



# **Design for Manufacturing, Assembly, and Reliability**

Module 3B Materials Selection

# Motivation

*Why is this module important?*



- The materials used to mass produce your product can mean the difference between success and failure

## **Material selection drives:**

- Cost and time to produce
- Performance and adaptability to design changes
- Look, feel, and sense of quality
- Reliability
- Environmental impact

*Spend the time now to select the right material for your product.  
You may not have a second chance!*

# Module Outline



- Learning objectives
- Overview of classes of materials:
  - Plastics, metals, ceramics, composites, advanced materials
- Material properties
  - Mechanical, physical, thermal, electrical, optical, environmental
- Materials selection processes

# Learning Objectives



- LO1. Appraise the benefits and drawbacks of alternative materials
- LO2. Identify material properties necessary to meet customer functional requirements
- LO3. Identify material modifications that can be used to enhance product performance

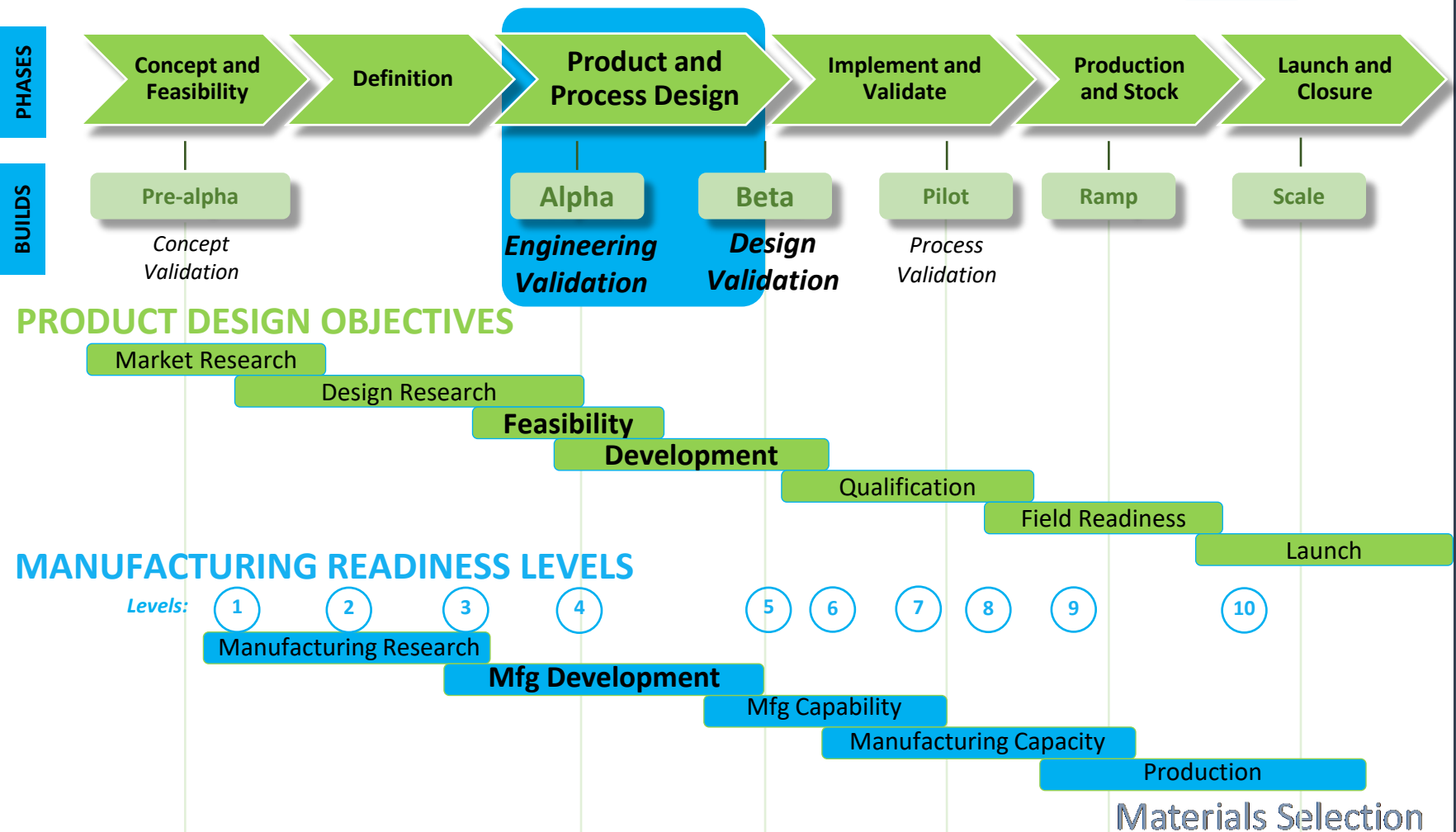
# What This Module Addresses



- The various classes of materials and how to select them
- How to assess material properties based on the application
- How to meet customer needs for product performance using selected materials properties
- An introduction of how materials influence product design

# Design For Manufacturing

*Where does this fit into the development cycle?*



# Materials

## *Classes and properties*



- Materials have a range of properties that can overlap and vary by class

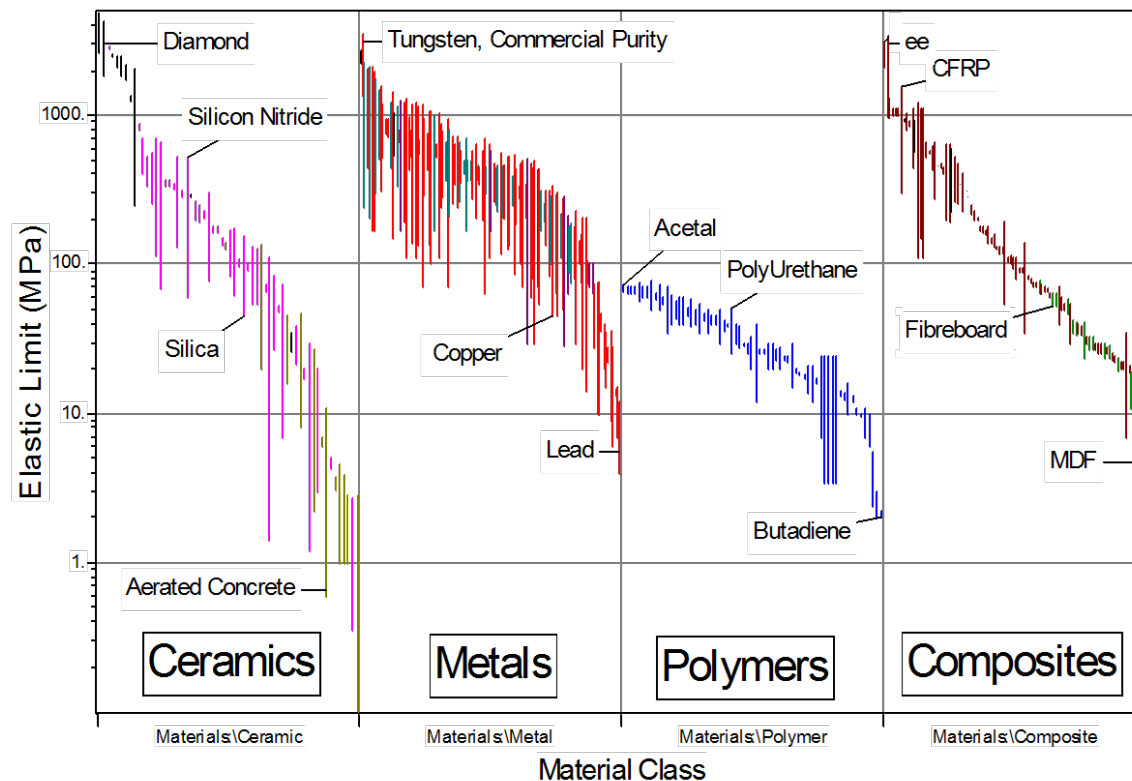
Properties	Metals			Plastics		Ceramics	Composites
	Low Alloy Steel	6000 Series Aluminum	Bronze	Polycarbonate	Phenolic	Tungsten Carbide	Carbon Fiber - Epoxy Composite
Density (g/cc)	7.5 - 8.08	2.68 - 2.9	6.4 - 9.25	0.960 - 1.51	1.35 - 2.13	15.7	1.15 - 2.25
Hardness (Rockwell B)	45 - 112	49 - 80	26 - 200	N/A	N/A	N/A	
Ultimate Strength (Mpa)	180 - 2730	89.6 - 560	96.5 - 1010	0.207 - 93.1	41.0 - 57.9	344	0.917 - 3790
Elongation at Break	1% - 37%	1% - 35%	0% - 70%	3% - 233%	N/A	N/A	
Fatigue Strength (Mpa)	138 - 772	55 - 375	90 - 352	N/A	N/A	N/A	0.5% - 11%
Electrical Resistivity (ohm-cm)	0.0000170 - 0.000142	0.00000280 - 0.00000500	0.00000360 - 0.0000250	1.00e+7 - 1.00e+17	1.00e+11 - 1.00e+13	0.0000530 - 0.0000800	100 - 1.30e+13
Specific Heat (J/g-C)	0.448 - 0.669	0.80 - 0.90	0.375 - 0.450	1.20 - 2.28	0.940 - 0.940	N/A	1.00 - 1.20
Thermal Conductivity (W/m-K)	25.3 - 93.0	130 - 226	33.0 - 208	0.163 - 0.260	N/A	N/A	0.220 - 400

# Materials

## *Selection goal*



*Find a material that meets the product design requirements and can be manufactured economically*





# Polymers

## *Basics*



- Different types of polymers

- There are dozens of polymer types that are used for various applications, from packaging to structural components

- **Thermoplastics** are molecules that are not connected to one another

- Thermoplastics tend to be softer and are used at lower temperatures than thermosets

- Thermoplastics can also be recycled or reheated

- **Thermosets** undergo irreversible “crosslinking,” which binds molecules together

- Thermosets are used for harder components that operate at higher temperatures

- Once cured, they cannot be reused or reheated

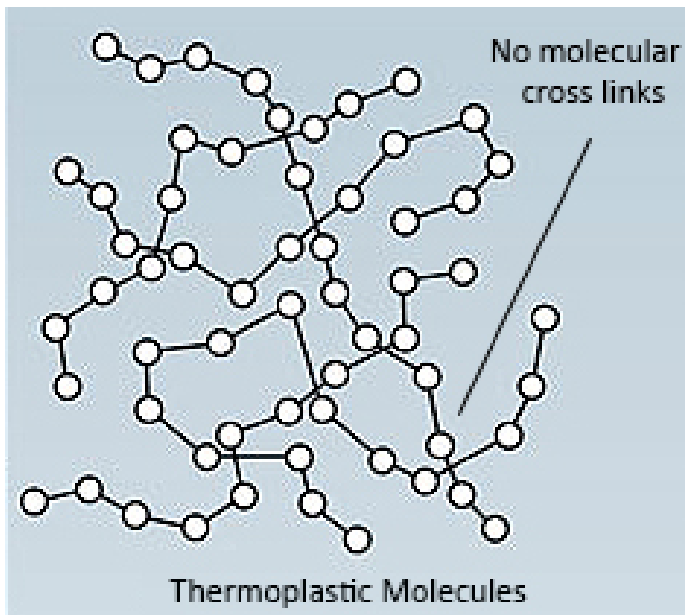
# Polymers

*Basics (cont.)*

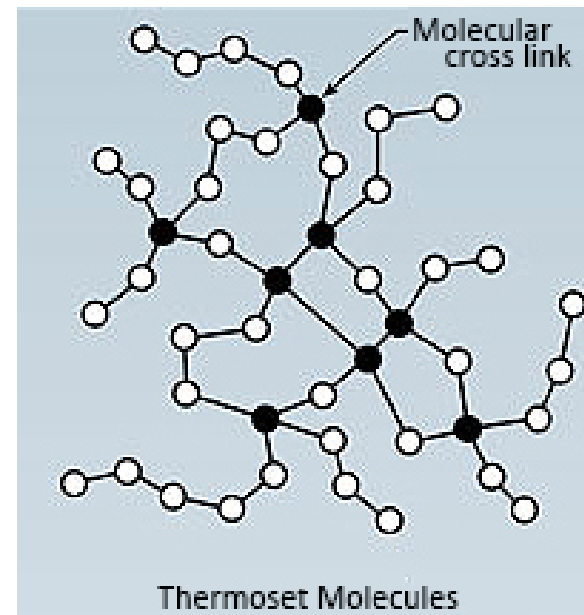


## Polymers

### Thermoplastics



### Thermosets



Materials Selection

# Polymers

## *Thermoplastics*

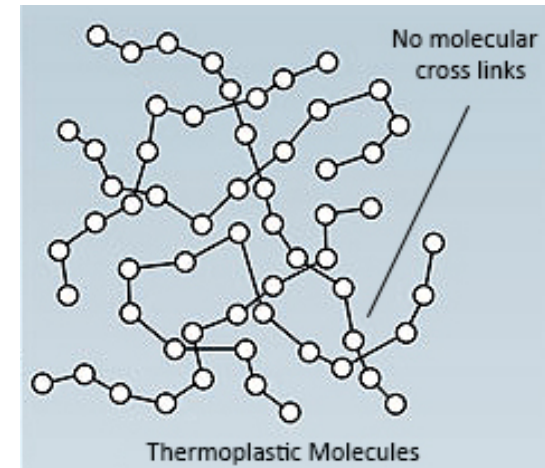


- Thermoplastics can be amorphous or crystalline
- Amorphous thermoplastics soften at the glass-transition temperature (They should not be used in environments that exceed that temperature)
- They can be transparent, tough, and strong

*Examples:* polycarbonate (PC), polymethylmethacrylate (PMMA)

- Crystalline thermoplastics have a higher melting temperature but are more susceptible to warping

*Examples:* include polyethylene, polypropylene, Nylon<sup>®</sup>, and Kevlar<sup>®</sup>

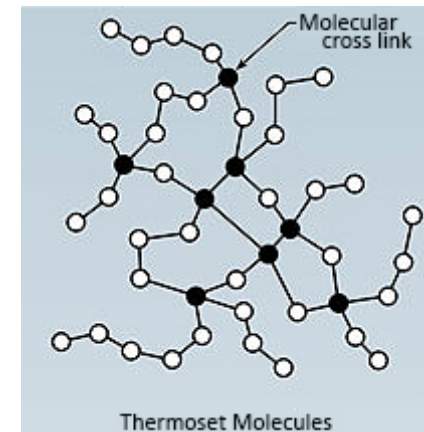


Materials Selection

# Polymers

## *Thermosets*

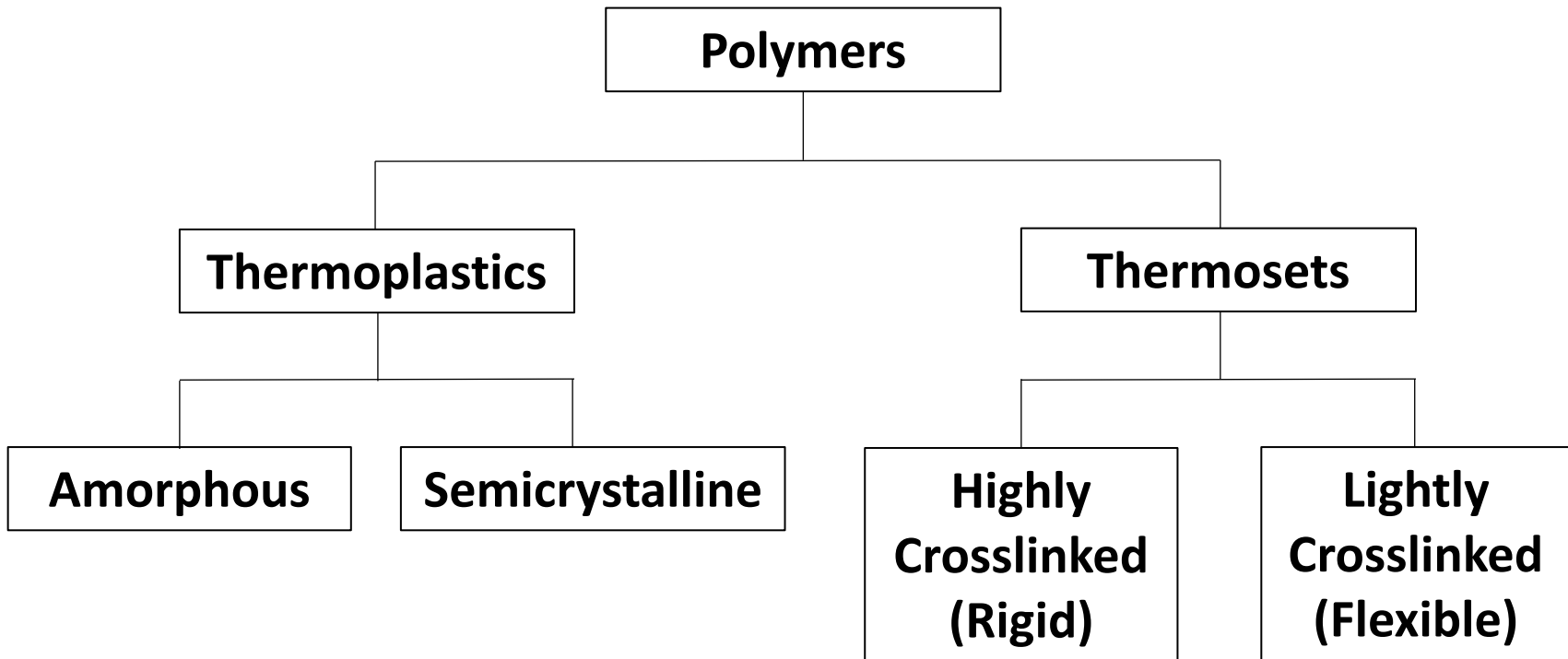
- Thermosets are polymers that undergo the irreversible process of molecular crosslinking; aka. 'curing'
- Crosslinking is initiated by heat, light, or chemical exposure  
—The crosslink process (sometimes called “curing”) can take minutes to several days
- Thermosets can be either rigid or flexible
  - Examples:* Rigid thermosets include epoxies and Bakelite plastics
  - Examples:* Flexible thermosets include vulcanized rubber and urethanes
- Thermosets are resistant to high heat and solvents
- Applications include: structural components, protective enclosures, padding, and seals (urethane)



Materials Selection

# Polymers

## *Summary*



# Polymers

## *Additives*



- Given the susceptibility of polymers (especially thermoplastics) to degradation by various environmental factors, additives are used to improve their physical properties
- UV stabilizers can reduce the damage done by UV light (This is very important for certain plastics that will be subjected to sunlight)
- Antioxidants prevent the breakdown of polymer chains resulting from reactions with oxygen (oxidation can significantly weaken certain polypropylenes and polyethylenes)
- Flame retardants and heat stabilizers can also be added to polymers (flame retardants are critical for ensuring compliance with safety regulations)

# Metals

## *Basics*



**Ferrous metals contain iron, including:**

- ☐ Steel
- ☐ Cast iron

**Non-ferrous metals do not contain iron, including:**

- ☐ Aluminum
- ☐ Magnesium
- ☐ Copper

# Metals

## *Basics (cont.)*



**Several government and non-government agencies have developed and maintain numbering and classification codes and standards for specific metal products (these can be used for materials selection and procurement):**

- ☐ American Society of Mechanical Engineers
- ☐ ASTM International
- ☐ Society of Automotive Engineers
- ☐ American Petroleum Institute



# Metals

## *Steel*

- Carbon steel has few other alloying elements other than carbon
  - Used for structural and other applications requiring strength
  - Properties vary significantly, based on heat treatment
- Alloy steel includes alloying elements
  - Alloy elements are added to provide specific beneficial characteristics and properties
  - Example: Boron can be added to harden steel
- SAE-AISI 6150 is Chromium-vanadium steel
  - It has a specific chemical composition
  - It is used for mechanical power-transmission components (e.g., gears, shafts, and pinions)
- Small changes in a metal's composition can have significant effects



# Metals

## *Steel manufacturing process/effects*



- ❑ Steel is formed into specific products, including rectangular billets, round stock, sheets, and structural shapes (girders, rebar, etc.)
- ❑ Hot finishing is a process whereby smaller shapes are formed while the material is still “red hot” (this does not harden the material or reduce its ability to be formed)
- ❑ Cold finishing is done at lower temperatures (this “work hardens” the steel and makes it more difficult to form)
- ❑ The finishing process affects material properties and should be taken into account when specifying a material

# Metals

## *Steel manufacturing process/effects (cont.)*



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# Metals

## *Steel manufacturing process/effects (cont.)*

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# Metals

## *Heat treatment*

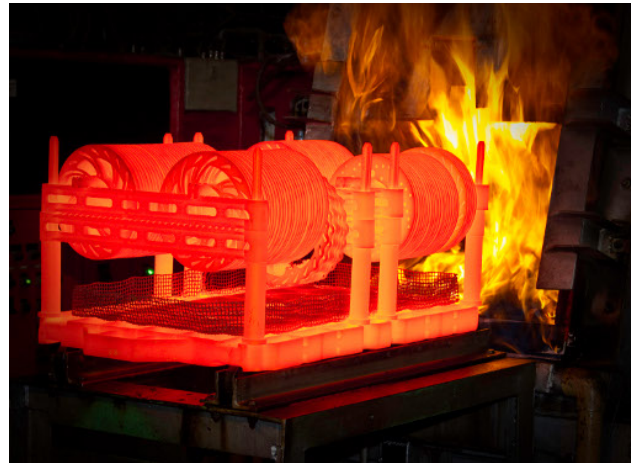


- Depending on the application and process requirements of the material, heat treating can improve a metal's properties
- **Hardening** is desirable in some cases (i.e., structural members or high stress application)
- Metal can be hardened by heating and quenching
- In some cases only the outside of a component can be hardened using a flame, induction, or a laser method
- A metallic component can be machined and then hardened once the required dimensions are achieved

# Metals

## *Heat treatment (cont.)*

- **Softening:** hardened materials sometimes become brittle and need to be softened
- **Annealing** is a process that can be used to heat and soften a steel (this process can be used in a situation where a mistake was made and the part needs to be re-machined)



# Metals

## *Other steel alloys*



- Ultra-high strength steel: hardened alloy steels can become ultra-high strength through heat treatment

### **Yield strengths (Megapascal, MPa):**

- Low carbon: 250–500
- Alloy grade: 500–1250
- Ultra-high strength: 1250–2100

*There are thousands of different composition, treatment, and shape combinations*

# Metals

## *Other steel alloys (cont.)*



- Need to assess mechanical design requirements, manufacturing process, and environmental conditions (corrosive, high stress/strain, etc.)
- The intended environment needs to be thoroughly understood and the correct materials and processes need to be used

*Example:* The new Bay Bridge in CA had bolts break due to embrittlement of the materials

- *“The bolts’ hardened, galvanized steel had been contaminated by hydrogen, which caused them to become brittle and crack. The bolts were contaminated either during manufacturing or from being left in holes that filled up with rainwater.”*

<https://www.nace.org/CORROSION-FAILURES-San-Francisco-Bay-Bridge-Bolt-Failure.aspx>



# Metals

## *Tool steel and stainless steel*

- Tool steel has been hardened to meet the needs of specific applications (i.e., machine tools, tool bits, dies, impact-resistant tools and components)

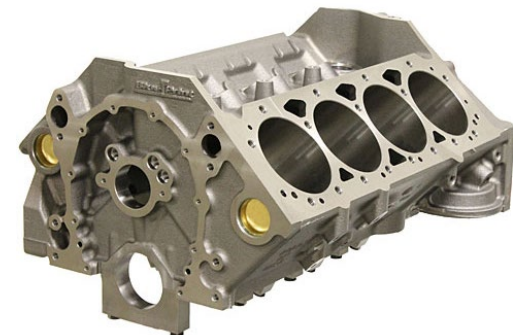


- Stainless steel contains 10.5 percent chromium and resists corrosion and oxidation
  - ‘Types’ are based on alloying agents and material properties
  - More difficult to machine and weld than typical steel
  - Corrosion resistance makes stainless steel a good candidate for chemical storage containers

# Metals

## *Cast iron*

- ❑ Cast iron is usually poured into sand molds or other types of molds with ceramic coatings
- ❑ The casting process facilitates the manufacture of relatively large parts
- ❑ Casting requires wider tolerances; a millimeter or more, depending on part size
- ❑ Parts also have a rough surface finish
  - This typically requires secondary operations (machining or polishing the casting)
  - Parts should be designed larger than necessary to allow for removal of excess material during machining



Materials Selection

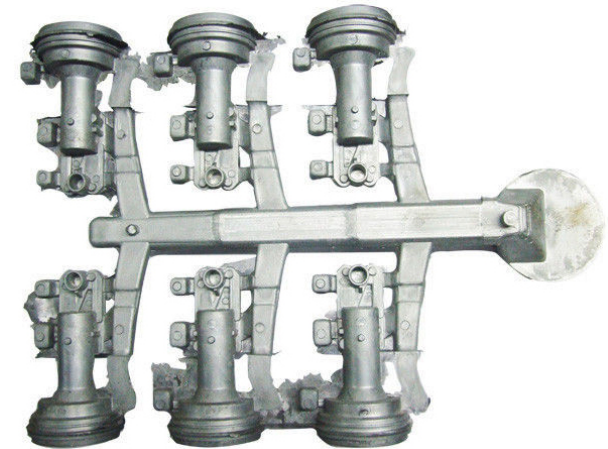
# Metals

## *Aluminum*

- Aluminum is relatively lightweight (compared to steel), ductile, a good conductor, and easy to machine

### **Wrought versus cast aluminum:**

- Cast products are formed from molten metal poured into a particular shape
- Wrought products are subsequently shaped into different forms



# Metals

## *Aluminum*

- ❑ Aluminum is often used for structural components because of its relatively high strength-to-weight ratio
- ❑ Aluminum can be die-cast into complex shapes and extruded, allowing production of more complex components at higher volumes
- ❑ Aluminum can be anodized; an electrochemical process that coats the component to prevent corrosion
- ❑ Anodizing treatments can also provide color



# Metals

*Titanium, copper, and associated alloys*

**Titanium is a strong lightweight (~55% as dense as steel) with mechanical properties that exceed some alloy steels:**

- It has excellent corrosion resistance
- Machining titanium can cause fires
- Titanium is very expensive

**Bronze, brass, and copper-nickel alloys categorization is similar to that of steel (numerical designations signify composition and subsequent treatment):**

- Brass is commonly used for fittings due to its resistance to corrosion
- Copper is highly conductive and is widely used for electrical applications



Materials Selection

# Metals

*Other*



## Refractory metals:

- Are resistant to heat and includes tungsten, tantalum, molybdenum, and zirconium
- They can withstand service temperatures above 1500° C
- Tungsten is the densest refractory metal with the highest melting point
- Tungsten is extremely stiff, hard, and expensive

## Exotic metals:

- Nickel alloys such as Invar and Inconel have unique physical properties, including low thermal-expansion coefficients and high strength under extreme heat conditions, respectively
- Inconel alloys can be used in extreme environments



# Ceramics

## Basics



**These materials can be applied as coatings to other materials to prevent wear:**

- Concrete is a widely used ceramic material
  - It can be cast into particular shapes & then hardens
  - It is brittle, but good for structural components
- Glasses are amorphous inorganic materials
  - Glasses are typically harder than metals, but very brittle
  - They can be used for their optical, electrical insulating, and corrosion resistance properties
- Carbides
  - Some carbides (i.e., silicon carbide) are used as abrasives



150 grit Silicon carbide  
**Materials Selection**

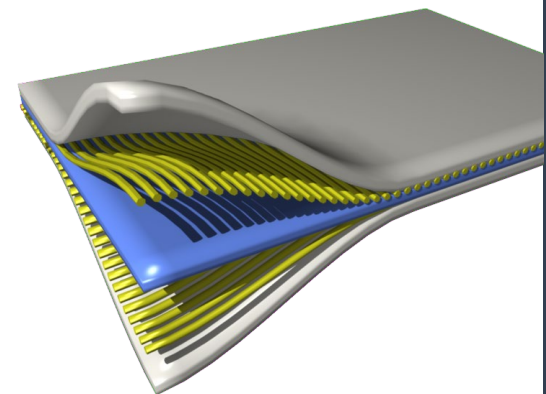
# Composites

## *Basics*



**Composites are combinations of two or more distinct materials:**

- ❑ Comprised of a matrix (the main component material) and the reinforcement (the added material)
- ❑ Reinforcements include plastics, metals, and ceramics
- ❑ Reinforcements can be particles, short fibers, or continuous fibers
- ❑ Common reinforcements include glass and carbon fibers
- ❑ The matrix can be plastic or metal

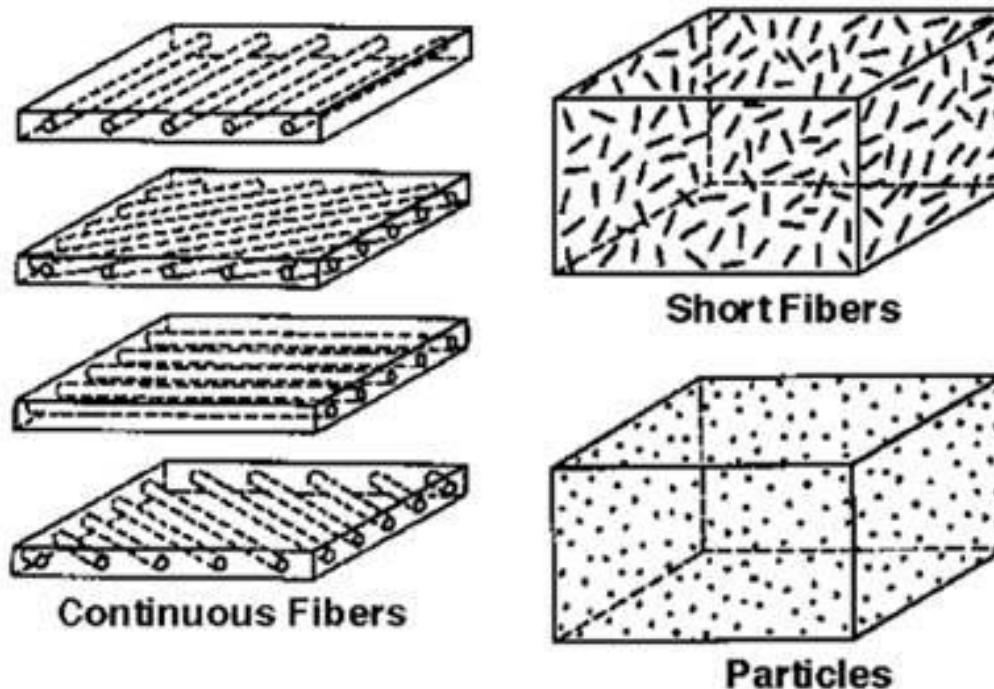




# Composites

## *Basics (cont.)*

- Composite properties are determined by the shape and orientation of the reinforcement. This makes composites anisotropic (i.e., they display different properties when oriented in different directions)



# Composites

## *Polymer based*



- ❑ Composites are lightweight and strong
- ❑ Composites have to be formed to their net shape
- ❑ Composites are difficult to machine
- ❑ Glass or carbon fiber reinforcement is often used in epoxy or nylon matrices for polymer composites

### **Common manufacturing processes:**

- ❑ Sheet molding compound (sheets containing the reinforcement and matrix are placed into a die; the matrix can then be cured)
- ❑ Pultrusion (the reinforcement is pulled through the matrix and then cured)

# Composites

## *Metal based*



- Aluminum can be reinforced with carbon, boron, or silicon-carbide fibers (this produces lightweight materials with extremely high tensile strength)
- Tungsten-carbide particles can be added to a steel or cobalt matrix (this can be used to make hardened materials that are resistant to wear)

# Advanced Materials

## *Smart materials*



**Shape-memory alloys are materials that, when subjected to some stimulus, revert to a predefined configuration:**

- This may be expanding, shrinking, or uncurling
- The stimulus can be heat, electricity, or a magnetic field
- These materials can be used for actuation, control, or safety purposes

**Piezoelectric materials produce an electric charge in response to a mechanical stimulus:**

- These materials can be used for sensors and switches

# Advanced Materials

## *Graphite/graphene*



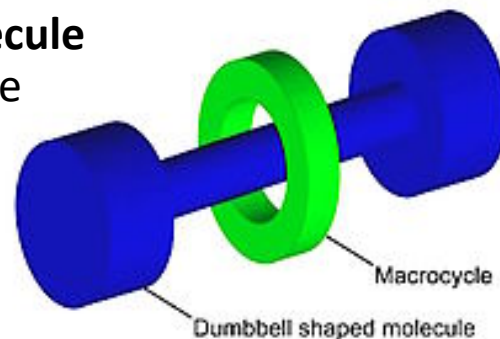
- Graphite is a stable form of carbon that is lightweight, high strength, and has good electrical conductivity
- Graphite can be added to a matrix material as a reinforcement fiber
- Graphite can be used as a coating to give a material electrical conductivity
- Graphene is a two-dimensional (i.e., single atomic layer) form of carbon that has extremely high strength and conductivity

# Advanced Materials

## *Nanomaterials*

- Materials that are at a molecular scale
- Special properties occur in materials at this scale (These include mechanical and optical properties)
- Nanomaterials can be added to other materials to dramatically affect the bulk material
- Nanoparticles can reduce shrinkage during curing in some thermoset polymers

**Note:** **Molecular scale electronics**, also called **single molecule electronics**, is a branch of nanotechnology that uses single molecules, or nanoscale collections of single molecules, as electronic components. Conventional electronic devices are traditionally made from bulk materials.



Materials Selection

# Material Properties

## *Selecting the right material*



- During the detailed design process, once component designs are being finalized, materials and their associated properties need to be specified
- Each category of materials has a collection of properties associated with it
  - Certain materials will excel in one aspect, while being less desirable in other

*Example:* Steel is very strong, but also very heavy; it can only be formed using specific manufacturing processes

- Different components will require different material properties
  - Structural components may require particular mechanical properties; cases and housing might need particular environmental properties
- Understanding how to assess different properties will help in choosing the right materials

# Types Of Material Properties

## *Basics*



### **Mechanical:**

- The response of the material to force and load

### **Physical:**

- Based on the inherent behavior of the material; usually molecularly driven

### **Thermal:**

- The reaction of the material in the presence of heat or cold

### **Electrical:**

- The ability of a material to transmit, store, or impede electricity



# Types Of Material Properties

*Basics (cont.)*



## **Optical:**

- The ability of the material to transmit, reflect, or absorb light

## **Environmental:**

- The ability of the material to maintain performance in its application environment

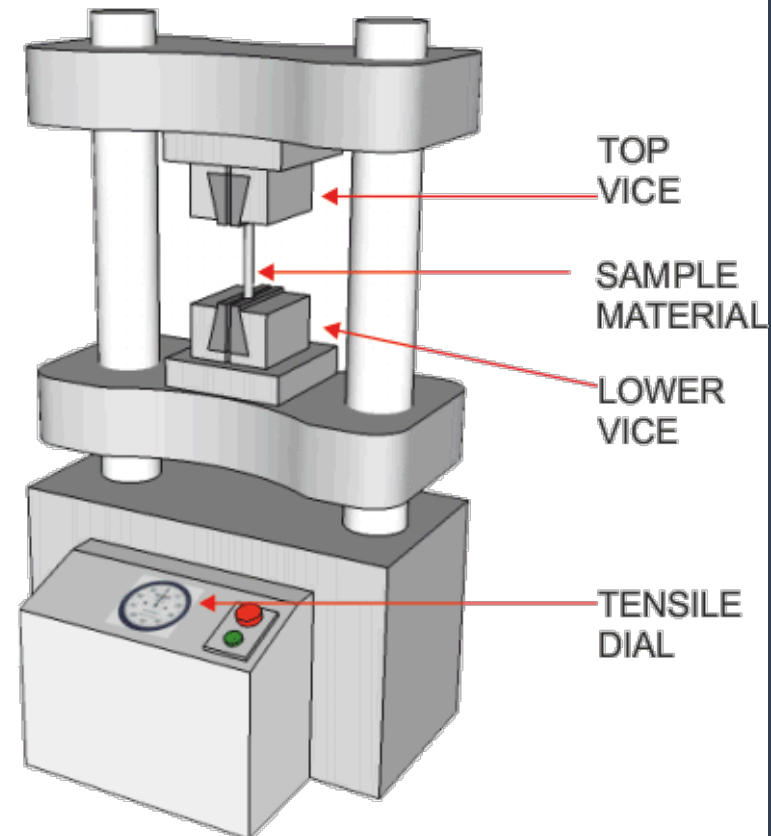
## **Deteriorative:**

- The deterioration in material properties due to chemicals or reactions with the environment

# Mechanical Properties

## *Testing*

- Tensile testing is used to determine the different types mechanical properties of test specimens
- These include the elastic modulus, tensile and yield strengths, and elongation (“necking”)



# Mechanical Properties

## *Testing*



**There are specific standards for tensile testing that are widely used to produce mechanical-property data:**

- Testing provides the properties for selecting the appropriate material
- Testing can be done either at external labs or internally

*Example:* when a component is loaded in tension, if the yield strength is exceeded, the component is permanently deformed and will likely fail

# Mechanical Properties

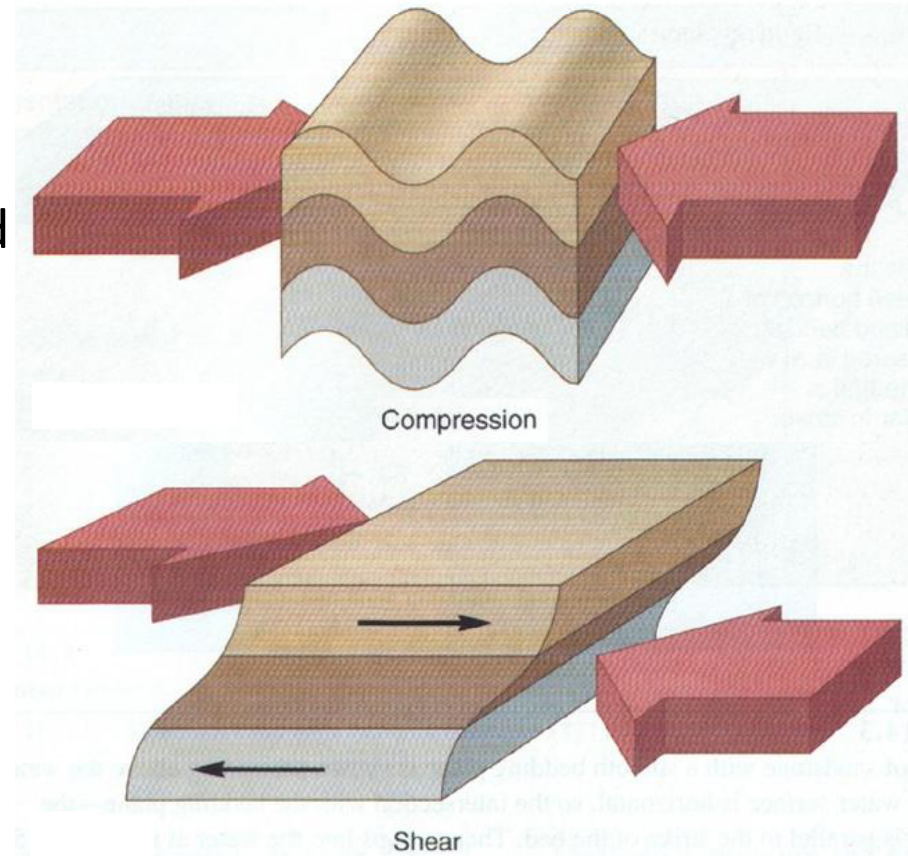
## *Compression and shear*

### Compression:

- Compression testing pushes on an object until failure
- When a component is loaded in compression, the compressive yield strength will determine the failure

### Shear:

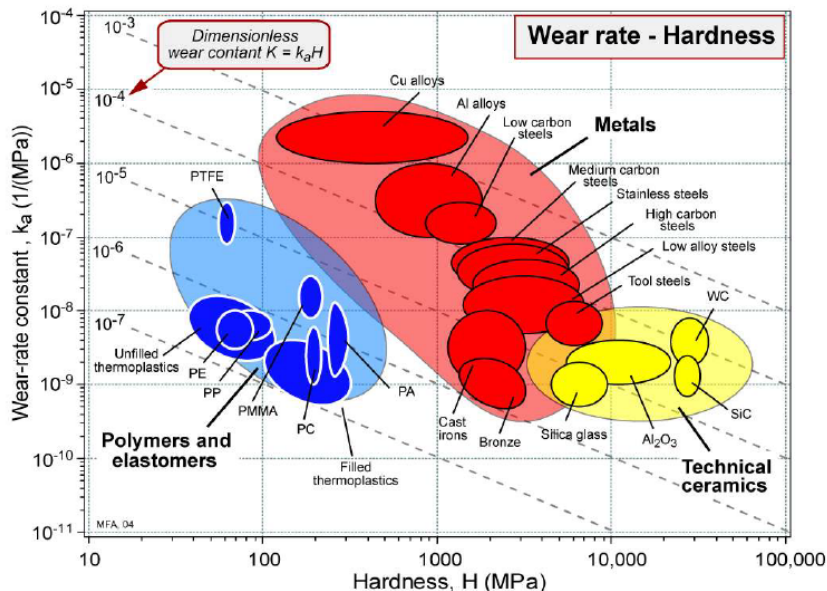
- Shear is the co-planar application of a load across the section of a material
- Shear stresses often cause catastrophic failure



# Mechanical Properties

## Hardness

- Hardness is the resistance of a material to indentation
- There are various methods for testing and scales for quantifying hardness
- If a component is going to be pressed against another component, materials with a high hardness rating may be

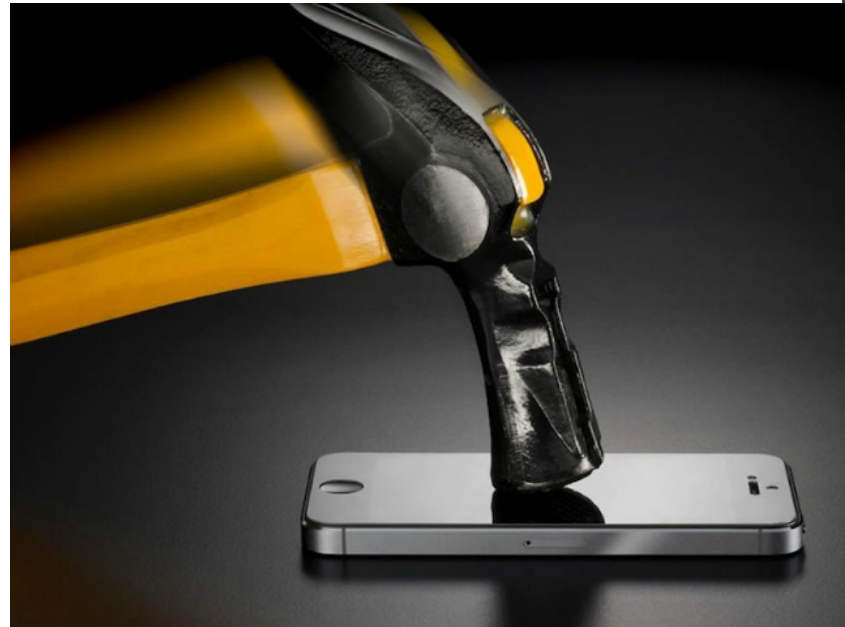


Materials Selection

# Mechanical Properties

## *Impact strength*

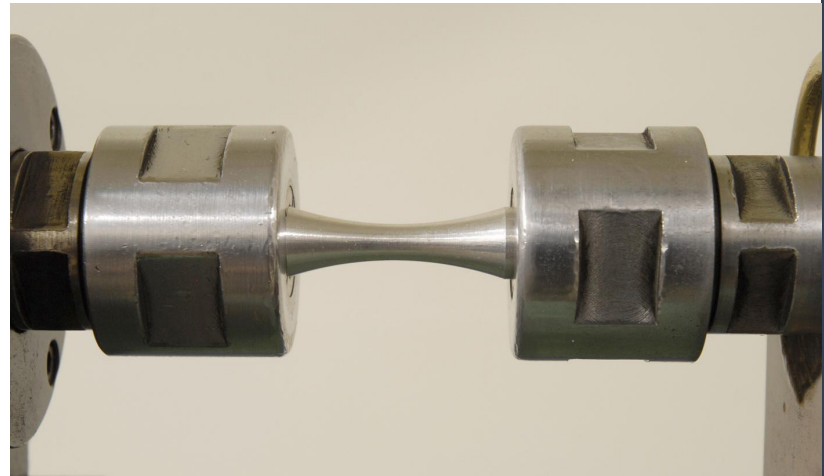
- Impact strength is the amount of energy absorbed in the fracture of a component
- Ductile materials absorb a lot of energy; brittle materials absorb relatively little energy
- Ductile materials limit catastrophic failure (This is important for components that are subjected to impacts)



# Mechanical Properties

## *Fatigue testing*

- Fatigue testing evaluates the number of cycles that a sample can withstand stress and/or strain until failure
- This is important for components that will continually flex in some way
- In this type of test, a component is repeatedly loaded until failure occurs

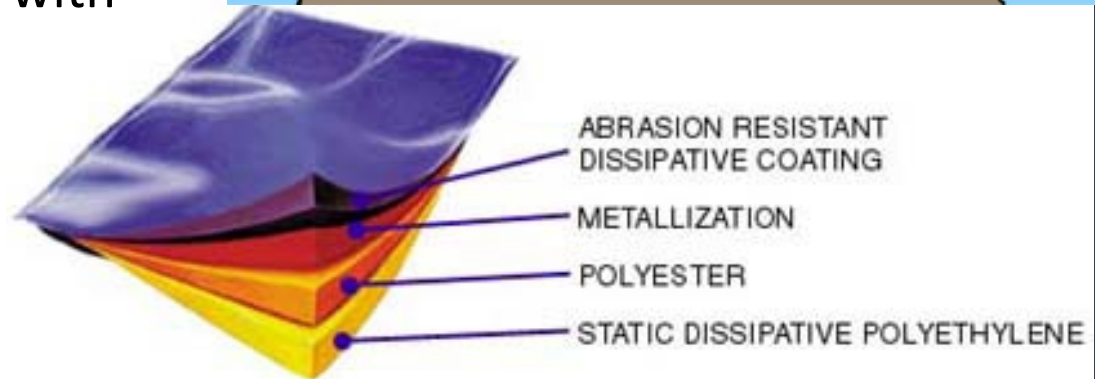
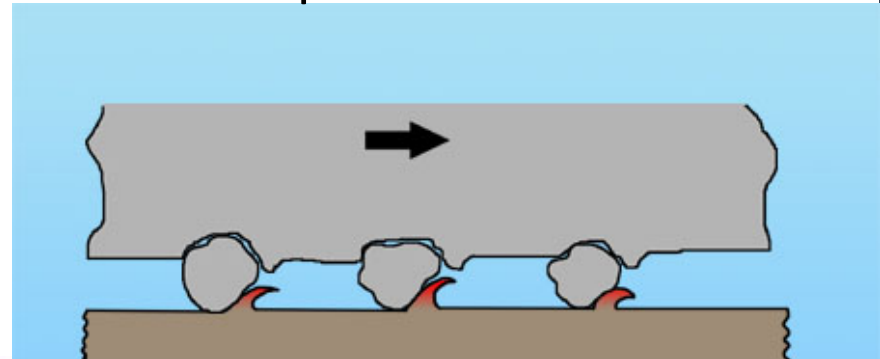




# Mechanical Properties

## *Abrasion resistance*

- Abrasion resistance is the ability of material to resist material loss from abrasion
- This is measured as the mass lost under a specified abrasion
- Surfaces that need to resist scratches (e.g., displays) should have high abrasion resistance
- This can be improved with certain coatings



Materials Selection



# Physical Properties

## *Density*



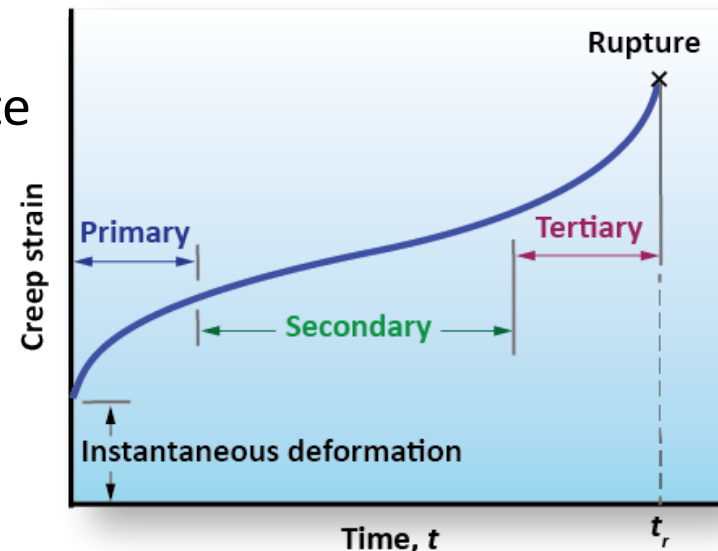
- Density is defined as the mass per unit volume of a material
- Usually quantified as a counterbalance against some other desirable property (such as mass and volume)
- Less dense materials result in lower weight components

$$\text{Density} = \frac{\text{Mass}}{\text{Volume}}$$

# Physical Properties

## *Creep*

- Creep is defined as material deformation over time, usually in the presence of heat caused by mechanical stress
- Creep is called “cold flow” when it occurs at room temperature
- Components that are subjected to high-temperature environments over a long period of time should be evaluated for creep
- ASTM D6815 is often used to evaluate materials for creep



Materials Selection

# Thermal Properties

## *Thermal conductivity*



- Thermal conductivity is the ability of a material to conduct heat (the higher the conductivity, the more heat is transferred)
- Some materials are insulators (i.e., they absorb heat); other materials are conductors (i.e., they transmit heat)
- Thermal conductivity is measured in watts per meter-kelvin (W/mK)
- The thermal conductivity of aluminum (237 W/mK) is three orders of magnitude greater than that of polycarbonate (0.250 W/mK)
- A polycarbonate case will hold significantly more heat than one made of aluminum

# Thermal Properties

## *Specific heat*



- Specific heat is the amount of heat energy required to raise the temperature of a material by one degree Celsius
- If operating temperatures need to be high, more energy is needed to heat a plastic than to heat a metal by an equivalent amount

# Thermal Properties

## *Thermal expansion*



- Thermal expansion is the tendency of a material to change in shape, area, and volume in response to a change in temperature
- Most materials expand when heated (in close-tolerance situations, this can cause problems)
- Plastic enclosures in outdoor applications may expand and cause failure due to excessive expansion
- When using materials with high coefficients of thermal expansion (i.e., plastics), look at the operating temperature range and examine the dimensional changes

# Thermal Properties

## *Flammability*



- ❑ Flammability is the ability of a substance to burn or ignite, causing fire or combustion
- ❑ In certain applications, how quickly a material is consumed by flame is strictly regulated (many consumer products have documented flammability requirements)
- ❑ The Consumer Product Safety Commission has flammability requirements on some products
- ❑ ASTM offers numerous fire and flammability standards for products and materials

# Thermal Properties

## *Deflection temperature*



- Deflection temperature is the temperature at which a polymer or plastic sample deforms under a specified load
- A high deflection temperature is the ability to maintain strength at a high temperature
- In high-temperature applications, components should be tested or materials specified that maintain strength at the desired deflection temperature
- Other materials can lose strength when heated

*Example:* Amorphous polymers can fail at high temperatures (this can occur when the temperature is higher than the glass transition temperature for the material,  $T_g$ )

# Electrical Properties

## *Basics*



- Some applications require the transmission of electricity, while others require insulation
- Electrical connections should have low resistance, while enclosures may require high resistance
- Arc resistance (measured in ampere, A) is the amount of current required to make the surface of a material conductive
  - It is an important property for isolation/insulation applications
- Insulation resistance between two conductors (measured in ohms/cm) is an important property of materials used for electrical isolation and insulation
- Dielectric strength (measured in volts/mm) is the voltage required to arc through a material
  - Also an important property of materials used for electrical isolation and insulation



# Optical Properties

## *Basics*



- Specular gloss is the reflection of light at various angles
  - In certain display applications this is important
- Luminous transmittance is the ratio of the angle of transmitted light to that of incident light
- Haze is the amount of cloudiness in a translucent material
- Transmittance is the amount of transmitted light measured and expressed as a percentage of incident light
  - High-grade polycarbonates can have haze amounts of less than one percent and transmittance amounts greater than 90 percent
  - This is an important property for certain display or optical applications
- Index of refraction is the reduction of the speed of light in a medium
  - This is a very important property in some display and other light-related technologies

# Environmental Properties

## *Basics*



- When products or materials are intended for use in various environments, their ability to withstand the elements needs to be assessed
- Artificial weathering simulates the elements of the outdoor environment (i.e., exposure to sun, rain, heat, and cold)
  - This method employs accelerated testing with qualitative data output
  - After being subjected to the elements, some materials may appear to be substantially degraded

# Environmental Properties

## *Basics (cont.)*



- Permeability is an important property for some safety-related applications
  - Certain gases or chemical substances may need to be contained, requiring that an enclosure's material act as an impermeable barrier
  - Other applications may require the presence of air and other gasses, or they may need to be made of a sufficiently permeable material to release gasses to prevent their accumulation
- Some materials are hygroscopic (i.e., they absorb water); this can negatively affect their performance

# Deteriorative Properties

## *Basics*

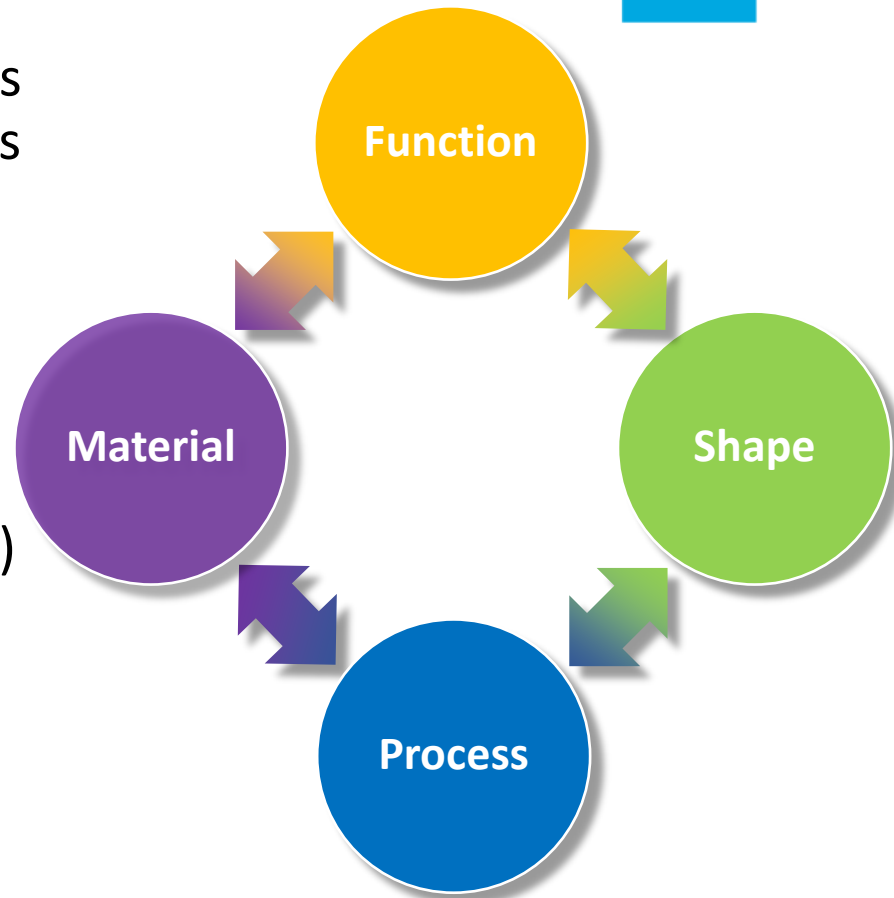
- Corrosion is the deterioration of material properties due to reaction of the material with the environment
  - Most corrosion occurs due to electrochemical processes
  - Corrosion, such as rust, can be reduced by material treatment or coating
- Oxidation is a form of electrochemical corrosion where the metal anode loses electrons to the ion cathode
  - This causes the formation of an oxide layer on the material
  - As this oxide layer grows, the part deteriorates
- Chemical reactivity refers to the chemical reactions that certain materials are subject to when in the presence of other materials
  - Sodium and potassium react explosively with water
  - It is important to understand chemical reactivity when using reactive materials or applications that put materials into reactive environments (i.e., oxygen or hydrogen rich)



# Materials Selection

## Process

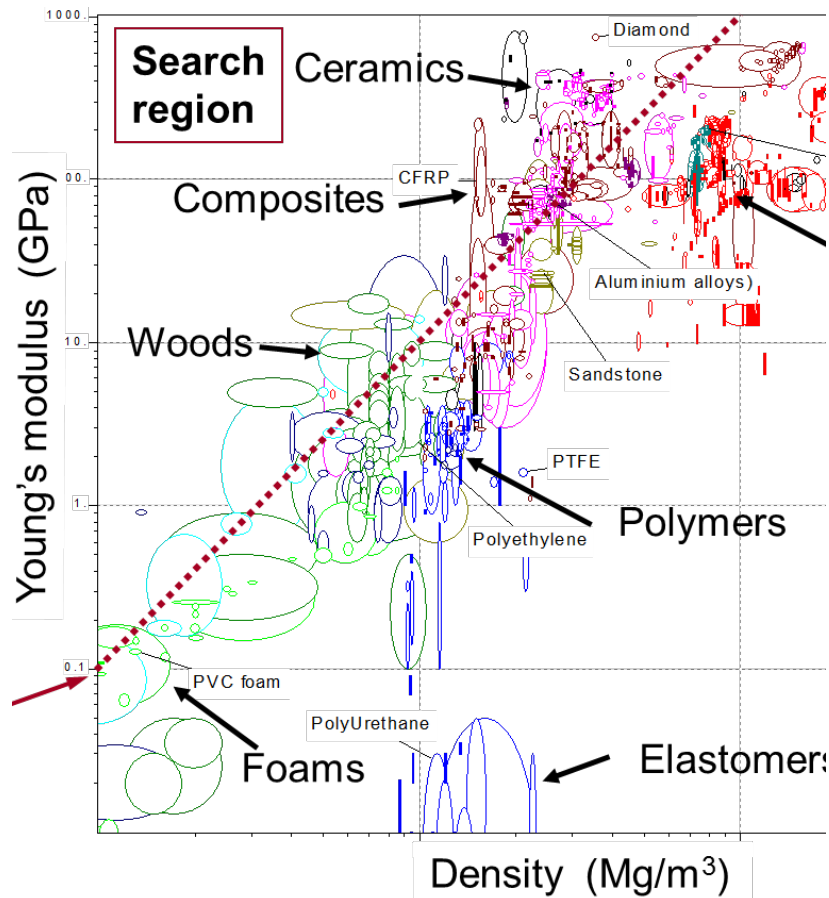
- Aligning key customer needs and functional requirements to material properties
- Ranking various material requirements (technical importance derived from functional requirements can be used for this ranking)
- Creating material indices



# Materials Selection

## Process (cont.)

- Material indices enable graphical selection



# Materials Selection

## *Process (cont.)*



- Each material comes with a set of attributes and properties (This includes processing capabilities, availability, cost, recyclability, and regulatory requirements)
- Materials selection begins by identifying the most important customer input related to the material (These are derived from the functional requirements in the House of Quality [HOQ])

**Note:** The HOQ, a part of the Quality Function Deployment (QFD) method, identifies and classifies customer desires, identifies the importance of those desires, identifies engineering characteristics relevant to those desires, correlates the two, allows for verification of those correlations, and then assigns objectives and priorities for the system requirements (i.e., for structural components, this may be yield strength)

# Materials Selection

## *Process (cont.)*



- Next, additional necessary attributes must be taken into account (i.e., the mass of the component may need to be minimized; this would require a low-density material)
- Finally, the operating environment may be a concern (i.e., the component is required to function in a brine solution or salt water environment)



# Material Selection

*Influence on design*



**Material selection affects the product design based on these attributes and requirements:**

- ☐ Geometric specifics
- ☐ Loading requirements
- ☐ Design constraints
- ☐ Performance objective
- ☐ Manufacturability

# Material Selection

*Influence on design (cont.)*



## Effects can be assessed analytically:

- A ratio of the important properties can be used to create ratios for material selection
- The ratio of strength to density can determine which materials are best suited for an application

## Other considerations:

- Keep the set of candidate materials as large as is feasible
- Sometimes customers specify plastic when aluminum might be preferable
- Strategic considerations are key and likely to affect overall choice
- The availability, scalability, and costs of materials are key

# Material Selection

## *Key considerations*



### **Cost:**

- Materials affect cost in numerous ways
  - The choice of material constrains manufacturing process selection for a given geometry (this affects both ongoing and capital costs)
  - Some material prices fluctuate based on the market (this can have significant effects)
  - “Brand name” materials (especially plastics) can be significantly more costly than others (make sure you understand your product’s requirements)

### **Quality:**

- Material attributes can dramatically affect quality
  - Material quality must be monitored to maintain product quality (material specifications are critical to this)

# Material Selection

## *Key considerations (cont.)*



### **Customer:**

- The translation of functional requirements into material specifications will ensure that the customer's requirements are met

### **Supplier:**

- A sustained supply of the specified materials is critical to business success
  - This is especially true in regulated applications (the material specified will become a requirement)
  - Do your materials suppliers have capacity for planned future growth? (their business plans should coincide with yours)
  - It may be preferable to ensure two materials meet the needs of the application and both get certified

# Material Selection

## *Key considerations (cont.)*



### **Business plan:**

- How robust is your business plan if it is subjected to a 10 percent increase in materials costs?
  - Looking at the sensitivity of materials' price changes can reduce risk

### **Iterations:**

- Materials selection affects product design
  - This is an iterative process where scale (i.e., increasing production volume) and cost can have significant impacts

# Material Selection

*Key considerations (cont.)*



## Risk:

- The inability to maintain a consistent supply at a price that is aligned with your business plan is a key risk associated with materials
  - Can alternative materials be used?
  - How robust is your business plan to price fluctuations?

# Resources



- Materials glossary
- Materials testing standards:
  - API <http://www.api.org/products-and-services/standards>
  - ASTM <https://www.astm.org/Standard/standards-and-publications.html>
  - SAE <http://standards.sae.org/automotive/materials/standards/current/>
- Ashby Selection Methods <https://www.grantadesign.com/>
  - <https://www.elsevier.com/books/materials-selection-in-mechanical-design/ashby/978-0-08-100599-6>

# List Of Terms

*In glossary*



- **Engineering Validation** tests the systems used to develop or manufacture products including measuring, analyzing and calibrating the equipment and processes to ensure the highest quality products are created.
- **Design Validation** is testing aimed at ensuring that a product or system fulfills the defined user needs and specified requirements, under specified operating conditions. (Repeat from 2B)
- **Feasibility** is the process in product life cycle which first translates feasible ideas into technically feasible and economically competitive product concepts, and then produces product concept through concept generation and selection. Two commonly used techniques to decide the best design candidate are design-to-cost and life-cycle-cost analyses. (Repeat from 2B)
- **Development** is the systematic use of scientific and technical knowledge to meet specific objectives or requirements. (Repeat from 2B)
- **Manufacturing Development** or Engineering & Manufacturing and Development (EMD) phase is where a system is developed and designed before going into production. (Repeat from 2B)
- **Polymer** is a large molecule, or macromolecule composed of many repeated subunits. A polymer matrix composite is a material consisting of a composite made stronger by adding fibers or particles to it. They used a polymer matrix composite, epoxy resin reinforced with glass fibers.
- **Thermoplastics** is a plastic material, a polymer, that becomes pliable or moldable above a specific temperature and solidifies upon cooling.
- **Thermoset** is a polymer that is irreversibly cured from a soft solid or viscous liquid prepolymer or resin. The process of curing changes the resin into an infusible, insoluble polymer network, and is induced by the action of heat or suitable radiation often under high pressure, or by mixing with a catalyst.
- **Composite** is a material that is made from several different substances.
- **Hardening** is a process by which a material acquires greater hardness, such as cold forming or heat treatment.



# List Of Terms

*In glossary (cont.)*



- ❑ **Softening** is a numerical trick used in N-body techniques to prevent numerical divergences when a particle comes too close to another.
- ❑ **Annealing** is a heat treatment that alters the physical and sometimes chemical properties of a material to increase its ductility and reduce its hardness, making it more workable.
- ❑ **Yield Strengths** (Megapascal MPa) also known as Tensile strength refers to the maximum amount of stress a material can withstand while being stretched or pulled without breaking. It is measured as a force per unit area - the unit being a pascal (Pa)/megapascal(MPa), a newton per square metre (N/m<sup>2</sup>) or pounds-force per square inch (psi).
- ❑ **Refractory Metals** are a class of metals that are extraordinarily resistant to heat and wear.
- ❑ **Exotic Metals** are more costly to manufacture and process, due to high temperatures required for heating and shaping of parts.
- ❑ **Mechanical Properties** are also used to help classify and identify material. The most common properties considered are strength, ductility, hardness, impact resistance, and fracture toughness. Most structural materials are anisotropic, which means that their material properties vary with orientation.
- ❑ **Physical** is any property that is measurable; whose value describes a state of a physical system.
- ❑ **Thermal** mass is a material's resistance to change in temperature as heat is added or removed, and is a key factor in dynamic heat transfer interactions within a building. The four factors to understand are: density, specific heat, thermal capacity, and thermal lag. Density is the mass of a material per unit volume.
- ❑ **Electrical** resistivity is the reciprocal of conductivity. It is the is the opposition of a body or substance to the flow of electrical current through it, resulting in a change of electrical energy into heat, light, or other forms of energy. The amount of resistance depends on the type of material.
- ❑ **Optical** property of a material is defined as its interaction with electro-magnetic radiation in the visible.

# List Of Terms

*In glossary (cont.)*



- **Environmental Properties** is the ability of a material to perform in its applicable environment.
- **Deteriorative Properties** is the response or deterioration due to with the environment.
- **Compression** is external force (stress) that tends to crush a material, squeezing its particles closer and shortening the dimension in the direction of its action.
- **Shear** is a deformation of a material substance in which parallel internal surfaces slide past one another. It is induced by a shear stress in the material.