains "glassy" and rigid. As the temperature rises above T_g , the chains continue to vibrate but don't loosen and move apart because they are tightly interconnected to the regions of crystallinity. The chains in the crystalline regions are densely packed and tend to remain that way. Therefore, it requires more energy to break them apart than the amount available at T_g . The crystalline polymer becomes rubbery above T_g , but it is still structural and will not flow because of the crystals.

STK 218



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Crystalline Polymers

- Contain Low Energy "Crystal" Regions
- These "Crystals" Are Present Below the Melting Point (T_M) but Are Dissociated (Broken Apart) by Heating Above It

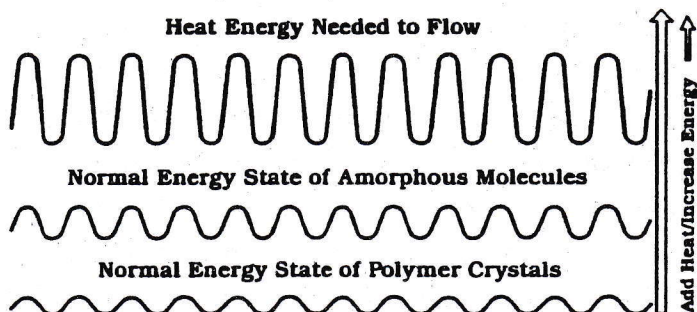
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Participant's Notes: _____



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Low Energy Crystalline Regions



Low energy crystalline regions require more energy in order to flow than amorphous regions.

2

Participant's Notes: _____

**Crystalline polymers
contain crystal regions.**

Crystalline Polymers

Crystalline polymers can be defined in terms of their physical structure and by the way that structure is manifested in terms of properties. A crystalline polymer is still structural above its T_g because it contains low energy crystalline regions.

STK 219

**Crystalline regions will
require more heating to
begin flowing.**

Low Energy Crystalline Regions

The normal energy state of an amorphous structure is higher than that of the low energy crystalline regions. Therefore more energy must be applied to the crystalline regions in order to reach the level of energy required to make the material flow.

STK 220



Crystalline Polymers

- Contain Low Energy "Crystal" Regions
- These "Crystals" Are Present Below the Melting Point (T_M) but Are Dissociated (Break Apart) by Heating Above It

2

Participant's Notes: _____



Melting Point (T_M)

Temperature at Which Crystalline Regions Dissociate (Break Apart) and Begin to Flow

2

Participant's Notes: _____

Crystalline regions melt or are destroyed at a temperature called melting point (T_M).

Crystalline Polymers

Below a crystalline polymer's melting point, there is not enough energy available to force these low energy crystalline regions to break apart and flow. Above its melting point, however, the crystal structures are broken apart and the material begins to flow. **STK 221**

Melting point is the temperature where crystalline order is lost on heating.

Melting Point (T_M)

Every crystalline polymer has a melting point. It is the temperature at which the crystalline regions break apart and begin to flow.

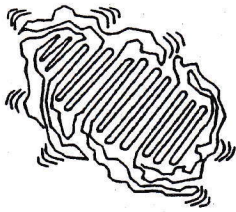
STK 222



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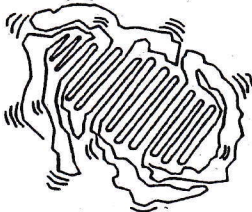
Model of Crystalline Polymers

Rigid Solid



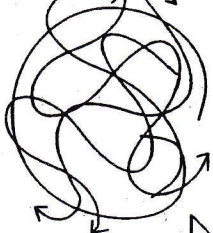
T_G

Soft Solid

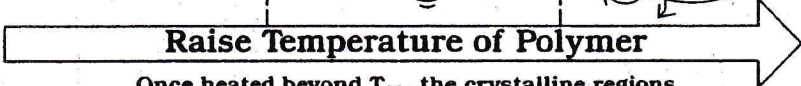


T_M

Flows Easily



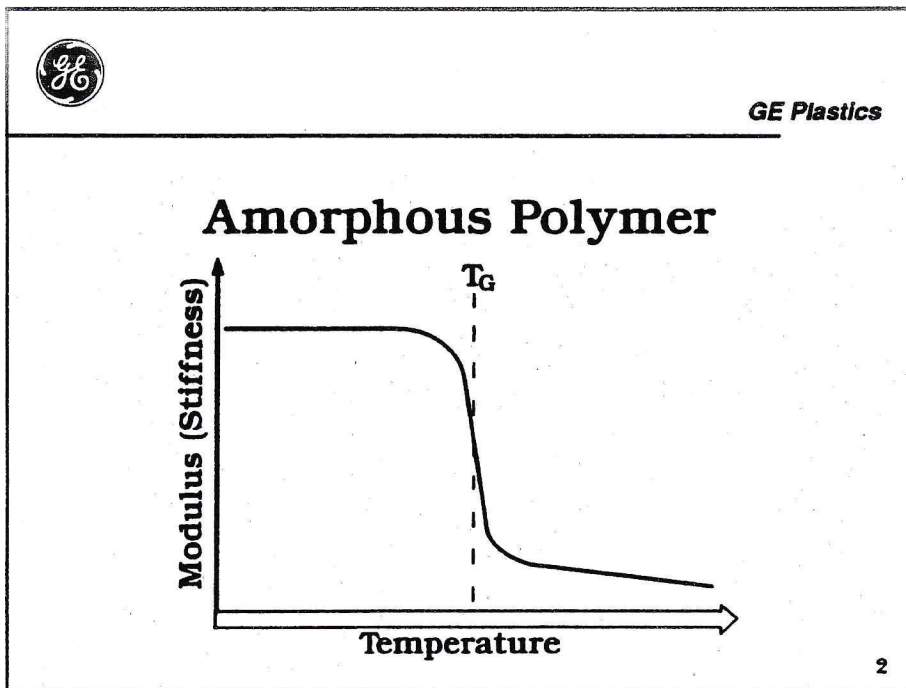
Raise Temperature of Polymer



Once heated beyond T_M , the crystalline regions dissociate and the polymer will flow.

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Participant's Notes: _____



Participant's Notes: _____

T_M is always a higher temperature than T_G .

Above T_M the material is all amorphous and flowable.

Flow Model of Crystalline Polymers

As heat energy is applied to the crystalline material, its molecular chains begin vibrating. Above T_G , they continue to vibrate but do not break apart or flow. Above T_M , enough energy is present to break apart the closely packed molecular chains in the crystalline regions. When these crystals finally disassociate, the molecular chains begin sliding past each other easily due to the high level of energy already stored in the structure. A crystalline material will flow above its T_M .

STK 223

Properties change dramatically at T_G for an amorphous polymer.

Amorphous Polymer

This graph illustrates how the modulus or stiffness of an amorphous material decreases as it passes T_G . The vertical axis indicates the material's degree of stiffness. Glass, for example would have a high degree of stiffness, while rubber would have a low degree of stiffness. The horizontal axis indicates the degree of heat energy being added to the material. As you can see, the stiffness of this amorphous polymer remains relatively constant below T_G and then begins to drop dramatically upon approaching T_G . It goes from a stiff, "glassy" solid to a soft, "rubbery" material when heated above its T_G .

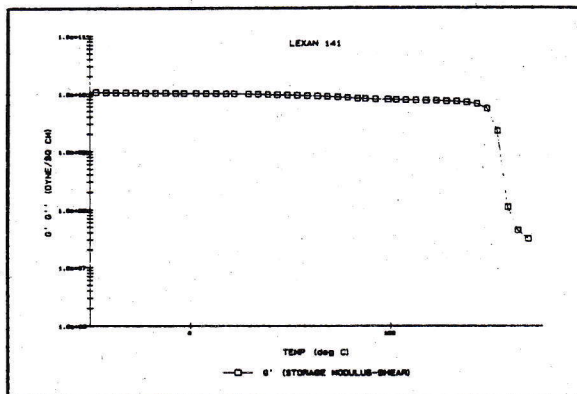
STK 224



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STK 225

Amorphous Polymer



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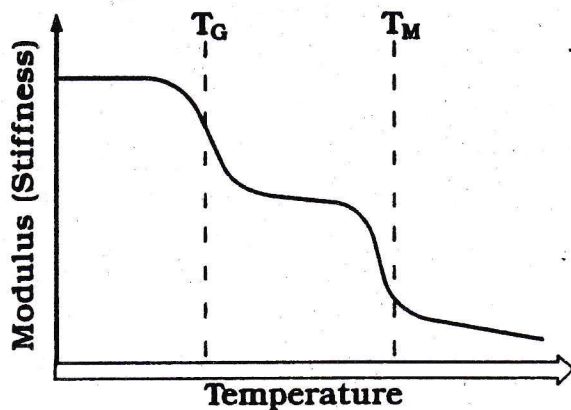
Participant's Notes: _____



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STK 226

Crystalline Polymer



2

Participant's Notes: _____

Actual curve.

This is an actual curve of LEXAN® polycarbonate.

STK 225

There will be less of a change at T_c with a crystalline polymer.

Crystalline Polymer

Using the same parameters, this graph illustrates how the modulus or stiffness of a crystalline material decreases only slightly upon passing T_c , then drops significantly at T_m . Until T_m , the material is structurally sound because the crystals are holding it together. But as you can see, upon reaching T_m , this crystalline material becomes fluid.

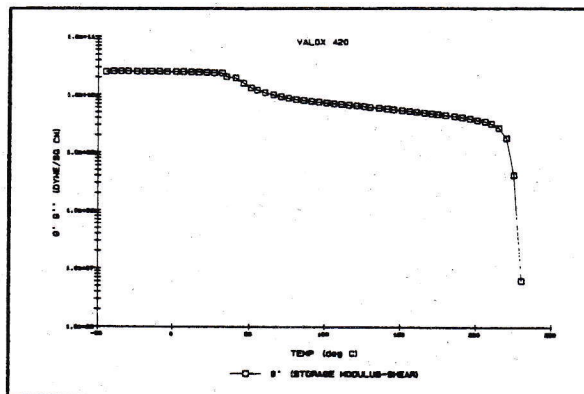
STK 226



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STK 227

Crystalline PBT (VALOX®)



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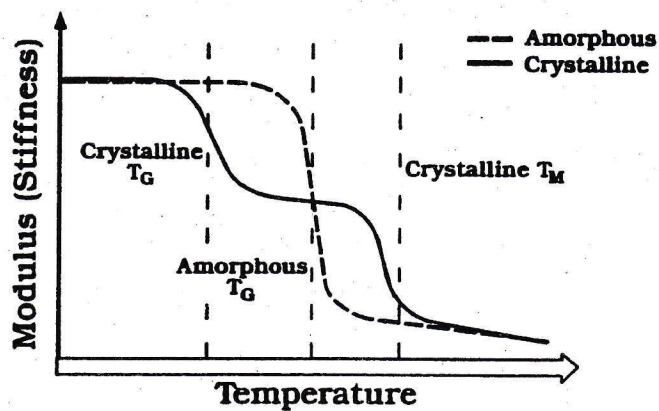
Participant's Notes: _____



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STK 228

Amorphous & Crystalline Comparison



2

Participant's Notes: _____

Actual curve.

This is an actual curve of PBT VALOX®.

STK 227

Processing

**Crystalline and
amorphous resins are
processed differently.**

Amorphous & Crystalline Comparison

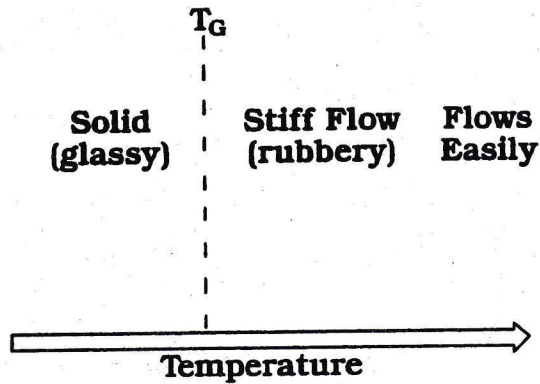
Crystalline resins are processed above their T_M and amorphous materials are processed above their T_G . While a crystalline material is fluid at T_M , an amorphous material still has some stiffness at T_G . Therefore the amorphous resin may not flow easily enough at T_G and may require additional heat energy for processing.

STK 228



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Amorphous Materials Have a Broad Softening Range



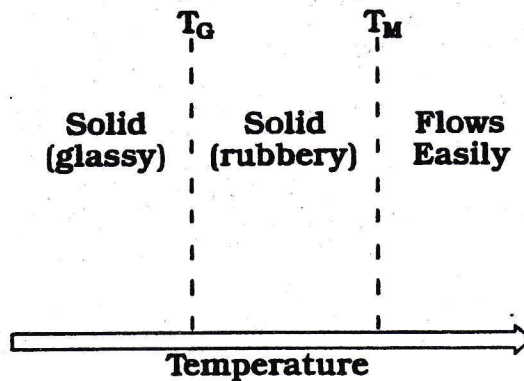
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Participant's Notes: _____



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Crystalline Materials Have a Sharp Melting Point



2

Participant's Notes: _____

T_g defines the lowest temperature at which processing can take place in an amorphous polymer.

Amorphous Materials Have a Broad Softening Range

Because an amorphous material softens gradually over a relatively wide temperature range, it will continue to flow more easily as the temperature is increased.

STK 229

T_m defines the lowest temperature at which processing can take place in a crystalline polymer.

Crystalline Materials Have a Sharp Melting Point

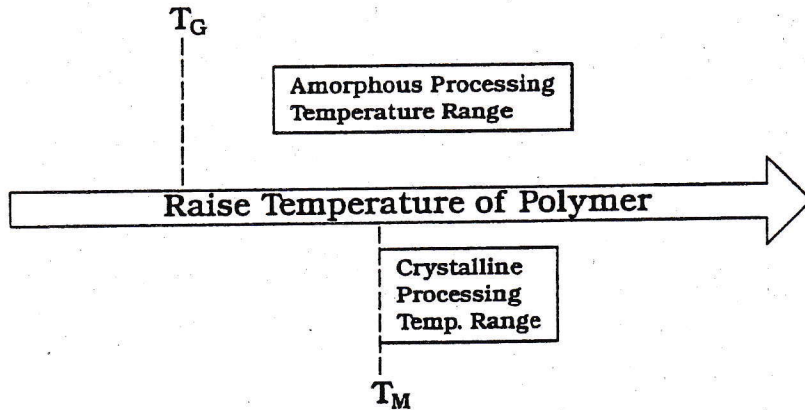
Because a crystalline material melts upon reaching T_m , it will flow easily above that temperature and may not require additional heating for processing.

STK 230



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Polymer Structure Dictates Processing



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Participant's Notes: _____



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Flow Characteristics

- Adding Heat to a Polymer Melt Will Increase Flow
- Adding Too Much Heat or Heating for Too Long May Cause Degradation
- It Is Important to Know the Processing Temperature Range for Each Plastic to Make Good Parts

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Participant's Notes: _____

Amorphous materials have broader processing ranges than crystalline materials.

Polymer Structure Dictates Processing

The temperature at which a material flows easily indicates its processing range. In general, amorphous materials tend to have a broader processing range than crystalline materials. Amorphous materials begin softening at T_g and eventually flow easily enough for processing. They will continue flowing with increasing ease as the temperature increases.

Crystalline materials will not flow until reaching T_m . Consequently, the crystalline material has a narrower processing range than the amorphous material.

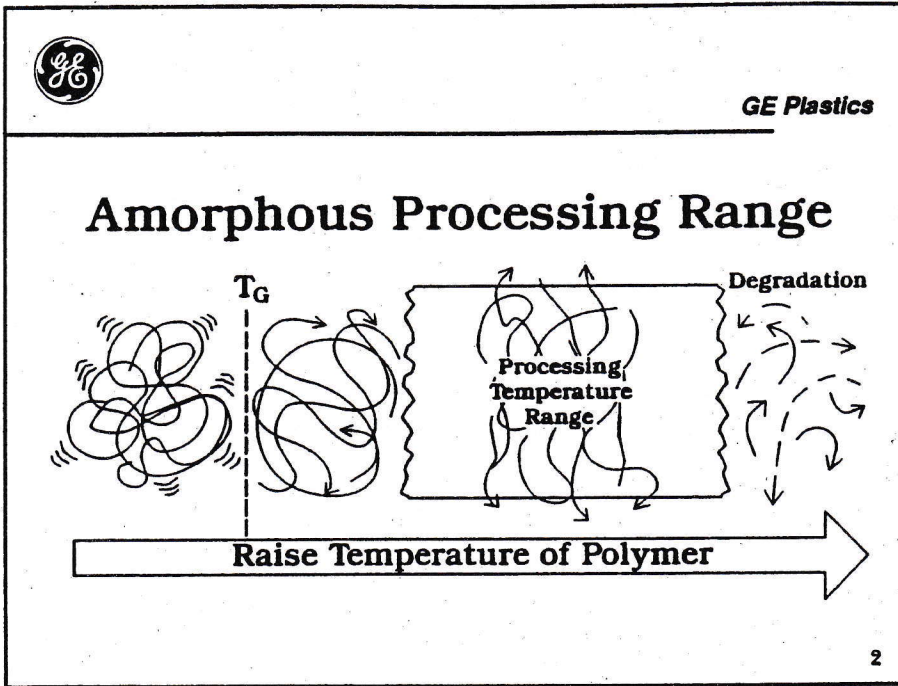
STK 231

Each polymer material has a limited processing range.

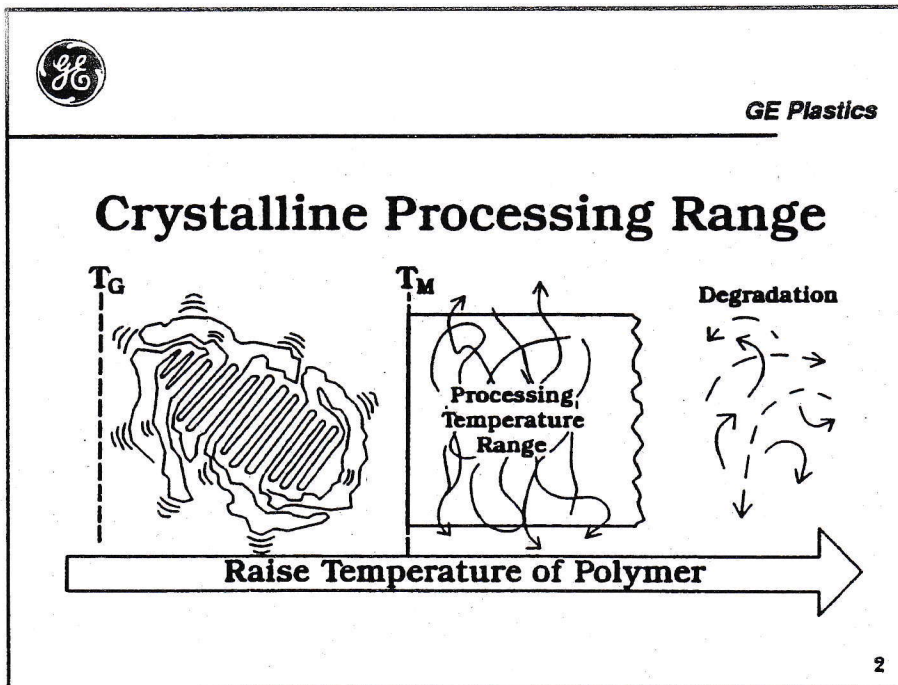
Flow Characteristics

While adding heat to a polymer will make it flow, adding too much heat or allowing it to be heated too long may cause degradation. It is very important to know the recommended processing temperature range for each resin to make high quality parts.

STK 232



Participant's Notes: _____



Participant's Notes: _____

Amorphous – wider processing range.

Amorphous Processing Range

An amorphous resin will flow stiffly just above T_g , then eventually flow easily enough for processing. Again, because amorphous materials soften gradually, they tend to have a wider processing range than crystalline materials. But if heated too high or too long, the long chain molecules that give the polymer its unique properties will begin to break apart. This is called degradation and it causes a loss in material properties and may result in substandard parts.

STK 233

T_M is the lowest temperature at which a crystalline material can be processed.

Crystalline Processing Range

A crystalline resin will not flow until it reaches T_M , whereupon it flows immediately. (T_M is the lowest temperature at which a crystalline material can be processed.) Above T_M , the crystalline resin is processable and should not require additional heat to allow it to flow. Also, like the amorphous resin, heating a crystalline resin too high or too long may cause degradation.

STK 234



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STK 235

In Processing . . .

To increase flow length of a crystalline polymer and lessen chance of degradation, increase mold temperature.

Increasing mold temperature slows cooling & therefore increases the amount of crystallization in the finished part.

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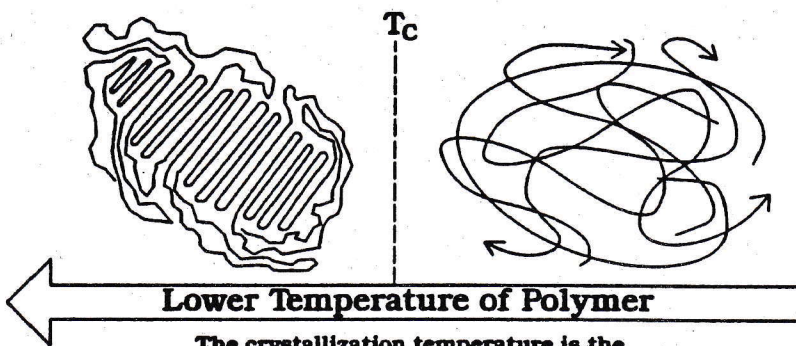
Participant's Notes: _____



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STK 236

Crystallization Temperature (T_c) on Cooling



The crystallization temperature is the temperature at which a material begins to build Crystalline Structure upon cooling.

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Participant's Notes: _____

Mold temperature can affect crystallization and flow length.

In Processing

If you want to increase the flow length of a crystalline polymer, it's better to increase the mold temperature. Increasing the melt temperature does not improve the flow very much and may cause degradation. Increasing the mold temperature will help the material to flow farther by slowing the cooling of the part. The more slowly a crystalline resin cools, the greater the degree of crystallinity.

STK 235

T_c is the temperature where crystals may form on cooling a crystalline polymer.

Crystallization Temperature (T_c) on Cooling

The crystallization temperature is the temperature at which a crystalline resin begins to crystallize on cooling. A crystalline material's T_c is higher than its T_g yet lower than its T_m . At T_c , a crystalline polymer's molecular chains begin lining up in an orderly fashion and forming into crystals. Notice that the arrow has been reversed to indicate cooling.

STK 236



Degree of Crystallinity

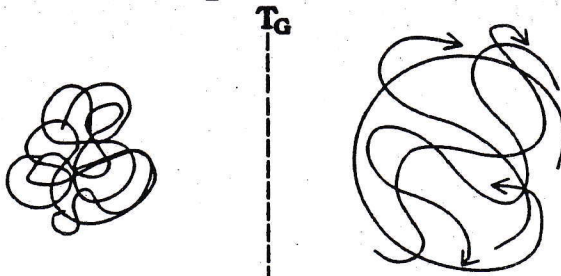
- The more slowly a melt of a crystalline polymer cools to its T_G - the greater the degree of crystallinity
- The more quickly a melt of a crystalline polymer cools to its T_G - the lesser the degree of crystallinity

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Participant's Notes: _____



Shrinkage on Cooling



← Lower Temperature of Polymer

Cooling causes a volume reduction or shrinkage in all polymers. Note the decrease in the amount of space between polymer chains when an amorphous material is cooled.

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Participant's Notes: _____

The amount of crystallinity is controlled by the rate of cooling.

Degree of Crystallinity

A crystalline material will begin building crystallinity at T_c and continue to crystallize until it cools below T_c . The more slowly the polymer cools, the greater the degree of crystallinity. The more quickly the polymer cools, the lesser the degree of crystallinity.

STK 237

Polymer chains come closer together during cooling, resulting in shrinkage.

Shrinkage on Cooling

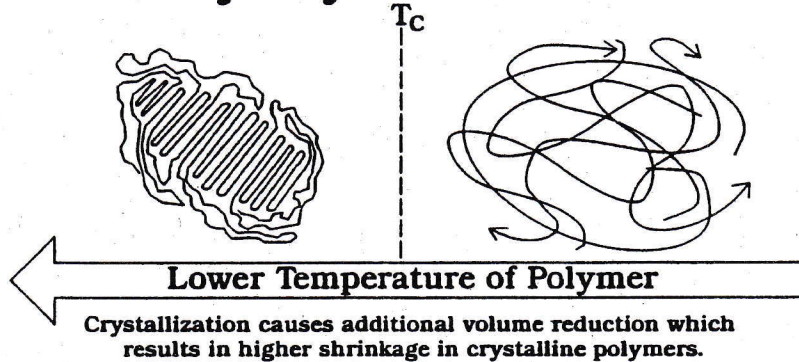
Cooling a polymer melt causes a volume reduction referred to as shrinkage. During processing, heat is added to a polymer creating enough space between the molecular chains to allow them to slide past each other and flow. This space causes an increase in the volume of the material in its melt state. Upon 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. Shrinkage occurs in both amorphous and crystalline polymers.

STK 238



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Shrinkage Is Increased by Crystallization



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Participant's Notes: _____



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Degree of Crystallization (Shrinkage)

The more slowly a crystalline polymer cools - the greater the degree of crystallization - the greater the in-mold shrinkage.

This technique may lead to longer cycle times.

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Participant's Notes: _____

Crystallization results in greater shrinkage.

Shrinkage Is Increased by Crystallization

Crystalline materials tend to shrink more than amorphous materials. 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.

STK 239

Polymer crystallinity can be increased in the mold.

Degree of Crystallization (Shrinkage)

The more crystallinity, the greater the degree of shrinkage. That means that the more slowly a crystalline polymer cools, the greater the degree of crystallization, and the greater the degree of in-mold shrinkage. Slow in-mold cooling is preferable and often necessary in smaller parts with many critical dimensions, such as connector plugs. But, slow in-mold cooling leads to longer cycle times.

STK 240



GE Plastics

STK 241

Post Mold Crystallization

Completing Crystallization by Heating Above T_g
Will Stabilize Part Dimensions:

- **Free Shrinkage** - Parts with no critical dimensions are free to move during crystallization.
- **Fixtured Shrinkage** - Critical dimensions are held during crystallization to maintain part tolerances.

2

Participant's Notes: _____



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STK 242

Increased Crystallinity Increased Shrinkage

- **Increased Chemical Resistance**
- **Increased Dimensional Stability**
- **Increased Heat Deflection Temperature (HDT)**
- **Less Chance of Additional Shrinkage**

2

Participant's Notes: _____

Crystallization can be completed through post mold treatment.

Post Mold Crystallization

Post mold cooling may be a cost effective alternative to in-mold cooling that allows for maximum crystallinity and minimum cycle time. Parts can be cooled quickly in the mold then reheated in an oven to allow for crystallization. When reheated above T_g , the material will begin building crystallinity again and will continue to build crystallinity until it reaches the maximum amount possible. A part with maximum crystallinity is more dimensionally stable than a part with unrealized crystallinity. Parts with unrealized crystallinity will continue to crystallize when raised above T_g , causing additional shrinkage and possibly warpage.

Parts with no critical dimensions such as cups, dishes, machine housings, and covers can be allowed to shrink freely (free shrinkage). Parts with certain critical dimensions can be fixtured at critical points to maintain part tolerance during shrinkage (fixtured shrinkage).

STK 241

Increased crystallinity maximizes material properties.

Benefits of Increased Crystallinity/Increased Shrinkage

Increased crystallinity is important not only for dimensional stability, but also for maximum property performance. Crystalline materials are often selected for inherent properties that are enhanced by their crystallinity. For example, increased crystallinity increases a material's chemical resistance and heat deflection temperature (HDT). Allowing a part to finish crystallizing/shrinking also reduces the chance of additional uncontrolled shrinkage during manufacturing and application.

STK 242



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STK 243

Plastic Part Production

- Part Dictates Performance
- Performance Dictates Material
- Material Dictates Tooling
- Tooling & Materials Dictate Processing
- Processing Dictates Performance

2

Participant's Notes: _____



GE Plastics

STK 244

Consistent Material Processing

- During start-up, temperatures vary effecting processing consistency causing processing inconsistency.
- Once proper processing parameters are stabilized, it is important to maintain processing consistency throughout the run to assure consistent part production.

2

Participant's Notes: _____

**Processing affects
performance.**

Plastic Part Production

The converter has an important role in high quality part production. The part dictates the performance requirements and the performance requirements dictate the material. For example, a container that will be exposed to certain chemicals will call for a material that has excellent chemical resistance. The material will then dictate the tooling requirements, and the material and the tooling will dictate the processing requirements. The converter must then follow the processing and tooling requirements exactly in order to make good parts. Processing dictates performance. Lower chemical resistance can result from excessive heating or a lack of crystallinity. Such a loss in chemical resistance could render the finished part useless. Proper processing is paramount to producing high performance, high quality parts.

STK 243

**Processing consistency
assures consistent part
production.**

Consistent Material Processing

In addition to knowing the processing "rules" for each resin, it is important that the converter maintains processing consistency throughout the run. During start-up, processing and mold temperatures will affect each other causing processing inconsistency. Once proper processing parameters are stabilized, it is important to maintain these parameters for consistent part production.

STK 244



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Polymer Structure Dictates Tooling

**Crystallization and shrinkage
dictate processing and
tooling design.**

2

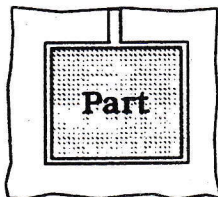
Participant's Notes: _____



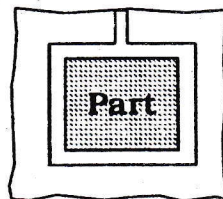
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Crystalline Materials Have Higher Shrinkage

Cavity for
Amorphous Material



Cavity for
Crystalline Material



2

Participant's Notes: _____

Tooling

Crystallization and shrinkage dictate processing and tooling design.

Polymer Structure Dictates Tooling

The material will also dictate certain tooling parameters. Crystallization and shrinkage dictate processing, and they dictate tooling design.

STK 245

The tool cavity for crystalline materials should accommodate for greater shrinkage.

Crystalline Materials Have Higher Shrinkage

Shrinkage in an amorphous polymer is rather consistent and therefore fairly easy to predict and accommodate for in tooling. Shrinkage in a crystalline polymer is higher due to crystallization and often more difficult to predict. Consequently, if molding the same part, the tool cavity for a crystalline material will be slightly larger than the cavity for an amorphous material. The structure of the polymer affects the design of the tool.

STK 246



Understanding Polymer Structure

2

Participant's Notes: _____



T_G or T_M ...

Which temperature is crucial
to the processing of amorphous
materials and why?

2

Participant's Notes: _____

Summary and Performance Feedback

Understanding Polymer Structure

It is important to understand the structure of the polymer and how that structure affects everything from material properties, to material tooling and processing, to material and part performance. It is also important to understand how processing can affect part performance.

Amorphous and crystalline polymers are very different in terms of structure and therefore have very different processing requirements. But if we can anticipate how each will respond during processing, we can then guard against those variables that may negatively affect the performance of the finished part.

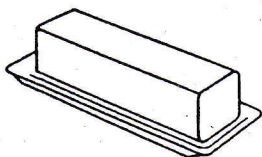
STK 247



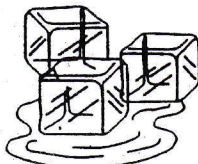
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T_G is Crucial When Processing Amorphous Materials

Amorphous
Broad Softening Range



Crystalline
Sharp Melting Point



T_m is ONLY a function of crystalline materials because without crystals there can be no melting.

2

Participant's Notes: _____



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Slow Cooling or Fast Cooling...

Which increases the amount of crystallinity and why?

2

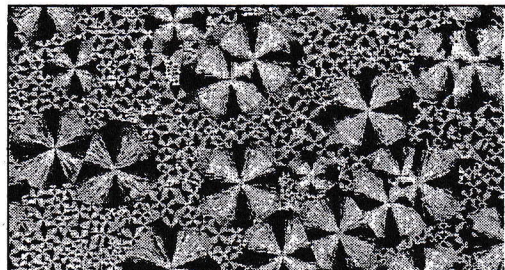
Participant's Notes: _____



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STK 251

Slow Cooling Increases the Amount of Crystallinity



Cooling slowly gives the material more time to form the crystalline regions that are so important to its property characteristics. The greater the degree of crystallinity, the lesser the chance of additional shrinkage.

2

Participant's Notes: _____



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STK 252

Amorphous or Crystalline Materials...

Which shrink more and why?

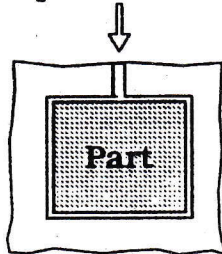
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Participant's Notes: _____

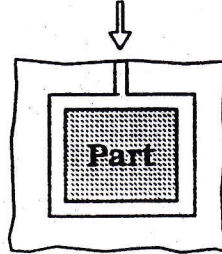


Crystalline Materials Shrink More

Cavity for
Amorphous Material



Cavity for
Crystalline Material



Crystalline materials shrink more due to crystallization which causes additional volume reduction.

2

Participant's Notes: _____



Module 3 Polymer Modification

- Methods of Modification
- Resin Modification
- Tooling
- Processing

2

Participant's Notes: _____



Module 2

Performance Feedback

1. Describe the difference between crystalline and amorphous resins.
2. Define the glass transition temperature (T_g).
3. Describe the impact of T_g on:
Crystalline polymers
Amorphous polymers
4. Define the melting temperature (T_m) and describe its impact on crystalline polymers.
5. Describe the implications of polymer structure on processing.
6. Describe the implications of polymer structure on tooling.
7. List the resins you are currently working with and indicate whether it is crystalline or amorphous. Identify T_g for all the resins you are working with and indicate T_m for the crystalline resins.