EME 50 Final Review

Review Questions Without Answers

Module 4 (Primary Shaping)(starting from slide 36)

- Can centrifugal casting be used for motor engines? Why or why not?
- Name and explain the causes of 3 casting defects.
- What is the function of the core in casting?
- Which casting process would you use for a large machine bed? Which for a mass production of Zinc zipper teeth?
- Name a casting process with expendable mold and one with disposable mold each.
- Explain the difference between the 2 most common primary shaping processes for metal, casting and sintering.
- What are the steps of powder metallurgy?

Module 5 (Metal Forming)

- Distinguish the material structure
  - a) after forging form
  - b) after milling an extruded billet
  - c) after casting
- What is strain hardening?
- What are the advantages and disadvantages of hot forming compared to cold forming?
- Name 3 bulk forming procedures.
- Name 3 manufacturing processes used for sheet metal processing.
- Why is the anisotropy in the rolled sheet metals important for sheet metal forming?
- How is shearing in sheet metal processing different from cutting or grinding?
- What is the difference between martensite from quenching and tempered martensite?
- Name reasons for annealing.
- When can heat treatment take place in the manufacturing chain of a part?

Module 6 (Polymer Manufacturing, Additive Manufacturing)

- What are the 3 main types of polymers?
- Are interlinked polymers thermosetting or thermoplastic?
- Name 3 manufacturing processes to shape polymers.
- What is the purpose of the rotating screw in the equipment for extrusion and injection molding?
- What functions do matrix and reinforcing agents in composites have?
- What implications come from the fact that additive manufacturing produces parts in layers?
- What is a support structure?
- What material is used in stereolithography and why?

- What additive manufacturing methods allow to produce metallic parts?

Module 7 (Assembly and Joining)

- What are ways of heat generation in fusion welding?
- Explain how arc welding works.
- What is the difference between fusion welding and solid-state welding?
- Explain how spot welding works.
- Name 5 joining methods. What are their physical principles?
- Which mechanical fasteners establish a non-permanent joint?
- Name 3 guidelines for design for assembly.
- What are factors for choosing a certain joining method for part assembly?
- What joining methods can be used for dissimilar materials?

Module 8 (Advanced Machining and Process Chains)

- Name 4 advanced machining processes.
- Explain the terms EDM and ECM.
- What are the removal mechanisms in ECM and EDM?
- What are the advantages of the chemical and electrochemical processes compared to EDM?
- What fundamental law defines the material removal rate of ECM?
- What do you have to consider in process planning?
- Compare soft and hard machining.
- Discuss different methods to produce dies made of high-alloy steels.
- Differentiate between process planning, production planning, and facility planning.

Module 9

Don’t worry about this :)

Review Questions With Answers

Module 4 (Primary Shaping) (starting from slide 36)

- Can centrifugal casting be used for motor engines? Why or why not?
  - No, centrifugal casting can only produce radially symmetrical parts.
- Name and explain the causes of 3 casting defects.
  - Misrun: material doesn’t run all the way into the mold because it solidified too early
  - Cold shut: The part is formed incorrectly due to a lack of fusion between some parts of the molten metal

    - Cold shots: splattered metal globules
    - Shrinkage cavity: unintentional cavity in part due to not having enough material
    - Microporosity: part has lots of small pores/holes due to bad cooling process
    - Hot cracks: cracks in part because mold prohibits shrinkage
- What is the function of the core in casting?
    - The function of the core is to define the internal holes/features of the cast part
- Which casting process would you use for a large machine bed? Which for a mass production of Zinc zipper teeth?
    - Machine bed: Sand Casting
    - Zinc Zipper teeth: Die casting
- Name a casting process with expendable mold and one with disposable mold each.
    - Expendable: lost wax, sand casting, investment casting
    - Permanent: centrifugal, die, continuous casting
- Explain the difference between the 2 most common primary shaping processes for metal, casting and sintering.
    - Casting involves melting the metal pieces, whereas sintering does not actually melt the metal.
- What are the steps of powder metallurgy?
    - Powder
    - Mixing
    - Pressing
    - Sintering
    - Sizing

Module 5 (Metal Forming)

- Distinguish the material structure
    - a) after forging form
    - b) after milling an extruded billet
    - c) after casting
- What is strain hardening?
    - Strengthening of a material by plastic deformation
- What are the advantages and disadvantages of hot forming compared to cold forming?
    - Advantages: lower forces, more deformation, isotropic properties
    - Disadvantages: lower accuracy and surface finish
- Name 3 bulk forming procedures.
    - Cold, warm, and hot forming
- Name 3 manufacturing processes used for sheet metal processing.
    - Rolling, shearing, and bending
- Why is the anisotropy in the rolled sheet metals important for sheet metal forming?
    - You need to bend parallel to the rolling direction to avoid seeing grain boundaries

- How is shearing in sheet metal processing different from cutting or grinding?
    - Shearing uses 1 pressing motion
- What is the difference between martensite from quenching and tempered martensite?
    - Untempered martensite is strong, hard, and brittle. Tempered martensite is more tough, but less strong.
- Name reasons for annealing.
    - More ductility, better machinability, less residual stresses
- When can heat treatment take place in the manufacturing chain of a part?
    - After all soft machining processes have been completed and the part is close to its final shape

Module 6 (Polymer Manufacturing, Additive Manufacturing)

- What are the 3 main types of polymers?
    - Thermoplastics
    - Thermosets
    - Elastomers
- Are interlinked polymers thermosetting or thermoplastic?
    - Thermosets
- Name 3 manufacturing processes to shape polymers.
    - Extrusion
    - Blow molding
    - Compression molding
    - Injection molding
    - Casting
- What is the purpose of the rotating screw in the equipment for extrusion and injection molding?
    - To feed the plastic at a uniform rate and move it through the heating tube very uniformly.
- What functions do matrix and reinforcing agents in composites have?
    - Matrix: hold everything in place
    - Reinforcing agent: provide structural rigidity and strength
- What implications come from the fact that additive manufacturing produces parts in layers?
    - The parts are always anisotropic
- What is a support structure?
    - A temporary structure that is produced to hold up the final part but should be removed after the manufacturing is done.
- What material is used in stereolithography and why?
    - Liquid photopolymer because it cures when UV light is shined on it.
- What additive manufacturing methods allow to produce metallic parts?
    - 3DP, Selective Laser Sintering, Electron-beam Melting

Module 7 (Assembly and Joining)

- What are ways of heat generation in fusion welding?
  - Arc, Oxyfuel, Beam
- Explain how arc welding works.
- What is the difference between fusion welding and solid-state welding?
- Explain how spot welding works.
  - 2 electrodes are brought together from different sides of the metal pieces. THe electrical resistance causes heat that melts the metal.
- Name 5 joining methods. What are their physical principles?
  - Arc Welding
  - Resistance Welding
    - Electrical resistance
  - Brazing, Soldering
    - Capillary action
  - Adhesive Bonding
  - Bolts + Nuts
    - friction
  - Riveting
  - Seaming and Crimping
    - friction
- Which mechanical fasteners establish a non-permanent joint?
  - screws/bolts + nuts
- Name 3 guidelines for design for assembly.
  - Use fewest number of parts possible
  - Reduce number of threaded fasteners
  - Standardize fasteners
  - Avoid parts that tangle
- What are factors for choosing a certain joining method for part assembly?
  - Needed joint strength, money, part materials, disassembly
- What joining methods can be used for dissimilar materials?
  - Seaming, crimping, interference fit, adhesive bonding

Module 8 (Advanced Machining and Process Chains)

- Name 4 advanced machining processes.
- Explain the terms EDM and ECM.
  - ECM(Electrochemical machining)
    - The metal is eroded through electricity transfer. The metal is the anode and the tool is the cathode
  - EDM(Electro Discharge machining)
    - High amounts of electricity are fed through a tiny wire. A spark causes the metal to dissolve instantly.

- What are the removal mechanisms in ECM and EDM?
  - ECM: anodic metal dissolution
  - EDM: thermal evaporation
- What are the advantages of the chemical and electrochemical processes compared to EDM?
  - No tool wear
  - No thermal damage on part surface
- What fundamental law defines the material removal rate of ECM?
  - Faraday's law
- What do you have to consider in process planning?
  - How many products?
  - Which processes?
  - What are parameters, tools, machines for each process?
- Compare soft and hard machining.
  - Soft machining
    - Lower forces on part and tool
    - Less tool wear
  - Hard machining
    - Higher forces on tool+ part
    - Better part accuracy
- Discuss different methods to produce dies made of high-alloy steels.
- Differentiate between process planning, production planning, and facility planning.
  - Process planning: decide manufacturing procedures, including batch size, machines, tools, and parameters
  - Production planning: decide exactly which product you want to manufacture
  - Facility planning: workstation design, number of stations, employees per station, product flow through factory.

Module 9

Don't worry about this :)

Interim Review Notes

Module 4 (Primary Shaping) (starting from slide 36)

- Powder metallurgy is used to shape a part from metal powders. The powders are molded, pressed, and sintered.
- Sintering is a primary shaping process from powders below the melting temperature.
- Ceramics are traditional products for sintering technology.
- Today, high-tech cemented carbides, tool steels, or porous parts(filters, gears, etc.) are also sintered.

- The powder particle size and shape define the final product’s structure and porosity.

Module 5 (Metal Forming)

- Dislocations explain plastic deformation(pure sliding would need much higher forces than experienced in practice.
- Lattice defects form dislocations, but lattice defects and grain boundaries also hinder the movement of dislocations.
- Strain hardening is a physical mechanism in the metal, where dislocations add up and strengthen the material. Without being relieved, dislocations ultimately lead to breakage under further load.
- Forging can improve the material flow compared to a cast or extruded product.
- Shearing is an important, chip-free cutting process for sheet metals. In the variant blanking the inner part is used, in punching the outer part.
- Sheet metal forming processes include bending, deep drawing, and incremental forming amongst others.
- In forming, it is important to understand tribology (friction, lubrication, and wear)
- The most important heat treatment operations for steels include annealing, martensitic hardening, and tempering.
- The design of the time-temperature curve (including potentially multiple heating and cooling cycles) allows for adjusted microstructures.
- In contrast to through hardening, surface hardening affects the rim zone of the part. Surface hardening is a heat treatment process with or without adding carbon, nitrogen, or other alloying elements to the part.
- Heat treatments lead to part deformations, which might need to be removed(hard machining).

Module 6 (Polymer Manufacturing, Additive Manufacturing)

- The interim review for the first part of module 6 is missing from the slide deck :(
- Additive manufacturing principles build parts in layers. They enable rapid prototyping, rapid tooling, and rapid manufacturing
    - In stereolithography, liquid polymer is cured through UV light
    - In fused-deposition modeling, heated polymer wires cool at air
    - In powder bed and inkjet head 3d printing, a binder consolidates powder material
    - Selective laser sintering and electron-beam melting are additive manufacturing variants, in which powder metal is molten or sintered
    - In laminated object modeling, layers of paper, polymer, or metal are glued together

Module 7 (Assembly and Joining)

- Assembly means joining parts together. The joining technique depends on the tolerances, the price and on the duration of the joint (permanent or disassembly possible) amongst others.
- In welding, material coalesces together either by fusion(through heat from arc, oxyfuel, or beam) or in a solid state(through softening and merging)
- In fusion welding, part distortion from heat needs to be considered
- In brazing and soldering, a filler is introduced to the joint and holds the parts together
- Soldering works at lower temperatures than brazing.
- Joints by adhesive bonding have a broad application range, but can only take limited load.
- Mechanical fastening includes the use of fasteners, seaming, crimping, and interference fits.
- Only threaded fasteners enable disassembly.
- Product designers and manufacturing engineers need to consider assembly in terms of design for assembly, design for disassembly, assembly sequence, and available assembly systems.

Module 8 (Advanced Machining and Process Chains)

- Missing for part 1 :(
- Product design determines the product development and manufacturing costs significantly. Concurrent design (interaction between design and manufacturing) helps to improve cost efficiency and reduce time to market.
- Manufacturing costs consist of a constant portion(material, tool,...) and a time-dependent portion (labor, machine, energy costs, …)
- Manufactured parts have a history of manufacturing processes, which defines shape, tolerances, properties, surface integrity,...
- In process planning, the manufacturing procedures are chosen including batch size, machine tools, tooling, and parameters.

Module 9

- Not on test :)

Detailed Notes

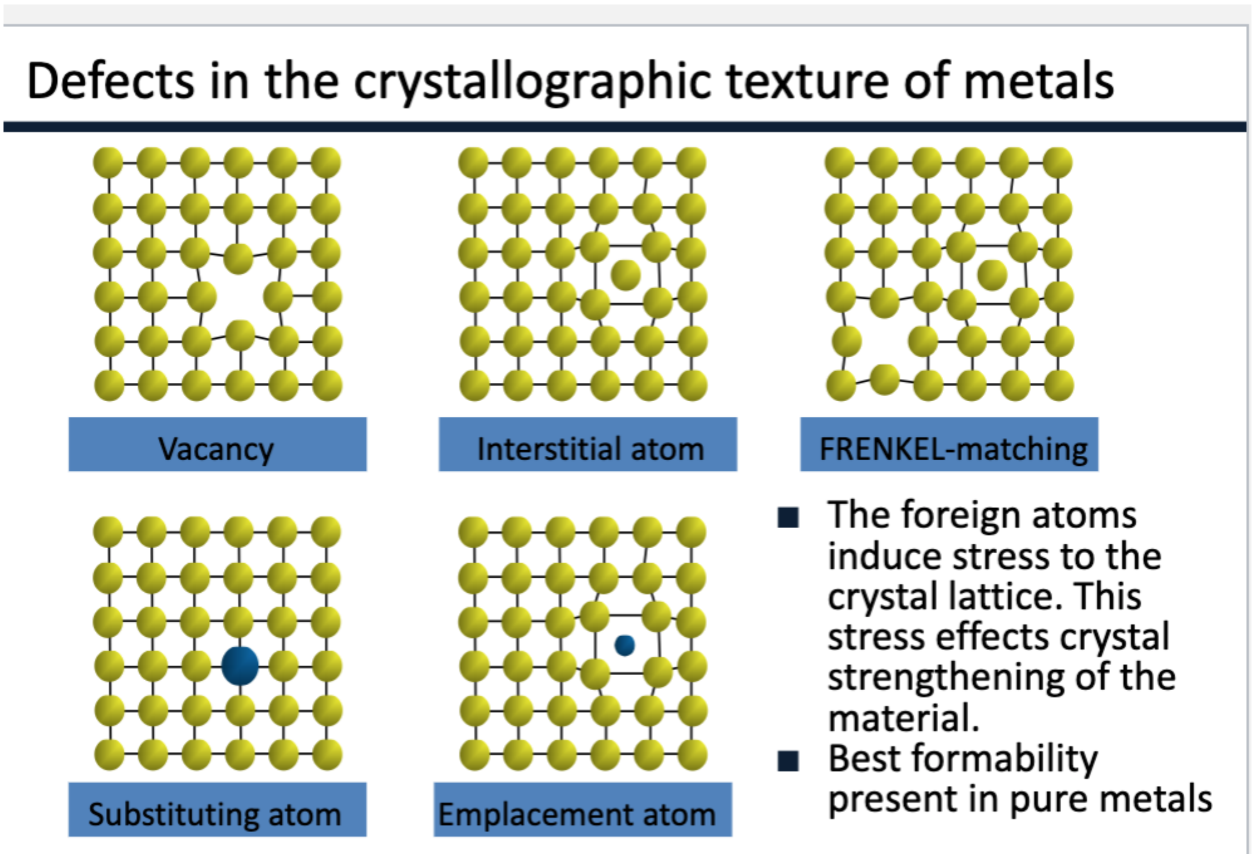
Module 4 (Primary Shaping) (starting from slide 36)

- Powder metallurgy steps
  - Powder

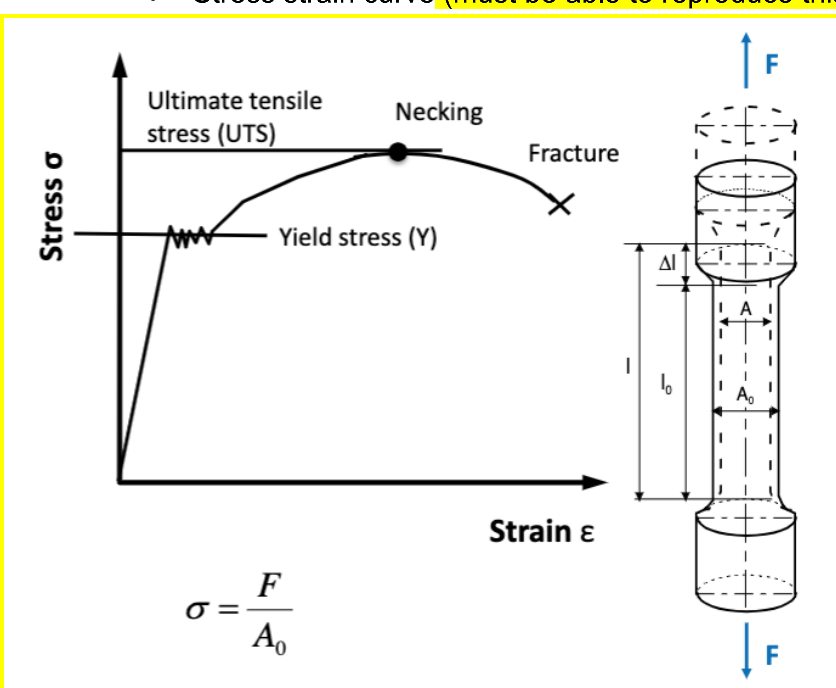
- Mixing
    - Pressing
    - Sintering
    - Sizing
- Powder metallurgy characteristics
    - High speed steels
    - Near net shape parts
    - High material utilization + efficiency
    - Specific porosity
- Powder metallurgy cons
    - Expensive equipment
    - Powder handling is dangerous
    - Expensive powder
- Sintering mechanisms
    - Particle bonding starts at contact points
    - Contact points grow into necks
    - Pores shrink
    - Grain boundaries replace necked regions
- Design for powder metallurgy
    - Avoid sharp corners and radii
    - Be aware of threads and transverse holes need to be machined afterwards

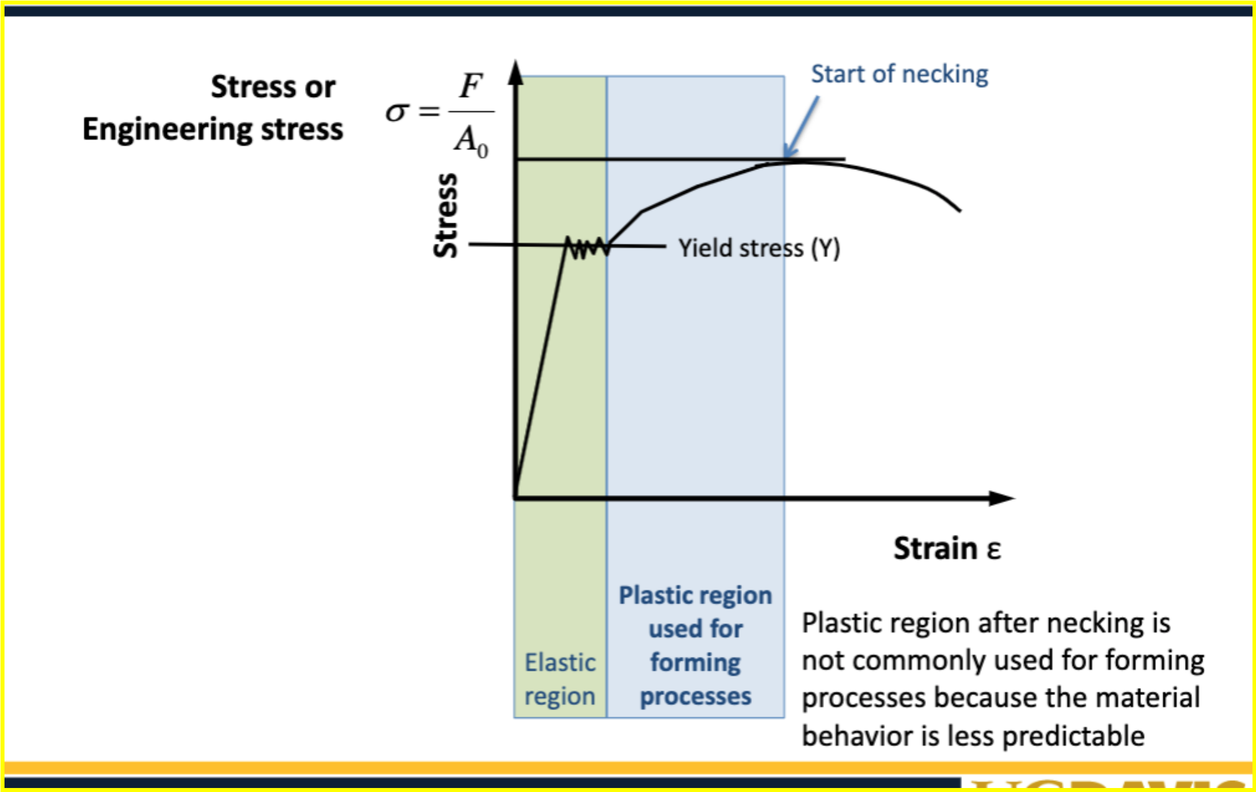
Module 5 (Metal Forming)

- Metal forming = producing finished product from semi-finished product through plastic deformation
- Uses compressive forces + plastic deformation
- More sliding systems => more formability
    - Formability = ability to undergo plastic deformation without being damaged
- Crystal defects

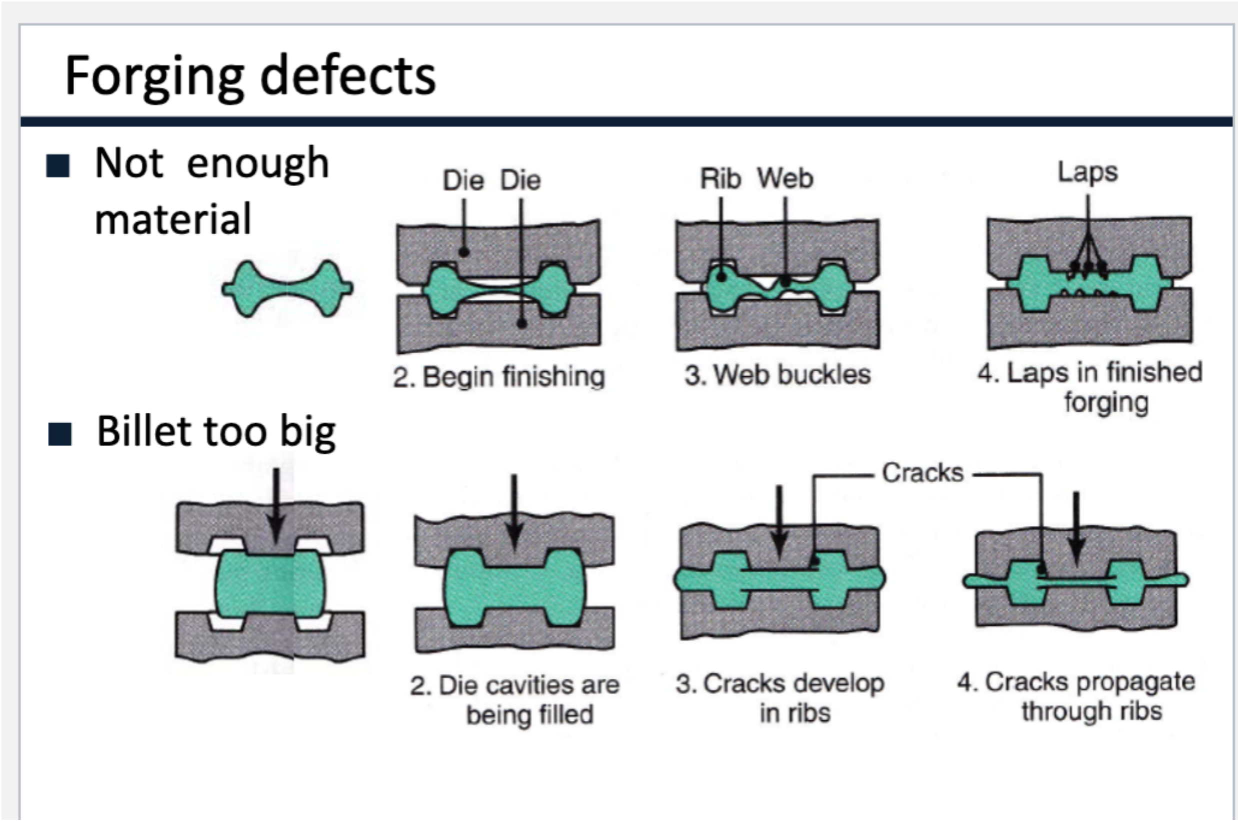


- Stress strain curve (must be able to reproduce this)

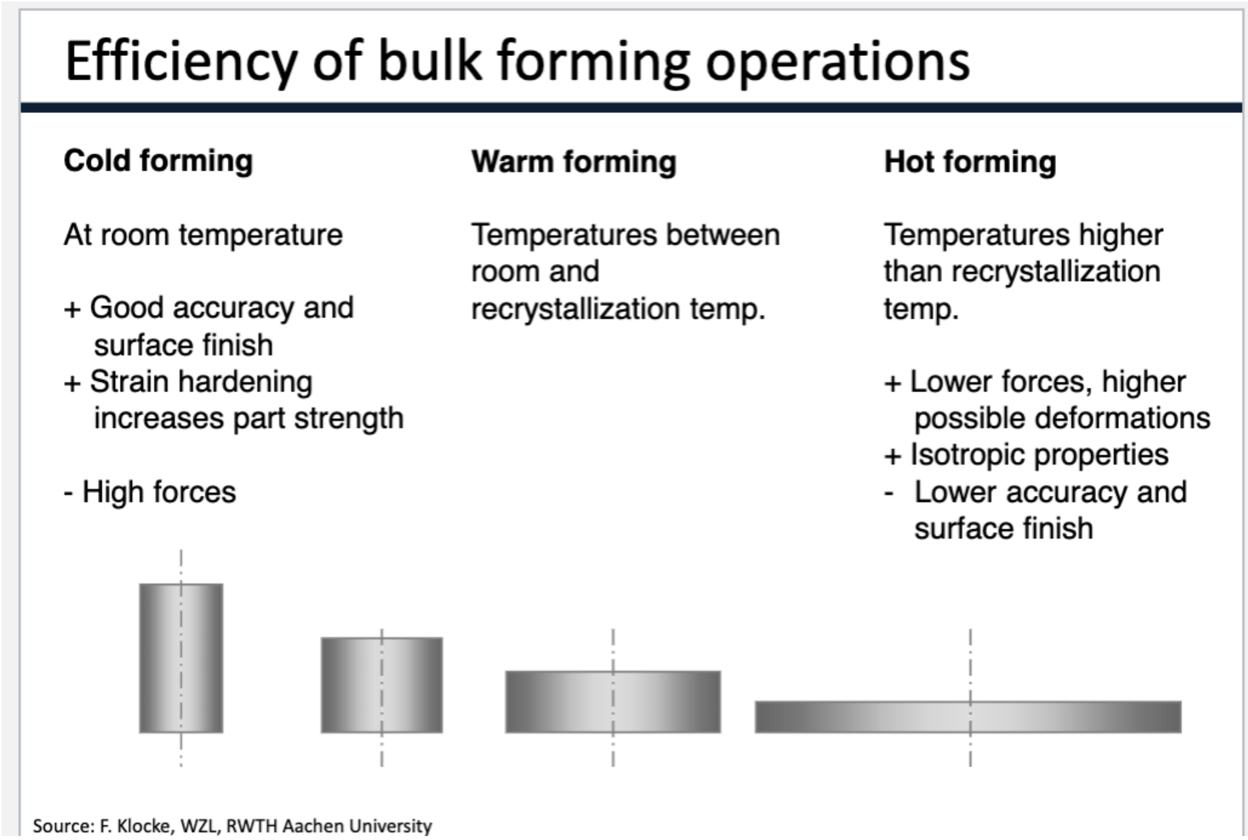




- Strain hardening = strengthening of material due to movement of existing dislocations and generation of new dislocations
- Forging can enhance material structure by aligning grain boundaries
- Forgeability = ability of a material to undergo deformation without cracking
- Factors of forgeability
    - Ductility, metal strength
    - Forging temp
    - Frictional behavior
    - Forging quality



- Rolling
  - Accounts for 90% of all metals produced
  - Plates >6 mm, sheets <6 mm
  - Works on
    - Metals
    - Polymers
    - Powder metals
    - Hot glass
    - Ceramic slurry
  - Hot rolling reduces grain size
  - Cold rolling is at room temp and leads to strain hardening
- Extrusion
  - Hot extrusion allows higher strains than cold
    - More expensive due to heat
  - Cold extrusion leads to work hardening
- Bulk forming summary



- Sheet metal processing
  - Rolling leads to sheets
  - Sheets can be sheared, bent, spun, or ironed
- Shearing
  - Before other forming operations
  - High output
  - Simple + cheap
  - Applications: automotive, med tech, household equipment
  - Punching
    - Included nibbling + blanking
- Sheet metal processes list
  - Shearing
  - Punching
  - Blanking
  - Deep drawing
  - Incremental forming
- Heat treatment
  - Heating + cooling processes to change material structure + properties
  - Includes

        - Softening before forming
        - During forming to relieve stress
        - At end for case hardening
- Annealing
    - Forms different microstructures with different properties
- Hardening
    - Based on forming martensitic steel
    - Carbon is frozen in austenitic lattice structure
- Tempering removes stresses
- Surface hardening
    - Can be done by flame or induction
    - Thermochemical methods
        - Carburizing
        - Nitriding
        - Carbonitriding
        - Chromizing
        - Boronizing

Thermochemical hardening principles

Method	Steel	Principle	Av. layer depth[mm]
Carburizing	Low-carbon steel (0.2% C)	Heating steel in C-rich environment, C diffuses into surface and generates a high-carbon steel (875 – 925°C)	(55 - 65HRC)
		pack carburizing	0.6 – 3.8
		gas carburizing	0.13 – 0.75
Nitriding	Alloy steels with Al or Cr	Heating in gaseous or liquid N-rich environment, N diffuses into surface and forms nitrides (around 510 °C)	0.025 – 0.5 (>HRC 70)
Carbo-nitriding		Combination of carburizing and nitriding	0.07 – 0.5
Chromizing	Low-carbon steels	Heating in Cr-rich environment, Cr diffuses into surface	0.025 – 0.05
Boronizing	Tool steels, Ni- and Co-based alloys, cast iron, carbon steels	Heating in B-rich environment, Cr diffuses into surface	0.025 – 0.05 (>HRC 70)

Source: M. Groover, Fundamentals of modern manufacturing, 1996

- Process order
  - Soft state material removal (do as much as possible here)
  - Heat treatment
  - Hard state material removal

Module 6 (Polymer Manufacturing, Additive Manufacturing)

- Polymer = material made of long molecules with repeating units, often carbon-based, also called plastics
  - Primary bonds: covalent
  - Secondary bonds: van der waals, hydrogen, and ionic
- Types:
  - Thermoplastics
    - Soft when heated
  - Thermosets
    - Hard when heated
  - Elastomers
    - Viscous and elastic. Think of rubber
- Pros
  - Cheap
  - Easy to form into complex shapes
  - Light weight
  - Electrical + thermal insulators
- Cons
  - Low strength/ toughness/ melting point
  - May degrade easily
  - May creep
- Plastic processing processes
  - Extrusion
    - Material is forced to flow through a small opening
    - Most common
  - Blow molding
  - Compression molding
  - Injection molding
    - Close mold
    - Inject melt into cavity
    - Retract screw
    - Open mold + eject part
  - Casting

Molding techniques for plastics overview

	Equipment and tooling costs	Production rate	Comments
Extrusion	Medium – low	Very high – high	One profile along the length, continuous process
Injection molding	Very high	Very high	Versatile
Blow molding	Medium	high – medium	Hollow parts
Compression molding	High – medium	Medium	widely used for thermosetting plastics
Casting	Medium – low	Medium – low	Low viscosity material

Many more processes: Foam molding, transfer molding, rotational molding, thermoforming, calendering, etc.

- Composites
  - Made up of primary matrix phase and secondary reinforcing phase
  - Can involve plastics, metals, or ceramics
- Curing
  - Can be room temp or heated
  - Usually pressurized
- Cutting composites
  - Hard to do once machined because different material properties and fibers are abrasive
  - Defects
    - Fiber pulling and tearing
    - Edge delamination
    - Waterlogging
- Additive manufacturing
  - Build up a part in layers
  - Layer thickness defines accuracy
  - Orientation matters
  - Finishing operations might be needed
  - Overhanging parts need supports
- Types of AM

- Stereolithography
  - Curing a liquid polymer
  - Vat is filled with liquid polymer, UV light source hardens top layer of liquid, platform is lowered in steps
- Fused deposition modeling
  - Melted polymer wire is extruded and deposited
  - Solidifies by cooling
- Inkjet head 3d printing
  - Printing a binder with an inkjet head onto powder
  - Powder materials can be sand, fibers, metals, or polymers
  - Binder can be polymers and starch
- Selective Laser Sintering
  - Sintering powders with a laser
- Electron beam melting
  - Melt/sinter powders with a beam of electrons
  - Need vacuum

Additive Manufacturing

Process	Principle	Materials	Estimated equipment costs
Fused-deposition modeling (FDM)	Melted polymer is extruded, solidifies by cooling	Polymers	\$200 – 300k Home printers down to \$1k
Stereolithography (SLA)	Liquid layers are cured through photopolymerization	Photopolymers	\$100k - \$400k
3D printing (3DP)	Powder material and binder are deposited, binder cures	Ceramic, polymer, metal powder, sand	\$20k - \$70k Polyjet up to \$1Mio
Laminated Object Manufacturing (LOM)	Coated sheet material is cut by laser into layers, layers are bonded by heated roller	Paper	low
Selective laser sintering	Layers of powders are sintered or molten by laser	Polymers, metals with binder, metals, ceramics, sand with binder	\$500k
Electron-beam melting	Layers of powder are molten by electron beam	Titanium and its alloys, cobalt chrome	[> \$1Mio]

Source: S. Kalpakjian, S. Schmid, Manufacturing Engineering and Technology, 2010

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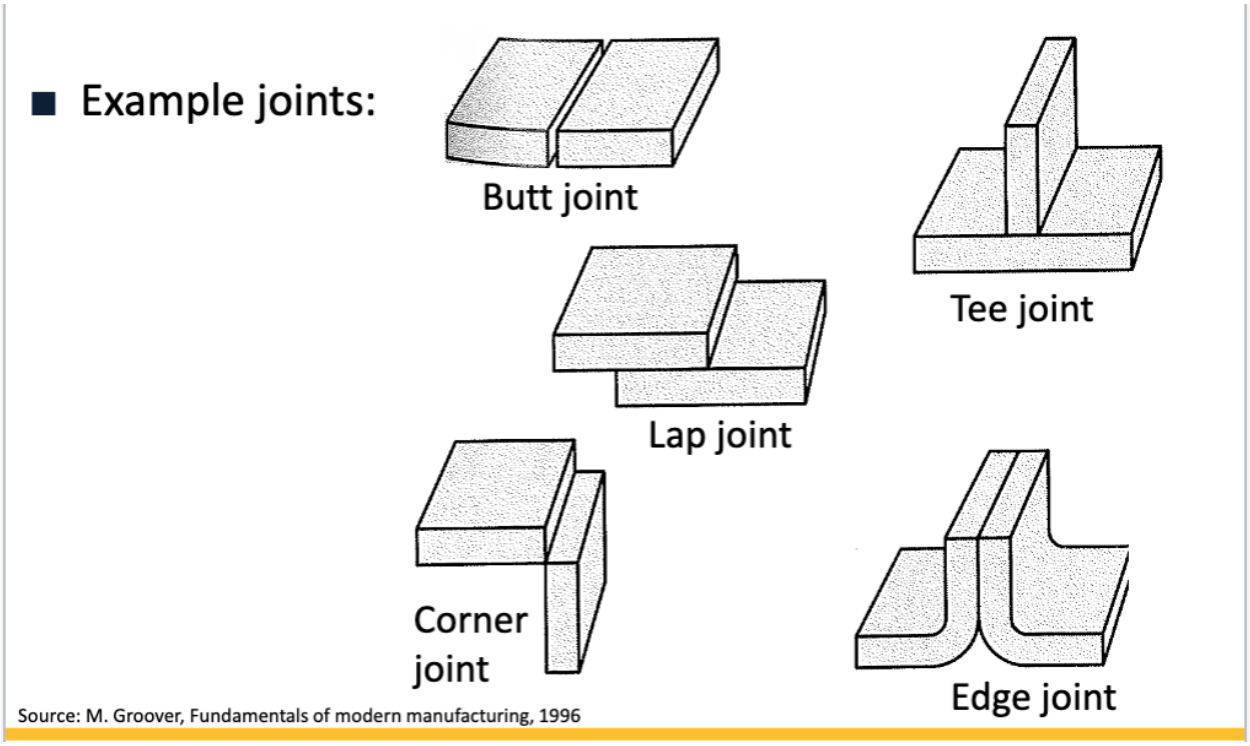
Module 7 (Assembly and Joining)

- Joint examples



- Welding
    - Types
        - Fusion welding- molten material
            - Arc
                - Needs shielding environment + filler
            - Oxyfuel
                - Fuel gas + oxygen => flame
                - Need torch + separate filler rod
            - Beam

Comparison of fusion welding methods

	Operation	Skill level required	Distortion	Typical cost of equipment	Power
Oxyfuel	Manual	High	Medium	Low ($500 +)	
Shielded metal arc	Manual	High	High	Low ($1500 +)	< 10 kW
Gas metal arc	Semiauto-matic or automatic	Low - high	Medium	Medium ($3000+)	
Gas tungsten arc	Manual or automatic	Low - high	Medium	Medium ($5000+)	8 – 20 kW
Electron beam, laser beam	Semiauto-matic or automatic	Medium - high	Low	High ($100k – 1mio)	< 100 kW

        - Solid state welding - soften and merged material
            - Electrical
            - Chemical
            - Mechanical
    - Weldability
        - Process factors
            - Shielding gases
            - Fluxes
            - Moisture in electrode
            - Welding speed
            - Cooling rate
            - Preheating level
        - Part design
        - Material properties
            - Hot crack susceptibility
            - Stresses, heat treatment
    - Friction stir welding
        - Material coalescing, heat due to friction
        - Material softens below melting point
        - Works for light metals
- Brazing + soldering
    - Filler is melted and distributed by capillary forces between joined parts
    - Soldering uses lower temps than brazing and is weaker

- Adhesive bonding
    - Types of adhesives
        - natural(starch, animal glues, …)
        - Inorganic
        - Synthetic organic/ polymer
    - Works between dissimilar metals or for plastics
    - Needs large contact areas
- Mechanical fastening with threaded fasteners
    - Allows for disassembly
- Rivets
    - unthreaded , headed pin
    - Used in structural + aerospace applications
    - Permanent
- Seaming + Crimping
    - Seaming = joining by folding thin pieces of material
    - Crimping = joining by beads or dimples
- Design for Assembly (DFA)
    - Use fewest number of parts possible to reduce amount of assembly needed
    - Reduce # of fasteners (only for assembly + disassembly)
    - Standardize fasteners
    - Avoid parts that tangle
    - Reduce part orientation difficulties

Module 8 (Advanced Machining and Process Chains)

- Characteristics of advanced machining processes
    - Used when traditional processes might not be economical
    - Used for high strength/hardness materials
    - Used with brittle materials
    - Good for flexible, slender parts
    - Generate complex shapes
    - High surface + dimensional quality
    - Chemical processes are used when low thermal stress is needed
- Chemical machining
    - Controlled chemical dissolution or chemical reaction of the workpiece material with an active fluid medium(strongly acidic or basic)
    - Steps
        - Workpiece cleaning
        - Coating with masking material
        - Scribing mask
        - Etching
        - Cleaning
- Electrochemical Machining (ECM)

- Anodic metal dissolution
  - Workpiece is the anode and must be metal
  - The tool is the cathode (brass, copper, bronze, stainless steel)
  - Electrolytic medium
- Electro Discharge Machining (EDM)
  - Physical principle is evaporation by thermal energy
  - Workpiece is usually a cathode and electrically conductive
  - Tool is usually an anode (graphite, copper, brass)
  - Dielectric medium
- Wire EDM
  - Uses a metal wire to cut the workpiece
- ECM vs EDM

Comparison of ECM and EDM

	Electrochemical machining (ECM)	Electro-discharge machining (EDM)
Workpiece and tool	Workpiece is the anode, tool is cathode Tool does not wear	Workpiece is commonly the cathode, tool is anode Tool wears
Medium	Electrolyte (carries electrons)	Dielectric (isolates)
Principle	Anodic metal dissolution, Faraday`s law	Thermal evaporation
Workpiece material	Only metals No thermal damage of surface layer	Metals and electrically conductive materials Surface layer might be damaged

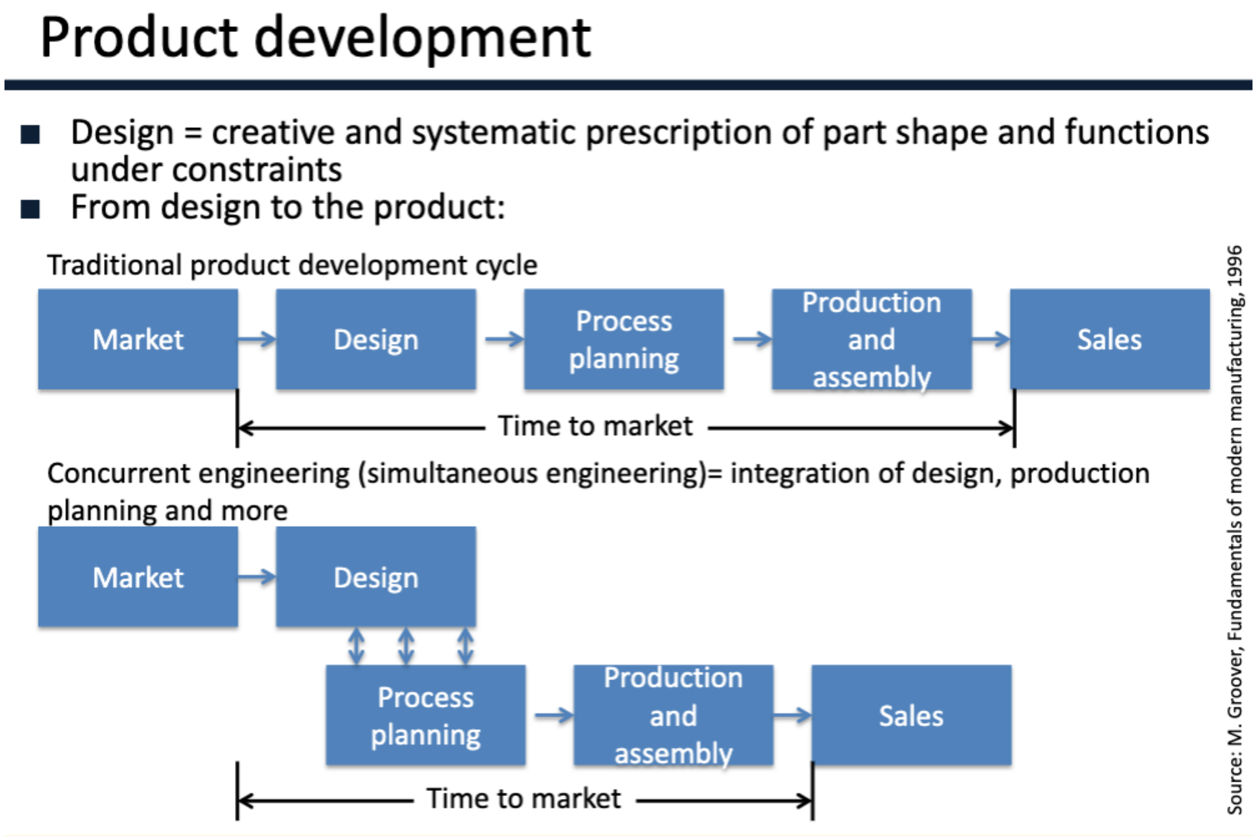
- Laser Beam Machining (LBM)
  - Energy source is a laser and the material is molten or evaporated in a controlled manner
  - Workpiece parameters include reflectivity, thermal conductivity, specific heat, melting point, evaporation point
  - Process parameters include laser power + laser speed
- Other processes
  - Water jet

- Electron beam machining
- Summary of advanced processes

Overview on Advanced machining processes

Process	Abbr.	Process rate	Comments
Chemical machining	CM	0.0025 – 0.1 mm/min	Small batch size, flat or curved surfaces, no effect on surface layer
Electrochemical machining	ECM	2.5 – 12 mm/min	Medium to large batch size, complex shapes, expensive tooling, no effect on surface layer; restricted to metals
Electro-discharge machining	EDM	300 mm^3/min (in mm^2/min for Wire EDM)	Complex parts, expensive tooling, heat can induce surface damage; restricted to metals and electrically conductive materials
Laser beam machining	LBM	0.5 – 7.5 m/min	Cutting and hole making, expensive equipment, surface damage
Electron beam machining	EBM	1 – 2 mm^3/min	Cutting and hole making, very small holes and slots, expensive equipment, requires vacuum
Water-jet machining	WJM	Varies	Nonmetallic materials, also flexible materials, no thermal damage, noisy
Abrasive water-jet machining	AWJM	Up to 7.5 m/min	Metallic and nonmetallic materials, also in layers

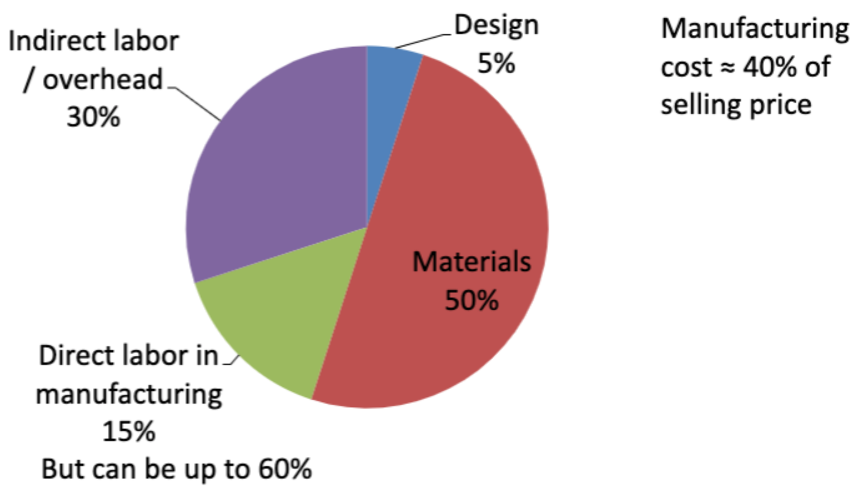
- Product development



- Design stage determines ~80% of cost of product development/ manufacture
- Cost breakdown

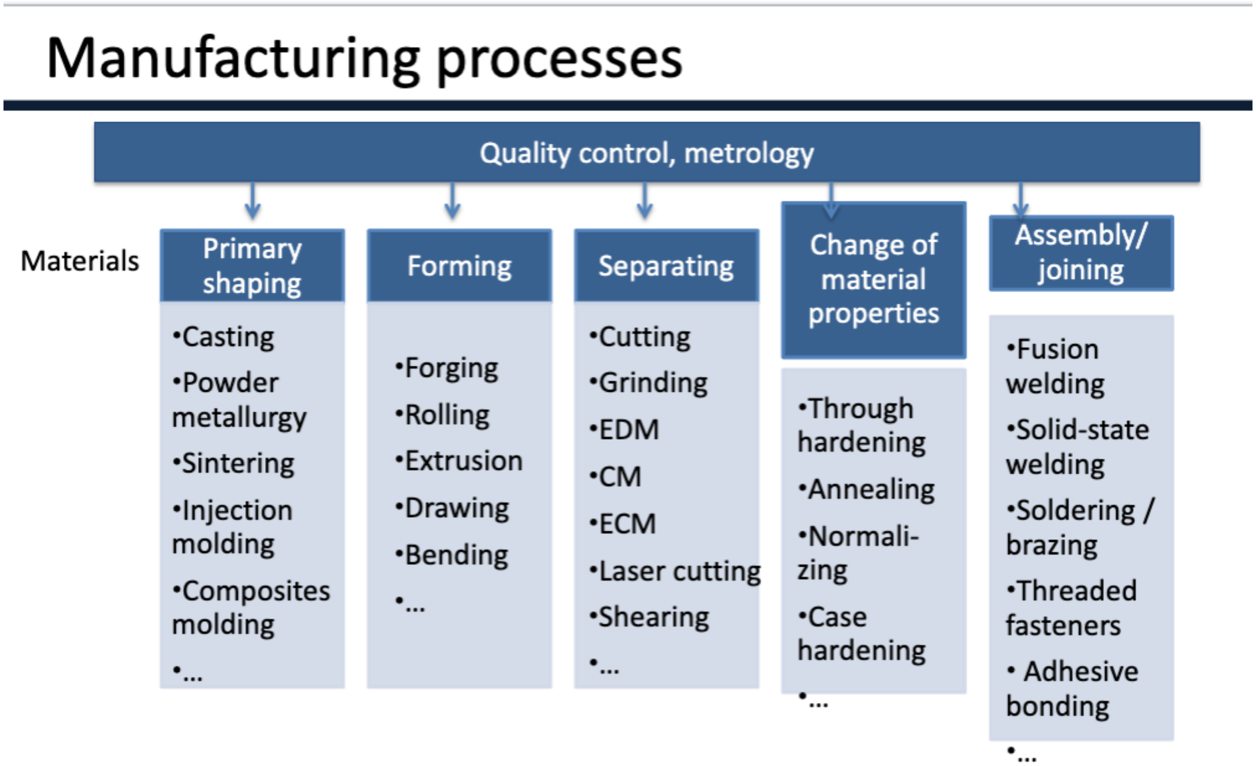
Typical cost breakdown in manufacturing

Cost calculations



- Manufacturing time
  - Non-productive time
    - Setting up machines
    - Changing tools
    - Time when tool is moving between work paths
  - Productive time
    - Workpiece is touching tool
- Production & Process Planning
  - Production planning
    - Which product is made?
  - Process Planning
    - How many products are made?
    - Which processes are used?
    - What are the parameters, machines, and tools for each process?
- Things to consider in process planning
  - Part design
  - Quantity
  - Available processes + machines
  - Sequencing
  - Reference surfaces
  - Minimize setups

    - Safety
    - Cost
- Overall Summary of all Manufacturing Processes



- Facility layout depends on
    - Material flow
    - Product flow
    - Buffers
    - Machine arrangement
- Trends in manufacturing management
    - Lean manufacturing -> eliminating wastes of time, money, materials, energy,...
    - Continuous improvement
    - Just in time production -> minimize inventory
    - Sustainability factors
        - Economic
        - Environmental
        - Social

Module 9

- Not on test :)