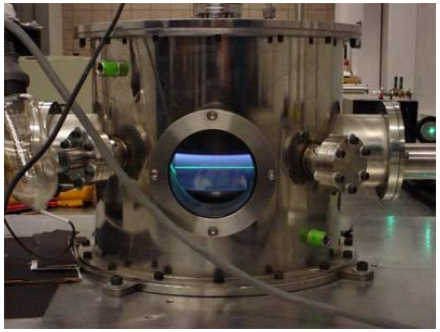
Manufacturing Processes - Overview

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

2.810

T. Gutowski

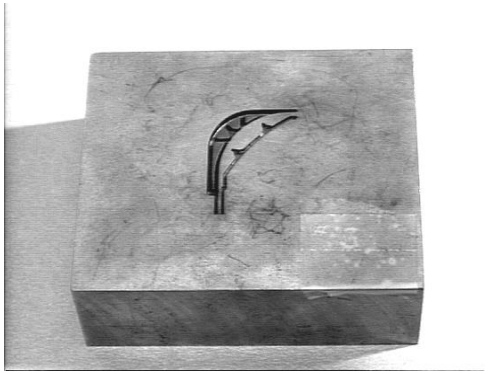
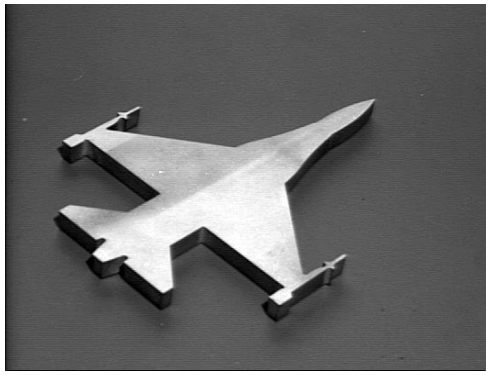


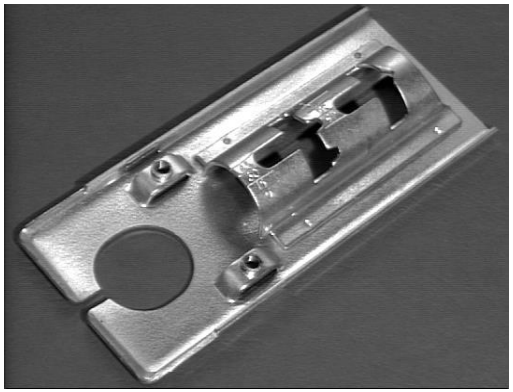
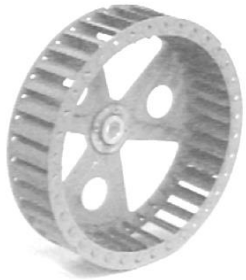
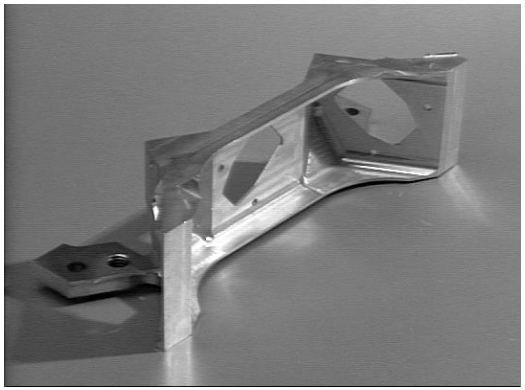
Many of these processes can be found in your text and online

Mechanisms of Geometry Formation

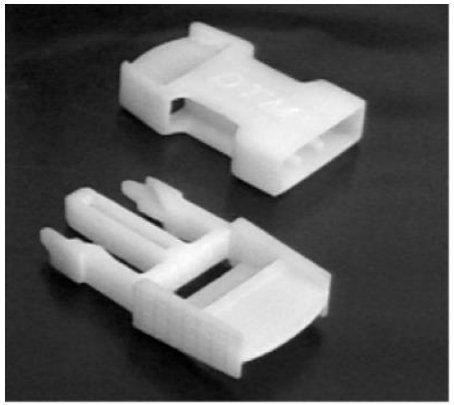
1. Subtractive
2. Additive
3. “Net shape”
4. Continuous

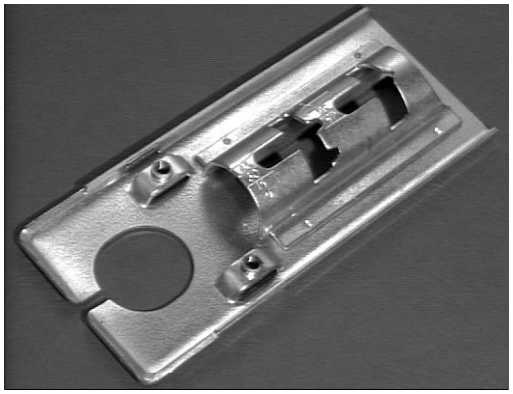
Examples of Subtractive processes from the parts we saw…

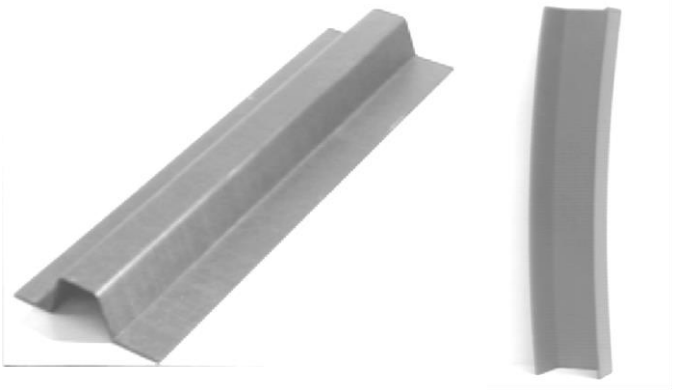



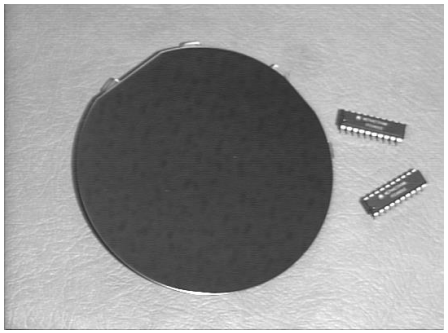




Examples of Additive parts

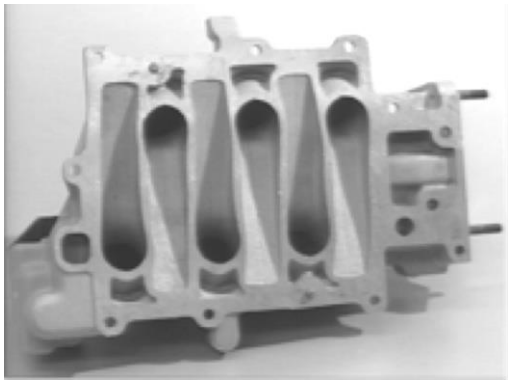


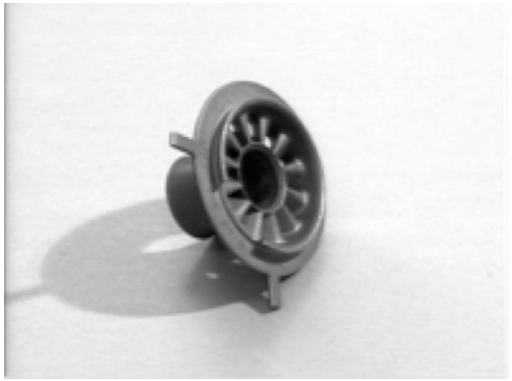


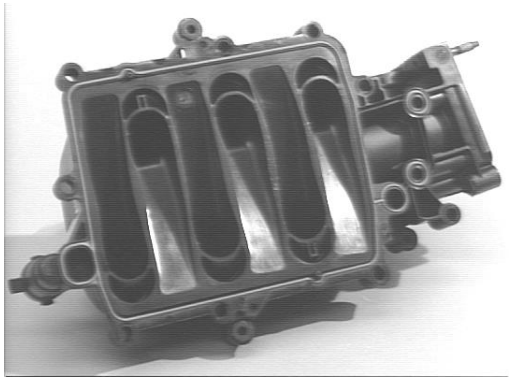




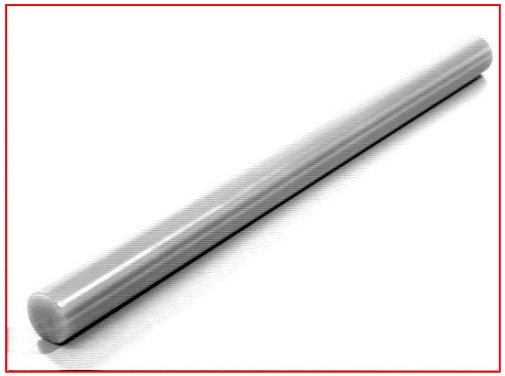
Examples of ”Net Shaped” parts we saw last time…

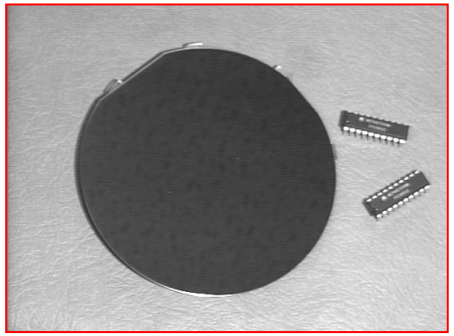






Examples of Continuous ”Net Shaped” parts

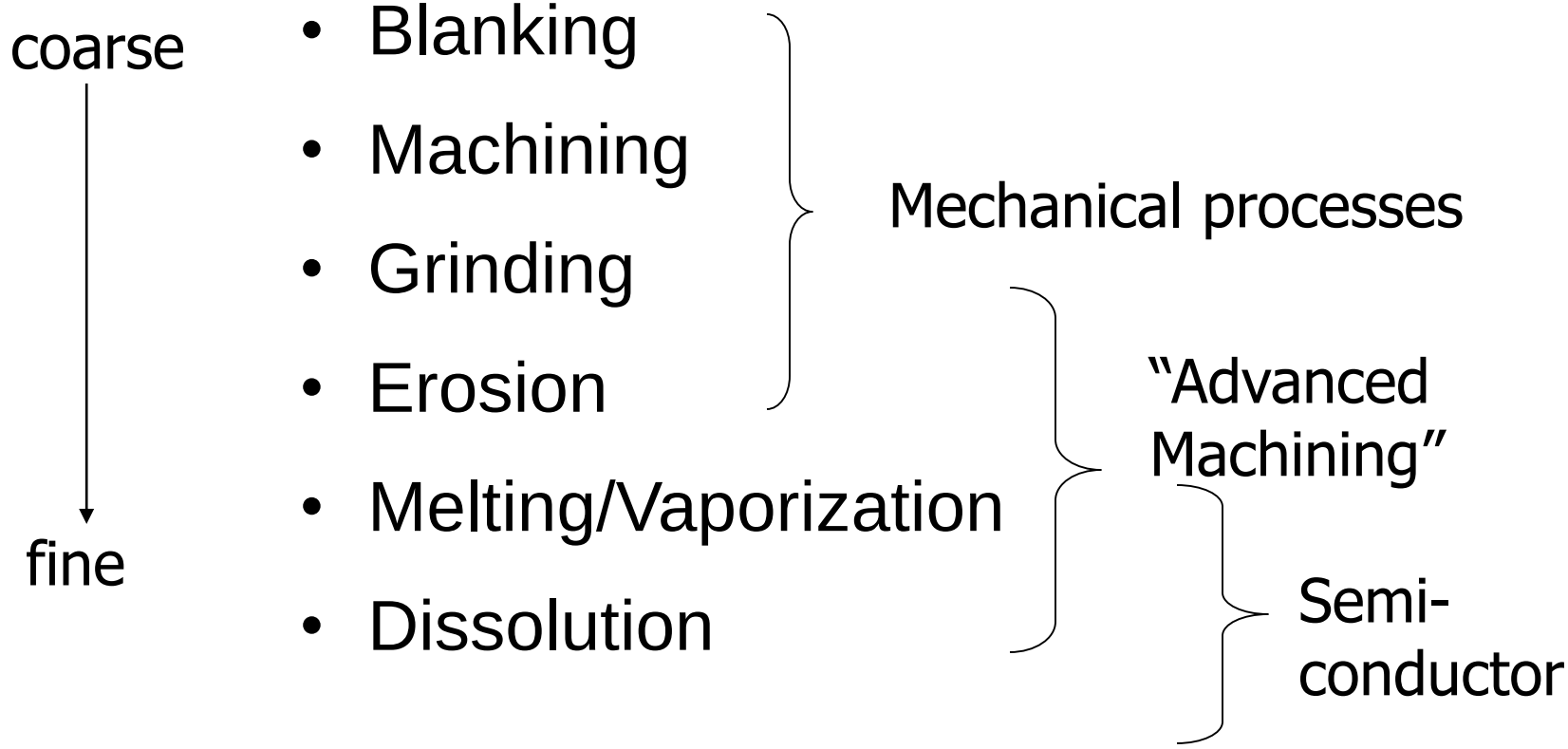




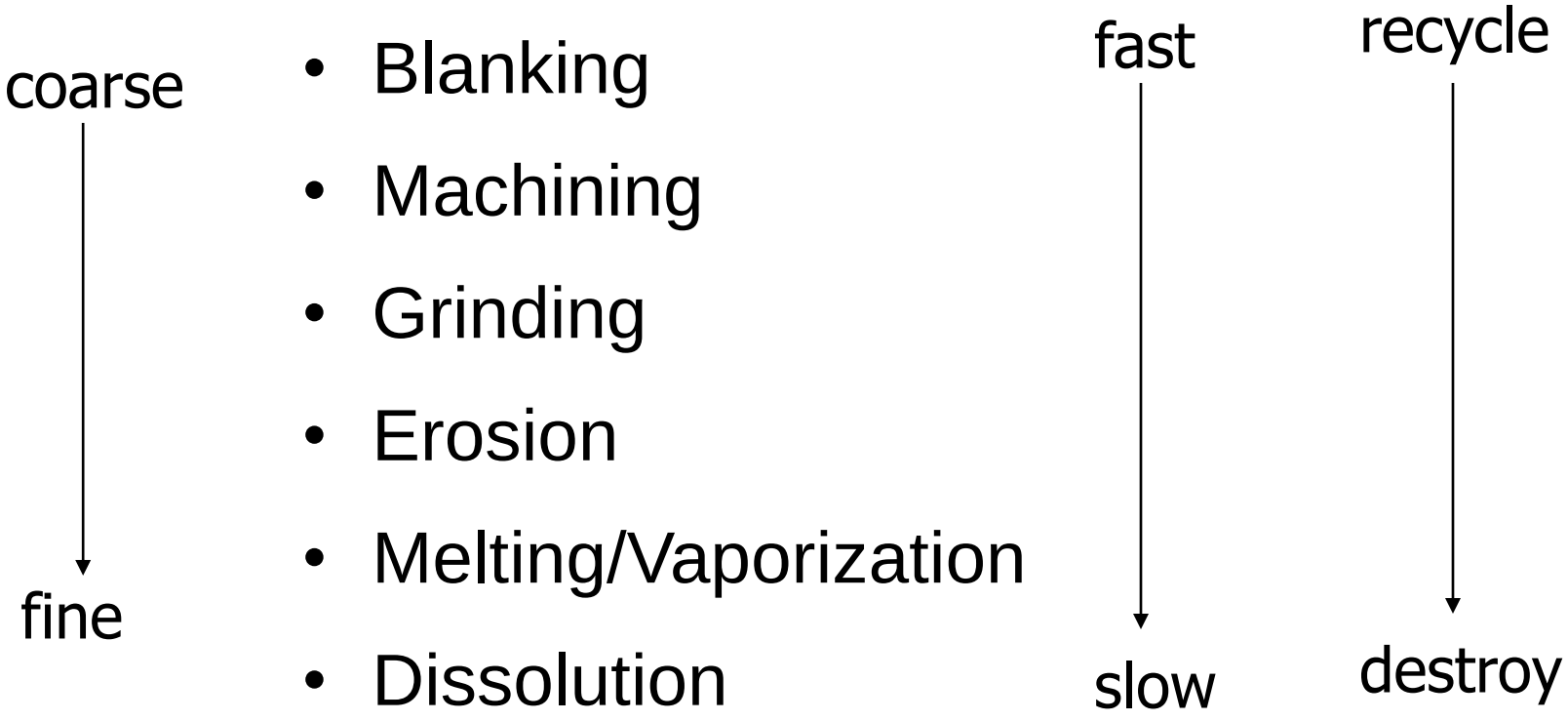
1. Subtractive Processes

- 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



1. General Observations*

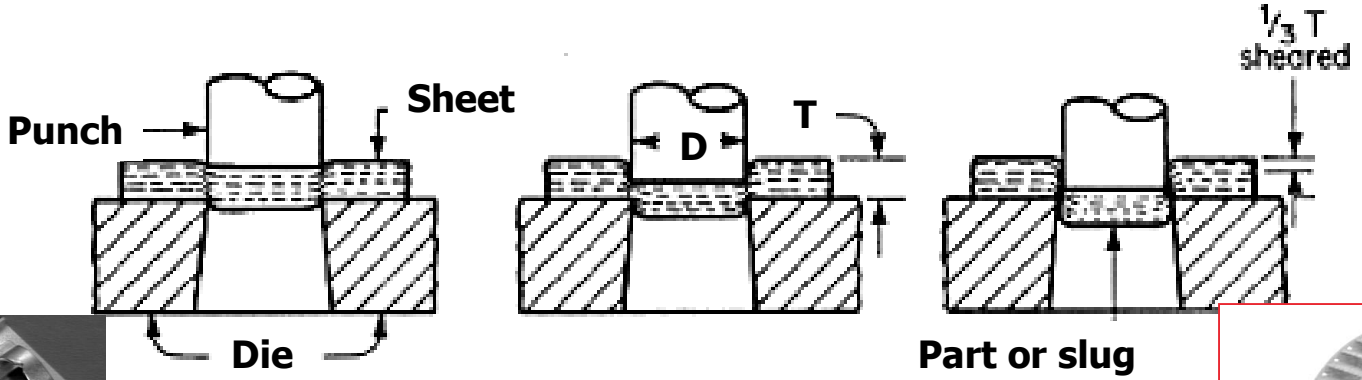


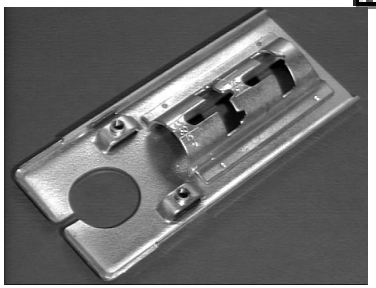
- Blanking
- Machining
- Grinding
- Erosion
- Melting/Vaporization
- Dissolution

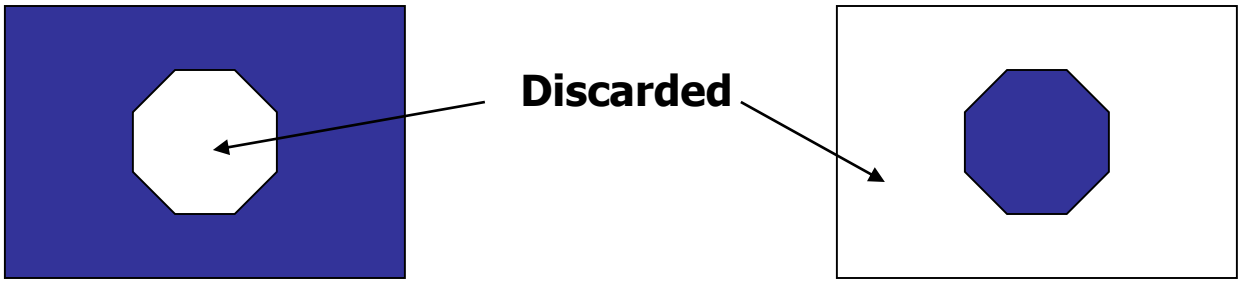
* There are exceptions, e.g. plasma cutting, while melting is both fast and coarse

Blanking and Punching

*

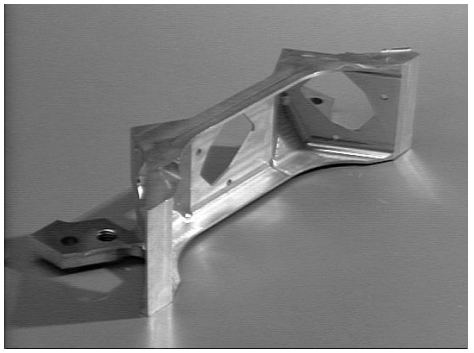






* Source: http://bdi-inc.qc.ca/processes/stamping/sp.html

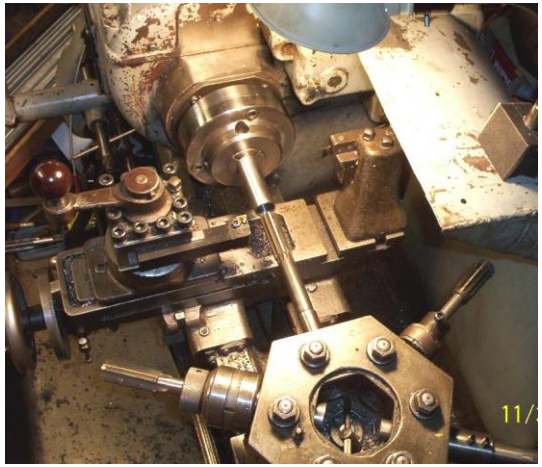
Machining

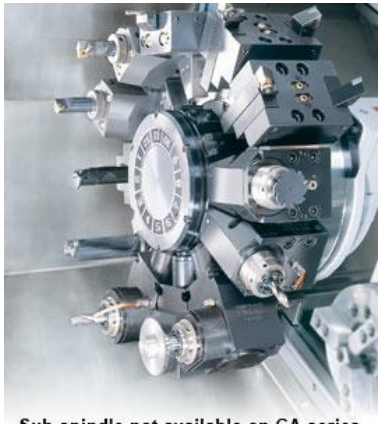


- Conventional Machining processes:
  - To first approx mat'l properties are independent of process
  - Very flexible
  - Good dimensional control (possible)
  - Good surface finish (possible)

Milling-rotating cutter

Turning-rotating part





Sub-spindle not available on GA series

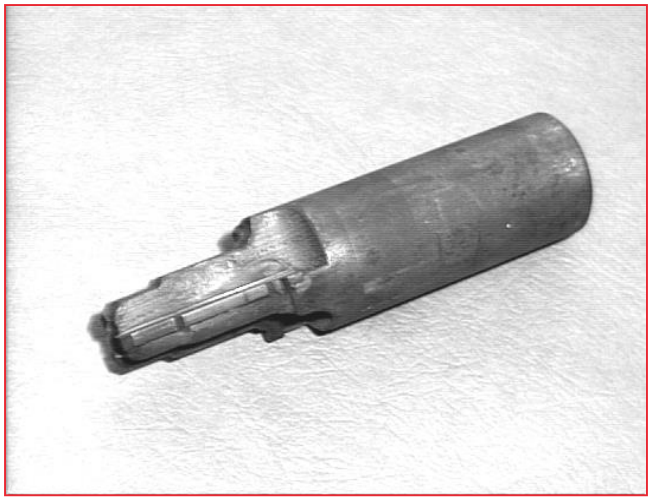
grinding

Surface grinding

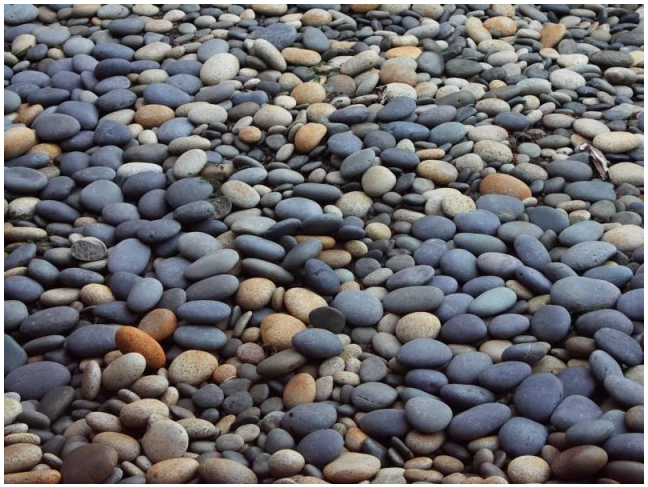
Cylindrical grinding

Variations

- Single point
- Multiple cutting teeth
- Form tools
- Multiple heads
- Fixturing
- Work handling
- Chip removal

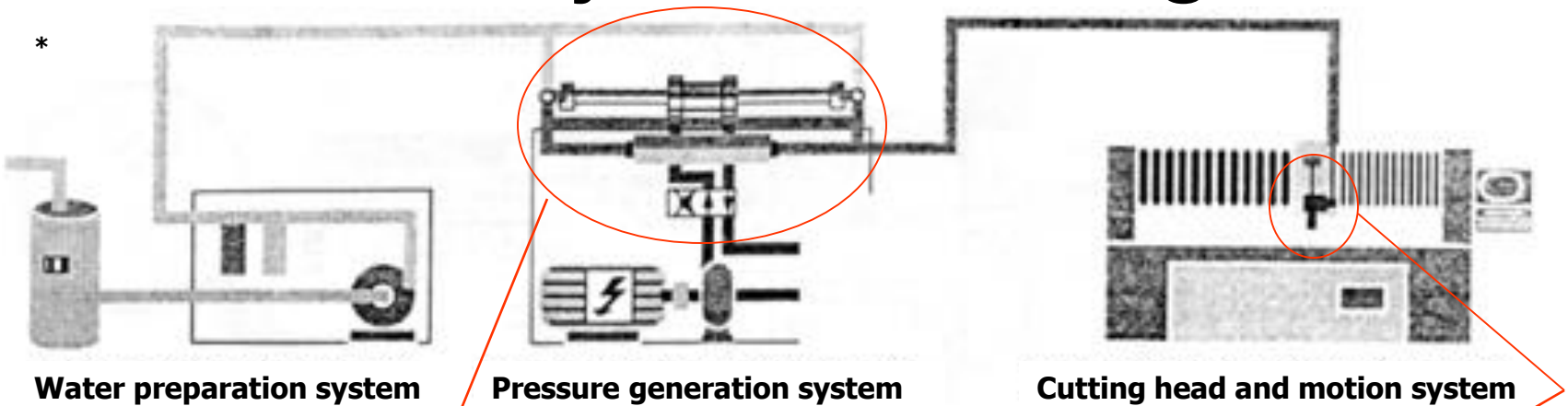


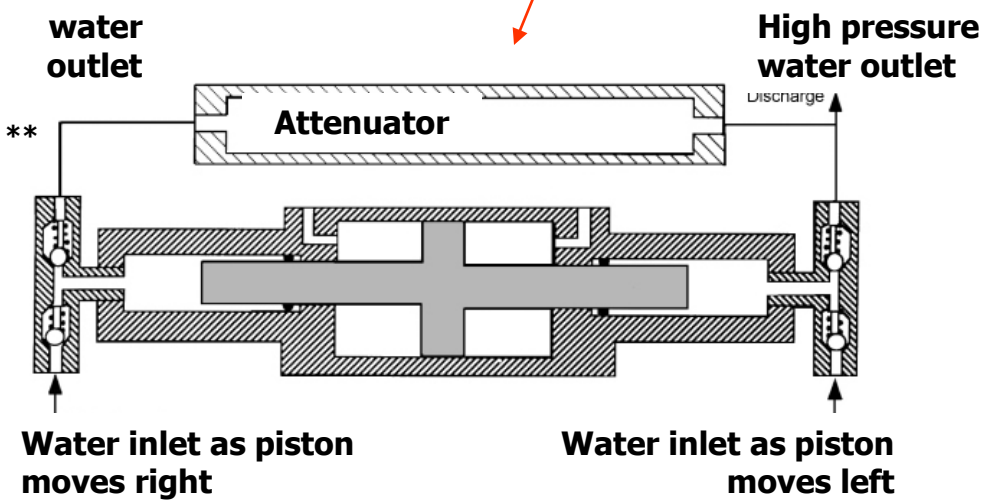
Removal by erosion

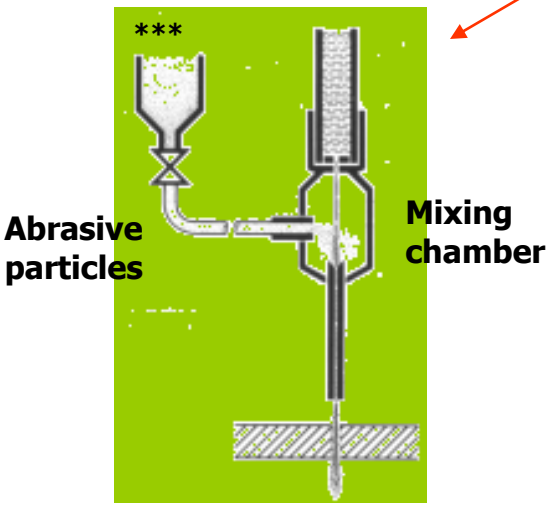


Water-jet in Bldg 35 Shop

Waterjet Machining



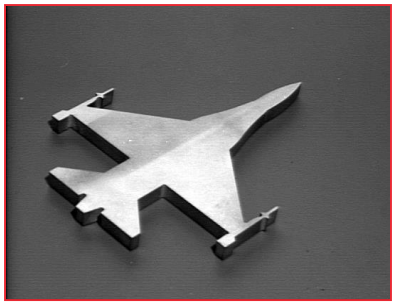




* Source: http://www.seas.smu.edu/rcam/research/waterjet/par1.html; ** http://www.seas.smu.edu/rcam/research/waterjet/par3.html;
*** http://kbm.mt.polsl.gliwice.pl/wjm/basics.html

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

Waterjet Machining



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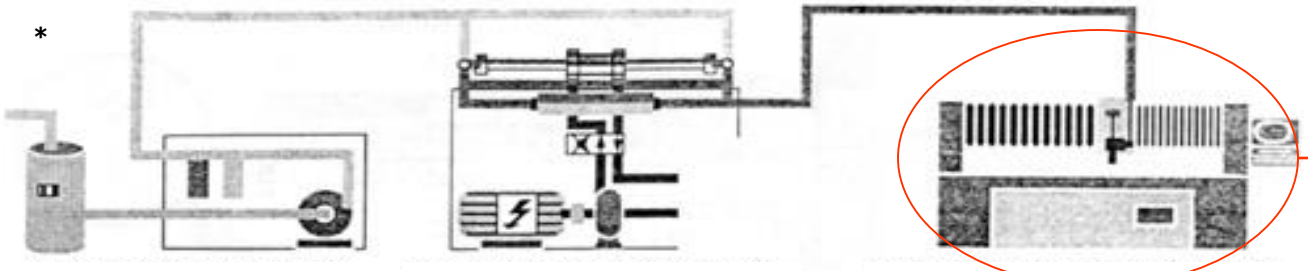
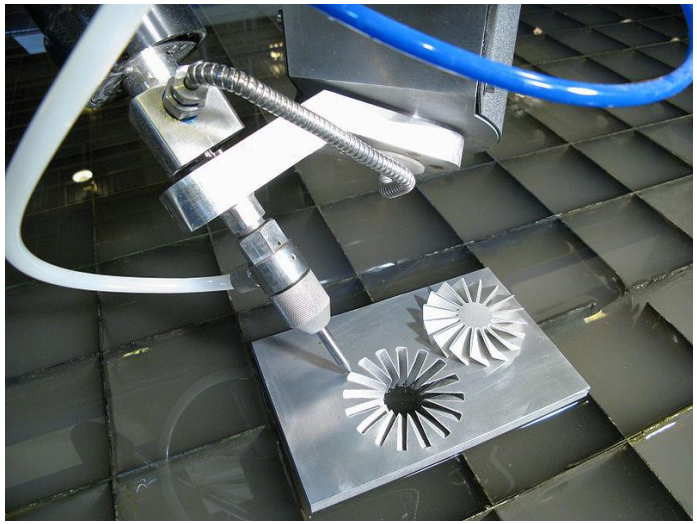


Water preparation system

Pressure generation system

Cutting head and motion system



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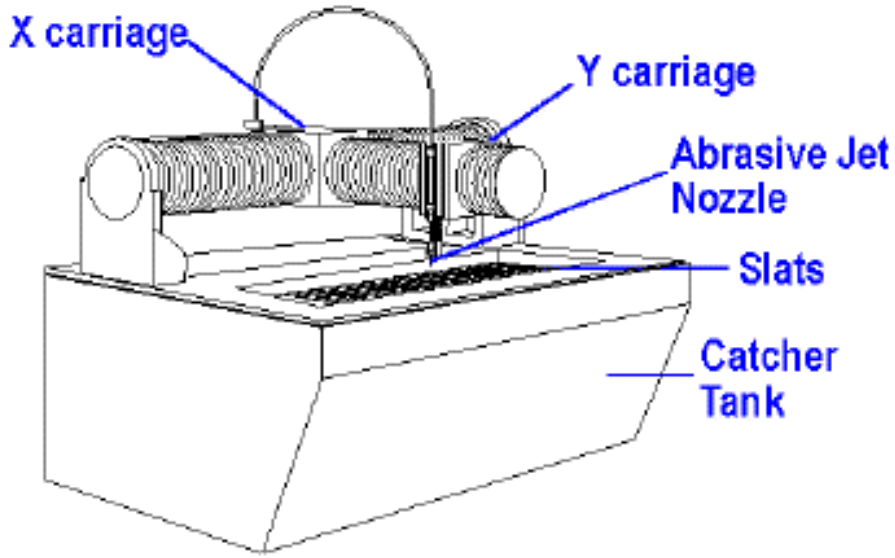
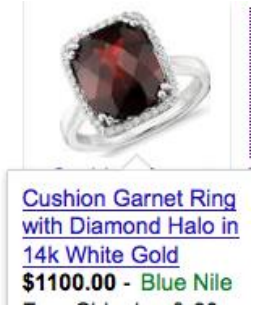


* Source: http://cybercut.berkeley.edu/mas2/html/processes/edm/index.html; ** http://www.omax.com/components_of_waterjet.html

Mohs Hardness scale



garnet

sapphire

Mohs hardness	Mineral	Chemical formula	Absolute hardness	Image
1	Talc	$Mg_3Si_4O_{10}(OH)_2$	1	
2	Gypsum	$CaSO_4 \cdot 2H_2O$	3	
3	Calcite	$CaCO_3$	9	
4	Fluorite	CaF_2	21	
5	Apatite	$Ca_5(PO_4)_3(OH^-,Cl^-,F^-)$	48	
6	Orthoclase Feldspar	$KAlSi_3O_8$	72	
7	Quartz	SiO_2	100	
8	Topaz	$Al_2SiO_4(OH^-,F^-)_2$	200	
9	Corundum	Al_2O_3	400	
10	Diamond	C	1600	

Mohs Hardness scale

Garnet Ring with Diamond...
$29.99

Cushion Garnet Ring with Diamond Halo in 14k White Gold
$1100.00 - Blue Nile

garnet

Cushion-Cut Sapphire and Diamond Halo Ring in 18k White Gold
$14,000

sapphire

Mohs hardness	Mineral	Chemical formula	Absolute hardness	Image
1	Talc	$Mg_3Si_4O_{10}(OH)_2$	1	
2	Gypsum	$CaSO_4 \cdot 2H_2O$	3	
3	Calcite	$CaCO_3$	9	
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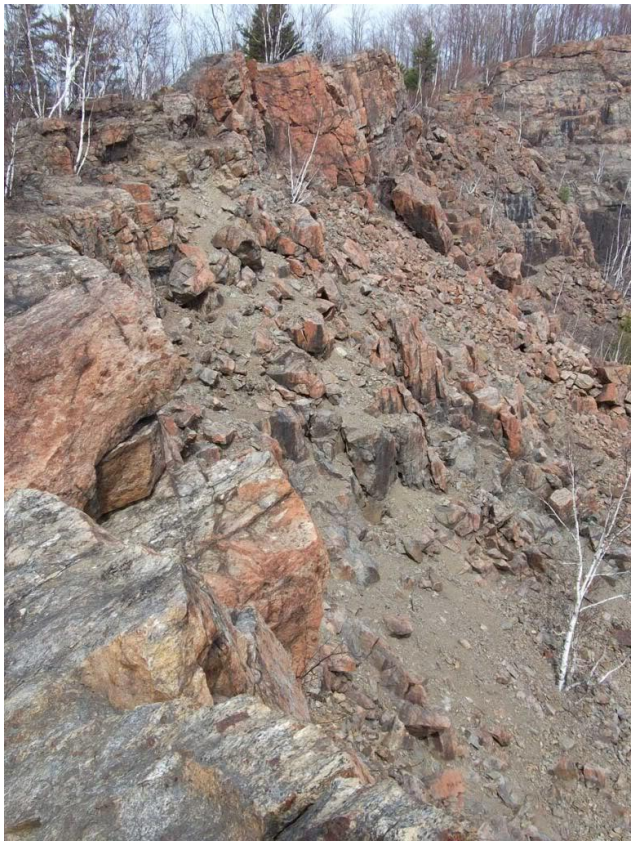
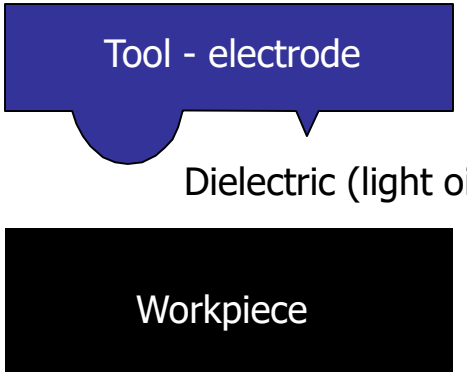
7	Quartz	SiO_2	100	
8	Topaz	$Al_2SiO_4(OH^-,F^-)_2$	200	
9	Corundum	Al_2O_3	400	
10	Diamond	C	1600	

Gore Mt, New York

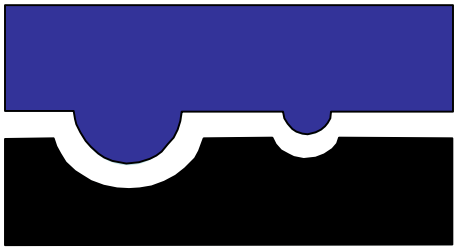


Waterjet Cleaning Up

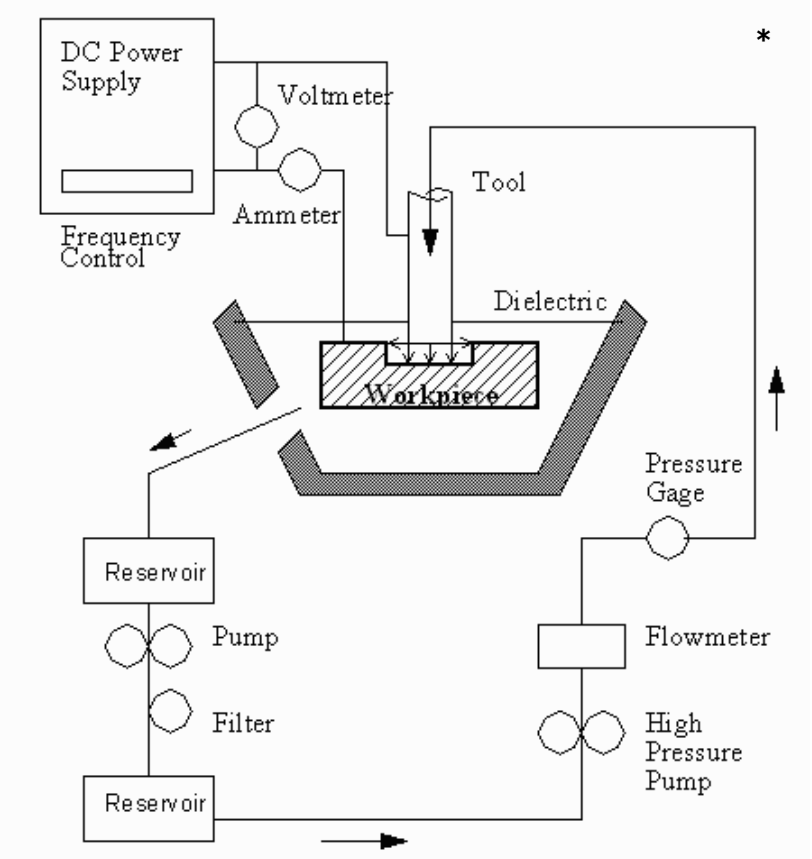
EDM (Electrical Discharge Machining)



Initial shapes of electrode and workpiece



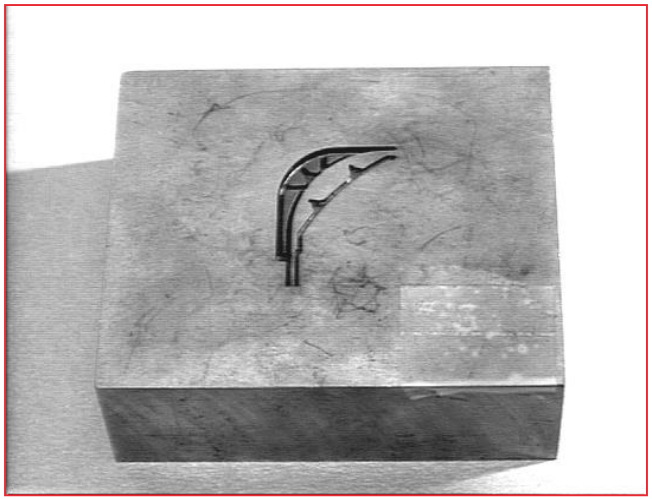
Final complementary shapes of electrode and workpiece

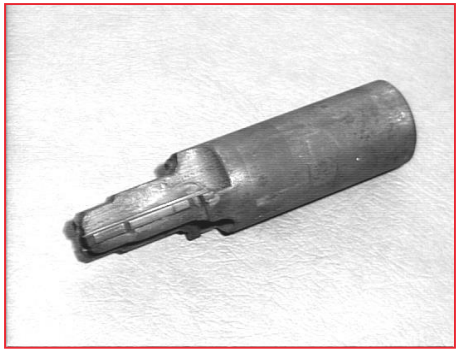


* Source: http://cybercut.berkeley.edu/mas2/html/processes/edm/index.html

Agitator for top loading washer

Mounted Electrode





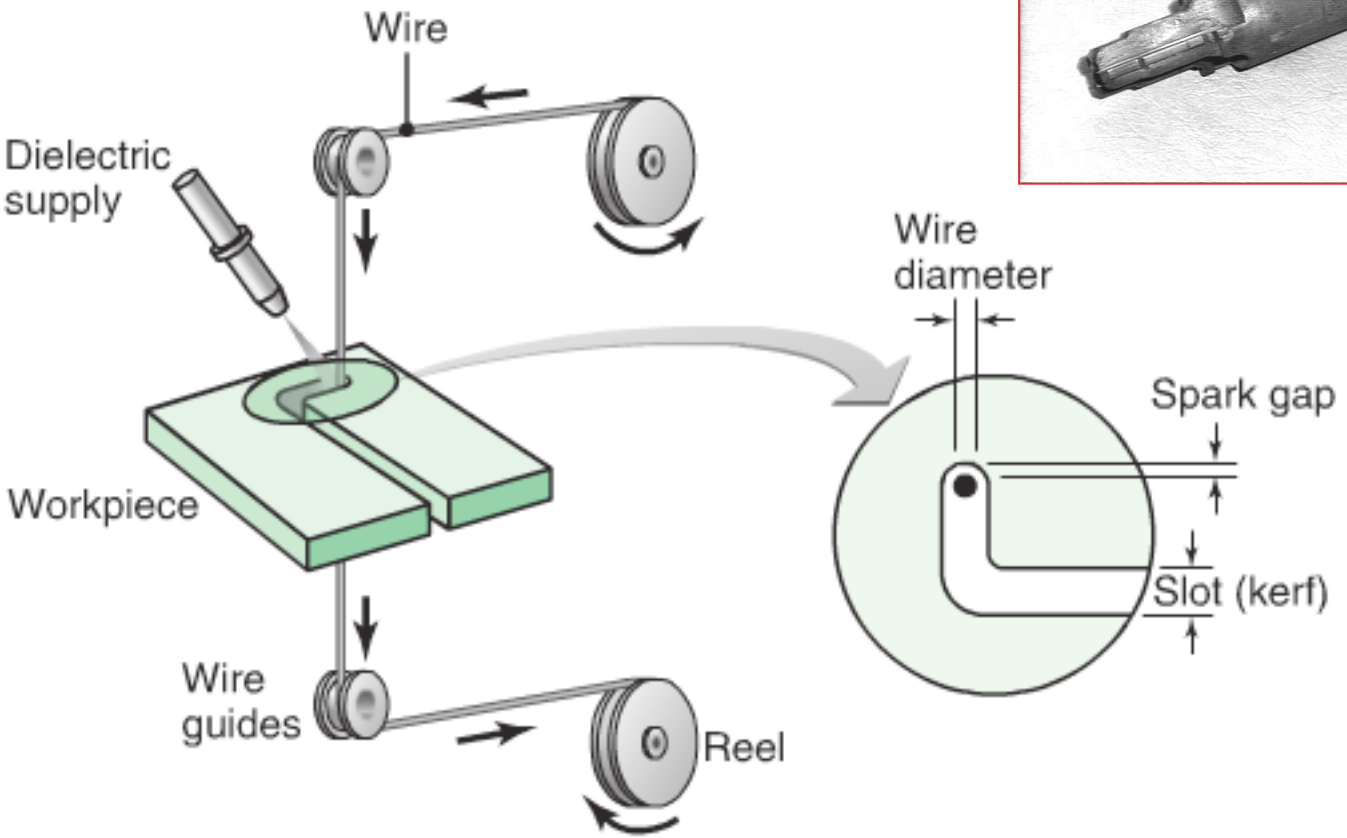
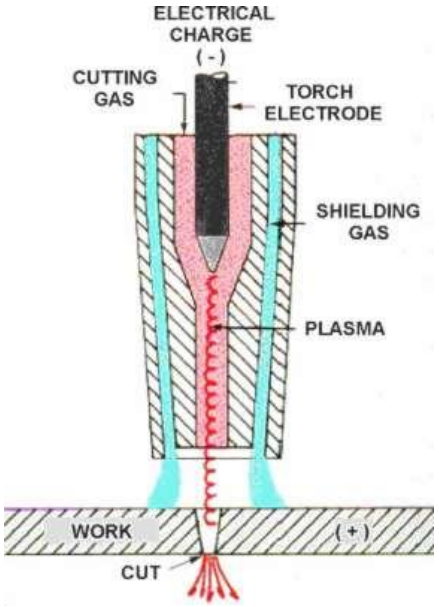
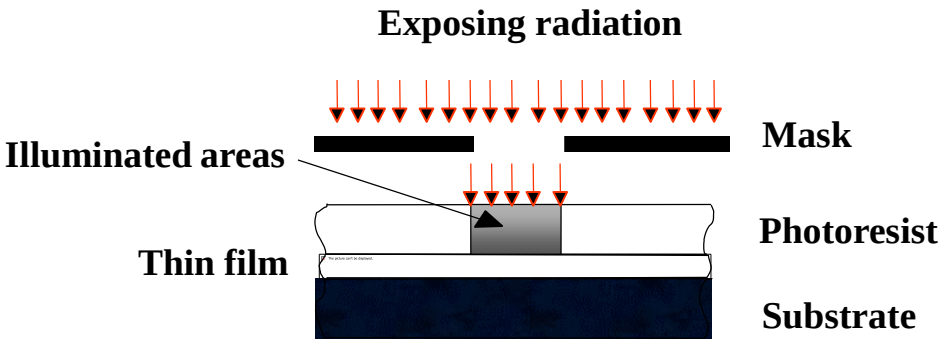


FIGURE 27.12 Schematic illustration of the wire EDM process. As many as 50 hours of machining can be performed with one reel of wire, which is then discarded.

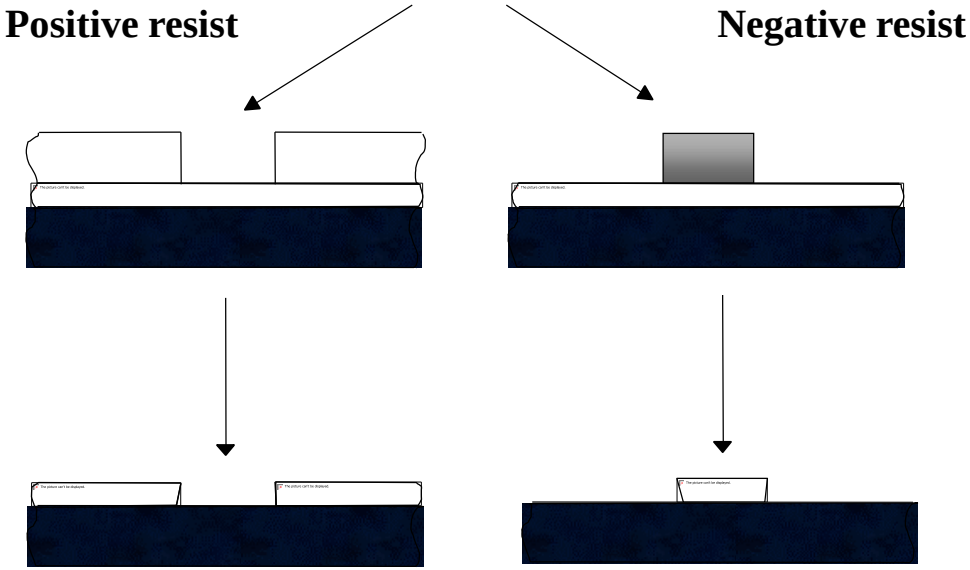
Plasma arc cutting



Lithography (additive + subtractive)



EXPOSURE



DEVELOPING

ETCHING AND STRIPPING

2. Additive Processes

coarse

fine

Assembly - manual, automated, robotic..

Joining - mechanical, adhesives, welding, brazing..

Composites layup- hand lay-up, tape lay-up, filament winding..

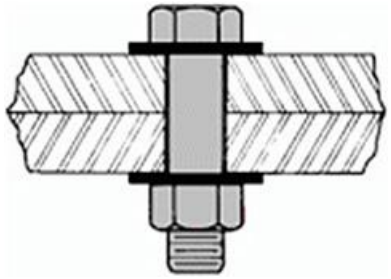
Additive manufacturing- 3D printing, stereo lithography…

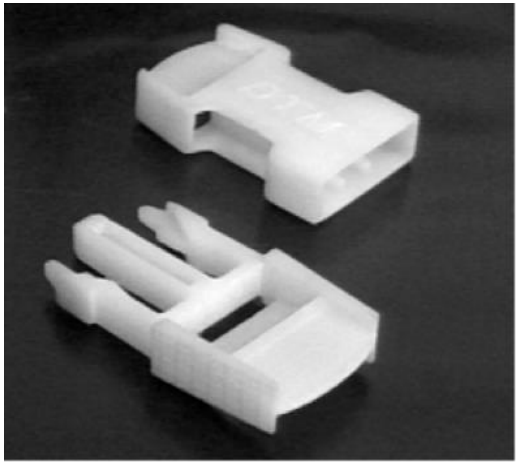
Surface & Thin Film Processes-

liquids - coatings, painting, printing, plating…

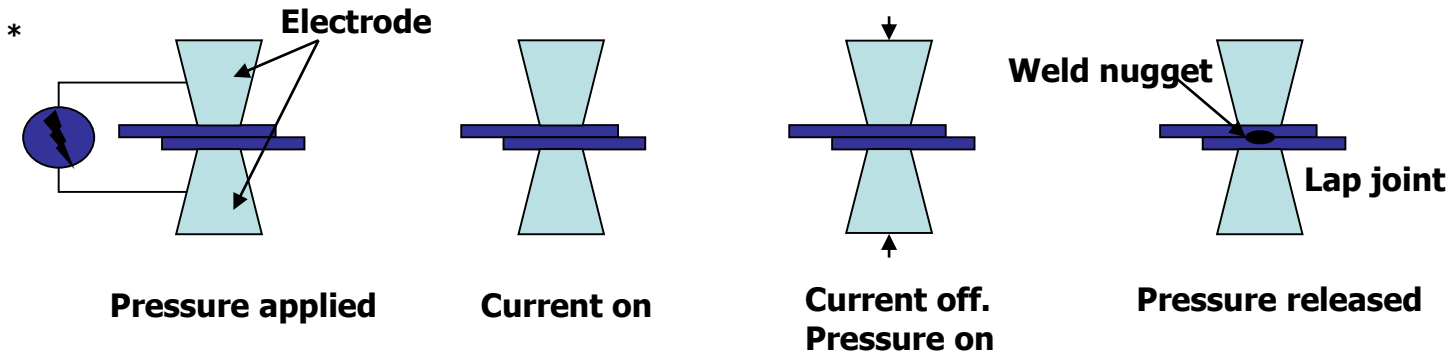
gases/vapor/atomic scale- CVD, PVD, sputtering

Mechanical joints

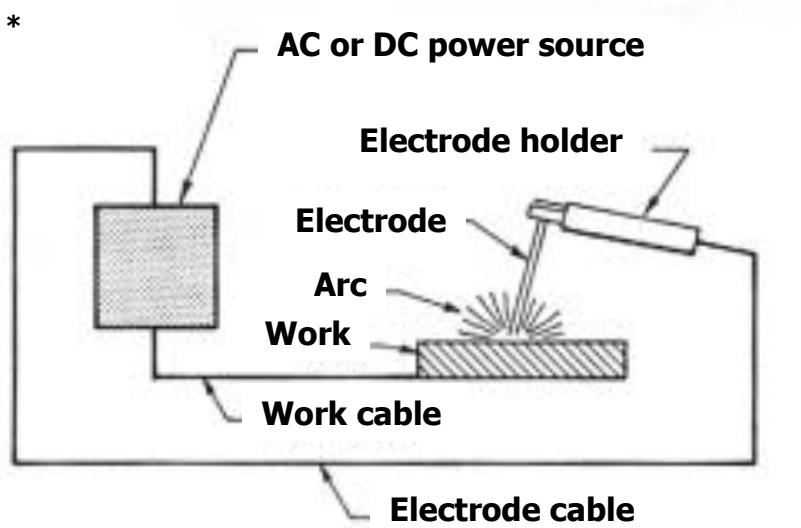




Welding



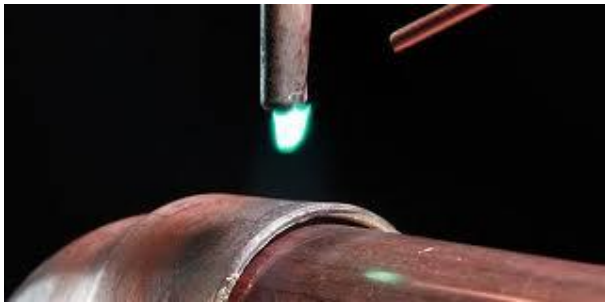
[Sequence in the resistance spot welding process]

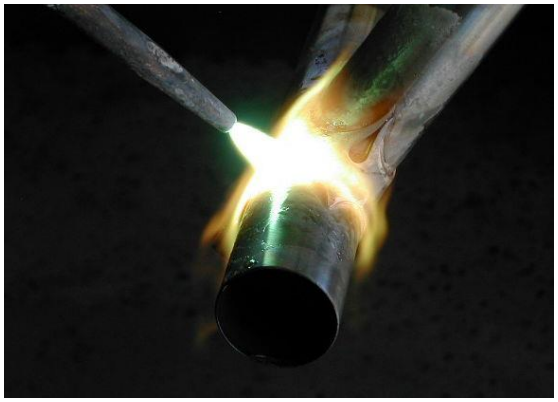


[Schematic illustration of the shielded metal-arc welding operation]

* Source: Kalpakjian, "Manufacturing Engineering and Technology"

Brazing



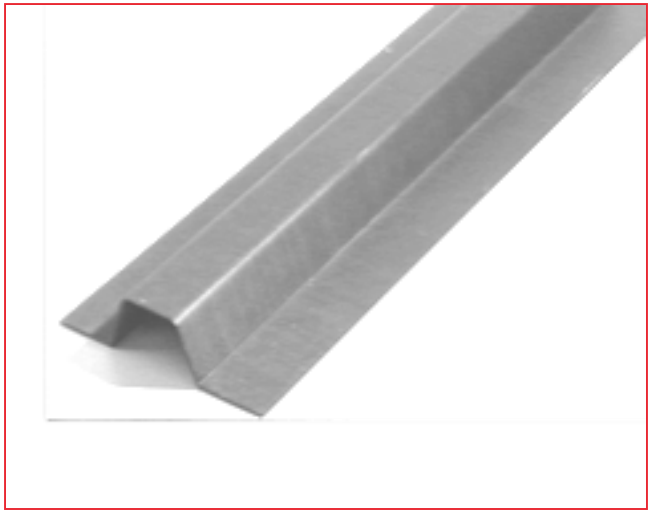


Furnace brazing

http://www.youtube.com/watch?v=3UBd1HIXegM

Lay-Up of Advanced Composites

*



Automated tape layup

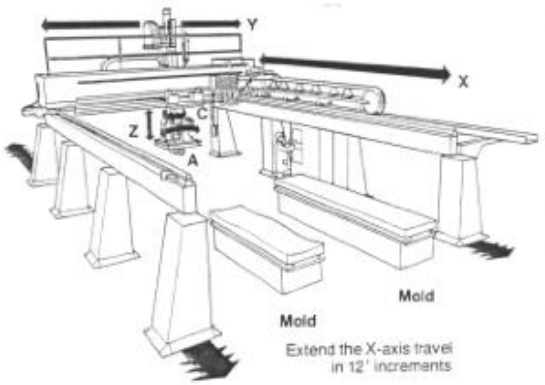
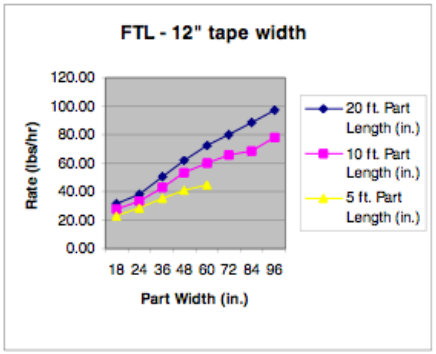


Fig 1.0 Tape Layer Configuration and Axis of Movement



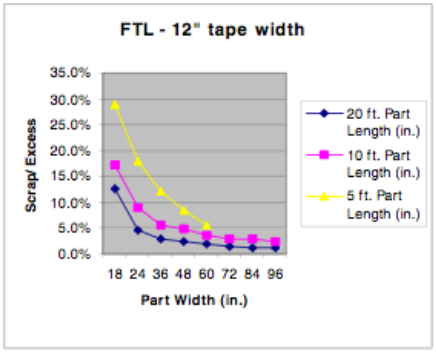


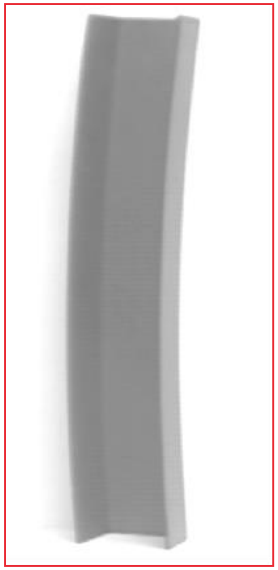
Fig 3.0 Simulation of FTLM Lay up and Scrap Rates

Ref Grimshaw, Grant, Luna Diaz

More complex shapes

Lay up

Forming



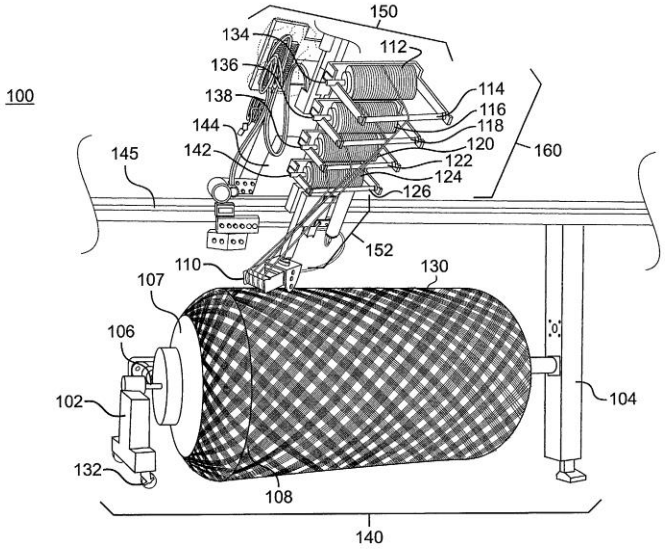
Sam Truslow, MIT,

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

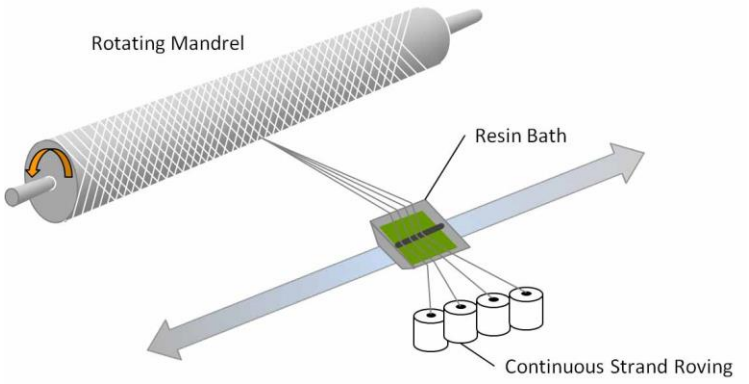
Wu, Tatting, Smith And Thornburg

Figure 2. Fiber placement machine.

Filament Winding



Filament Winding

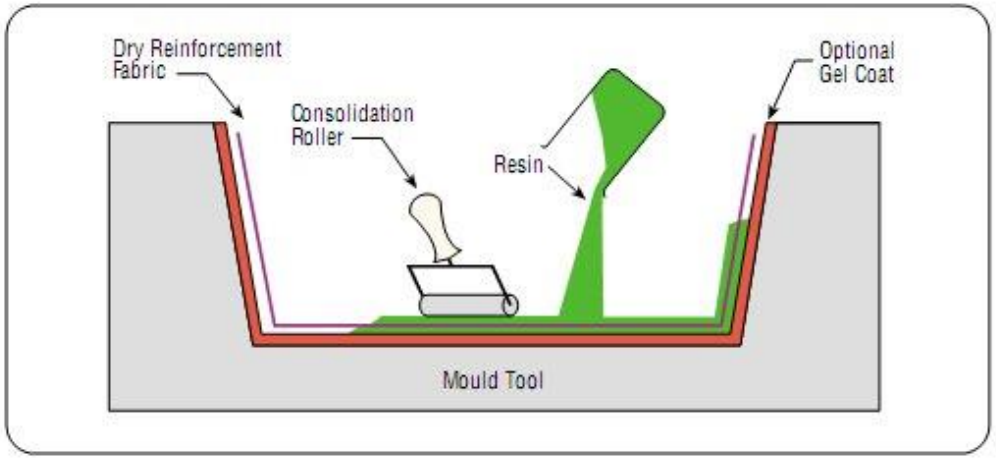


braiding

Braiding Videos

http://www.youtube.com/watch?v=zOhj7X1-x10

http://www.youtube.com/watch?v=j19na8LMBnE&NR=1

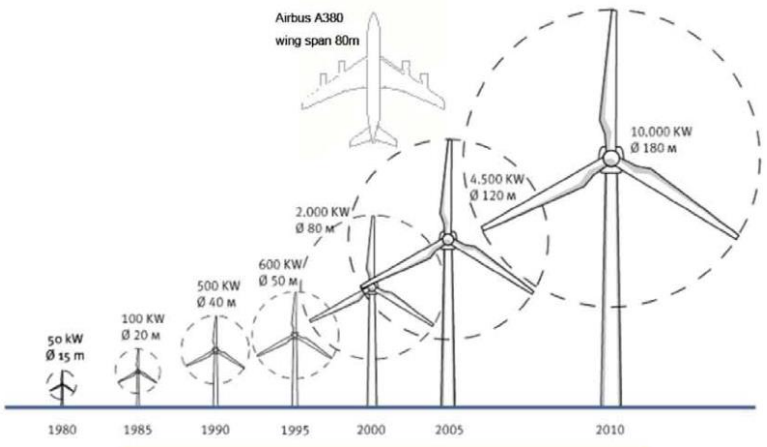


- Hand lay-up
- Spray-up
- Vacuum molding

Vacuum mold video
Jump to 4 min

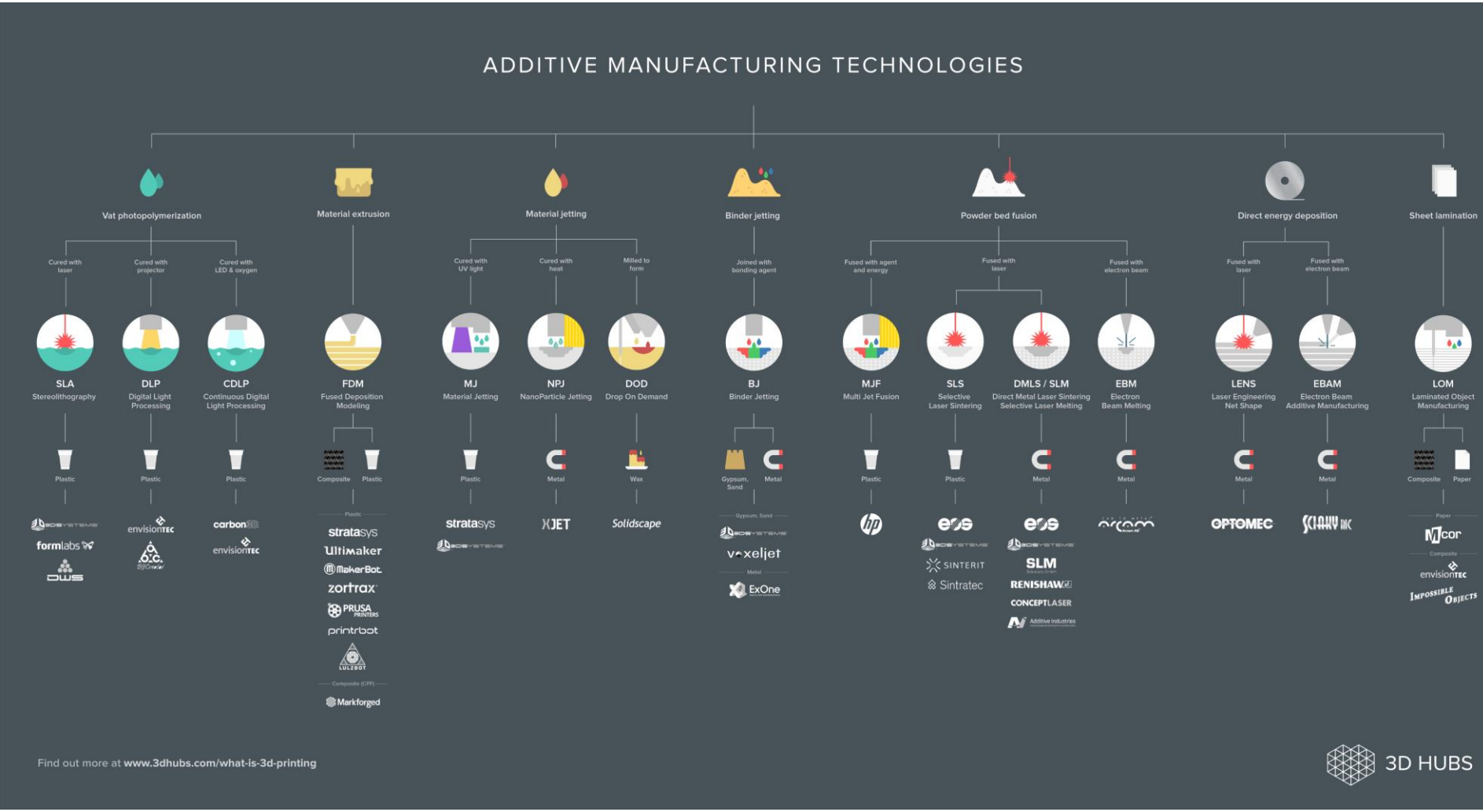
http://www.youtube.com/watch?v=YZAkf1E2Jcs

Growing Wind Turbine Size



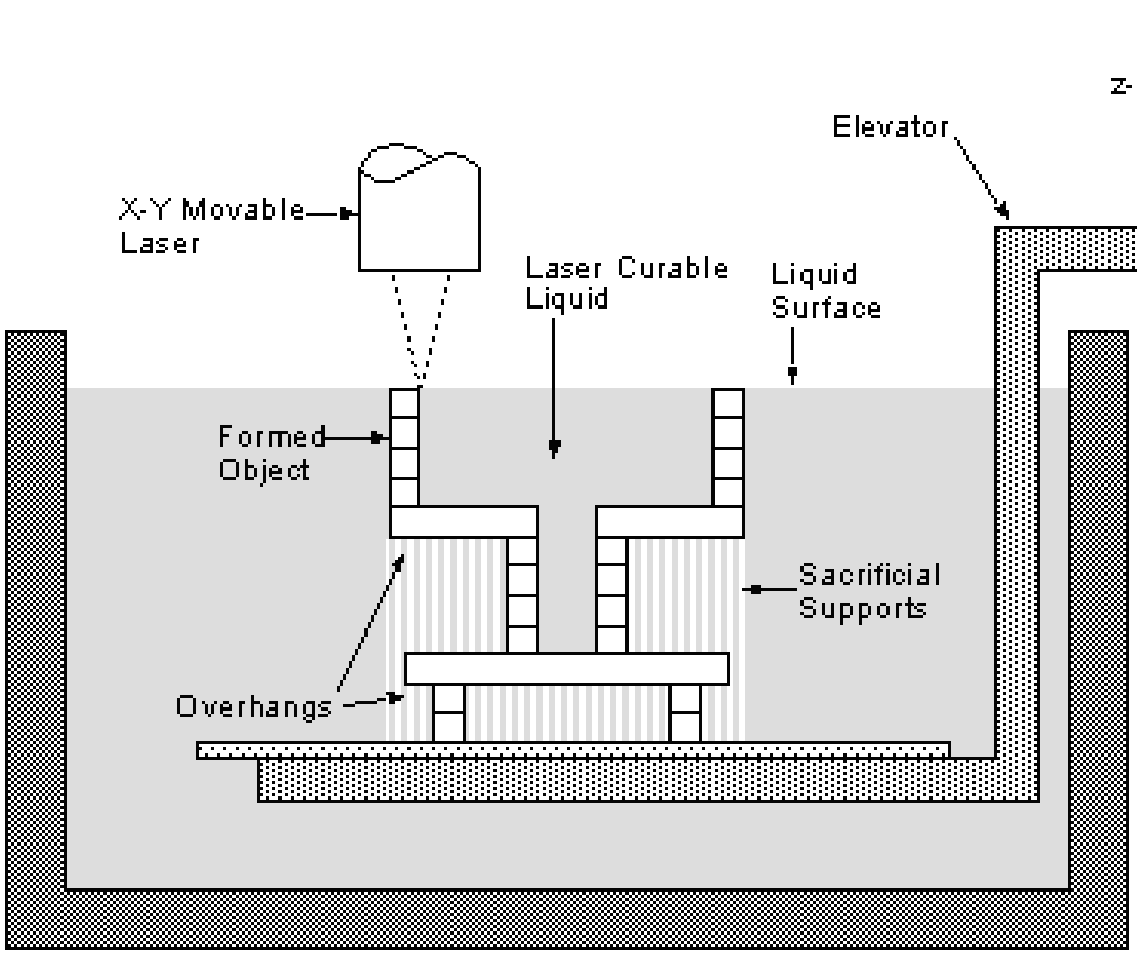
Additive Manufacturing

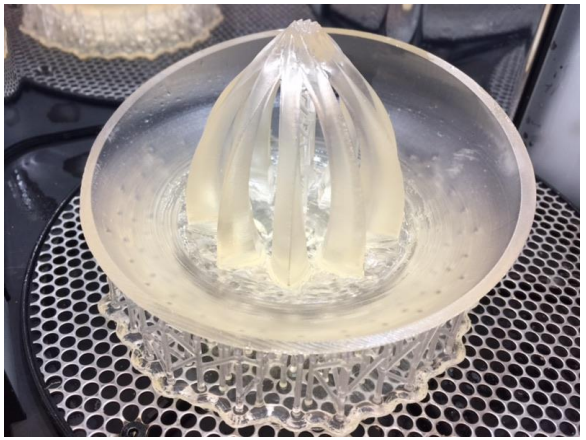
The Economist


ADDITIVE MANUFACTURING TECHNOLOGIES
Vat photopolymerization
Cured with laser
Cured with projector
Cured with LED & oxygen
SLA
Stereolithography
DLP
Digital Light Processing
CDLP
Continuous Digital Light Processing
Plastic
Material extrusion
FDM
Fused Deposition Modeling
Composite
Plastic
Material jetting
Cured with UV light
Cured with heat
Milled to form
MJ
Material Jetting
NPJ
NanoParticle Jetting
DOD
Drop On Demand
Metal
Wax
Binder jetting
Joined with bonding agent
BJ
Binder Jetting
Gypsum, Sand
Metal
Powder bed fusion
Fused with agent and energy
Fused with laser
Fused with electron beam
MJF
Multi Jet Fusion
SLS
Selective Laser Sintering
DMLS / SLM
Direct Metal Laser Sintering
Selective Laser Melting
EBM
Electron Beam Melting
Direct energy deposition
LENS
Laser Engineering Net Shape
EBAM
Electron Beam Additive Manufacturing
Sheet lamination
LOM
Laminated Object Manufacturing
Paper
Find out more at www.3dhubs.com/what-is-3d-printing
3D HUBS

Stereolithography (SLA)

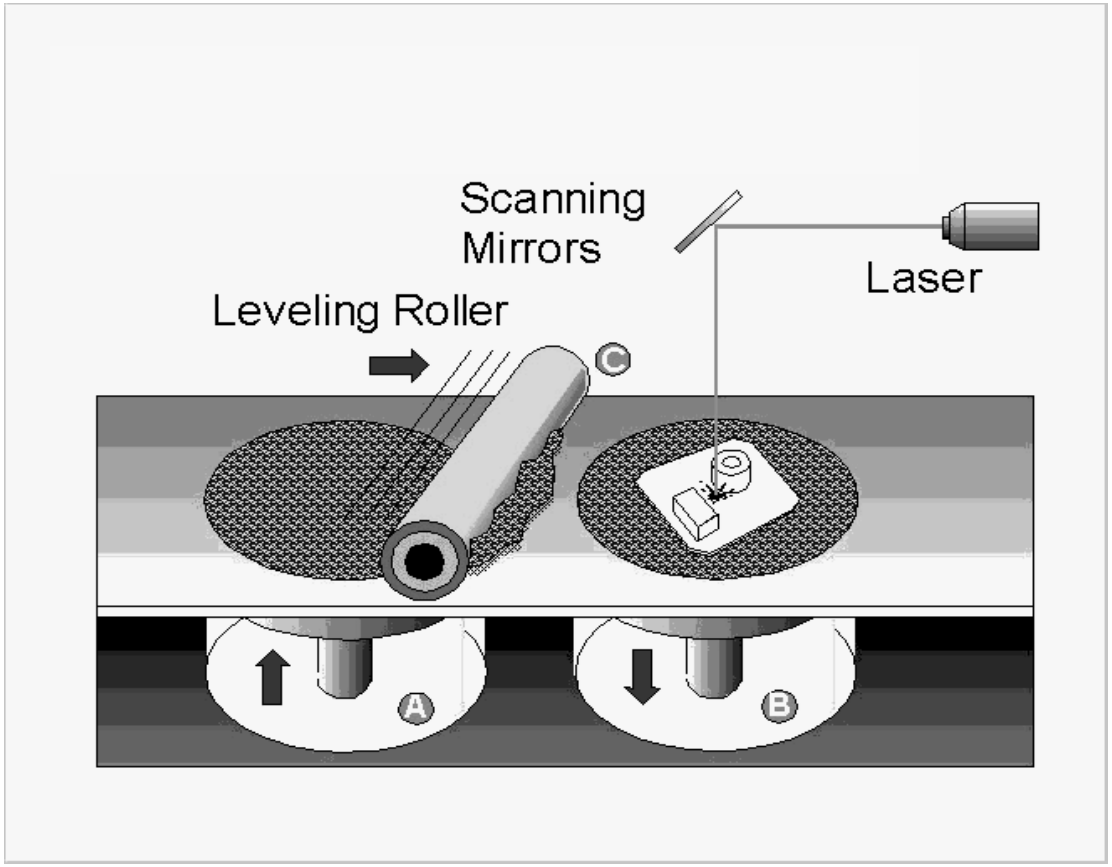
*





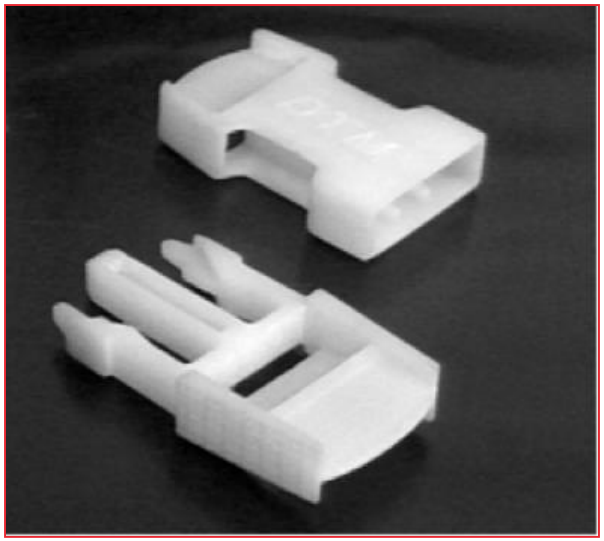
* Source: http://cybercut.berkeley.edu/mas2/html/processes/stereolith/more.html

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)

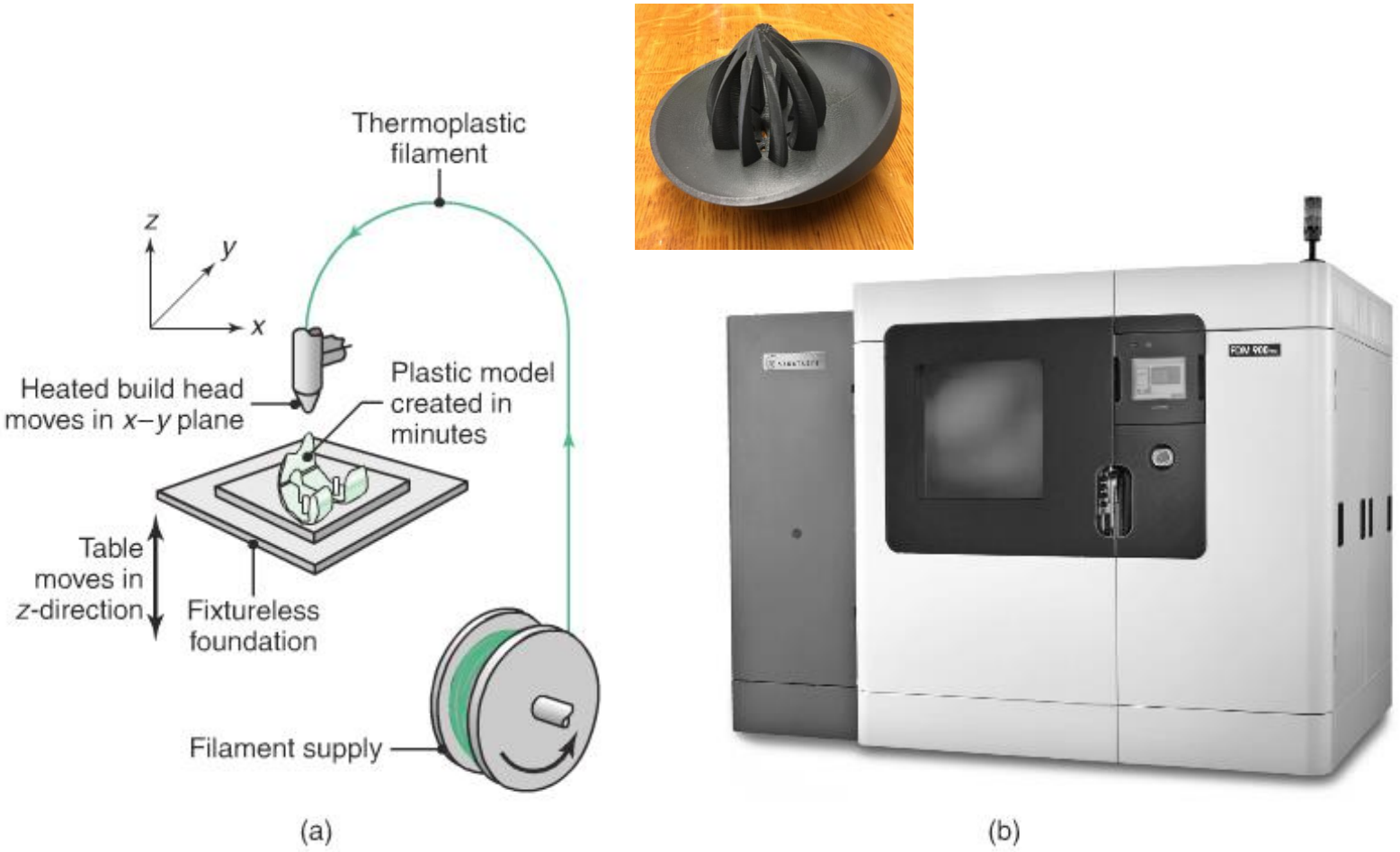
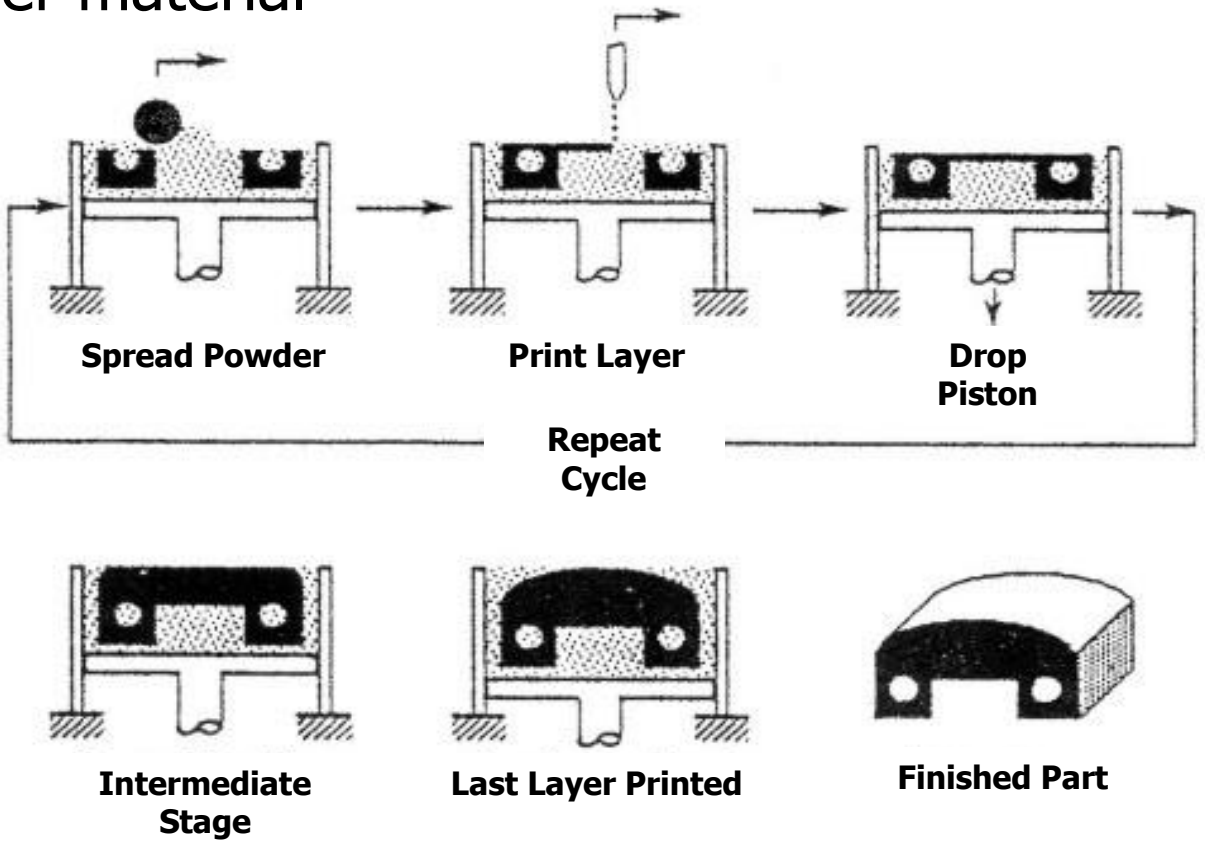


FIGURE 20.4 (a) Schematic illustration of the fused-deposition-modeling process. (b) The FDM 900mc, a fused-deposition-modeling machine. *Source*: Courtesy of Stratasys, Inc.

Plastic extrusion used in rapid prototyping

“3D Printing” binder jetting

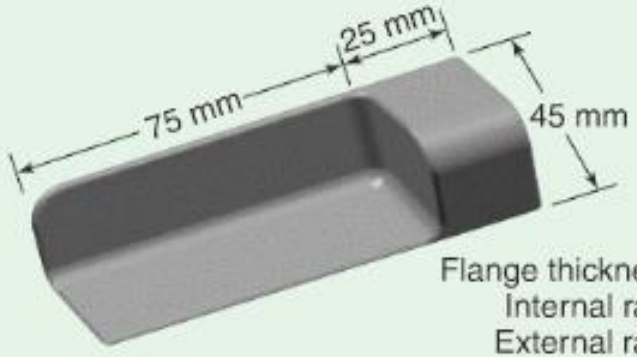
Selective joining of powder using ink-jet printing of a binder material



* Source: Kruth, J.P. (1991), “Material incress manufacturing by rapid prototyping techniques”

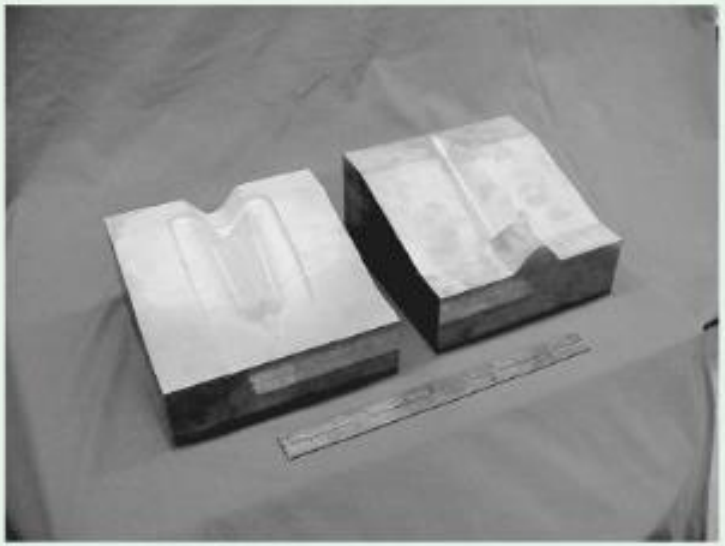
Direct Printing of Metal Tooling;
ExtrudeHone Corp., Irwin, PA

- Directly print metal parts and tooling.
  - Polymer binder into

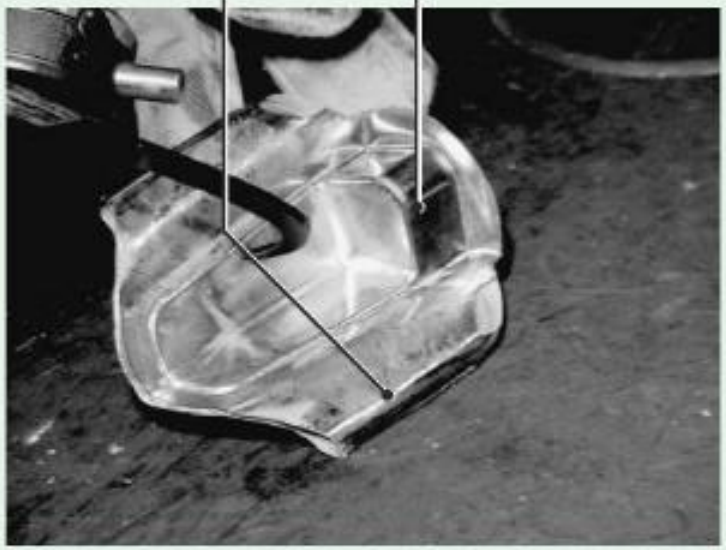


Flange thickness = 3 mm
Internal radii = 5 mm
External radii = 10 mm

(a)



(b)

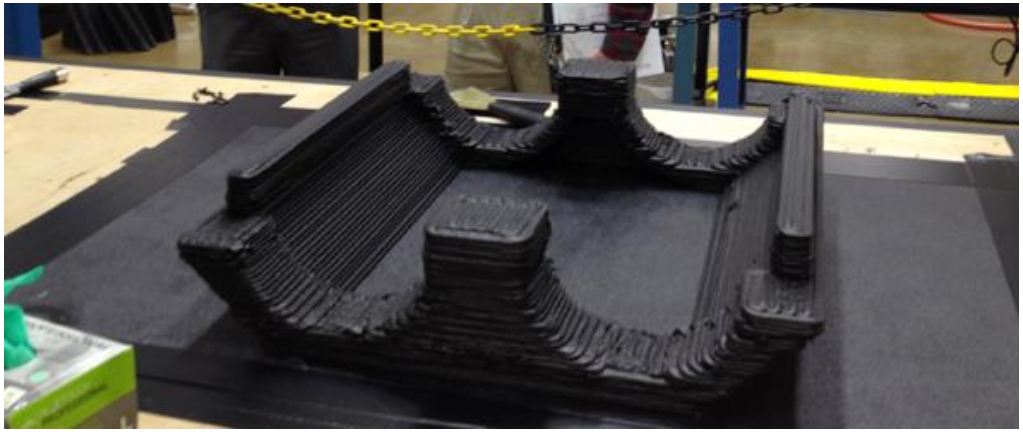


(c)

Forging Die made by 3D printing

BAAM CI

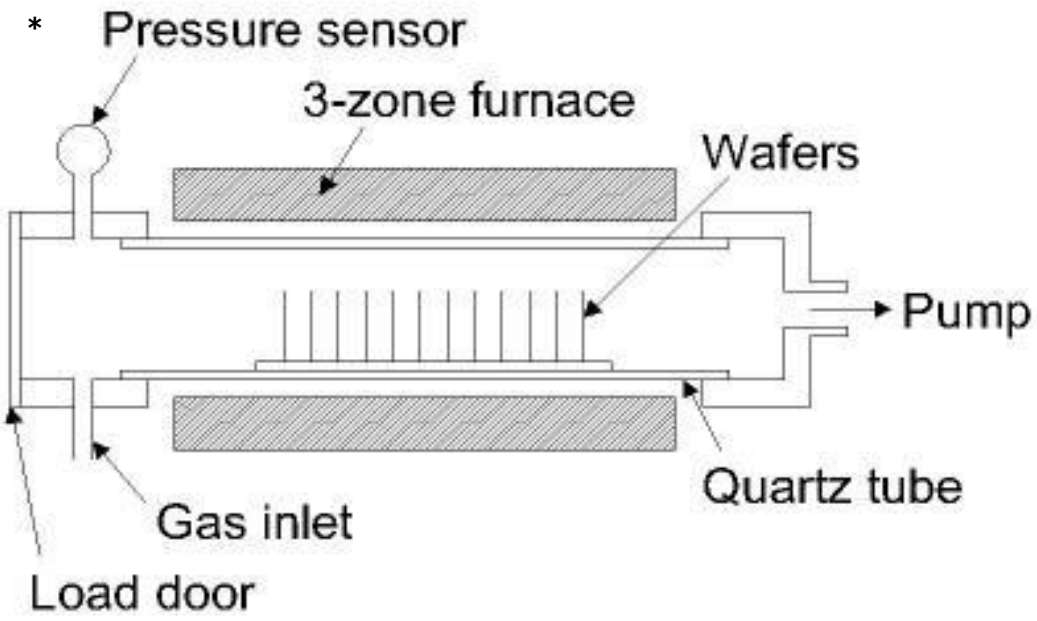
BIG AREA ADDITIVE MANUFACTURING



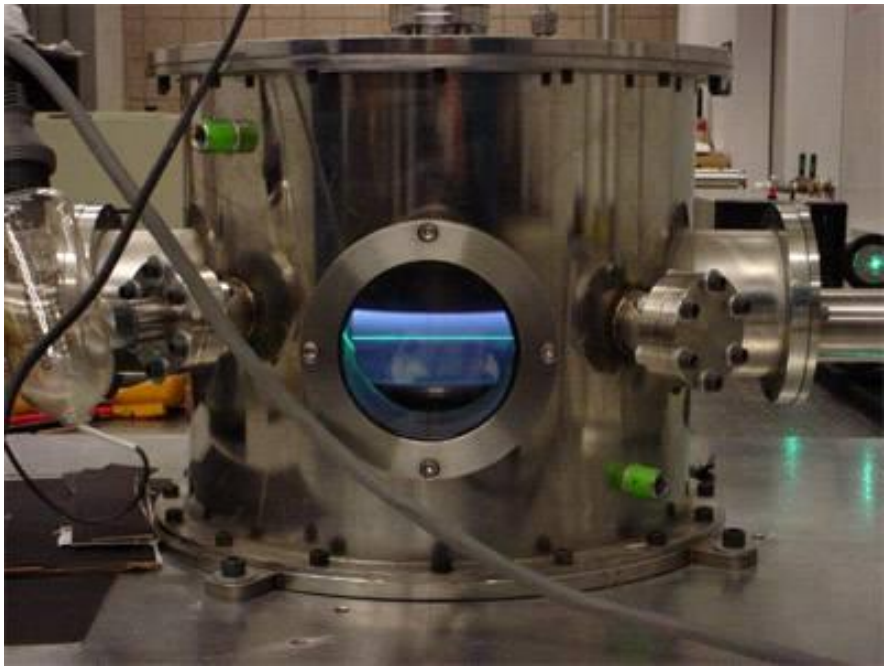
CVD (Chemical Vapor Deposition)

- 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

Typical hot-wall LP(Low Pressure) CVD



* Source: http://www.memsnet.org/mems/beginner/deposition.html



Deposition of SiO_2 from Silane gas by PECVD

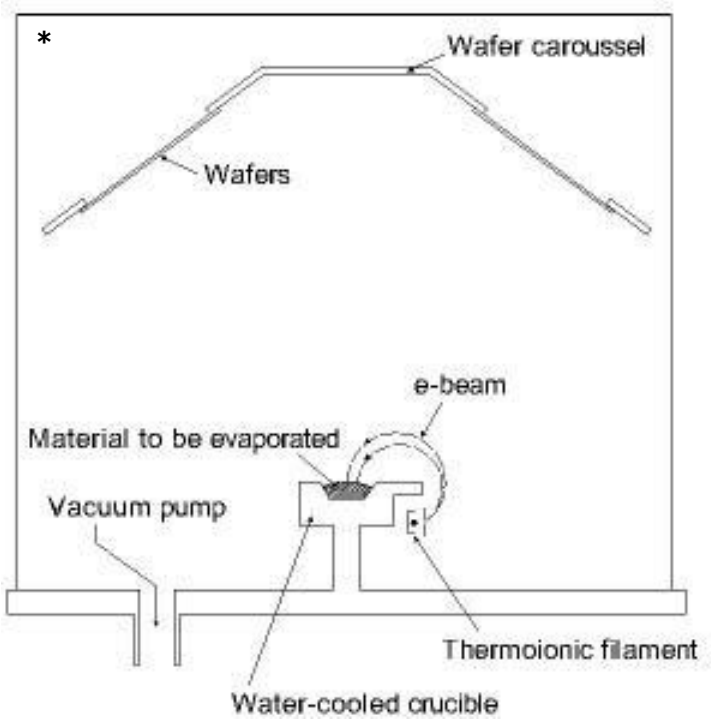
$SiH_4 + O_2 \rightarrow SiO_2 + 2H_2$

Siemens CVD Process for the Purification of Si

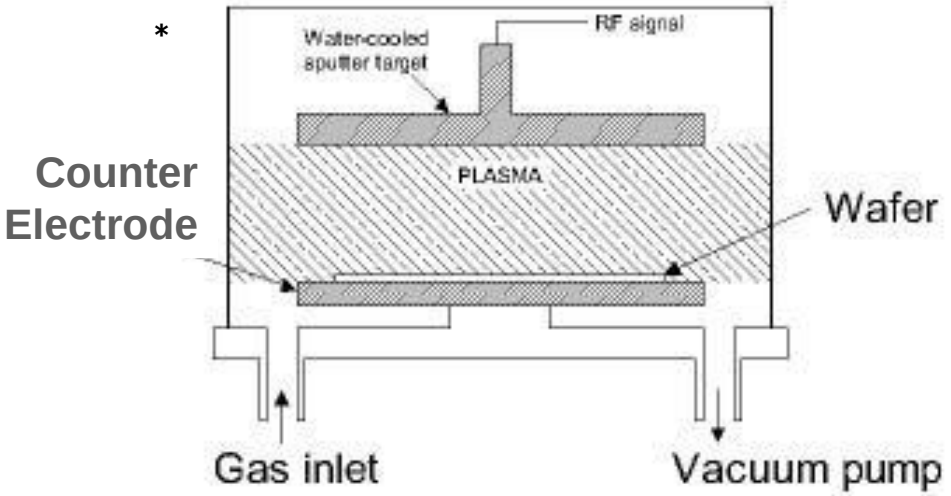
$2\ HSiCl_3 \rightarrow Si + 2\ HCl + SiCl_4$

PVD (Physical Vapor Deposition)

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



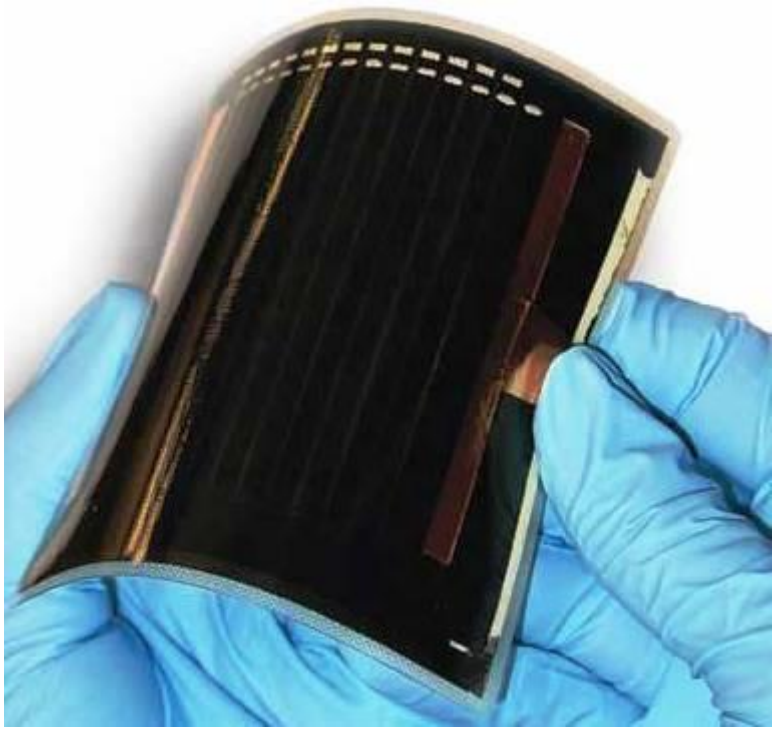
e-beam evaporation system



RF sputtering system

* Source: http://www.memsnet.org/mems/beginner/deposition.html

Thin film PV cell - CIGS



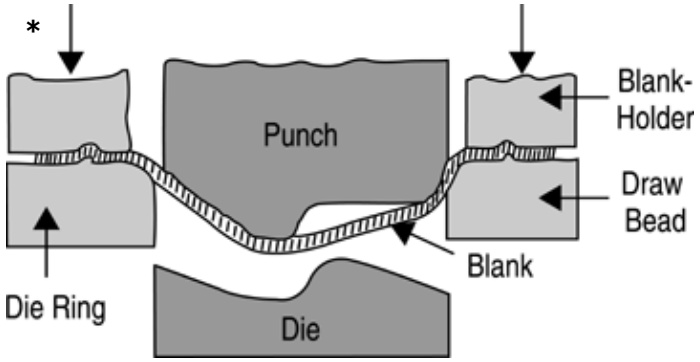
Ascent CIGS Solar Cell

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

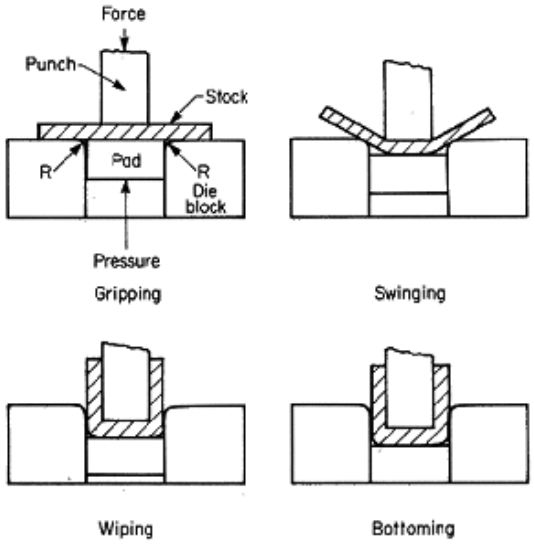
*



Typical Stamping Die

**

**



Drawing

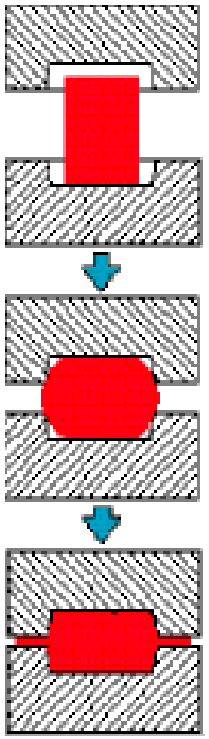
GM stamping plant go to
Around 2:39

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

* Source: http://www.tms.org/pubs/journals/JOM/9911/Hosford-9911-figure1.html; **: http://bdi-inc.qc.ca/processes/stamping/sp.html

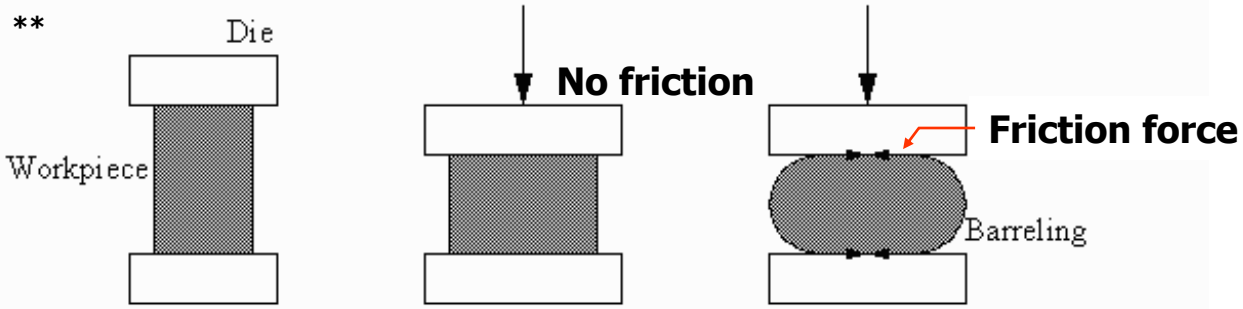
Forging

*



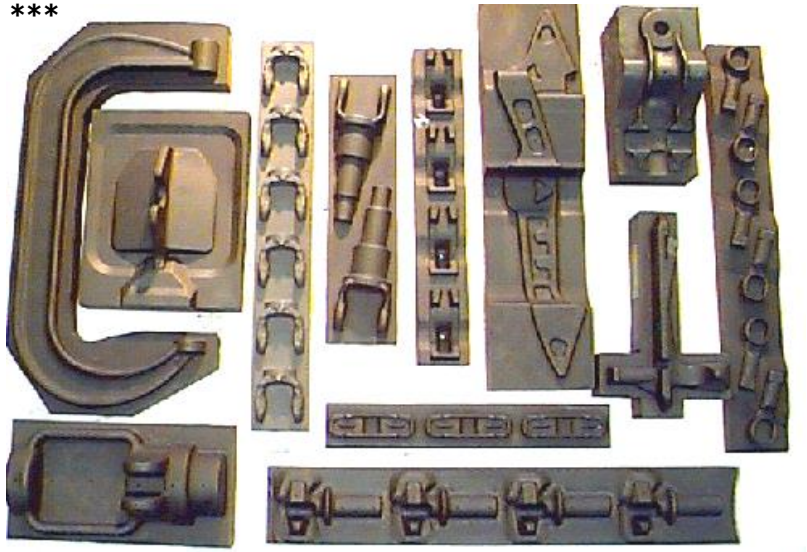
Closed Die Forging

**



Open Die Forging

***



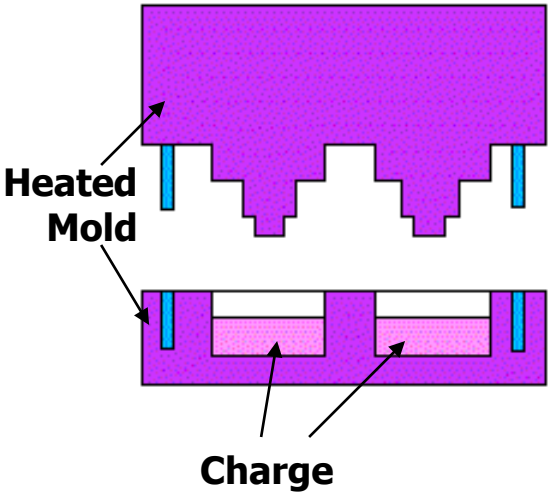
* Source: http://www.forging.org/facts/wwhy6.htm#fig3; **: Kalpakjian, “Manufacturing Engineering and Technology”; ***: http://www.johnsonforging.com

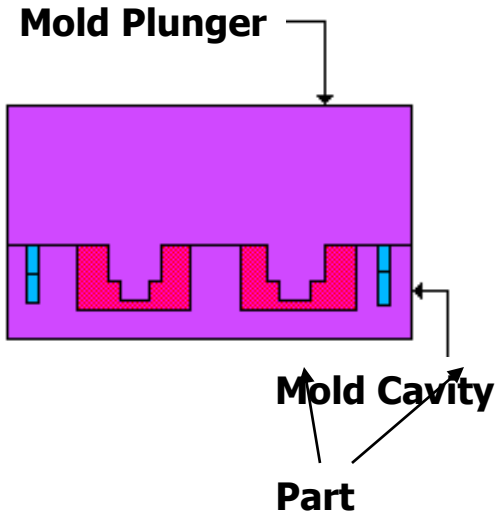

WYMAN
GORDON


LION
SABATIER
FRANCE

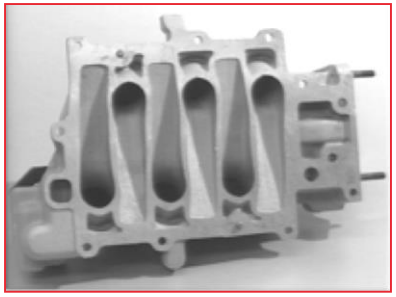
Compression Molding

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



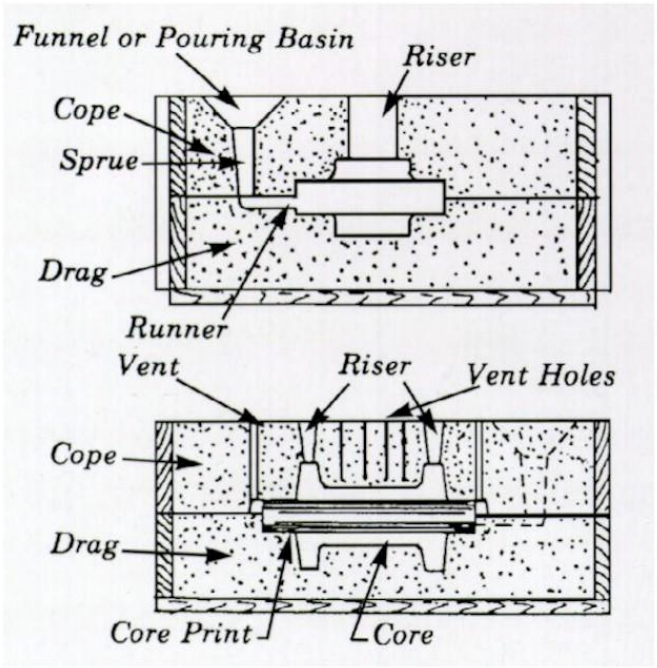


* Source: http://www.mahidol.ac.th/mahidol/eg/em_proj/group7/htm1text.htm

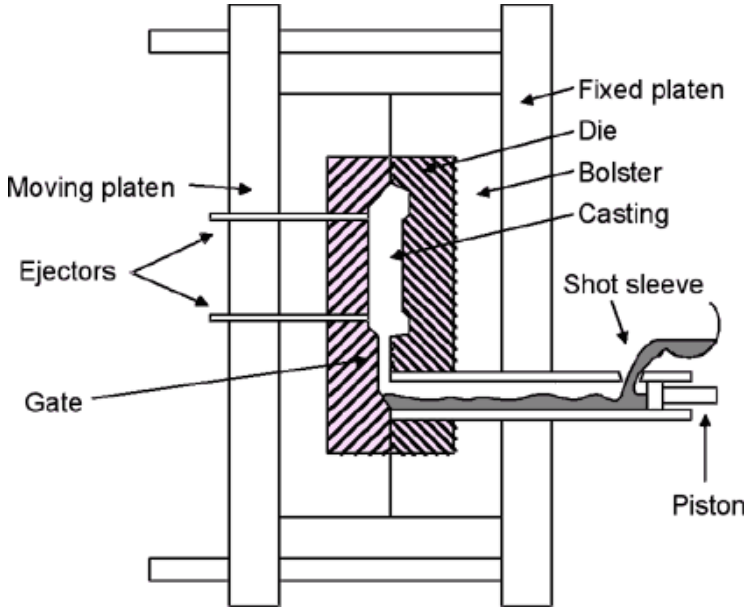


Metal Casting

* **



Sand Casting Mold

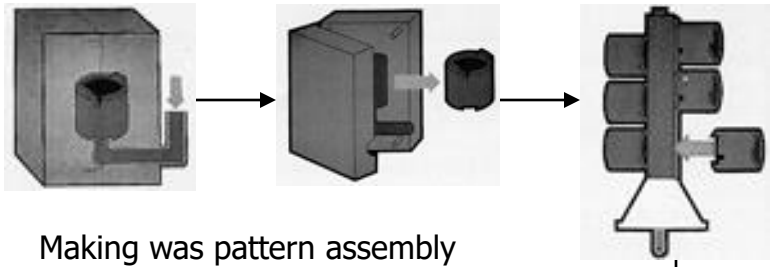


Die Casting machine

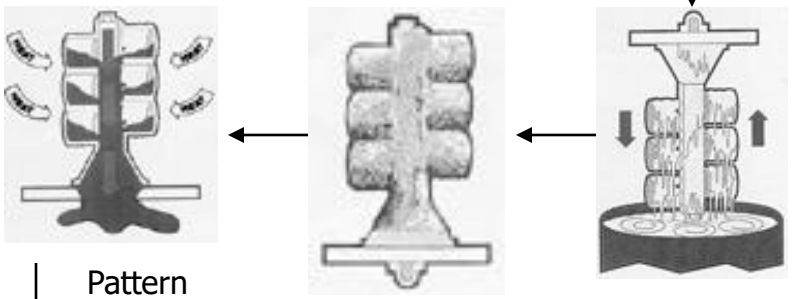
* Source: http://www.cepsales.com/Castings.htm ; ** http://www.eaa.net/pages/material/casting.html

Metal Casting

*



Making was pattern assembly

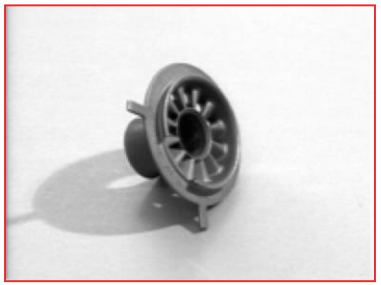


Slurry coating

Pattern meltout

Pouring molten metal

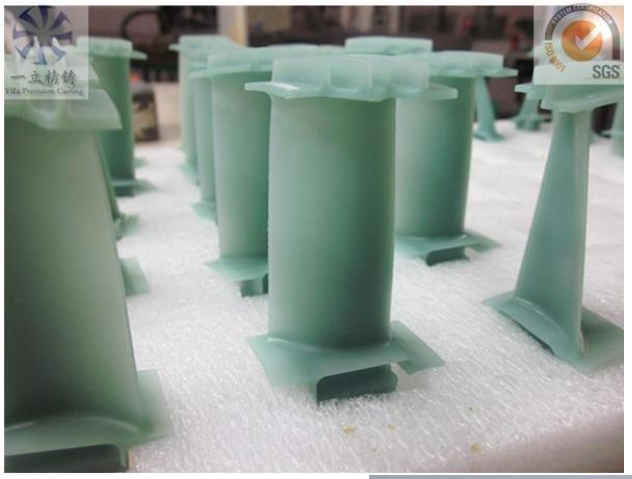
**

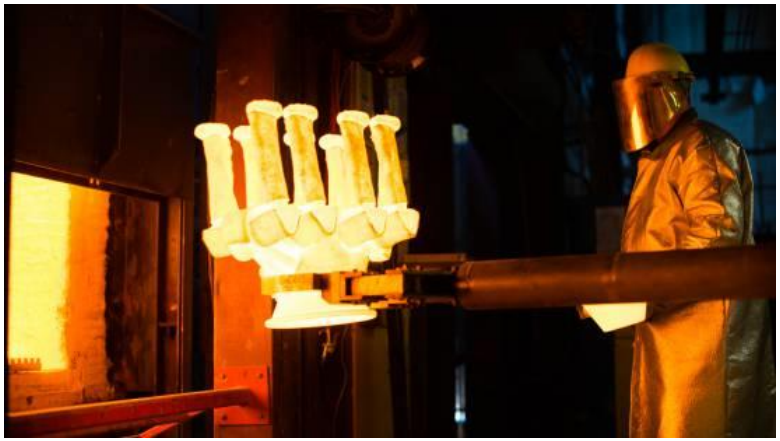


Investment or Lost Wax Casting

* Source: Kalpakjian, "Manufacturing Engineering and Technology"; ** http://cybercut.berkeley.edu/mas2/html/processes/castshell/more.html

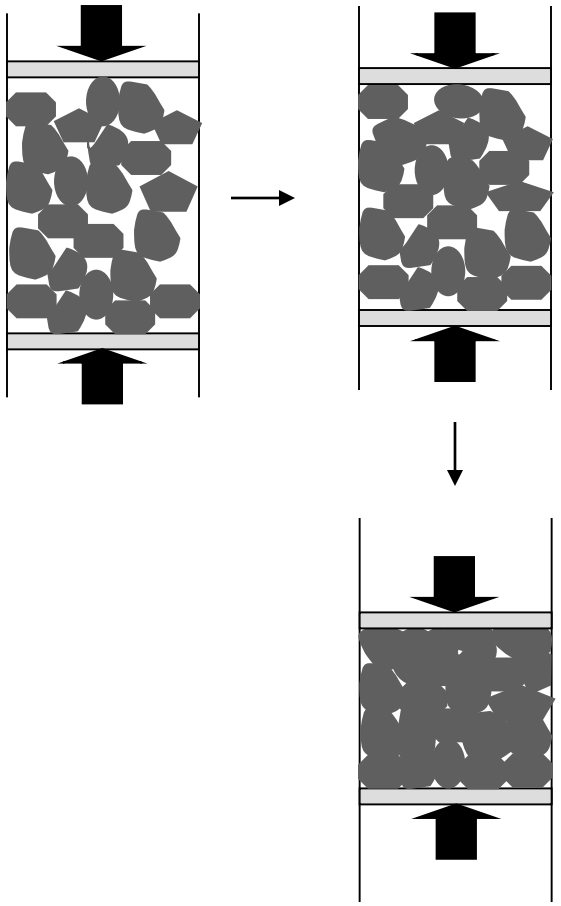
Investment Casting of Turbine Blades

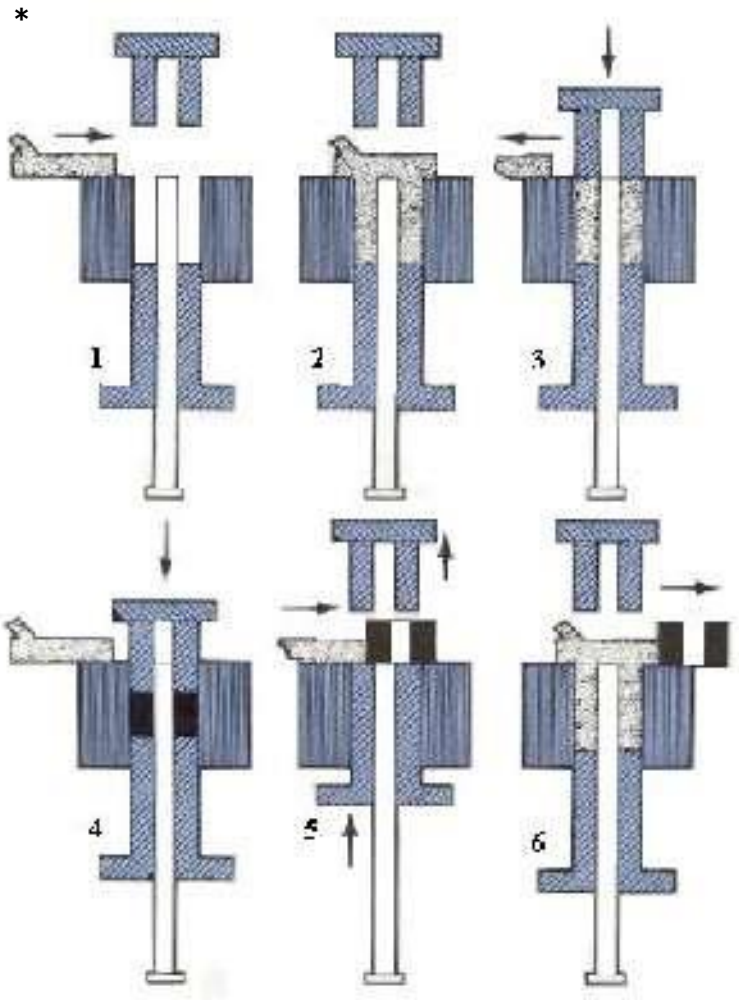




http://www.youtube.com/watch?v=1Mjsi2F2MrY&feature=channel

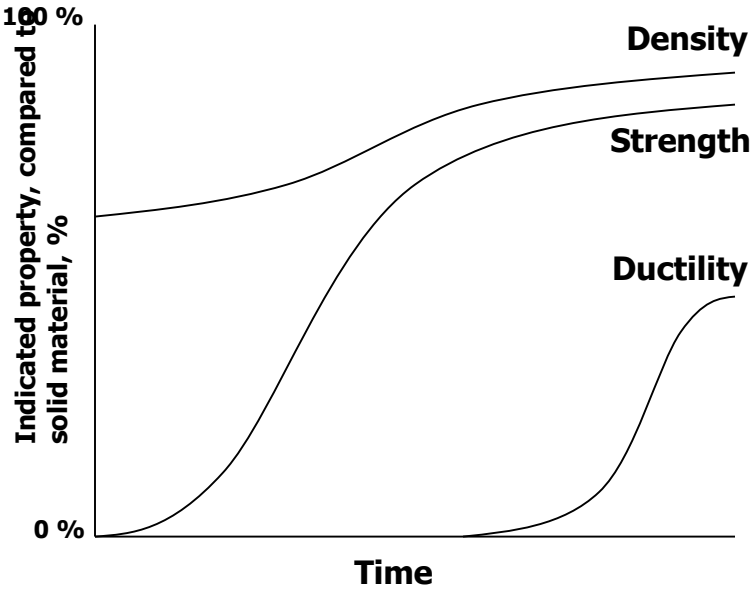
P/M: Powder Compaction

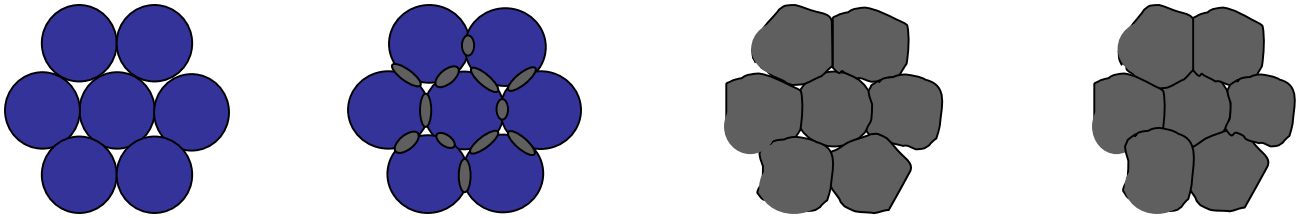




* Source: http://www.turkishpm.org/en_tozmetal.htm

Sintering

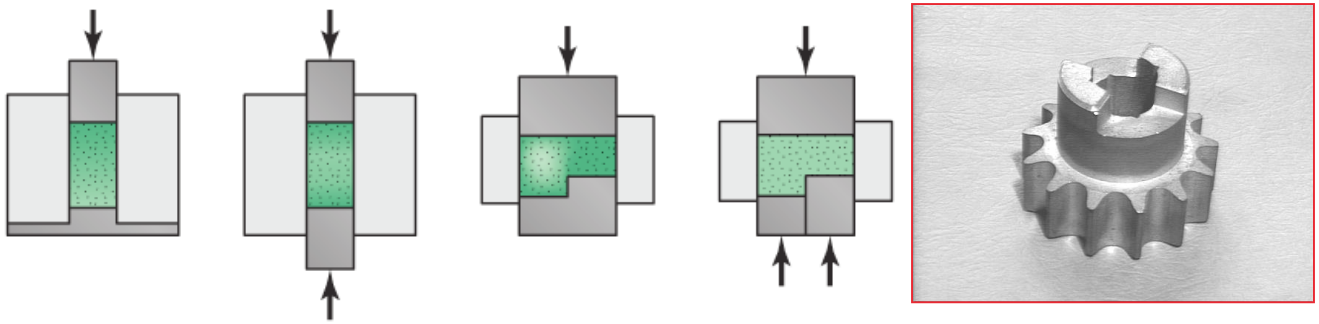




Green compact | Necks formed | Pore size reduced | Fully sintered

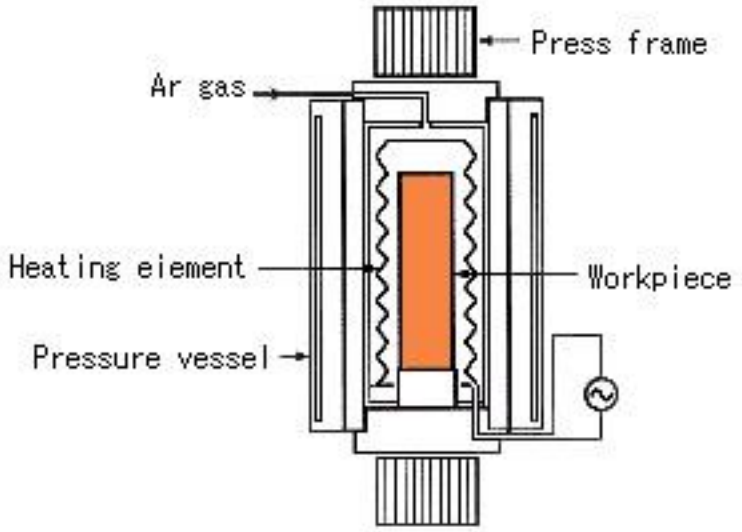
(a) (b) (c)

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.



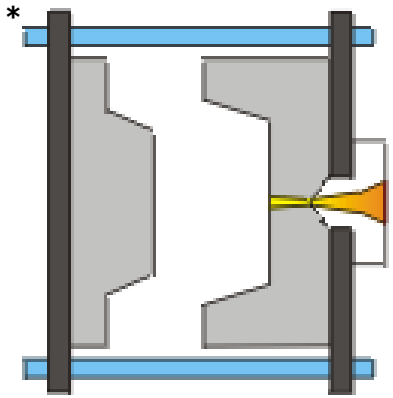
(a) (b) (c) (d)

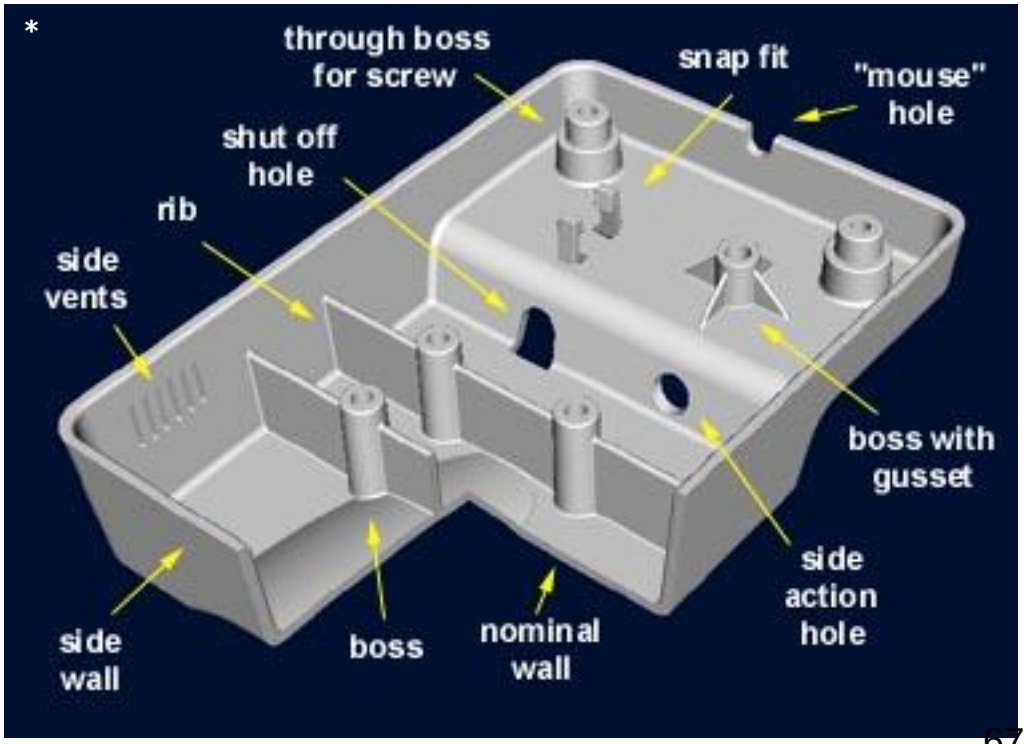
Hot Isostatic Pressing - HIP



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

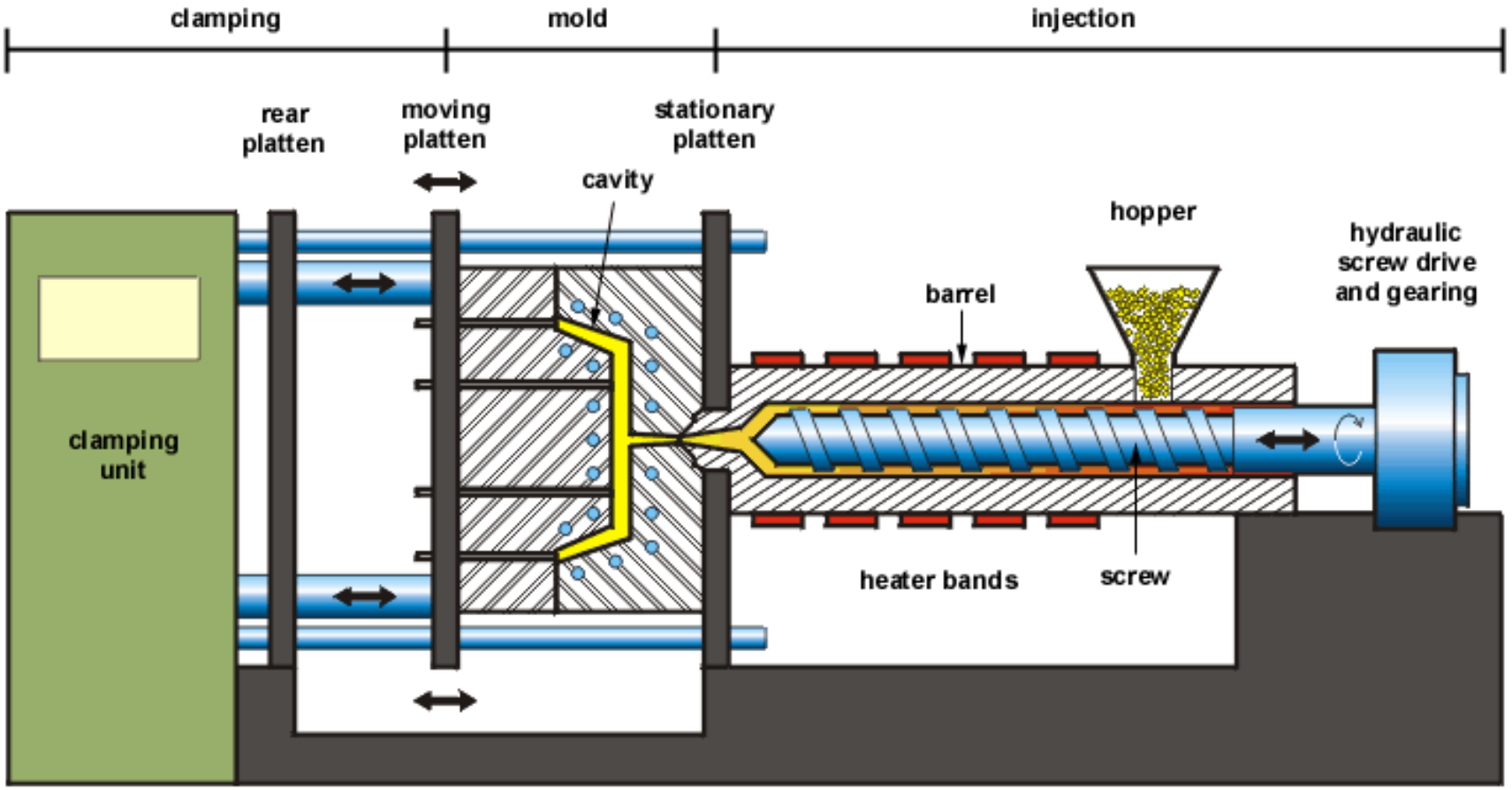
Injection Molding





* Source: http://www.idsa-mp.org/proc/plastic/injection/injection_process.htm

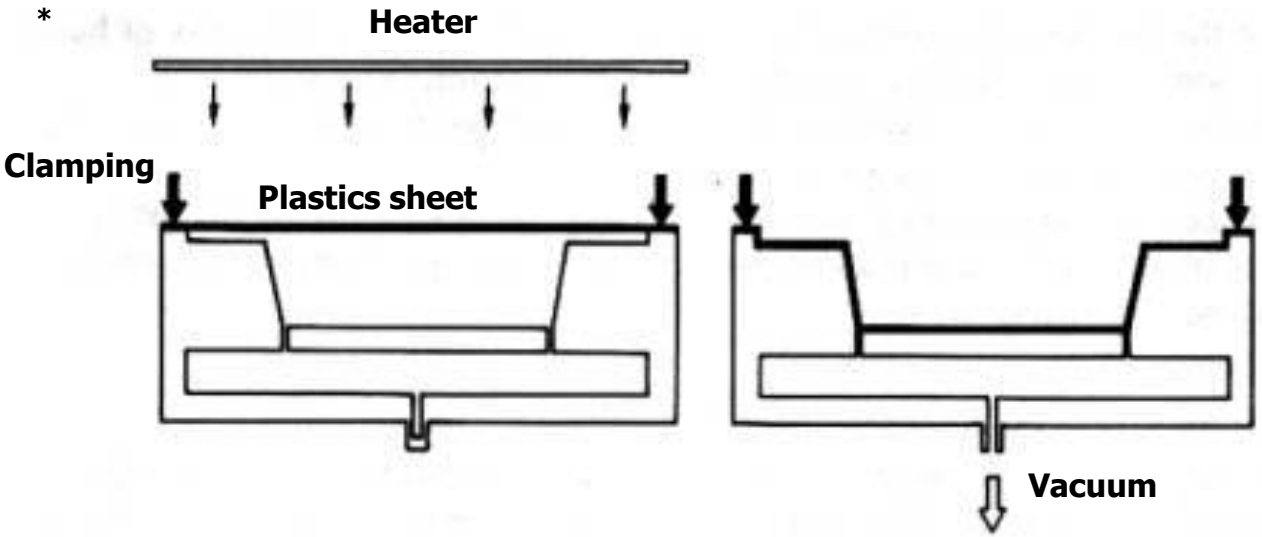
Injection Molding

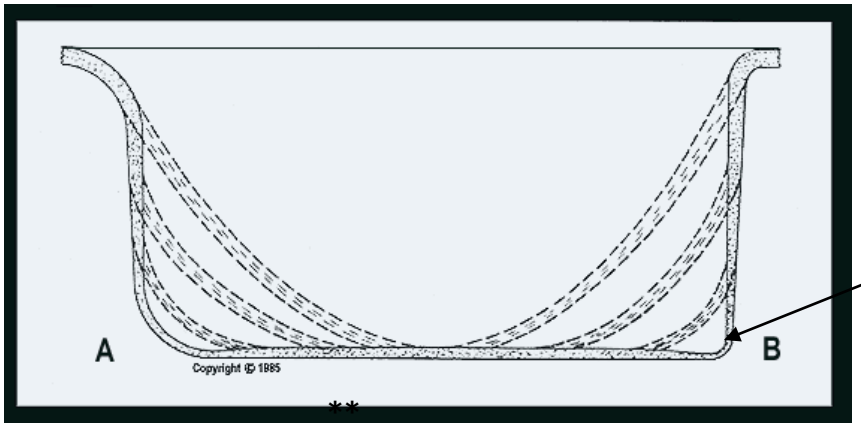


schematic of thermoplastic injection molding machine

* Source: http://www.idsa-mp.org/proc/plastic/injection/injection_process.htm

Thermoforming

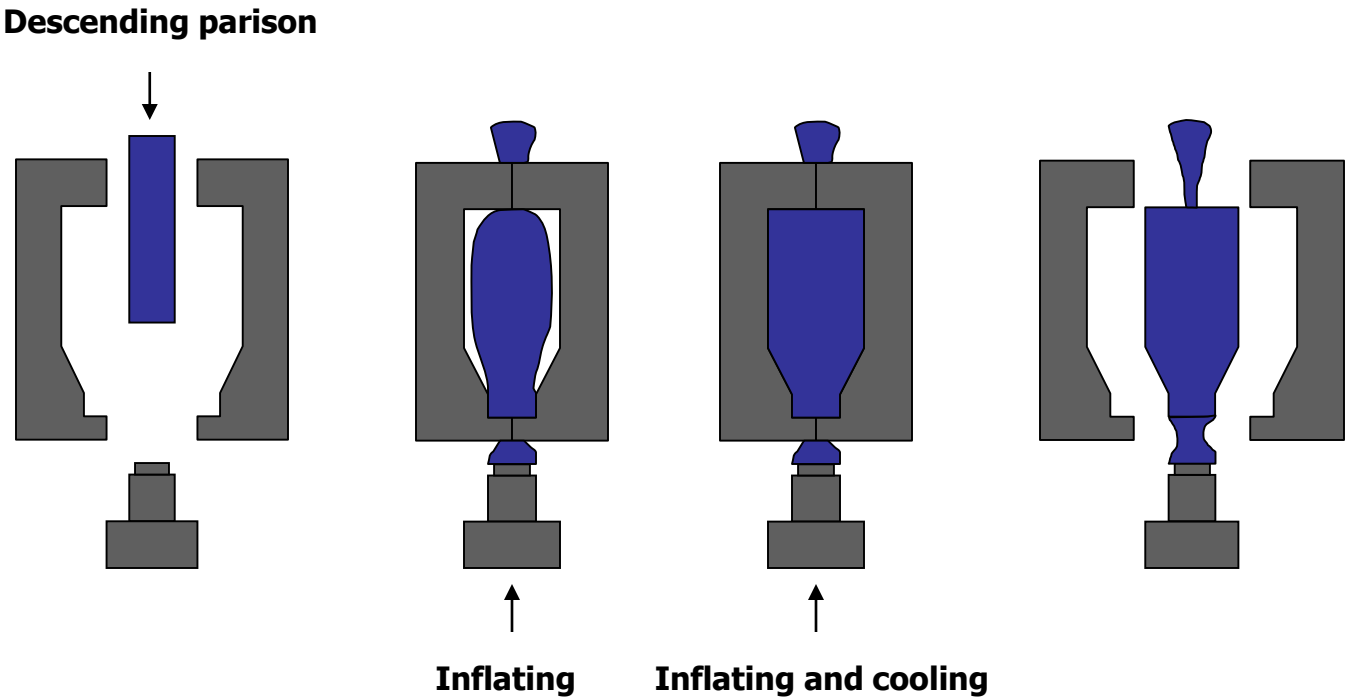




Thin corner

* Source: R. Ogorkiewicz, "Engineering Properties of Thermoplastics."; ** http://www.arrem.com/designguide/dgprocesscap.htm

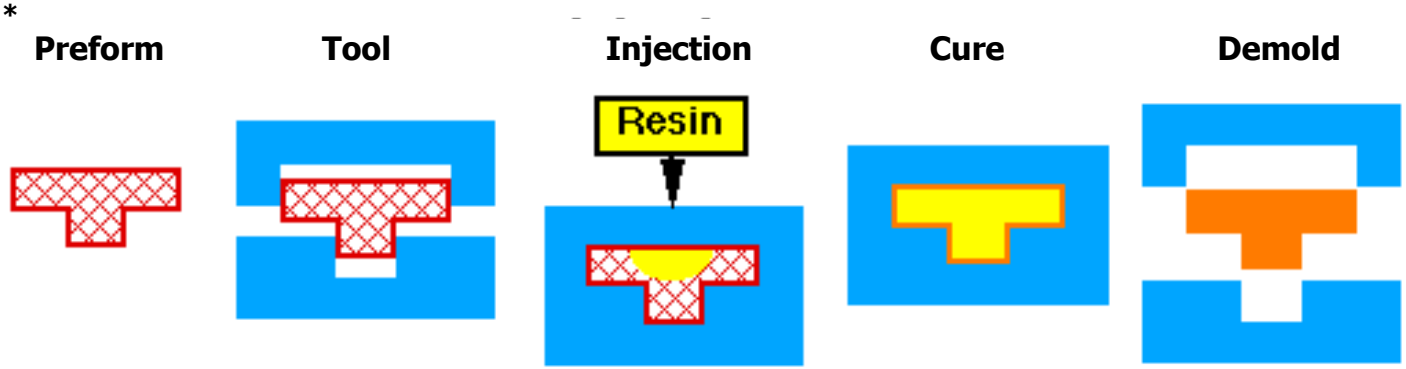
Blow Molding

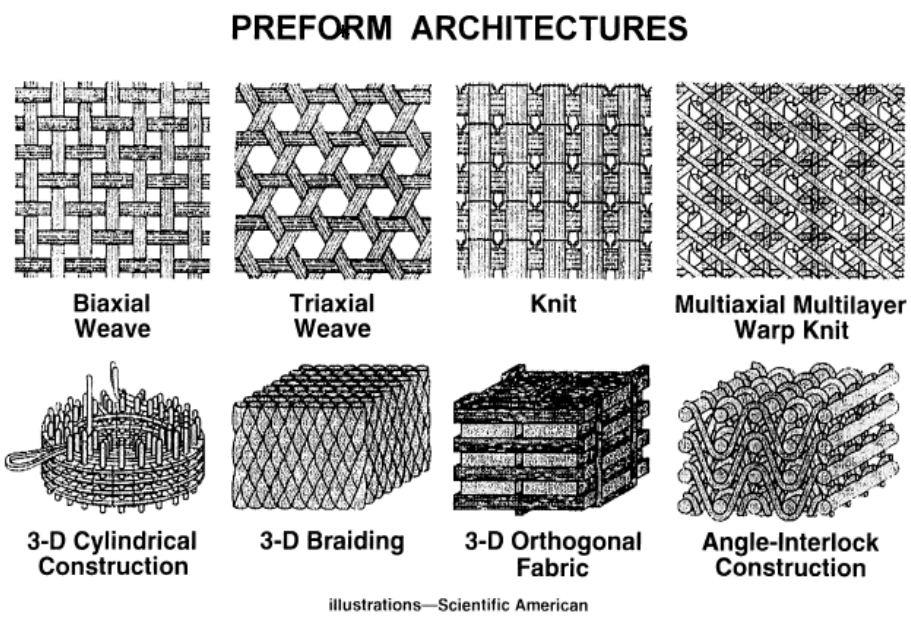


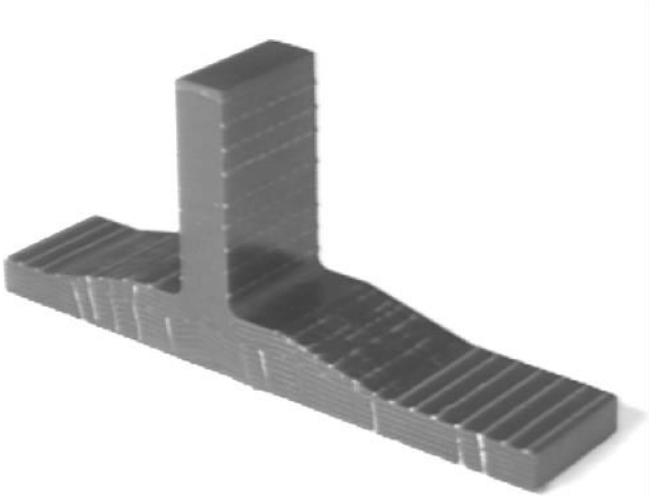
* Source: W.A.Holmes Walker, “Polymer Conversion”

Resin Transfer Molding (RTM)

*

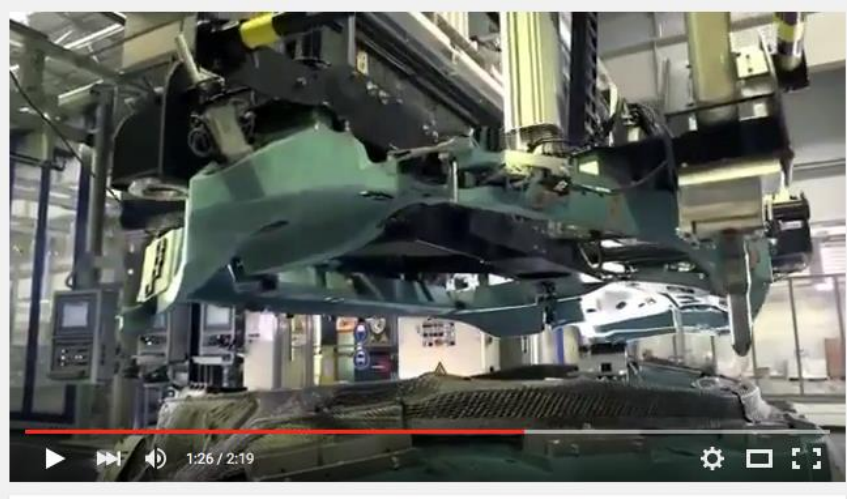






* Source: http://howard.engr.siu.edu/staff2/abrate/rtm

BMW i3 RTM door frame



4. Continuous Processes

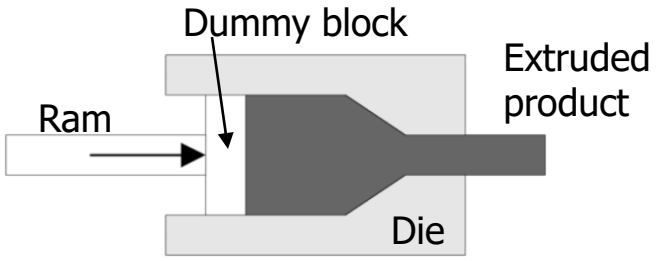
- Pushing
  - Metals extrusion
  - Plastics extrusion

- Pulling
  - Pultrusion of composites
  - Crystal pulling (Czochralski process)
  - String ribbon process (Ely Sachs)
  - Continuous casting

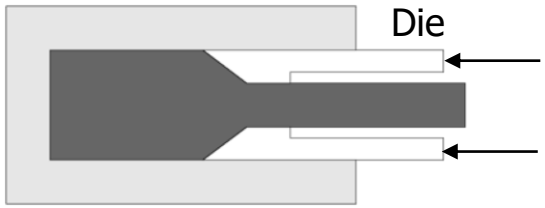
Pros and Cons

- + 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

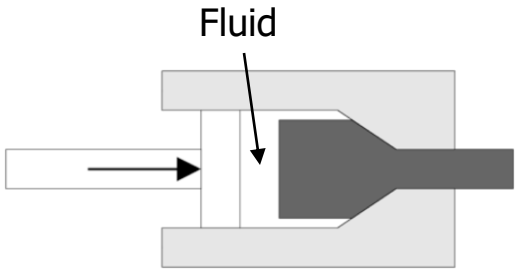
Metal Extrusion



Direct extrusion process



Indirect extrusion process



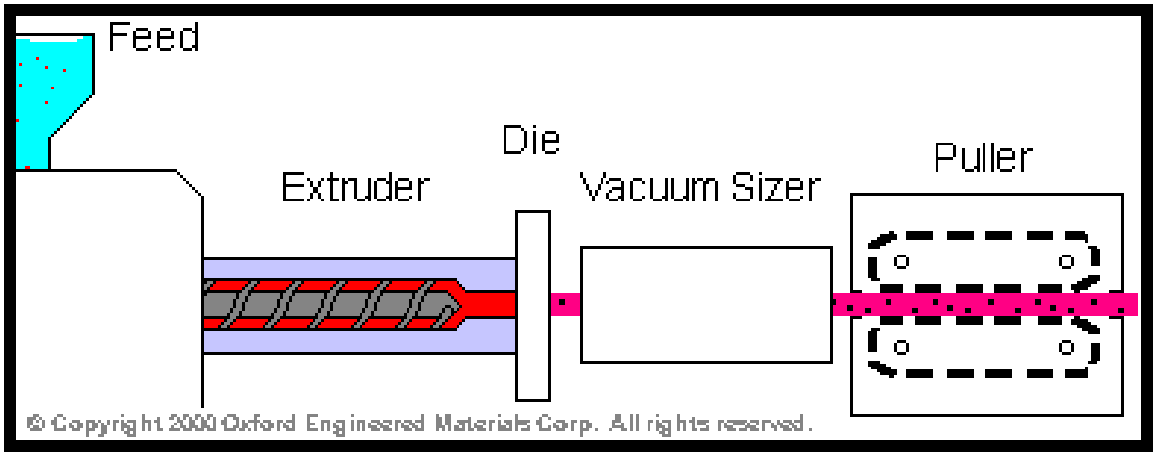
Hydrostatic extrusion process

* Source: http://www.eaa.net/pages/material/extruded.html

Aluminum extrusion dies

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

Plastic Extrusion



Single Screw Plastics Extruder

* Source: http://www.telfordsmith.com.au/products/

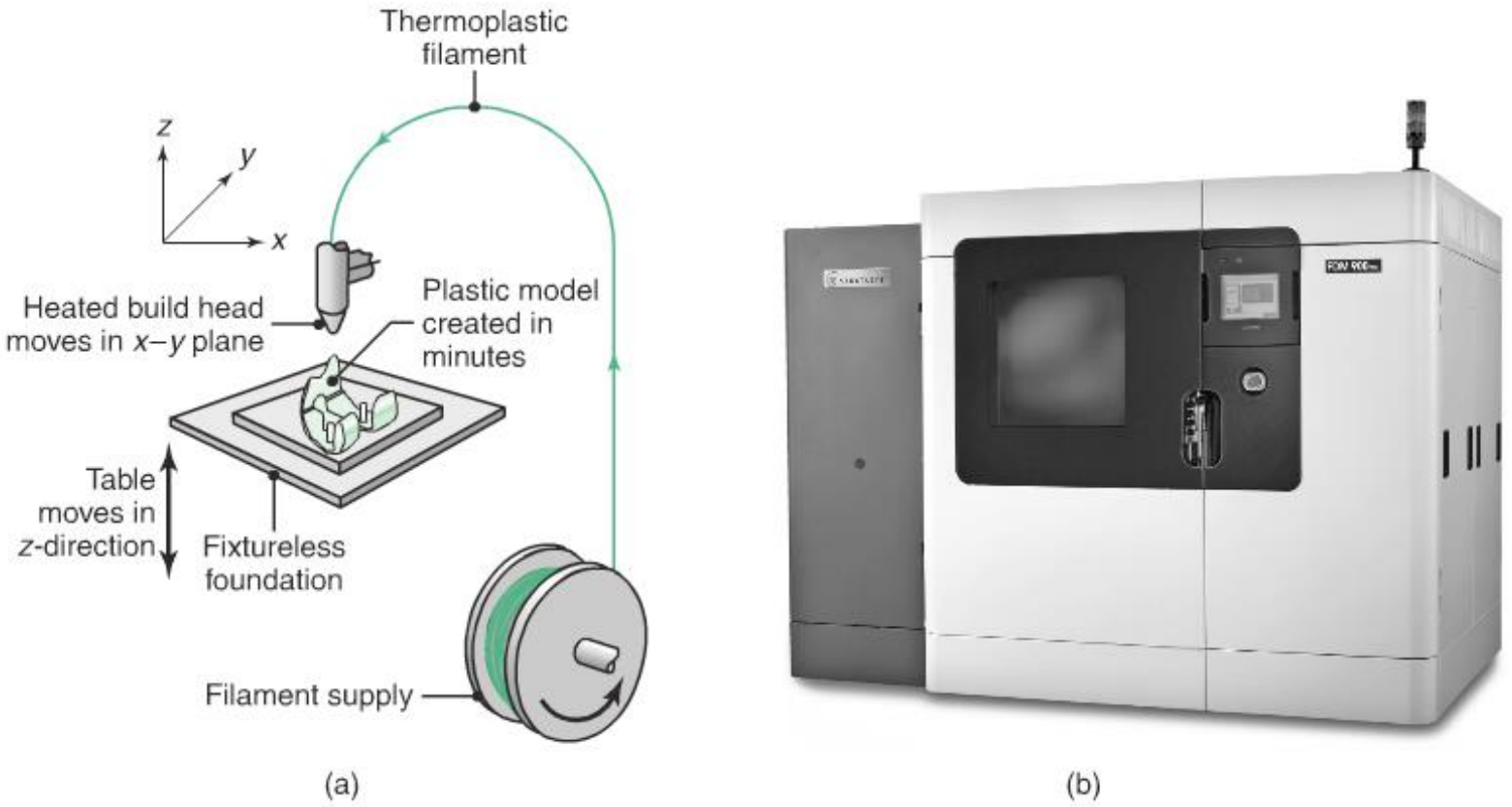
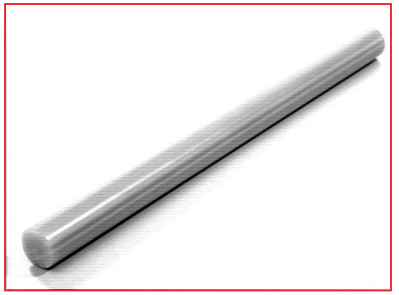


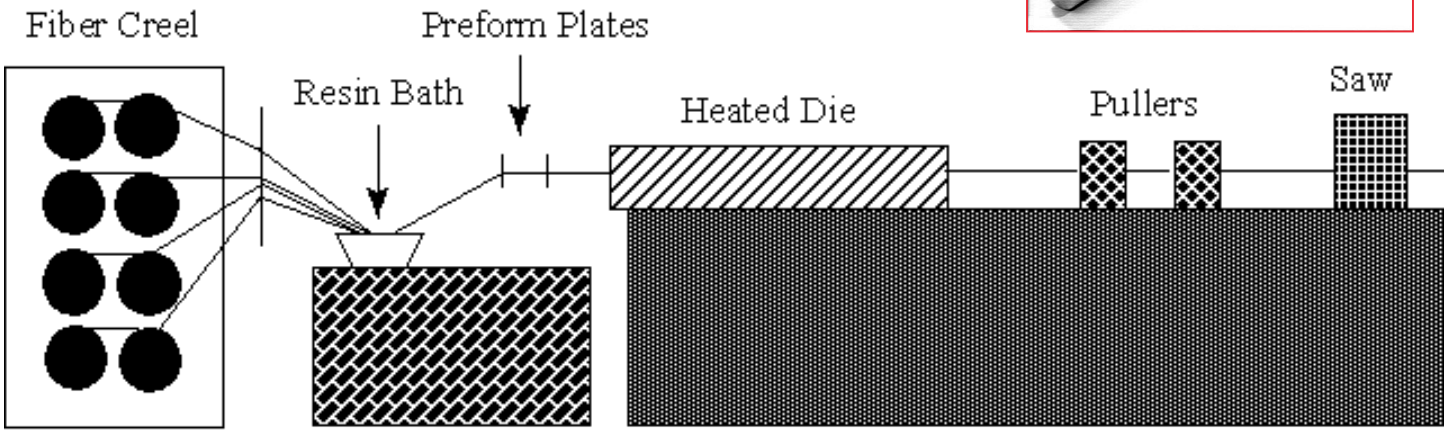
FIGURE 20.4 (a) Schematic illustration of the fused-deposition-modeling process. (b) The FDM 900mc, a fused-deposition-modeling machine. *Source*: Courtesy of Stratasys, Inc.

Plastic extrusion used in rapid prototyping

Pultrusion of Composites

*





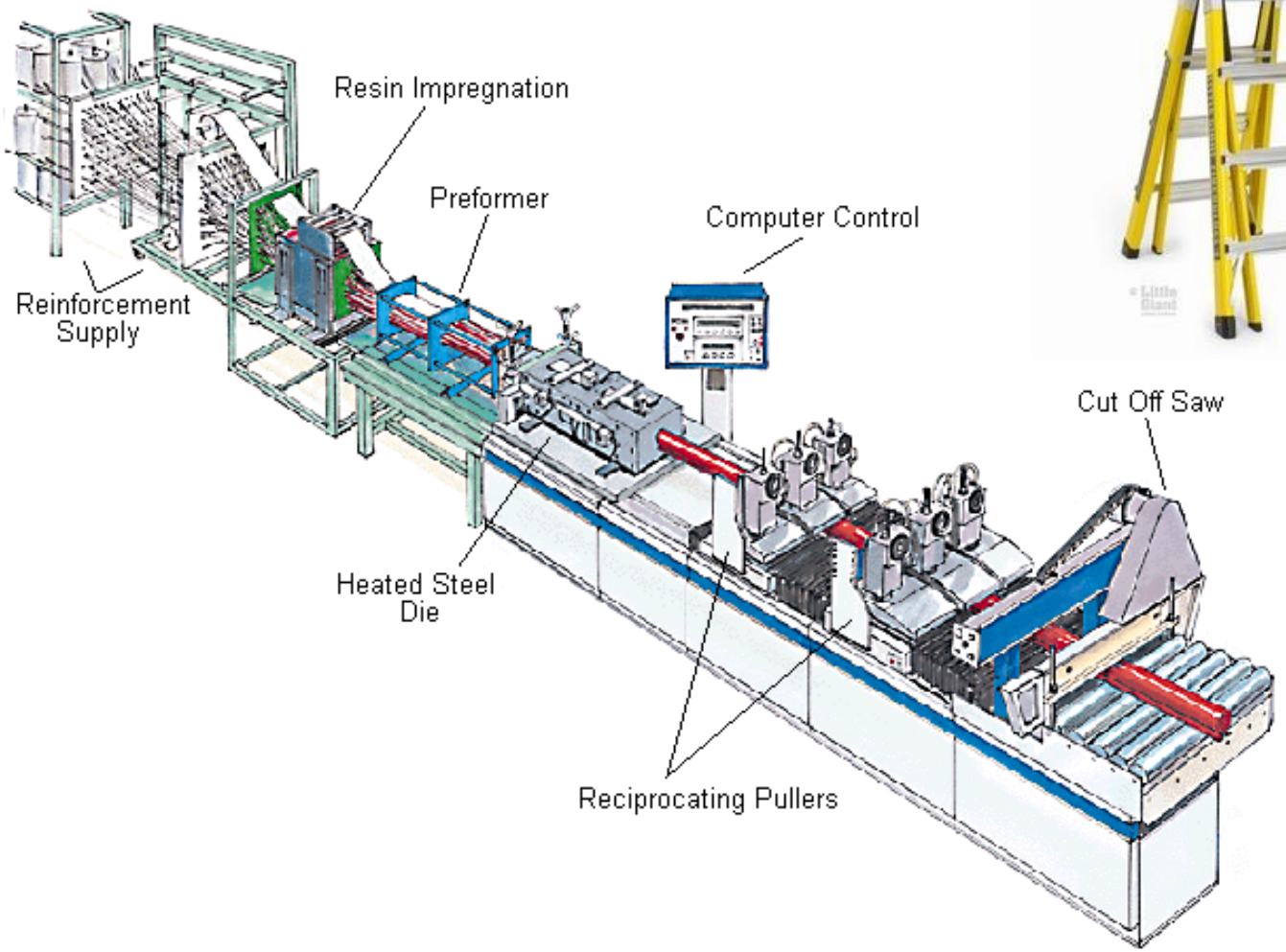
Schematic Diagram of the Pultrusion Process

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

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

Pultrusion machine

*

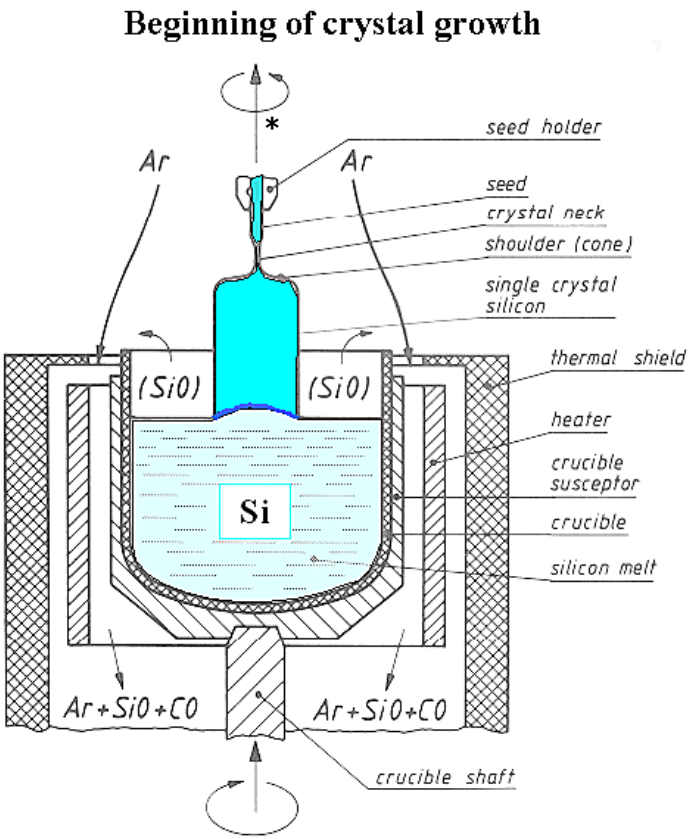


* Source: http://howard.engr.siu.edu/staff2/abrate/NSFATE/camps/pult.htm

youtube videos

- Pultrusion
- https://www.youtube.com/watch?v=4MoHNZB5b_Y
- https://www.youtube.com/watch?v=bRjU4na-ol8

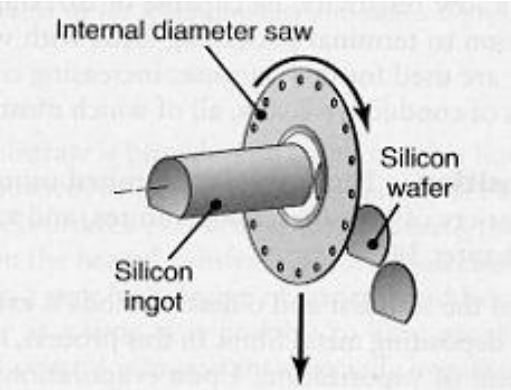
Czochralski(CZ) Crystal Growth



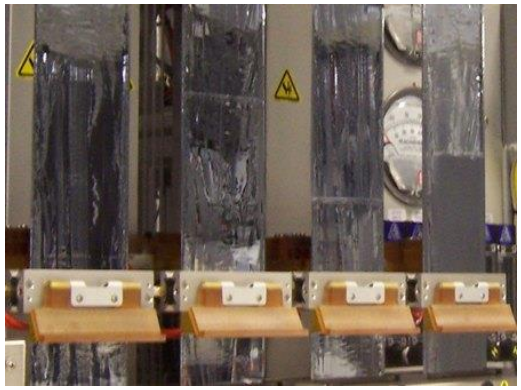
http://www.youtube.com/watch?v=cYj_vqcyI78

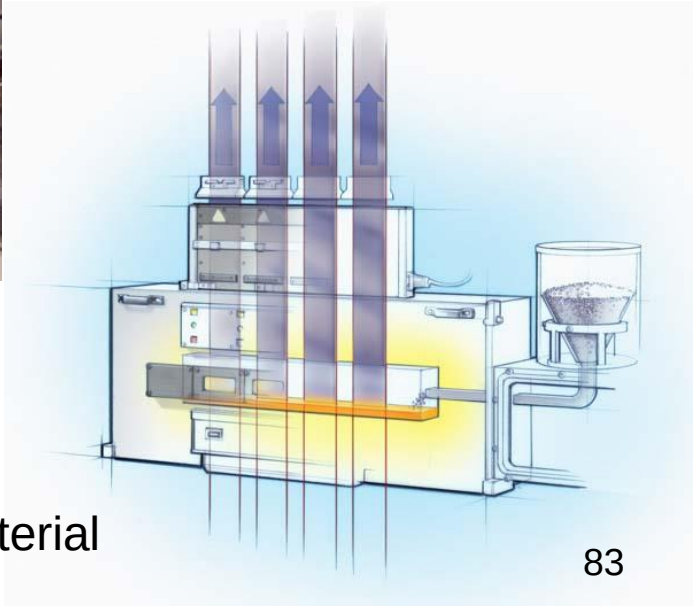
* Source: http://www.techfak.uni-kiel.de/matwis/amat/elmat_en/kap_5/illustr/i5_1_1.html

String Ribbon Process



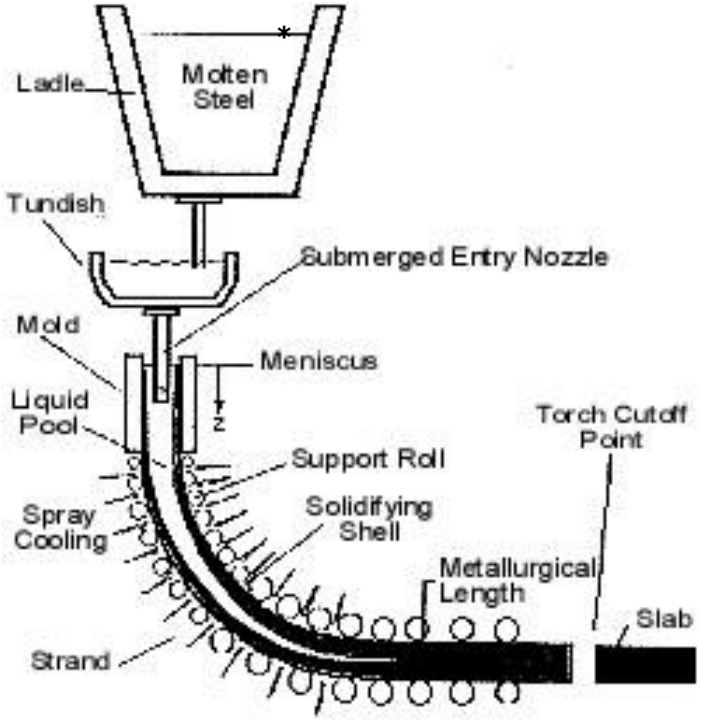
In ID and wire sawing of Si ingots, the kerf material represents lost material & Energy

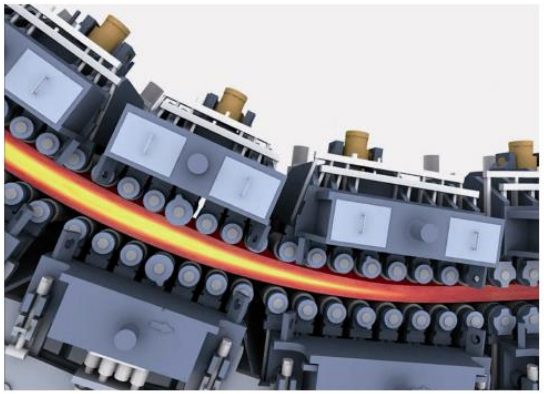




String-Ribbon Invented by Ely Sachs saves this material

Continuous Casting





* Source: Thomas, B. G., “Continuous Casting: Modeling”, The Encyclopedia of Advanced Materials (Dantzig, J., Greenwell, A., Michalczyk, J., eds.)

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