INSTITUTE OF AERONAUTICAL ENGINEERING

(Autonomous)

Dundigal, Hyderabad – 500 043

PRODUCTION TECHNOLOGY

Course Code: AME006

IV Semester (IARE – R16)

PREPARED BY

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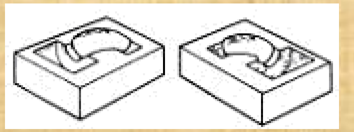
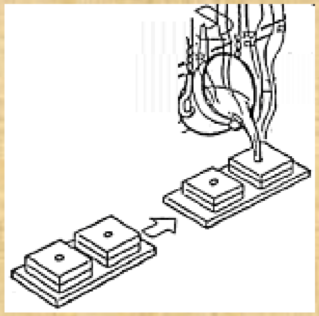
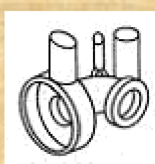
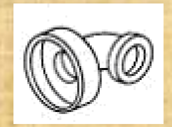
Mechanical Engineering

UNIT- I

CASTING PROCESS

Casting

Refractory mold → pour liquid metal → solidify, remove → finish

- VERSATILE: complex geometry, internal cavities, hollow sections
- VERSATILE: small (~10 grams) → very large parts (~1000 Kg)
- ECONOMICAL: little wastage (extra metal is re-used)
- ISOTROPIC: cast parts have same properties along all directions

- **Casting Process**;
- Casting is the process of pouring molten metal into the previously made cavity to the desired shape and allow it to solidify.
- **The following are the basic operations of casting process**
  - Pattern making
  - Melting the metal
  - Pouring it into a previously made mould which confirms to the shape of desired component.

- **Pattern**
- A pattern is an element used for making cavities in the mould, into which molten
- metal is poured to produce a casting.
- **Requirements of a good pattern, and pattern allowances.**
  - Secure the desired shape and size of the casting
  - Simple in design, for ease of manufacture
  - Cheap and readily availableLight in mass and convenient to handle
  - Have high strength

- **Pattern materials**
  - Wood
  - Common metals such as Brass, cast Iron, Aluminium and white metal etc.
  - Plastic
  - Gypsum
  - **Pattern allowances**
  - Shrinkage allowance
  - Machining allowance
  - Draft allowance
  - Shake allowance
- Distortion allowance

- <u>**Different types of patterns**</u>
- Split or Parted Pattern
- Loose Piece Pattern
- Draw backs
- Gated Patterns.
- Match Plate pattern
- Cope and Drag Pattern
- Sweep Patterns.

- **MOULD PREPARATION**
- **Green sand mould :**
- A green sand mould is composed of mixture of sand, clay and water.
- **Dry sand mould :**
- Dry sand moulds are basically green sand moulds with 1 to 2% cereal flour and 1 to 2% pitch.
- **Materials used in mould preparation**
- Silica sand, Binder, Additives and water
- .

- **<u>Various properties of moulding sand</u> .**
- Permeability
- Strength or CohesivenessRefractoriness.
- Plasticity or flowability
- Collapsibility
- Adhesiveness.
- Co-efficient of Expansion

- **Different moulding sand test procedures.**
- The following tests have been recommended by B.I.S.
- 1. Moisture content test
- 2. Clay content test
- 3. Permeability test
- 4. Fineness test or Sand grain size test (Sieve analysis)
- 5. Strength test
- 6. Mould hardness test.

- **CORE MAKING**
- **Core**
- is a body made of refractory material (sand or metal, metal cores being less frequently used), which is set into the prepared mould before closing and pouring it, for forming through holes, recesses, projections, undercuts and internal cavities.
- **Core Prints.** Core prints are the projections on a pattern and are used to make recesses (core seats) in the mould to locate the core

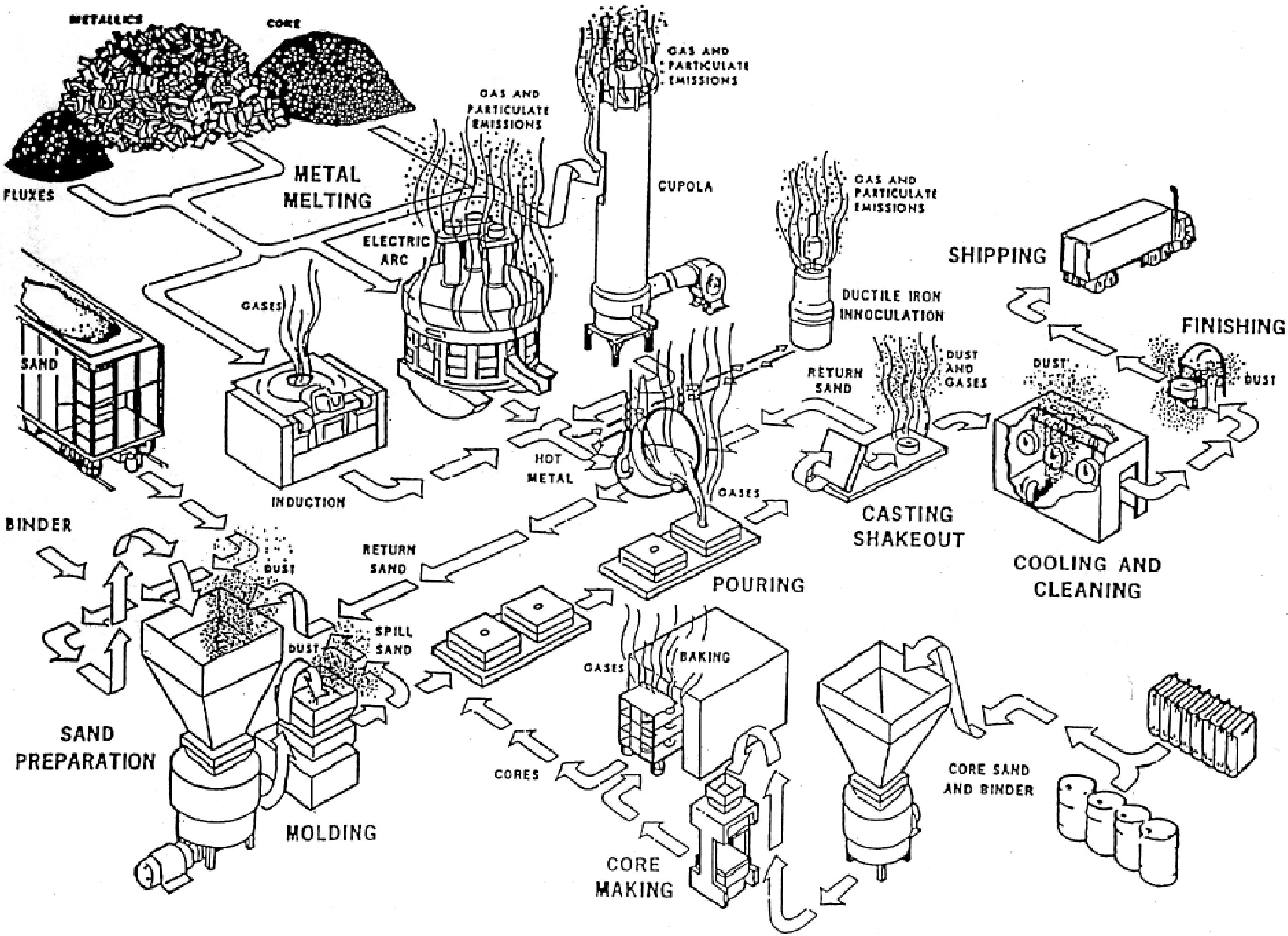
- **<u>Casting</u>**
- **Factors to be considered for selecting a furnace for a job**
- Capacity of molten metal
- Melting rate and temp armature control desired, Quality of melt required
- Method of pouring and types of product contemplated.
-

- **<u>Cupola Furnace operation</u>**
- The cupola is the most widely used furnace in the foundry for melting ferrous and non-ferrous metals and alloys. A cross-section of a cupola is shown. A cupola is a shaft furnace of cylindrical shape erected on legs or columns. The cupola shell is made of steel plate 8 or 10 mm thick. The interior is lined with refractory bricks to protect the shell from getting over-heated. The charge for the cupola consists of metallic materials, fuel and fluxes.

Different Casting Processes

Process	Advantages	Disadvantages	Examples
Sand	many metals, sizes, shapes, cheap	poor finish & tolerance	engine blocks, cylinder heads
Shell mold	better accuracy, finish, higher production rate	limited part size	connecting rods, gear housings
Expendable pattern	Wide range of metals, sizes, shapes	patterns have low strength	cylinder heads, brake components
Plaster mold	complex shapes, good surface finish	non-ferrous metals, low production rate	prototypes of mechanical parts
Ceramic mold	complex shapes, high accuracy, good finish	small sizes	impellers, injection mold tooling
Investment	complex shapes, excellent finish	small parts, expensive	jewellery
Permanent mold	good finish, low porosity, high production rate	Costly mold, simpler shapes only	gears, gear housings
Die	Excellent dimensional accuracy, high production rate	costly dies, small parts, non-ferrous metals	gears, camera bodies, car wheels
Centrifugal	Large cylindrical parts, good quality	Expensive, few shapes	pipes, boilers, flywheels

Sand Casting



Sand Casting

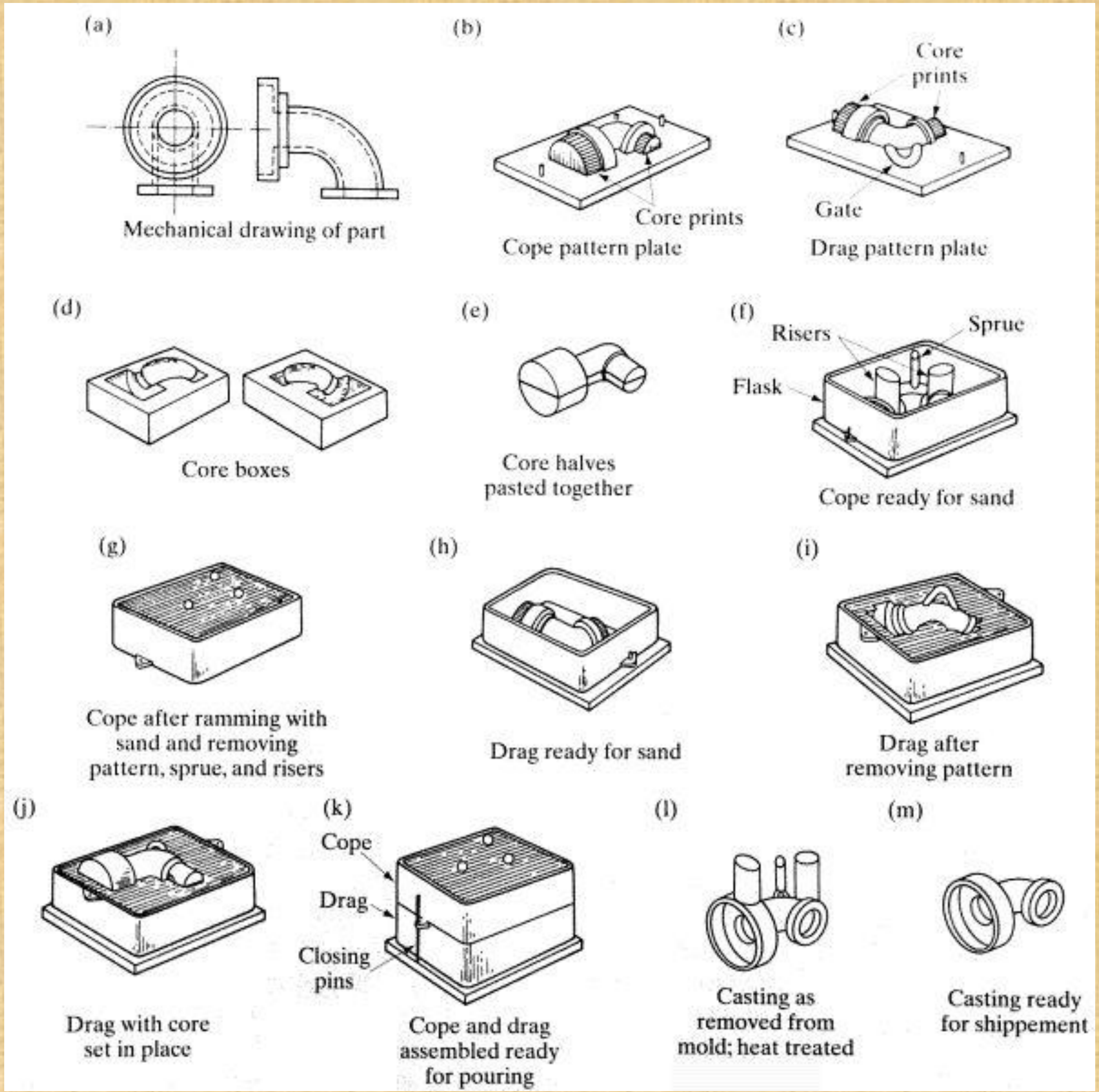
cope: top half

drag: bottom half

core: for internal cavities

pattern: positive

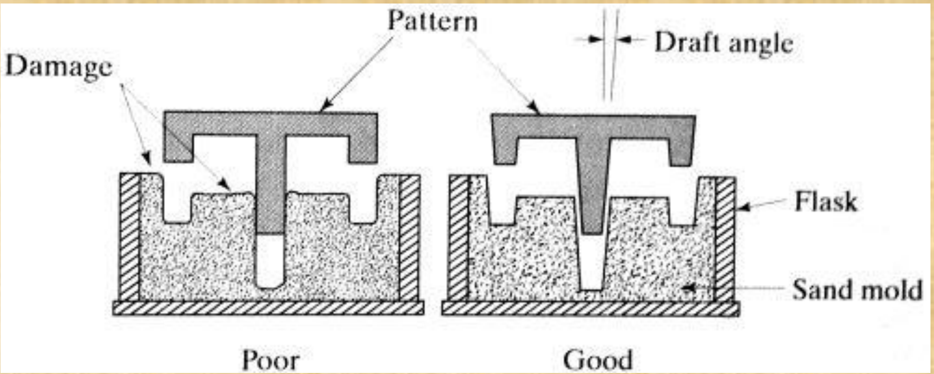
funnel → sprue →
→ runners → gate →
→ cavity →
→ {risers, vents}



Sand Casting Considerations..

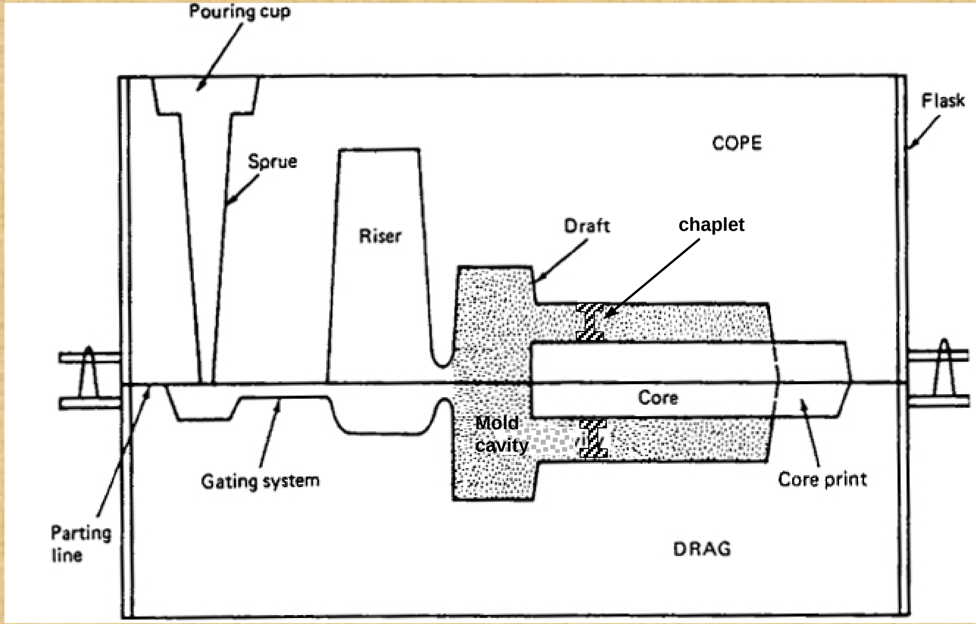
(d) **taper**

- do we need it ?



(e) **core prints, chaplets**

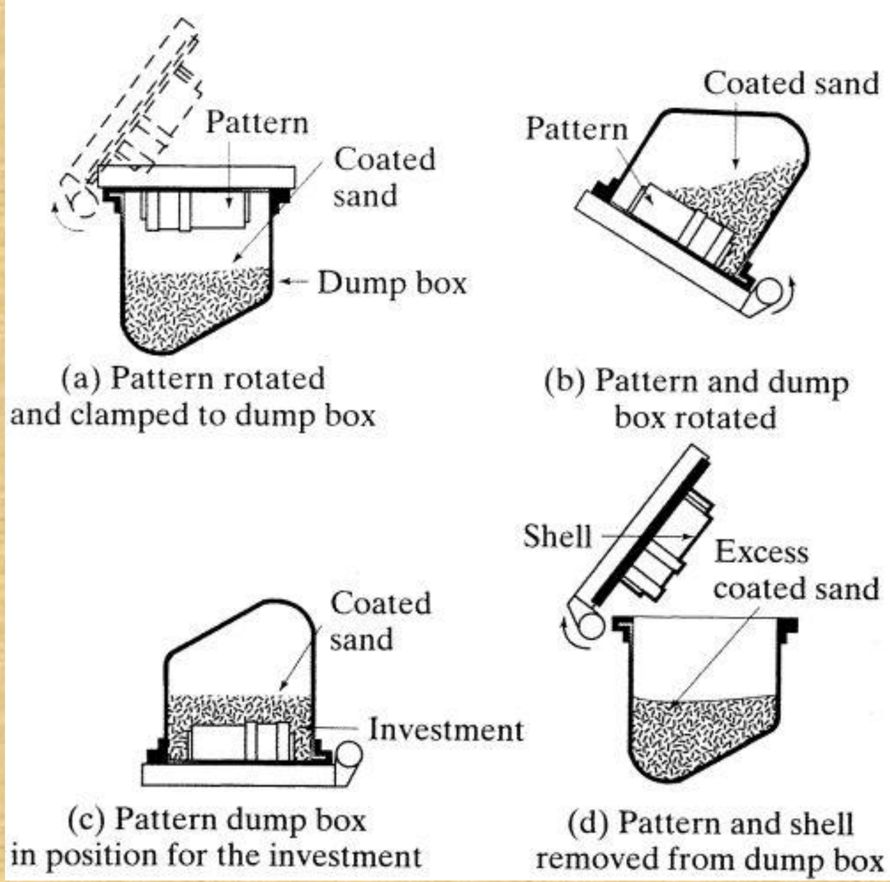
- hold the core in position
- chaplet is metal (why?)

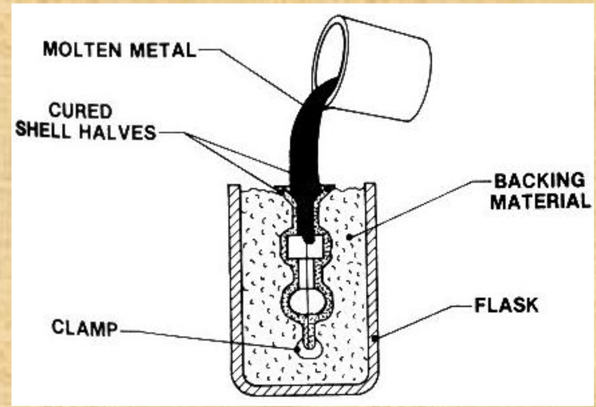


(f) **cut-off, finishing**

Shell mold casting

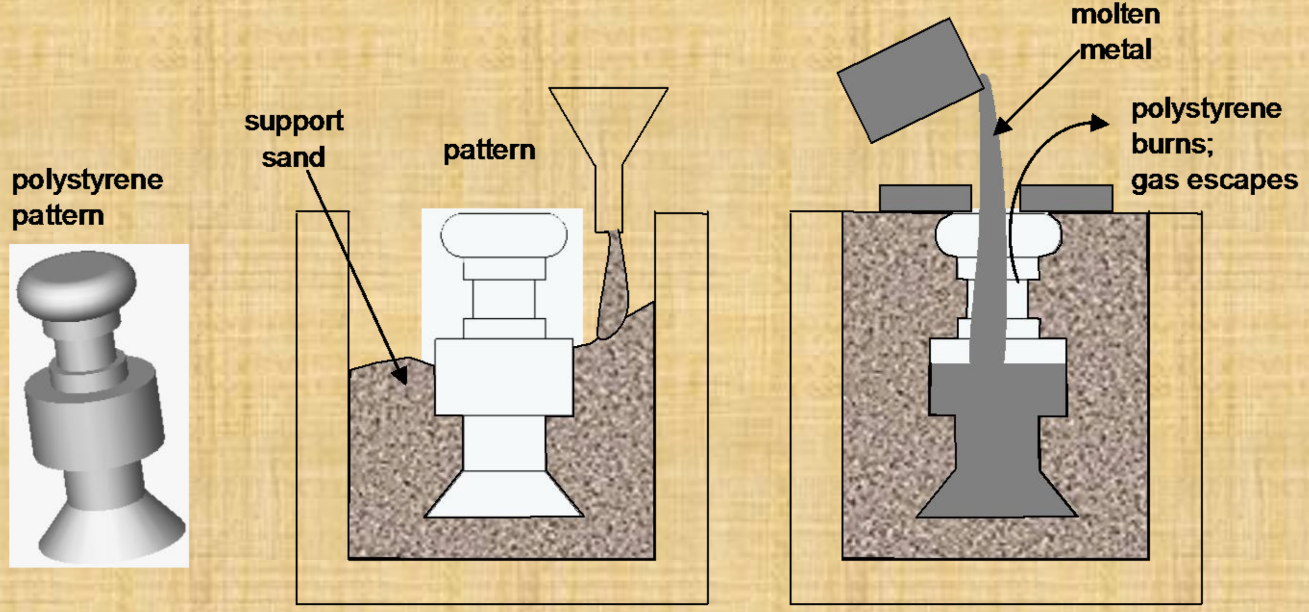
- metal, 2-piece *pattern*, 175°C-370°C
- coated with a lubricant (silicone)
- mixture of sand, thermoset resin/epoxy
- cure (baking)
- remove patterns, join half-shells → mold
- pour metal
- solidify (cooling)
- break shell → part





Expendable Mold Casting

- Styrofoam pattern
- dipped in refractory slurry → dried
- sand (support)
- pour liquid metal
- foam evaporates, metal fills the shell
- cool, solidify
- break shell → part



Plaster-mold, Ceramic-mold casting

Plaster-mold slurry: *plaster of paris* ($CaSO_4$), talc, silica flour

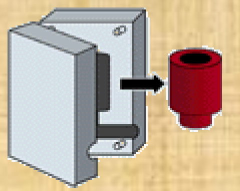
Ceramic-mold slurry: silica, powdered Zircon ($ZrSiO_4$)

- The slurry forms a shell over the pattern
- Dried in a low temperature oven
- Remove pattern
- Backed by clay (strength), baked (burn-off volatiles)
- cast the metal
- break mold → part

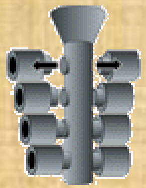
Plaster-mold: *good finish (Why ?)*
plaster: low conductivity => low warpage, residual stress
low mp metal (Zn, Al, Cu, Mg)

Ceramic-mold: good finish
high mp metals (steel, …) => impeller blades, turbines, …

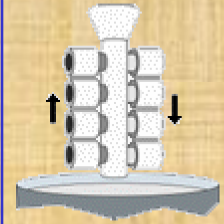
Investment casting (lost wax casting)



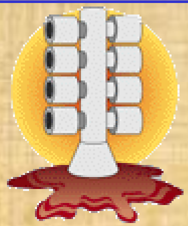
(a) Wax pattern
(injection molding)



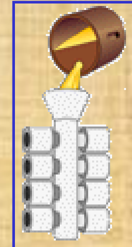
(b) Multiple patterns
assembled to wax sprue



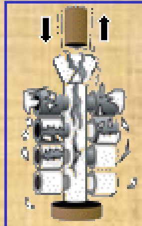
(c) Shell built →
immerse into ceramic slurry
→ immerse into fine sand
(few layers)



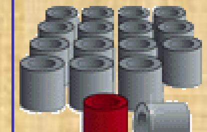
(d) dry ceramic
melt out the wax
fire ceramic (burn wax)



(e) Pour molten metal (gravity)
→ cool, solidify
[Hollow casting:
pouring excess metal before solidification



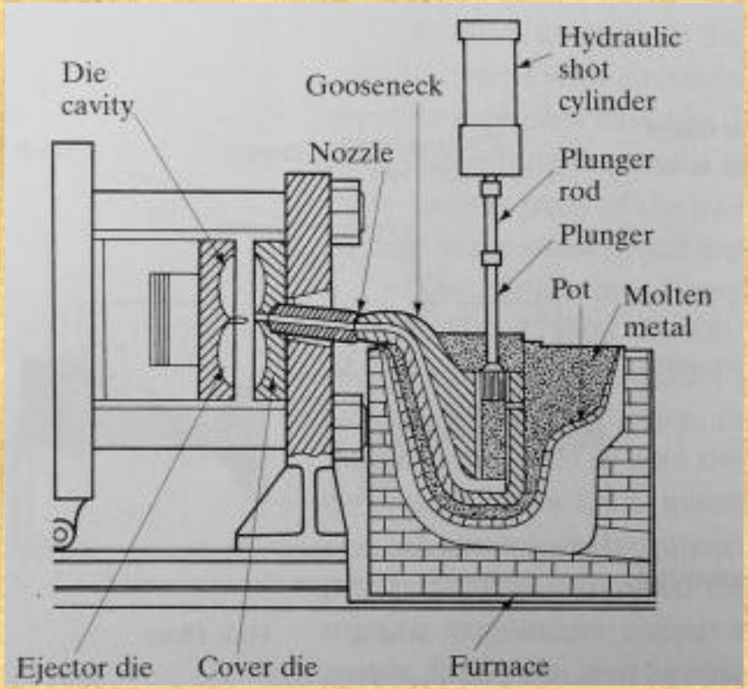
(f) Break ceramic shell
(vibration or water blasting)



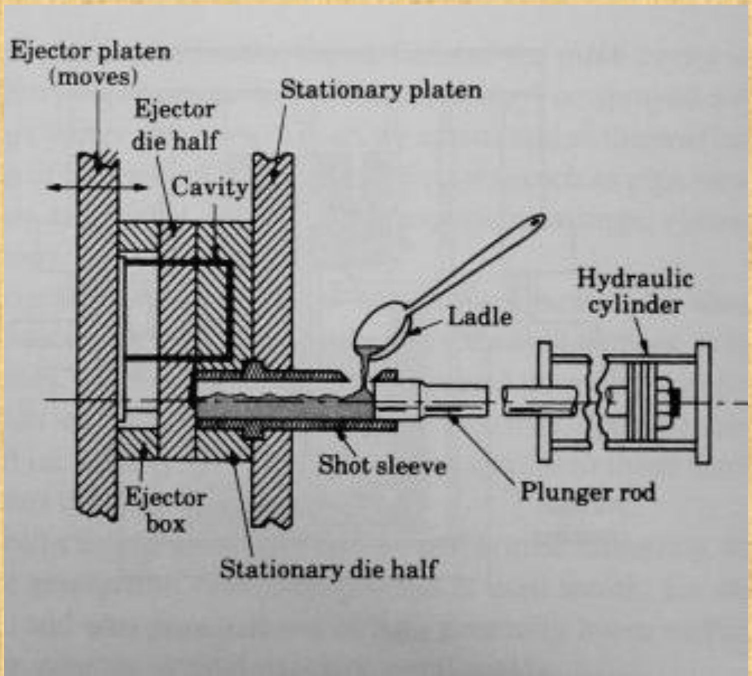
(g) Cut off parts
(high-speed friction saw)
→ finishing (polish)

Die casting

- a type of permanent mold casting
- common uses: components for
  rice cookers, stoves, fans, washing-, drying machines, fridges, motors, toys, hand-tools, car wheels, …



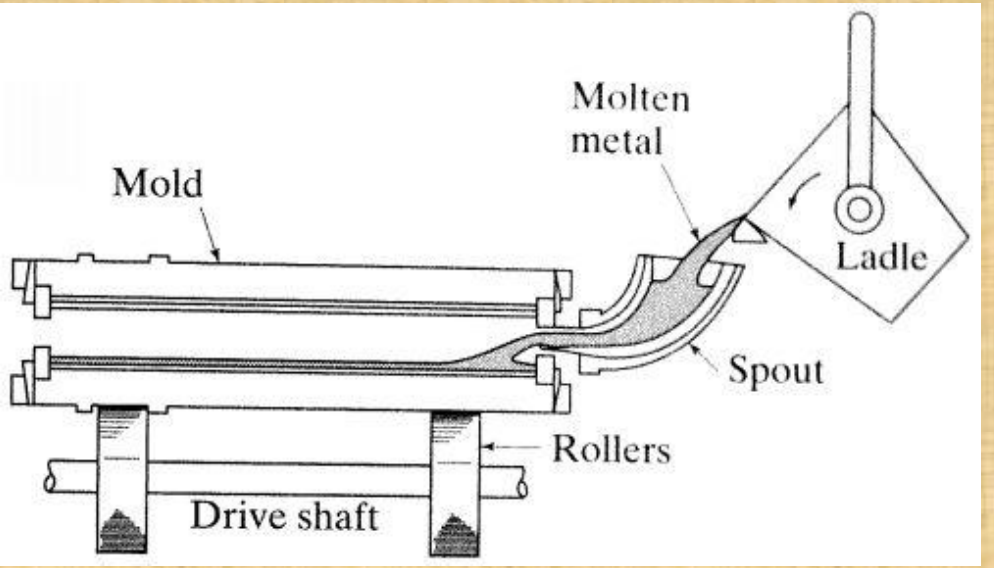
HOT CHAMBER: (low mp e.g. Zn, Pb; non-alloying)
(i) die is closed, gooseneck cylinder is filled with molten metal
(ii) plunger pushes molten metal through gooseneck into cavity
(iii) metal is held under pressure until it solidifies
(iv) die opens, cores retracted; plunger returns
(v) ejector pins push casting out of ejector die



COLD CHAMBER: (high mp e.g. Cu, Al)
(i) die closed, molten metal is ladled into cylinder
(ii) plunger pushes molten metal into die cavity
(iii) metal is held under high pressure until it solidifies
(iv) die opens, plunger pushes solidified slug from the cylinder
(v) cores retracted
(iv) ejector pins push casting off ejector die

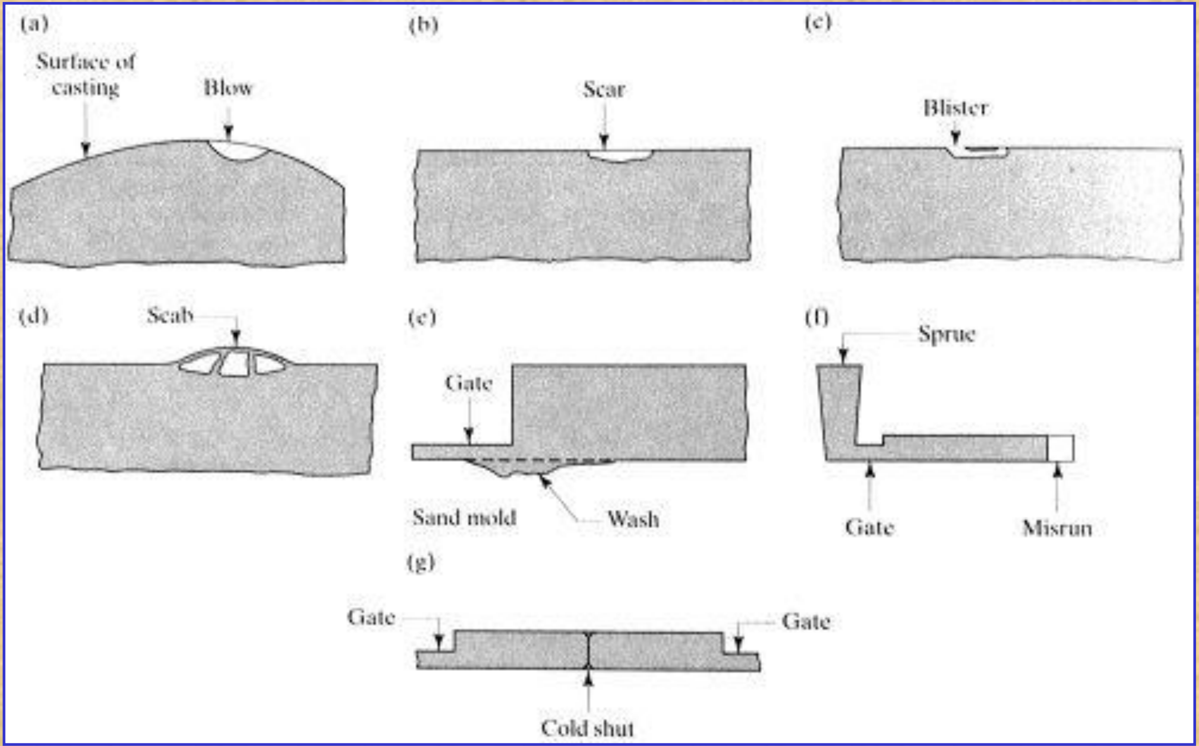
Centrifugal casting

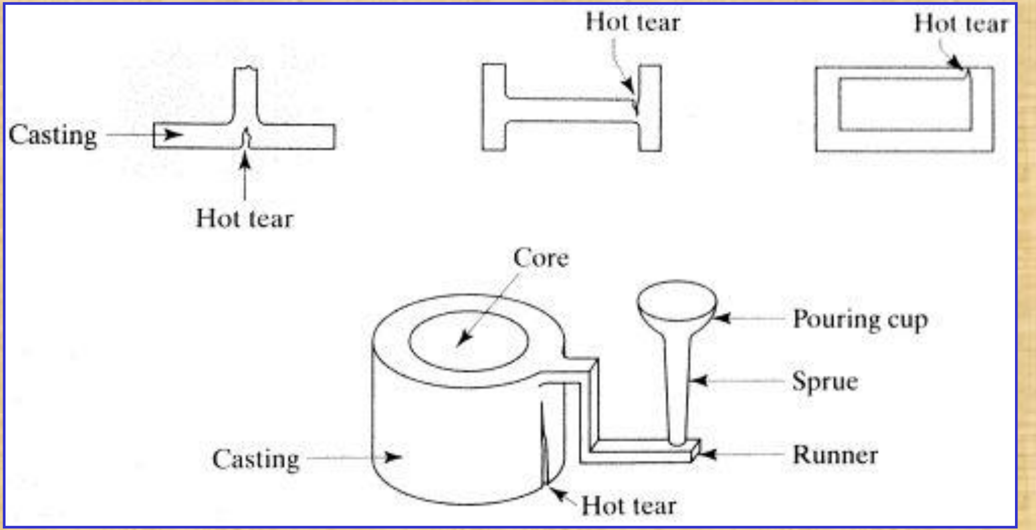
- permanent mold
- rotated about its axis at 300 ~ 3000 rpm
- molten metal is poured



- Surface finish: better along outer diameter than inner,
- Impurities, inclusions, closer to the inner diameter (why ?)

Typical casting defects





UNIT-II

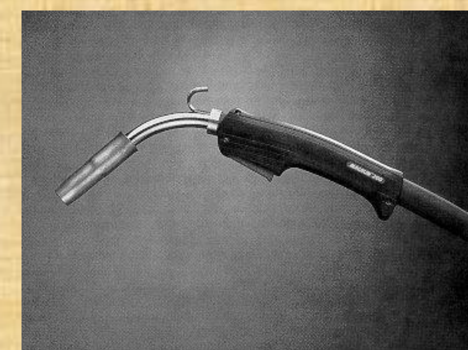
WELDING-I

Consumable Electrode

SMAW – Shielded Metal Arc Welding

GMAW – Gas Metal Arc Welding

SAW – Submerged Arc Welding



Non-Consumable Electrode

GTAW – Gas Tungsten Arc Welding

PAW – Plasma Arc Welding

High Energy Beam

Electron Beam Welding

Laser Beam Welding

Welding

Welding is defined as an localized coalescence of metals, where in coalescence is obtained by heating to suitable temperature, with or without the application of pressure and with or without the use of filler metal.

Different welding processes.

- Fusion Welding, Brazing & Soldering
- Solid State Welding
- Chemical, welding
- Electrical Resistance
- Diffusion, Explosion
- Mechanical
- Cold Friction Ultrasonic
- Oxyfuel gas, hermit welding
- Electron Beam, Laser Beam,Plasma arc welding

Gaswelding.

Gas welding is a group of welding processes where in coalescence is produced by heating with a flame or flames with or without the application of pressure and with or without the use of filler material.

- Consumable electrode
- Flux coated rod
- Flux produces protective gas around weld pool
- Slag keeps oxygen off weld bead during cooling

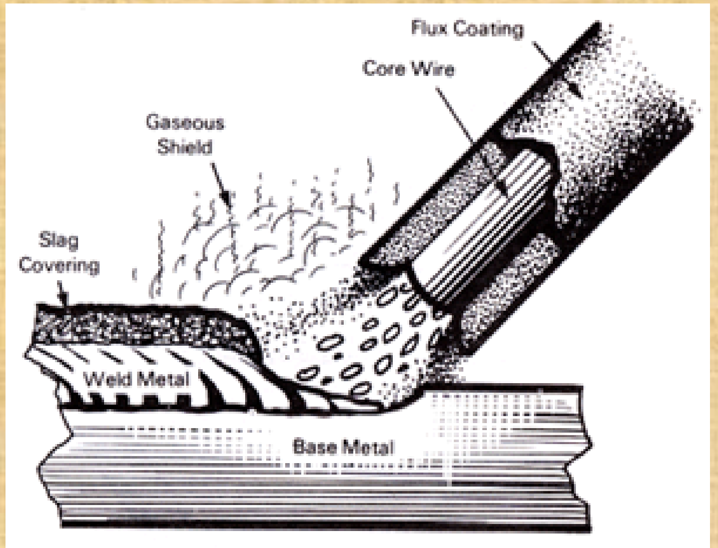


Fig. 6

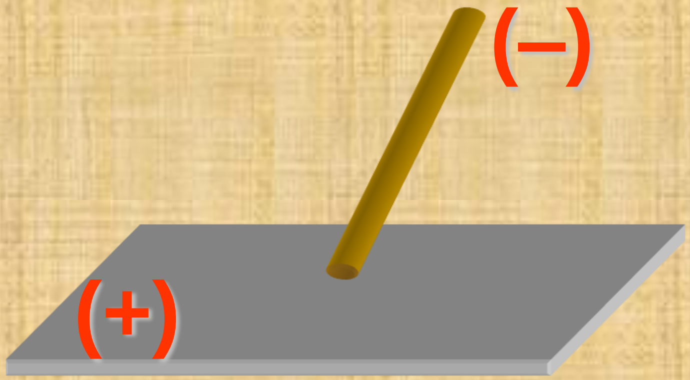
- General purpose welding—widely used
- Thicknesses 1/8” – 3/4”
- Portable

Power... Current I (50 - 300 amps)
Voltage V (15 - 45 volts)

Power = VI $\approx$ 10 kW

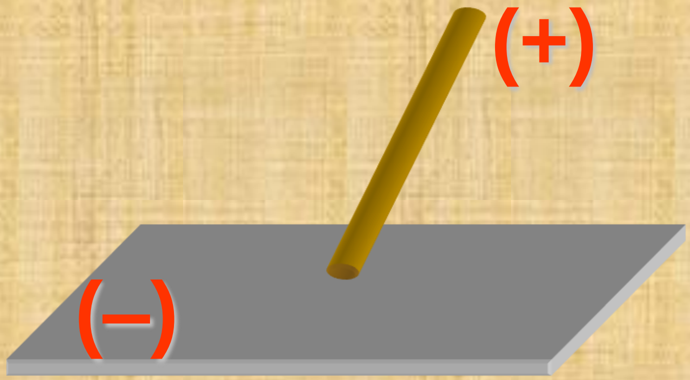
SMAW - DC Polarity

Straight Polarity



Shallow penetration
(thin metal)

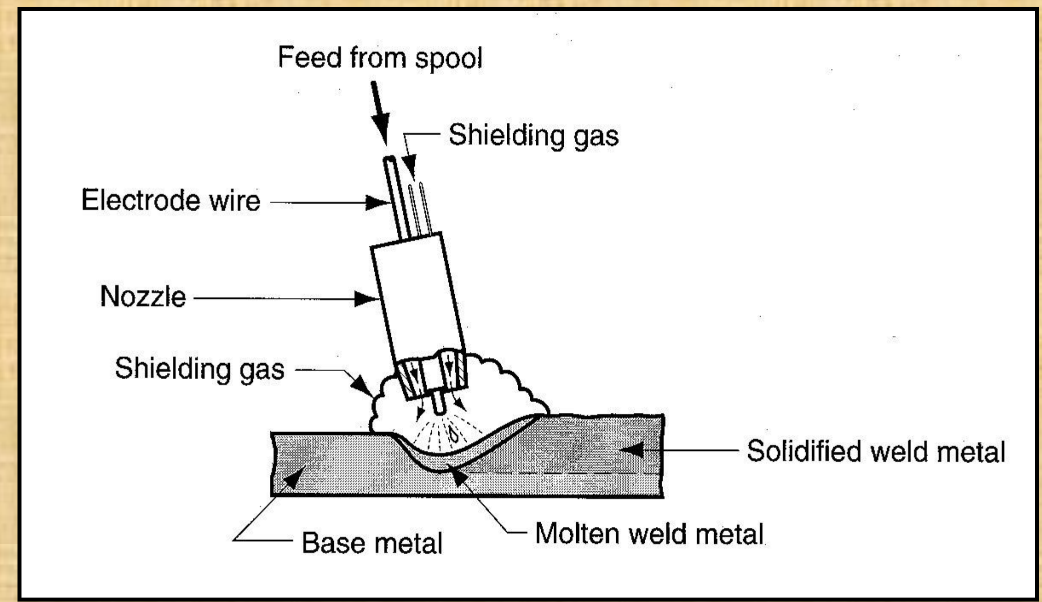
Reverse Polarity



Deeper weld penetration

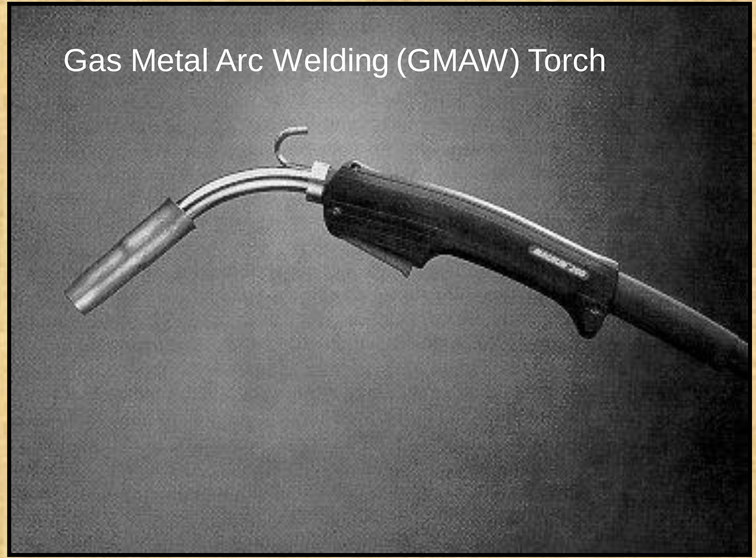
AC - Gives pulsing arc

- used for welding thick sections



- DC reverse polarity - hottest arc
- AC - unstable arc

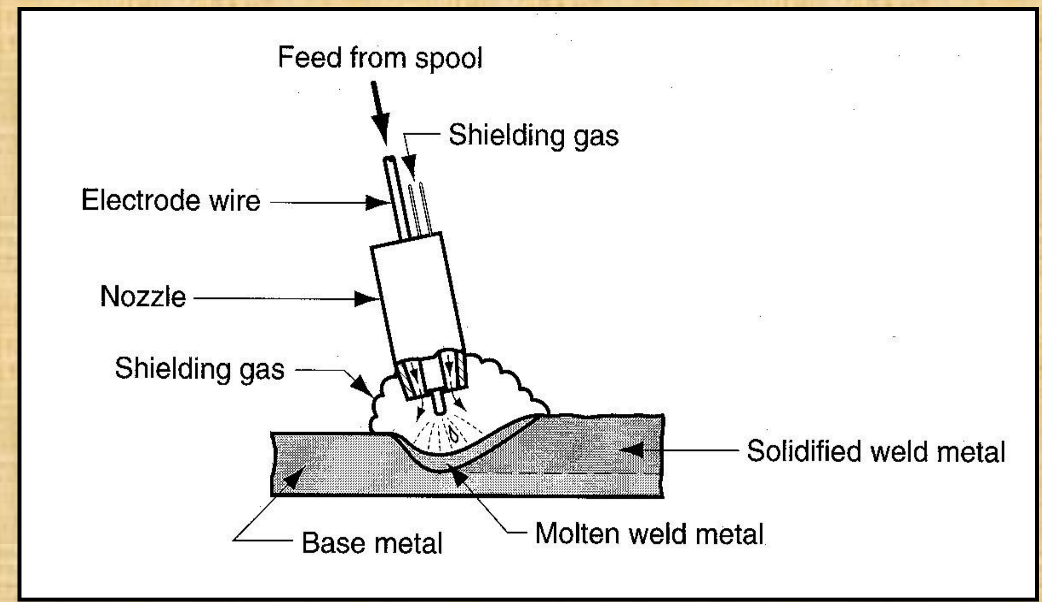
- MIG - Metal Inert Gas
- Consumable wire electrode
- Shielding provided by gas
- Double productivity of SMAW
- Easily automated



Groover, M., *Fundamentals of Modern Manufacturing*,, p. 734, 1996

GMAW

- An arc welding process that uses an arc between a continuous filler metal electrode and the weld pool to produce a fusion (melting) together of the base metal
- The process is used with a shielding gas supplied from an external source without pressure.



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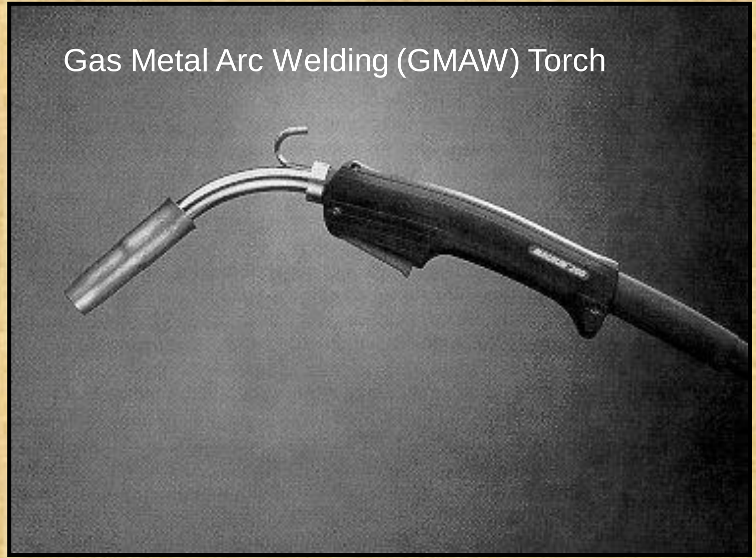
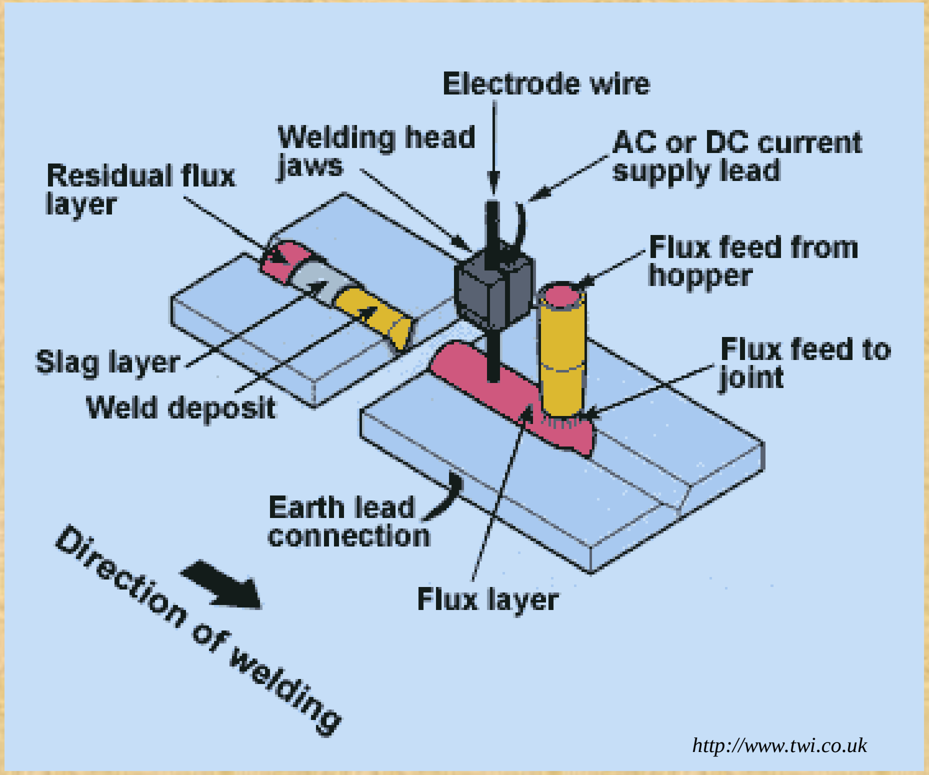
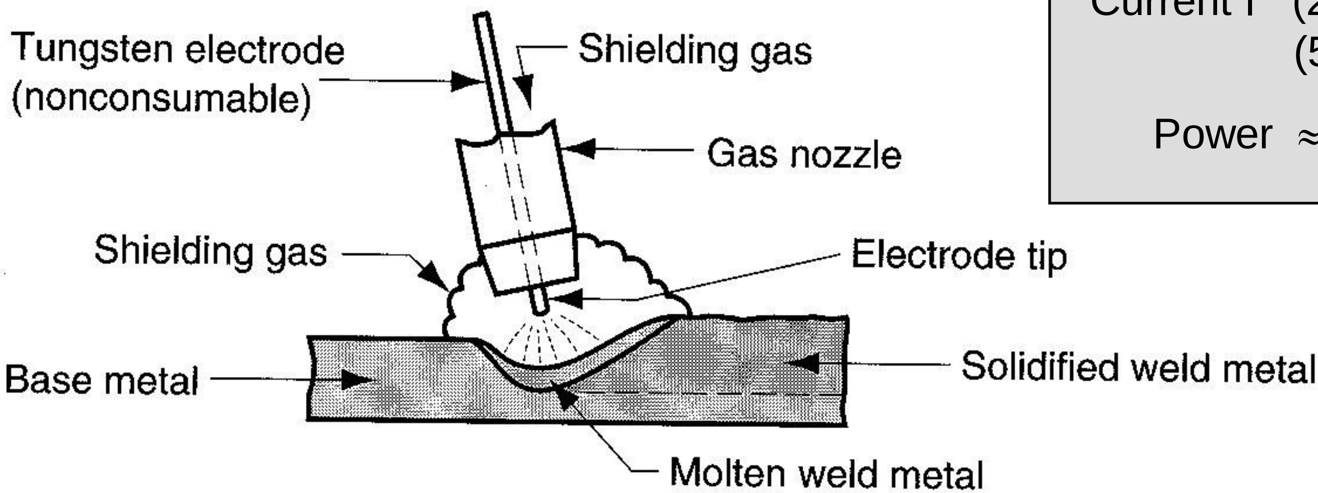


Groover, M., *Fundamentals of Modern Manufacturing*,, p. 734, 1996

- 300 – 2000 amps (440 V)



- Consumable wire electrode
- Shielding provided by flux granules
- Low UV radiation & fumes
- Flux acts as thermal insulator
- Automated process (limited to flats)
- High speed & quality (4 – 10x SMAW)
- Suitable for thick plates

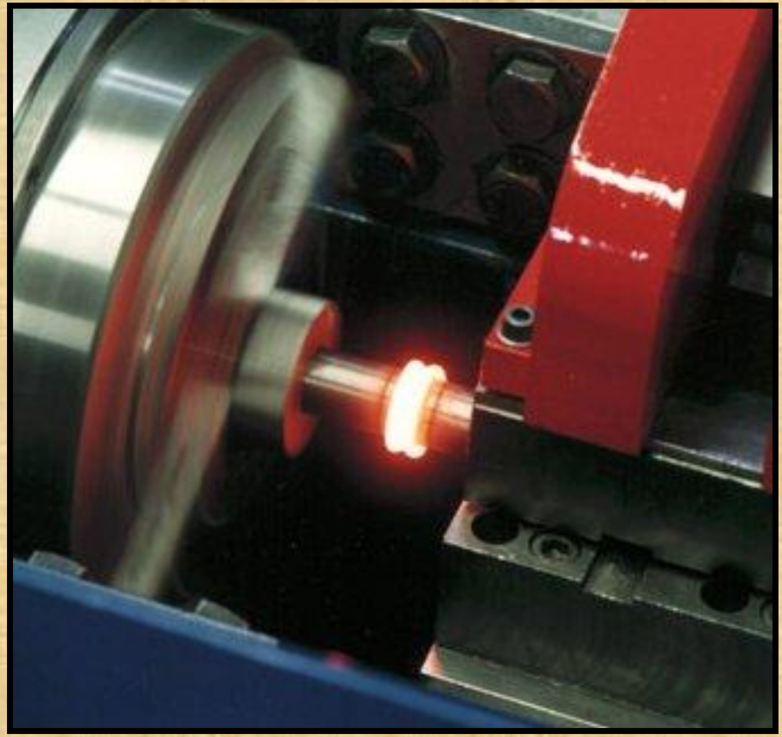


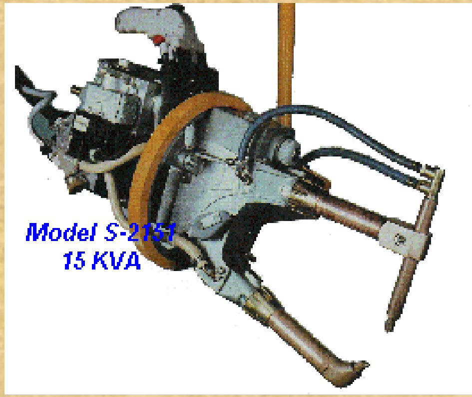
Current I (200 A DC)
(500 A AC)

Power ≈ 8-20 kW

- a.k.a. TIG - Tungsten Inert Gas
- Non-consumable electrode
- With or without filler metal
- Shield gas usually argon
- Used for thin sections of Al, Mg, Ti.
- Most expensive, highest quality

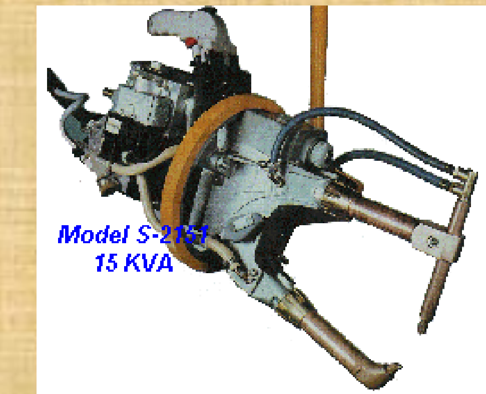
- One part rotated, one stationary
- Stationary part forced against rotating part
- Friction converts kinetic energy to thermal energy
- Metal at interface melts and is joined
- When sufficiently hot, rotation is stopped & axial force increased





Resistance Welding is the coordinated application of electric current and mechanical pressure in the proper magnitudes and for a precise period of time to create a coalescent bond between two base metals.

- Heat provided by resistance to electrical current ($Q=I^2Rt$)
- Typical 0.5 – 10 V but up to 100,000 amps!
- Force applied by pneumatic cylinder
- Often fully or partially automated
  - Spot welding
  - Seam welding



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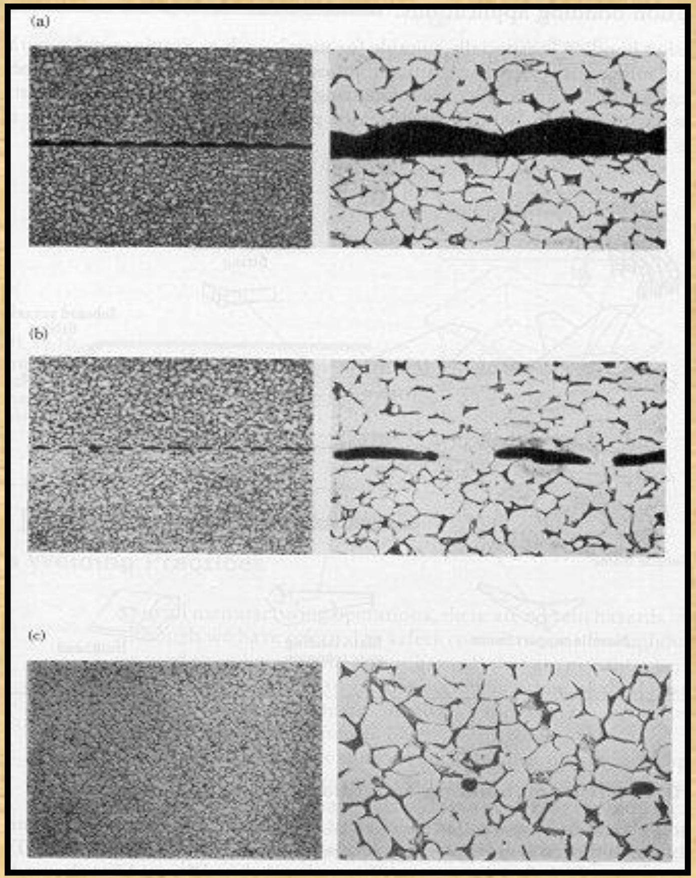
  - Spot welding
  - Seam welding

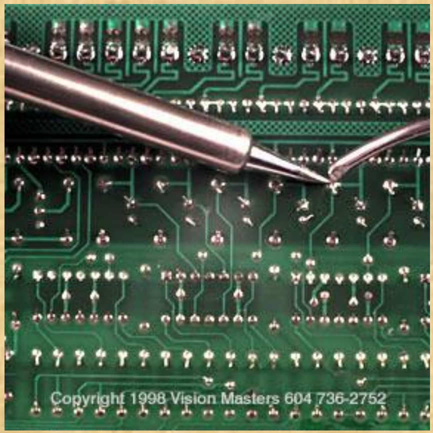
- Parts forced together at high temperature (< 0.5Tm absolute) and pressure
- Heated in furnace or by resistance heating
- Atoms diffuse across interface
- After sufficient time the interface disappears
- Good for dissimilar metals
- Bond can be weakened by surface impurities



Kalpakjian, S., *Manufacturing Engineering & Technology*, p. 889, 1992

UNIT-III

WELDING-II

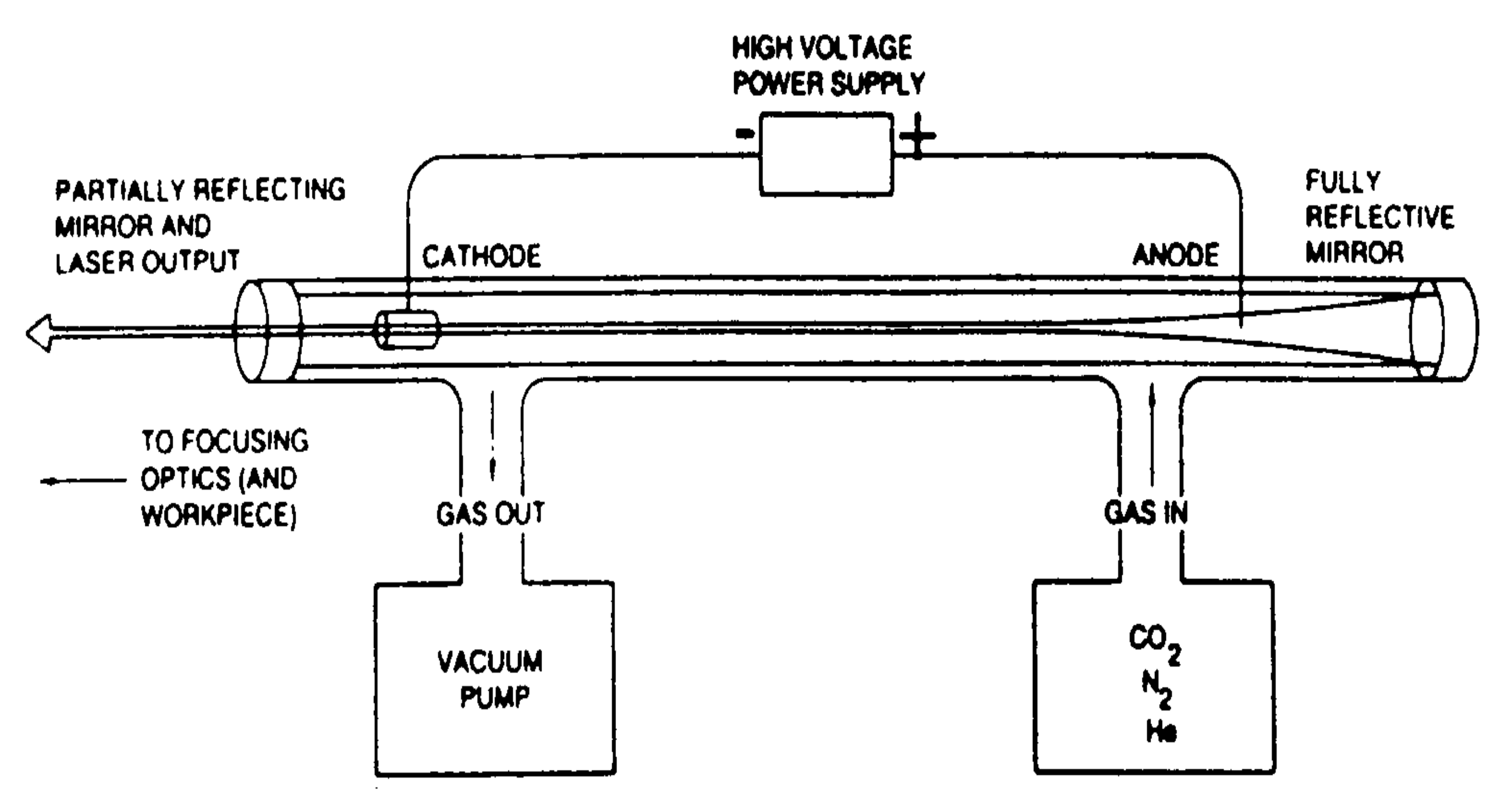


Soldering & Brazing

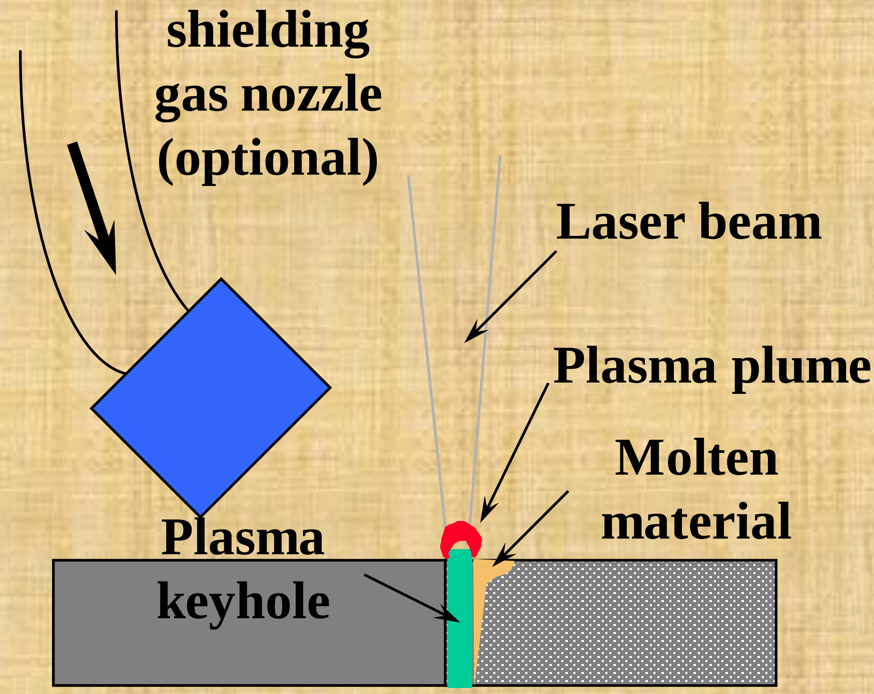
- Only filler metal is melted, not base metal
- Lower temperatures than welding
- Filler metal distributed by capillary action
- Metallurgical bond formed between filler & base metals
- Strength of joint typically
  - stronger than filler metal itself
  - weaker than base metal
  - gap at joint important (0.001 – 0.010”)

- Pros & Cons
  - Can join dissimilar metals
  - Less heat - can join thinner sections (relative to welding)
  - Excessive heat during service can weaken joint

LASER BEAM WELDING



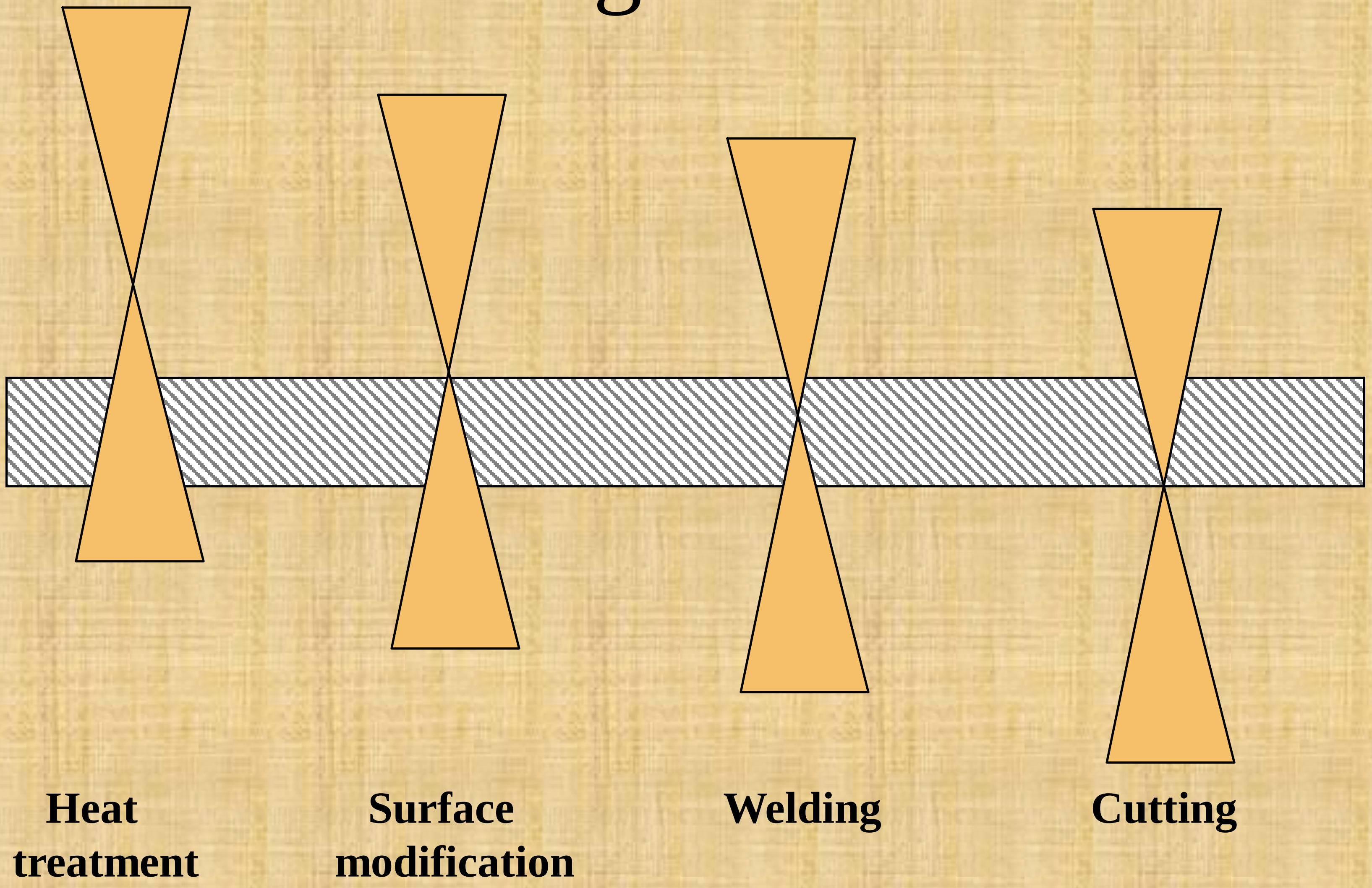
Laser Beam Welding (LBW)



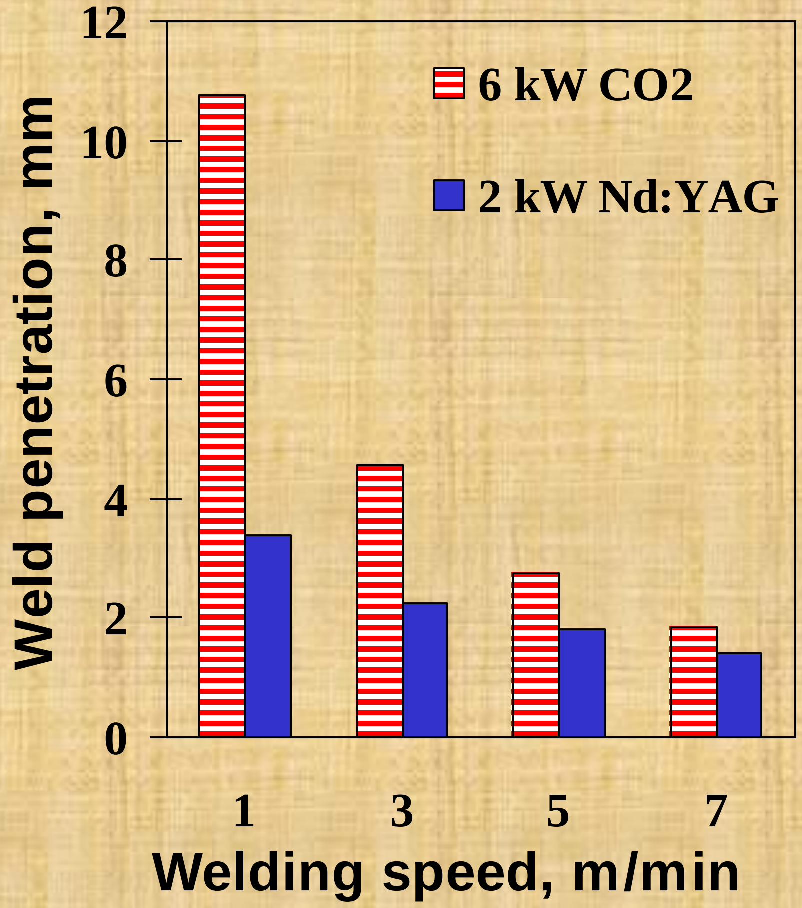
workpiece motion →

Keyhole welding

Focusing the Beam



Advantages

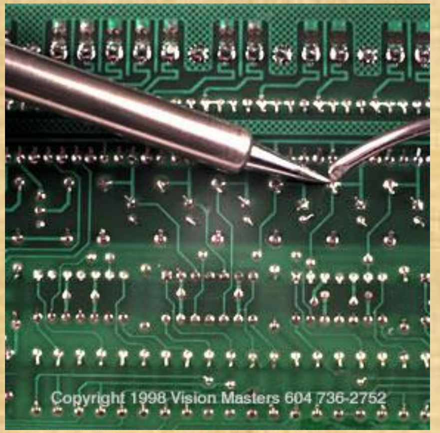


- **Single pass weld penetration up to 3/4" in steel**
- **High Travel speed**
- **Materials need not be conductive**
- **No filler metal required**
- **Low heat input produces low distortion**
- **Does not require a vacuum**

Soldering

Solder = Filler metal

- Alloys of Tin (silver, bismuth, lead)
- Melt point typically below 840 F



Flux used to clean joint & prevent oxidation

- separate or in core of wire (rosin-core)

Tinning = pre-coating with thin layer of solder

Applications:

- Printed Circuit Board (PCB) manufacture
- Pipe joining (copper pipe)
- Jewelry manufacture
- Typically non-load bearing

Easy to solder: copper, silver, gold

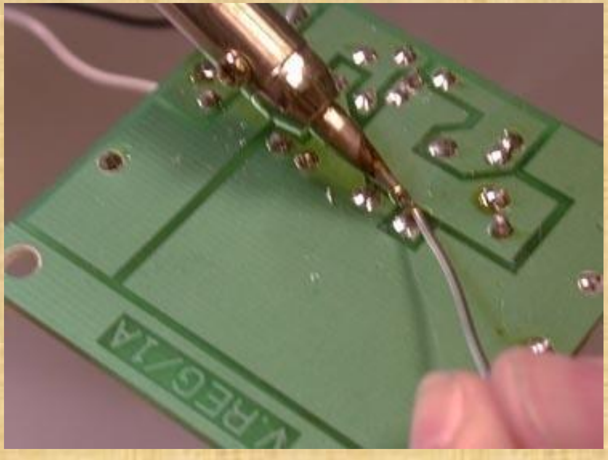
Difficult to solder: aluminum, stainless steels

(can pre-plate difficult to solder metals to aid process)

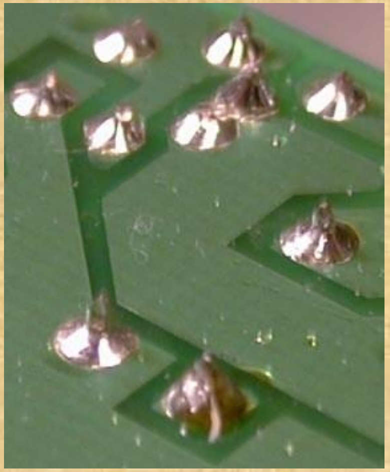
Manual PCB Soldering

• Soldering Iron & Solder Wire

• Heating lead & placing solder



• Heat for 2-3 sec. & place wire opposite iron

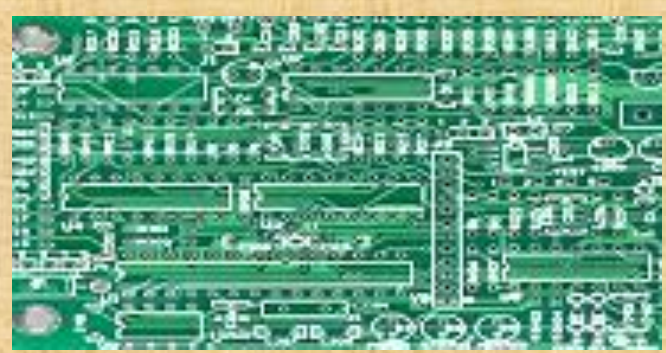


• Trim excess lead

Automated Reflow Soldering

SMT = Surface Mount Technology

• Solder/Flux paste mixture applied to PCB using screen print or similar transfer method



Printed solder paste on a printed circuit board (PCB)

• Solder Paste serves the following functions:
  – supply solder material to the soldering spot,
  – hold the components in place prior to soldering,
  – clean the solder lands and component leads
  – prevent further oxidation of the solder lands.

• PCB assembly then heated in “Reflow” oven to melt solder and secure connection

Brazing

Use of low melt point filler metal to fill thin gap between mating surfaces to be joined utilizing capillary action

- Filler metals include Al, Mg & Cu alloys (melt point typically above 840 F)
- Flux also used
- Types of brazing classified by heating method:
  - Torch, Furnace, Resistance

Applications:

- Automotive - joining tubes
- Pipe/Tubing joining (HVAC)
- Electrical equipment - joining wires
- Jewelry Making
- Joint can possess significant strength

Figure 7. Typical brazed pipe/tube applications. (Photo courtesy of Handy & Harman)

Figure 11. Typical brazing filler metal preforms. (Photo courtesy of Handy & Harman)

Brazing

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Figure 9. Typical carbide cutting tools brazed to metal in a brazing furnace. (Photo courtesy of Handy & Harman)

Welding defects

- **Misalignment** (hi-lo)
- **Undercut**
- **Underfill**
- **Concavity or Convexity**
- **Excessive reinforcement**
- **Improper reinforcement**
- **Overlap**
- **Burn-through**
- **Incomplete or Insufficient Penetration**
- **Incomplete Fusion**
- **Surface irregularity**
  - Overlap
- **Arc Strikes**
- **Inclusions**
  - Slag
  - Wagontracks
  - Tungsten
- **Spatter**
- **Arc Craters**
- **Cracks**
  - Longitudinal
  - Transverse
  - Crater
  - Throat
  - Toe
  - Root
  - Underbead and Heat-affected zone
  - Hot
  - Cold or delayed
- **Base Metal Discontinuities**
  - Lamellar tearing
  - Laminations and Delaminations
  - Laps and Seams
- **Porosity**
  - Uniformly Scattered
  - Cluster
  - Linear
  - Piping
- **Heat-affected zone microstructure alteration**
- **Base Plate laminations**
- **Size or dimensions**

UNIT IV
FORMING PROCESS

Forming process

- **Hot working :**
- The Metal working process which is done above recrystallaisation temperature is known as **hot working.**
- **Cold working:**
- The metal working process which is done below recrystallaisation temperature is known as **cold working**.

- **<u>Hot working :</u>**
- The Metal working process which is done <u>above recrystallaisation temperature</u> is known as **hot working.**
- **<u>Cold working:</u>**
- The metal working process which is done <u>below recrystallaisation temperature</u> is known as **cold working**.

- **Recrystallaisation temperature.**
- When a metal is heated and deformed under mechanical force, an energy level will be reached when the old grain structure starts disintegrating, and entirely new grain structure (equip axed, stress free) with reduced grain size starts forming simultaneously. This phenomenon is known as recrystallaisation, and the temperature at which this phenomenon starts called recrystallaisation temperature.

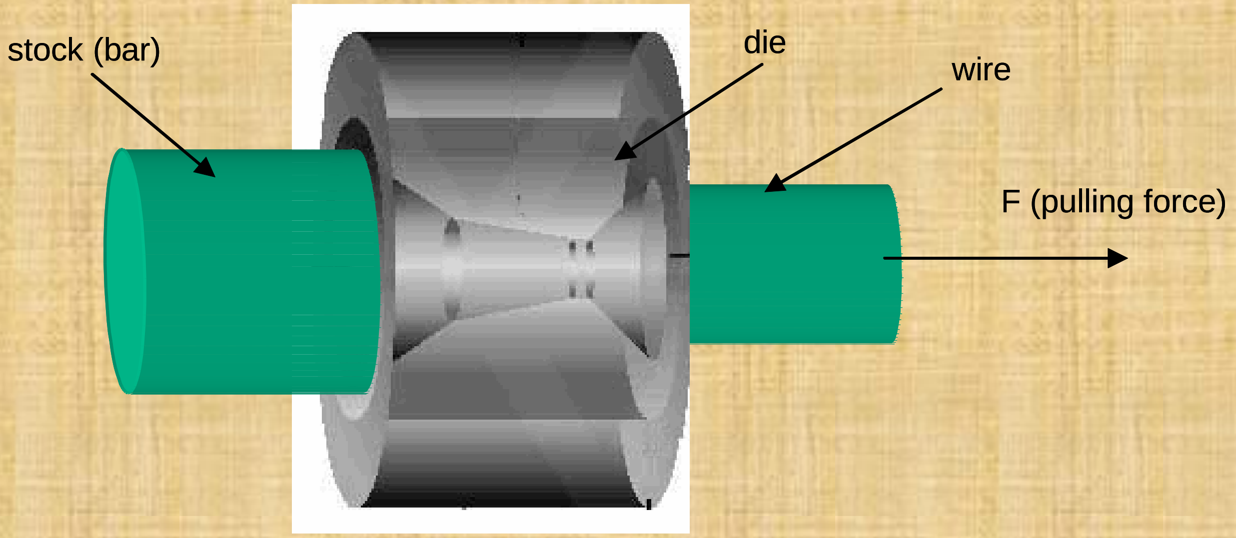
- **<u>Advantages of hot working:-</u>**
- Very large work pieces can be deformed with equipment of reasonable size
- Strength of the metal is low at high temperature. Hence low tonnage equipments are adequate for hot working.
- Gra in size can be controlled to be minimum.
- **<u>Advantages of cold working:-</u>**
- Surface defects are removed.
- High dimensional accuracy.
- Cold working is done at room temperature, no oxidation and scaling of the work material occurs.

<u>Drawing.</u>

- **Drawing** is a cold working process in which the work piece is pulled through a tapered hole in a die so as to reduce its diameter. The process imparts accurate dimensions, specified cross – section and a clean excellent Quality of surface to the work.
- <u>**Degree of drawing (RA).**</u>
- The degree of drawing is measured in terms of “reduction of area” which is defined as the ratio of the difference in cross – sectional area before and after drawing to the initial cross sectional area expressed in percent.
-

Drawing

Similar to extrusion, except: ***pulling force*** is applied



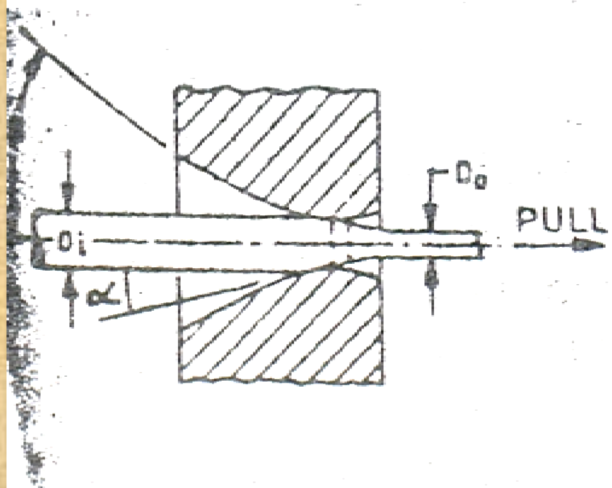
Commonly used to make wires from round bars

- **DRAWING**
- Drawing is a cold working process in which the work piece (wire, rod or tube) is pulled through a tapered hole in a die so as to reduce its diameter. The process imparts accurate dimensions, specified cross section and a clean and excellent quality of surface to the work. The process may appreciably increase the strength and hardness of metal.

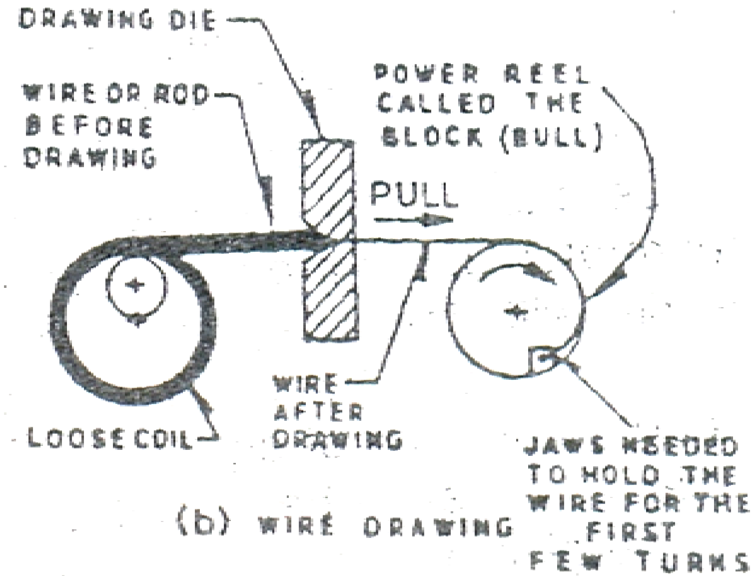
Rolling.

- Rolling is the process in which the metals and alloys are plastically deformed into semi-finished or finished condition by passing these between circular rolls. The main objective in rolling is to decrease the thickness of metal.
- The faster method is to pass the stock through a series of rolls for successive reduction, but this method requires more investment in equipment.

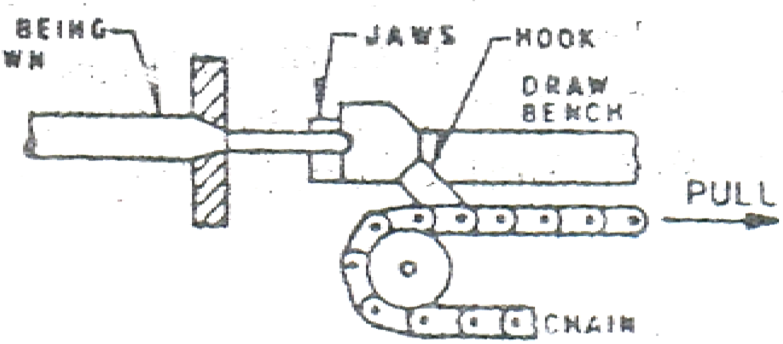
- **Tube drawing**
- Tubes which are made by hot metal working, processes are finally cold drawn to obtain better surface finish and dimensional tolerances, to enhance the mechanical properties of the pipe, and to produce tubes of reduced wall thickness.



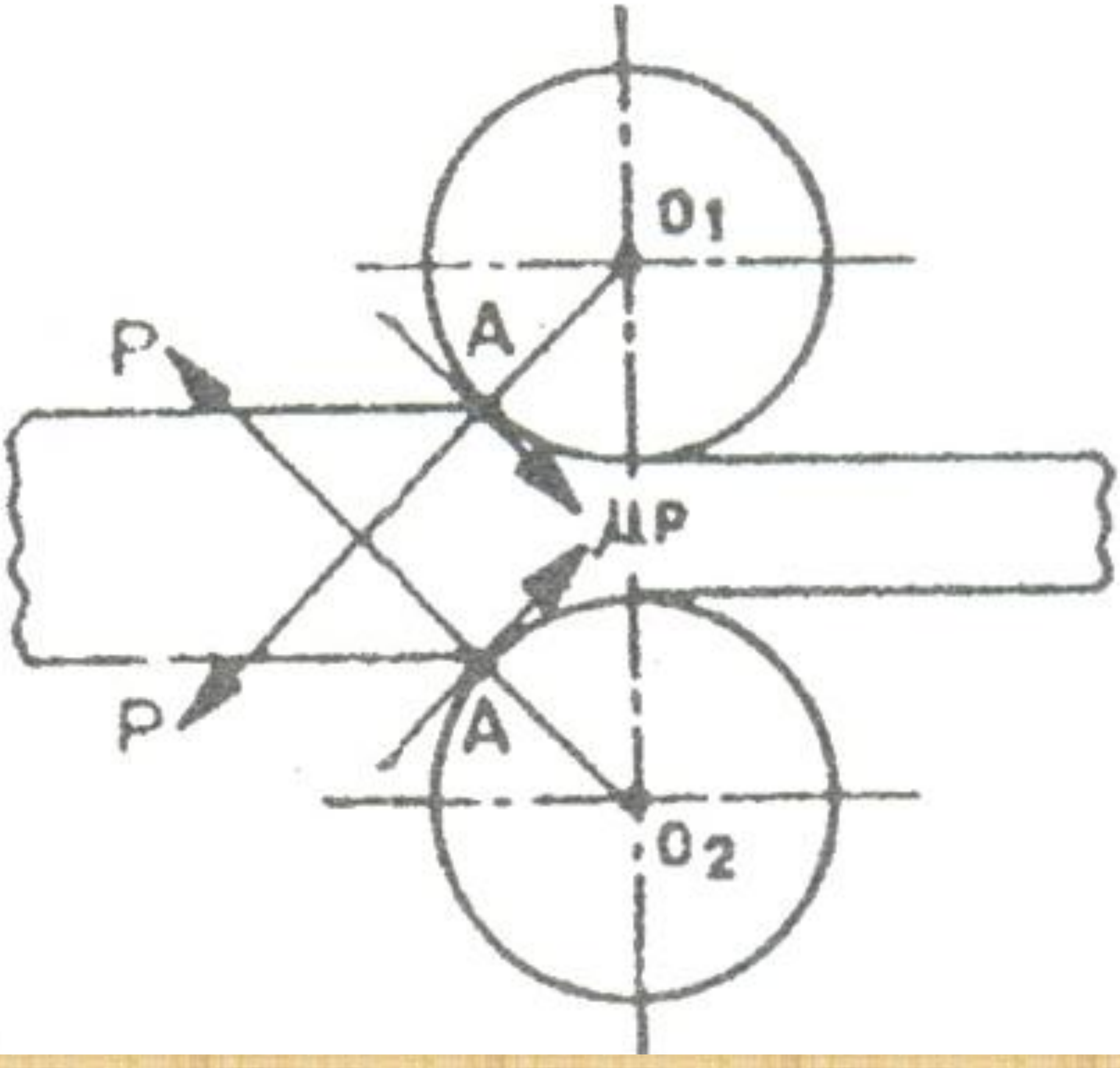
(a) A TYPICAL DRAWING DIE



(b) WIRE DRAWING



(c) ROD DRAWING



O1
A
P
ЦР
P
A
O2

Types of rolling mills

- ***Two high rolling mill***
- ***Three high rolling mill***
- ***Four-high rolling mil***
- **Multiple –roll mills**

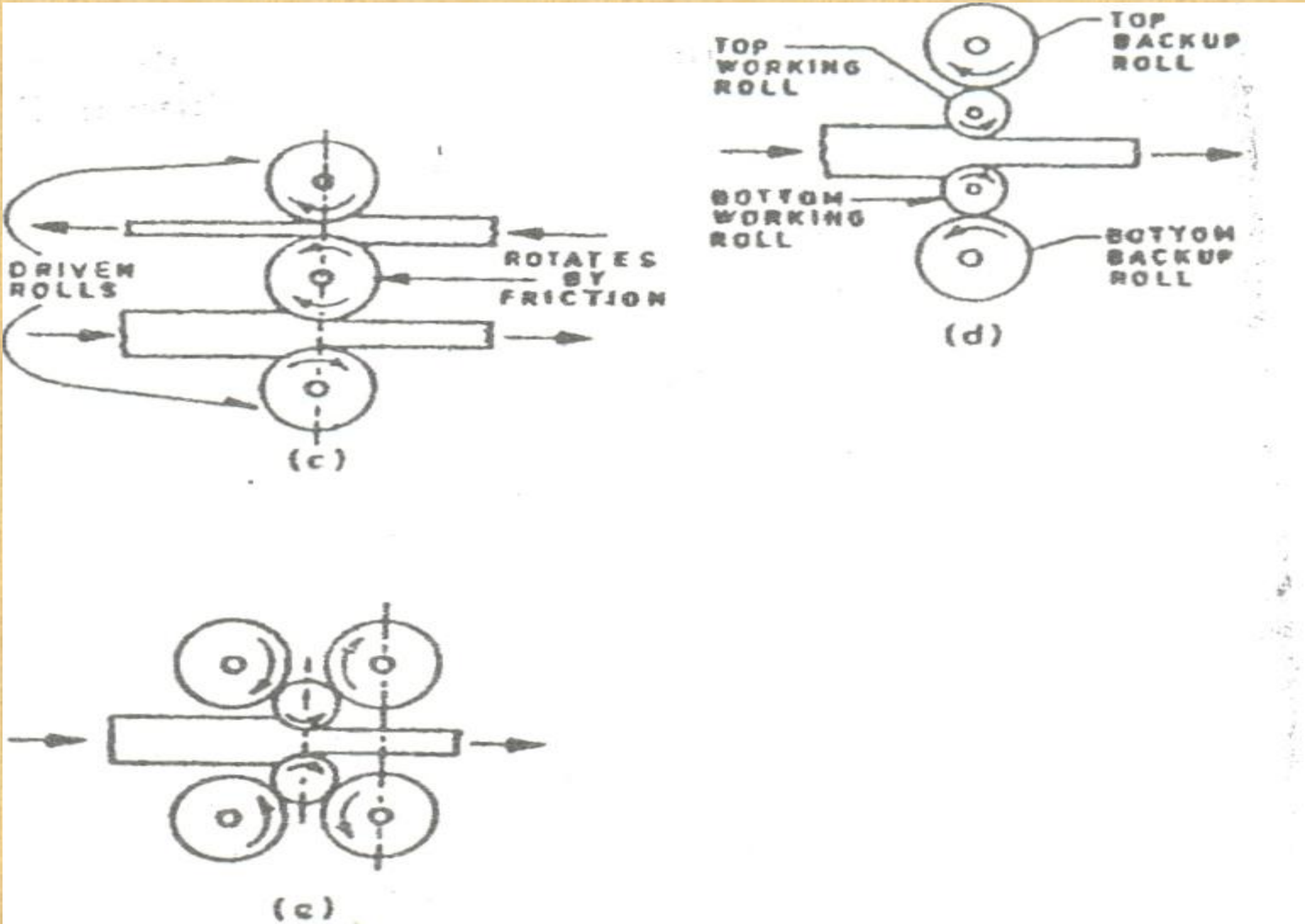


Fig. . Rolling Mills.

UNIT-V

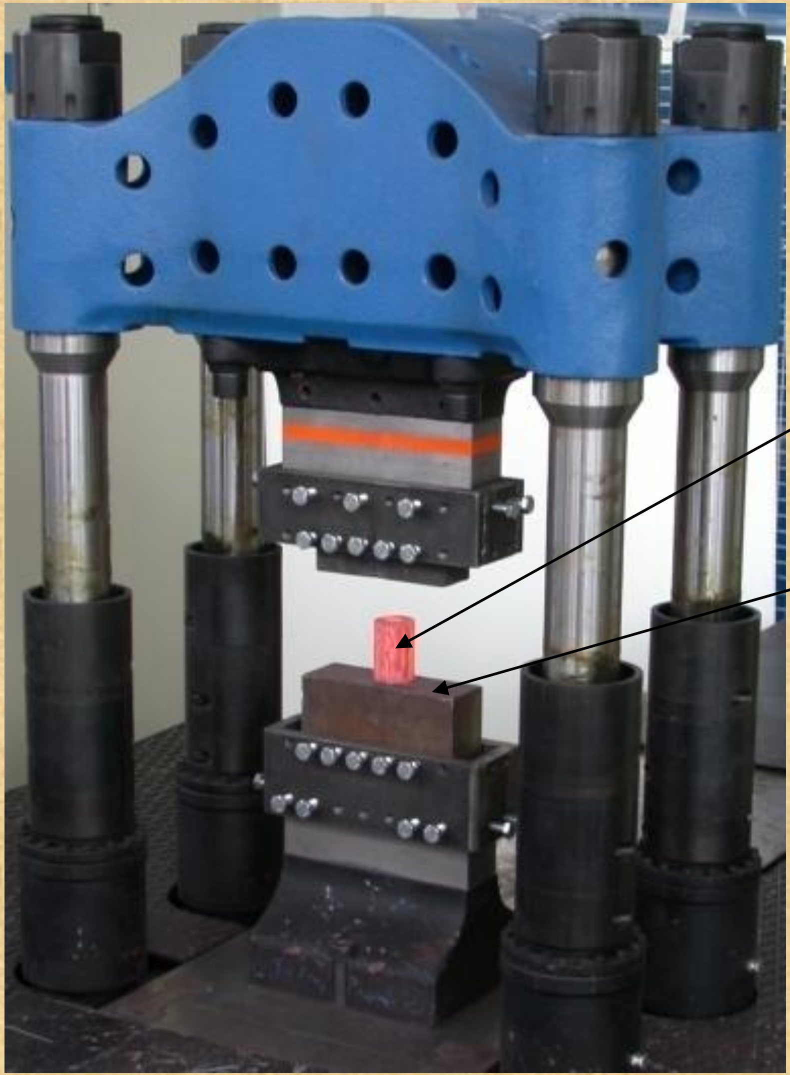
FORGING PROCESS

Forging

- Forging may be defined as a metal working process by which metals and alloys are plastically deformed to desired shapes by the application of compressive force. Forging may done either hot or cold.

Forging

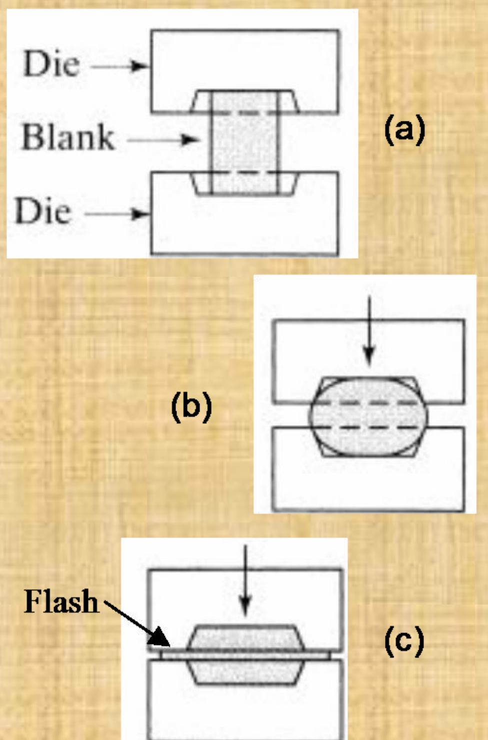
[Heated] metal is beaten with a heavy hammer to give it the required shape

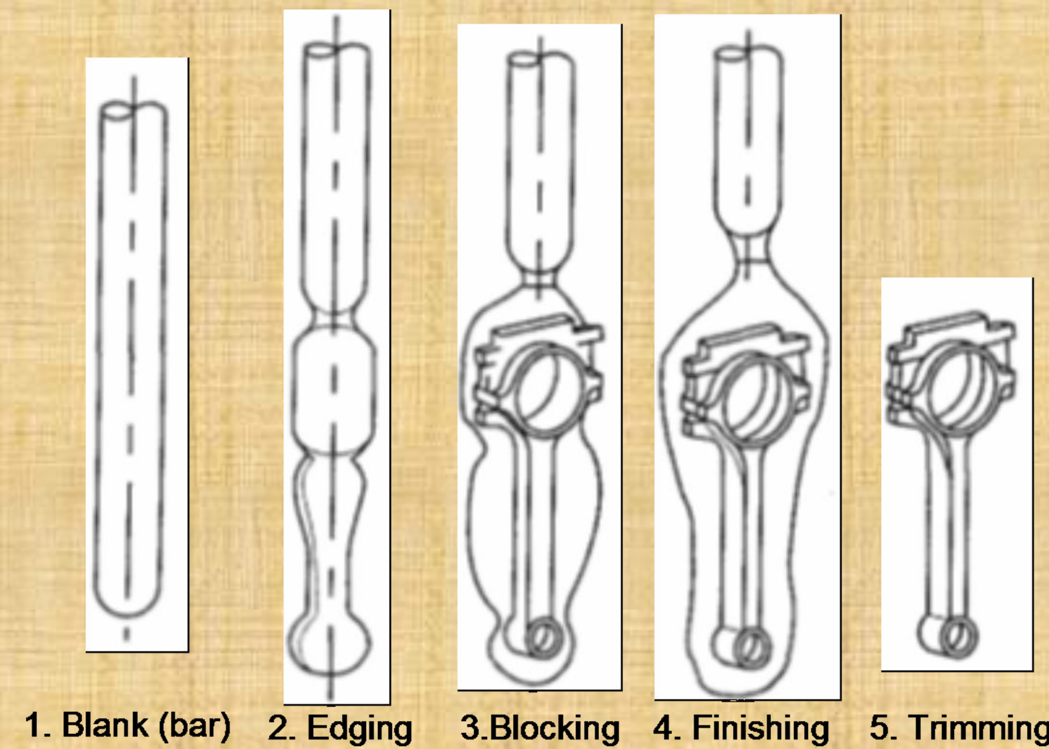


Hot forging,

open-die

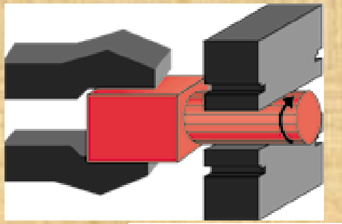
Stages in Closed-Die Forging



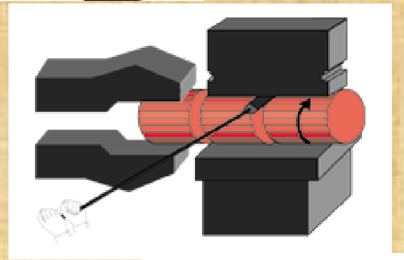


[source:Kalpakjian & Schmid]

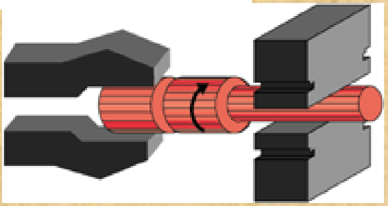
Stages in Open-Die Forging



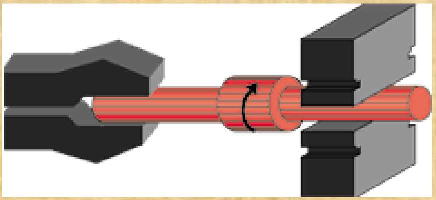
(a) forge hot billet to max diameter



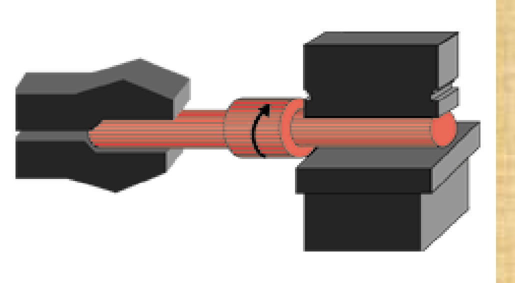
(b) “fuller: tool to mark step-locations



(c) forge right side



(d) reverse part, forge left side



(e) finish (dimension control)

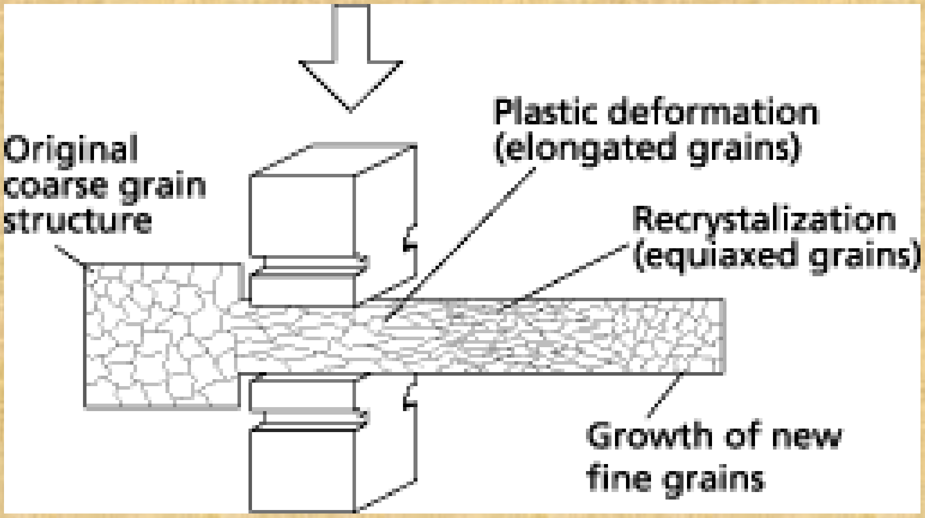
[source:www.scotforge.com]

- **<u>Basic Forging Operations</u>**
- . Upsetting
- Heading
- Fullering
- . Drawing down
- Edging
- . Bending
- Flattening
- . Blocking
- Cut – off
- Piercing
- Punching

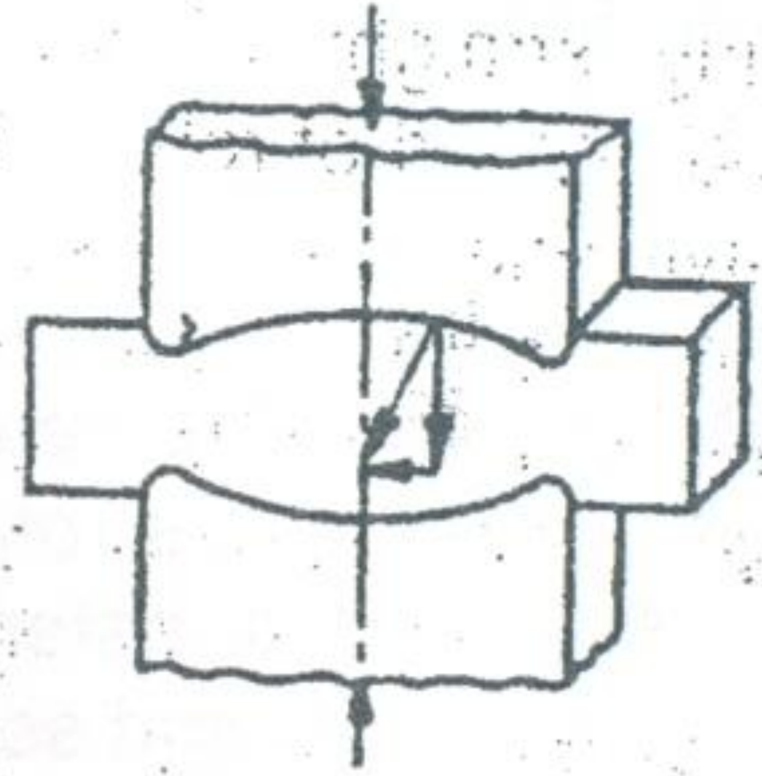
Quality of forged parts

Surface finish/Dimensional control:
Better than casting (typically)

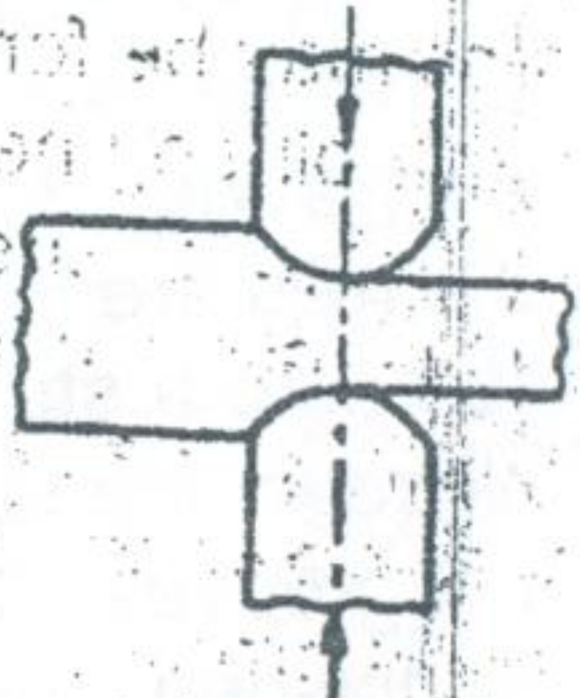
Stronger/tougher than cast/machined parts of same material



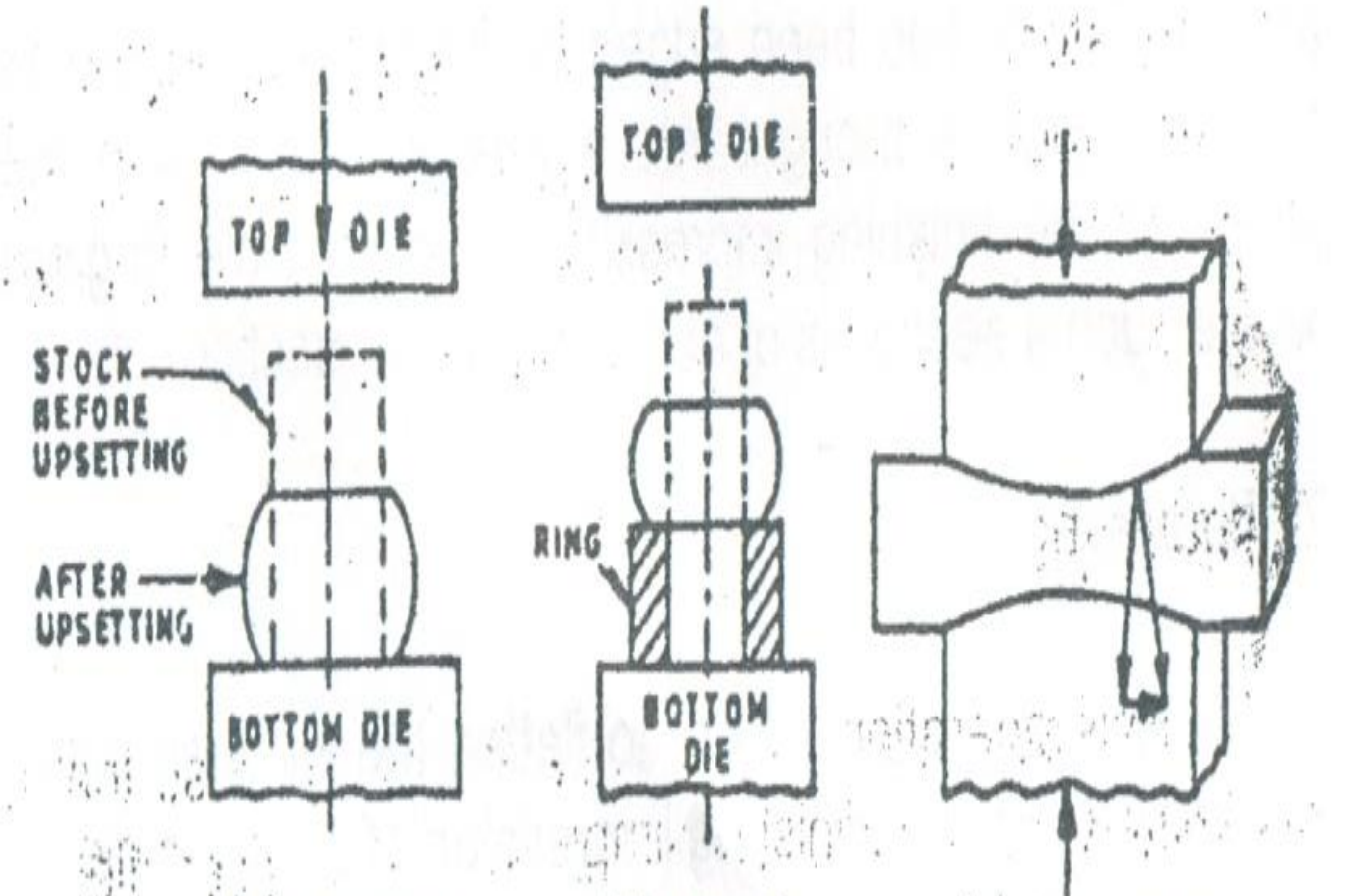
[source:www.scotforge.com]



(d) EDGING



(e) DRAWING DOWN



(a) UPSETTING (b) HEADING (c) FULLERING

Extrusion.

- Extrusion may be defined as the manufacturing process in which a block of metal enclosed in a container is forced to flow through the opening of a die. The metal is subjected to plastic deformation and it undergoes reduction and elongation during extrusion.

Extrusion

[source:www.magnode.com]

Metal forced/squeezed out through a hole (die)

Typical use: ductile metals (Cu, Steel, Al, Mg), Plastics, Rubbers

Common products:

Al frames of white-boards, doors, windows, …

- **<u>Direct Extrusion:</u>**
- eated billet is placed in the container. It is pushed by ram towards the die. The metal is subjected to plastic deformation, slides along the wall of the container and is forced to flow through die opening.
- Ram movement = Extruded material movement.
- **<u>Indirect Extrusion:-</u>**
- In this type of extrusion, the <u>extruded material movement is opposite to that of ram movement</u>. In indirect extrusion there is practically no slip of billet with respect to container walls

FORGING HAMMERS

- **Pneumatic forging hammer**
- **Hydraulic presses Direct – drive hydraulic presses**
- **Accumulator – driven hydraulic presses**

Sheet Metal Processes

Raw material: sheets of metal, rectangular, large

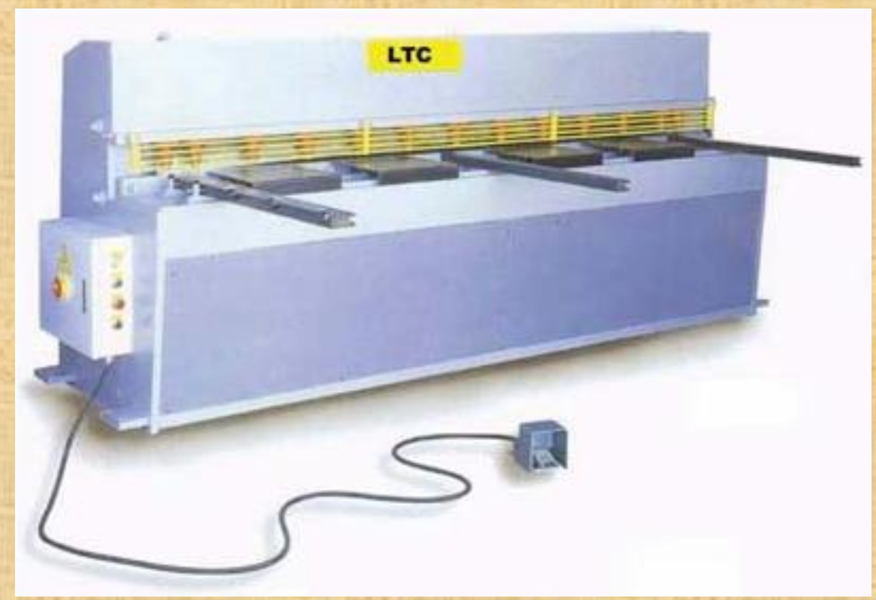
Raw material Processing: Rolling (anisotropic properties)

Processes:

- Shearing
- Punching
- Bending
- Deep drawing

Shearing

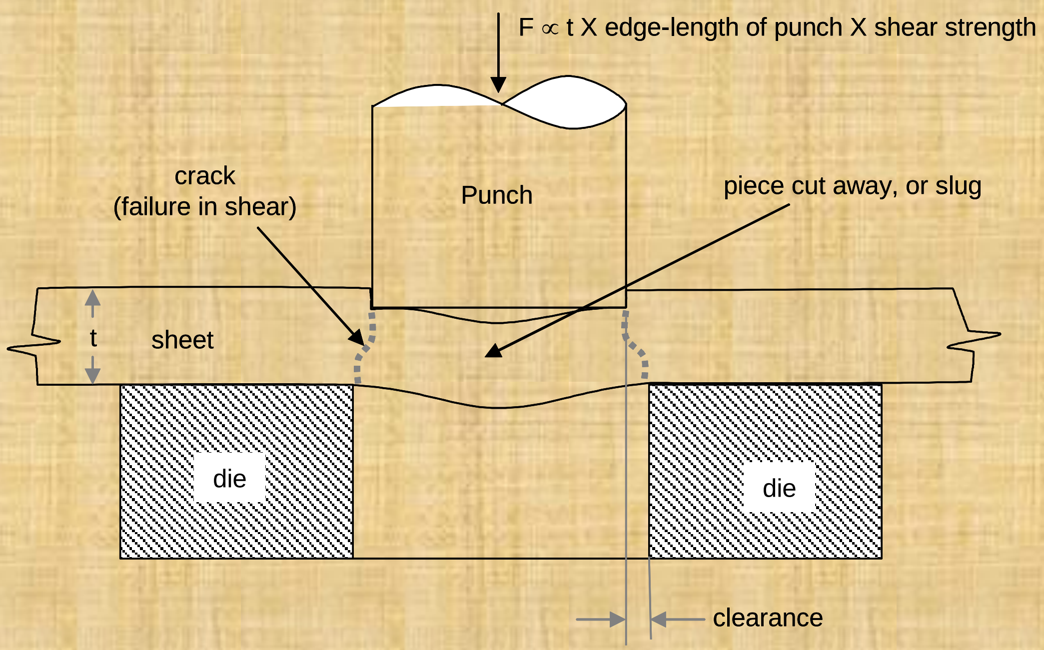
A large scissors action, cutting the sheet along a straight line



Main use: to cut large sheet into smaller sizes for making parts.

Punching

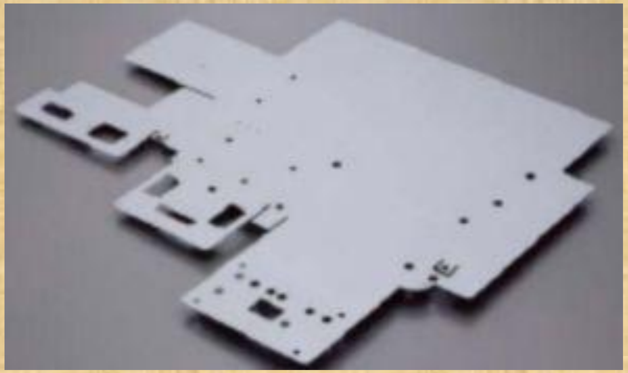
Cutting tool is a round/rectangular punch,
that goes through a hole, or die of same shape



Punching

Main uses: cutting holes in sheets; cutting sheet to required shape

nesting of parts

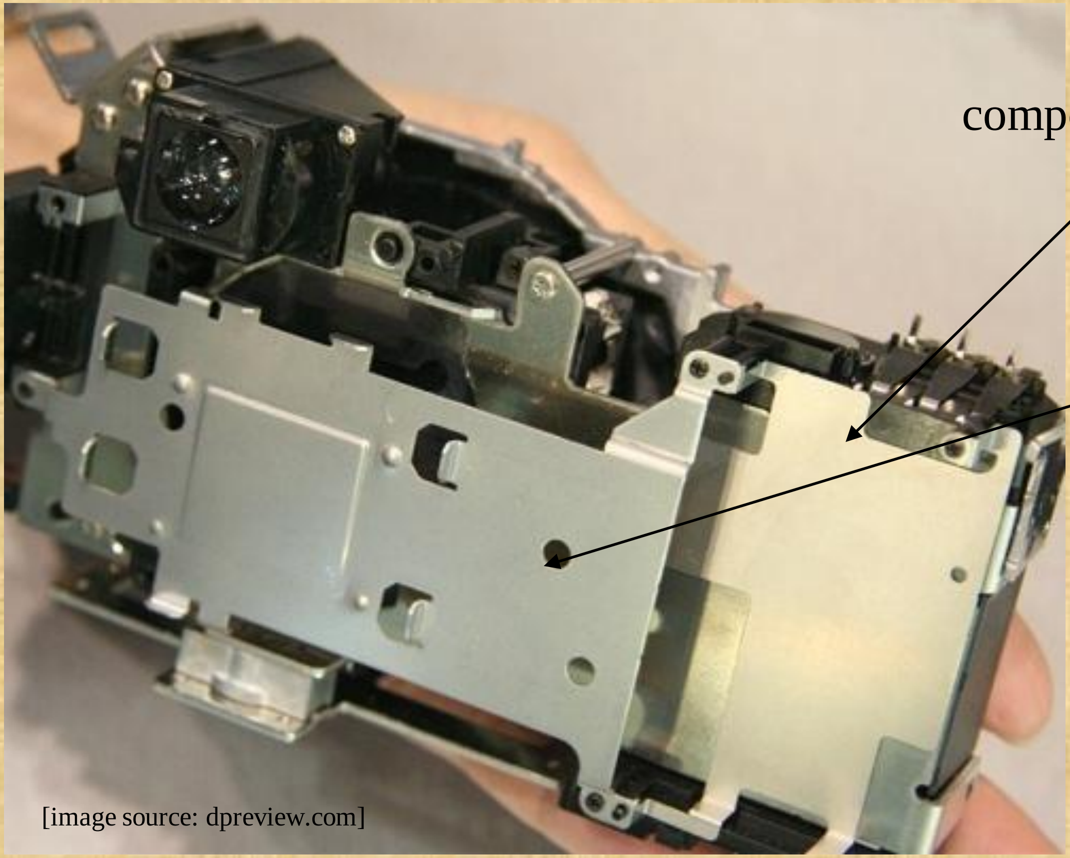


typical punched part

Exercise: how to determine optimal nesting?

Bending

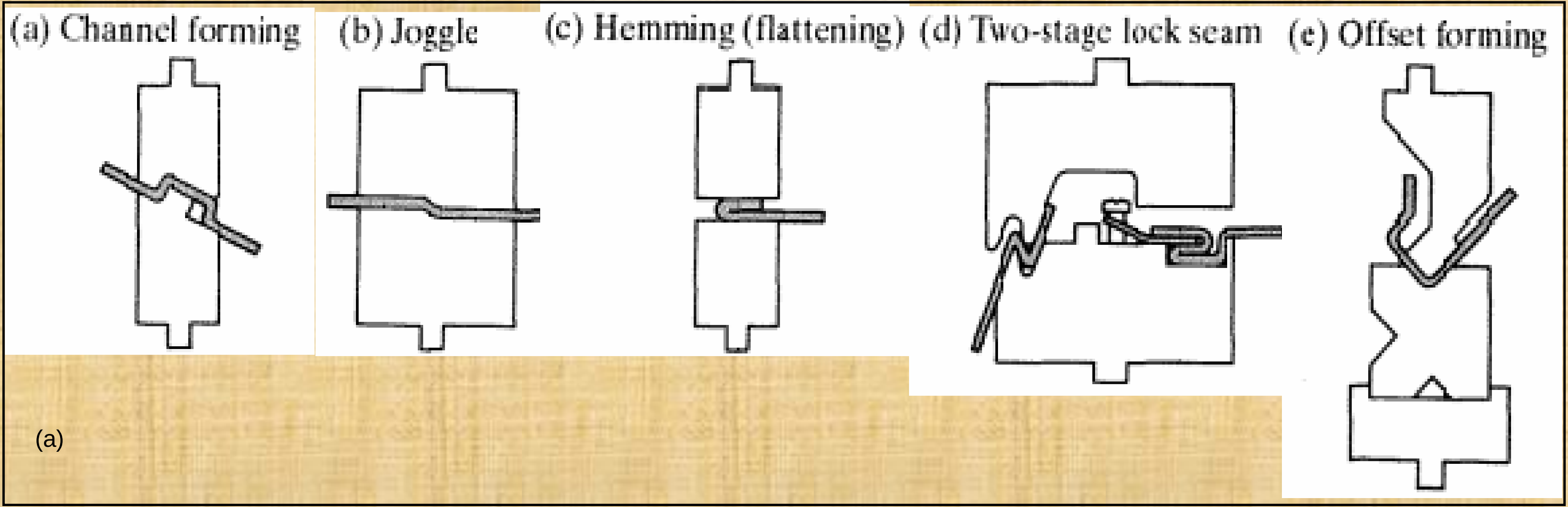
Body of Olympus E-300 camera



component with multiple bending operations

component with punching,
bending, drawing operations

Typical bending operations and shapes

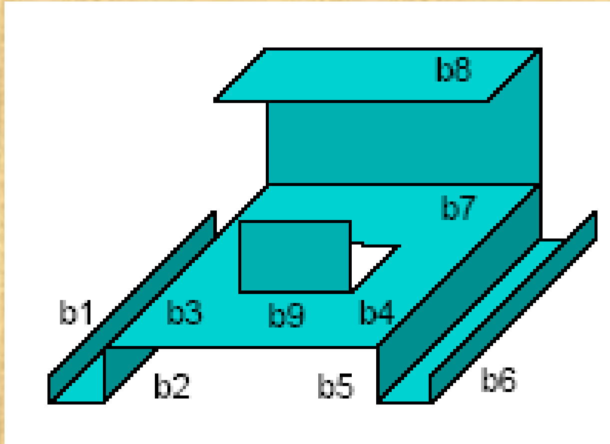


(a)

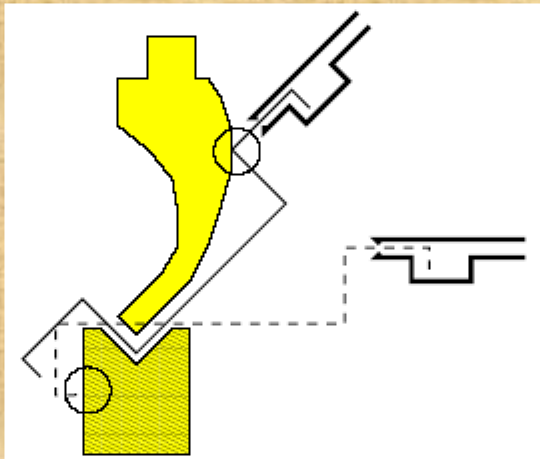
(b)

Sheet metal bending

Planning problem: what is the sequence in which we do the bending operations?

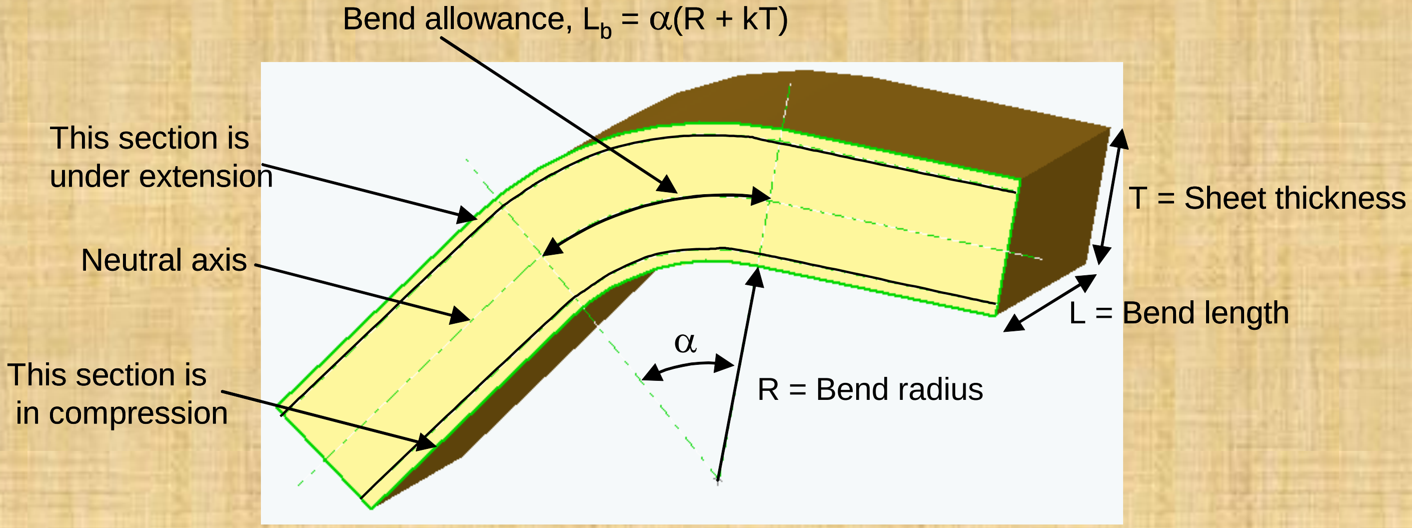


Avoid: part-tool, part-part, part-machine interference



Bending mechanics

Bending Planning ➔ what is the length of blank we must use?



Ideal case: k = 0.5

Real cases: k = 0.33 (R < 2T) ~~ k = 0.5 (R > 2T)

Bending: cracking, anisotropic effects, Poisson effect

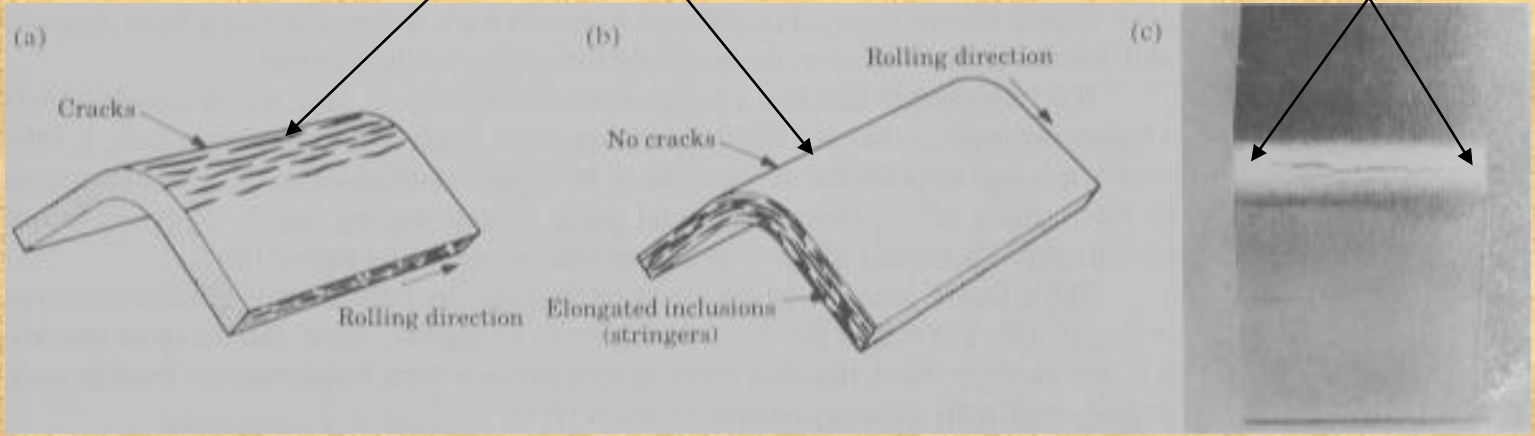
Bending ➔ plastic deformation

Engineering strain in bending = e = 1/(1 + 2R/T)

Bending ➔ disallow failure (cracking) ➔ limits on corner radius: bend radius ≥ 3T

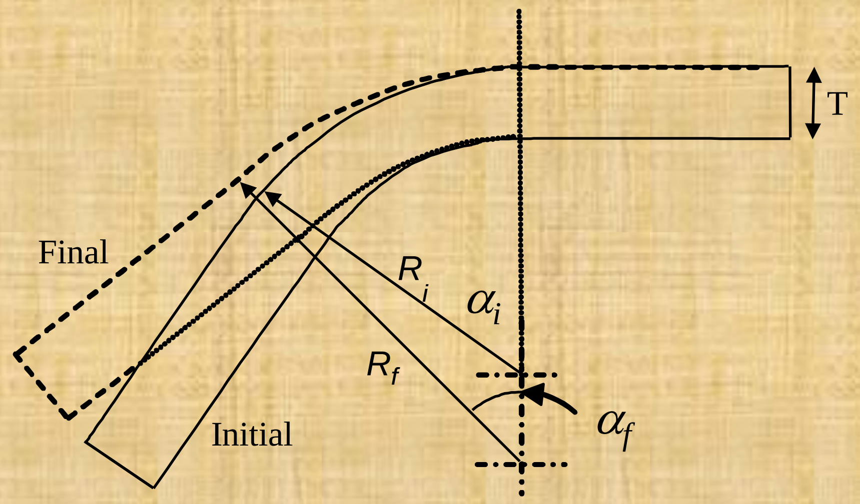
effect of anisotropic stock

Poisson effect



Exercise: how does anisotropic behavior affect planning?

Bending: springback



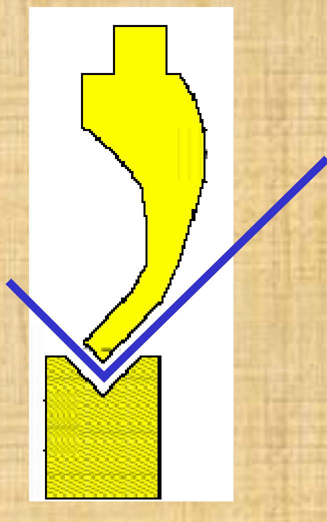
How to handle springback:

(a) Compensation: the metal is bent by a larger angle $\frac{R_i}{R_f} = 4\left(\frac{R_i Y}{ET}\right)^3 - 3\left(\frac{R_i Y}{ET}\right) + 1$

(b) Coining the bend:

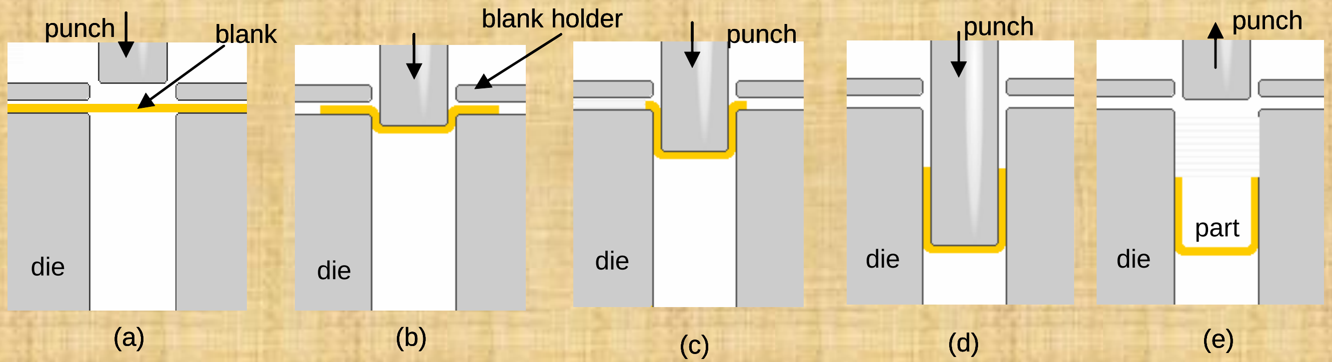
at end of bend cycle, tool exerts large force, dwells

coining: press down hard, wait, release



Deep Drawing

Tooling: similar to punching operation,
Mechanics: similar to bending operation

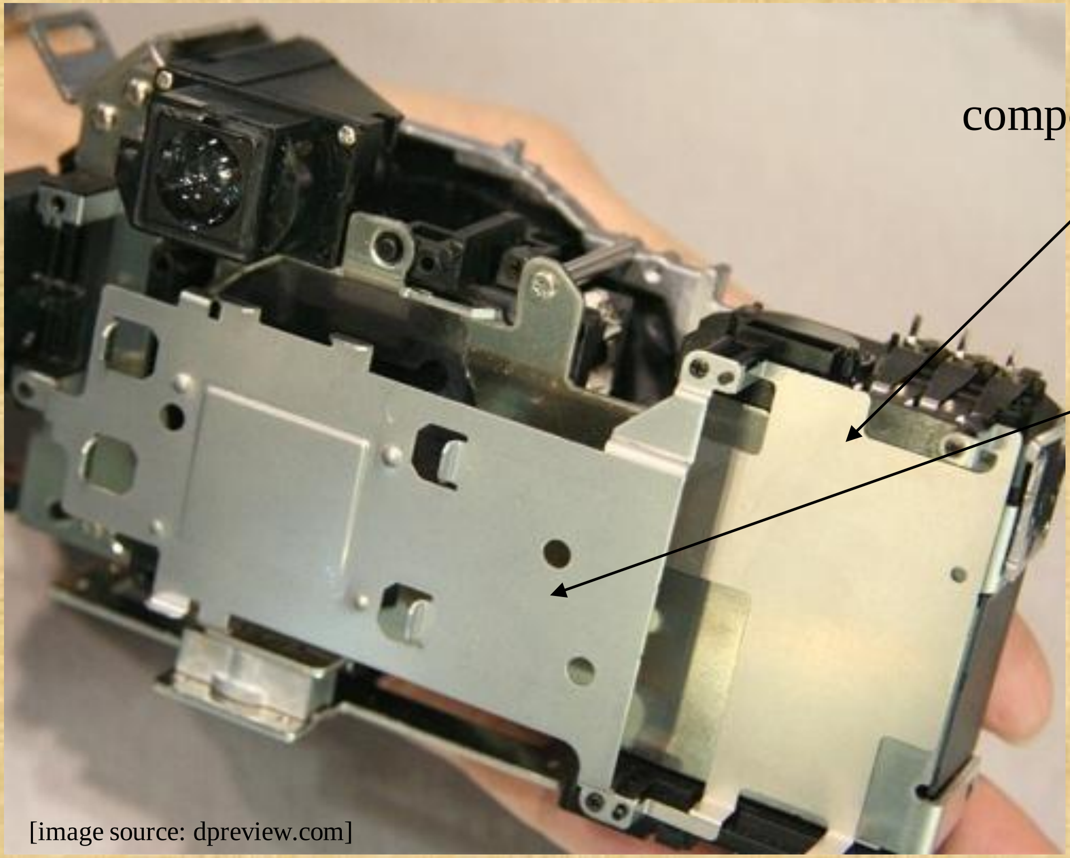


Examples of deep drawn parts

Common applications: cooking pots, containers, …

Sheet metal parts with combination of operations

Body of Olympus E-300 camera



component with multiple bending operations

component with punching, bending, drawing operations

THE END