ME 4563

Introduction to Manufacturing Processes

College of Engineering
Arkansas State University

Materials Selection

Material Selection

Failure and Fracture of Materials in Manufacturing

- FAILURE – Most important aspect in Manufacturing
  - directly influences selection of materials for a particular application
  - methods of manufacturing and
  - the service life of the component

Material Selection

Failure and Fracture of Materials in Manufacturing

- Generally TWO types of FAILURE
  - FRACTURE – necking & fracture of ductile materials; brittle materials in compression; cracking of barreled surface of ductile materials in compression
  - BUCKLING – ductile materials under compressive load

Material Selection

Failure and Fracture of Materials in Manufacturing

- Although FAILURE is undesirable, some products are designed in such a way that failure is essential for their function !
  - screw caps for bottles
  - cola cans where the tops are to be removed

Material Selection

Failure and Fracture of Materials in Manufacturing

TWO types of FRACTURES

- DUCTILE FRACTURE
- BRITTLE FRACTURE

Material Selection

Ductile Fracture of Materials

- Characterized by plastic deformation before failure
  - In Tension test – necking to a point before failure
- Takes place along a plane in which shear stress is maximum
- Failure is initiated by formation of voids in the metal which grow and coalesce, developing into cracks which grow in size and lead to failure

Material Selection

Ductile Fracture of Materials

Critical factors in Ductile Fracture

- Inclusions – assist in formation of voids
- Transition Temperature – changes Ductility due to temperature
- Strain Aging – reduced Ductility

Material Selection

Brittle Fracture of Materials

- Occurs with little or no gross plastic deformation
  - In Tension test – no necking before failure
- Takes place along the crystallographic plane on which normal tensile stress is maximum
- In general, low temperature and a high rate of deformation promote brittle failure
- Chalk, gray cast iron and concrete - examples

Material Selection

Brittle Fracture of Materials

Critical factors in Brittle Fracture

- Defects – scratches, flaws, internal cracks, etc., propagate rapidly under tension and cause catastrophic failure
- Fatigue Fracture – Occurs in materials that are basically brittle in nature: can be improved by metal working such as case hardening, fine finish, etc.
- Stress Corrosion Cracking – Developing cracks over a period of time after manufacture: depends on the material and residual stresses

Material Selection

Brittle Fracture of Materials

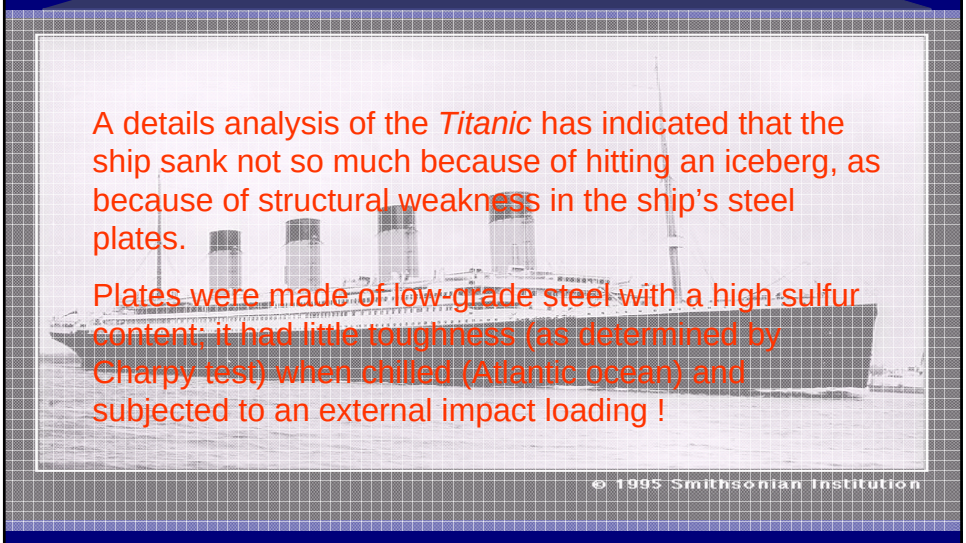
Critical factors in Brittle Fracture

- Hydrogen Embrittlement – Presence of Hydrogen in the material can reduce ductility and cause premature failure in many metals, alloys, and non-metallic materials
  - especially severe in high-strength steels
  - possible sources – during melting, pickling (oxide removal process), electroplating, water vapor, etc.
  - Oxygen can also cause embrittlement in Cu alloys

Material Selection

A details analysis of the *Titanic* has indicated that the ship sank not so much because of hitting an iceberg, as because of structural weakness in the ship's steel plates.

Plates were made of low-grade steel with a high sulfur content; it had little toughness (as determined by Charpy test) when chilled (Atlantic ocean) and subjected to an external impact loading !



Material Selection

Residual Stresses

- Residual Stresses are those that remain in a work-piece after it has been plastically deformed and then has had all external forces removed.
  - Result – distortion of parts or warping
- Can also be caused by temperature gradients in the part – during cooling of a casting or forging
- Surface tensile residual stress are undesirable: stress cracks
  - may be reduced or eliminated by stress-relief annealing or further plastic deformation or by relaxation over a period of time

Mechanical Behavior

Residual Stress – What is it ?

- When a part is subjected to deformation that is not uniform throughout, it develops residual stresses
- These are stresses that remain within the part after it has been formed and all external forces have been removed
- Example – Bending of a beam …

Residual Stresses may be caused due to:

- Temperature Gradients: such as in
  - Machining operation
  - Welding
  - Casting process
  - Heat treatment process
  - expansion and contraction due to thermal gradient is analogous to non uniform plastic deformation
- Phase Changes: in metals during or after processing – due to density differences between the phases
  - Results in changes at the microscopic level which leads to residual stresses

Reduction of Residual Stress

- Further plastic deformation – apply forces to make the stress distribution uniform
- Thermal treatment - Stress-relief annealing – heating and then slow cooling
- May be diminished at room temperature by "relaxation"
  - relaxation leads to warpage, hence allowances in dimensions (machining allowances) are usually made when subject to stress-relief annealing or relaxation

Material Selection

Physical & Chemical Properties

- Can have various important effects on manufacturing
- Must be considered during material selection as they affect design, service requirements, and compatibility with other materials such as tools, dies and work pieces
- Density, Melting point, Specific heat, Thermal conductivity, Thermal expansion, Electric & magnetic, Corrosion resistance

Material Selection

Physical Properties to be considered

- Density, Melting point, Specific heat
- Thermal – conductivity, expansion
- Tribological – Adhesion, Friction, Lubrication
  - Wear – adhesive, abrasive, fatigue, chemical
- Electric – Resistance, Conductivity
- Corrosion resistance
- Etc.

Material Selection

Physical & Chemical Properties

- Thermal Conductivity & Expansion – major factors in development of thermal stresses and of thermal fatigue and shock; effects which are important in tool and die life in manufacturing operations

- Electrical and Chemical properties – important in many advanced machining processes such as electrical-discharge, chemical and electrochemical machining

Material Selection

Physical & Chemical Properties

- Chemical reactions including oxidation and corrosion are important considerations in material selection, design and manufacturing, as well as on the service life of components. E.g. Stress corrosion

- Corrosion Resistance – important aspect of material selection in chemical, food, petrochemical industries. Corrosion leads to degradation of the surface of components and also reduces structural integrity

Material Selection

Physical & Chemical Properties

- Example – Electric Wires in homes

Due to increased costs, Cu was replaced by Al wiring in homes between 1965 & 1973. This can be a potential fire hazard because oxidation of Al increases resistance and promotes resistance heating.

Have since been redesigned !

Material Selection

Material Selection for Coins !

Criteria:

- Subjective factors – appearance, color, weight and its "ring"
- Intended life of the coin – resistance to corrosion and wear
- Manufacturing – formability of the material, life of dies used in coining and capacity of materials and processes to resist counterfeiting !
- Suitability for use – in coin operated machines such as pay phones
- Cost factor – raw materials and processing

Material Selection

Materials in Design and Manufacturing

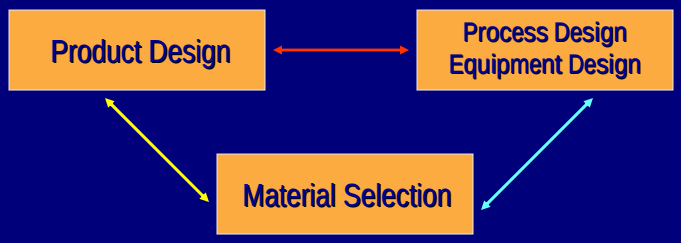
Manufacturing Processes cannot stand on their own !

- Interactions between material selection, process choice and part or component design are interconnected
- The term Concurrent or Simultaneous Engineering is often applied to this group of activities

Material Selection

Materials in Design and Manufacturing

A Narrow focus on Concurrent Engineering may be shown as follows: Interaction between Product and Process Design, as influenced by Material Selection



Material Selection

Considerations in Design and Manufacturing Processes

1. Function of the Part – with regard to
   - operating conditions
   - safety aspects
   - regulatory requirements
   - product liability implications
   - ease of maintenance
   - ease of manufacture
   - packaging requirements
   - service life
   - environmental aspects (storage and disposal)

Material Selection

Considerations in Design and Manufacturing Processes

2. Analysis of Design for Loads and Stresses
3. Choice of Material that satisfies service criteria

   Factors: minimum cost, weight, etc.
4. Tolerances and finishes for the application under consideration
5. Choice of appropriate process or process sequence with due regard to cost of processing, assembly, number of parts to be produced, etc.

Material Selection

Considerations in Design and Manufacturing Processes

6. Establishing acceptance and rejection criteria – some processes are not suitable for parts below or above a certain size; or cannot produce varying thickness; only suitable for mass production, etc.
7. Optimizing design with regard to choice of manufacturing process and cost implications – while a material may fulfill the required function, it may present substantial difficulties in manufacturing
8. Others: Disposal of waste material, energy consumption, availability of raw material, etc.

Material Selection

Considerations in Design and Manufacturing Processes

Example: The UltraLight Steel Auto Body (USLAB) project is representative of Concurrent Engineering in one sense

Intense competition from Al, plastics, and space-frame construction prompted a consortium of 35 steel companies from 18 nations to demonstrate the feasibility of developing a unibody that saves weight, outperforms present structures, can be manufactured without the need to develop new technology and does all this at a potentially lower cost !

Introduction to Manufacturing Processes, John Schey, McGraw-Hill, 3rd Ed. 2000

Material Selection

Considerations in Design and Manufacturing Processes

- Porsche Engineering – was contracted to perform the engineering and manufacturing management
- Goals – Outperform current benchmarks and a superior structure
- Computers – for design optimization, crash simulation, metal forming simulation
- Final Structure – 94 major parts all built and assembled by WELDING to prove feasibility of manufacture
- Performance criteria – were met or exceeded !!!

Material Selection

Considerations in Design and Manufacturing Processes

- Example: Bumpers of Cars
- Earlier: Metal, heavy steel pressings, separately attached, chrome-plated for corrosion protection, complex shape, with substantial difficulties in manufacturing
- Today: complex structures metallic with plastic surface layer for durability, color-coordinated with body for visual appeal, impact resistant, pressing of relatively simple shape, attached to the body through an energy absorbing device designed to minimize damage in small collisions – satisfy esthetic demands with safety, protection, durability and ease of manufacturing !!!

Material Selection

Processing of Materials in Manufacturing

Manufacturing – concerned with parts and assemblies made of materials capable of carrying loads or fulfilling other technical functions.

Hence – the transformation of input materials into usable products

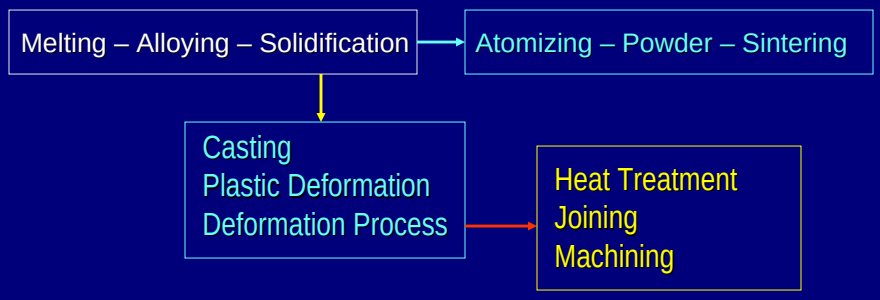
Most Materials – are products of prior manufacturing processes (primary processes). The input material may be obtained through a number of routes !

Material Selection

Processing of Materials in Manufacturing

METALS: Still the most generally employed engineering material

Several Processes in which engineering products/parts are produced:



Material Selection

Processing of Materials in Manufacturing

- PURE METALS: Specific use only (Cu or Al for wires)
- Mostly Alloys are used
- Processed by the “melt route” – some cast into parts of complex shapes, but majority cast into simple forms suitable for deformation processing
- The resulting forgings – for construction sections, wire, tubes, or sheets maybe directly used, but further deformed
- Into more complex shapes (auto body panels, beverage cans)

Material Selection

Processing of Materials in Manufacturing

- Different Route followed – when metal powder is used (primary process itself from atomization of the melt)
- In another method, atoms are used to “deposit” a coating or a plating – electroformed parts
- Finally, properties may be improved by heat treatment
- Machining creates special shape features, improves dimensional tolerances and surface finish of cast or worked parts; May also be used to produce parts directly
- All these processes not only impart the shape, dimensions and finish, but also affect mechanical and other properties

Material Selection

Processing of Materials in Manufacturing

Example: Aluminum-Lithium Alloys have long been investigated because Li reduced density and increases elastic modulus

- It was necessary to develop special processing techniques to allow the development of alloys of high strength, fatigue resistance and toughness at cryogenic temperatures
- Uses in aerospace industry
- On the space shuttle – they reduce the weight of the Liquid Hydrogen tank by 3400kg !!!!

Introduction to Manufacturing Processes, John Schey, McGraw-Hill, 3rd Ed. 2000

Shuttle picture courtesy NASA

Material Selection

Processing of Materials in Manufacturing

CERAMICS: Special Applications

Are Oxides, Borides, Carbides or Nitrides

Characterized by low density and high temperature capability and are always processed at high temperatures

Traditional ceramics are processed in large quantities (pottery, china)

Engineering ceramics are derived from specially processed or manufactured starting materials

Material Selection

Processing of Materials in Manufacturing

Melting – Sintering – Glass Processes

↓

Joining
Machining

→

Composites (carbon Fiber)
Coatings (on Metals)
Semiconductor Devices

Ceramics: Silicon-di-oxide; Zirconia; Glass; Porcelain; Aluminum Oxide, etc.

Material Selection

Processing of Materials in Manufacturing

PLASTICS: Products in which Polymers are the major ingredient

Polymers derived from Oil, Gas or Coal

Low temperature capability has limited their application

Advanced engineering plastics are used as load bearing components

Easily made through molding process

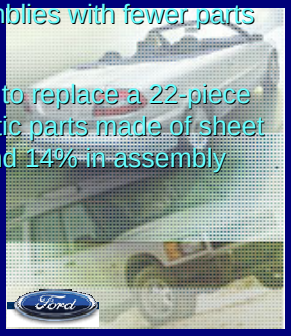
Engineering Plastics: HDPE, Nylon, Polycarbonate, Polyester, Epoxy, etc.

Material Selection

Processing of Materials in Manufacturing

Example: In many applications, plastics are competitive with metals with the potential to replace complex assemblies with fewer parts and greater shape flexibility

At Ford – concurrent engineering allowed them to replace a 22-piece sheet metal front-end module with two plastic parts made of sheet molding compound, saving 22% in mass and 14% in assembly cost



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Ford website

Material Selection

Processing of Materials in Manufacturing

COMPOSITES:

Optimum properties may sometimes be more closely approximated by combining two or more chemically different materials in such a way that the benefits are retained but limitations are circumvented

The term composites is applied to structures in which one of the components (typically fibers or particles) is surrounded by a continuous matrix of the other component (polymer, metal, ceramic or carbon)

Material Selection

Processing of Materials in Manufacturing

COMPOSITES:

- Epoxy – with Kevlar fiber
- Polyester – with glass fiber or fabric
- Al – with Carbon fiber
- Glass – with Silicon Nitride
- Carbon fiber

Glass fiber composite

Higher tensile and flexural strength, softer feel, superior surface,

Material Selection

Processing of Materials in Manufacturing

COMPOSITES Advantages

- High Strength
- Reduced Weight
- Design Flexibility
- Dimensional Stability
- Corrosion Resistance
- Cost Performance

Material Selection

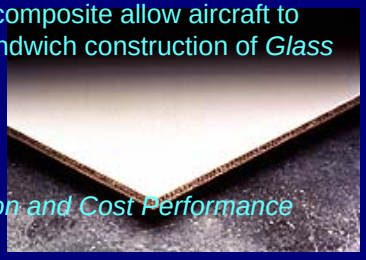
Processing of Materials in Manufacturing

Example: Aircraft Flooring

By combining light weight with the ability to withstand high loads, composite floors molded with Glass fiber composite allow aircraft to increase payloads. The composite is a sandwich construction of *Glass* fiber/epoxy over a honeycomb core

Process – Compression Molding

Benefits – High Strength, Weight Reduction and Cost Performance



Courtesy – Owens Corning website

Material Selection

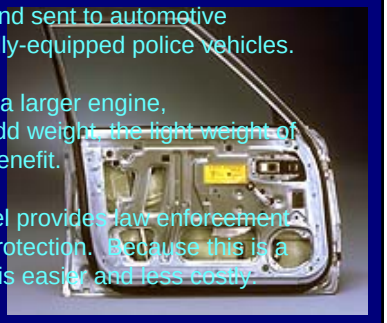
Processing of Materials in Manufacturing

Example: Doors of Police Cars

Ballistic armor for police cars is illustrated by special composite panels being made in Mexico. Panels are fabricated and sent to automotive manufacturers who install the panels on specially-equipped police vehicles.

Because vehicle modification typically includes a larger engine, communications gear and other features that add weight, the light weight of composites versus metal armor is a welcome benefit.

Installed in the door of police cruisers, this panel provides law enforcement officers with tactical gunfire and side collision protection. Because this is a glass fiber composite, machining and trimming is easier and less costly.



Courtesy – Owens Corning website

Material Selection

Processing of Materials in Manufacturing

RECYCLING of Materials

METALS – Good (scrap, segregated scrap, mixed scrap, old scrap)

CERAMICS – Limited; Glass can be easily recycled

PLASTICS – Limited; Due to different types of plastics available today; a lot of segregation required

CERAMICS – presents challenges; polymer matrix composites can be recycled to some extent

Metal Processing

Metal Processing

Can be broadly categorized in to the following:

- Metal Casting
- Forming and Shaping
- Material Removal Processes
- Joining Processes
- Surface Treatments
- Other Processes …

Metal Processing

Metal Casting

- The OLDEST of manufacturing processes
- Using molten metal and a mold to produce a component or a product that is further processed or machined for final use
- Several types of casting processes have evolved over time based on product requirements and advances in technology
- Capable of intricate shapes and sizes
- Wide variety of products and metals can be cast

Metal Processing

Metal Casting

- Intricate shape sin one piece, often with cavities
- Each casting process has its own advantages and limitations, of course
- Almost all metals can be cast in, or nearly in, the final desired shape often with only minor finishing required
- This capability places casting among the most important of the manufacturing processes

Typical Cast Parts in an Automobile

Front Grille

Water Pump

Intake & Exhaust Manifolds

Wheels, disk brakes

Door handles

Locks

Brake Drums

Brake Cylinders

Lettering

Transmission Housing

Engine Block

From: Manufacturing Engineering & Technology – Kalpakjian and Schmid, 4th Ed., 2001, Prentice-Hall

Metal Processing

Metal Forming

"Cast" Structures are converted to "wrought" structures through some means of deformation

- Forming – changing the shape of an existing body
- Normally starts with material that has been cast (ingots, slabs, rods or pipes)
- Several different parts may be formed
- The process involves heat (in most cases) and "force" to create the shape

Metal Processing

Metal Forming

- Forming can be done while the body is hot or cold
- Falls into the following major categories –
  - Rolling – flat shapes and uniform cross sections; hot and cold
  - Forging – discrete parts with a set of dies
  - Extrusion – long lengths of solid or hollow parts with constant cross sections; hot & cold
  - Drawing – long rods and wires
  - Sheet-metal forming – shapes with thin walls and geometries

Typical Formed and Shaped Parts in an Automobile

- Ceramic Spark Plug
- Stamped wheel covers
- Springs
- Cold-rolled sheet metal body
- Stamped plates
- Drawn tube for antenna

Metal and plastics

- Forged Valves
- Molded dashboard
- Shaped Windshield
- Molded tires
- Blow molded plastic tanks for fluids
- Tail light lenses

From: Manufacturing Engineering & Technology – Kalpakjian and Schmid, 4th Ed., 2001, Prentice-Hall

Metal Processing

Material Removal Processes ("Machining")

- Parts made by Casting, Forming and Shaping often require further operations before the product is finally ready for use
- Machining or Material Removal from a work piece covers several processes:
  - Cutting – involving single point or multi-point tool
  - Abrasive Process – such as grinding
  - Advanced Machining processes – utilizing electrical, chemical, and other methods

Metal Processing

Material Removal Processes ("Machining")

Is required for the following reasons

- Used as a "finishing process" in many cases
- Better dimensional accuracy than casting & forming
- Features such as sharp corners, edges cannot be produced otherwise
- Used as additional finishing operation from a previous process (such as grinding for better surface finish)
- Parts may require special surface characteristics or texture that cannot be produced by other means
- May be more economical as compared to any other process, especially if the numbers are small

Typical Machined Parts in an Automobile

Pistons

Cylinders

Engine Block

Crankshaft

Nuts and Bolts

Connecting rod

Valves

Brake Rotor

Drilled and Tapped holes

Keys

Fuel injection nozzle

Door locks

From: Manufacturing Engineering & Technology – Kalpakjian and Schmid, 4th Ed., 2001, Prentice-Hall

Metal Processing

Joining Processes

- Most products are made from assembled components that are manufactured as individual parts
- Even relatively simple products are made this way
- Joining – covers a variety of processes such as welding, brazing, soldering, adhesive bonding, and mechanical fastening
- Without joining of some form or the other, we very rarely have a product !!

Metal Processing

Joining Processes

- Joining is important for the following reasons
  - product is impossible to manufacture as a single piece
  - more economical to manufacture as individual pieces and joining them, as against manufacturing as a single piece
  - products need to be designed to be taken apart for maintenance (car)
  - different properties for different parts, hence different materials, hence different processes
  - different functional purposes
  - transporting parts are easier – to be assembled at a different site, etc., etc.

Typical Parts Assembled in an Automobile

Bolted engine assembly

Soldered circuitry

Bonding of windshield to the body

Brazed joints

Adhesive bonded fabric

Spot welded body

Mechanical fastening of body trim

Welded exhaust pipes

Seam welded muffler

From: Manufacturing Engineering & Technology – Kalpakjian and Schmid, 4th Ed., 2001, Prentice-Hall

Metal Processing

Surface Treatments

- Our first Visual or Tactile contact with objects around us is through their surfaces
- Feel surface roughness, smoothness, texture, waviness, scratches, nicks, etc.
- Most processes are worried about the “bulk” characteristics such as strength, hardness, ductility, etc.
- Surface preparation also influences the components use, its life, etc.

Metal Processing

Surface Treatments

- Why Surface treatment or preparation ?

We need parts that are subjected to various surface properties for a variety of reasons – sliding, support loads, temperatures, smoothness against roughness, etc.

- Surface Integrity – mechanical, physical and chemical characteristics depend on manufacturing processes; because of this, the surface properties differ significantly from the bulk properties
- Bulk – overall mechanical properties; Surface – influence the components performance

Metal Processing

Surface Treatments – How does it help ?

- Friction and Wear – Tools and Dies
- Effectiveness of Lubricants during a parts service life
- Appearance and Geometric features – plays a role in subsequent operations such as welding, soldering, adhesive bonding, painting, coating, resistance to corrosion
- Initiation of cracks as a result of surface defects such as roughness, scratches, etc.
- Thermal and Electrical conductivity of bodies that are in contact with each other

Components in an Automobile subject to surface treatments

- Copper wiring
- Plating
- Coating
- Galvanized steel
- Corrosion protection
- Triboloy – oiling, grease, bearings

- Valves, seals, piston rings
- Brake drums and disks

From: Manufacturing Engineering & Technology – Kalpakjian and Schmid, 4th Ed., 2001, Prentice-Hall