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. Continuous
4. Net shape

Material phase

- Solid phase - e.g. machining, bending
- Liquid phase - e.g. casting, injection molding
- Mixed phase - e.g. composites molding
- Vapor phase - e.g. chemical vapor deposition

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

coarse → fine

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

Mechanical processes (Blanking, Machining, Grinding, Erosion)

"Advanced Machining" (Erosion, Melting/Vaporization, Dissolution)

Semi-conductor (Melting/Vaporization, Dissolution)

1. General Observations*

coarse → fine

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

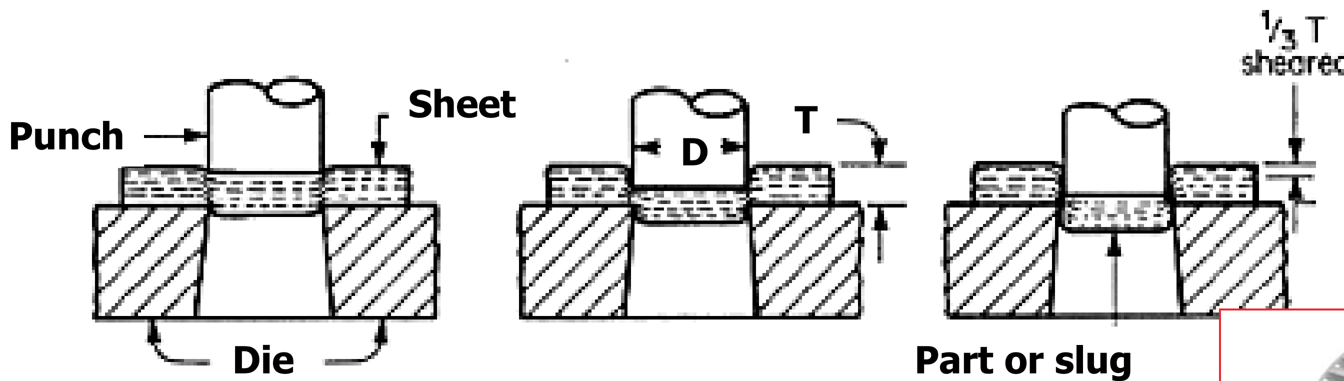
fast → slow

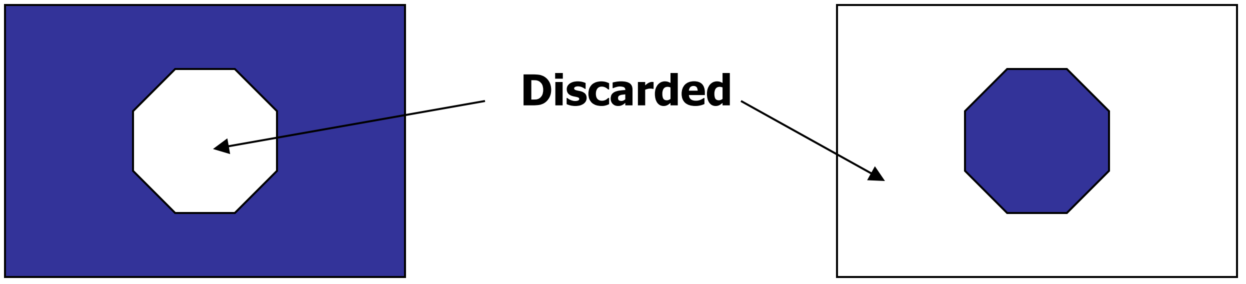
recycle → destroy

* There are exceptions, e.g. plasma cutting

Blanking and Punching

*

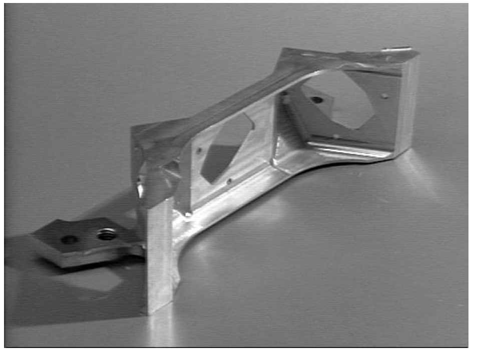




Punching **Blanking**

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

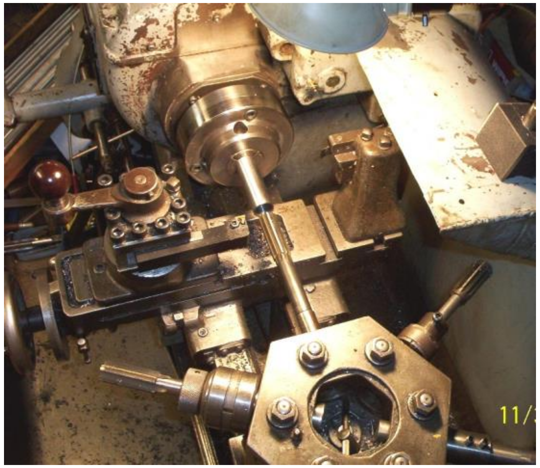
Machining

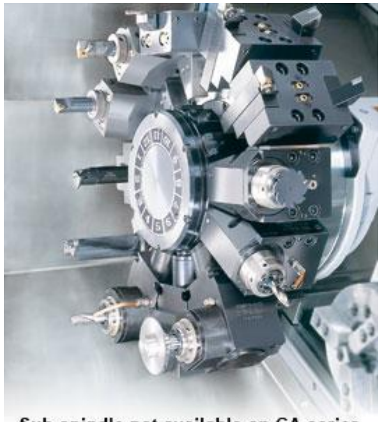


- Conventional Machining processes:
  - To first approx mat'l properties are independent of process
  - Very flexible
  - Good dimensional control (possible)
  - Good surface finish (possible)

Milling-rotating cutter

Turning-rotating part





Sub-spindle not available on GA series

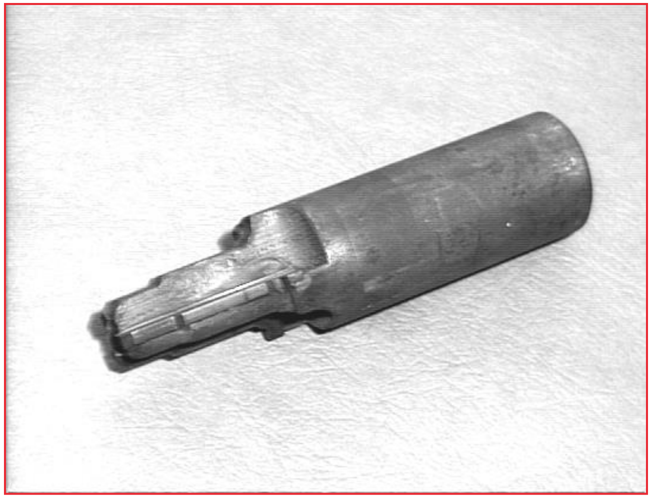
grinding

Surface grinding

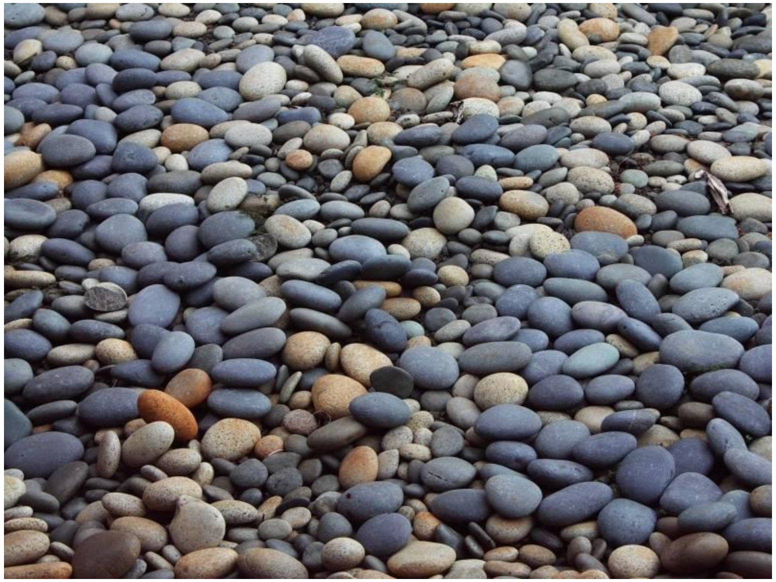
Cylindrical grinding

Variations

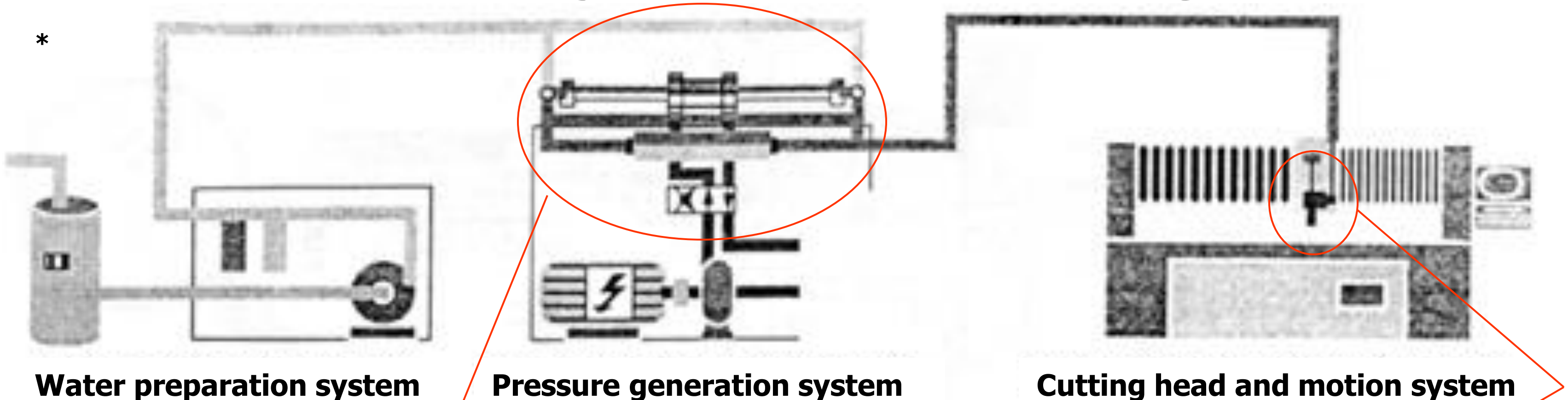
- Single point
- Multiple cutting teeth
- Form tools
- Multiple heads
- Fixturing
- Work handling
- Chip removal

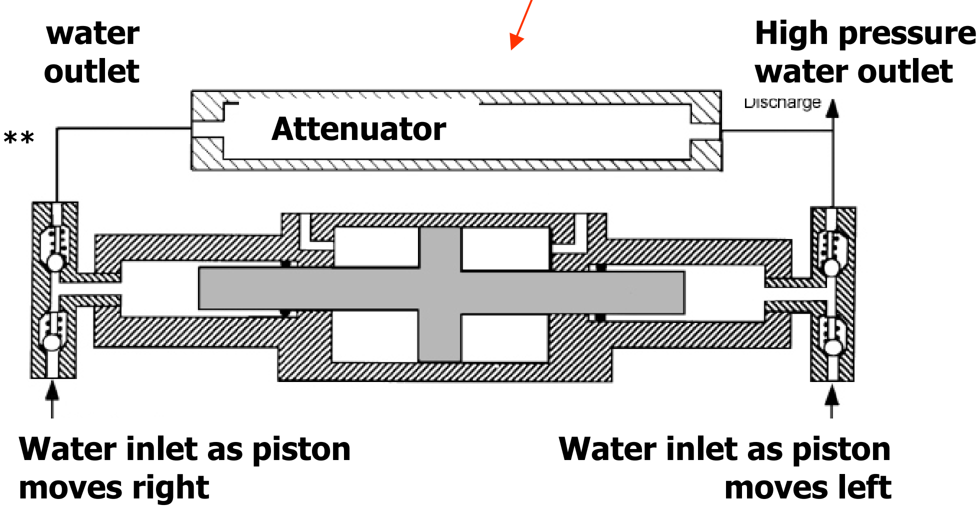


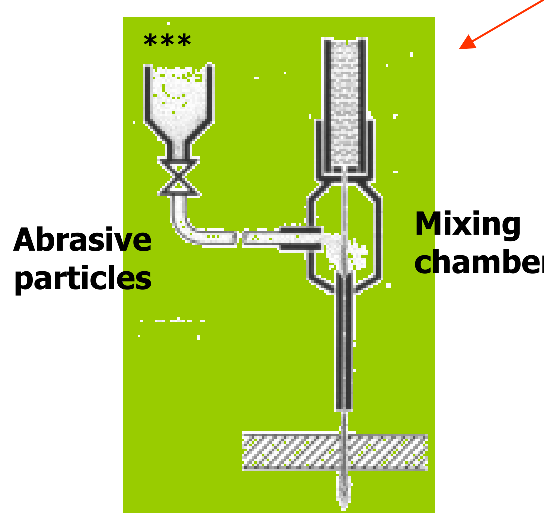
Removal by erosion



Waterjet Machining



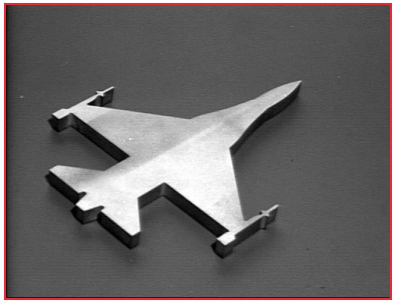




* Source: http://www.seas.smu.edu/rcam/research/waterjet/par1.html; ** http://www.seas.smu.edu/rcam/research/waterjet/par3.html;
*** http://kbm.mt.polsl.gliwice.pl/wjm/basics.html

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

Waterjet Machining



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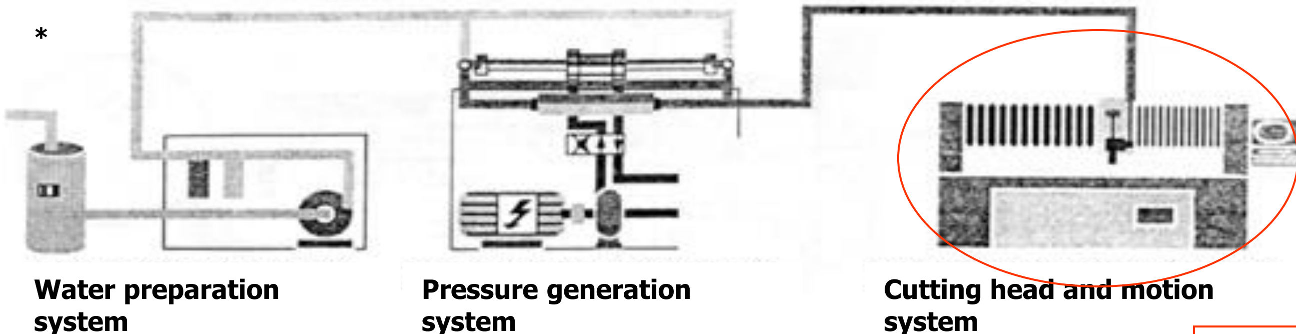

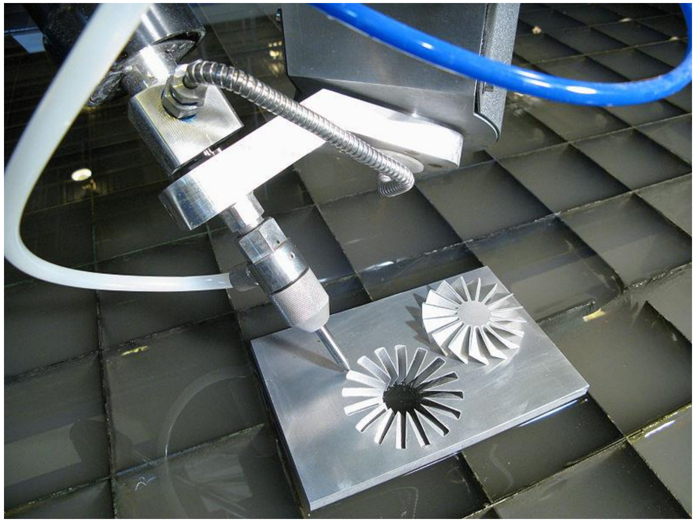

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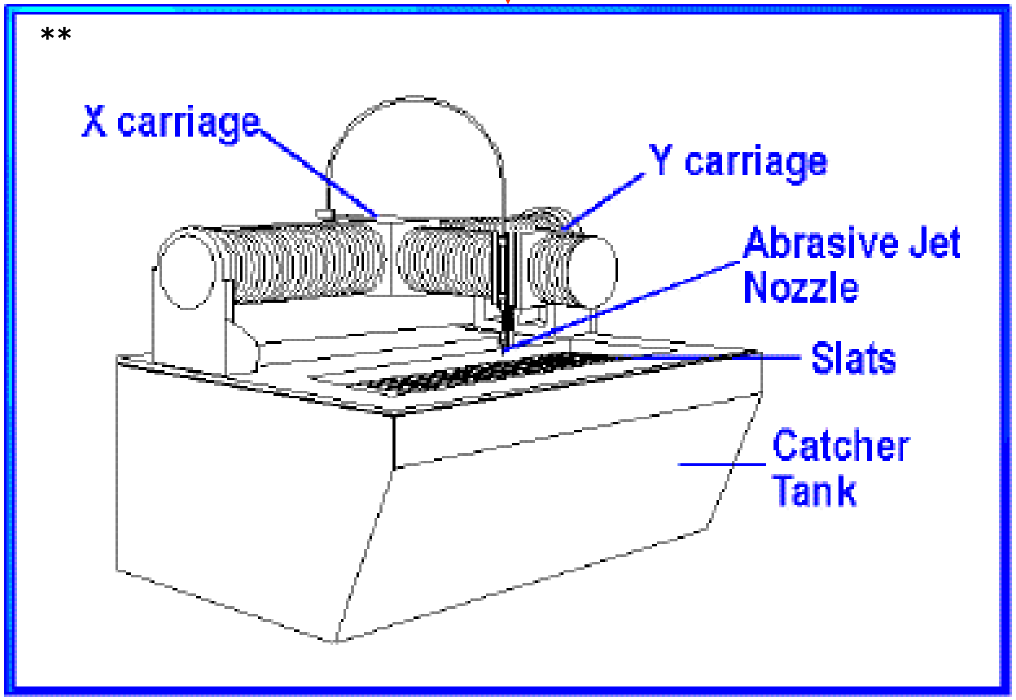
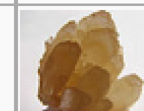
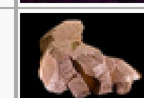
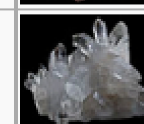
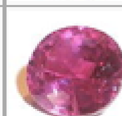
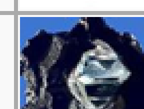


* Source: http://cybercut.berkeley.edu/mas2/html/processes/edm/index.html; ** http://www.omax.com/components_of_waterjet.html

Mohs Hardness scale

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	

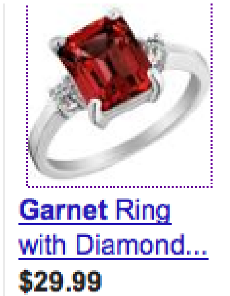
Cushion Garnet Ring with Diamond Halo in 14k White Gold
$1100.00 - Blue Nile

garnet

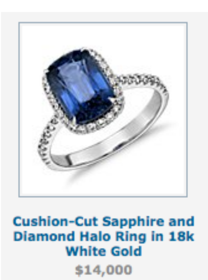
Cushion-Cut Sapphire and Diamond Halo Ring in 18k White Gold
$14,000

sapphire

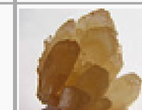
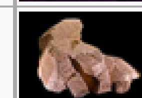
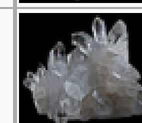
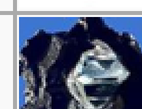
Mohs Hardness scale



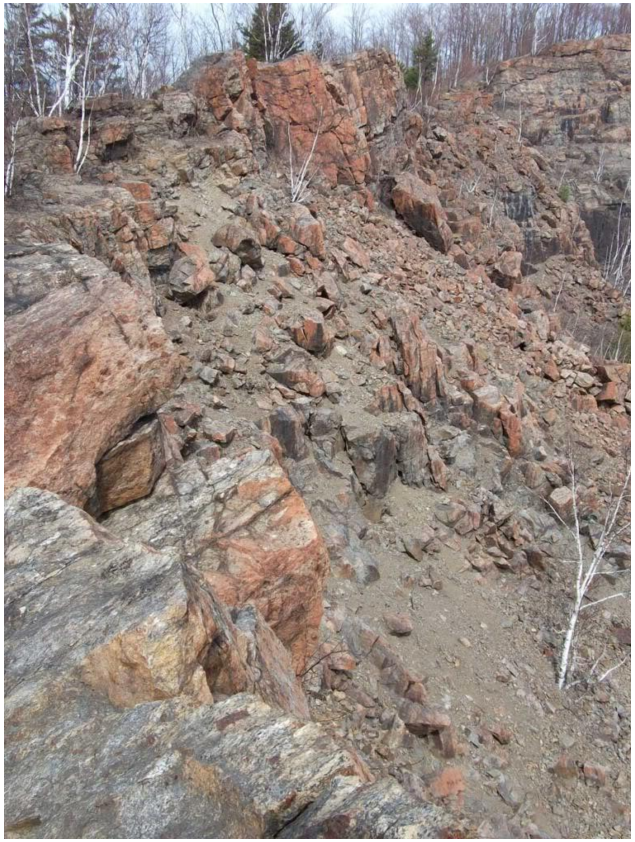
garnet



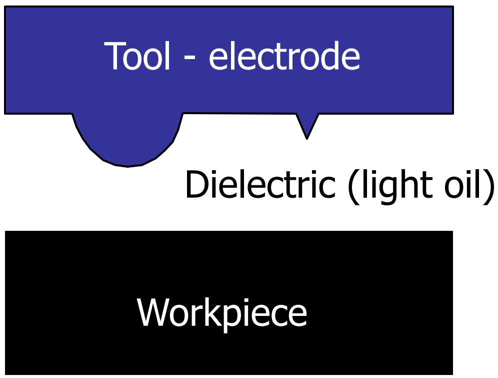
sapphire

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	

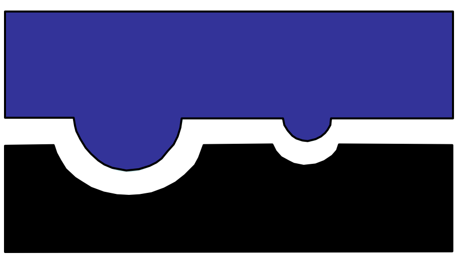
Gore Mt, New York



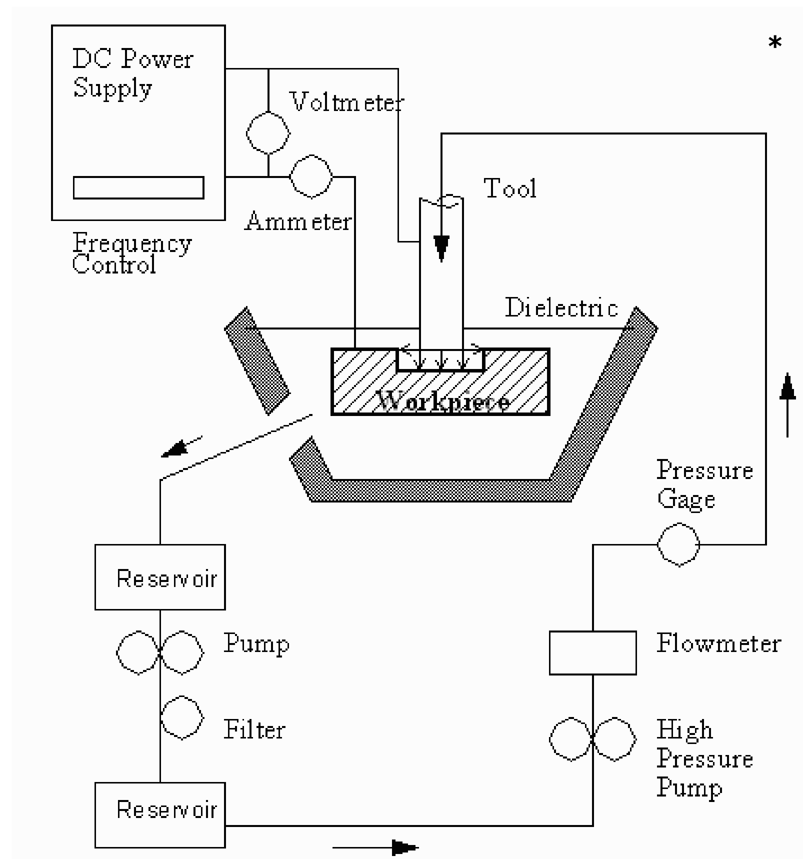
EDM (Electrical Discharge Machining)



Initial shapes of electrode and workpiece



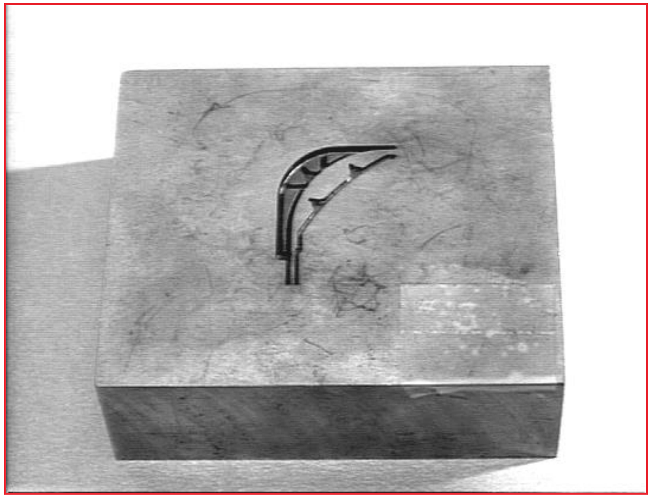
Final complementary shapes of electrode and workpiece

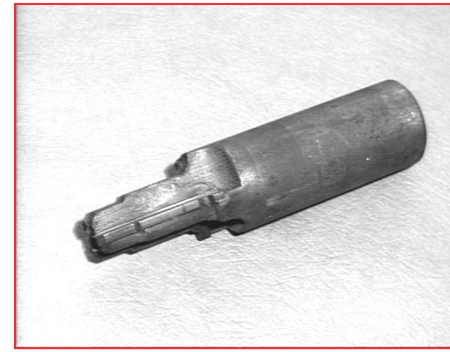


* Source: http://cybercut.berkeley.edu/mas2/html/processes/edm/index.html

Agitator for top loading washer

Mounted Electrode





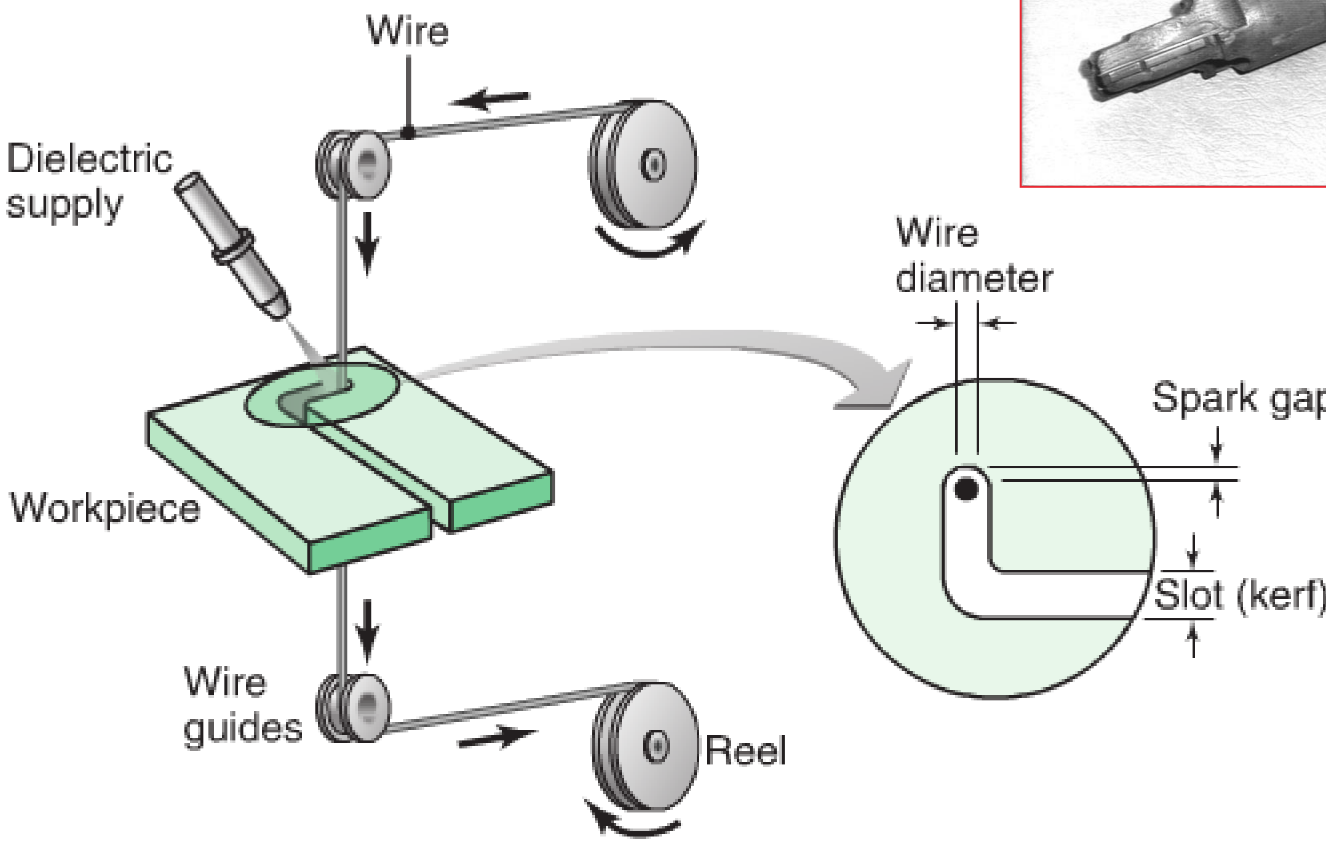
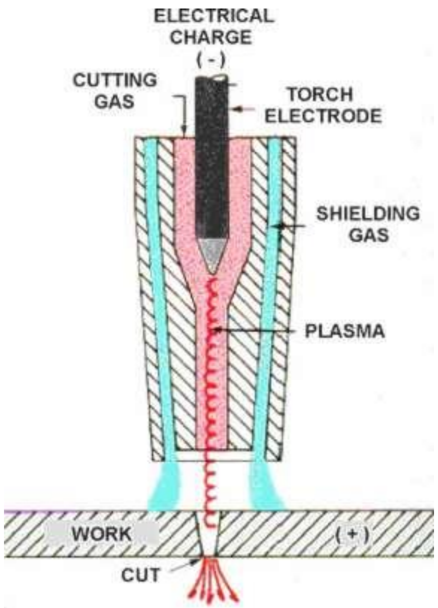
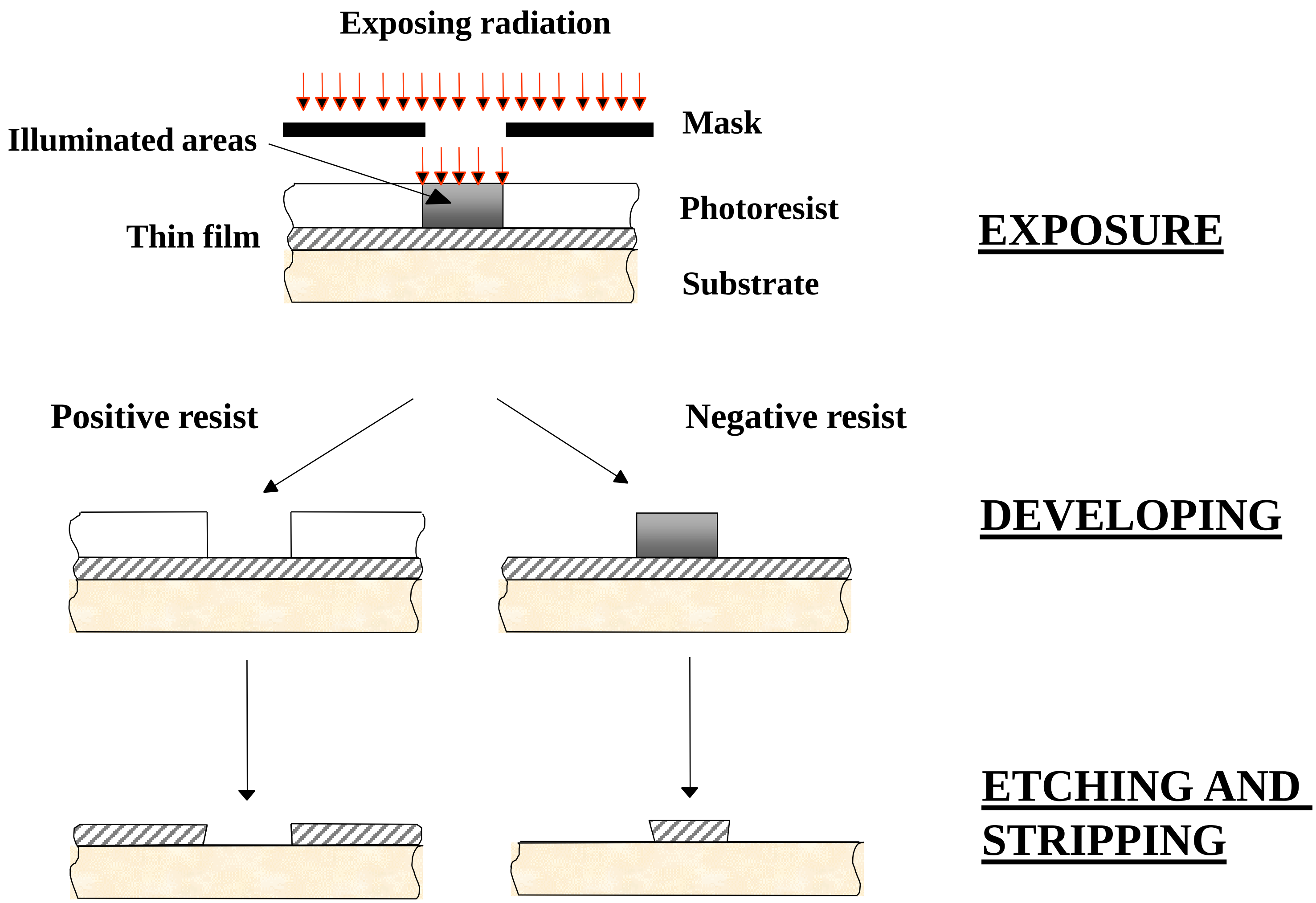


FIGURE 27.12 Schematic illustration of the wire EDM process. As many as 50 hours of machining can be performed with one reel of wire, which is then discarded.

Plasma arc cutting



Lithography (additive + subtractive)



2. Additive Processes

coarse

Assembly - manual, automated, robotic..

Joining - mechanical, adhesives, welding, brazing..

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

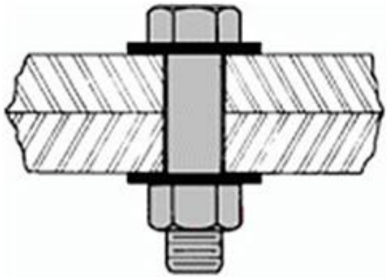
Additive manufacturing- 3D printing, stereo lithography…

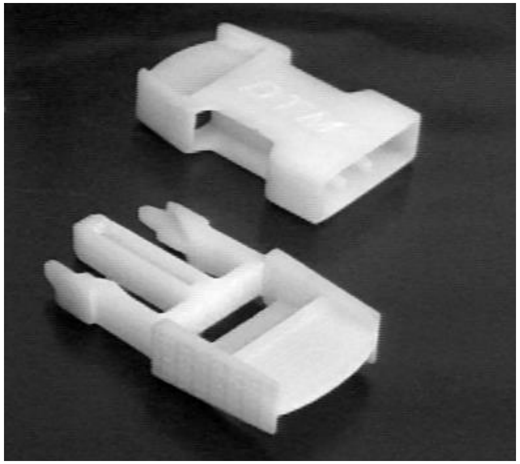
Surface & Thin Film Processes-

- liquids - coatings, painting, printing, plating…
- gases/vapor/atomic scale- CVD, PVD, sputtering

fine

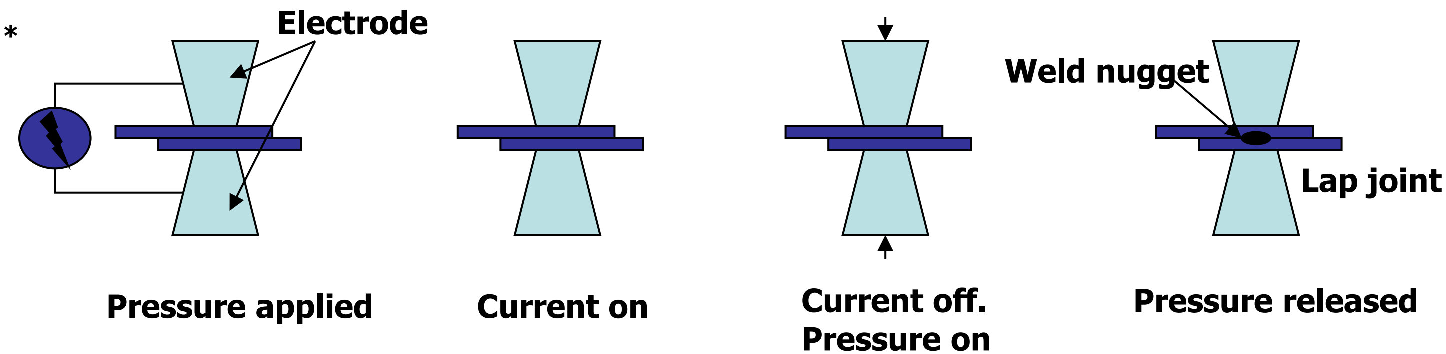
Mechanical joints





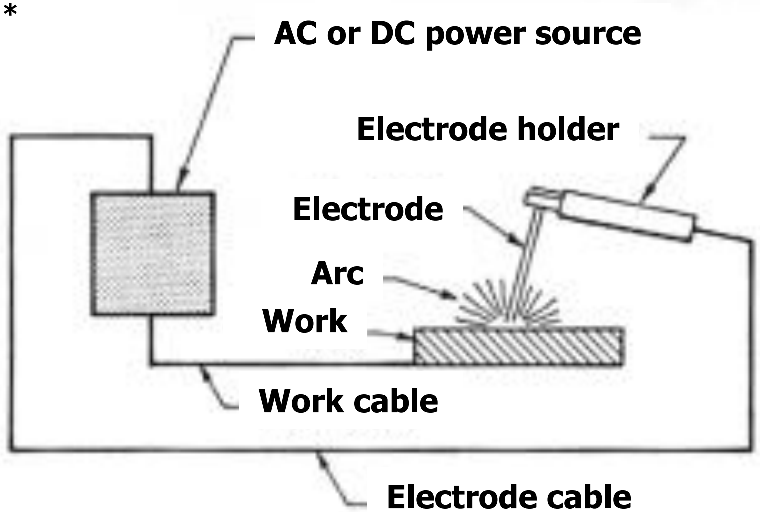
Welding

*



[Sequence in the resistance spot welding process]

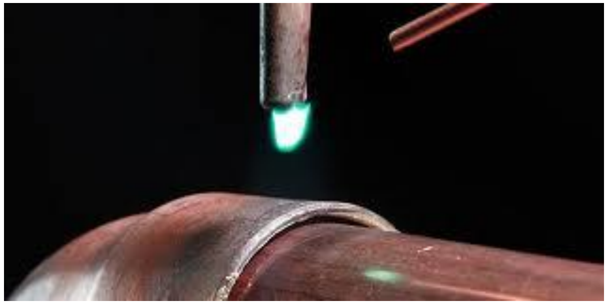
*

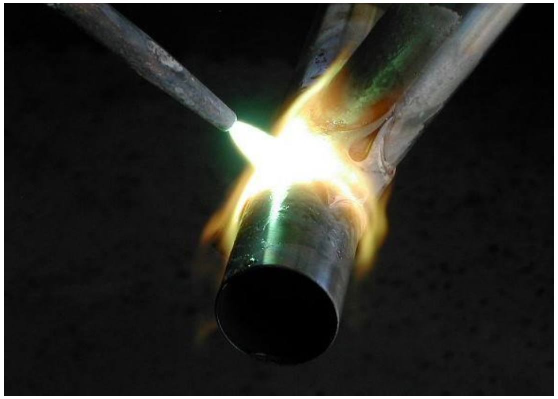


[Schematic illustration of the shielded metal-arc welding operation]

* Source: Kalpakjian, "Manufacturing Engineering and Technology"

Brazing



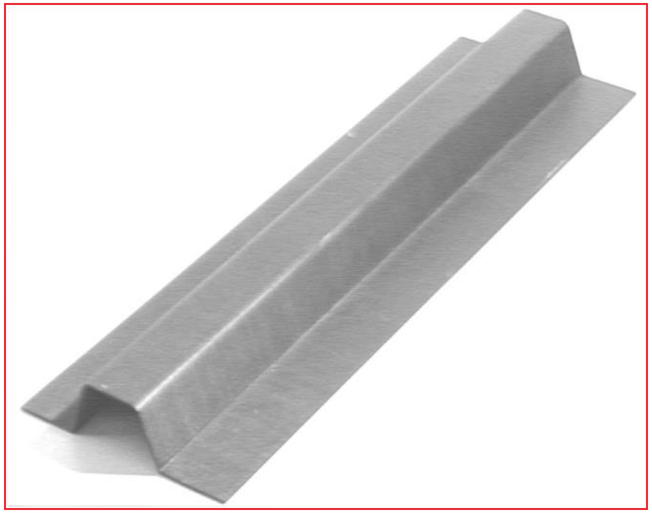


Furnace brazing

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

Lay-Up of Advanced Composites

*



Automated tape layup

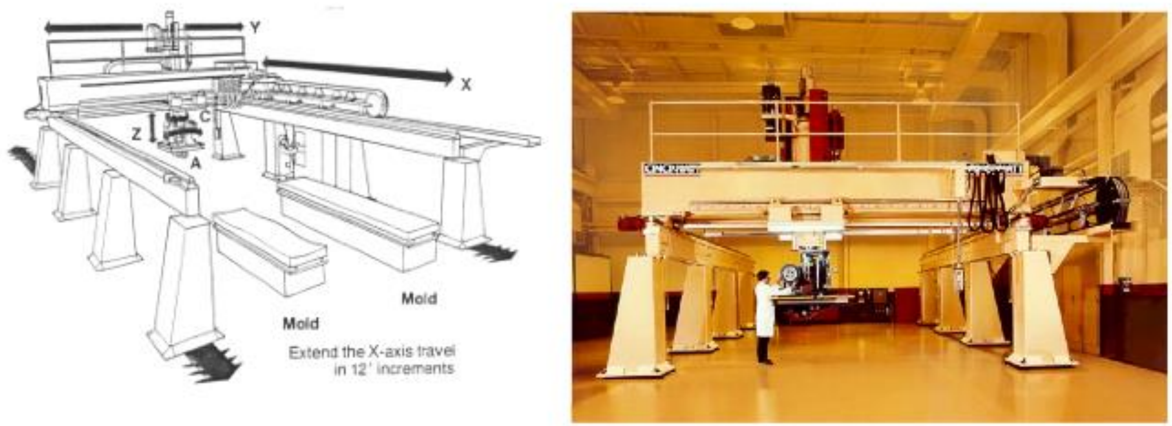


Fig 1.0 Tape Layer Configuration and Axis of Movement

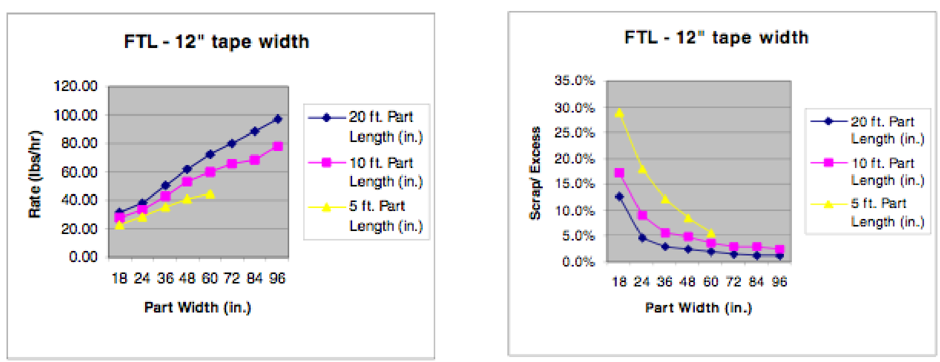


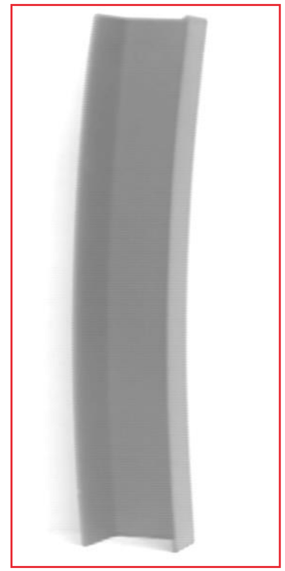
Fig 3.0 Simulation of FTLM Lay up and Scrap Rates

Ref Grimshaw, Grant, Luna Diaz

More complex shapes

Lay up

Forming



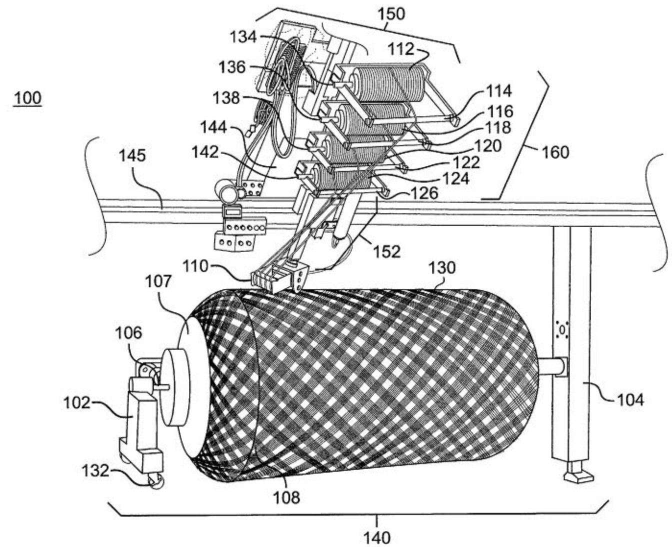
Aviation Week: Skunk Works' Cargo X-Plane Complete
Posted by Graham Warwick at 3/6/2009 12:14 PM CST

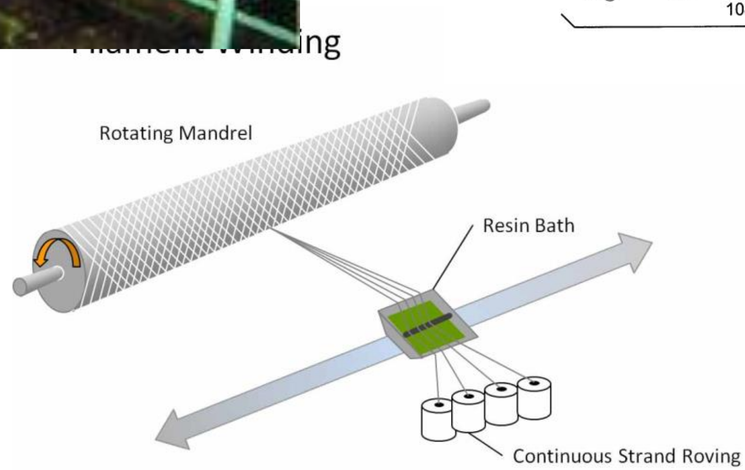
Wu, Tatting, Smith
And Thornburg

Figure 2. Fiber placement machine.

Sam Truslow, MIT,

Filament Winding



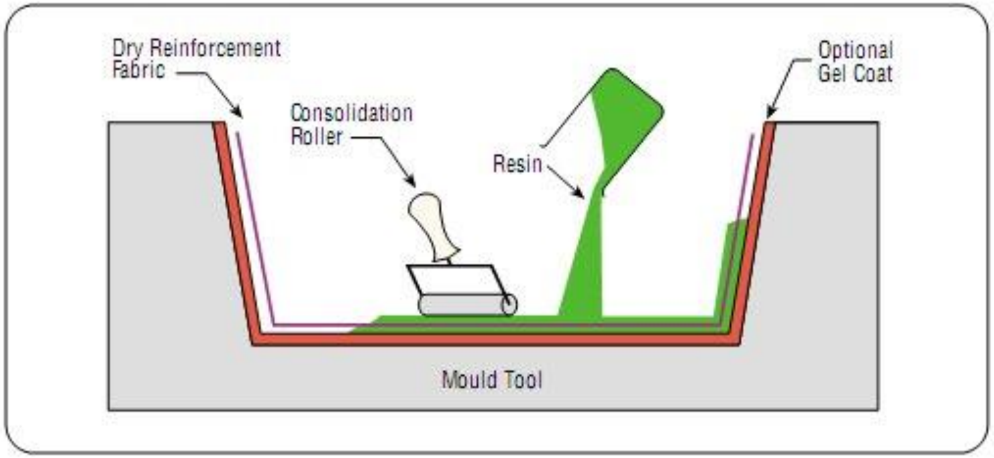


braiding

Braiding Videos

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

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

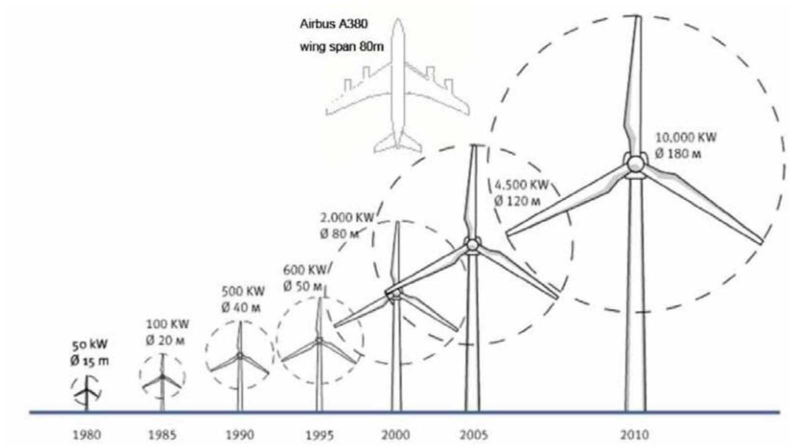


- Hand lay-up
- Spray-up
- Vacuum molding

Vacuum mold video
Jump to 4 min

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

Growing Wind Turbine Size



Additive Manufacturing

The Economist

The Third Industrial Revolution?

The Economist

Additive manufacturing

Print me a jet engine

Nov 22nd 2012, 12:54 by P.M.

Like 1.5k Tweet 126

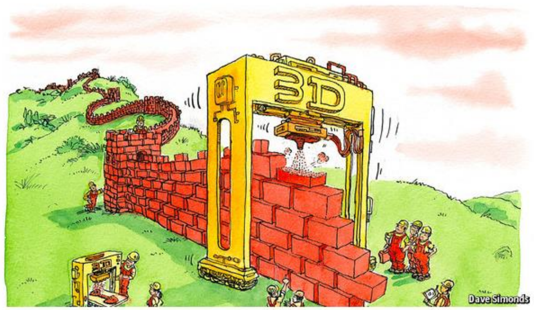
CONFIRMATION as to how seriously some companies are taking additive manufacturing, popularly known as 3D printing, came on November 20th when GE Aviation, part of the

A new brick in the Great Wall

Additive manufacturing is growing apace in China

Apr 27th 2013 | BEIJING | From the print edition

Like 939 Tweet 155



ALTHOUGH it is the weekend, a small factory in the Haidian district of Beijing is hard at work. Eight machines, the biggest the size of a delivery van, are busy making things. Yet

Print me a Stradivarius

How a new manufacturing technology will change the world

Feb 10th 2011 | From the print edition

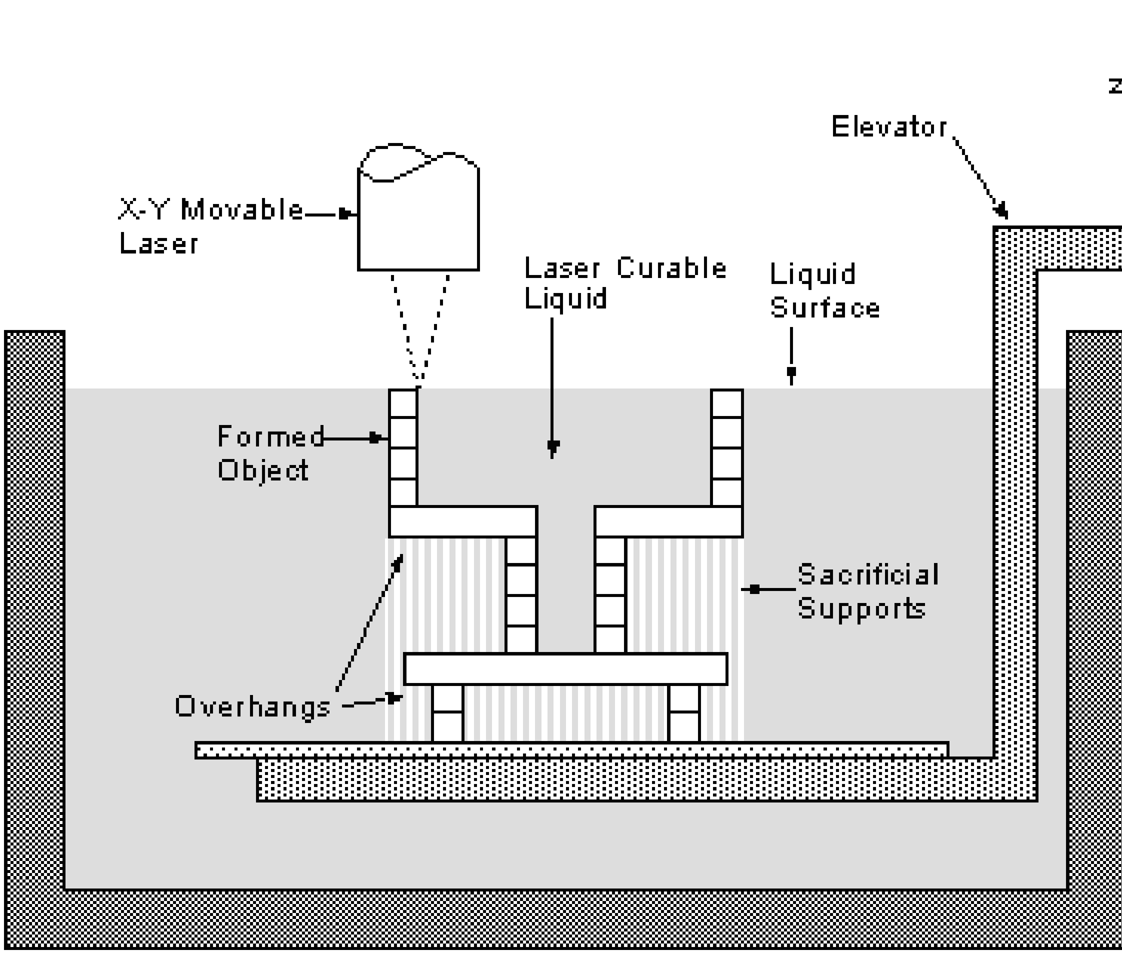
Like 10k Tweet 1,030

THE industrial revolution of the late 18th century made possible the mass production of goods, thereby creating economies of scale which changed the economy—and

Transition from prototypes, to tooling, to parts

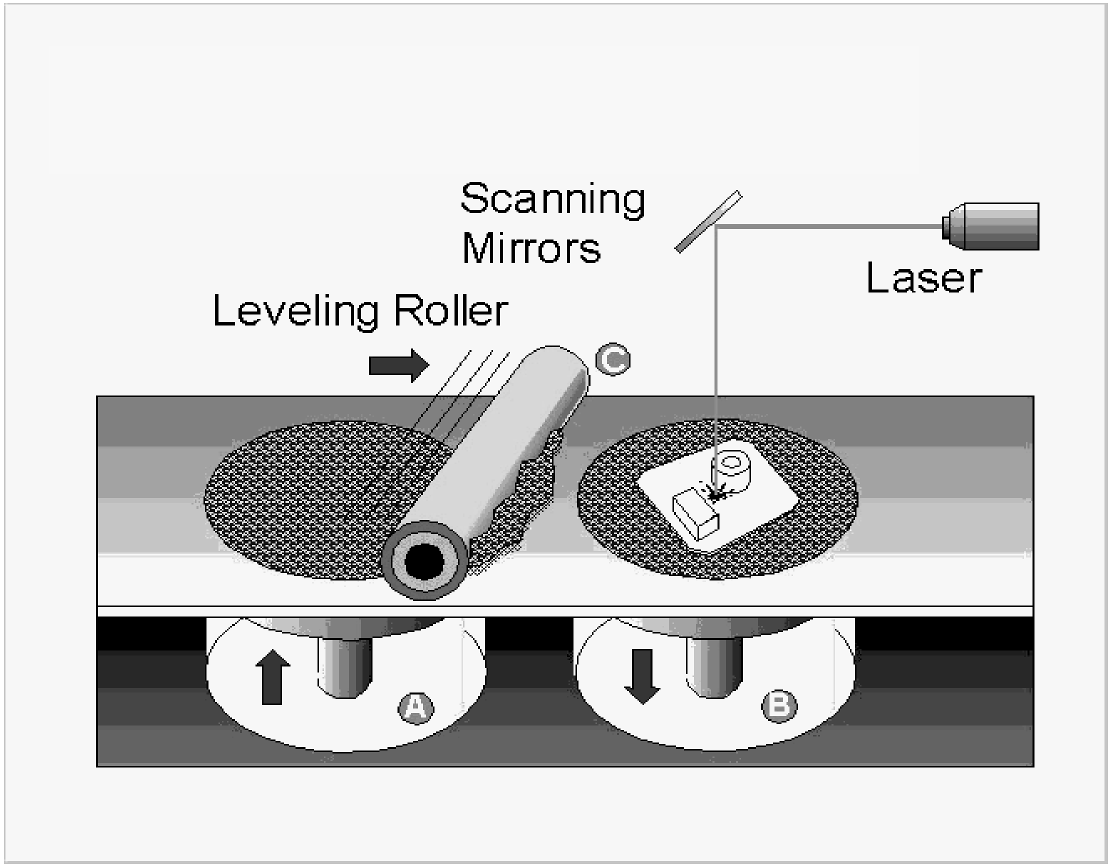
Stereolithography (SLA)

*



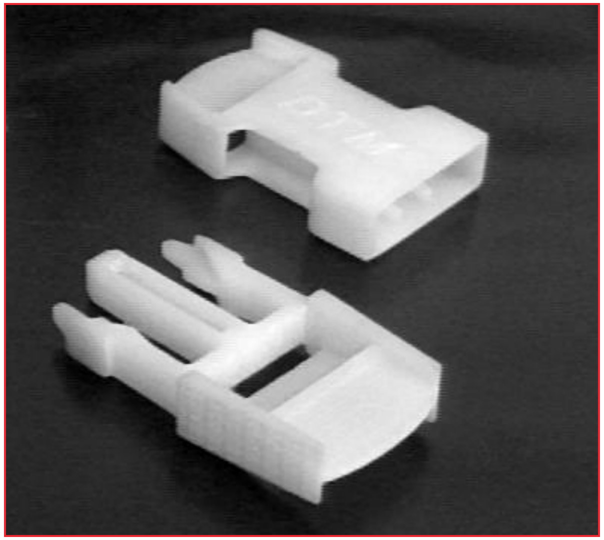
* Source: http://cybercut.berkeley.edu/mas2/html/processes/stereolith/more.html

Selective Laser Sintering (SLS)



* Source: Michelle Griffith and John S. Lamancusa, "Rapid Prototyping Technologies," Rapid Prototyping. 1998

Selective Laser Sintering (SLS)



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

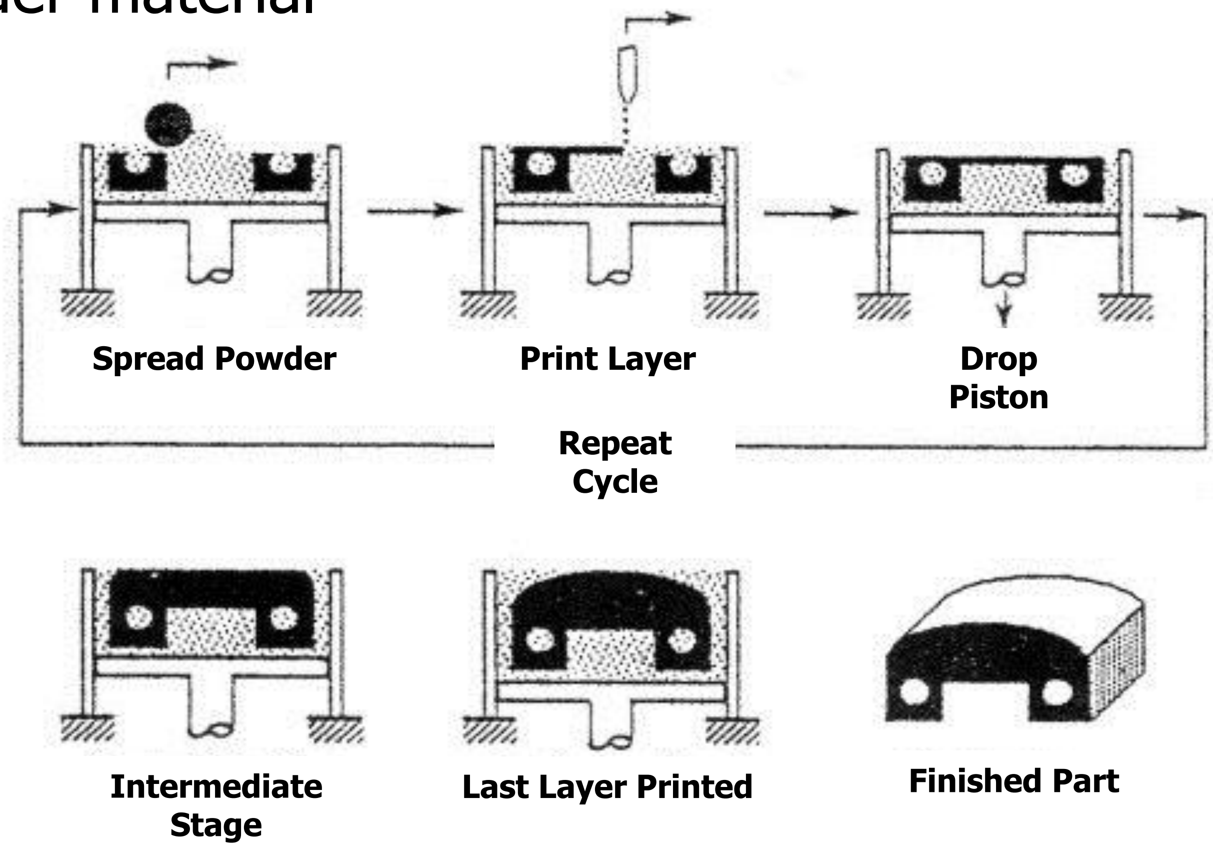
http://www.youtube.com/watch?v=SVkUwqzjGJY

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

* Source: DTM Corporation (3D Systems)

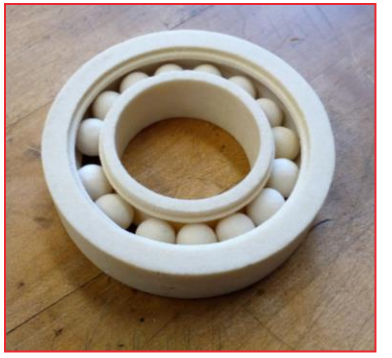
3D Printing

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



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

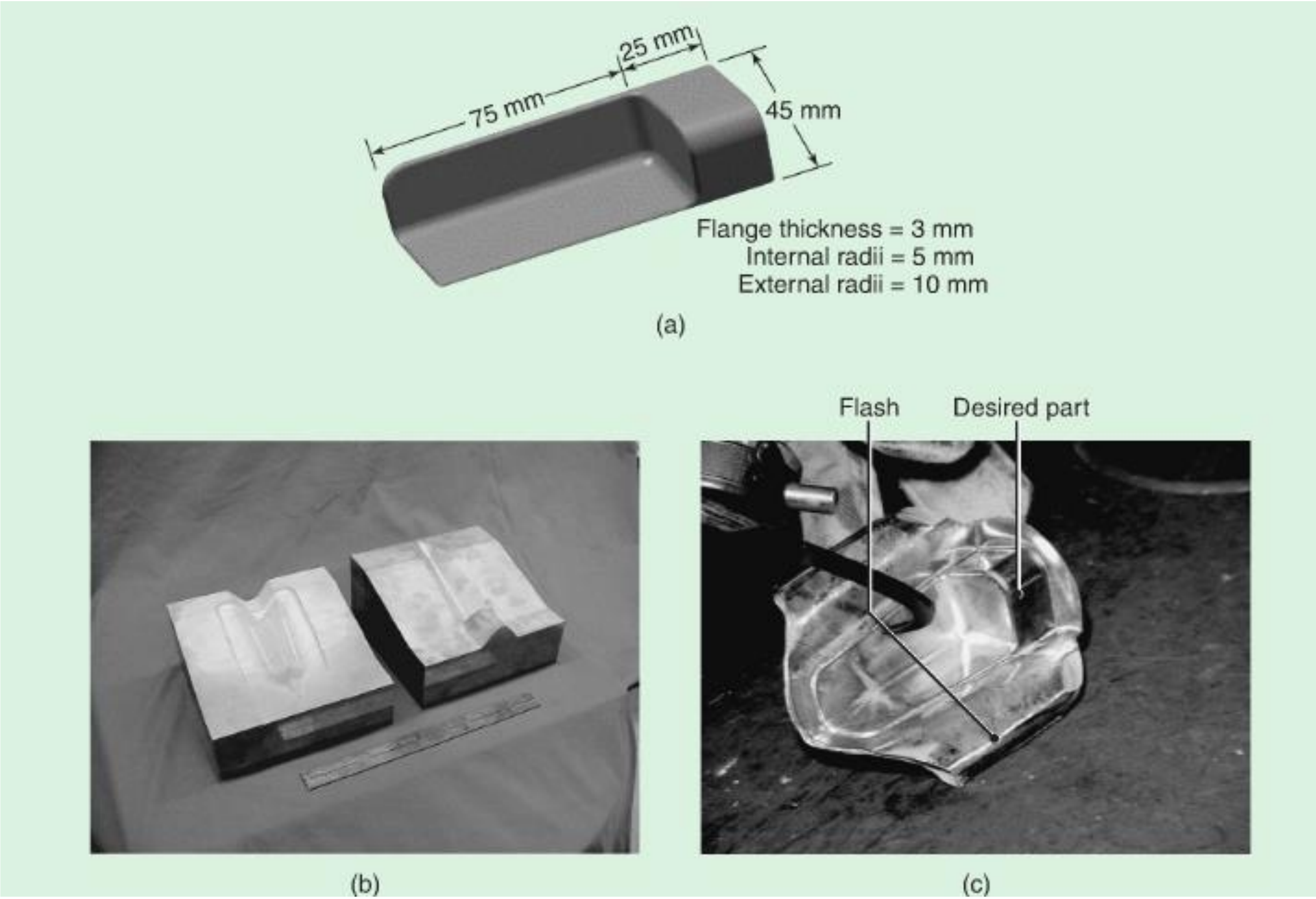
Z corp rapid prototyping



http://www.youtube.com/watch?v=u7h09dTVkdw

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

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



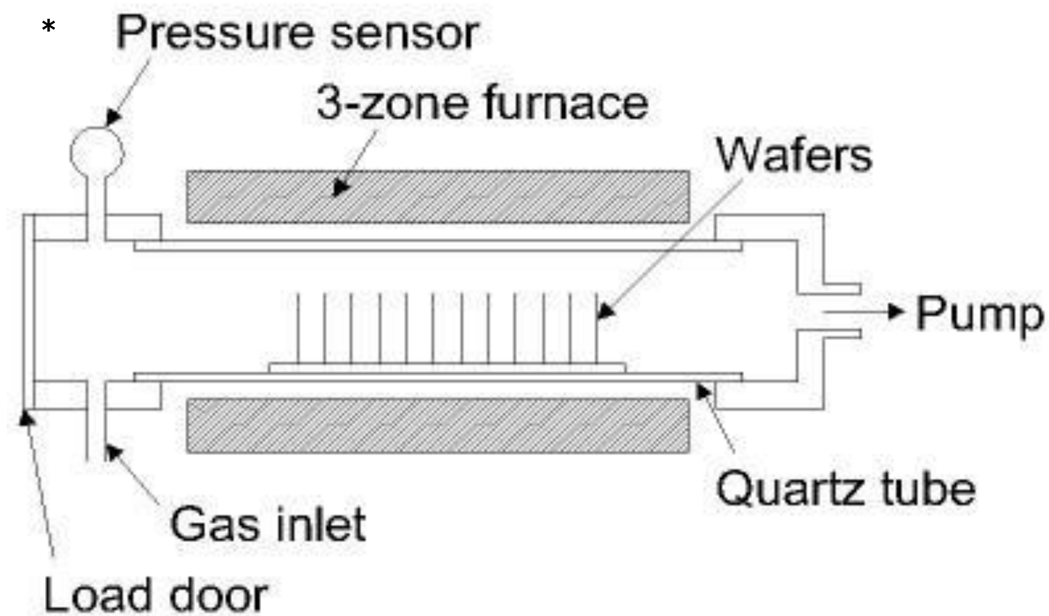
Forging Die made by 3D printing

CVD (Chemical Vapor Deposition)

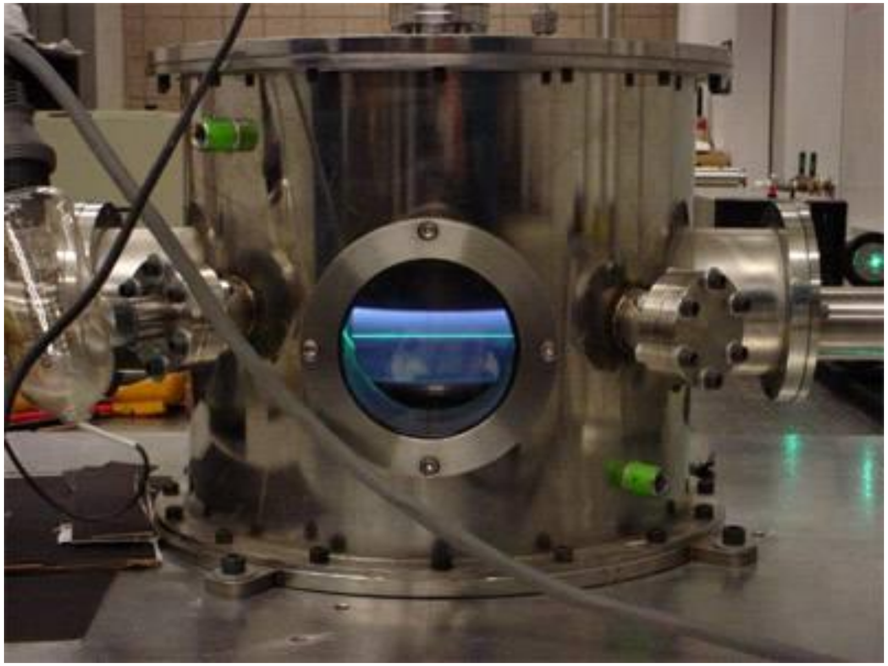
- Creates solid materials directly from chemical reactions in gas and/or liquid compositions or with the substrate material
- LP(Low Pressure) CVD, PE(Plasma Enhanced) CVD

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

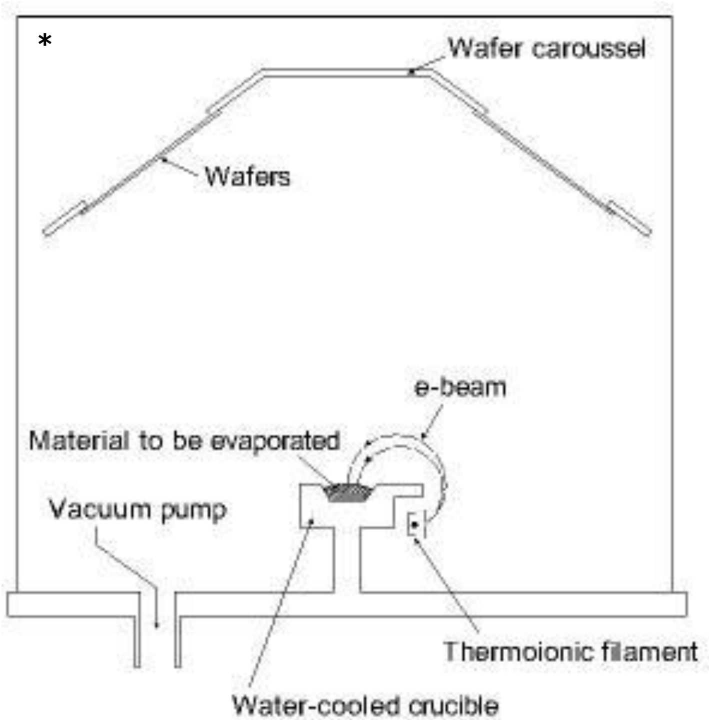
$$SiH_4 + O_2 \rightarrow SiO_2 + 2H_2$$

Siemens CVD Process for the Purification of Si

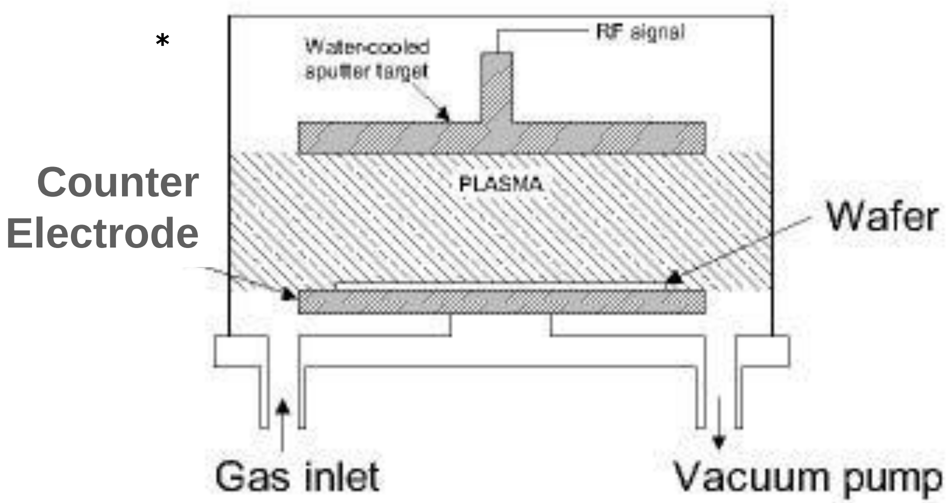
$$2\ HSiCl_3 \rightarrow$$
$$Si + 2\ HCl + SiCl_4$$

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

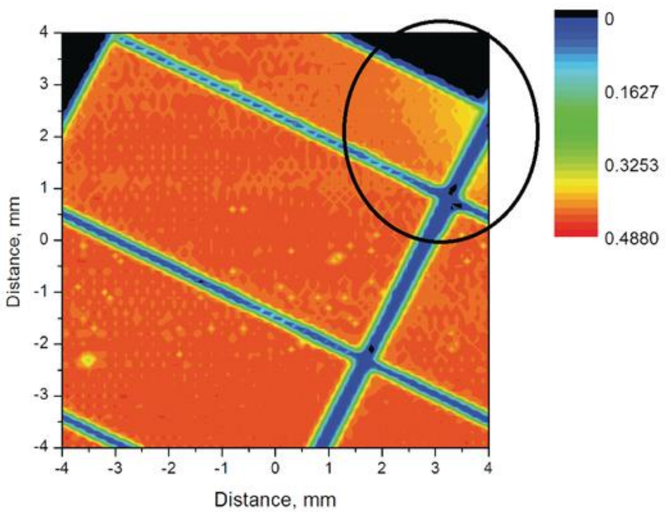
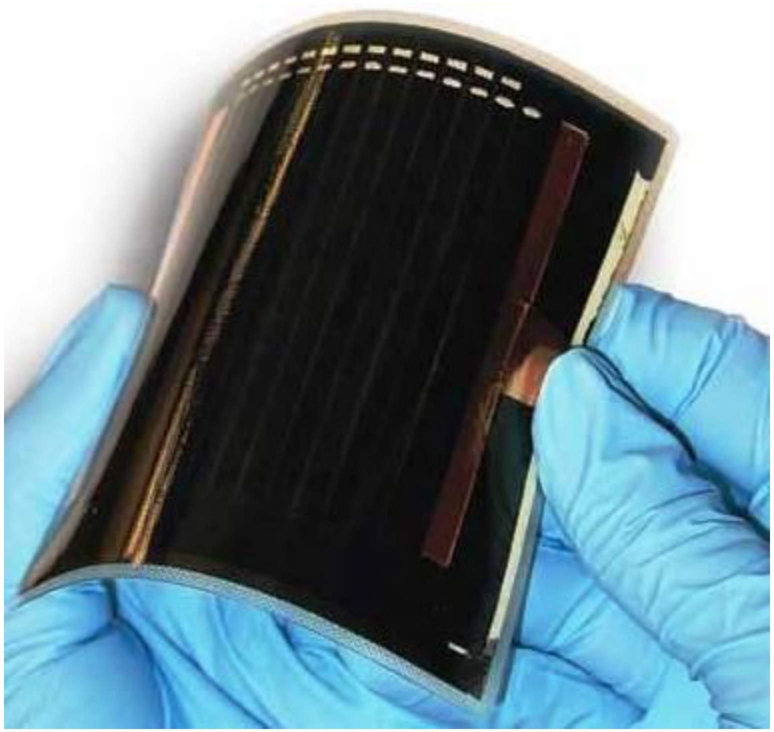


Photo-response mapping
Of a CIGS cell



Ascent CIGS Solar Cell

3. Continuous Processes

- Pushing
  - Metals extrusion
  - Plastics extrusion
  - Continuous casting

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

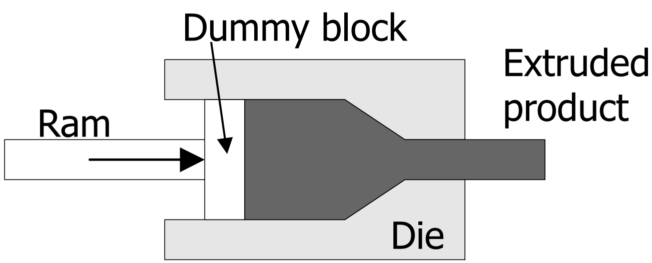
Pros and Cons

- + Low unit cost for large runs
- + Low unit cost for large runs
- + Low unit cost for large runs

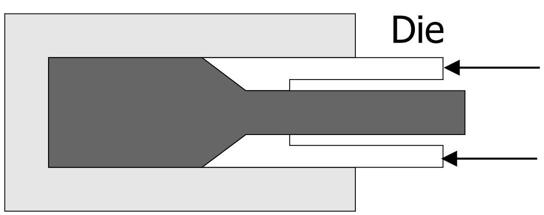
- - constant cross section
- - constant cross section
- - constant cross section

Examples of extruded products

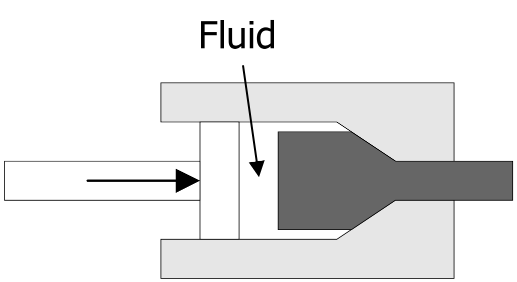
Metal Extrusion



Direct extrusion process



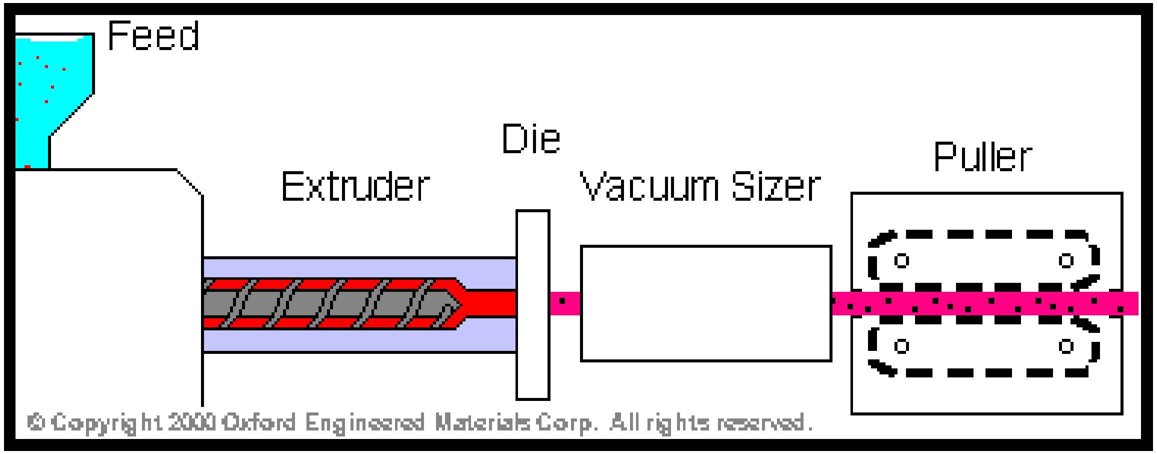
Indirect extrusion process



Hydrostatic extrusion process

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

Plastic Extrusion



Single Screw Plastics Extruder

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

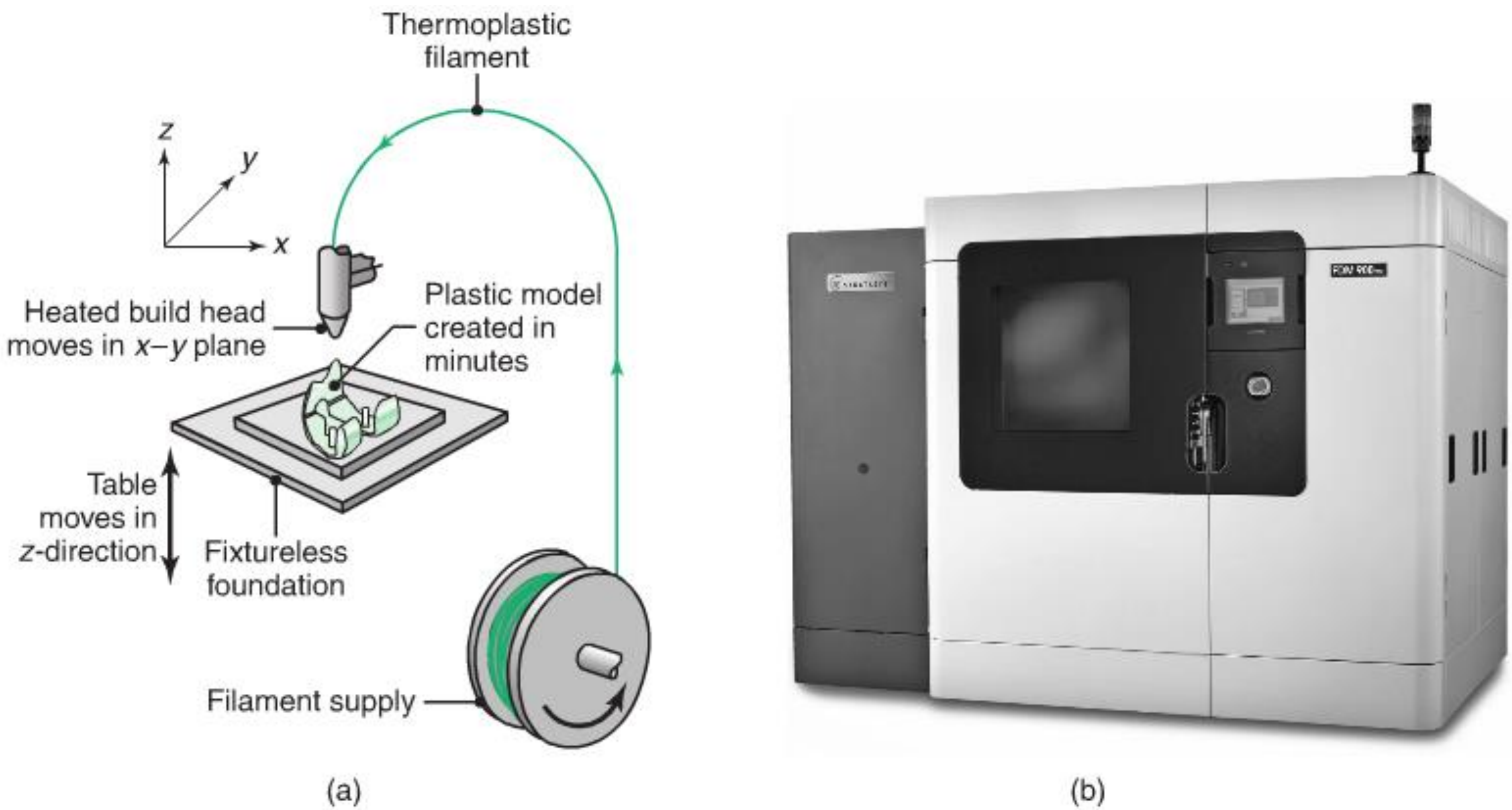
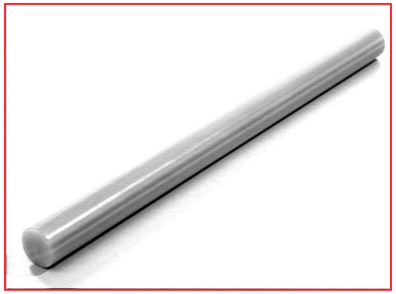


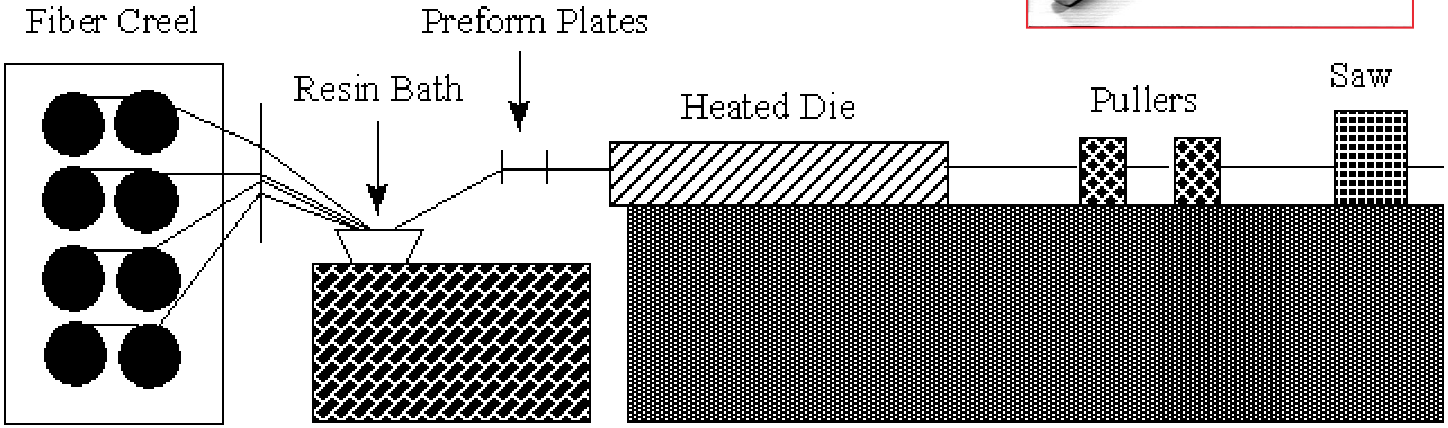
FIGURE 20.4 (a) Schematic illustration of the fused-deposition-modeling process. (b) The FDM 900mc, a fused-deposition-modeling machine. *Source*: Courtesy of Stratasys, Inc.

Plastic extrusion used in rapid prototyping

Pultrusion of Composites



*



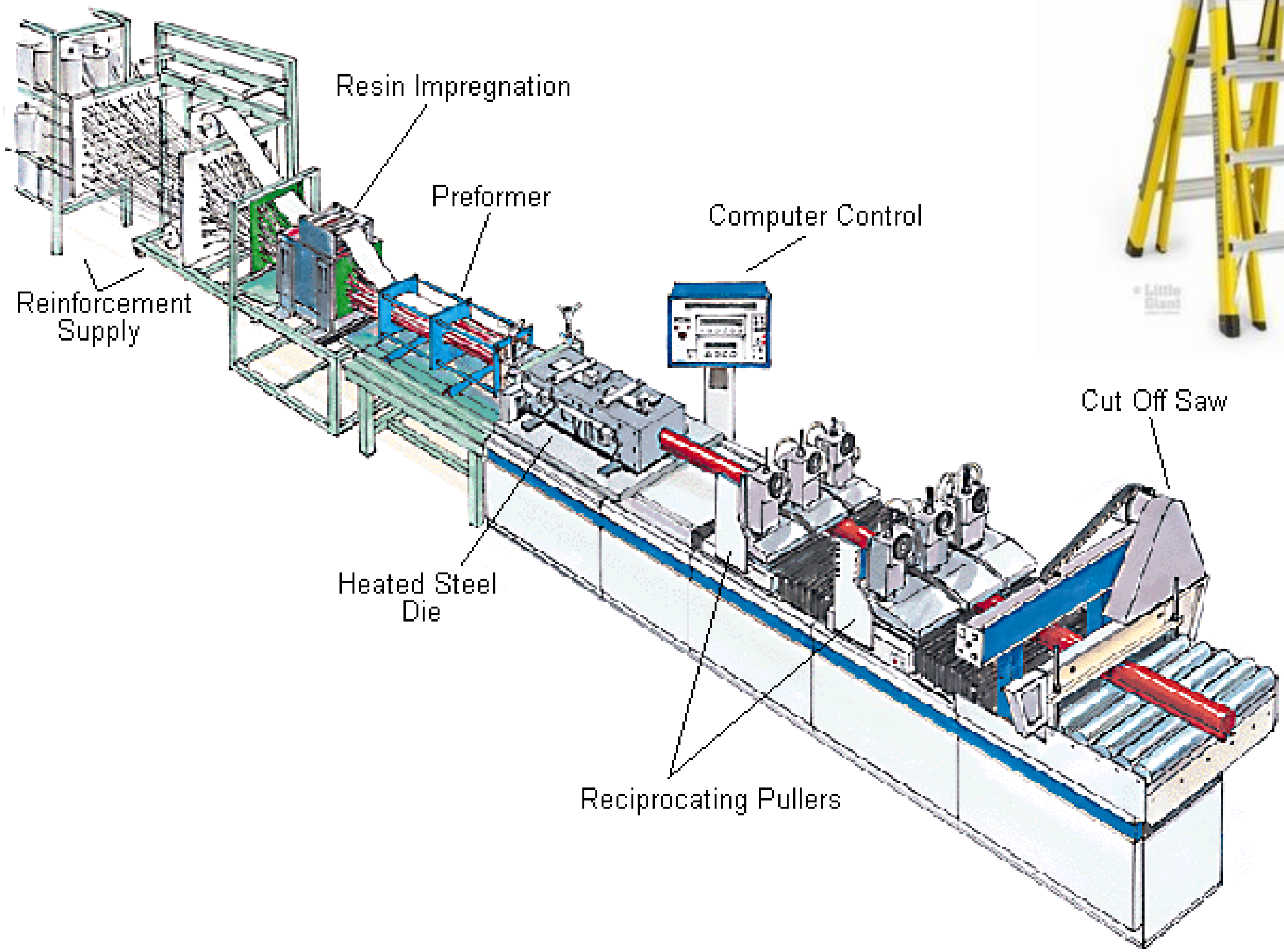
Schematic Diagram of the Pultrusion Process

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

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

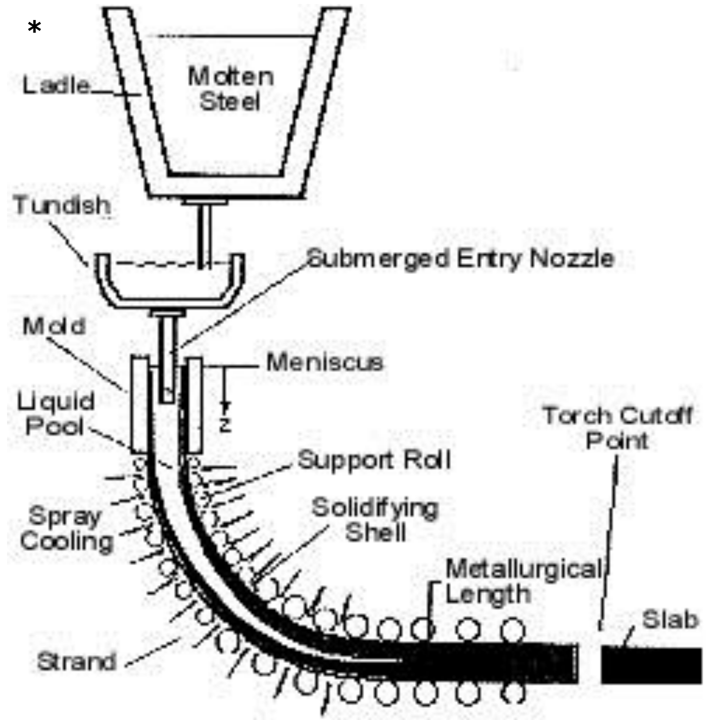
Pultrusion machine

*



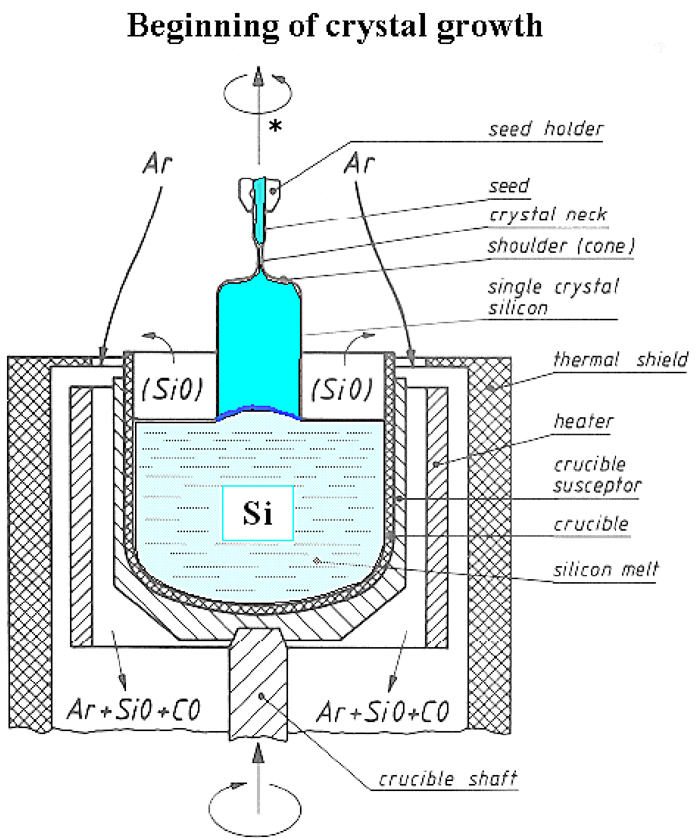
* Source: http://howard.engr.siu.edu/staff2/abrate/NSFATE/camps/pult.htm

Continuous Casting



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

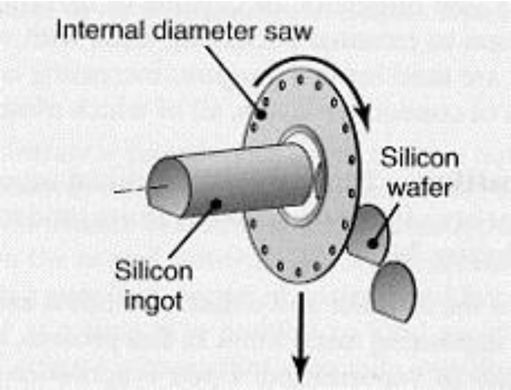
Czochralski(CZ) Crystal Growth

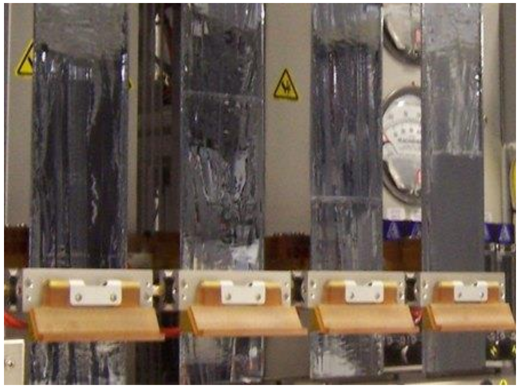


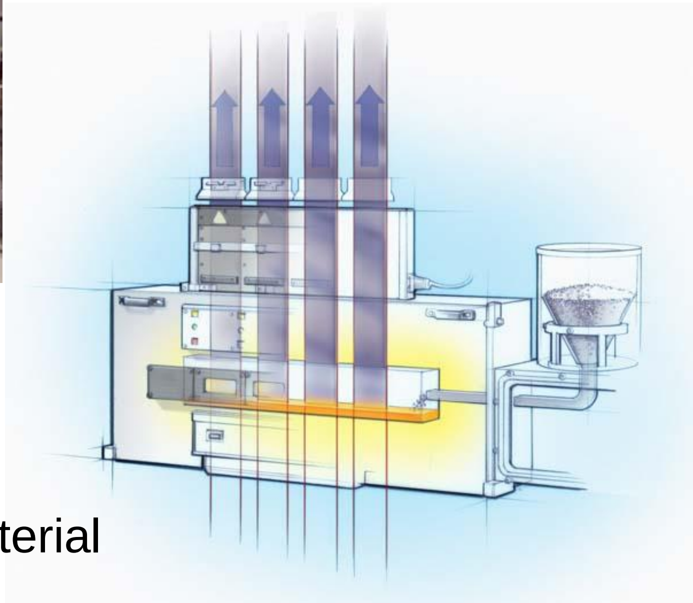
http://www.youtube.com/watch?v=cYj_vqcyI78

* 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 exergy

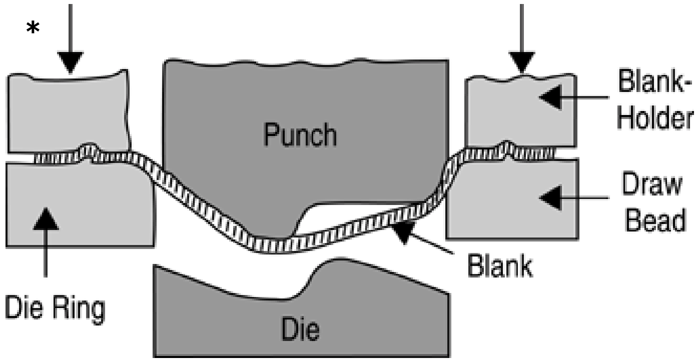
String-Ribbon
Invented by
Ely Sachs
saves this material

4. Net Shape: Molding

- Types
  - Solids: Metal Forming, Powders, Others
  - Liquids: Casting, Injection Molding, Others
  - Mixtures: Infiltration, Viscoelastics, Others
- Characteristics
  - Hard tooling
  - Solid forming – very fast cycle time
  - Thermal processes – slower and depend upon cooling rate
  - Dimensional control is not as good as machining

Sheet Metal Stamping

*

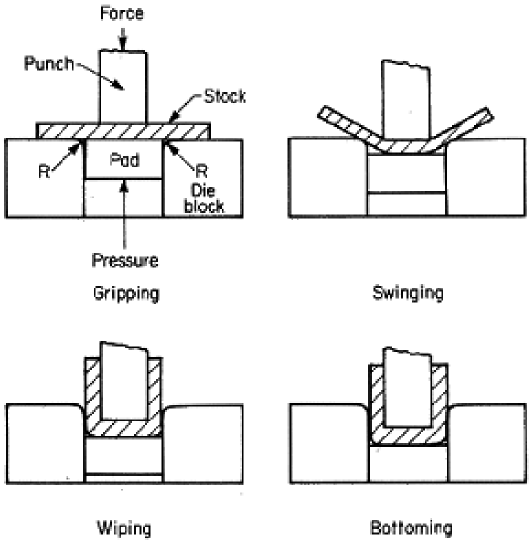


Typical Stamping Die

**

GM stamping plant go to
Around 2:39

**



Drawing

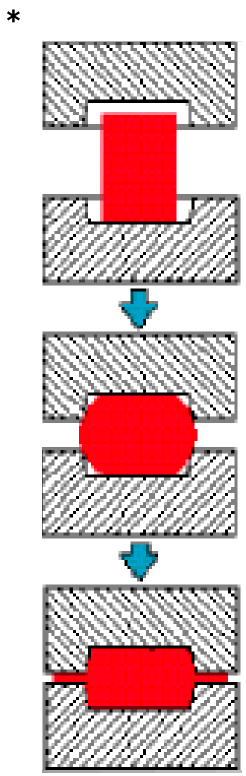
http://www.youtube.com/watch?v=ixPhogfZTHU&feature=related

Forming

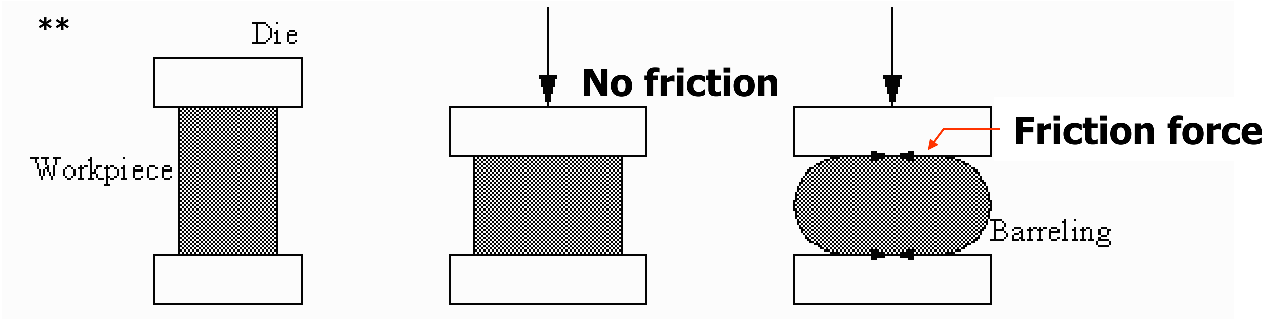
* Source: http://www.tms.org/pubs/journals/JOM/9911/Hosford-9911-figure1.html; **: http://bdi-inc.qc.ca/processes/stamping/sp.html

http://www.youtube.com/watch?v=mRA6RY2o9Lg

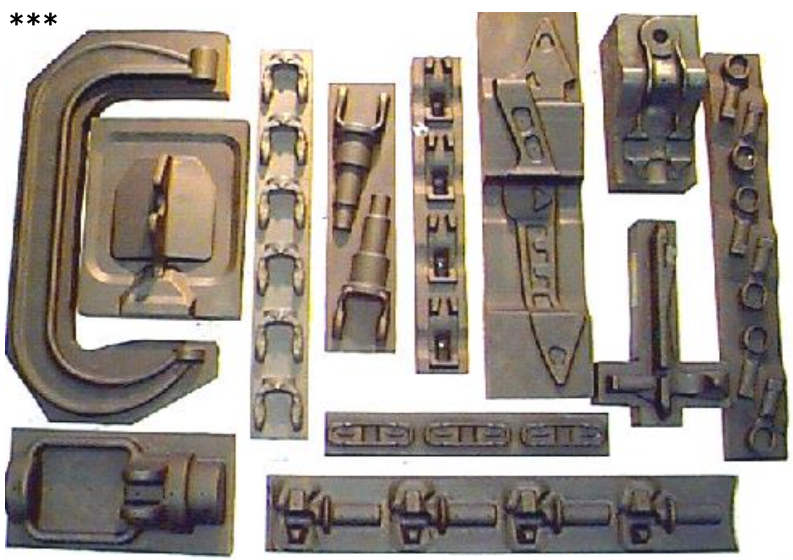
Forging



Closed Die Forging



Open Die Forging

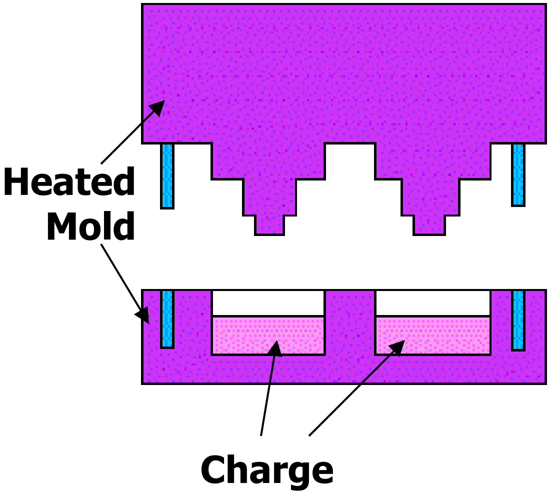


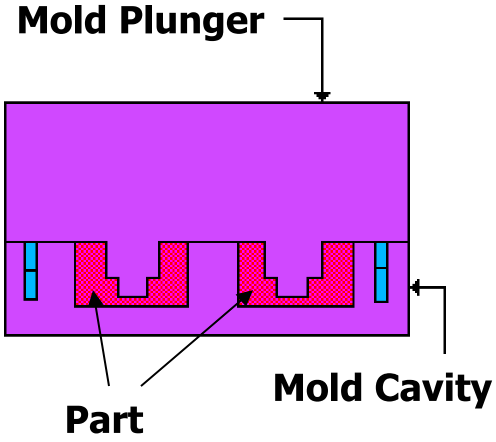
* Source: http://www.forging.org/facts/wwhy6.htm#fig3; **: Kalpakjian, "Manufacturing Engineering and Technology"; ***: http://www.johnsonforging.com


LION
SABATIER®
FRANCE

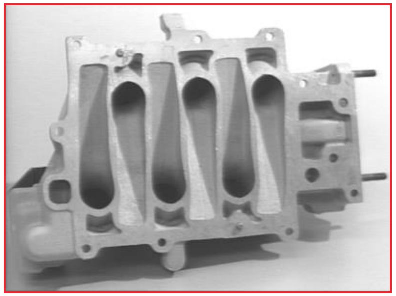
Compression Molding

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



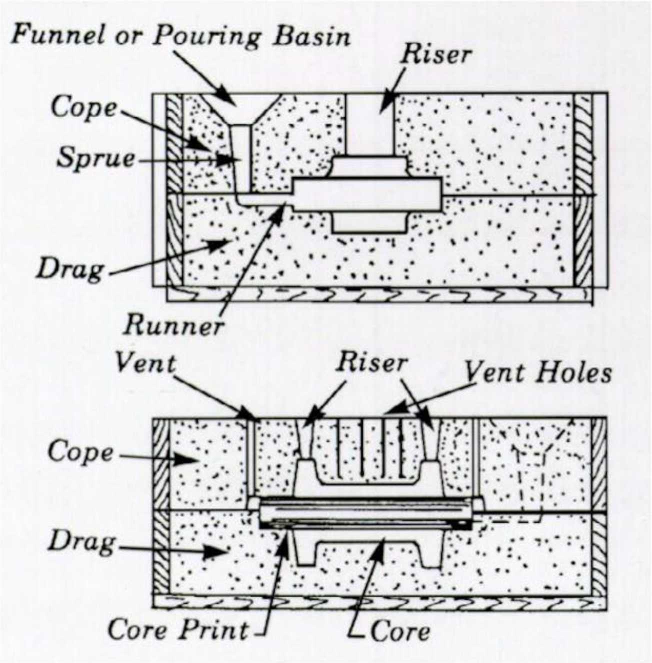


* Source: http://www.mahidol.ac.th/mahidol/eg/em_proj/group7/htm1text.htm

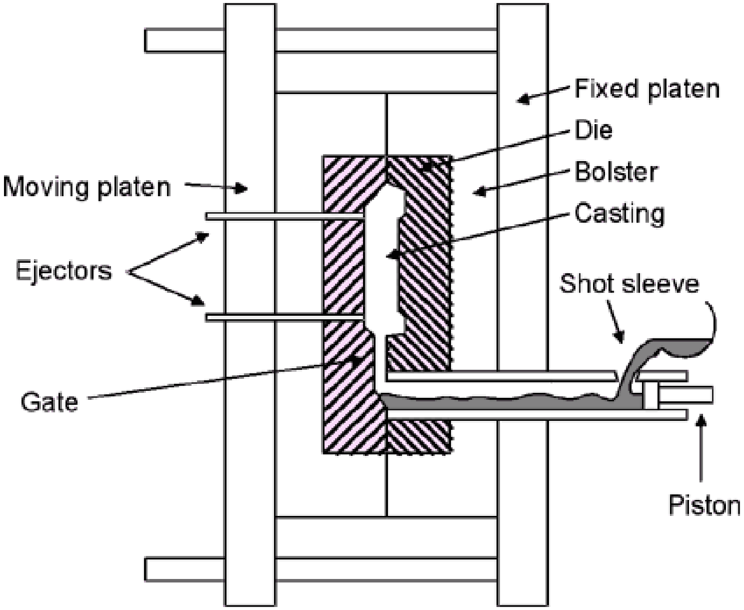


Metal Casting

*   **



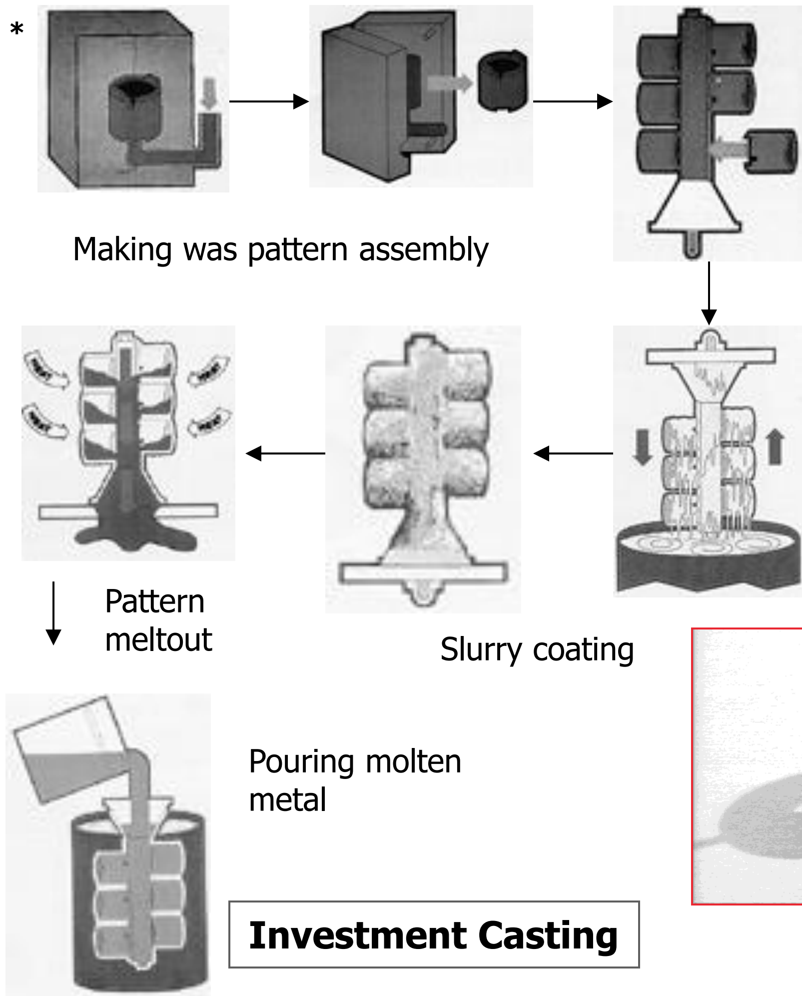
Sand Casting Mold



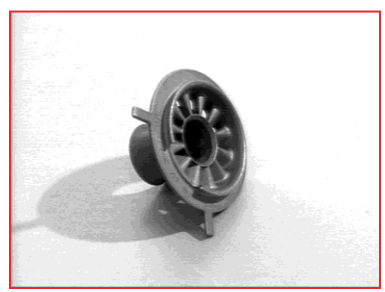
Die Casting machine

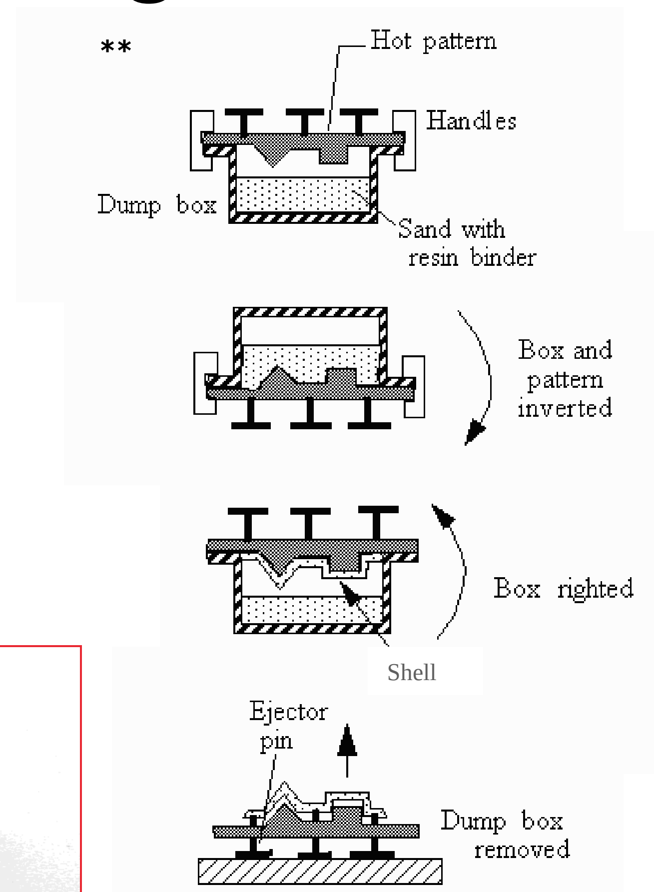
* Source: http://www.cepsales.com/Castings.htm ; ** http://www.eaa.net/pages/material/casting.html

Metal Casting



Investment Casting



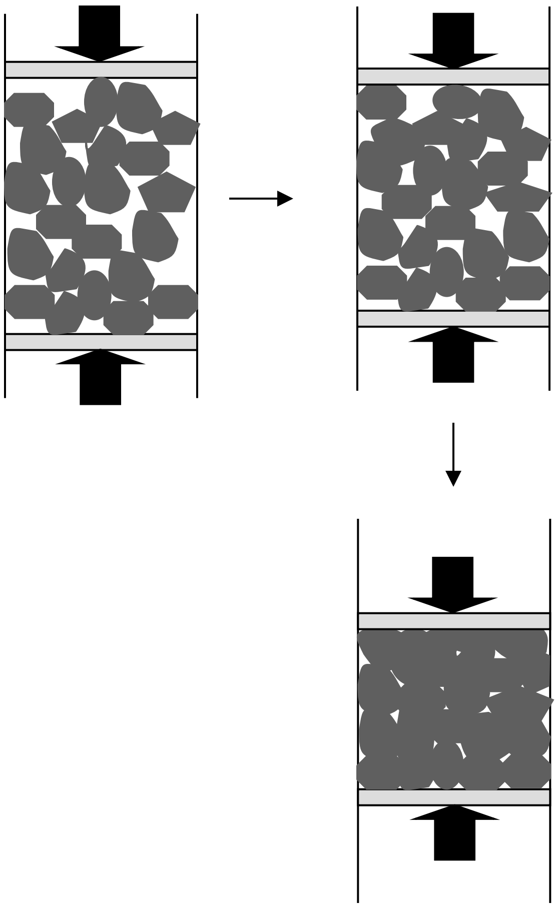


Shell Mold Casting

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

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

P/M: Powder Compaction



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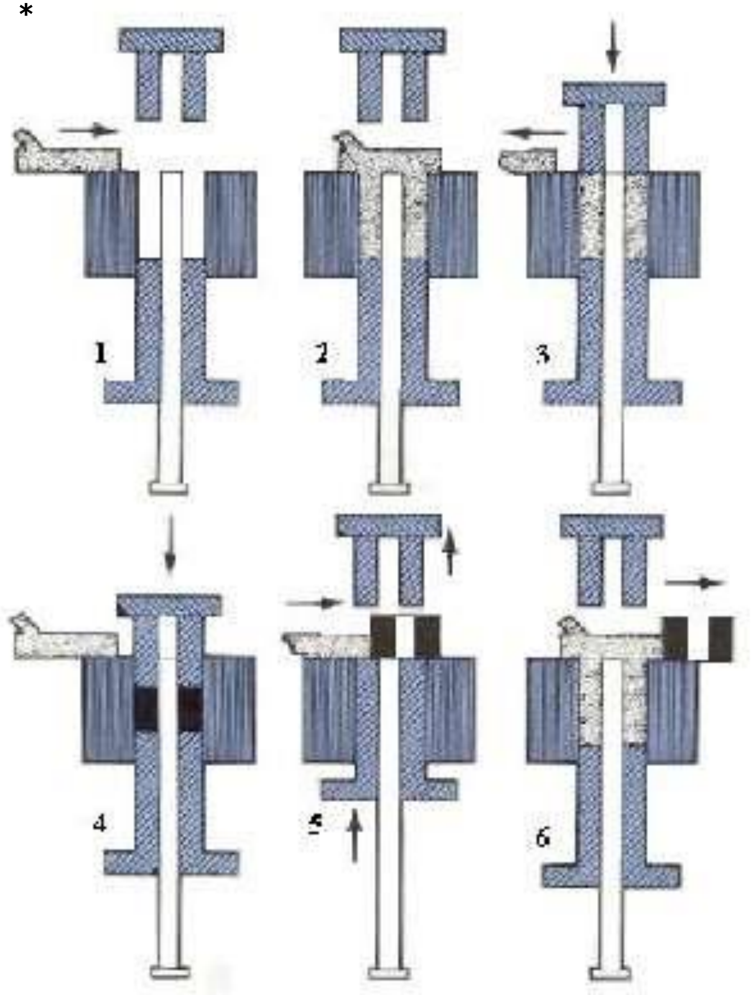
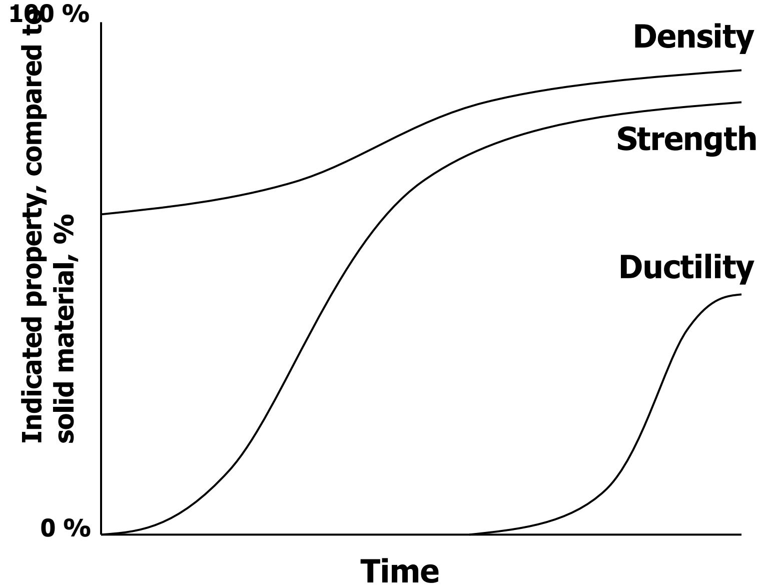
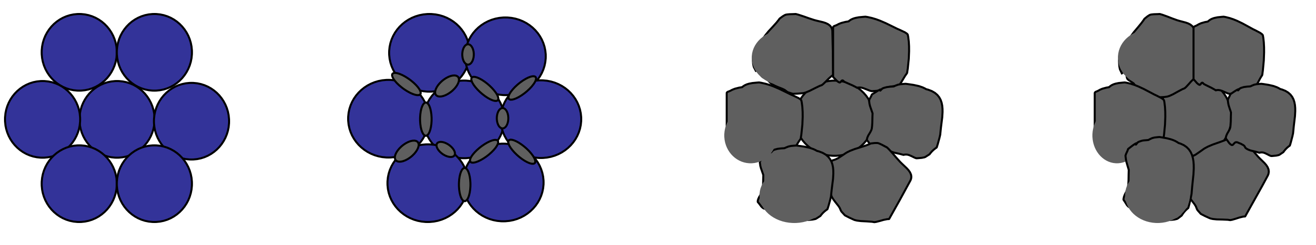


* Source: http://www.turkishpm.org/en_tozmetal.htm

Sintering





Green compact

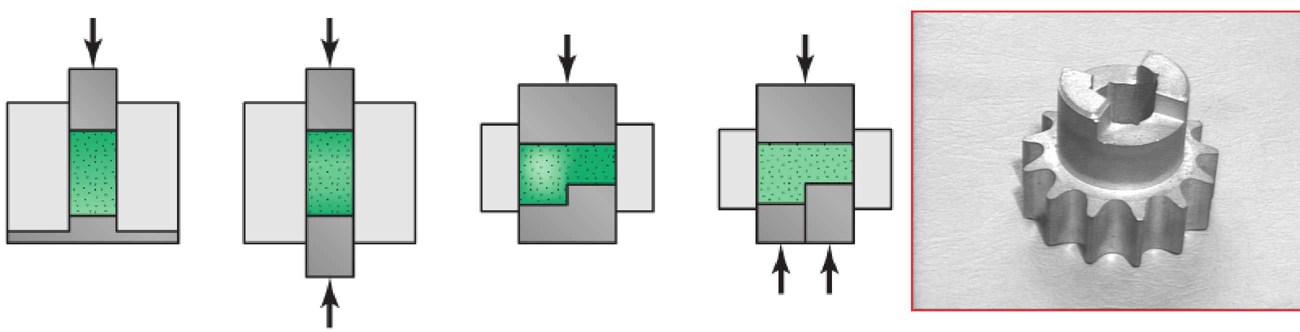
Necks formed

Pore size reduced

Fully sintered

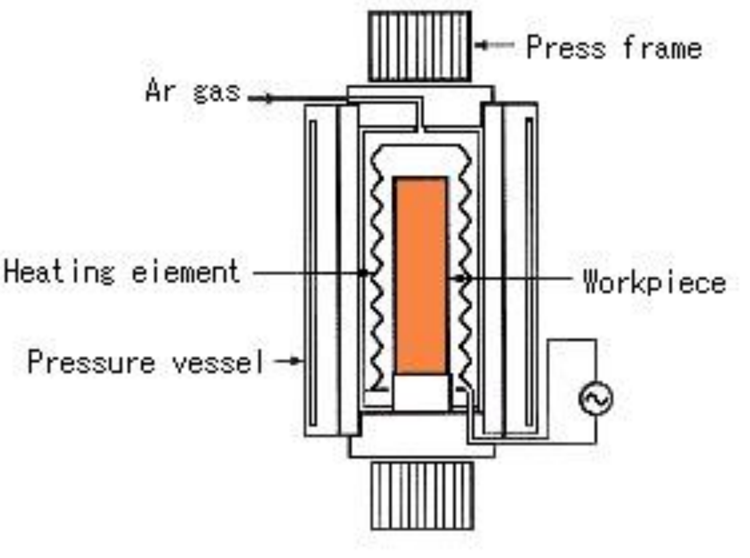
(a) (b) (c)

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.



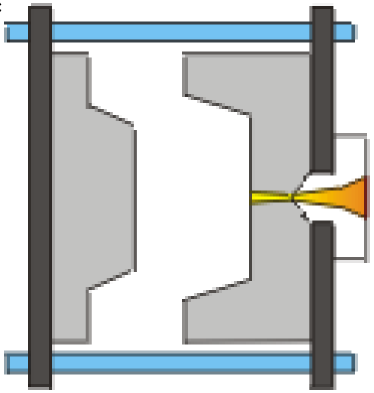
(a) (b) (c) (d)

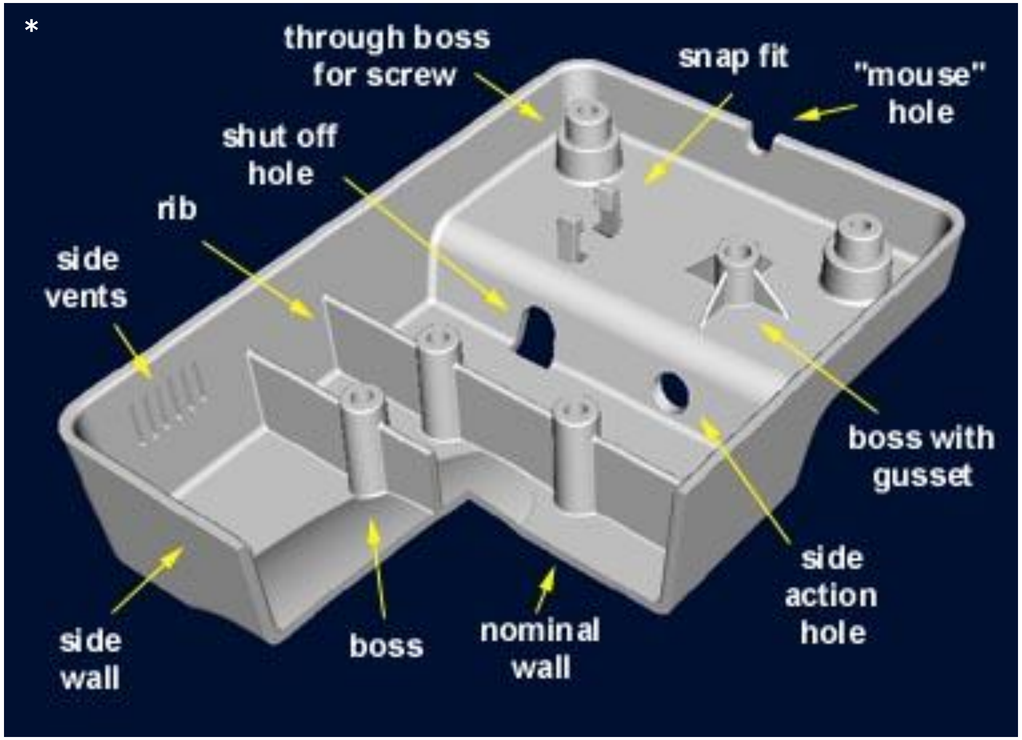
Hot Isostatic Pressing - HIP



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

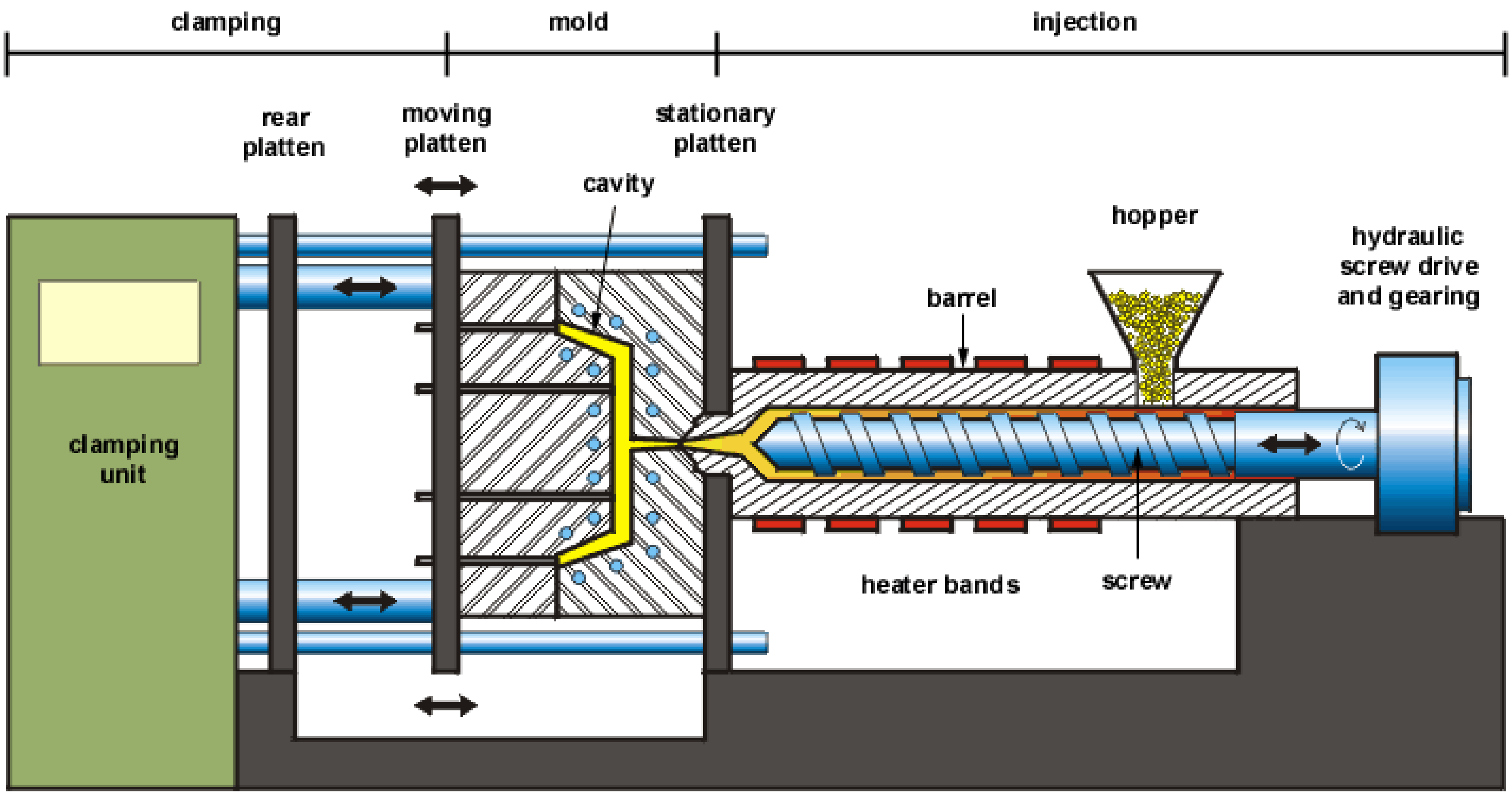
Injection Molding

*




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

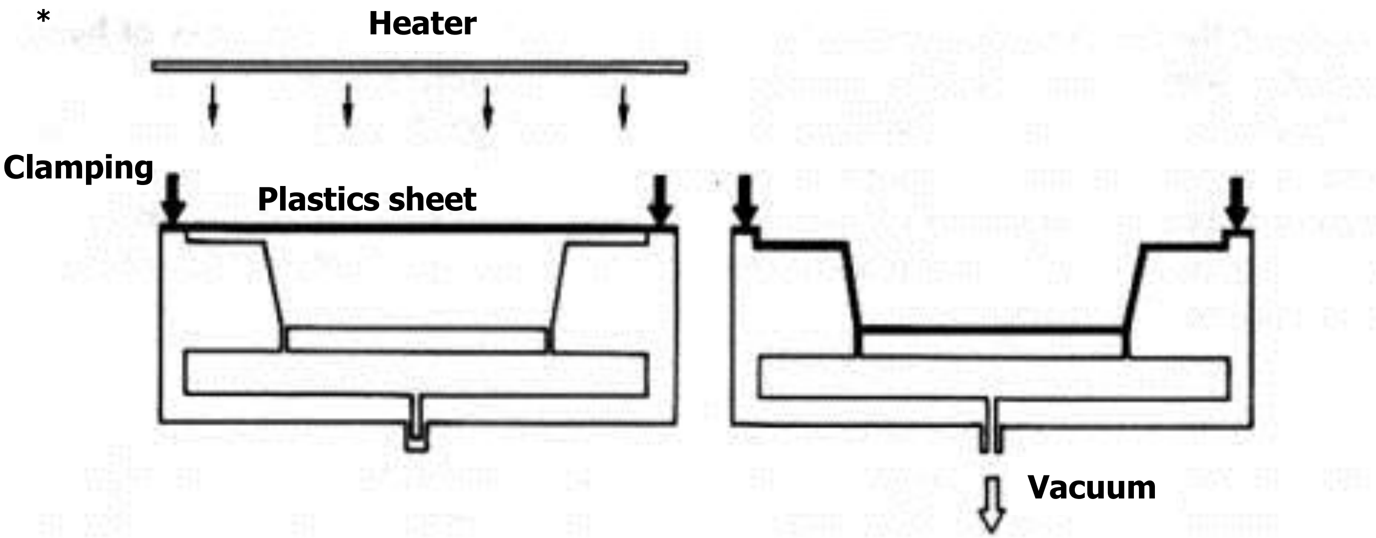
Injection Molding

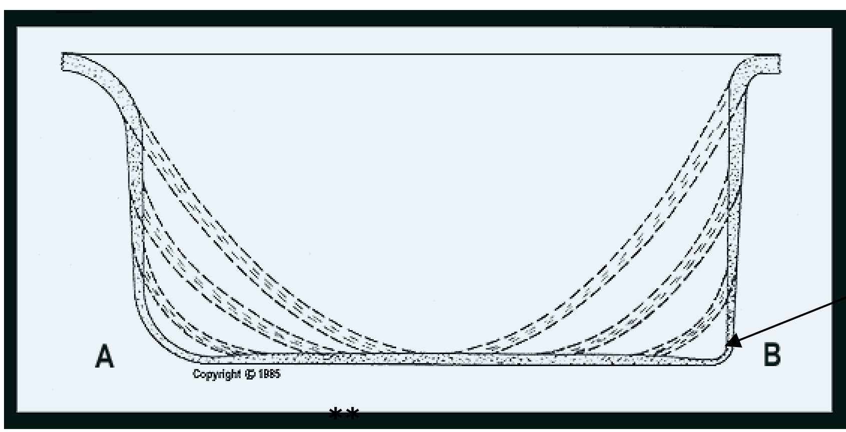


schematic of thermoplastic injection molding machine

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

Thermoforming

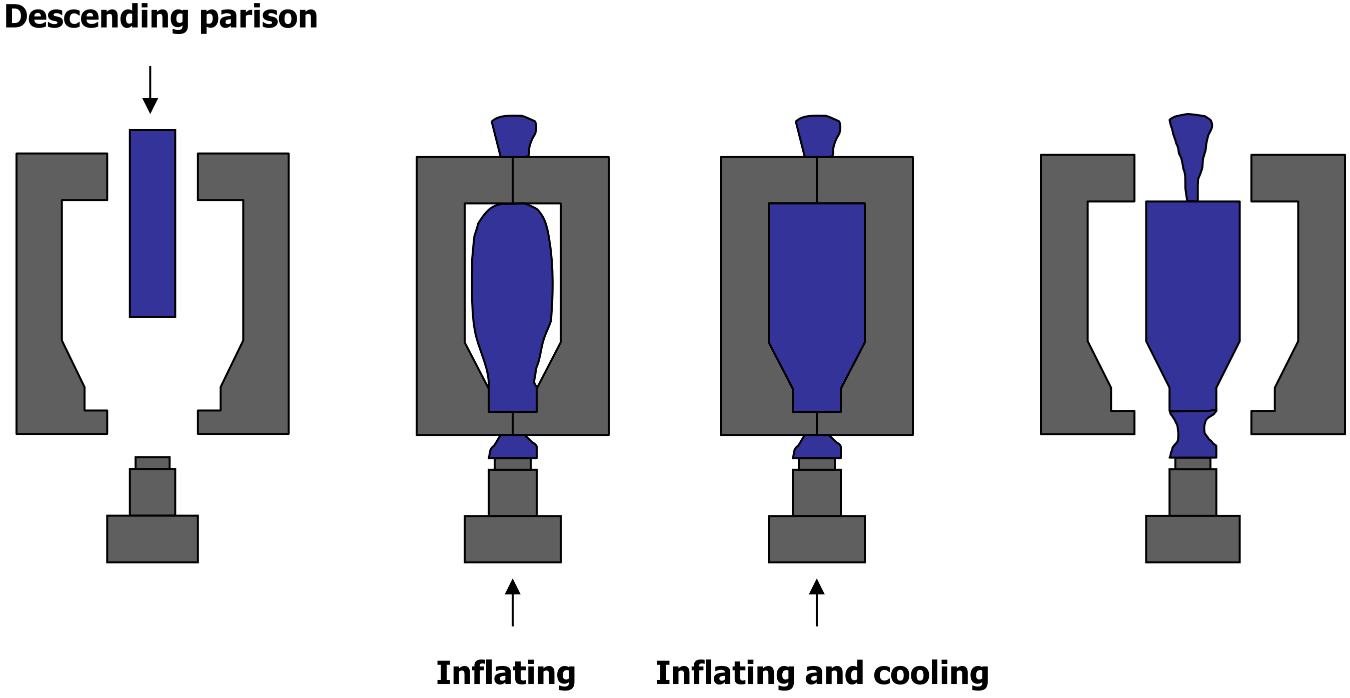




Thin corner

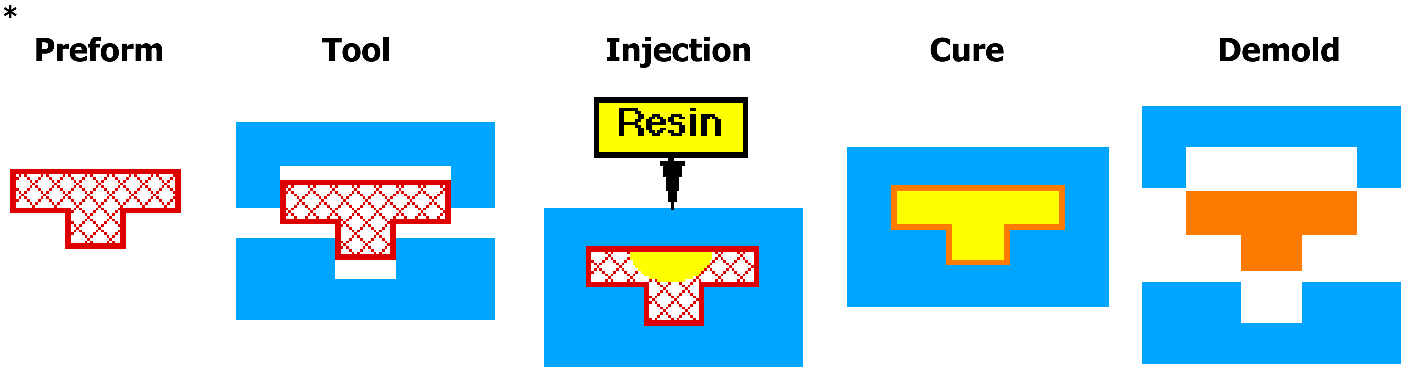
* Source: R. Ogorkiewicz, "Engineering Properties of Thermoplastics."; ** http://www.arrem.com/designguide/dgprocesscap.htm

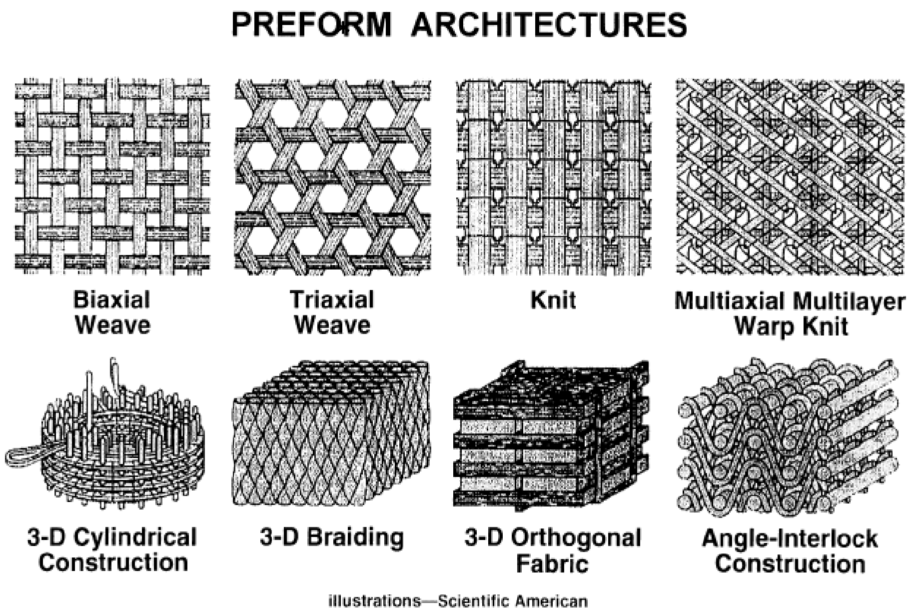
Blow Molding

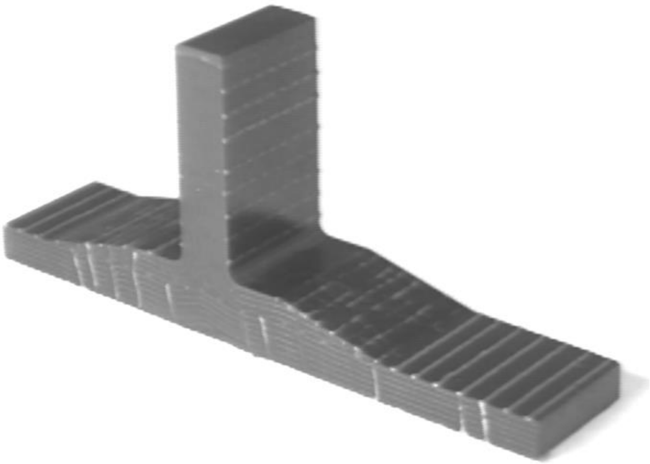


* Source: W.A.Holmes Walker, “Polymer Conversion”

Resin Transfer Molding (RTM)







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

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

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

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