Sharing The Knowledge
Module 4

Properties of Polymers

STK 401

GE Plastics

Module 4

Properties of Polymers

- Sources of Information
- Properties
  - Mechanical
  - Thermal
  - Electrical
  - Flammability
  - Physical

4

Participant's Notes: ____________________

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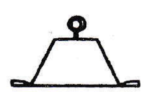
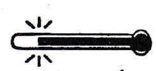
Properties of Polymers

Mechanical Performance 

Thermal Performance 

Electrical Performance 

Flammability 

Physical Characteristics 

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Participant's Notes: ____________________

Introduction

Properties of Polymers

When manufacturing a product, a designer chooses a material that meets the performance requirements dictated by the product and its application. Any material, be it wood, metal, or plastic, is selected according to its own inherent ability to meet these performance requirements. Every material has distinguishing characteristics that indicate how well it will perform in a variety of applications. These "distinguishing characteristics" are the material's properties.

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Objectives:

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

- Describe five categories of properties used to distinguish thermoplastic materials.
- Identify two sources of property information and describe how to read them.
- Identify which tests are used to measure different properties under various conditions.
- For a part that you are producing, identify the key properties in the application.

Properties of Polymers

Material properties indicate how a material will perform.

Numerous material properties are used to describe and compare material performance. We are, of course, interested in the properties that are used to compare and select thermoplastic materials. For our discussion, we've broken them down into five categories: mechanical performance, thermal performance, electrical performance, flammability, and physical characteristics. Each of these categories contains specific material properties that measure material behavior.

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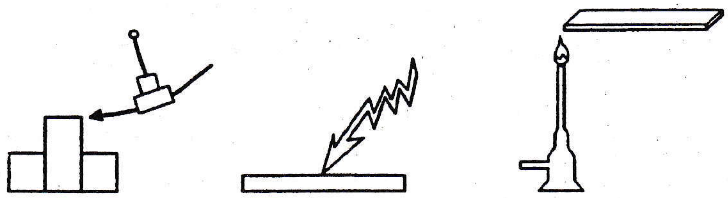
Material Properties



Properties describe how well a material performs in a variety of tests that simulate application requirements.

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Product Data Sheets

PROPERTY	UNIT	METHOD	TYPICAL DATA
MECHANICAL			
Tensile Strength, break	psi	ASTM D 638	13300
Flexural Strength, break	psi	ASTM D 790	20000
Flexural Modulus	psi	ASTM D 790	780000
Compressive Strength	psi	ASTM D 695	10800
Hardness, Rockwell R	-	ASTM D 785	109
IMPACT			
Izod Impact, unnotched	ft - lb / in	ASTM D 256	12.0
Izod Impact, notched	ft - lb / in	ASTM D 256	3.2
THERMAL			
DTUL, 66 psi	deg F	ASTM D 648	400
DTUL, 264 psi	deg F	ASTM D 648	300
CTE, flow, -40F to 100F	in / in - F	ASTM E 831	1.50 E-5
CTE, flow, 140F to 280F	in / in - F	ASTM E 831	1.10 E-5

Product Data Sheets report standardized test results for material comparisons.

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Participant's Notes:

Material properties fall under several categories.

Material Properties

There are properties that are attributed to thermoplastics in general, and to each resin product in particular. Thermoplastics, for example, provide high heat performance – but how high? And polycarbonate is said to provide excellent impact resistance – but how much? It is important for the product designer to know exactly "how high" and "how much" to establish whether the resin will perform well under the conditions set forth by the product application. Each resin grade has its own property profile that indicates how well it will perform in a given application. These properties are qualified and quantified according to established industry standards on each resin's product data sheet. **STK 403**

Sources of Property Information

Product data sheets report standardized test results.

Product Data Sheet

Each resin is subjected to an assortment of standard tests. Engineers then report the test results on the resin's product data sheet for material comparison.

The product data sheet can only provide a "snapshot" of how a material will respond in application. The test results can only measure how well a material will perform when tested under one distinct set of conditions and variables. **STK 404**

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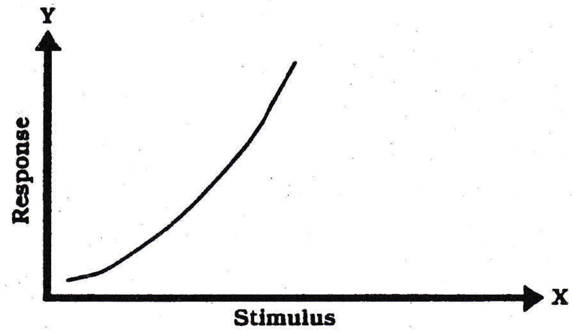
Graphical Data



Graphical data is used to describe a material's response to changing conditions.

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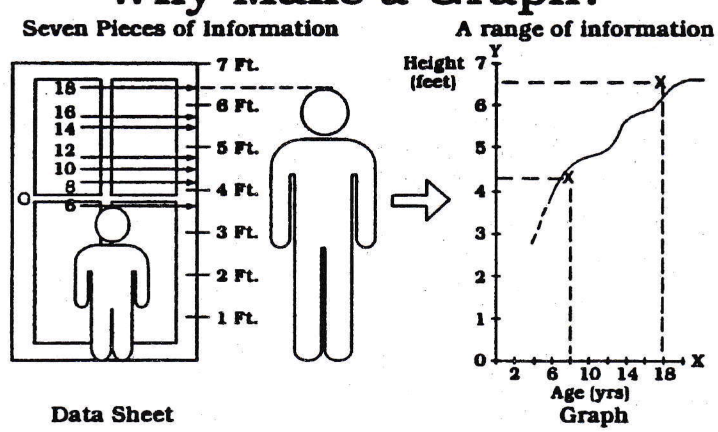
Why Make a Graph?



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Participant's Notes:

A graph provides the entire performance curve over a range of conditions.

Graphical Data

A graph, on the other hand, can provide an entire "motion picture" of material performance. Graphical data is used to describe a material's response to changing conditions. A graph provides performance data over a range of conditions, supplying realistic information that is ultimately more useful to the product designer. **STK 405**

A graph is a more complete picture of tabular data.

Why Make a Graph?

To understand the usefulness of a graph, consider the following example. A child's height was measured every two years from the ages of 6 to 18, providing seven discrete pieces of information: seven ages with seven corresponding heights. From these seven discrete facts, we can create a graph that reveals a range of information.

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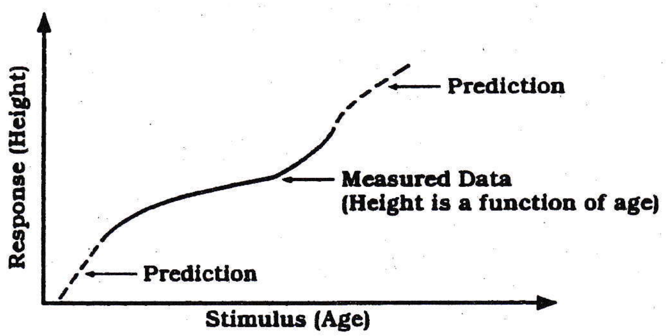
How to Read a Graph



A graph gives you a means of interpreting information on many levels.

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Participant's Notes:

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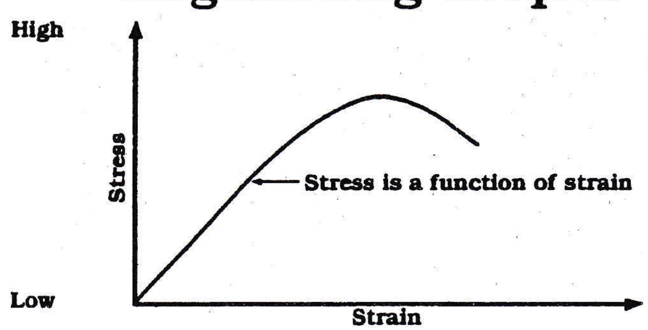
Engineering Graphs



- GE's Engineering Design Database contains graphical data.
- This data describes the material through its useful performance ranges.

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Participant's Notes:

A graph allows you to predict values or data at specific points.

How to Read a Graph

The increase in the child's height is a response to his increase in age. His age is the stimulus and is represented by the horizontal axis. His height is the response to his age and is represented by the vertical axis. Height is a function of age. That is to say, as he grows older, he grows taller accordingly.

By plotting the seven sets of coordinates and connecting the points, we can estimate how tall the child was at seven although he was never measured then. This is an example of interpolation. And we can interpret how tall the child will be at 20 though he's still only 18. This is an example of extrapolation. A graph allows us to predict data values at specific points.

STK 407

Engineering data can be represented as graphs.

Engineering Graphs

GE's Engineering Design Database (EDD) contains many plots which use graphical presentations of data to thoroughly describe a material's responses to independent variables of elongation, stress, temperature, or environment. The Stress/Strain relationship is typical of these graphical presentations. By convention, a Stress/Strain graph is generated by pulling a specimen at a constant rate (controlling the elongation of strain) and measuring the resulting stress (or resistant load) in the specimen. The graph shows how stress changes as we vary the strain - hence the plot describing the Stress/Strain relationship in the material when Stress is a function of Strain.

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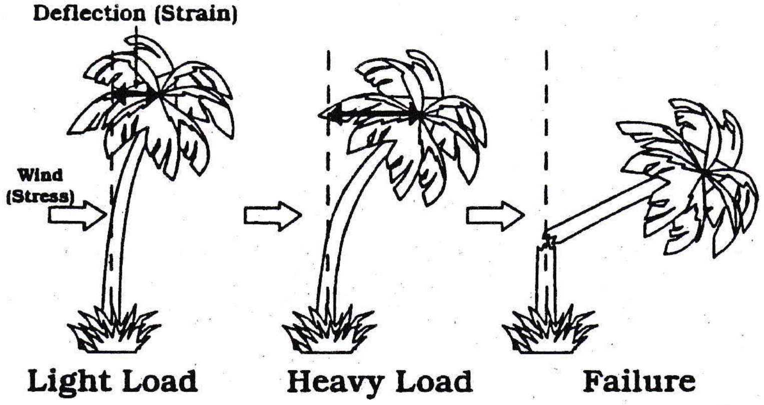
Stress vs. Strain



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Participant's Notes:

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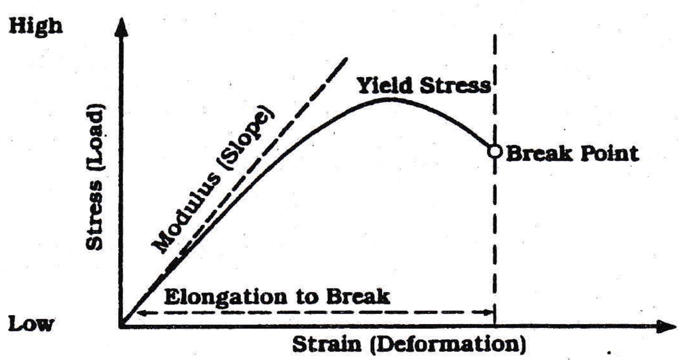
How to Read an Engineering Graph



Data sheet properties are developed from engineering graphs.

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Participant's Notes:

Stress vs. Strain

Stress causes a certain deflection (strain) – ultimately, a great enough amount of stress will cause failure.

Stress/Strain relationships are not just an academic venture. All around us in the physical world are examples of materials being deformed which demonstrate this relationship. When a fish in the lake grabs your hook and starts to run with the line, he feels an increasing resistance from the fishing pole which tries to resist bending. The fish is doing a pure measure of the Stress/Strain relationship in the fishing pole - in this case he is controlling the strain and feeling the resulting stress from the rigidity of the pole. But the same relationship could also be measured by controlling the stress and watching the strain change. While this is not practical in the laboratory, it is often seen in nature. When the wind blows, the trees respond by bending. The bend (or strain) in the tree will be proportional to the wind load (or stress). If the tree is brittle, the tree will reach a maximum strain and break. However, if the tree were made of rubber, it would bend to some maximum amount - beyond which more wind would cause no change. For this reason, it is more practical to describe stress as a function of strain (because we can continue to deform a material long after it has yielded and reached a maximum resistance or stress).

STK 409

How to Read an Engineering Graph

This is the kind of useful information that is available on an engineering graph. The curve describes the increase in the stress on the material as the strain on the material increases. The more we pull on the tree and strain the material, the greater the stress the material is forced to withstand. In an engineering graph, stress is a function of strain.

Graphical data contains a lot of information.

A load is placed on a material that causes it to deform, and this deformation in turn creates stress on the material that is comparable to the applied load. An engineering curve shows us the maximum load the material will withstand and still recover, or the farthest the material will bend and still return to its initial position (yield). It also shows us at what point the material yields or bends so far that it will not return to its initial orientation, even after the load is removed. Finally an engineering graph shows us the point at which the material fails, or breaks. The elongation to break is the degree of deformation at which the material will break.

The maximum load the material withstands before breaking is then recorded as the strength of the material. Data sheet properties are developed from engineering graphs.

STK 410

STK 411

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Properties of Polymers

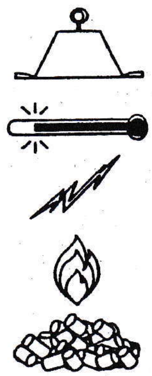
Mechanical Performance

Thermal Performance

Electrical Performance

Flammability

Physical Characteristics



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Participant's Notes:

STK 412

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Mechanical Properties

- Modulus (Stiffness)
- Strength
- Impact Strength
- Hardness
- Elongation

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Participant's Notes:

Mechanical

Mechanical performance.

Properties of Polymers

There are a variety of different loads that can be applied to a material. Weight, heat, and electricity all cause stress to a material and may eventually cause it to fail. A material is tested under these various kinds of load and the information is recorded graphically to reveal a range of data that indicates the material's mechanical, thermal, and electrical properties. For example, the maximum stress that the material withstands before failing mechanically is recorded as its mechanical strength. **STK 411**

There are many mechanical properties.

Mechanical Properties

There are several different kinds of mechanical properties that are important for material selection. Properties such as stiffness, impact resistance, hardness, and elongation all indicate important kinds of mechanical performance. **STK 412**

STK 413

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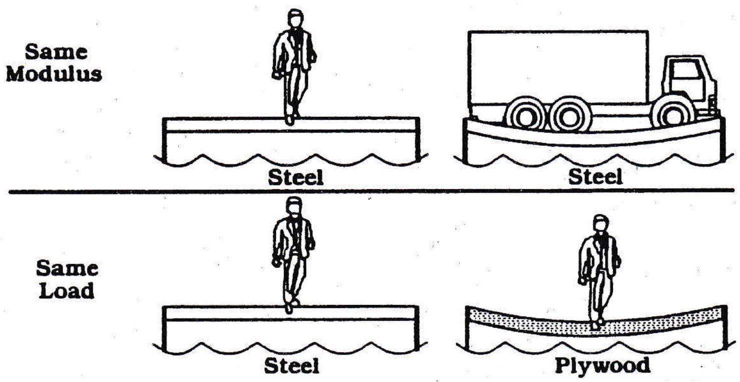
Modulus (Stiffness)

Modulus refers to a material's resistance to deformation under load:



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Participant's Notes:

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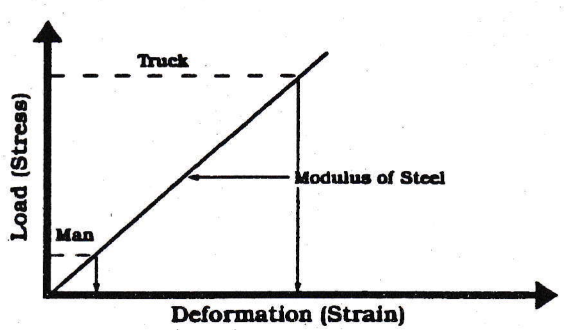
Same Modulus / Different Load



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Participant's Notes:

Modulus (Stiffness)

Just to review, the bending of the tree was a kind of deformation. Deformation refers to the change in displacement of a material versus its initial orientation. Modulus refers to a material's resistance to deformation under load. The same material will show more deformation under a greater load than it will under a smaller load. For example, this piece of steel shows more deformation under the weight of a truck than it does under the weight of a man. This is an example of the effect of two different loads on a material of the same modulus.

Modulus refers to a material's resistance to deformation.

In addition, the same load will show more deformation when applied to a material with a lower modulus than it will when applied to a material with a higher modulus. For example, this piece of plywood shows more deformation under the weight of a man than this piece of steel displays under the same load. This is an example of two different moduli under the same load. **STK 413**

Same Modulus/Different Load

This is a graphical representation of the steel vs. steel example.

Consider this graphical representation of the same modulus under different loads. Modulus is determined by measuring the slope of a material's stress/strain curve. This straight line shows the modulus of the steel. As you can see, the deformation, or strain, caused by the man is considerably less than the material deformation caused by the truck. The truck is a heavier load than the man, and therefore a greater applied stress. **STK 414**

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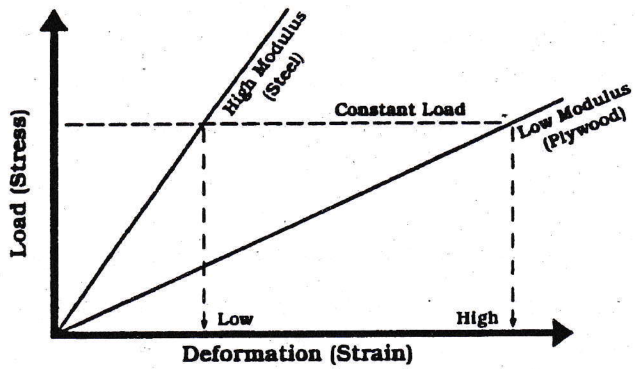
Same Load / Different Modulus



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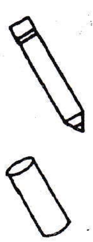
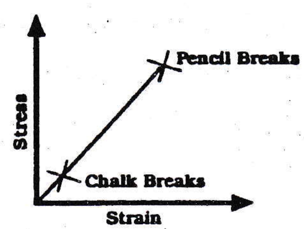
Modulus vs. Strength



Modulus (Stiffness)	Strength
2,000,000 PSI	High
2,000,000 PSI	Low



Pencil & chalk have the same modulus (slope of the line) but the pencil is much stronger than the chalk.

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Participant's Notes:

This is a graphical representation of the plywood vs. steel example.

Same Load/Different Modulus

Now consider this graphical representation of the two different moduli under the same load. The steel and the plywood have two different moduli, so their moduli are indicated by two different slopes. The steel's higher modulus is represented by the steeper line. While the plywood's lower modulus is represented by the flatter line. As you can see, under the same constant load, the steel shows less deformation than the plywood. **STK 415**

Strength and modulus are independent.

Modulus vs. Strength

Modulus and strength are two mechanical properties that are often confused. To better understand the differentiation, notice how two materials with the same modulus can have totally different strengths. The modulus of the pencil and the chalk is the same, and is therefore indicated by the same slope. But the chalk is not as strong as the pencil and therefore fails, or breaks, at a much lower load than the pencil. Since strength is measured by the maximum load a material can withstand before breaking, you can see that the pencil can withstand a much higher load and therefore has much higher strength than the chalk. **STK 416**

STK 417

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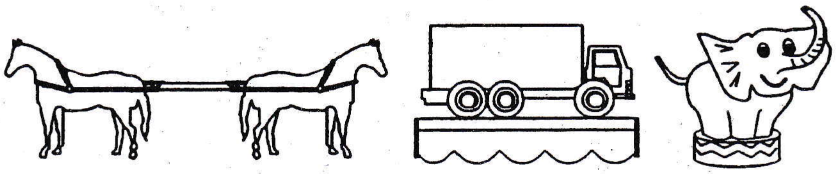
Mechanical Strength

Strength refers to the maximum load a material can support before yielding or breaking.



Tensile Strength	Flexural Strength	Compressive Strength
Pull	**Bend**	**Squeeze**

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Participant's Notes: ____________________

STK 418

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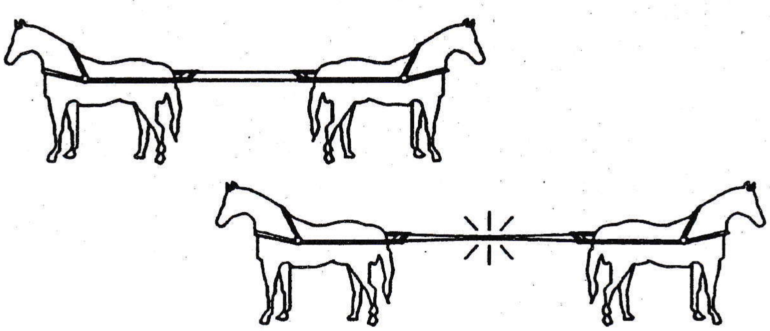
Tensile Strength



Tensile strength is the maximum pulling load a material can support before yielding or breaking.

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Participant's Notes: ____________________

Strength is the maximum stress a material can support before yielding or breaking.

Mechanical Strength

Strength refers to the maximum load a material can support before yielding or breaking. Mechanical strength can refer to a material's ability to withstand such mechanical stresses as pulling, bending, or squeezing. The material's ability to withstand these loads is then recorded as tensile, flexural, or compressive strength. **STK 417**

Tensile strength is the maximum pulling stress a material can support before yielding or breaking.

Tensile Strength (Illustration)

Tensile strength is the maximum pulling load a material can support before yielding or breaking. **STK 418**

STK 419

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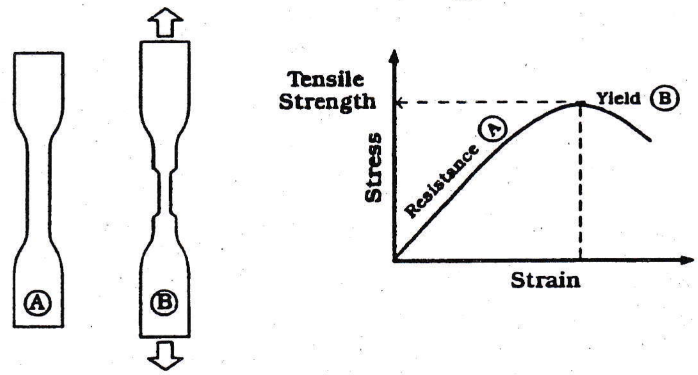
Tensile Strength



Tensile strength is tested using a tensile bar.

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Participant's Notes:

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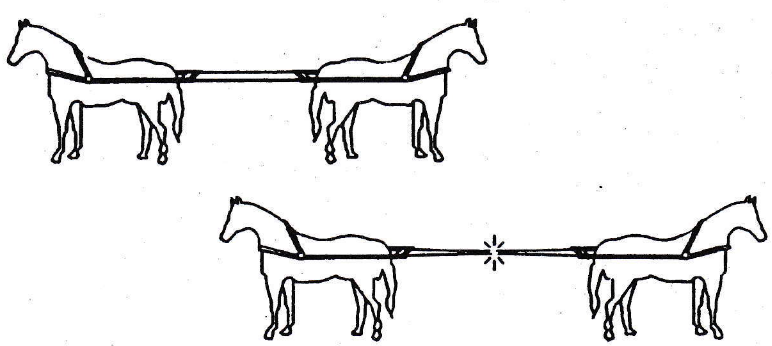
Ultimate Elongation



Tensile elongation is the maximum length a material extends before breaking.

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Participant's Notes:

At yield the bar will be permanently deformed.

Tensile Strength (Graph)

A material is molded into a tensile bar to test its tensile strength. As the bar is pulled, the material shows deformation, as indicated by the rising curve, but is still able to recover (A). But the more it is pulled, the more deformation it shows, until it finally yields and is no longer able to fully recover (B). At yield, the bar will be permanently deformed. **STK 419**

Ultimate elongation is the maximum extension before breaking.

Ultimate Elongation (Illustration)

Maximum tensile elongation is the maximum length a material will extend before breaking. **STK 420**

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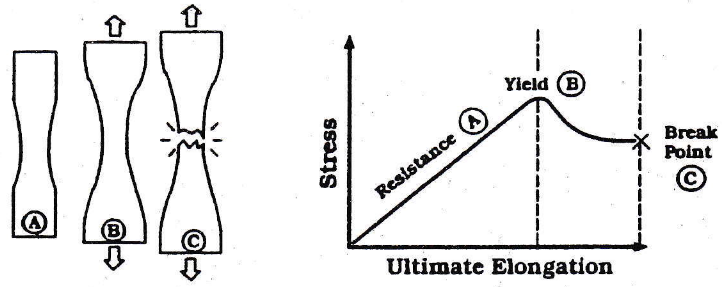
Ultimate Elongation



- Ultimate Elongation is measured using a tensile bar and reported as a percentage beyond the original length.
- For example, if a 100 inch part has 15% elongation it will stretch to 115 inches before it breaks.

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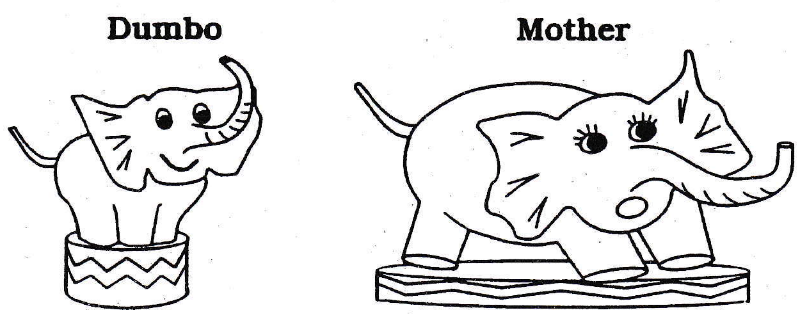
Compressive Strength



Compressive Strength is the maximum squeezing load a material can support before breaking or yielding.

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Participant's Notes: ______________________________

Ultimate Elongation (Graph)

Ultimate elongation is the elongation of a material before fracturing.

Tensile strength measures the maximum load a material will withstand before yielding. As the tensile bar is pulled, the material shows deformation, as indicated by the rising curve, but is still able to recover (A). But the more it is pulled, the more deformation it shows, until it finally yields and is no longer able to recover (B). The maximum stress the material withstands before yielding is the tensile strength. The material will then continue to deform under the applied stress until it finally breaks (C). Ultimate elongation measures how far the material will extend before breaking as a percentage beyond its original length. For example, if a 100 inch part has 15% elongation, it will stretch to 115 inches before it breaks. **STK 421**

Compressive Strength (Illustration)

Compressive strength is measured by squeezing a test specimen.

Compressive strength is the maximum squeezing load a material can support before yielding or breaking. **STK 422**

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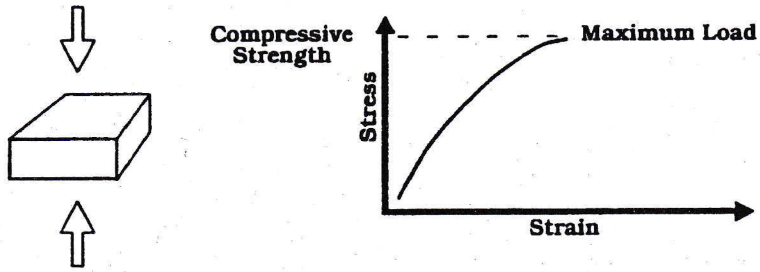
Compressive Strength



Compressive strength is the maximum load a material can support before yielding or breaking.

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Participant's Notes: ____________________

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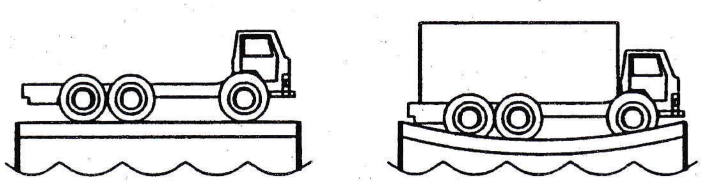
Flexural Strength



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Compressive Strength (Graph)

Compressive strength is the maximum squeezing stress a material can support before breaking or yielding.

A material specimen is squeezed to measure compressive strength. As the material is pressed, or squeezed, it shows deformation. Compressive strength measures the maximum load applied, or the maximum stress the material will withstand, before it yields and is no longer able to fully recover. By understanding the information that is indicated on these various graphs, we can more accurately anticipate how a material will perform during application. **STK 423**

Flexural Strength (Illustration)

Flexural strength is the maximum bending stress a material can support before yielding or breaking.

Flexural strength is the maximum bending load a material can support before yielding or breaking. **STK 424**

STK 425

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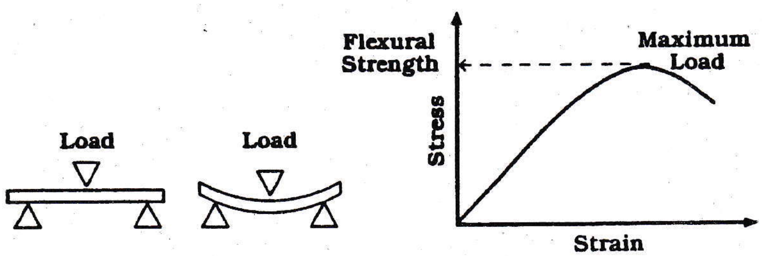
Flexural Strength



Flexural strength is measured by bending a material specimen.

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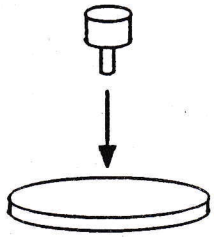
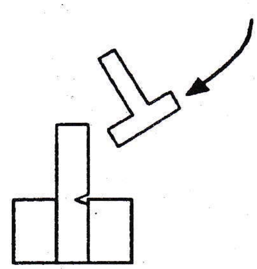
Impact Strength

Impact strength is the energy required to break a material.



Falling Dart Test



Izod Impact Test

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Participant's Notes: ______________________________

Flexural strength is measured by bending a test bar.

Flexural Strength (Graph)

A test bar is used to measure flexural strength as well. As the bar is bent, it shows deformation but will still recover. Flexural strength measures the maximum stress applied before it yields and is no longer able to recover. **STK 425**

Impact strength is the amount of energy required to break a material.

Impact Strength

Whereas tensile, flexural, and compressive strength indicate how well a material will perform under "static" loads, impact strength is an indication of how well a material will perform when subjected to a "dynamic" load. Impact strength measures the amount of energy required to break a material. Falling Dart and Izod Impact are two popular tests that attempt to quantify a material's ability to withstand impact. **STK 426**

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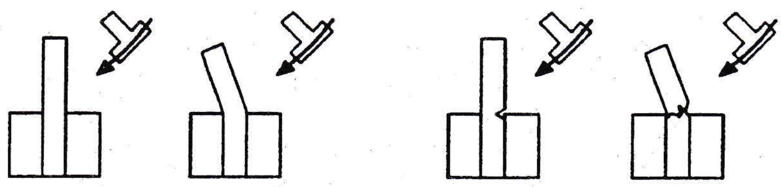
Izod Impact Test

Unnotched Izod **Notched Izod**



Izod Impact is reported in ft/lbs per inch.

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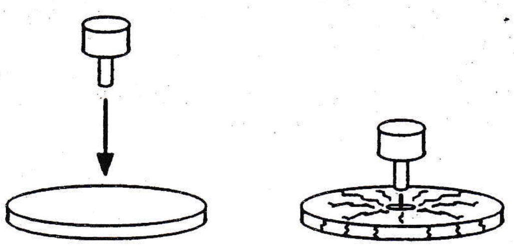
Falling Dart Impact

Typical names for this test are Gardner Impact & Dynatup™ Impact.



Falling Dart tests measure the ability of a material to resist breaking when struck on a surface.

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Participant's Notes:

The Notched Izod test measures the ability of a material to resist breaking when notches are present.

Izod Impact Test

The Izod Impact Test may be used to measure both notched and unnotched material specimens. A notch in the material is designed to simulate an actual part angle, indentation, or corner. Notched Izod Impact tries to determine how well a material will resist breaking in the presence of a notch or defect. Comparison of the two sets of test results should indicate the notch sensitivity of the material.

STK 427

The Falling Dart Test measures the ability of a material to resist breaking when struck on the surface.

Falling Dart Impact

The Falling Dart Test describes a more practical impact than the Izod Tests. Falling Dart Tests, such as the Gardner Impact and the Dynatup Impact, measure the ability of a material to resist breaking when struck on its surface. A material that is said to be ductile is very capable of absorbing impact. Fracture is a material's failure to absorb impact.

STK 428

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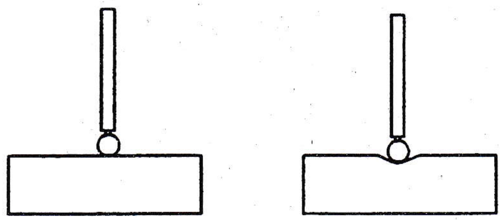
Hardness

Hardness refers to a material's surface stiffness.



- **Rockwell Hardness tests a material's ability to resist surface indentation.**
- **Hardness is reported on a relative scale for comparing materials.**

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Participant's Notes:

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Properties of Polymers

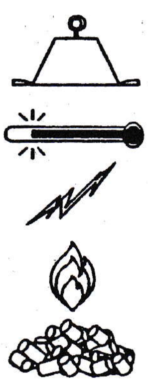
Mechanical Performance

Thermal Performance

Electrical Performance

Flammability

Physical Characteristics



4

Participant's Notes:

Hardness is a measure of a material's surface stiffness or resistance to indentation.

Hardness

Hardness is a measure of a material's surface stiffness as opposed to modulus, which measures stiffness throughout. The Rockwell Hardness test measures a material's resistance to surface indentation. Since hardness is reported on a relative scale for material comparison, it is important to know the scale being used to accurately compare material hardness. **STK 429**

Thermal

Thermal performance.

Properties of Polymers

Thermal performance measures how a material responds to changing temperatures, and its ability to perform at different temperatures. **STK 430**

STK 431

GE Plastics

Thermal Properties

- Heat Deflection Temperature (HDT)
- Thermal Conductivity
- Coefficient of Thermal Expansion (CTE)
- Relative Thermal Index (RTI)

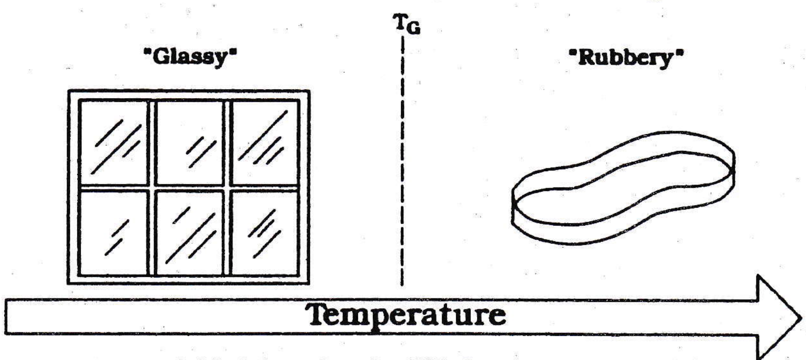
4

Participant's Notes:

STK 432

GE Plastics

Heat Affects Thermoplastic Properties



A material is "glassy" and stiff below its glass transition temperature and "rubbery" and soft above T_G

4

Participant's Notes:

It is important to consider thermal properties when selecting and processing materials.

Thermal Properties

We will consider four fundamental thermal properties that are very important when selecting and processing a material: heat deflection temperature (HDT), thermal conductivity, coefficient of thermal expansion (CTE), and Relative Thermal Index (RTI).

STK 431

Heat affects thermoplastic's properties.

Heat Affects Thermoplastic Properties

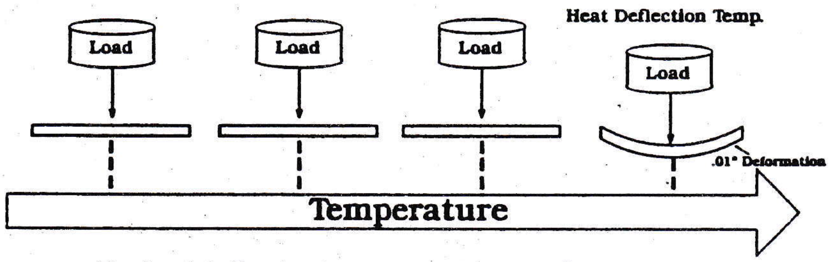
When plastics are processed, they are heated until they soften or melt. It is quite obvious then, that heat affects thermoplastic properties. As the temperature of a polymer is raised, it goes through a glass transition: from a "glassy" material to a "rubbery" material. Consequently, as its structural properties change so does its ability to perform under a variety of stresses.

STK 432

STK 433

GE Plastics

Heat Deflection Temperature



- The heat deflection temperature reports the temperature at which a material shows .01 inches deformation under load
- It is reported in °F or °C at loads of both 66psi and 264psi

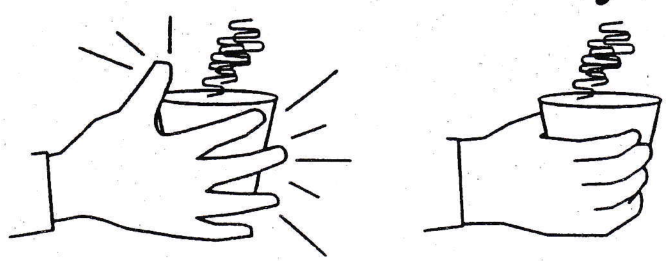
4

Participant's Notes:

STK 434

GE Plastics

Thermal Conductivity



Metal Coffee Cup
High Thermal Conductivity

Styrofoam Coffee Cup
Low Thermal Conductivity

Thermal conductivity measures how fast heat moves through a material.

4

Participant's Notes:

Heat deflection temperature is the temperature at which a material shows 10 mils of deformation under load.

Heat Deflection Temperature

The heat deflection temperature attempts to indicate the degree to which a material's properties are affected by a rise in temperature. A load is applied to a material specimen and the temperature is slowly raised. The heat deflection temperature is the temperature at which a material shows significant deformation under load: .01 inches. It is usually reported under two different levels of stress: 264 psi and 66 psi. **STK 433**

Thermal conductivity measures how fast heat moves through a material.

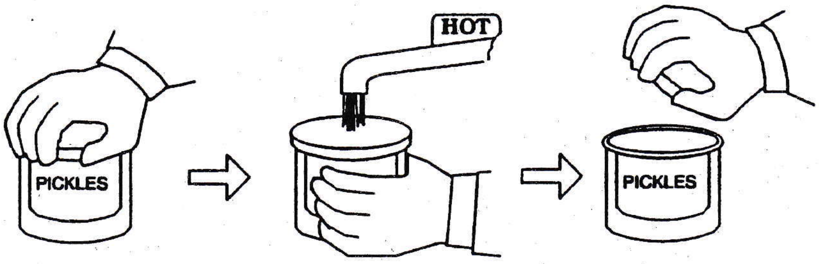
Thermal Conductivity

Thermal conductivity indicates whether or not a material would conduct heat. High thermal conductivity means that heat moves quickly through a material, the way the heat from the coffee travels quickly through this metal coffee cup and burns the person's hand. Metal is not an insulator, but a conductor of heat. Low thermal conductivity means that heat moves slowly through a material, the way the heat from the coffee travels slowly through the styrofoam cup. Styrofoam is a good insulator and therefore protects the person's hand from the hot coffee. The thermal conductivity of a material is also an indication of how quickly the material will cool. This is especially important to the converter concerned with quick cooling and short cycle times. **STK 434**

STK 435

GE Plastics

Thermal Expansion



The lid on the jar is loosened under hot water due to thermal expansion.

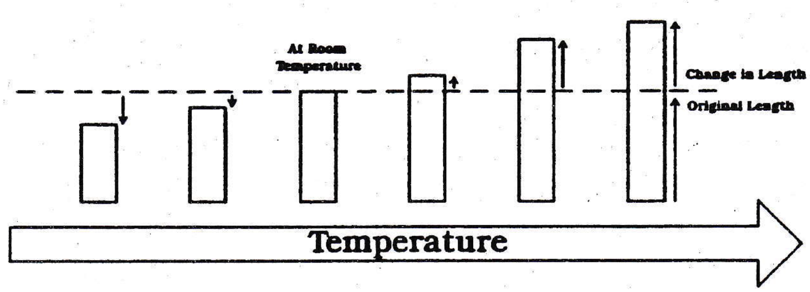
4

Participant's Notes:

STK 436

GE Plastics

Coefficient of Thermal Expansion (CTE)



The coefficient of thermal expansion is a measurement of a material's expansion upon heating and contraction upon cooling.

4

Participant's Notes:

Materials tend to expand as temperature is increased and contract as temperature is lowered.

Thermal Expansion

Materials tend to expand upon heating and contract upon cooling. This phenomenon is referred to as thermal expansion. Some materials have a greater tendency to expand than others. The metal lid on this jar, for example, expands more upon heating than the glass jar. When run under hot water, the metal lid expands and loosens for easy removal. Metal has a higher coefficient of thermal expansion than glass. **STK 435**

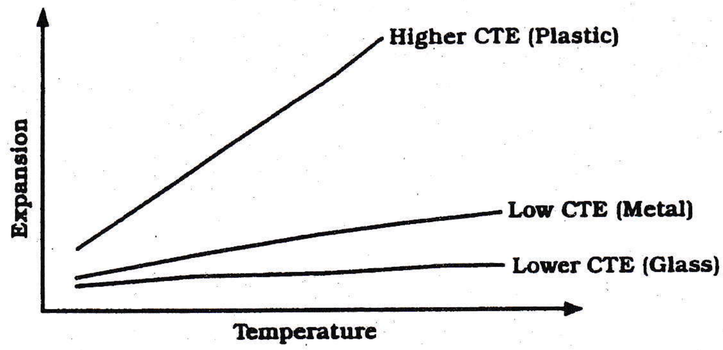
Coefficient of thermal expansion is a measurement of how much a material expands and contracts with thermal changes.

Coefficient of Thermal Expansion (CTE)

The coefficient of thermal expansion (CTE) numerically measures the tendency of a material to expand upon heating and contract upon cooling. As the temperature rises, some materials expand more than others. Likewise, as the temperature decreases, some materials contract more than others, though every material will stop contracting at absolute zero (-459.67°F). In order to test this tendency, the degree to which a material expands or contracts is measured over a range of temperatures. **STK 436**

GE Plastics

CTE Comparison



The slope of the curve = Coefficient of Thermal Expansion.

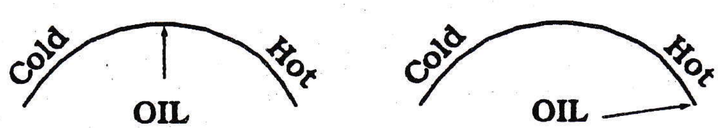
4

Participant's Notes: ______________________________

GE Plastics

Relative Thermal Index (RTI)

Sunday Driving | Racing



Long Life of Oil | Short Life of Oil

- Oil will degrade more quickly when run at higher temp than its suggested use temperature.
- Plastics age faster at higher temperatures.

4

Participant's Notes: ______________________________

Coefficient of thermal expansion can be represented graphically.

CTE Comparison

The degree of expansion or contraction of the material versus the rise or drop in temperature is then plotted on a graph and the slope of the resulting curve is calculated. This number represents the material's expansion with respect to temperature. It is referred to as the coefficient of thermal expansion. The higher the slope of the curve, the greater the expansion, and the higher the coefficient of thermal expansion. Therefore, metal has a higher CTE than glass, and plastic has a higher CTE than metal. **STK 437**

Relative Thermal Index indicates the highest temperature at which a material will retain good performance properties over a long period of time.

Relative Thermal Index

The Relative Thermal Index (RTI) is the highest temperature at which a material can be used and still retain its good performance properties for a long period of time. Just as oil will degrade more quickly when run at a higher temperature than its recommended use temperature, so will plastics age faster at higher temperatures.

STK 438

STK 439

GE Plastics

U.L. Relative Thermal Index

The highest constant temperature at which a material will survive relative to the application requirements.

4

Participant's Notes:

STK 440

GE Plastics

Properties of Polymers

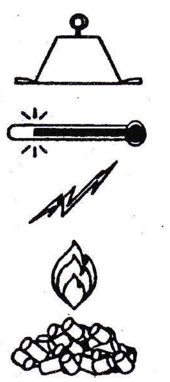
Mechanical Performance

Thermal Performance

Electrical Performance

Flammability

Physical Characteristics



4

Participant's Notes:

Relative Thermal Index is the highest constant temperature at which a material will survive relative to the application requirements.

U.L. Relative Thermal Index

The Relative Thermal Index is the highest constant temperature at which a material will survive relative to the application requirements.

STK 439

Properties

Electrical

Electrical performance.

Properties of Polymers

Electrical performance measures how a material responds when exposed to electrical currents, and its ability to perform under electrical stress.

STK 440

STK 441

GE Plastics

Electrical Properties

- Dielectric Strength
- Volume Resistivity
- Arc Resistance
- Arc Track Rate

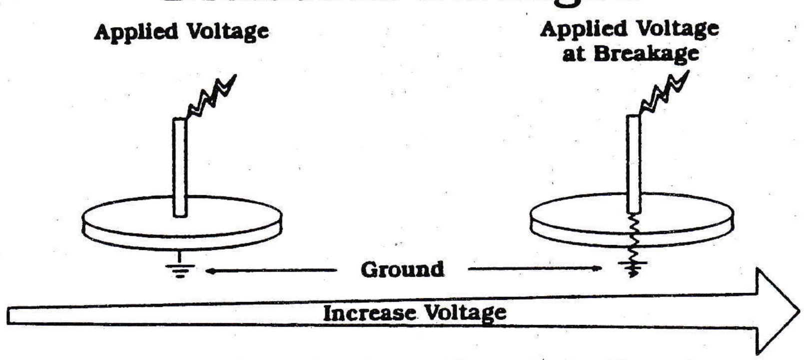
4

Participant's Notes: ____

STK 442

GE Plastics

Dielectric Strength



Dielectric strength measures the applied voltage at breakdown (to burn a track through the specimen).

4

Participant's Notes: ____

Electrical Properties

Four electrical properties.

We will consider four fundamental electrical properties that are often important when selecting a material: dielectric strength, volume resistivity, arc resistance, and high voltage arc track rate.

STK 441

Dielectric Strength

Just as mechanical strength measures the maximum mechanical load a material can withstand before failure, dielectric strength measures the maximum electrical load a material can withstand before failure. Voltage is an electrical load. It refers to any electrical potential that creates a current. To test dielectric strength, increasing amounts of voltage are applied to a material specimen until it "breaks."

Dielectric strength measures the voltage at which material breakdown will occur.

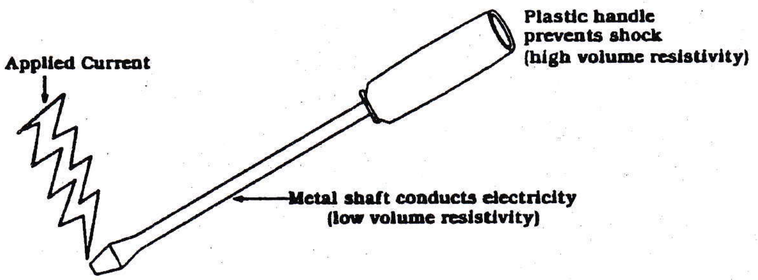
Electrical breakdown is in the form of a carbon track burned through the material. As voltage is initially applied, the material resists the charge. But once a track is burned, the material will conduct electricity. Dielectric strength measures the maximum voltage the material withstands and is reported in volts per thickness.

STK 442

STK 443

GE Plastics

Volume Resistivity



Volume resistivity measures the resistance to current flow.

Above 10^8 OHM-cm	= insulator
10^3 - 10^8 OHM-cm	= semiconductor
Below 10^3 OHM-cm	= conductor

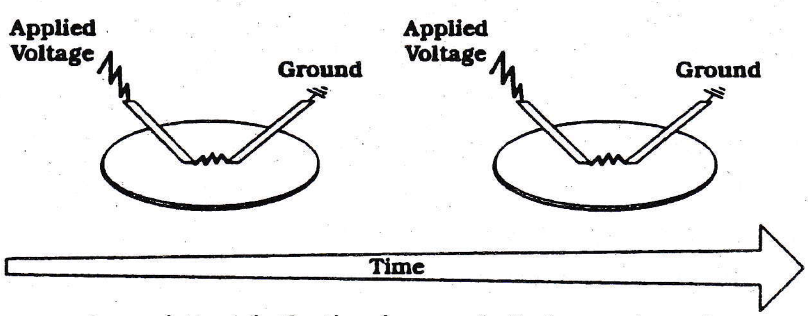
4

Participant's Notes:

STK 444

GE Plastics

Arc Resistance



Arc resistance is the time in seconds that a spark can be applied to a material surface before it chars rendering it conductive.

4

Participant's Notes:

Volume resistivity measures a material's resistance to electrical current flow.

Volume Resistivity

Volume resistivity measures a material's resistance to the flow of an electrical current. It is measured in OHM-cm which represents the material's resistance at a thickness of one cm. Metal has low volume resistivity - less than 10^5 OHM-cm - and is therefore considered to be a conductor of electricity. Plastic is resistant to the flow of an electrical current. It has high volume resistivity - more than 10^8 OHM-cm - and is therefore considered to be an insulator. A material with volume resistivity between 10^5 and 10^8 OHM-cm is considered to be a semiconductor. **STK 443**

Arc resistance measures a material's resistance to an applied voltage at the surface over time.

Arc Resistance

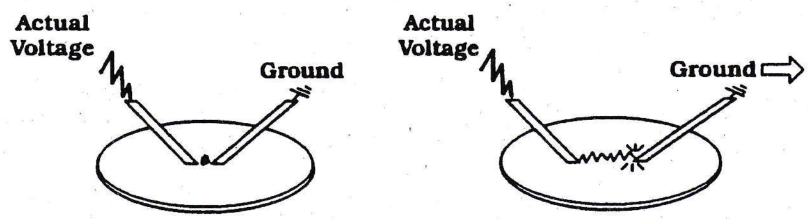
While dielectric strength measures the maximum voltage a material can withstand, and volume resistivity measures a material's resistance to the flow of electricity per a given thickness, arc resistance measures a material's resistance to an applied voltage over time. Arc resistance measures the time, in seconds, that an electrical spark can be applied to a material surface before it chars. Charring is the "drawing" or "cutting" of a carbon track across the material's surface. Once charred, a material is then rendered conductive.

STK 444

STK 445

GE Plastics

High Voltage Arc Track Rate



High Voltage Arc Track Test measures the rate an arc can carbonize the surface and produce a conductive path.

4

Participant's Notes:

STK 446

GE Plastics

Properties of Polymers

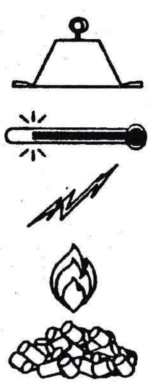
Mechanical Performance

Thermal Performance

Electrical Performance

Flammability

Physical Characteristics



4

Participant's Notes:

The high voltage arc track test measures the rate at which an arc can carbonize the surface and produce a conductive path.

High Voltage Arc Track Rate

The high voltage track rate is an Underwriters Laboratory (U.L.) test that measures how quickly an electrical track can be drawn on the surface of a material. The test measures the tendency of a material to continue charring once charred. The result of the test indicates how susceptible a material is to burning from an electrical charge. The quicker the track can be drawn, the higher the track rate, and the more susceptible the material is to electrical burning. Slowness indicates difficulty in drawing the track, a lower track rate, and therefore a material that is less susceptible to electrical burning.

STK 445

Flammability

Properties of Polymers

We have just concluded a discussion of mechanical, thermal, and electrical properties and have identified some standard tests. The major standard setting body in the plastics industry is The American Society for Testing and Materials (ASTM), founded in 1891. It is a scientific and technical organization formed for the development of standards on characteristics and performance of materials, products, systems and services and the promotion of related knowledge. The testing and reporting standards established by ASTM are universally used to measure plastic properties throughout the world.

ASTM standard tests are used to measure a variety of mechanical, thermal, and electrical properties. Underwriters Laboratory prescribes standard tests for measuring a material's response in a flame environment and certifies the test results.

Underwriters Laboratories (U.L.) Inc. is an independent safety testing organization that investigates products voluntarily submitted from manufacturers to determine if they are reasonably free from fire, electrical shock and related accident hazards. **STK 446**

STK 447

GE Plastics

Flammability

- Oxygen Index
- U.L. 94 Flammability

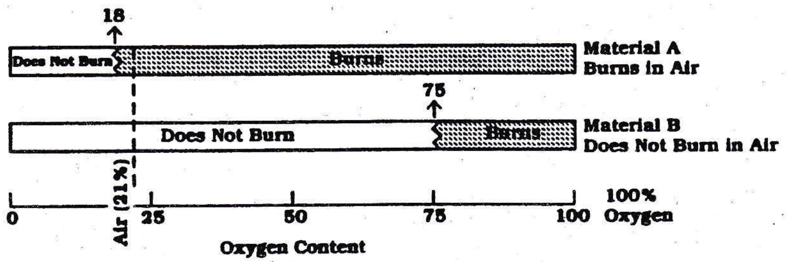
4

Participant's Notes:

STK 448

GE Plastics

Oxygen Index



Oxygen index above 28 is flame resistance in most applications.

4

Participant's Notes:

Oxygen index and U.L. 94 flammability are two measures of material performance.

Flammability

U.L. properties provide a standard throughout industry and act as a means of comparing certain material properties. We will discuss oxygen index and U.L. 94 flammability as measures of plastics performance under flame environments.

STK 447

The oxygen index measures the amount of oxygen required for a material to support combustion.

Oxygen Index

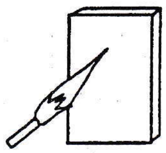
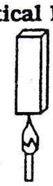
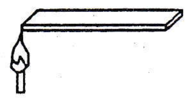
The oxygen index measures the amount of oxygen required for a material to support combustion. For example, material (A) does not burn in 17% oxygen, but does burn in 18% oxygen. Therefore it has an oxygen index of 18. It will, of course, continue to burn as the available oxygen continues to increase. Since air is 21% oxygen, and since material (A) burns in 18% oxygen, then material (A) burns readily in air. Material (B), on the other hand, needs at least 75% oxygen before it will finally burn. Therefore it has an oxygen index of 75 and is considered flame resistant. In general, any material with an index greater than 28 is considered flame resistant. **STK 448**

STK 449

GE Plastics

UL 94 Flammability

Underwriters Laboratories reports the following flammability ratings per Bulletin 94.

94 5-V	Vertical Burn	Horizontal Burn
		
Best Rating	**Self Extinguishing**	**Slow Burn Rating**
Doesn't ignite under hotter flame	94 V-0 (Best) 94 V-1 (Good) 94 V-2 (Drips)	Takes more than 3 minutes to burn 4 inches

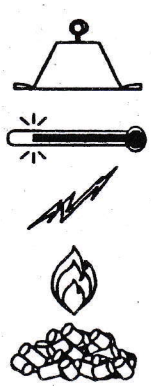
4

Participant's Notes: ____________________

STK 450

GE Plastics

Properties of Polymers



Mechanical Performance

Thermal Performance

Electrical Performance

Flammability

Physical Characteristics

4

Participant's Notes: ____________________

U.L. 94 Flammability

Several different tests are done to describe a material's flammability.

Underwriters Laboratory reports flammability ratings per U.L. Bulletin 94. A highly flame retardant material may be exposed to a very hot flame. If it ignites, it must then undergo the vertical burn test. In the vertical burn test, if the material extinguishes itself quickly it is given a rating of 94 V-0. If the material takes longer to extinguish itself, it is given a rating of 94 V-1. If it takes longer and drips without igniting a ball of cotton under the speciman it may be given a rating of 94 V-2. Finally, if the material is still unable to extinguish itself, it may undergo the horizontal burn test. The horizontal burn test measures how quickly it takes the material to burn. If it takes more than 3 minutes to burn 4 inches, it will be given a slow burn rating. This is the lowest of the U.L. flammability ratings. **STK 449**

Physical

Properties of Polymers

There are also important physical characteristics that are particular to each resin and therefore important in material selection, tooling, and processing. **STK 450**

STK 451

GE Plastics

Physical Properties

- Shrinkage
- Specific Gravity

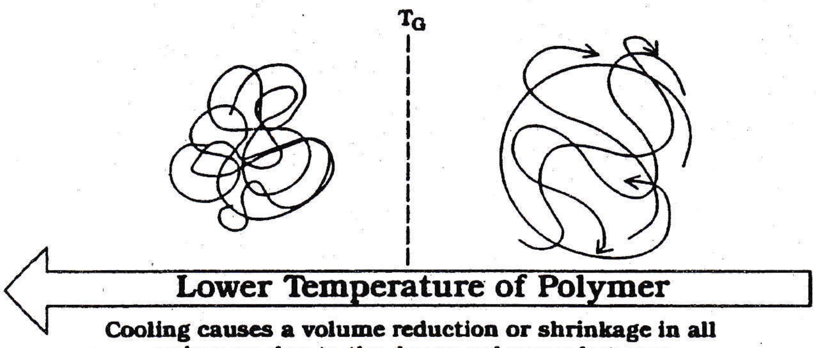
4

Participant's Notes:

STK 452

GE Plastics

Shrinkage



Cooling causes a volume reduction or shrinkage in all polymers due to the decreased space between the polymer chains in a cooled material.

4

Participant's Notes:

Physical properties: shrinkage and specific gravity.

Physical Properties

We are going to discuss two fundamental physical characteristics : shrinkage and specific gravity.

STK 451

Shrinkage occurs on cooling from the melt during conversion.

Shrinkage

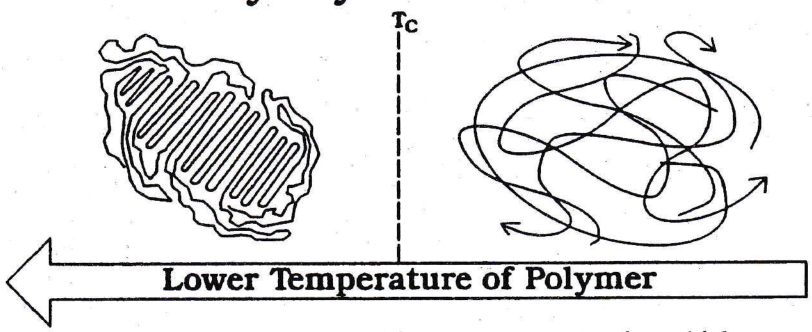
Shrinkage is caused by the same phenomenon that causes thermal expansion and contraction. Heating a polymer material will not only cause it to soften and flow, but to expand. As the polymer is heated, its molecular chains begin to loosen and spread apart. This space allows the molecules to slide easily past one another which causes the material to flow. Thermal expansion results from the increased space between the heated molecules. This expansion is particularly high when the material is in its melt state. Subsequent cooling of the melt during processing causes the polymer chains to move back together again. Upon cooling, the space between the molecules decreases causing a reduction in material volume referred to as shrinkage.

STK 452

STK 453

GE Plastics

Shrinkage Is Affected by Crystallization



Crystallization causes additional volume reduction which results in higher shrinkage in crystalline polymers.

4

Participant's Notes:

STK 454

GE Plastics

Shrinkage

The amount of material shrinkage that must be accomodated for in the tooling design is reported in inches / inch, mils / inch, or as a percent.

.005 inches / inch = 5 mils / inch = .5%

All three readings are the same.

4

Participant's Notes:

Crystallization results in higher shrinkage in crystalline polymers.

Shrinkage Is Affected by Crystallization

Shrinkage is especially high in crystalline polymers due to the increased volume reduction caused by crystallization. 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 to a solid state. Crystalline materials such as PVT tend to have higher shrinkage values than amorphous materials like ABS. **STK 453**

It is important to take into account a material's shrinkage when designing a tool.

Shrinkage

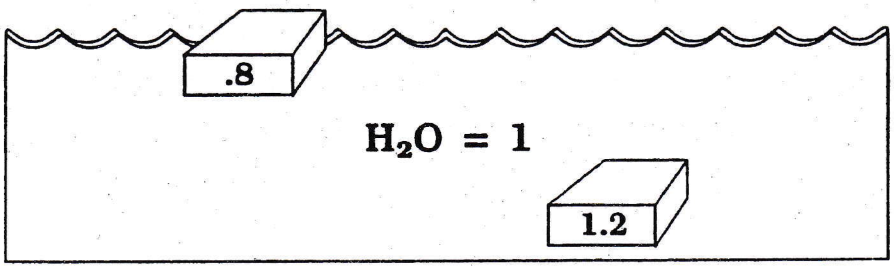
Whether high or low, a material's shrinkage must be accommodated for in the tooling design. Shrinkage may be reported in either inches per inch, mils per inch, or as a percent. For example, .005 inches/inch, 5 mils/inch, and .5% all indicate the same amount of shrinkage. **STK 454**

STK 455

GE Plastics

Specific Gravity

Specific gravity expresses density relative to the density of water.



Two objects with the same volume can have different density and therefore, different weights.

4

Participant's Notes: ____________________

STK 456

GE Plastics

Cost Per Pound vs. Cost Per Cubic Inch

Higher Specific Gravity ⇨ Fewer Parts Per Pound

Lower Specific Gravity ⇨ More Parts Per Pound

Cost per volume is a more accurate means of comparing the cost of a part.

4

Participant's Notes: ____________________

Specific Gravity

Specific gravity describes a material's density in relation to water. It is the density of the material divided by the density of water.

Specific gravity expresses the density of a material relative to the density of water.

Since water has a specific gravity of one, any material with a specific gravity of greater than one, sinks in water, and any material with a specific gravity of less than one, floats in water. Two objects with the same volume can have different densities and therefore different specific gravities. This is a point that is very important to a converter if he is buying material by weight. **STK 455**

Cost Per Pound vs. Cost Per Cubic Inch

The cost per volume is a more accurate means of comparing the cost of a part.

Specific gravity provides a more accurate means of comparing material costs because plastic parts are sold by volume, not weight. A material with a high specific gravity will produce fewer parts per pound than a material with a low specific gravity. For example, ten pounds of a material with a specific gravity of 1.2 may only yield 100 parts, while ten pounds of a material with a specific gravity of .8 may yield over 150 parts. Consequently, cost per cubic inch is a more accurate means of comparing material costs than cost per pound.

STK 456

STK 457

GE Plastics

Understanding Properties of Polymers

4

Participant's Notes:

STK 458

GE Plastics

Product Data Sheets

PROPERTY	UNIT	METHOD	TYPICAL DATA
MECHANICAL			
Tensile Strength, break	psi	ASTM D 638	13300
Flexural Strength, break	psi	ASTM D 790	20000
Flexural Modulus	psi	ASTM D 790	780000
Compressive Strength	psi	ASTM D 695	10800
Hardness, Rockwell R	-	ASTM D 785	109
IMPACT			
Izod Impact, unnotched	ft - lb / in	ASTM D 256	12.0
Izod Impact, notched	ft - lb / in	ASTM D 256	3.2
THERMAL			
DTUL, 66 psi	deg F	ASTM D 648	400
DTUL, 264 psi	deg F	ASTM D 648	300
CTE, flow, -40F to 100F	in / in - F	ASTM E 831	1.50 E-5
CTE, flow, 140F to 280F	in / in - F	ASTM E 831	1.10 E-5

4

Participant's Notes:

Summary and Performance Feedback

Understanding Properties of Polymers

The properties reported on the material data sheet are indispensable to the product designer, the toolmaker, and the converter. The mechanical performance, thermal performance, electrical performance, flammability characteristics, and physical characteristics of a material are all important considerations when selecting and processing a material.

STK 457

Understanding Product Data Sheets

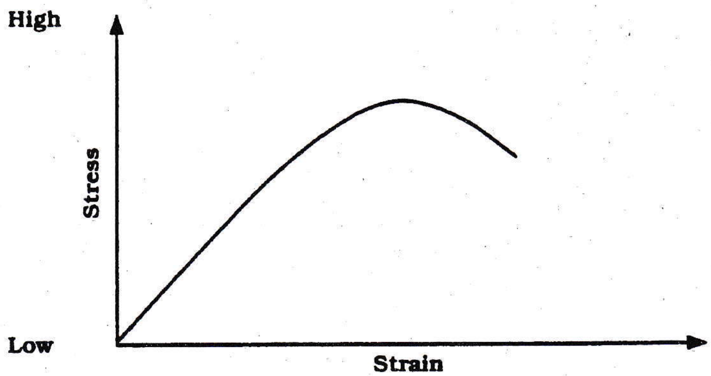
Therefore it is important to understand the property values listed on the product data sheets to accurately compare material performance, and to accurately establish material processing parameters.

STK 458

STK 459

GE Plastics

Engineering Design Data Base



4

Participant's Notes:

STK 460

GE Plastics

List two sources of information on material properties.

4

Participant's Notes:

Understanding Engineering Design Data Base

It is very useful to understand how to read an engineering graph. Graphs like those provided by GE Plastics Engineering Design Database provide useful material performance information over a range of conditions and variables. An engineering graph allows the product designer to more accurately predict material performance in application, often resulting in higher performance parts.

STK 459

STK 461

GE Plastics

Product Data Sheets

Graphs

4

Participant's Notes: ______________________________

STK 462

GE Plastics

Why make a graph?

4

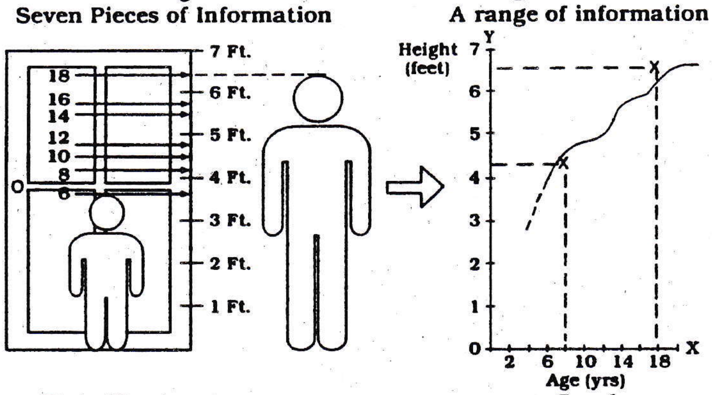
Participant's Notes: ______________________________

STK 463

GE Plastics

Why Make a Graph?

Seven Pieces of Information | A range of information



Data Sheet

Graph

4

Participant's Notes:

STK 464

GE Plastics

List 5 categories of properties used to distinguish thermoplastic materials.

4

Participant's Notes:

STK 465

GE Plastics

Properties of Polymers

- Mechanical Performance
- Thermal Performance
- Electrical Performance
- Flammability
- Physical Characteristics

4

Participant's Notes: ____________________

STK 466

GE Plastics

Which test measures the ability of a material to resist breaking when struck on the surface?

4

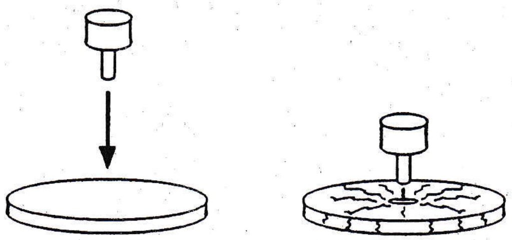
Participant's Notes: ____________________

STK 467

GE Plastics

Falling Dart Impact

Typical names for this test are Gardner Impact & Dynatup™ Impact.



Falling Dart tests measure the ability of a material to resist breaking when struck on a surface.

4

Participant's Notes:

STK 468

GE Plastics

Module 5

Conversion Processes

- Types
  - Extrusion
  - Blow Molding
  - Injection Molding

4

Participant's Notes:

Module 4

Performance Feedback

1. List two sources of information on material properties.

2. Describe 5 categories of properties used to distinguish thermoplastic materials.

3. Identify which tests are used to measure different properties under various conditions.

4. For a part that you are converting, identify the key properties required in the application.