# EME 50 Final Review

**Introduction**

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**Review Questions With Answers**

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**Interim Review Notes**

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</table>
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 :)
• 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
Defects in the crystallographic texture of metals

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

- The foreign atoms induce stress to the crystal lattice. This stress effects crystal strengthening of the material.
- Best formability present in pure metals
- 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**
### Efficiency of bulk forming operations

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<tr>
<th>Cold forming</th>
<th>Warm forming</th>
<th>Hot forming</th>
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<tr>
<td>At room temperature</td>
<td>Temperatures between room and recrystallization temp.</td>
<td>Temperatures higher than recrystallization temp.</td>
</tr>
<tr>
<td>+ Good accuracy and surface finish</td>
<td>+ Lower forces, higher possible deformations</td>
<td>+ Lower forces, higher possible deformations</td>
</tr>
<tr>
<td>+ Strain hardening increases part strength</td>
<td>+ Isotropic properties</td>
<td>- Lower accuracy and surface finish</td>
</tr>
<tr>
<td>- High forces</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

![Diagram showing the efficiency of bulk forming operations]

- **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

Source: F. Klocke, WZL, RWTH Aachen University
- 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

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**Thermochemical hardening principles**

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

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

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

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

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### Additive Manufacturing

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

Source: S. Kajaljeevan, S. Schmid, Manufacturing Engineering and Technology, 2018
Module 7 (Assembly and Joining)

- Joint examples

**Example joints:**

- Butt joint
- Lap joint
- Tee joint
- Corner joint
- Edge joint

---

**Welding**

- **Types**
  - **Fusion welding** - molten material
    - **Arc**
      - Needs shielding environment + filler
    - **Oxyfuel**
      - Fuel gas + oxygen $\Rightarrow$ flame
      - Need torch + separate filler rod
    - **Beam**

---

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

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

• **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

<table>
<thead>
<tr>
<th>Process</th>
<th>Abbr.</th>
<th>Process rate</th>
<th>Comments</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical machining</td>
<td>CM</td>
<td>0.0025 – 0.1 mm/min</td>
<td>Small batch size, flat or curved surfaces, no effect on surface layer</td>
</tr>
<tr>
<td>Electrochemical machining</td>
<td>ECM</td>
<td>2.5 – 12 mm/min</td>
<td>Medium to large batch size, complex shapes, expensive tooling, no effect on surface layer; restricted to metals</td>
</tr>
<tr>
<td>Electro-discharge machining</td>
<td>EDM</td>
<td>300 mm³/min (in mm³/min for Wire EDM)</td>
<td>Complex parts, expensive tooling, heat can induce surface damage; restricted to metals and electrically conductive materials</td>
</tr>
<tr>
<td>Laser beam machining</td>
<td>LBM</td>
<td>0.5 – 7.5 m/min</td>
<td>Cutting and hole making, expensive equipment, surface damage</td>
</tr>
<tr>
<td>Electron beam machining</td>
<td>EBM</td>
<td>1 – 2 mm³/min</td>
<td>Cutting and hole making, very small holes and slots, expensive equipment, requires vacuum</td>
</tr>
<tr>
<td>Water-jet machining</td>
<td>WJM</td>
<td>Varies</td>
<td>Nonmetallic materials, also flexible materials, no thermal damage, noisy</td>
</tr>
<tr>
<td>Abrasive water-jet machining</td>
<td>AWJM</td>
<td>Up to 7.5 m/min</td>
<td>Metallic and nonmetallic materials, also in layers</td>
</tr>
</tbody>
</table>

• Product development
Product development

- Design = creative and systematic prescription of part shape and functions under constraints
- From design to the product:

Traditional product development cycle

- Market → Design → Process planning → Production and assembly → Sales
- Time to market

Concurrent engineering (simultaneous engineering) = integration of design, production planning and more

- Market → Design → Process planning → Production and assembly → Sales
- Time to market

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

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

**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 :)