Manufacturing Processes - Overview

Part 1: mechanisms of geometry formation
Part 2: performance (rate, quality, cost, energy)

Many of these processes can be found in your text and online.
Mechanisms of Geometry Formation

1. Subtractive
2. Additive
3. “Net shape”
4. Continuous
Examples of Subtractive processes from the parts we saw...
Examples of Additive parts
Examples of “Net Shaped” parts we saw last time...
Examples of Continuous “Net Shaped” parts
1. Subtractive Processes

- **Blanking** - shearing, punching...
- **Machining** - turning, milling, boring, reaming…
- **Grinding** - surface, cylindrical, honing,
- **Erosion** - water jet, abrasive water jet, slurries..
- **Melting/Vaporization** - EDM, laser cutting…
- **Dissolution** - plasmas, ECM, solvents…
1. Removal Mechanisms

- Blanking
- Machining
- Grinding
- Erosion
- Melting/Vaporization
- Dissolution

Mechanical processes

“Advanced Machining”

Semi-conductor

course

fine
1. General Observations*

- Blanking
- Machining
- Grinding
- Erosion
- Melting/Vaporization
- Dissolution

* There are exceptions, e.g. plasma cutting, while melting is both fast and coarse.
Blanking and Punching

* Source: http://bdi-inc.qc.ca/processes/stamping/sp.html
Machining

• Conventional Machining processes:
  – To first approx mat’l properties are independent of process
  – Very flexible
  – Good dimensional control (possible)
  – Good surface finish (possible)
Milling-rotating cutter
Turning-rotating part
grinding

Surface grinding

Cylindrical grinding
Variations

• Single point
• Multiple cutting teeth
• Form tools
• Multiple heads
• Fixturing
• Work handling
• Chip removal
Removal by erosion
Water-jet in Bldg 35 Shop
Waterjet Machining

**Waterjet Machining**

Water preparation system

Pressure generation system

Cutting head and motion system


[http://www.youtube.com/watch?v=_FIsrYzyvlg](http://www.youtube.com/watch?v=_FIsrYzyvlg)
Mohs Hardness scale

<table>
<thead>
<tr>
<th>Mohs hardness</th>
<th>Mineral</th>
<th>Chemical formula</th>
<th>Absolute hardness</th>
<th>Image</th>
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<tr>
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<td>Talc</td>
<td>Mg₃Si₄O₁₀(OH)₂</td>
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<tr>
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<td>Apatite</td>
<td>Ca₅(PO₄)₃(OH,Cl,F)²⁻</td>
<td>48</td>
<td><img src="image5.png" alt="Image" /></td>
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<tr>
<td>6</td>
<td>Orthoclase Feldspar</td>
<td>KAlSi₃O₈</td>
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<td><img src="image6.png" alt="Image" /></td>
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<td><img src="image7.png" alt="Image" /></td>
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<td>8</td>
<td>Topaz</td>
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<td>Corundum</td>
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<td>10</td>
<td>Diamond</td>
<td>C</td>
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</tr>
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- **Garnet Ring with Diamond... $29.99**
- **Cushion Garnet Ring with Diamond Halo in 14k White Gold $1100.00 - Blue Nile**
- **Cushion-Cut Sapphire and Diamond Halo Ring in 18k White Gold $14,000**

- **Garnet**
- **Sapphire**
Gore Mt, New York
Waterjet Cleaning Up
EDM (Electrical Discharge Machining)

Initial shapes of electrode and workpiece

Final complementary shapes of electrode and workpiece

* Source: http://cybercut.berkeley.edu/mas2/html/processes/edm/index.html
Agitator for top loading washer
FIGURE 27.12  Schematic illustration of the wire EDM process. As many as 50 hours of machining can be performed with one reel of wire, which is then discarded.
Plasma arc cutting
Lithography (additive + subtractive)

Exposing radiation

Illuminated areas

Mask

Thin film

Photoresist

Substrate

EXPOSURE

Positive resist

Negative resist

DEVELOPING

ETCHING AND STRIPPING
2. Additive Processes

Coarse

Assembly - manual, automated, robotic..
Joining - mechanical, adhesives, welding, brazing..
Composites layup- hand lay-up, tape lay-up, filament winding..
Additive manufacturing- 3D printing, stereo lithography…

Fine

Surface & Thin Film Processes-
liquids - coatings, painting, printing, plating…
gases/vapor/atomic scale- CVD, PVD, sputtering
Mechanical joints
Welding

[Sequence in the resistance spot welding process]

[Schematic illustration of the shielded metal-arc welding operation]

* Source: Kalpakjian, “Manufacturing Engineering and Technology”
Brazing

Furnace brazing

http://www.youtube.com/watch?v=3UBd1HIXegM
Lay-Up of Advanced Composites
Automated tape layup

Fig 1.0  Tape Layer Configuration and Axis of Movement

Fig 3.0  Simulation of FTLM Lay up and Scrap Rates

Ref Grimshaw, Grant, Luna Diaz
More complex shapes
Lay up

Forming

Sam Truslow, MIT,

Aviation Week: Skunk Works' Cargo X-Plane Complete
Posted by Graham Warwick at 3/6/2009 12:14 PM CST

Wu, Tatting, Smith And Thornburg

Figure 2. Fiber placement machine.
Filament Winding

[Diagram of filament winding machine with label: Filament Winding]

[Diagram of filament winding process with labels: Rotating Mandrel, Resin Bath, Continuous Strand Roving]
braiding

Braiding Videos

http://www.youtube.com/watch?v=zOhj7X1-x10
http://www.youtube.com/watch?v=j19na8LMBnE&NR=1
• Hand lay-up
• Spray-up
• Vacuum molding

Vacuum mold video
Jump to 4 min

http://www.youtube.com/watch?v=YZAkf1E2Jcs
Growing Wind Turbine Size
Additive Manufacturing
Stereolithography (SLA)

* Source: http://cybercut.berkeley.edu/mas2/html/processes/stereolith/more.html
Selective Laser Melting (SLM) for metals

* Source: Michelle Griffith and John S. Lamancusa, "Rapid Prototyping Technologies," Rapid Prototyping. 1998
Selective Laser Sintering (SLS) for plastics

http://web.mit.edu/2.810/www/lecture/sinter_movie.mov

http://www.youtube.com/watch?v=SVkUwqzjGJY

http://www.youtube.com/watch?v=gLxve3ZOmvc

* Source: DTM Corporation (3D Systems)
Plastic extrusion used in rapid prototyping
“3D Printing” binder jetting

Selective joining of powder using ink-jet printing of a binder material

Direct Printing of Metal Tooling;
ExtrudeHone Corp., Irwin, PA

- Directly print metal parts and tooling.
  - Polymer binder into
Forging Die made by 3D printing
CVD (Chemical Vapor Deposition)

- Creates solid materials directly from chemical reactions in gas and/or liquid compositions or with the substrate material
- LP(Low Pressure) CVD, PE(Plasma Enhanced) CVD

* Source: http://www.memsnet.org/mems/beginner/deposition.html
Deposition of SiO₂ from Silane gas by PECVD

SiH₄ + O₂ → SiO₂ + 2H₂

Siemens CVD Process for the Purification of Si

2 HSiCl₃ → Si + 2 HCl + SiCl₄
PVD (Physical Vapor Deposition)

- Material to be deposited is released from a source and transferred to the substrate
- Evaporation, Sputtering

*e-beam evaporation system*

*e-beam evaporation system*

*Source: http://www.memsnet.org/mems/beginner/deposition.html*
Thin film PV cell - CIGS

Ascent CIGS Solar Cell
3. Net Shape: Molding

• Characteristics
  – Hard tooling
  – Solid forming – very fast cycle time
  – Thermal processes – slower and depend upon cooling rate and/or chemical kinetics
  – Dimensional control is not as good as machining
Sheet Metal Stamping

**Typical Stamping Die**

**GM stamping plant go to Around 2:39**

http://www.youtube.com/watch?v=ixPhogfZTHU&feature=related

Forging

** Open Die Forging

- No friction
- Friction force
- Barreling

*** Closed Die Forging

Compression Molding

- Similar to metal forging process
- Most common method of processing thermosets

* Source: [http://www.mahidol.ac.th/mahidol/eg/em_proj/group7/htm1text.htm](http://www.mahidol.ac.th/mahidol/eg/em_proj/group7/htm1text.htm)
Metal Casting


**Sand Casting Mold**

**Die Casting machine**
Metal Casting

* Source: Kalpakjian, “Manufacturing Engineering and Technology”; ** [http://cybercut.berkeley.edu/mas2/html/processes/castshell/more.html](http://cybercut.berkeley.edu/mas2/html/processes/castshell/more.html)
Investment Casting of Turbine Blades
P/M: Powder Compaction

[Diagram of powder compaction process]

* Source: http://www.turkishpm.org/en_tozmetal.htm

http://www.youtube.com/watch?v=1Mjsi2F2MrY&feature=channel
Sintering

- Green compact
- Necks formed
- Pore size reduced
- Fully sintered
FIGURE 17.1 (a) Examples of typical parts made by powder-metallurgy processes. (b) Upper trip lever for a commercial irrigation sprinkler made by PM. This part is made of an unleaded brass alloy; it replaces a die-cast part with a 60% cost savings. (c) Main-bearing metal-powder caps for 3.8- and 3.1-liter General Motors automotive engines. Source: (a) and (b) Reproduced with permission from Success Stories on PM Parts, 1998. Metal Powder Industries Federation, Princeton, New Jersey, 1998. (c) Courtesy of Zenith Sintered Products, Inc., Milwaukee, Wisconsin.
Hot Isostatic Pressing - HIP

http://www.youtube.com/watch?v=BsnzgsEXT_A
Injection Molding

* Source: [http://www.idsa-mp.org/proc/plastic/injection/injection_process.htm](http://www.idsa-mp.org/proc/plastic/injection/injection_process.htm)
Injection Molding

*schematic of thermoplastic injection molding machine*

* Source: [http://www.idsa-mp.org/proc/plastic/injection/injection_process.htm](http://www.idsa-mp.org/proc/plastic/injection/injection_process.htm)
Thermoforming

Blow Molding

Descending parison

Inflating

Inflating and cooling

* Source: W.A.Holmes Walker, “Polymer Conversion”
Resin Transfer Molding (RTM)

* Source: http://howard.engr.siu.edu/staff2/abrate/rtm
BMW i3 RTM door frame
4. Continuous Processes

• Pushing
  – Metals extrusion
  – Plastics extrusion

• Pulling
  – Pultrusion of composites
  – Crystal pulling (Czochralski process)
  – String ribbon process (Ely Sachs)
  – Continuous casting
Pros and Cons

• + Low unit cost for large runs
• + High production rates
• - generally limited to constant cross section
• - dimensional control along the length can be challenging for some applications
Metal Extrusion

Examples of extruded products

Direct extrusion process

Indirect extrusion process

Hydrostatic extrusion process

* Source: [http://www.eaa.net/pages/material/extruded.html](http://www.eaa.net/pages/material/extruded.html)
Aluminum extrusion dies

- Kaiser Aluminum Extrusion
- https://www.youtube.com/watch?v=s99aSFkV2aY
Plastic Extrusion

Plastic extrusion used in rapid prototyping

**FIGURE 20.4** (a) Schematic illustration of the fused-deposition-modeling process. (b) The FDM 900mc, a fused-deposition-modeling machine. *Source: Courtesy of Stratasys, Inc.*
Pultrusion of Composites

http://www.youtube.com/watch?v=4MoHNZB5b_Y

*S* Source: http://users.techline.com/lord/manu.html
Pultrusion machine

* Source: http://howard.engr.siu.edu/staff2/abrate/NSFATE/camps/pult.htm
youtube videos

• Pultrusion
  • https://www.youtube.com/watch?v=4MoHNZB5b_Y
  • https://www.youtube.com/watch?v=bRjU4na-ol8
Czochralski (CZ) Crystal Growth

http://www.youtube.com/watch?v=cYj_vqcyI78

* Source: http://www.techfak.uni-kiel.de/matwis/amat/elmat_en/kap_5/illustr/i5_1_1.html
String Ribbon Process

In ID and wire sawing of Si ingots, the kerf material represents lost material & Energy.

String-Ribbon Invented by Ely Sachs saves this material.
Continuous Casting

Summary

1. Additive & subtractive processes
   - are mostly serial, potential for real time control
   - very flexible in geometry
   - But additive is more flexible, with higher degree of automation.
   - additive also has the potential to mix materials
   - Subtractive usually ensures consistent material properties for the part
Summary

2. Net Shape are essentially molding processes
   - Tooling requires lead time and high volumes
   - Flow can have significant effect on the material properties both improving them e.g. forging, as well as degrading them e.g. brittle behavior of some castings, but mostly causing them to vary
Summary

3. Continuous processes are;
   • Generally limited to 2D
   • Generally have poorer dimensional control in the long direction (e.g. warping, twisting) compared to other options
   • But they are less costly