



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

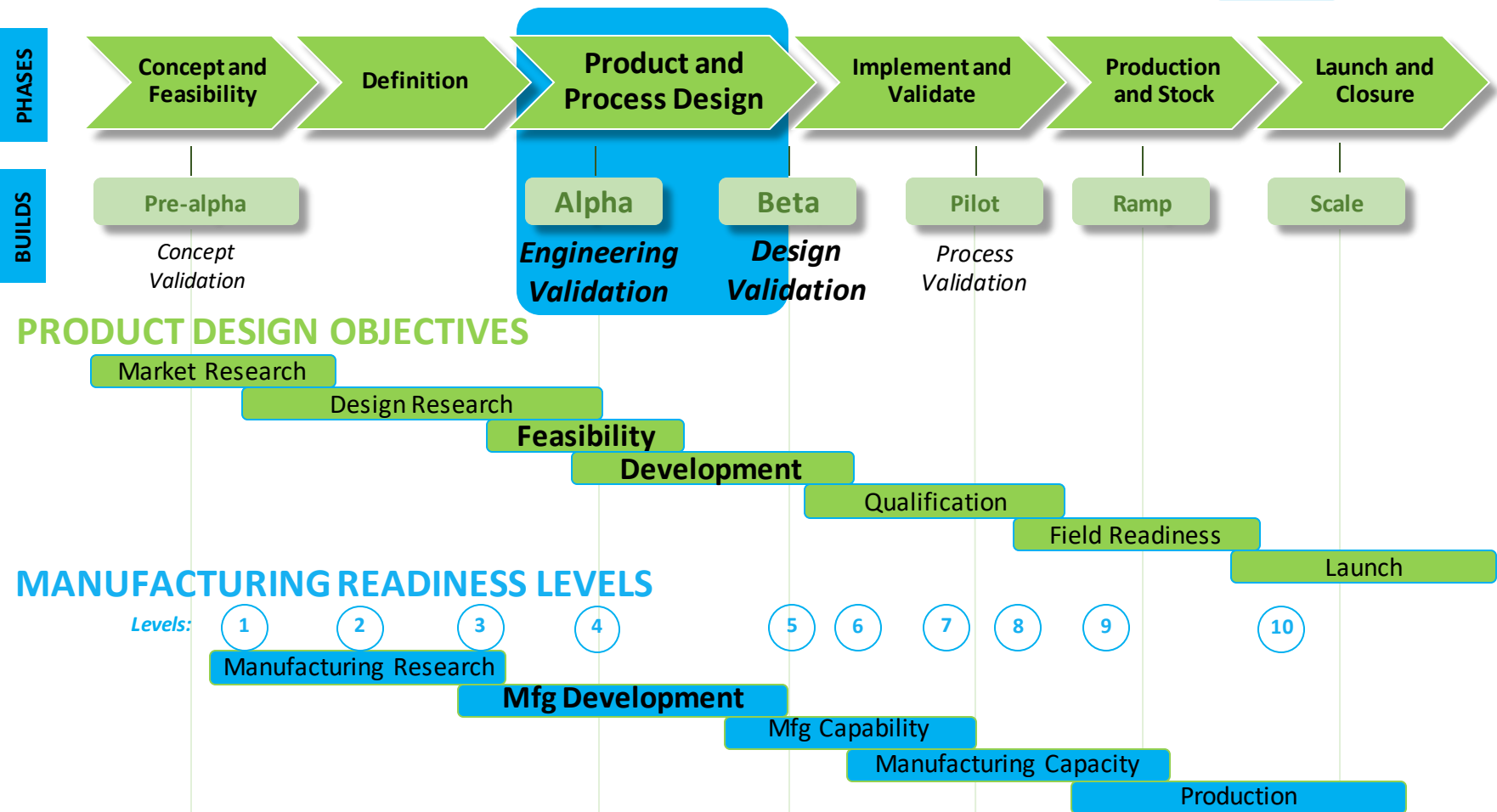
What This Module Addresses



- 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 Selection

Materials

Classes and properties



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

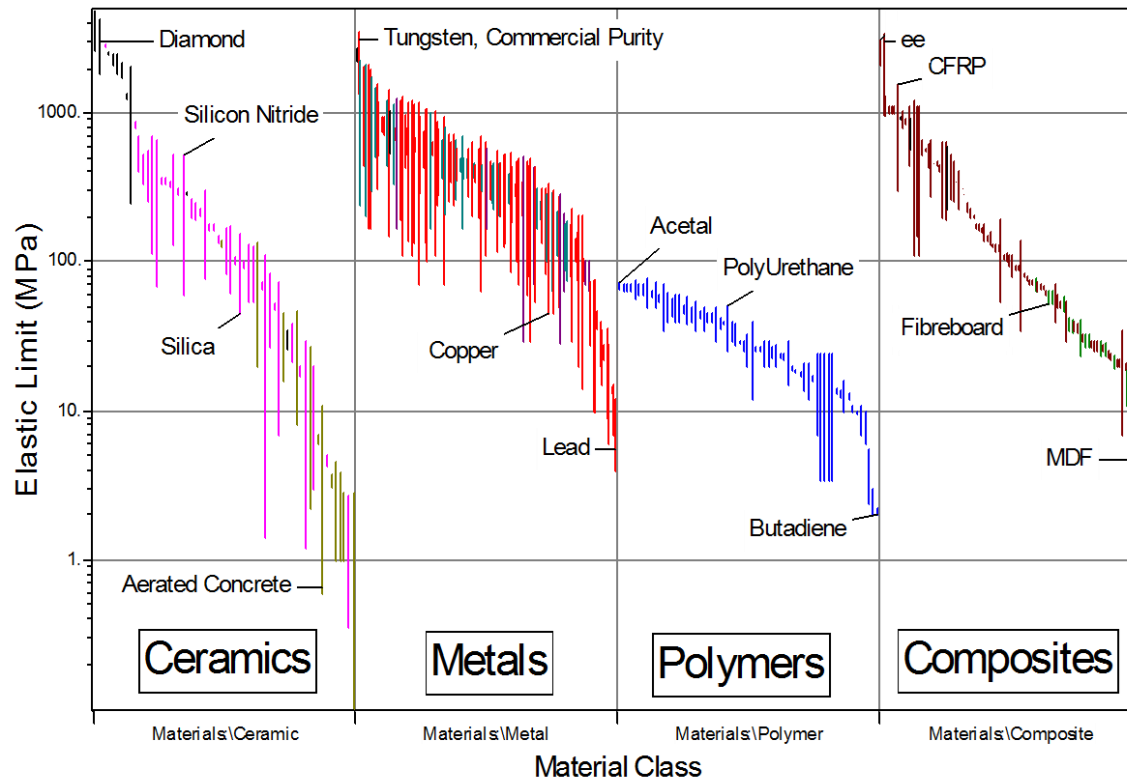
Properties	Metals			Plastics		Ceramics	Composites
	Low Alloy Steel	6000 Series Aluminum	Bronze	Polycarbonate	Phenolic	Tungsten Carbide	Carbon Fiber - Epoxy Composite
Density (g/cc)	7.5 - 8.08	2.68 - 2.9	6.4 - 9.25	0.960 - 1.51	1.35 - 2.13	15.7	1.15 - 2.25
Hardness (Rockwell B)	45 - 112	49 - 80	26 - 200	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

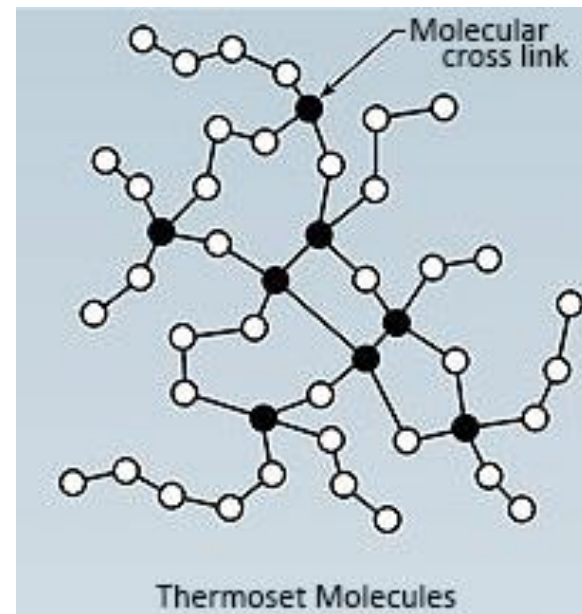
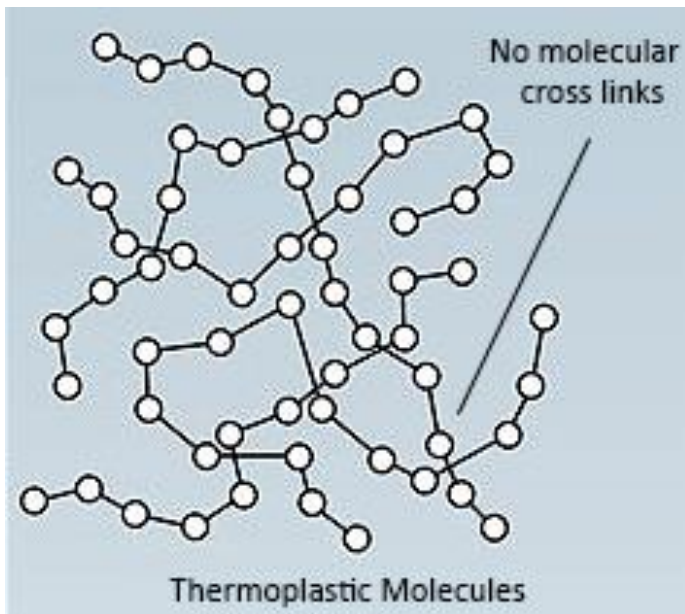
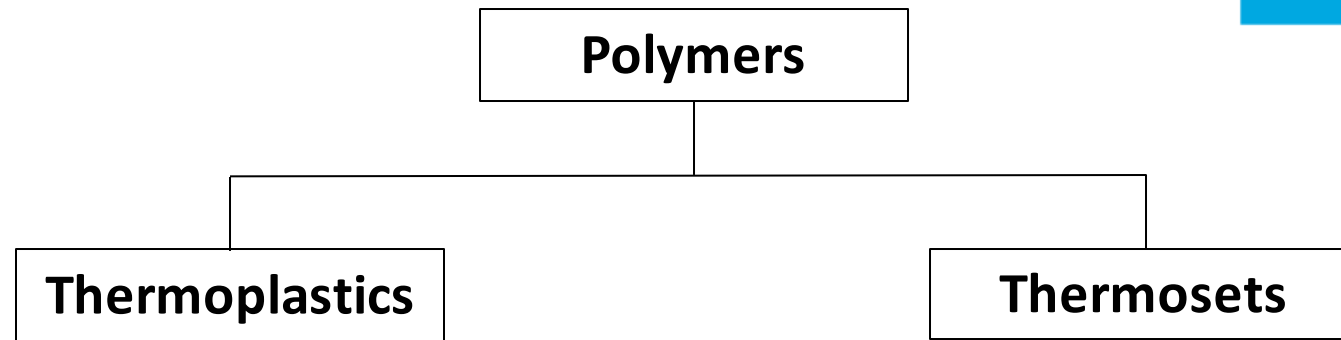
- **Thermosets** undergo irreversible “crosslinking,” which binds molecules together

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

- Once cured, they cannot be reused or reheated

Polymers

Basics (cont.)



Materials Selection

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Polymers

Thermoplastics

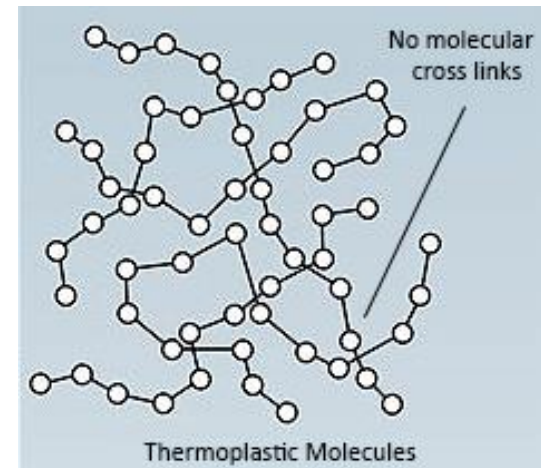


- Thermoplastics can be amorphous or crystalline
- Amorphous thermoplastics soften at the glass-transition temperature (They should not be used in environments that exceed that temperature)
- They can be transparent, tough, and strong

Examples: polycarbonate (PC), polymethylmethacrylate (PMMA)

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

Examples: include polyethylene, polypropylene, Nylon[®], and Kevlar[®]



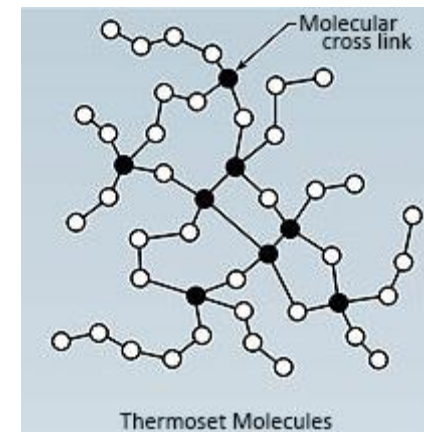
Materials Selection

Polymers

Thermosets



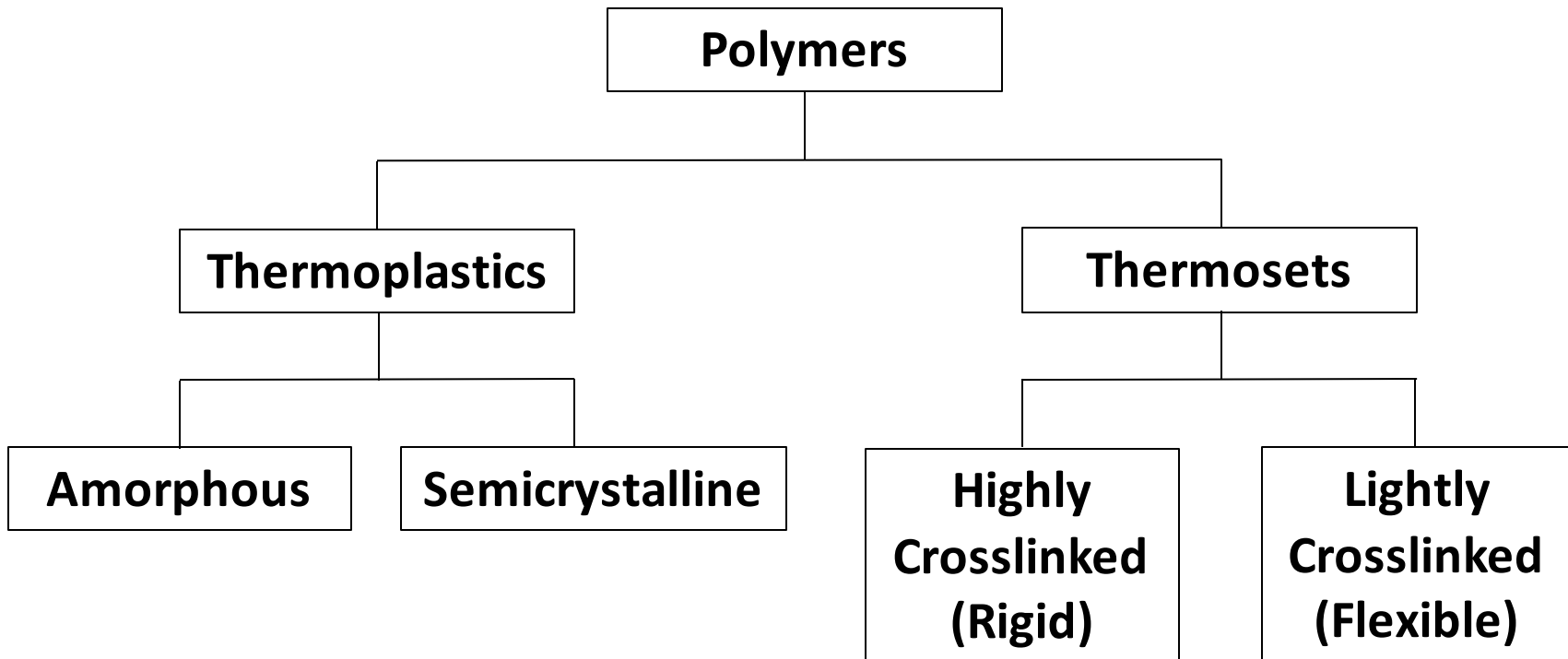
- Thermosets are polymers that undergo the irreversible process of molecular crosslinking; aka. ‘curing’
- Crosslinking is initiated by heat, light, or chemical exposure
—The crosslink process (sometimes called “curing”) can take minutes to several days
- Thermosets can be either rigid or flexible
 - 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

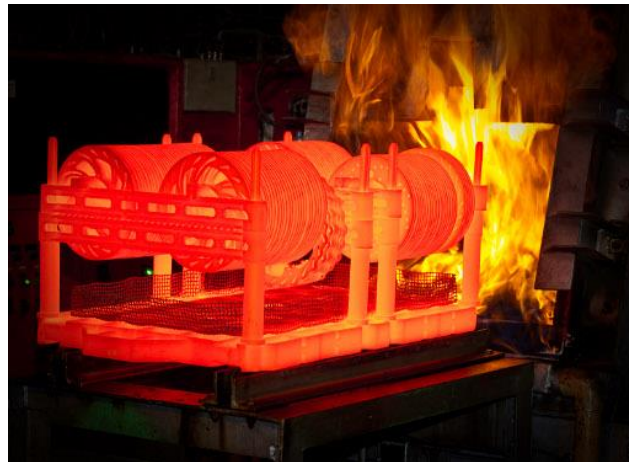


- Depending on the application and process requirements of the material, heat treating can improve a metal's properties
- **Hardening** is desirable in some cases (i.e., structural members or high stress application)
- Metal can be hardened by heating and quenching
- In some cases only the outside of 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.)

- Depending on the application and process requirements of the material, heat treating can improve a metal's properties
- **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

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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



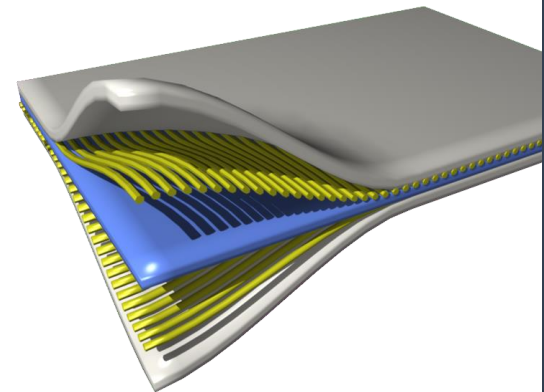
Composites

Basics



Composites are combinations of two or more distinct materials:

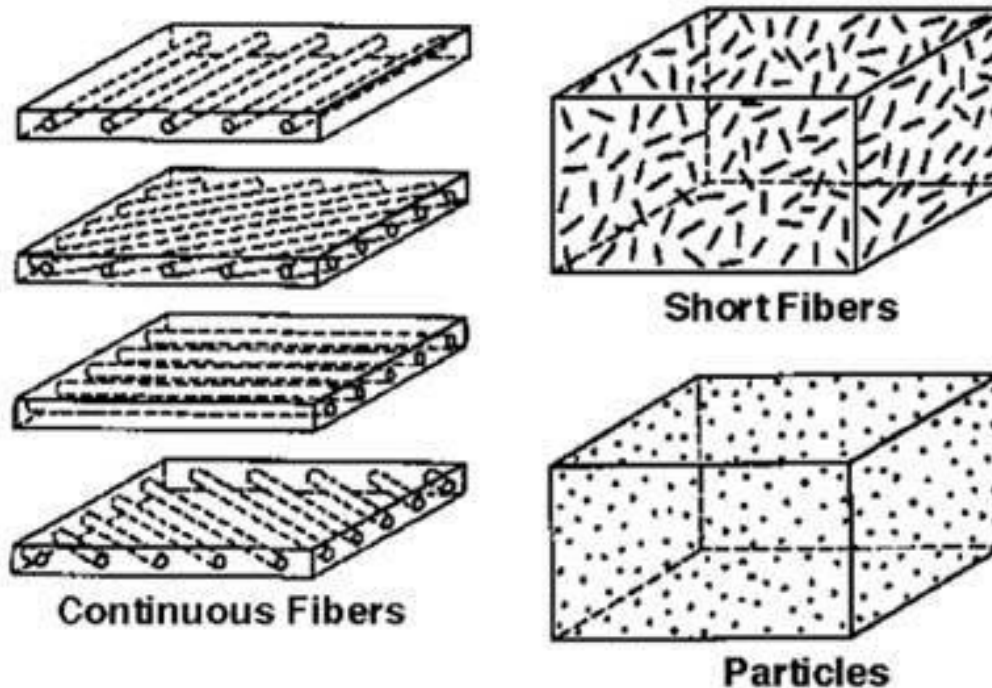
- ❑ Comprised of a matrix (the main component material) and the reinforcement (the added material)
- ❑ Reinforcements include plastics, metals, and ceramics
- ❑ Reinforcements can be particles, short fibers, or continuous fibers
- ❑ Common reinforcements include glass and carbon fibers
- ❑ The matrix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

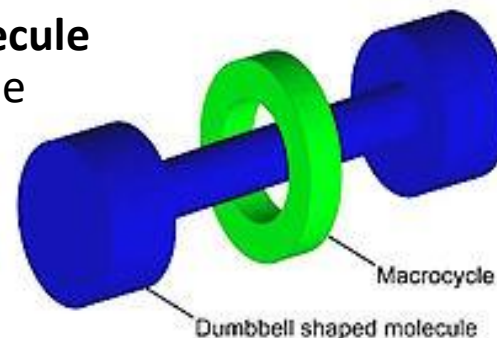
Advanced Materials

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

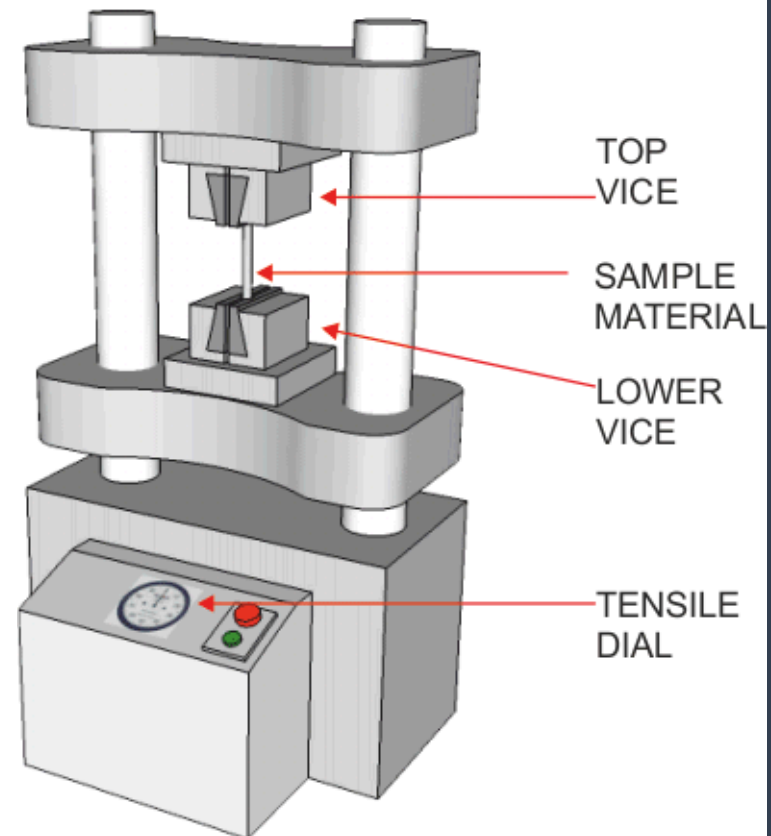
Deteriorative:

- 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

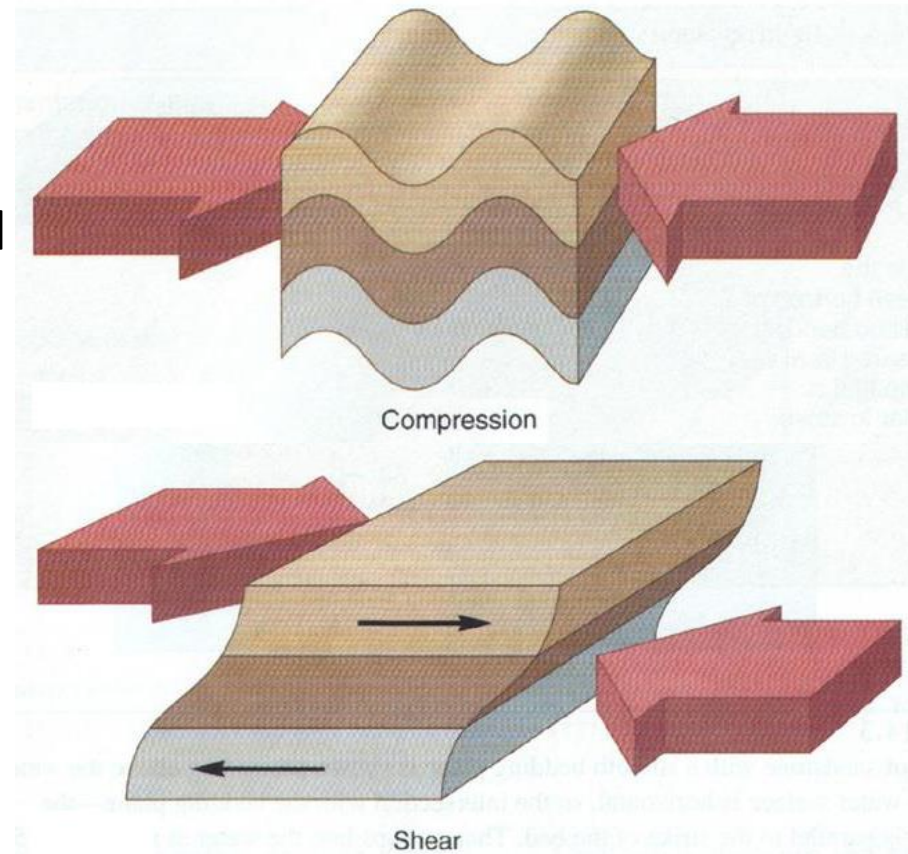


Compression:

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

Shear:

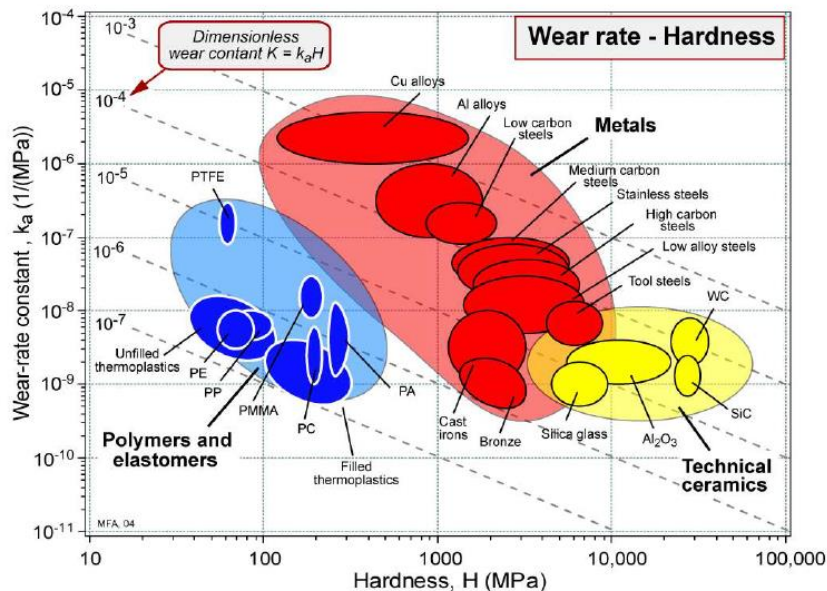
- Shear is the co-planar application of a load across the section of a material
- Shear stresses often cause catastrophic failure



Mechanical Properties

Hardness

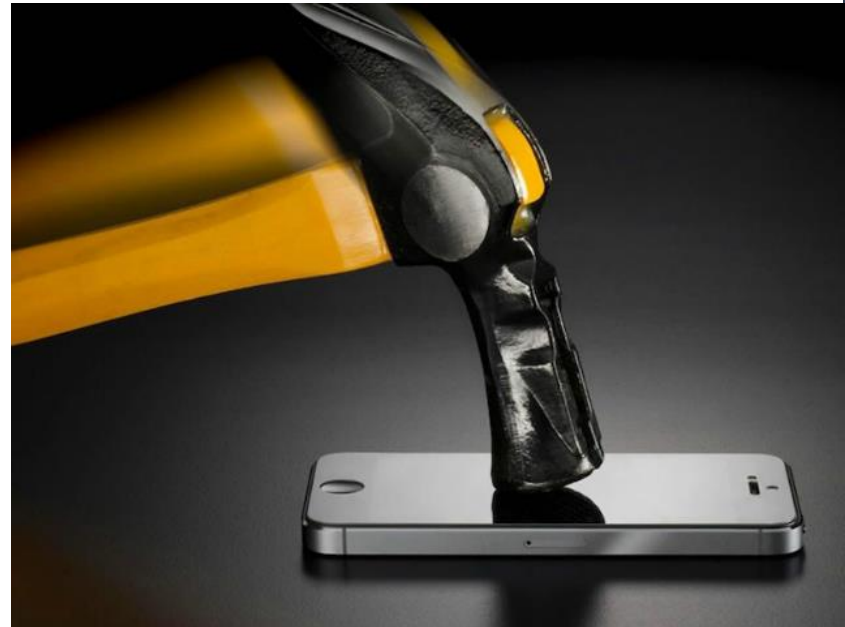
- Hardness is the resistance of a material to indentation
- There are various methods for testing and scales for quantifying hardness
- If a component is going to be pressed against another component, materials with a high hardness rating may be



Mechanical Properties

Impact strength

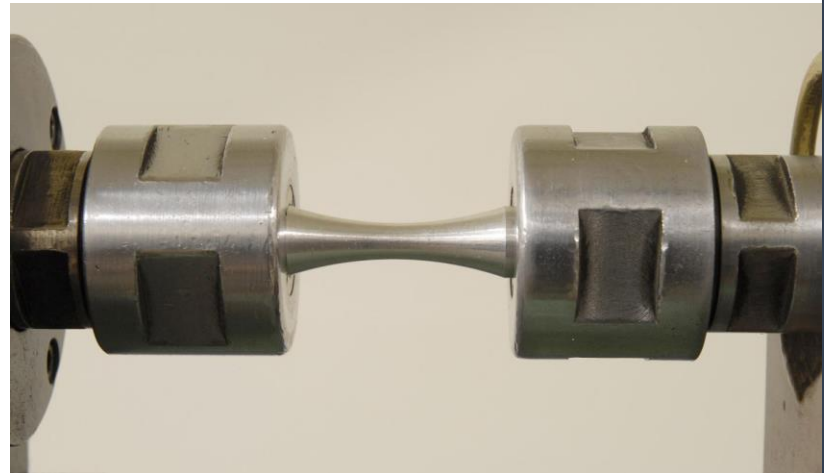
- Impact strength is the amount of energy absorbed in the fracture of a component
- Ductile materials absorb a lot of energy; brittle materials absorb relatively little energy
- Ductile materials limit catastrophic failure (This is important for components that are subjected to impacts)



Mechanical Properties

Fatigue testing

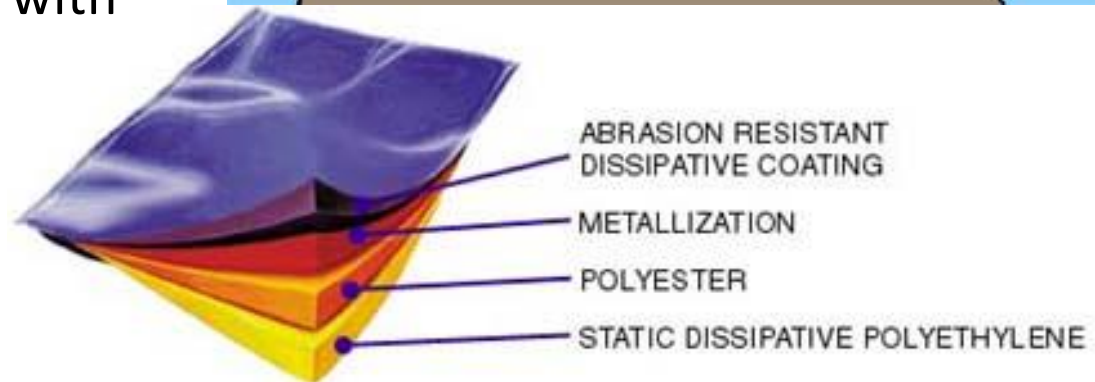
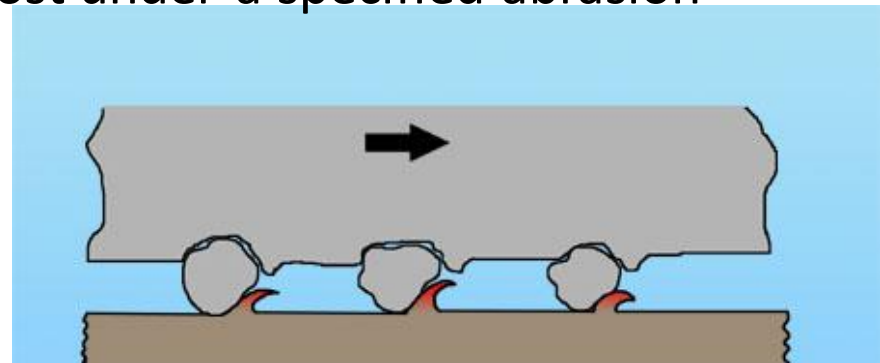
- Fatigue testing evaluates the number of cycles that a sample can withstand stress and/or strain until failure
- This is important for components that will continually flex in some way
- In this type of test, a component is repeatedly loaded until failure occurs



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



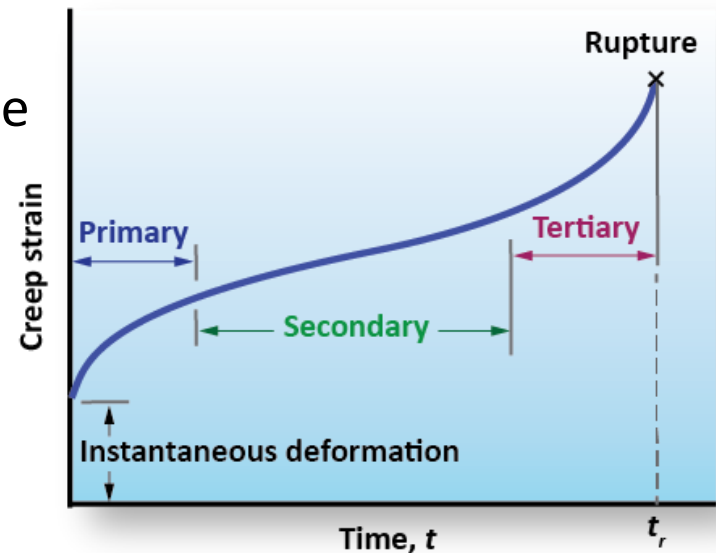
- Density is defined as the mass per unit volume of a material
- Usually quantified as a counterbalance against some other desirable property (such as mass and volume)
- Less dense materials result in lower weight components

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

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

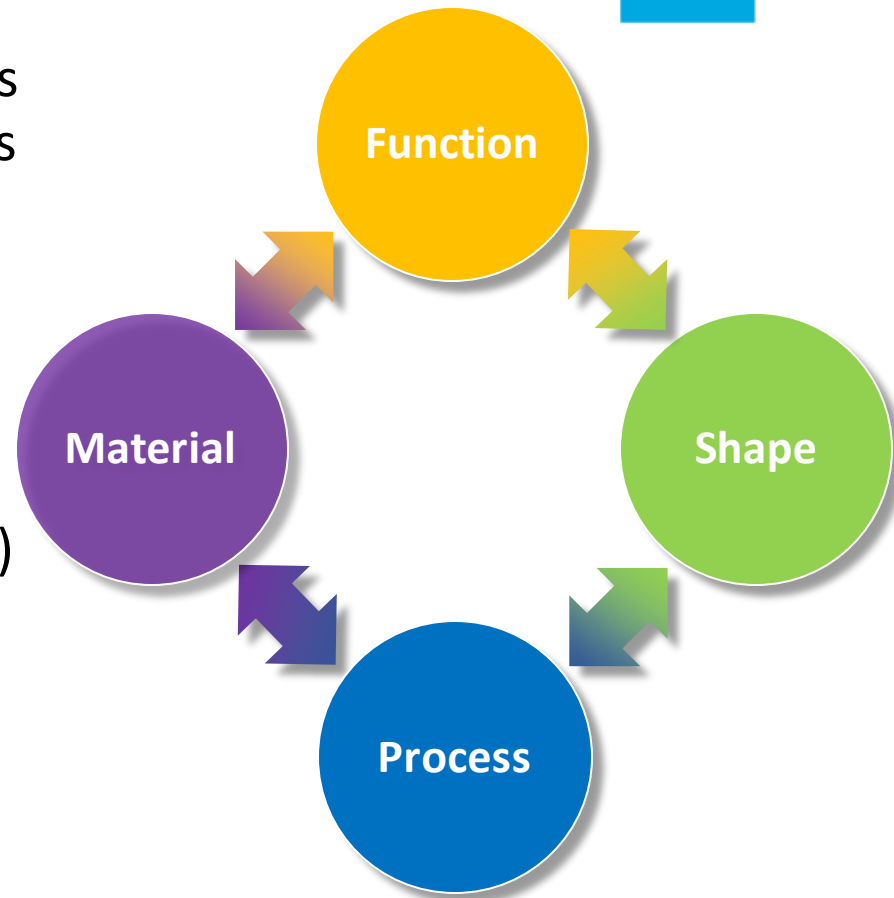
- Corrosion is the deterioration of material properties due to reaction of the material with the environment
 - Most corrosion occurs due to electrochemical processes
 - Corrosion, such as rust, can be reduced by material treatment or coating
- Oxidation is a form of electrochemical corrosion where the 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

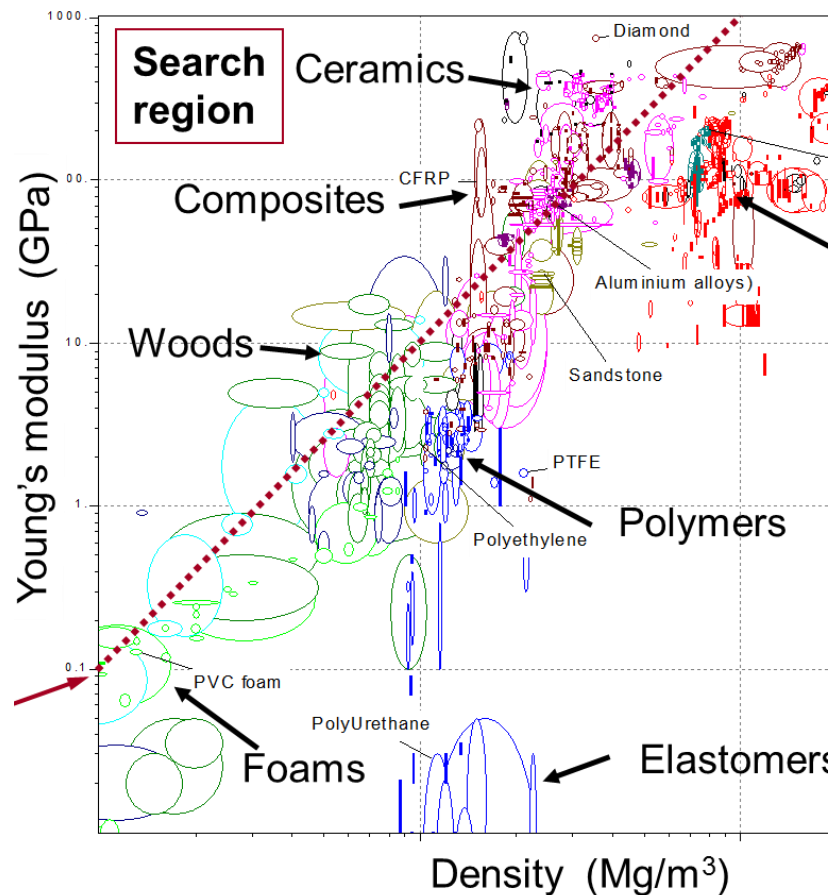
- Aligning key customer needs and functional requirements to material properties
- Ranking various material requirements (technical importance derived from functional requirements can be used for this ranking)
- Creating material indices



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>