Manufacturing Science-I

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Department of Mechanical Engineering

Dr. Rahul Jain

Education Background

✓**PhD, IIT Kharagpur (2013-2017)**

Research area: Numerical modelling of friction stir welding process

✓**M.Tech, IIT Kharagpur (2008-10)**

Research area: Modeling of orthogonal machining process

✓**B.E., GEC Bilaspur (2004-2008)**

Industrial Experience

✓ **Tata Motors, Pune (2010-2012)**

Research area: Finite element modelling of manufacturing process, Friction stir welding, Wire arc additive manufacturing

Student can contact if they are interested in any project work on above mentioned topic (Email: rahul@iitbhilai.ac.in)

Mechanical Engineering: Where Manufacturing stand and Why to study

Mechanical Engineering

Design Thermal Manufacturing IE/management

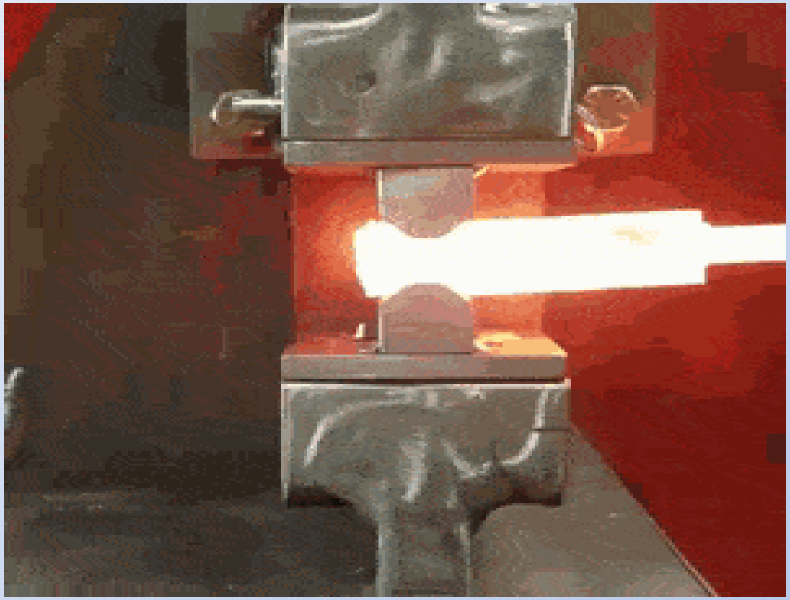
Course objective and Learning outcomes

- Course objective
  - Understand the importance of manufacturing process and study the fundamental science behind the various processes such as casting, forming and welding

- Learning outcome
  - Student will learn the basics and capabilities of the various manufacturing processes
  - Student would be capable to select an appropriate process for a product
  - Understand the basics casting process such as pattern making, gating design etc
  - Differentiate between various hot and cold working process such as rolling, forging, Extrusion etc
  - Understand the various fabrication/joining process

Course content (Theory and relevant numerical)

- Casting: Definition, pattern design and allowances, Gating system, Riser design, casting defects, types of casting process and solidification process



Forming: Stress-strain curve, Fundamental of plasticity, Hot working versus cold working, Force analysis of forming processes such as rolling, wire drawing, extrusion, deep drawing, Defects, Sheet metal operation

Course content (Theory and relevant numerical)

- Welding: Types of welding process, Gas welding, How arc is ignited, Arc welding (TIG, MIG, SAW etc), Power source characteristics, Resistance spot welding, Brazing, Soldering

- Powder metallurgy

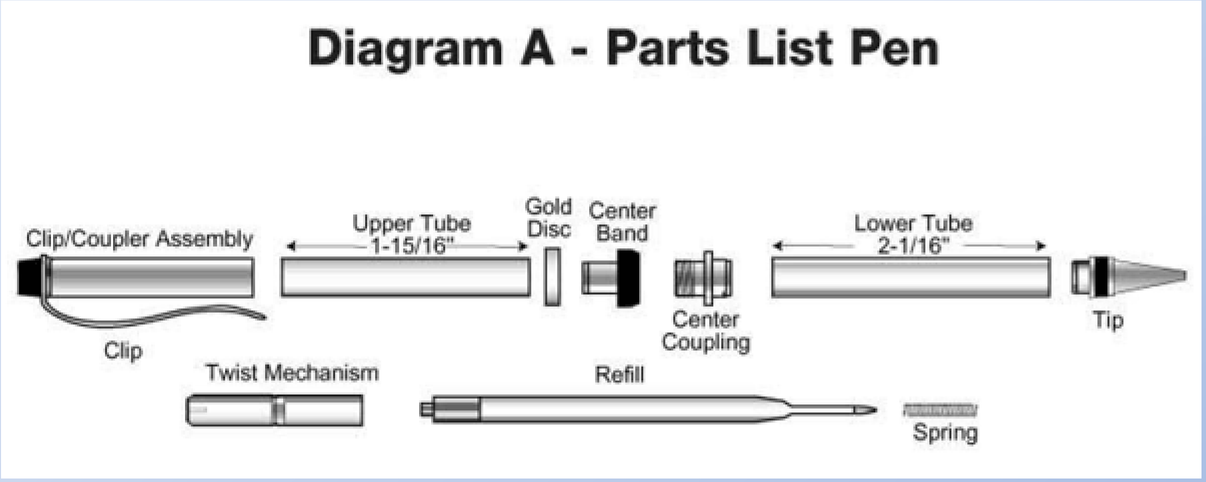
Evaluation Scheme

- Mid term and End term:45 each
- Class assessment: 10

Suggested books
Manufacturing Technology by PN Rao
Manufacturing science by Ghosh and Mallik

Reference book
Manufacturing processes by Kalpakjian and Schmid
Materials and processes in Manufacturing by Degarmo, JT Black

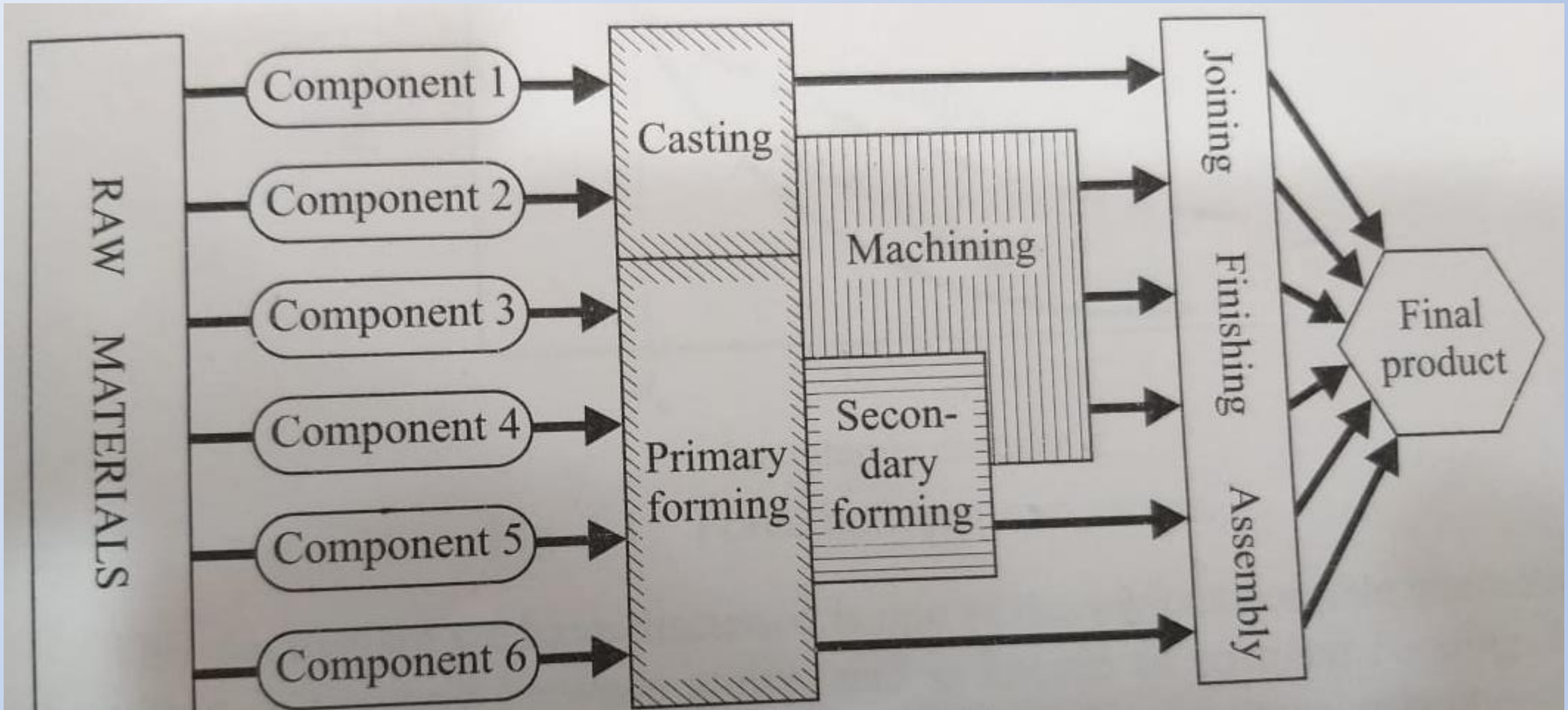
- Why selecting an appropriate manufacturing process is important?
  - Functionality and aesthetics
  - Economic feasibility



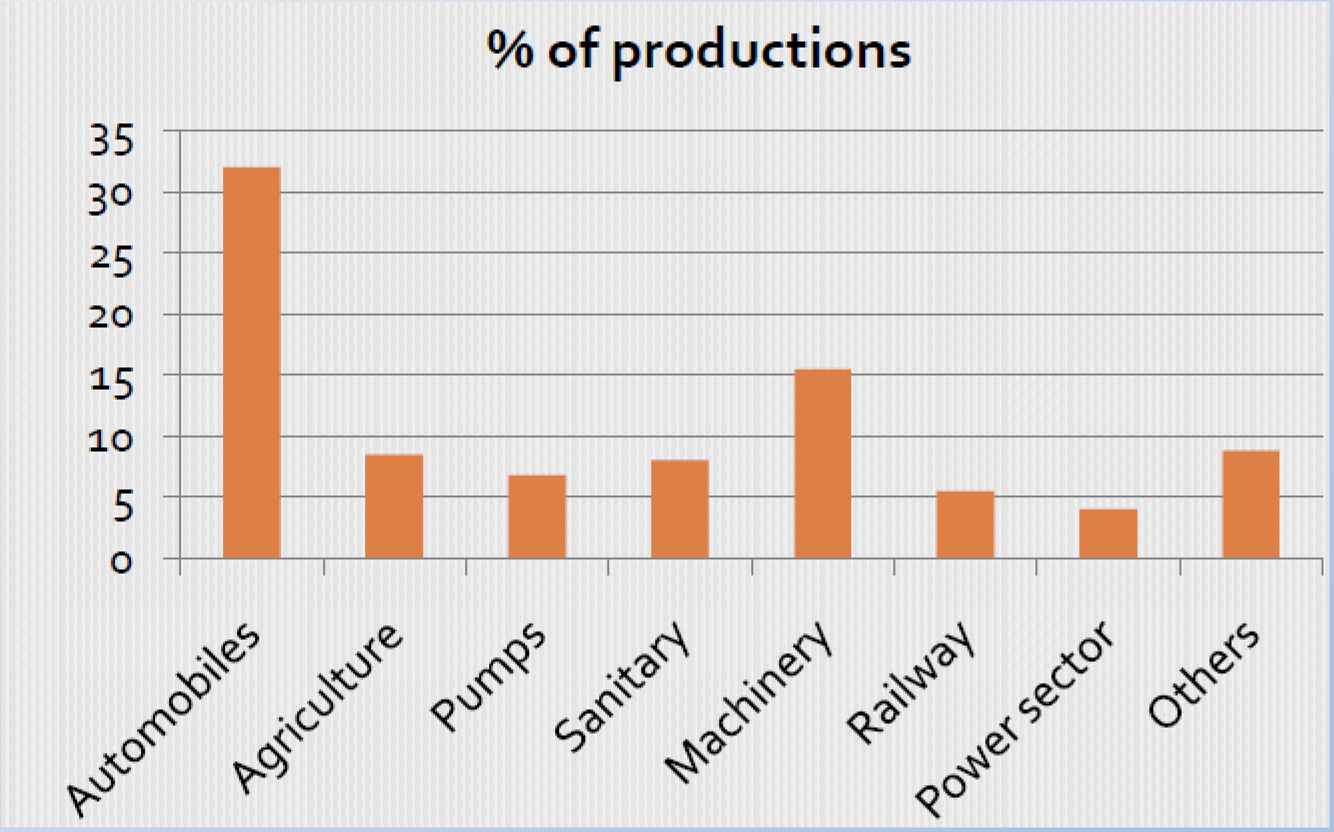
Manufacturing: Raw material ⟶ Finished/semi-finished product

Manufacturing: Raw material $\longrightarrow$ Finished/semi-finished product

Steps involved in manufacturing

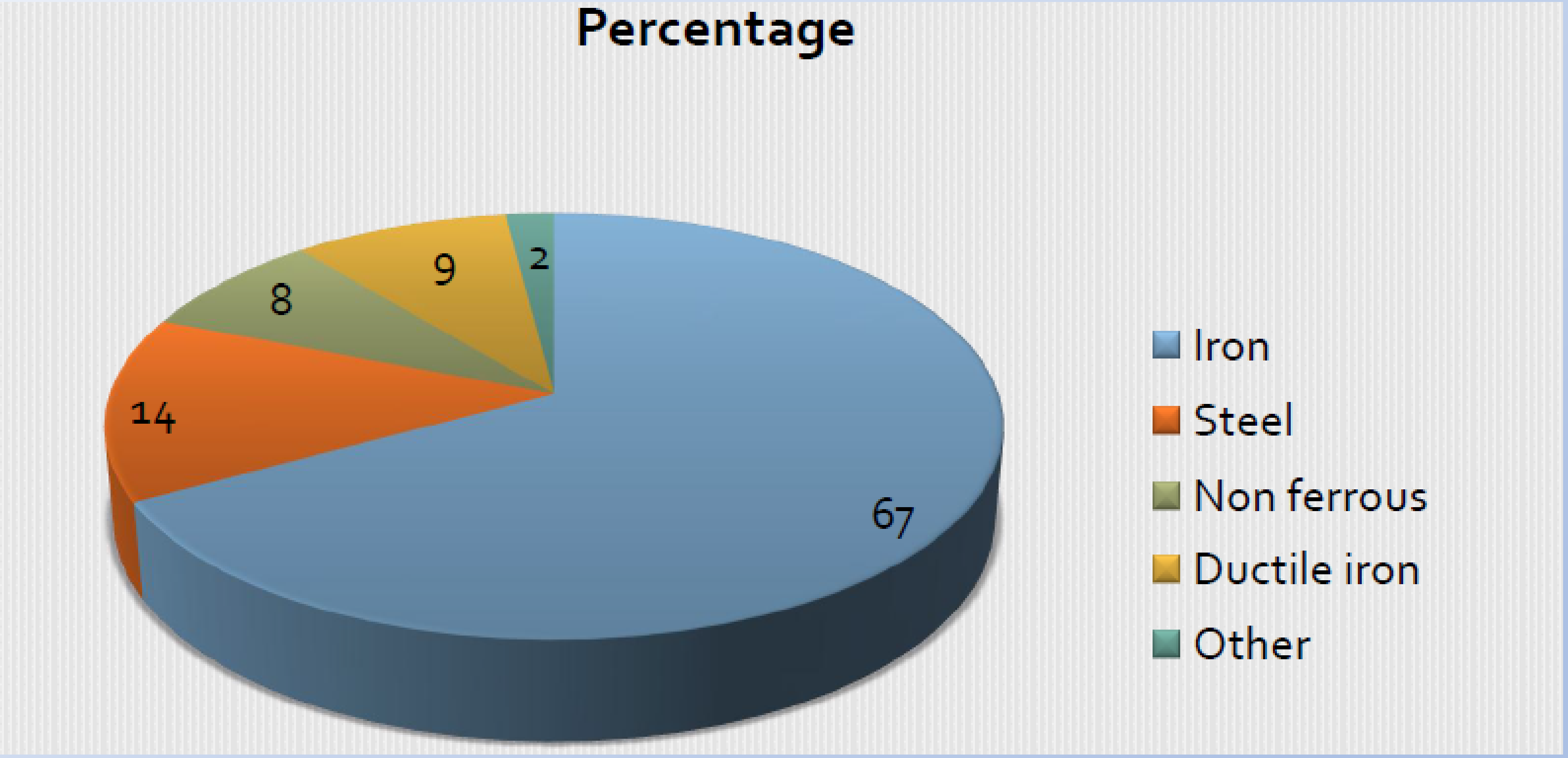


Casting in Industry



As per survey of casting foundries in India

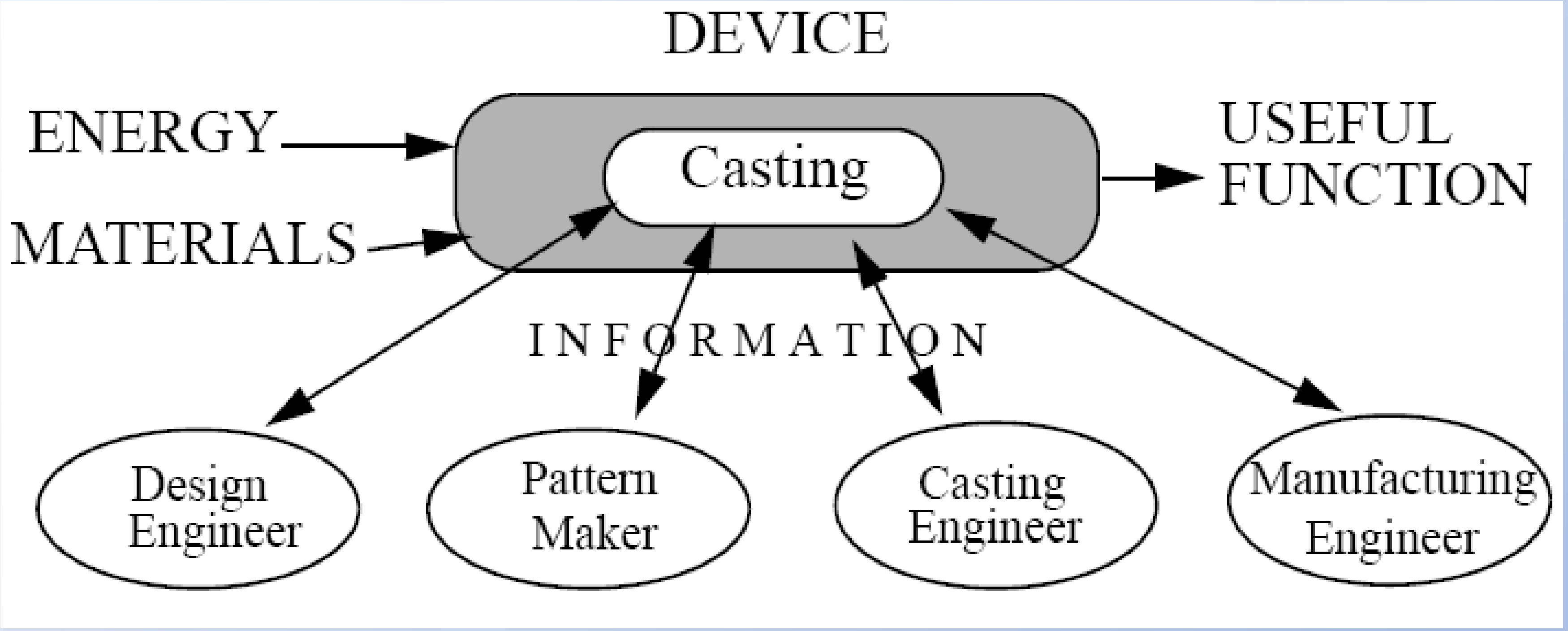
Casting Materials



The casting foundries in India is the seventh largest in the world with annual production of 4.5 Million units in 2015

As per survey of casting foundries in India

Casting- a multidisciplinary approach



Shape, size, tolerance, dimensional change during processing.

Pattern production for molds and core (CAD).

Gating and riser design (fluid and heat transfer-CAE), selection of casting processes.

After cast processing (inspection, machining & welding), cost.

Casting

- Liquid metal is poured into a mould cavity, where it is allowed to solidify. The solidified object is called as cast product
- Casting requires knowledge in following area
  - Preparation of mould and pattern
  - Melting and pouring of liquefied metal
  - Solidification and further cooling to room temperature
  - Defects and inspection

$$\begin{tikzcd} \text{Liquid metal} \arrow[r, "\text{Poured}", "\text{Gating system}"'] & \text{Mould} \arrow[r] & \text{Solidification} \\ & \text{Pattern} \arrow[u] & \end{tikzcd}$$

Metal casting Video

SAND CASTING ANIMATION

HEPSIBA SEELI

E-FOUNDRY, IIT BOMBAY

Application of Al-casting

Engine Block

Wheel

Piston head

light weight and easy to machine the components

Products from Casting

Pros of Casting

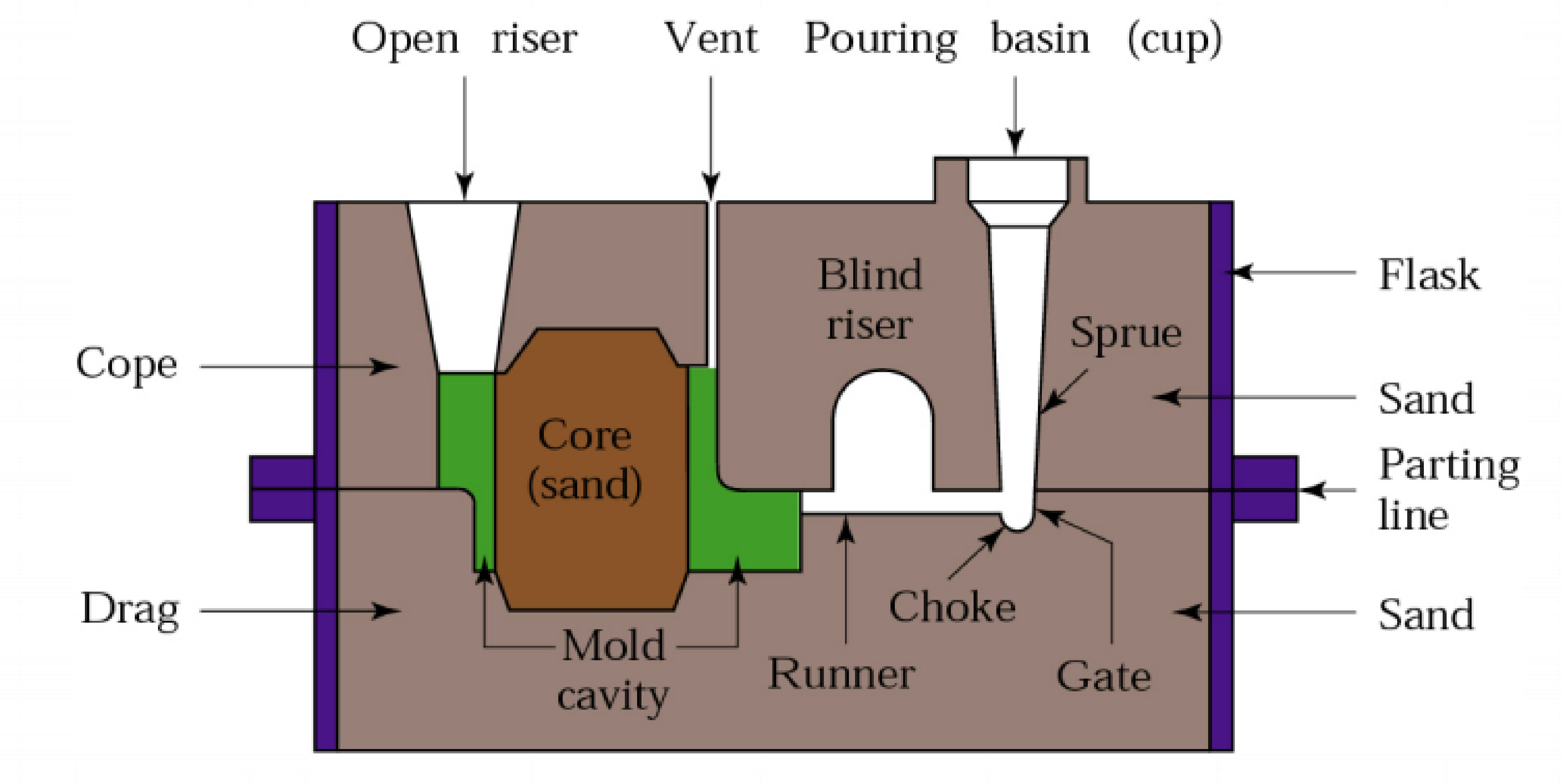
- ✓ Metal can flow through small shapes so intricate shapes can be manufactured
- ✓ Practically any material can be cast i.e. ferrous or non-ferrous
- ✓ Required tools are simple and inexpensive
- ✓ Size and weight of the product is not the limitation

Upper ram for counter blow hammer (100 tons)

Cons of Casting

- × Metal casting process is labour intensive
- × Surface finish and dimensional accuracy of sand casting is not good though there are some casting method which produces good surface finish

Casting terminology



Schematic illustration of sand casting (Source: Kalpakjian, 2017)

Pattern

- Replica of the final product.
- Material: Wood or metal
- Wood: Pine, mahogany, teak, deodar

			Rating[a]		
Characteristic	*Wood*	*Aluminum*	*Steel*	*Plastic*	*Cast iron*
Machinability	E	G	F	G	G
Wear resistance	P	G	E	F	E
Strength	F	G	E	G	G
Weight **b**	E	G	P	G	P
Repairability	E	P	G	F	G
Resistance to:					
Corrosion **c**	E	E	P	E	P
Swelling **c**	P	E	E	E	E

a E, Excellent; G, good; F, fair; P, poor.

b As a factor in operator fatigue.

c By water.

Source: D.C. Ekey and W.R. Winter, Introduction to Foundry Technology. New York. McGraw-Hill, 1958.

Pattern material

- Depends on size of the casting, the number of casting and dimensional accuracy
- Metal pattern is generally used for large scale production and closer tolerances
- Plastics: Low weight, easier formability, smooth surfaces and durability.
  - Do not absorb moisture, therefore better dimensional accuracy
  - Epoxy resins with additives
  - Lower shrinkage allowance
- Polyurethane foam is also used
  - Light weight,
  - Used for light duty work, small numbers

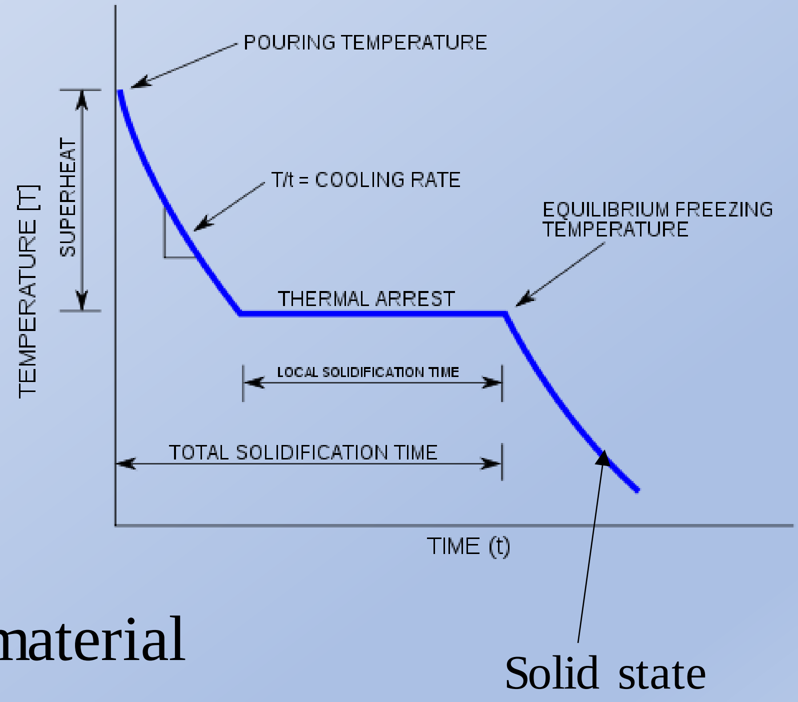
Expected life of pattern

TABLE 3.5 Pattern materials based on expected life

Number of Castings Produced before Pattern Equipment Repair		Pattern Material
Pattern	Core	
Small castings (under 600 mm)		
2 000 6 000 100 000	2 000 6 000 100 000	Hard wood Aluminium, Plastic Cast iron
Medium castings (600–1800 mm)		
1 000 3 000	750 3 000	Hard wood Aluminium, Plastic
Large castings (above 1800 mm)		
200 500	150 500	Soft wood Hard wood metal reinforced

Pattern allowances

1. Shrinkage or contraction allowance
2. Draft or taper allowance
3. Machining or finish allowance
4. Distortion or camber allowance
5. Rapping allowance

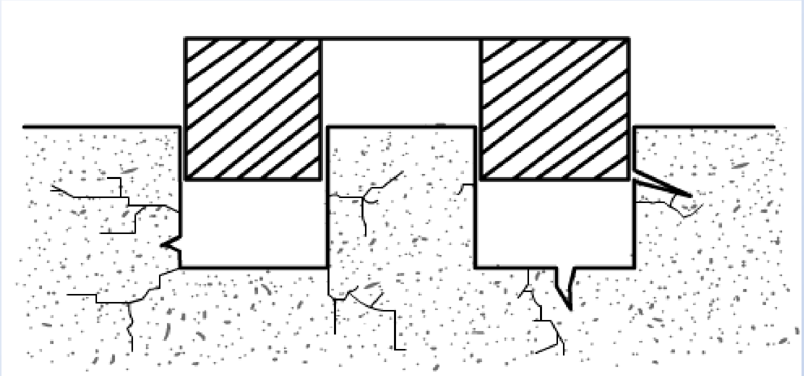


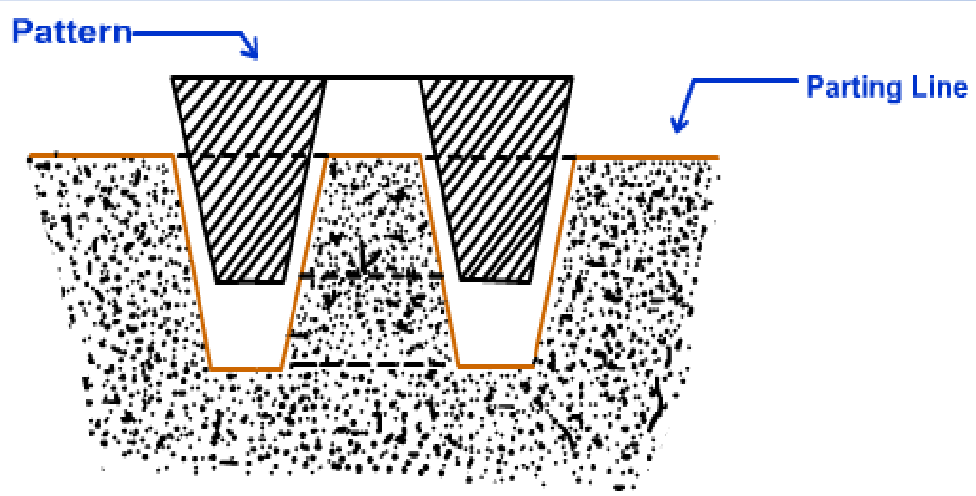
- Shrinkage allowance
  - Liquid shrinkage: Riser
  - Solid shrinkage: Allowance
- Amount of shrinkage depends upon material
- Shrinkage allowance = $\alpha(T_f - T_r)l$

Shrinkage allowance for different material

Material	Dimension	Shrinkage allowance (inch/ft)
Grey Cast Iron	Up to 2 feet 2 feet to 4 feet over 4 feet	0.125 0.105 0.083
Cast Steel	Up to 2 feet 2 feet to 6 feet over 6 feet	0.251 0.191 0.155
Aluminum	Up to 4 feet 4 feet to 6 feet over 6 feet	0.155 0.143 0.125
Magnesium	Up to 4 feet Over 4 feet	0.173 0.155

Draft allowance





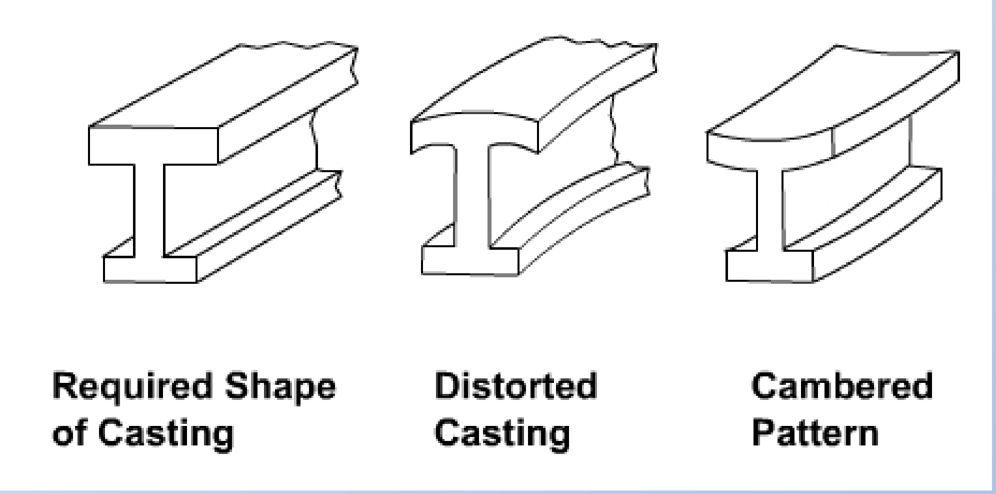
Draft is the taper provided by the pattern maker on all vertical surfaces of the pattern so that it can be removed from the sand without tearing away the sides of the sand mold.

Draft allowance

Pattern Material	Height of the Given Surface, mm	Draft Angle of Surfaces, Degrees	
		External Surface	Internal Surface
Wood	20	3.00	3.00
	21 to 50	1.50	2.50
	51 to 100	1.00	1.50
	101 to 200	0.75	1.00
	201 to 300	0.50	1.00
	301 to 800	0.50	0.75
	801 to 2000	0.35	0.50
	over 2000	—	0.25
Metal and plastic	20	1.50	3.00
	21 to 50	1.00	2.00
	51 to 100	0.75	1.00
	101 to 200	0.50	0.75
	201 to 300	0.50	0.75
	301 to 800	0.35	0.50

Distortion or camber allowance

The distortion in casting may occur due to internal stresses. These internal stresses are caused on account of unequal cooling of different section of the casting.

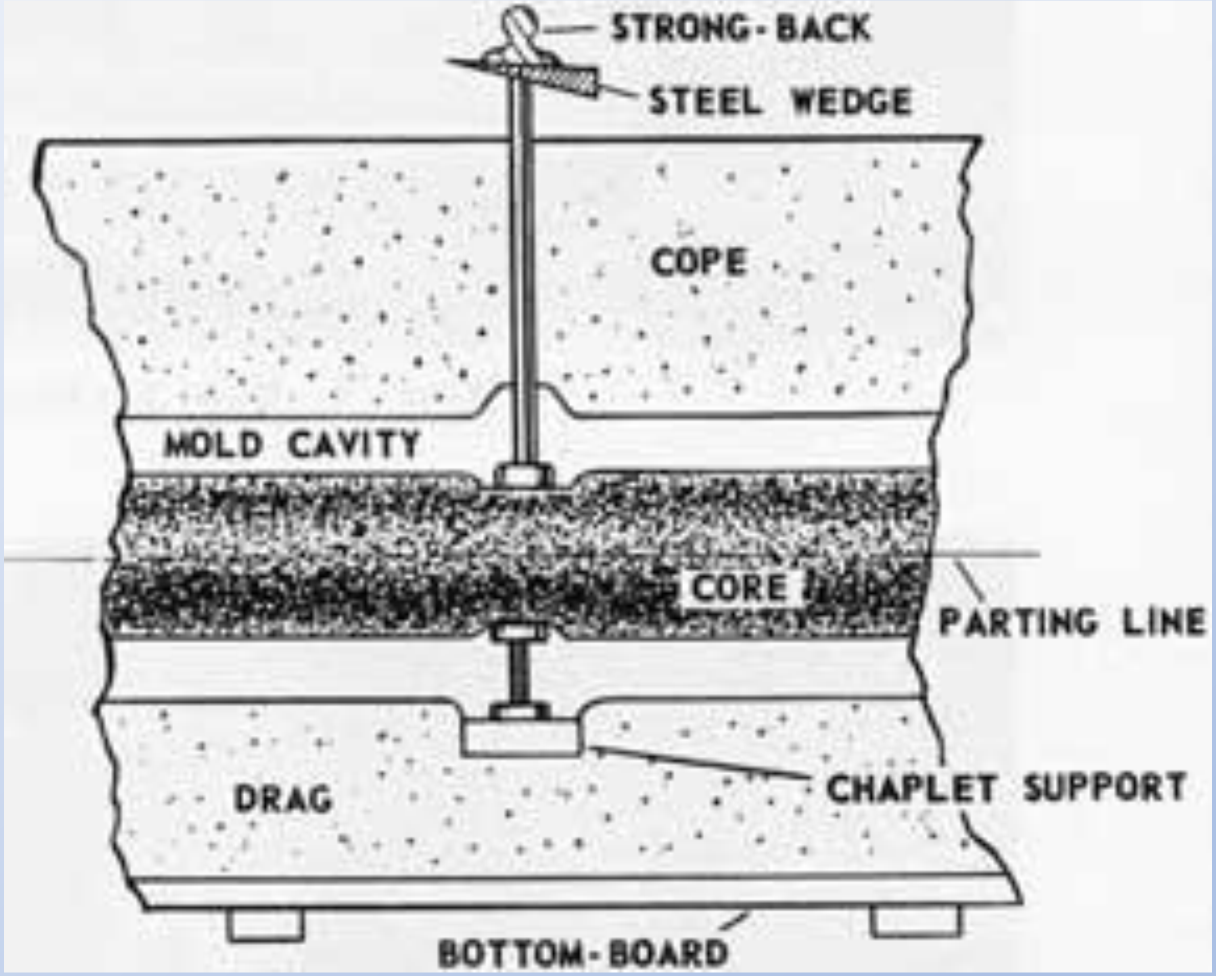


Machining allowance

- Surface finish of the cast product is not good.
- All ferrous material have scale on the skin, which needs to be removed by cleaning
- Putting major part in drag reduces the defects generated from parting line

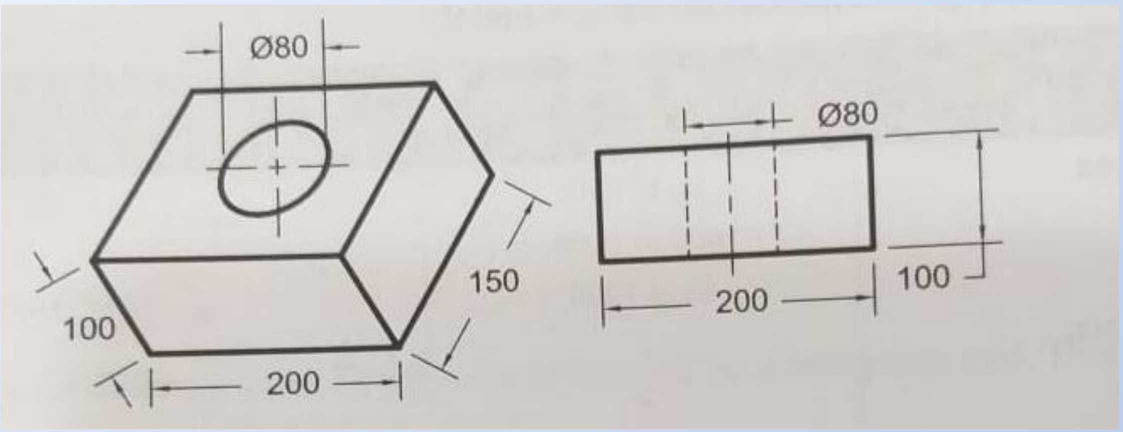
Shake allowance

- Pattern is rapped all around the vertical surfaces to enlarge the mould cavity
- Highly dependent on the skill of the person
- It's the negative allowance
- One method of reducing is to provide proper draft allowance

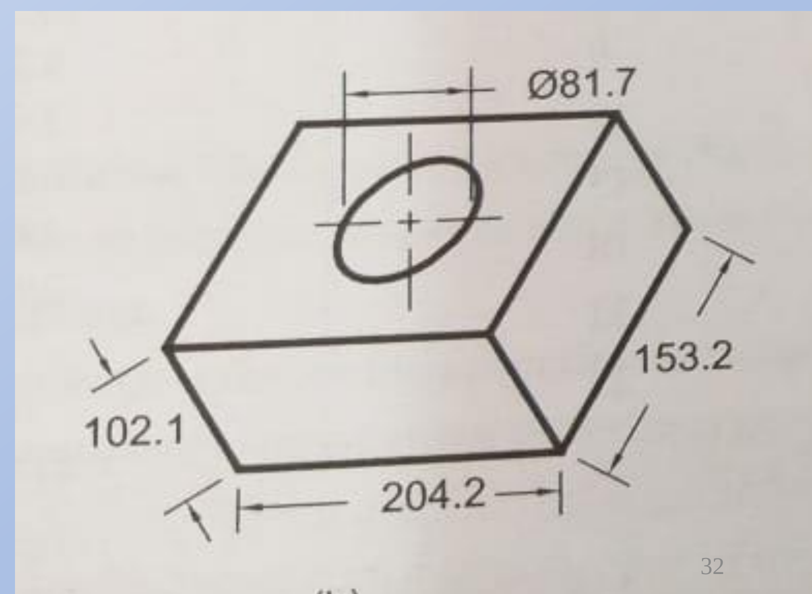


Core and chaplet

Q1) The casting shown is to be made in plain carbon steel using a wood pattern. Assuming only shrinkage allowance, calculate the dimension of the pattern. (Shrinkage: 21 mm/m)



For dimension 200, allowance is 200*(21/1000) = 4.2 mm

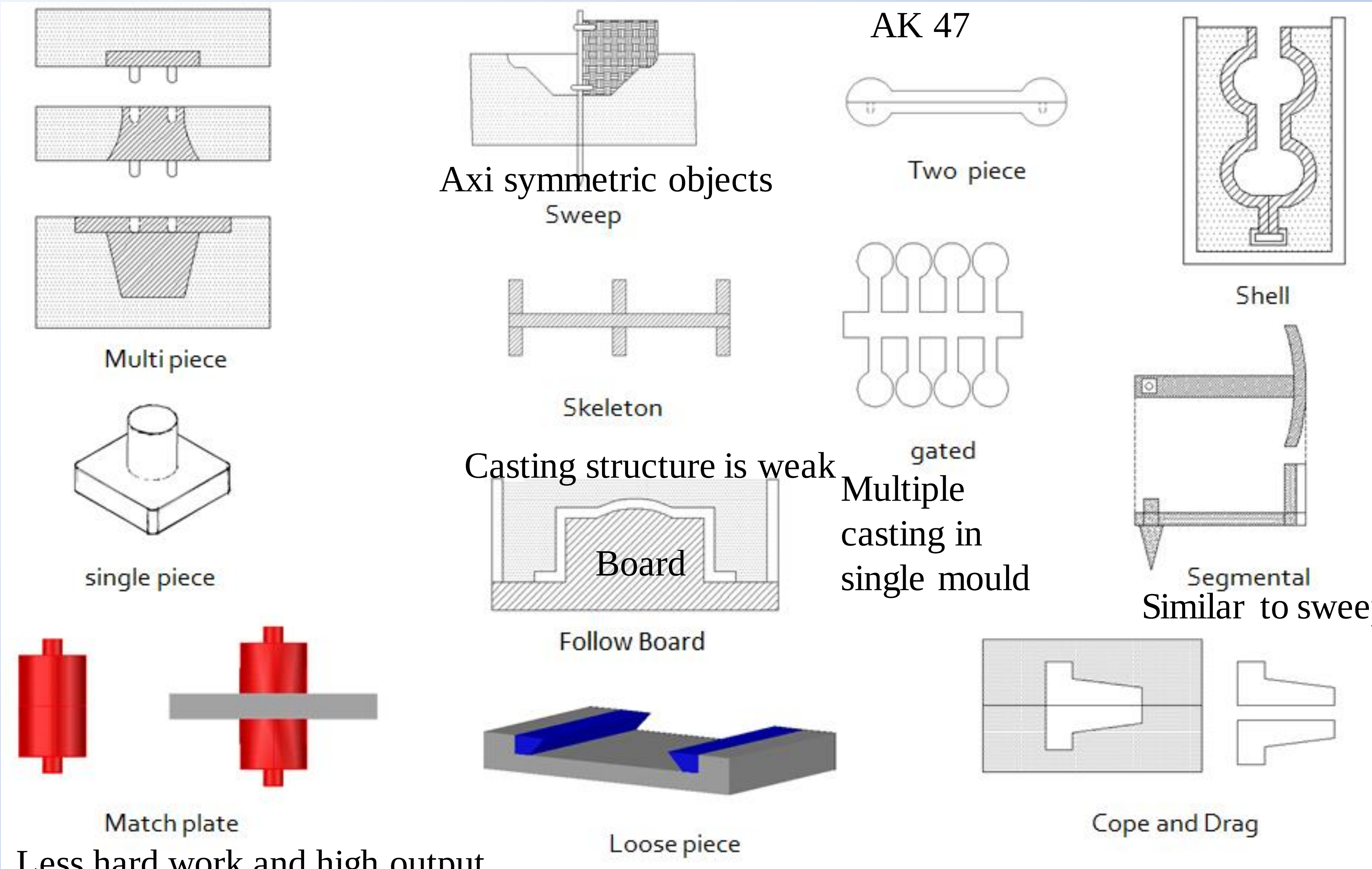


Types of pattern

Dowel Joint

Steam valves

AK 47



Axi symmetric objects

Casting structure is weak

Board

Multiple casting in single mould

Similar to sweep

Less hard work and high output

Piston ring

Heavy and inconvenient for handling; Gates are attached

Types of pattern

Source: https://www.youtube.com/watch?v=tB2ga9mISks accessed on 4-8-20 at 5:47 PM

Molding sand

1. Base sand (silica, zircon or chromite sand)
2. Binder (clay, cereal, coal dust, portland cement, organic oil, resin etc)
3. Moisture (water) for activating clay/binder

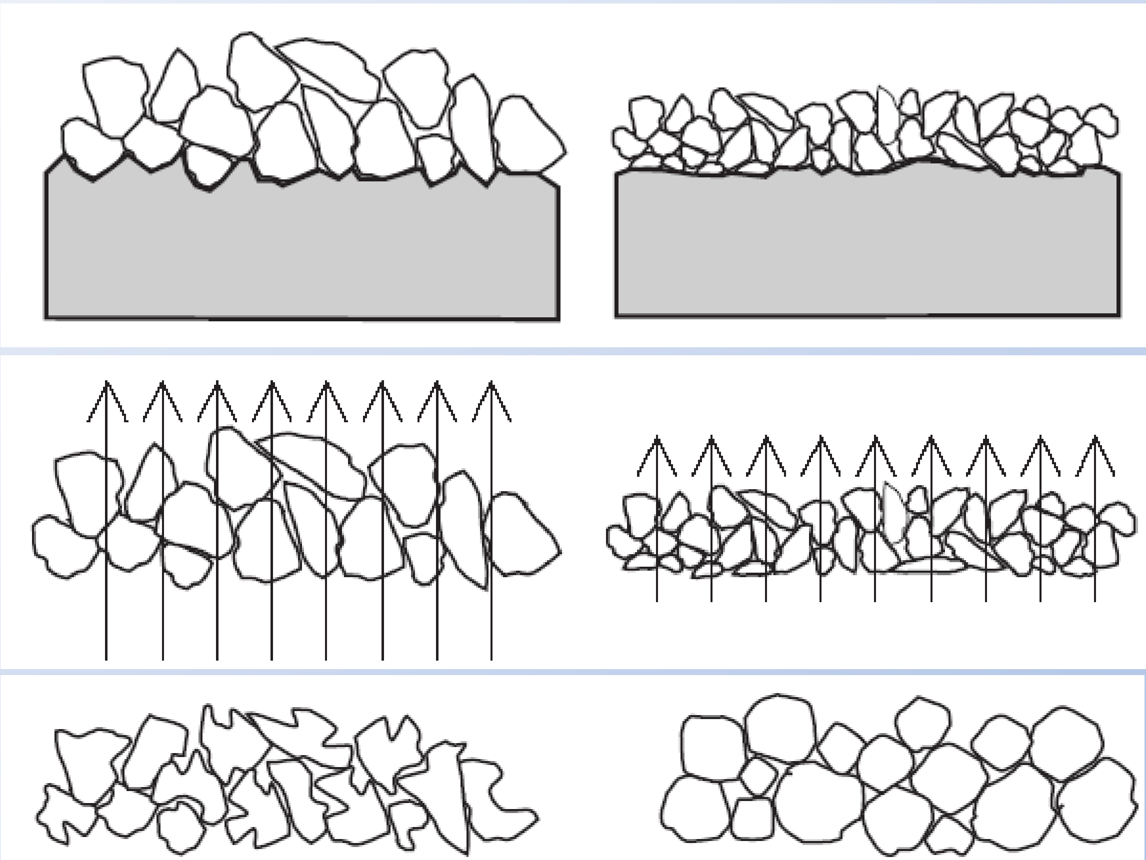
Properties

- Green strength: Strength of sand containing moisture
- Dry strength: Strength of sand without moisture
- Hot strength:
- Permeability
- Refractoriness: Ability of mold sand to withstand high temperature without breaking down or fusing
- Plasticity / flowability
- Produce good surface finish
- Reusable

Composition %	Silica	Olivine	Chromite	Ziron
SiO_2	98.82	41.2	1.34	33.5
MgO	0.031	49.4	8.75	-
Cr_2O_3	-	-	45.8	-
ZrO_2	-	-	-	65
Al_2O_3	0.049	1.8	21.34	1
Fe_2O_3	0.019	7.1	19.50	0.03
CaO	0.0016	0.2	0.94	-
TiO_2	0.012	-	0.03	0.19
Melting Point (C)	1710	1875	2093	2538
Bulk Density	95-97	96-103	156-165	152-183
Temp Reaction (pH)	Acidic	Basic	Basic/Neutral	Slightly Acidic
Shape	Varied	Angular	Angular	Rounded

Zircon sand: Manufacture precision steel, casting requiring better surface finish
Chromite sand: Manufacturing of heavy steel casting. Suited for austenitic manganese steel casting

Grain size and shape



Bigger grain results worse surface finish

Bigger grain ensures better permeability

Irregular grain produces stronger mold

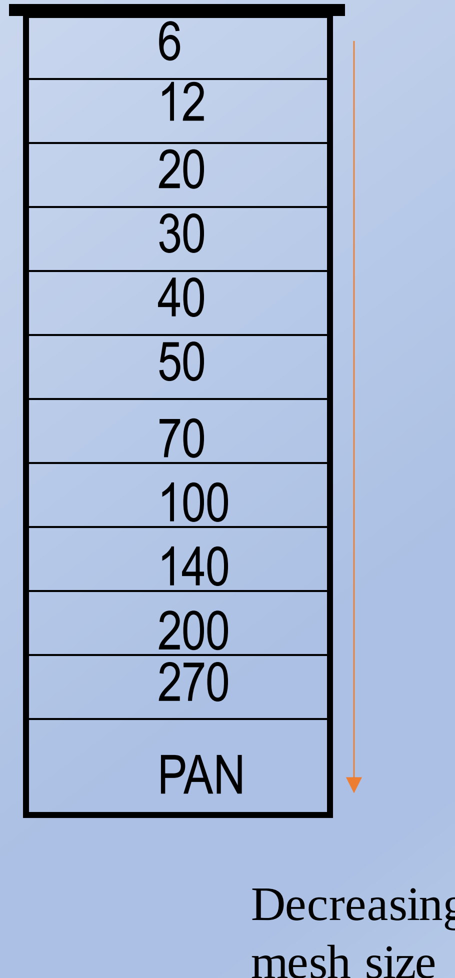
AFS grain fineness number

1. Take 50 gm of dried sand on the topmost sieve. The whole assembly is placed on the sieve shaker and is agitate for 15 minutes.

2. Weigh the amount of sand remaining on each sieve and record in terms of % of original 50gm sample.

3. Multiply the results for each sieve by a multiplying factor.

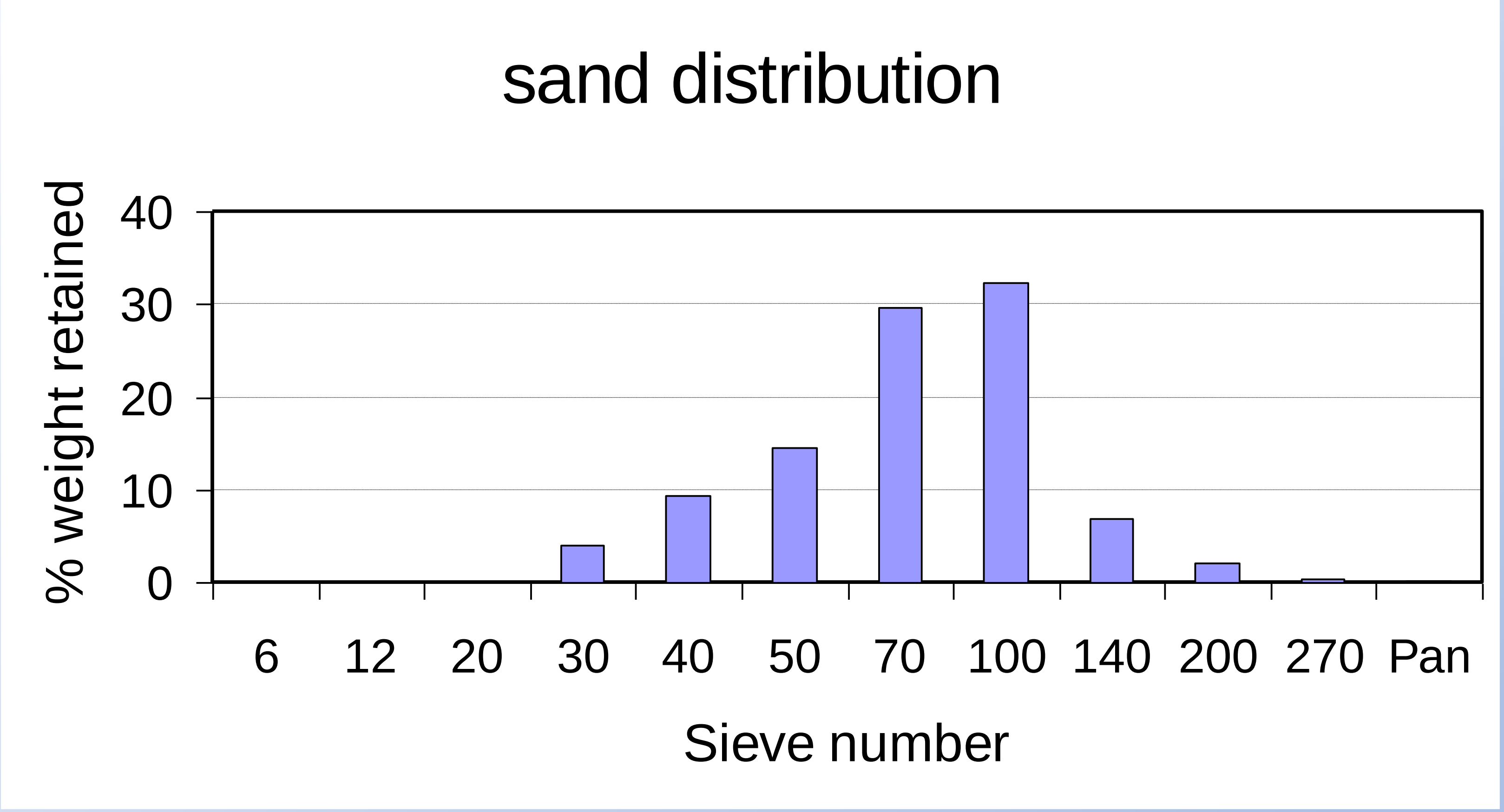
4. The multiplication products are summed and then divided by sum of grain % obtained.



AFS: American foundry society

Sieve No	Aperture(mm)	Multiplier (A)	Weight retained (gm)	Weight retained in % (B)	C=A×B
6	3.327	3	-	-	0
12	1.651	5	-	-	0
20	0.833	10	-	-	0
30	0.589	20	2.0	4.0	80
40	0.414	30	4.7	9.4	282
50	0.295	40	7.3	14.6	584
70	0.208	50	14.8	29.6	1480
100	0.147	70	16.2	32.4	2268
140	0.104	100	3.4	6.8	680
200	0.074	140	1.1	2.2	308
270	0.053	200	0.2	0.4	80
Pan	-	300	0.1	0.2	54
Total	-	-	49.8	99.6	5814

AFS Grain Fineness number=$(\sum C)/(\sum B)$= 5814/99.6=58.3≈58



This AFS#GFN-58 is a 3 screen sand which can be used for hotter metal and larger casting.

GFN is the average grain size and corresponds to a sieve number through which all the grains pass through, if they were all of the same size

Sieve Number	Multiplying factor (M)	Retained sample (f) (gram)	% retained (P)	M*P
40	30	2.495	5	150
50	40	13.972	28	1120
70	50	23.952	48	2400
100	70	6.986	14	980
140	100	2.495	5	500
		49.9 (total)		5150 (total)

GFN = 5150/100 = 51.5

Or GFN = 2569.85/49.9 = 51.5

TABLE 3.12 Typical sand sieve analysis

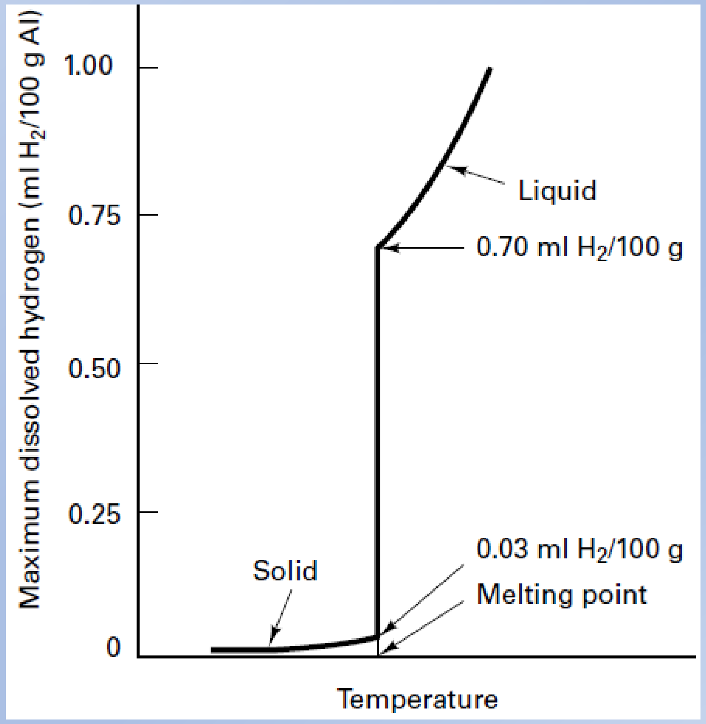
Sieve Number	Multiplier M_i	Sand 1 Retained % P_i	Sand 1 $M_i P_i$	Sand 2 P_i	Sand 2 $M_i P_i$	Sand 3 P_i	Sand 3 $M_i P_i$	Sand 4 P_i	Sand 4 $M_i P_i$
30	20	1	20	—	—	—	—	—	—
40	30	33	990	1	30	0.6	18	1.2	36
50	40	44	1760	15	600	1.4	56	6	240
70	50	15	750	32	1600	7	350	7.2	360
100	70	4	280	32	2240	26	1820	14.4	1008
140	100	3	300	15	1500	37	3700	18	1800
200	140	—	—	4	560	22	3080	16.8	2352
270	200	—	—	1	200	4	800	18	3600
Pan	300	—	—	—	—	2	600	18.7	5610
	Total		4100		6730		10 424		15 006
	GFN		41.00		67.30		104.24		150.06

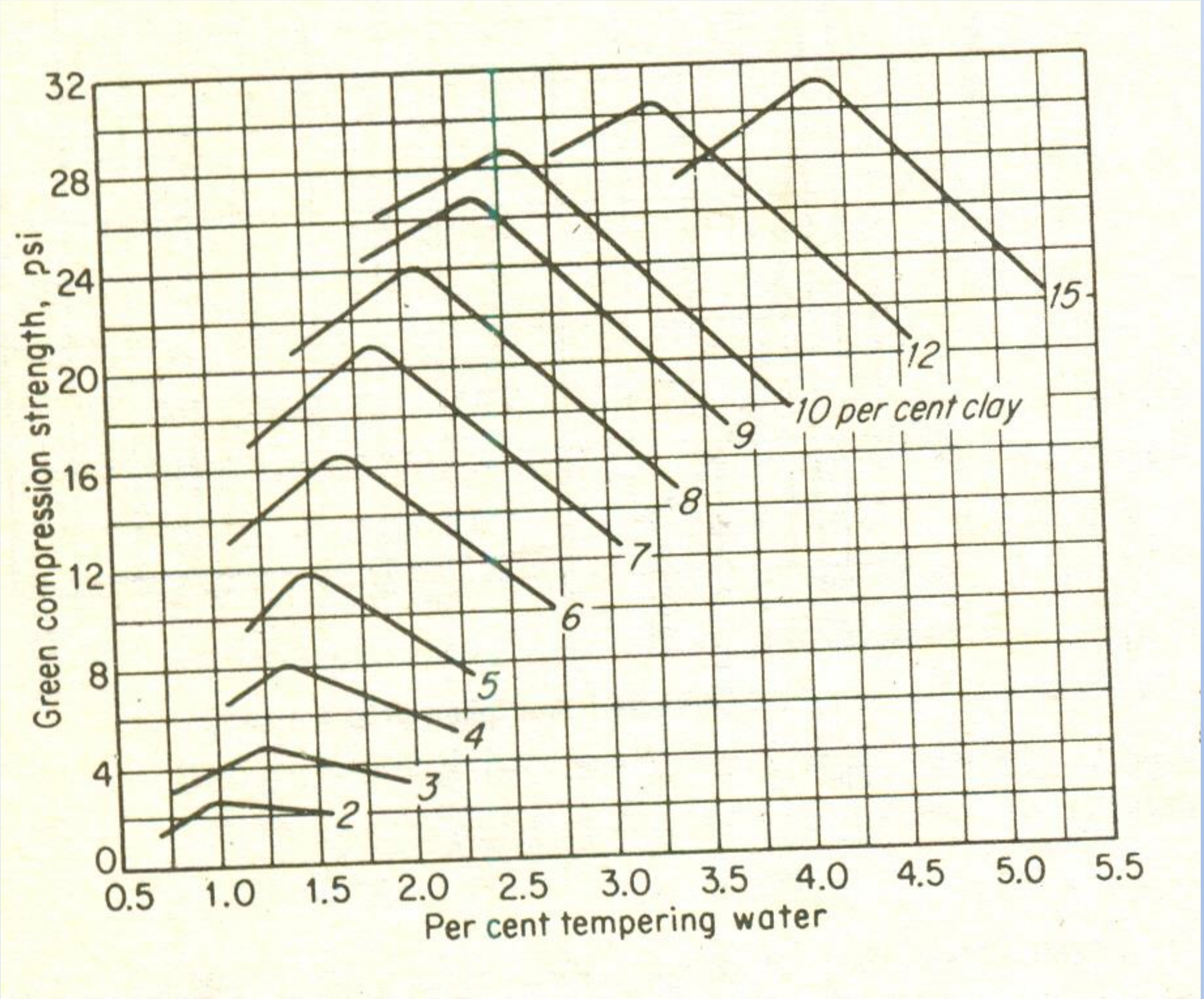
Sand 1: Steel castings 50 kg and more
Sand 2: Small steel castings
Sand 3: Light cast iron and copper castings
Sand 4: Aluminium alloy castings

- Fine grain produces good surface finish and lower refractoriness value.
- Widely distributed sand grains would have more permeability than the one with same GFN Where all grains with same size
- The coarser round grains would have higher permeability as compared to the finer ones

Permeability

- 2000 cubic cm of air at a pressure typically of 980 Pa to pass through a standard sand specimen confined in a specimen tube.
- Standard sand specimen is cylindrical tube of diameter and length 50.8 mm
- $P = \frac{V*H}{p*A*T}$
- V = Volume of air, H = height of specimen
- p = pressure, A = cross sectional area
- T = time in minutes to pass the air





Green compression strength, psi
0
4
8
12
16
20
24
28
32
0.5
1.0
1.5
2.0
2.5
3.0
3.5
4.0
4.5
5.0
5.5
Per cent tempering water
2
3
4
5
6
7
8
9
10 per cent clay
12
15

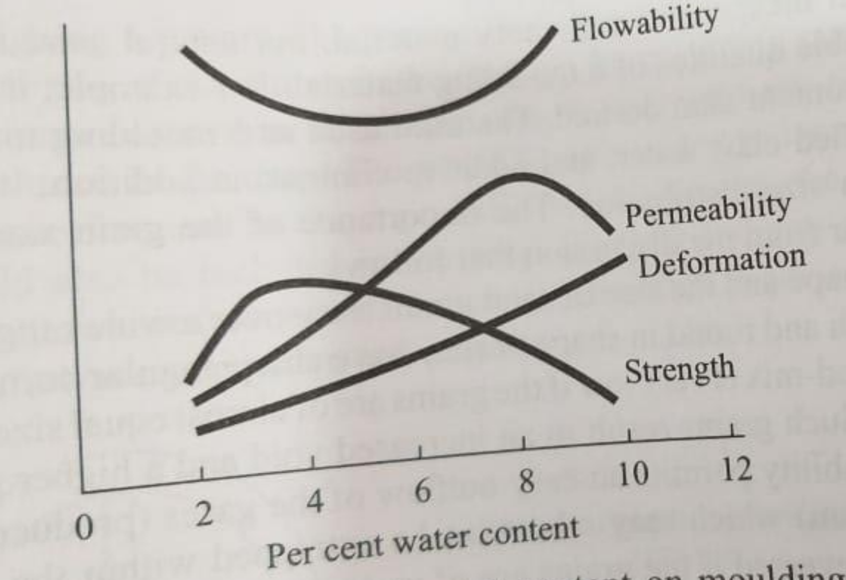
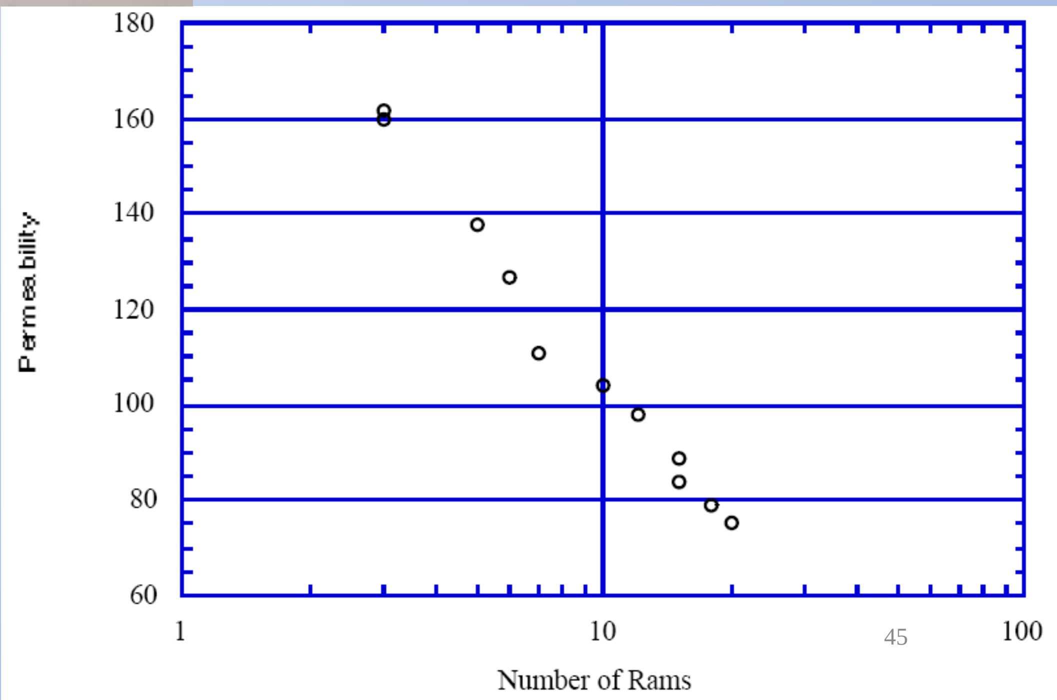


Fig. 2.2 Effect of water content on moulding sand properties.



Melting

- The gases leads to faulty castings, but controlled amount of certain gases can be beneficial
- Most commonly entrapped gas is H_2 and N_2
- Endothermic material: Al, Mg, Cu, Fe, Ni. It absorbs less hydrogen as compared with Exothermic material.
- Solubility of gas increases with increase in temperature for Endothermic
- Siverts law: % hydrogen present = $K(p_{H2})^{1/2}$, p_{H2} is partial pressure of hydrogen in the atmosphere over the melt

Metal	Liquid solubility (cc/ kg)	Solid solubility
Iron	270	70
Magnesium	260	180
Copper	55	20
Aluminum	7	0.4

- Reducing partial pressure of hydrogen by bubbling some dry insoluble gas through melt.
- For non-ferrous metal: Chlorine, Nitrogen, Helium or argon
- Nitrogen should not be used for ferrous and nickel alloys
- Ferrous: CO, further carbon content is controlled by subsequent oxidation and recarburization
- Vacuum melting is one way of preventing the solution of gases in metals

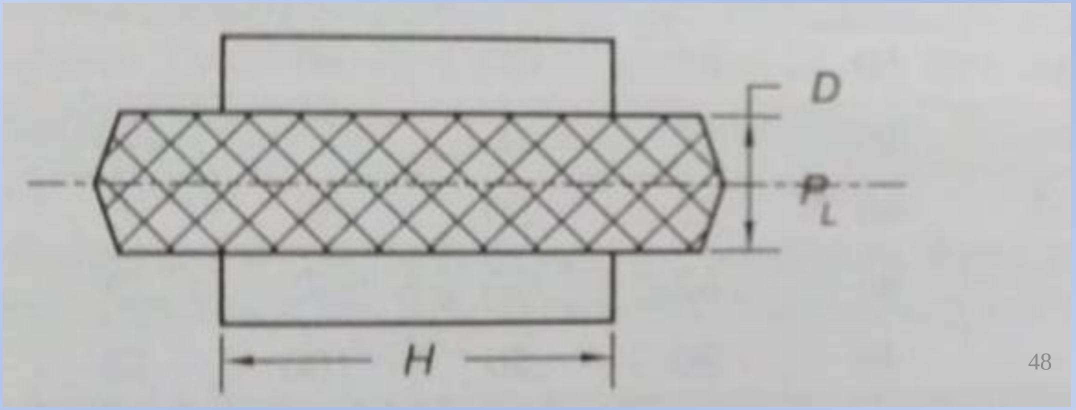
Core prints

- It is provided so that the cores securely and correctly positioned in the mould cavity
- The design of core prints is such as to take care of the weight of the core before pouring and the upward metallostatic pressure of the molten metal after pouring

- Buoyancy force = Difference in weight of the liquid metal to that of the core material of the same volume as that of exposed core
- $P = V(\rho - d)$
- P = Buoyant force; V = Volume of the core in the mould cavity
- ρ = weight density of liquid metal; d = Weight density of the core material

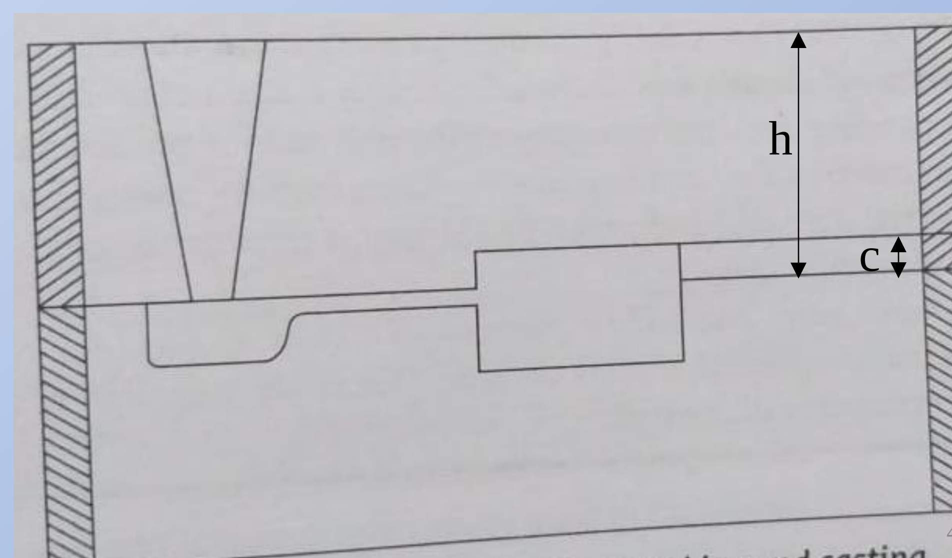
Empirical condition: P<=350 A.
A= Core print area

If above is not satisfied use chaplet



Forces acting on the moulding flask

- Metallostatic force is exerted by the molten metal in all direction
- Our interest is only in upward direction. This force is coming because of the head with which metal is entering the mould cavity.
- $F_m = A_p \rho (h - c)$
- A_p = Projected area of casting in the parting plane



Q) Find the weight that need to be kept to compensate for the forces during the pouring in a sand casting of a cast iron pipe of 12.5 cm OD and 10 cm Id with a length of 180 cm. The metal head is to be about 20 cm while the moulding flask size used for the purpose is 200*25*20 cm in size. Take the density of the core sand to be 0.0165 N/cm^3 and the liquid metal density to be 0.0771 N/cm^3

Volume of core= $(3.14*10^2*180)/4 = 14137.2\ cm^3$

Buoyancy force = V(ρ-d) = 14137.2 (0.0771-0.0165) = 856.7 N

Projected area of casting = 180*12.5 = 2250 cm^2

Upward metallostatic force = 2250*0.0771*20 = 3469.5 N

Total force = 3469.5+856.7 = 4326.7 N

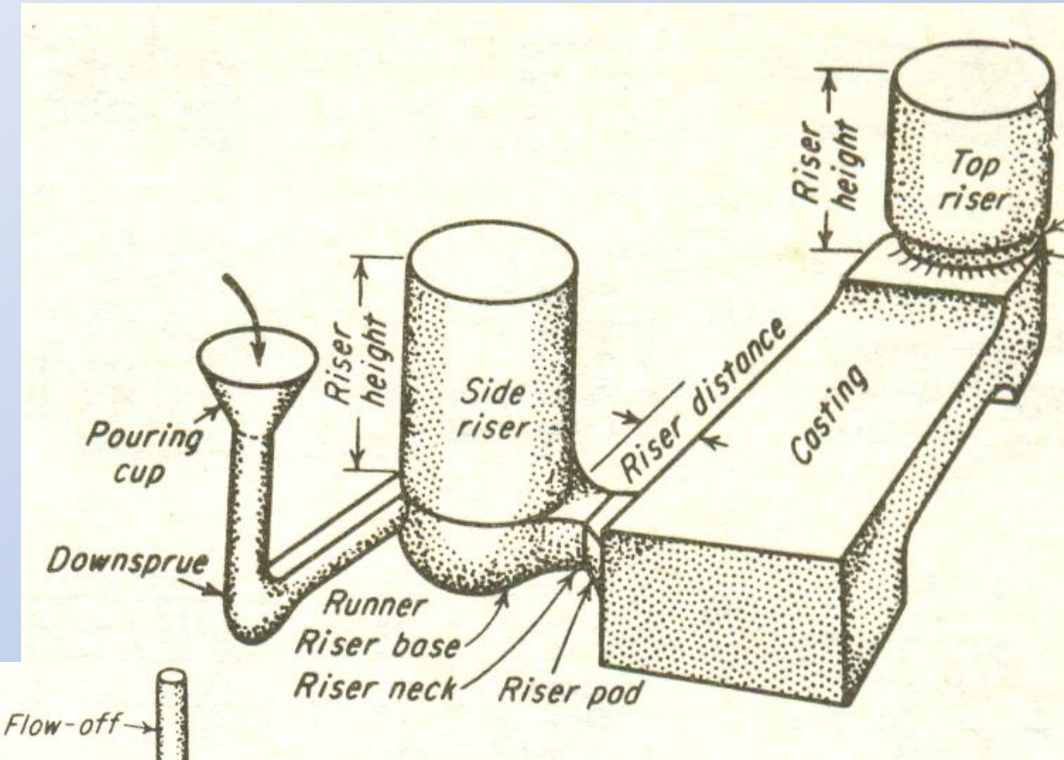
Volume of sand in cope: 200*25*20 = 100000 cm^3

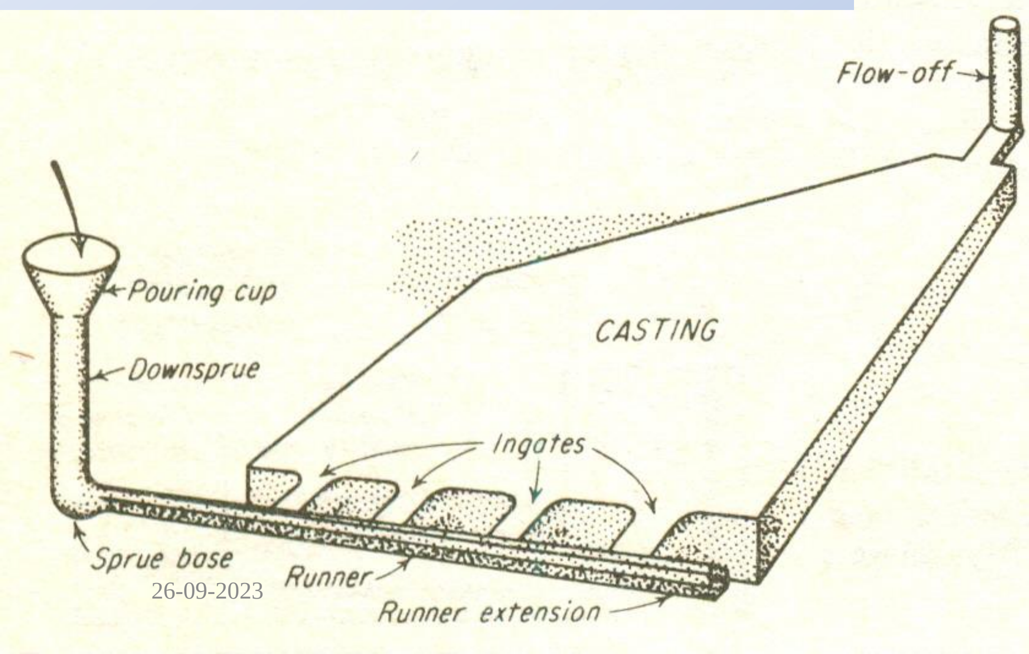
Weight of the cope: 100000*0.0165 = 1650 N

Net upwards force = 4326.7-1650 = 2676.7 N

Gating system

- Pouring basing
- Sprue
- Sprue base well
- Runner
- Runner extension
- Ingate
- Riser

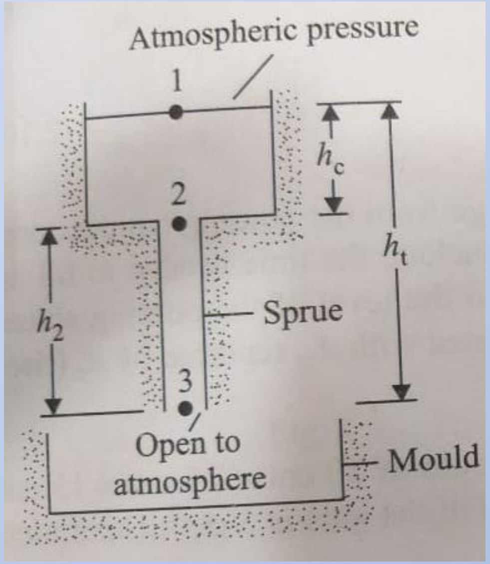




Attributes of good gating system

- The mould should be filled in the smallest time possible without having to raise the metal temperatures or use higher metal heads
- The metal should flow smoothly into the mould without any turbulence.
- Unwanted material such as drag, slag, dross and other molten material should not be allowed to enter the mould cavity
- The metal entry into the mould cavity should be properly controlled in such a way that aspiration of the atmospheric air is prevented
- A proper thermal gradient be maintained
- No gating or mould erosion
- Enough metal should reach mould cavity
- Casting yield should be maximized

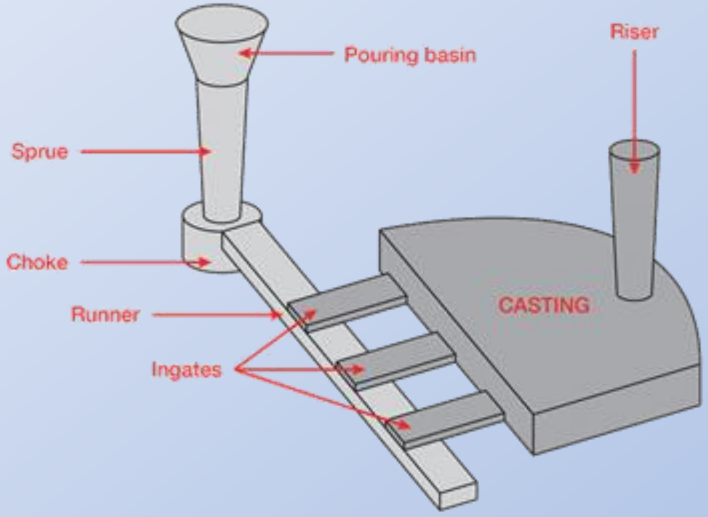
Types of gating system

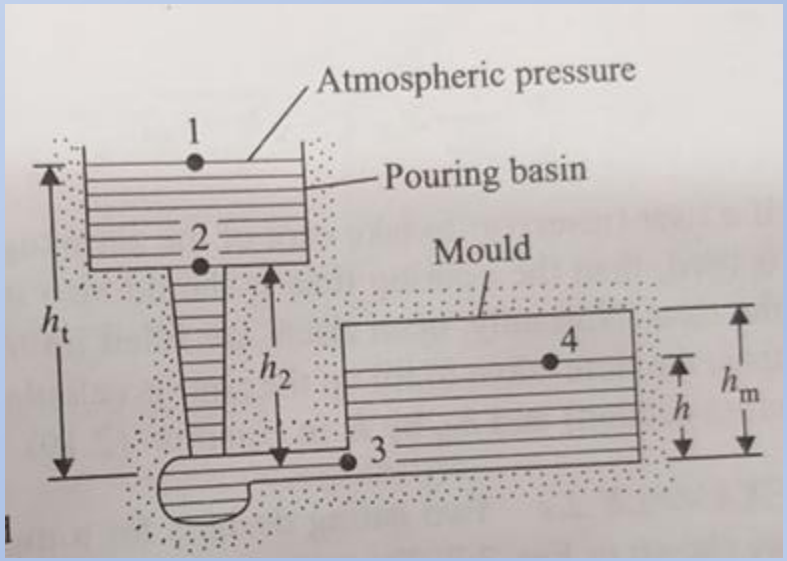


Vertical gate: Liquid metal is poured vertically to fill the mould with atmospheric pressure. Preferred for Cast iron with short path in come cases

Bottom gate

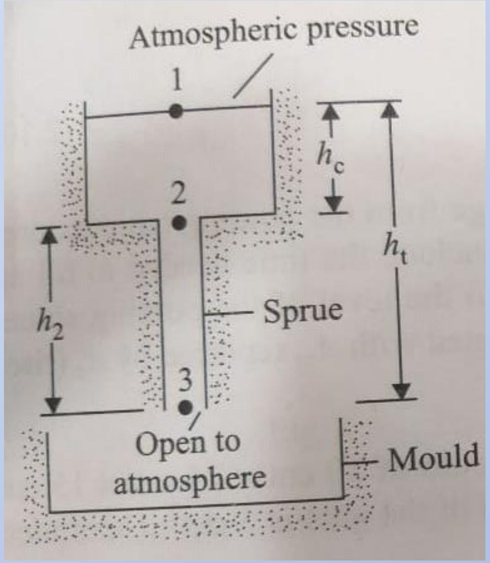
Horizontal gate





Refer class notes for derivation

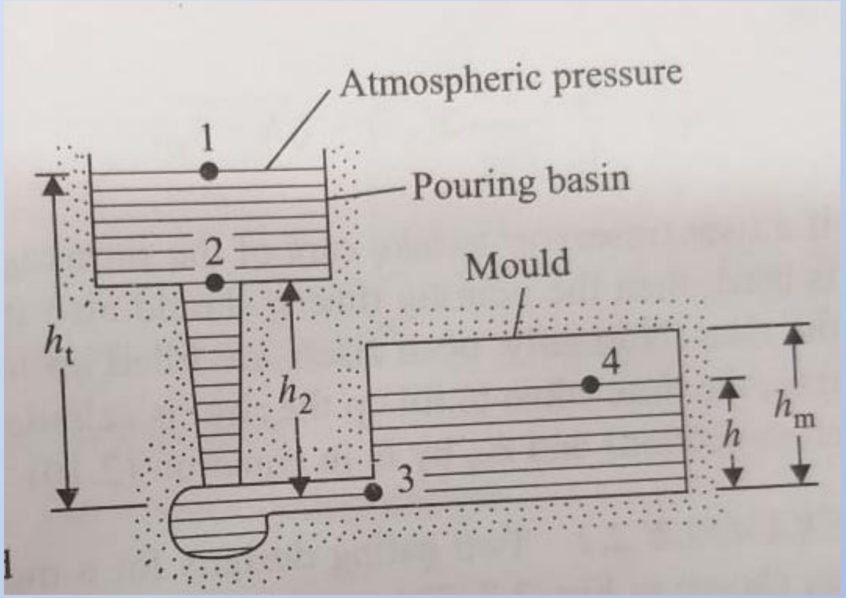
Calculation for filling the mould



Vertical gate: Liquid metal is poured vertically to fill the mould with atmospheric pressure. Preferred for Cast iron with short path in come cases

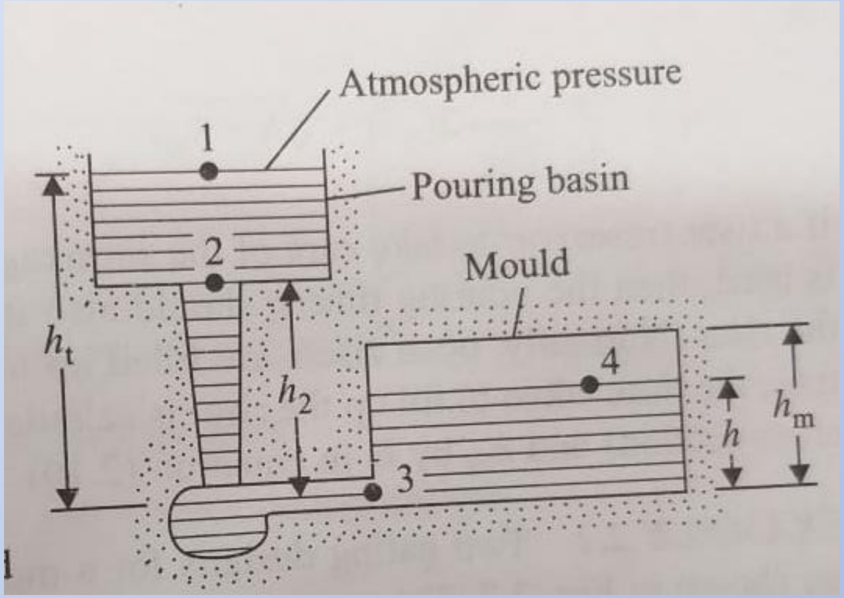
Time required to fill the mould:

Calculation for filling the mould

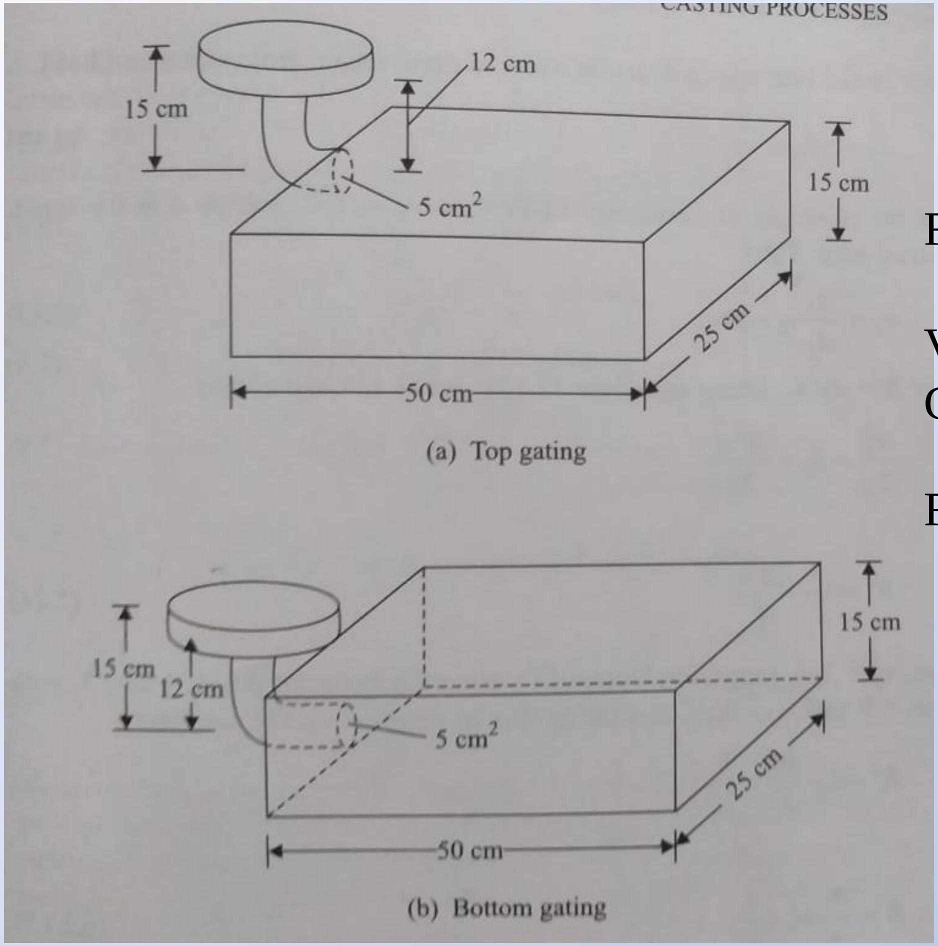


Refer class notes for derivation

Calculation for filling the mould



Refer class notes for derivation



Calculate the filling time for both the casting

For top gating: $v_3 = \sqrt{2 * 981 * 15}$ =171.6 cm/s

Volume of mould = 20*25*15 cm^3
CS area of gate = 5 cm^2

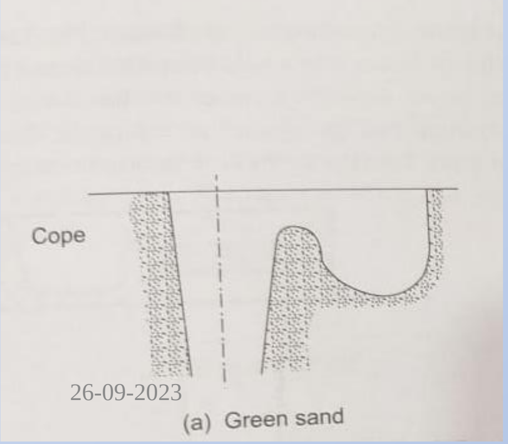
Filling time = $\frac{50*25*15}{5*171.6} = 21.86\ s$

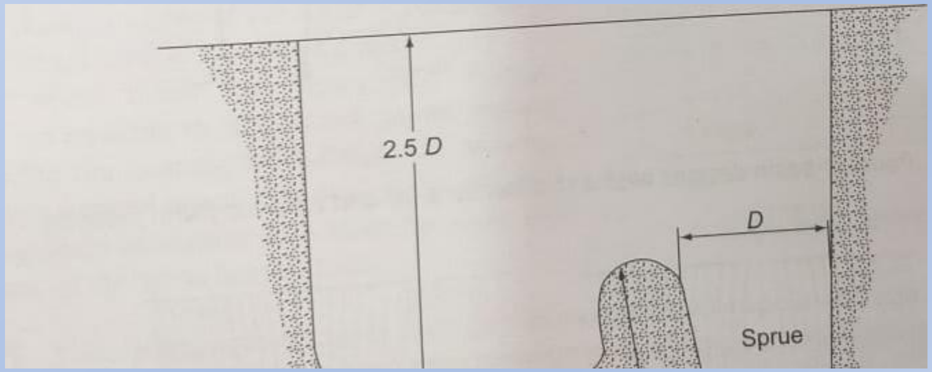
For bottom gating:

$t_f = \frac{50*25*\sqrt{2}*\sqrt{15}}{5*\sqrt{981}}$ = 43.71 s

Pouring Basin

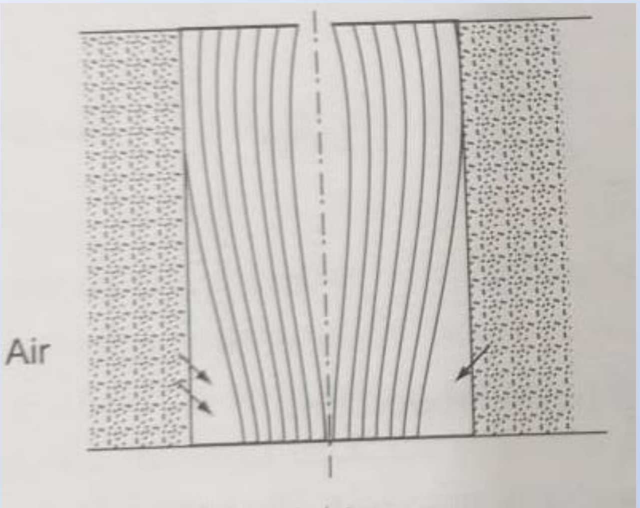
- Molten metal cannot be directly poured into the mould cavity because it may cause mould erosion
- Pouring basin act as a reservoir from which molten metal moves smoothly into the sprue.
- It also stop the slag from entering the mould cavity by means of a skimmer or skin core
- The main function of pouring basin is to reduce momentum of the liquid flowing into the mould by settling first into it.
- It is important to have pouring basin be deep enough, and also the entrance to sprue be smooth radius atleast 25 mm.
- Pouring basins are most desirable with castings in alloys which form troublesome oxide skins (Al, Aluminum-bronze)



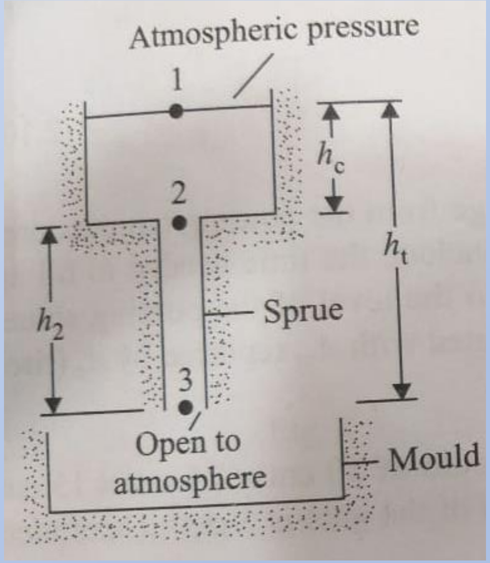


Sprue

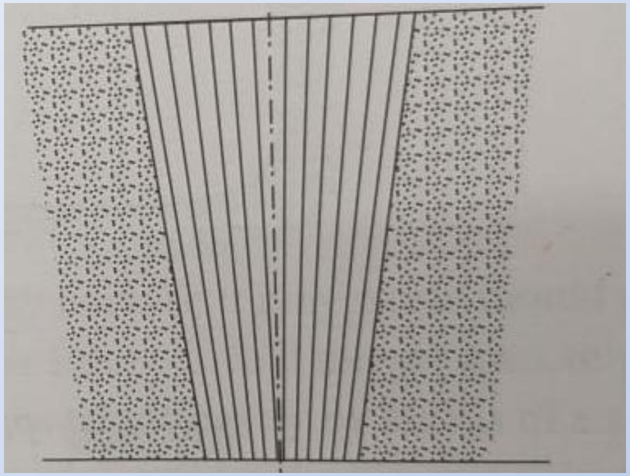
- Sprue is channel through which the molten metal is brough into the parting plane.
- If cross-section area of inlet and outlet of sprue is same it lead to aspiration effect

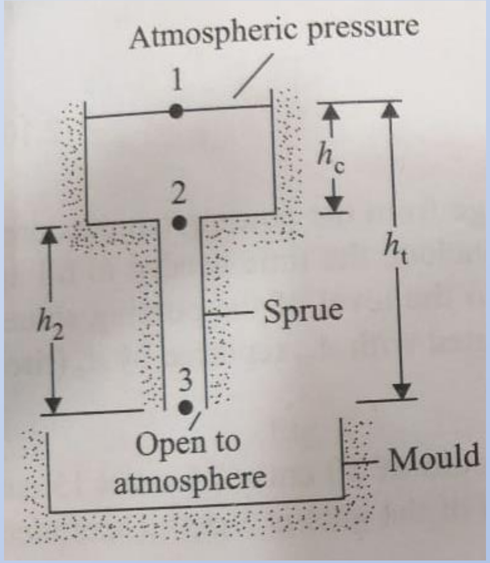


(a) Straight sprue



Sprue

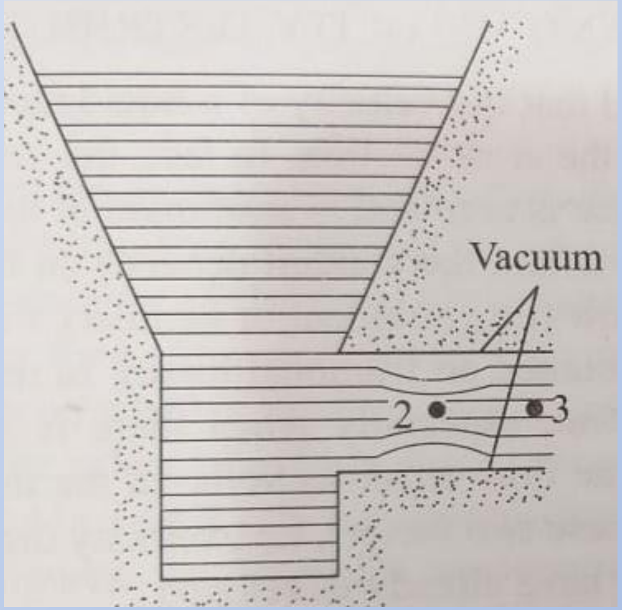


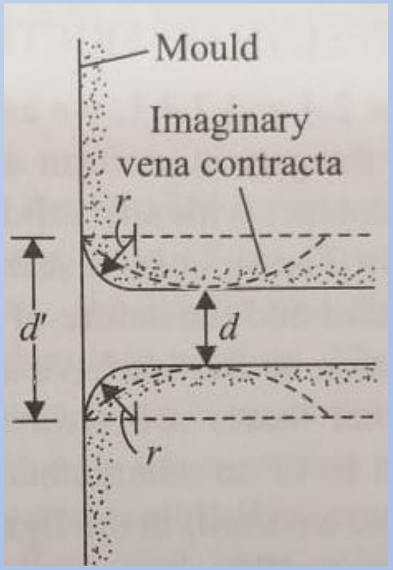


Atmospheric pressure
1
2
3
h_c
h_t
h_2
Sprue
Open to
atmosphere
Mould

Sprue

- Sprue is channel through which the molten metal is brough into the parting plane.
- If cross-section area of inlet and outlet of sprue is same it lead to aspiration effect



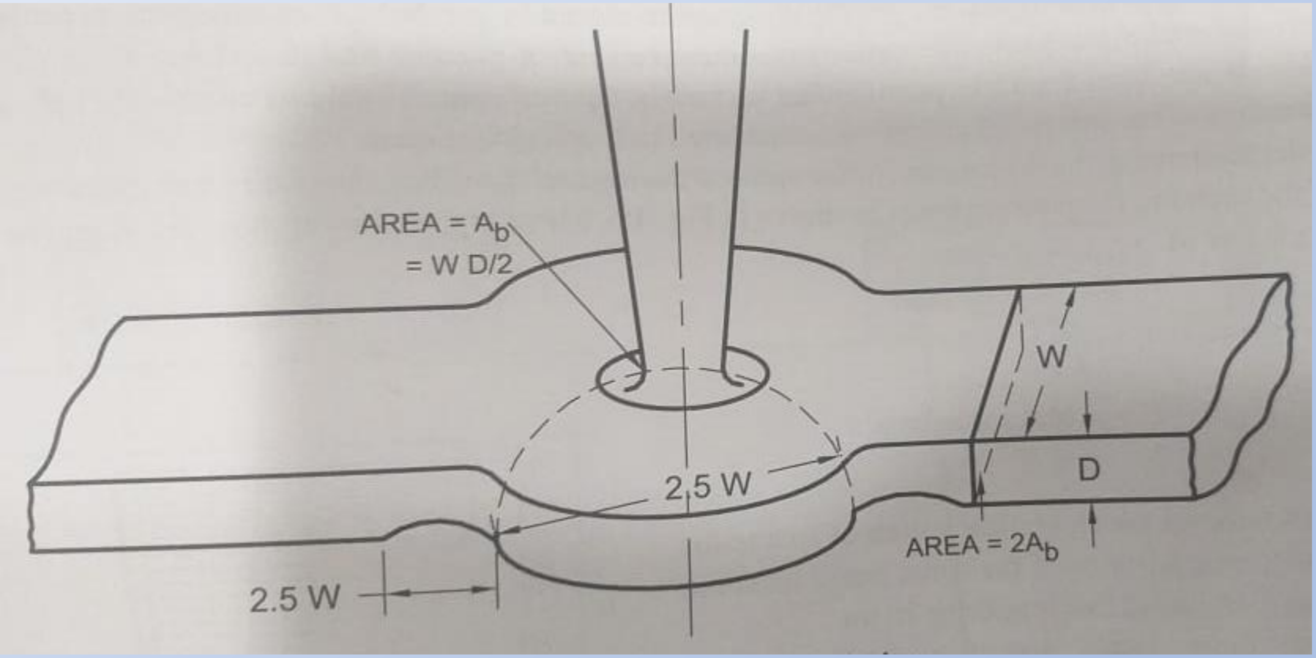


d’/d= 1.3 (approx.)
r is approximately 0.15d

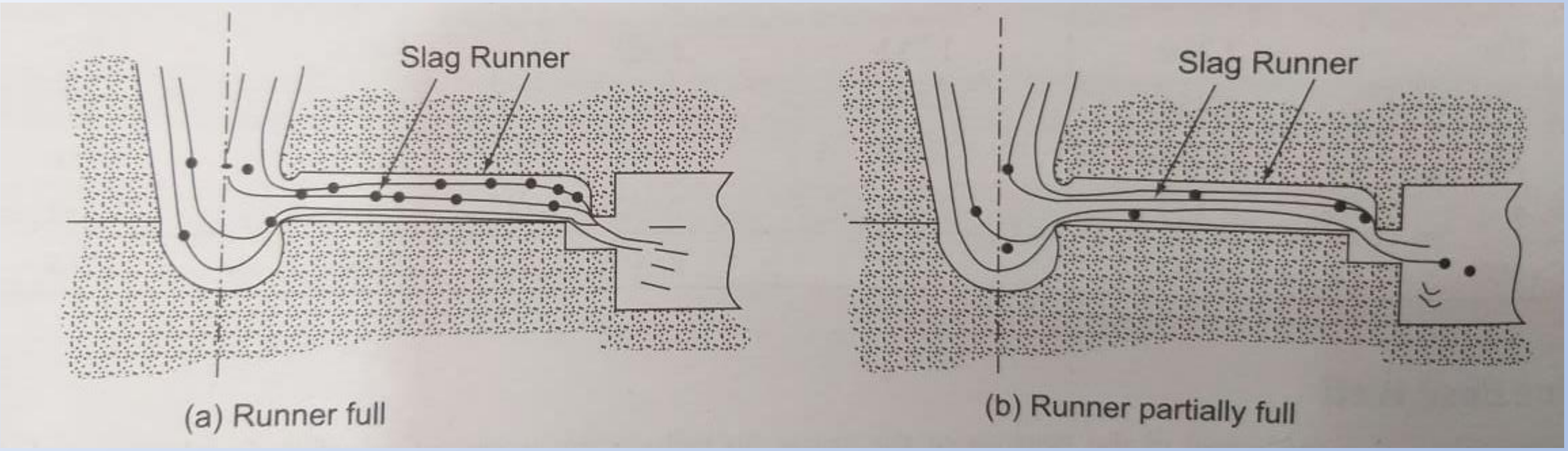
Refer class notes for derivation

Sprue base well

- This is reservoir for metal at the bottom of the sprue to reduce momentum



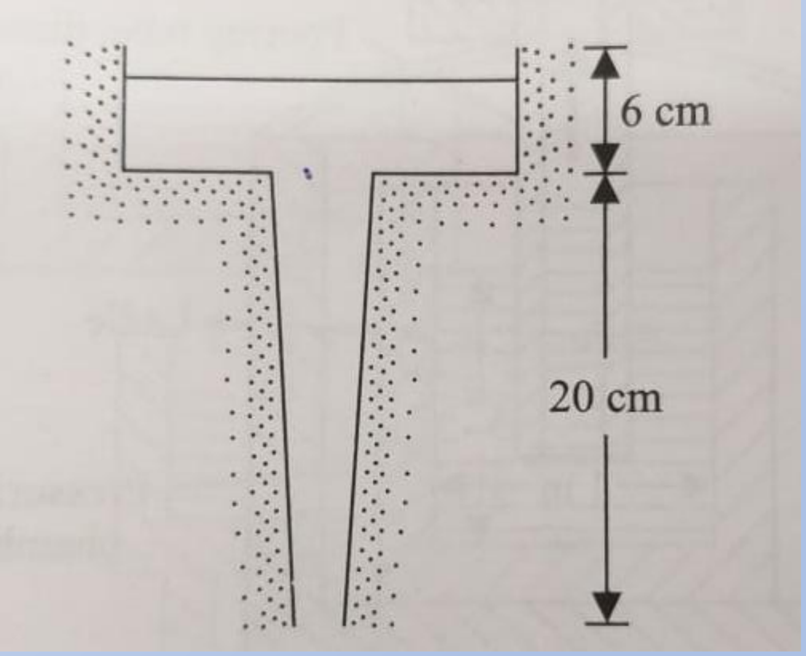
Runner



- Generally trapezoidal shape in cross section
- For ferrous material runner is cut in cope while ingate is cut in drag to trap the dross
- Runner should always flow full

- Q) In order to remove hydrogen from liquid iron of mass 100 kg, CO bubbles are used so that the partial pressure of hydrogen falls to 0.1 atm. Determine the total volume of hydrogen in the liquid. Liquid and solid solubility of hydrogen in iron at 1 atm are 270 cc/kg and 70 cc/kg, respectively

- Design a downsprue, avoiding aspiration as shown to deliver liquid cast iron of density 7800 kg/m^3 at a rate of 10 kg/s against no head at the base of the sprue. Neglect friction and orifice loss

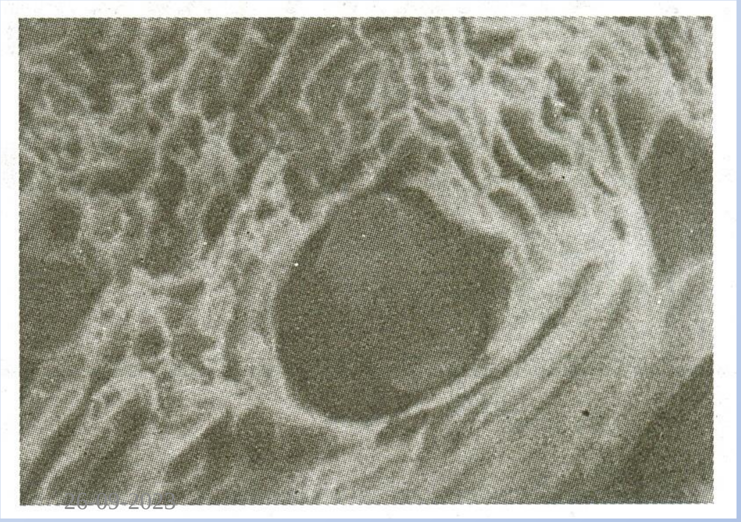


Casting defects

Casting defects may rise due to one or more of the following

- Design of casting and pattern
- Moulding sand and design of mould and core
- Metal composition
- Melting and pouring
- Gating and riser design

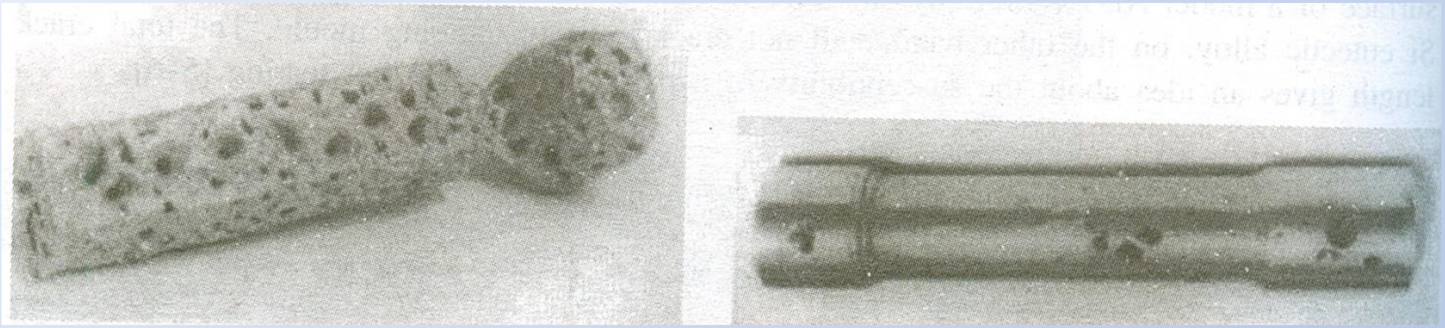
1. Inclusions



Sand, slag, dross, oxides or other materials embedded in casting

Quality control during melting by deoxidation and degassing, design of gating system to minimize turbulence, erosion of mold wall and aspiration, and adoption of filtration technique.

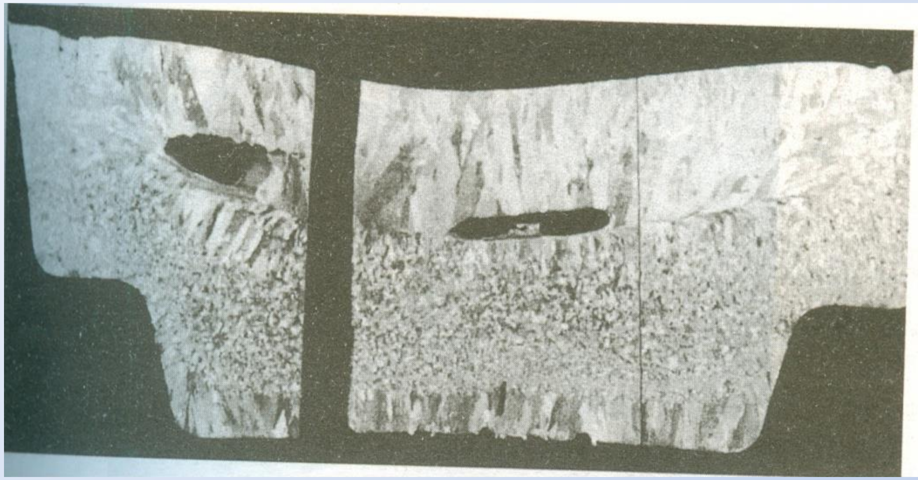
2. Blow holes and pin holes (gas porosity)

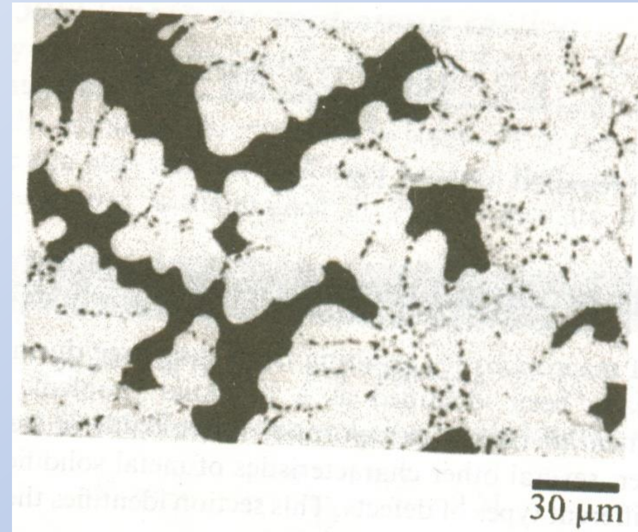


Caused by entrapped gases like CO, H or steam.

Proper melting practice with degassing, reducing moisture content in the mold, proper gating system to avoid aspiration, high permeable mold and core, and avoid use of rusty chaplets and chills.

3. Macro and micro porosity due to shrinkage

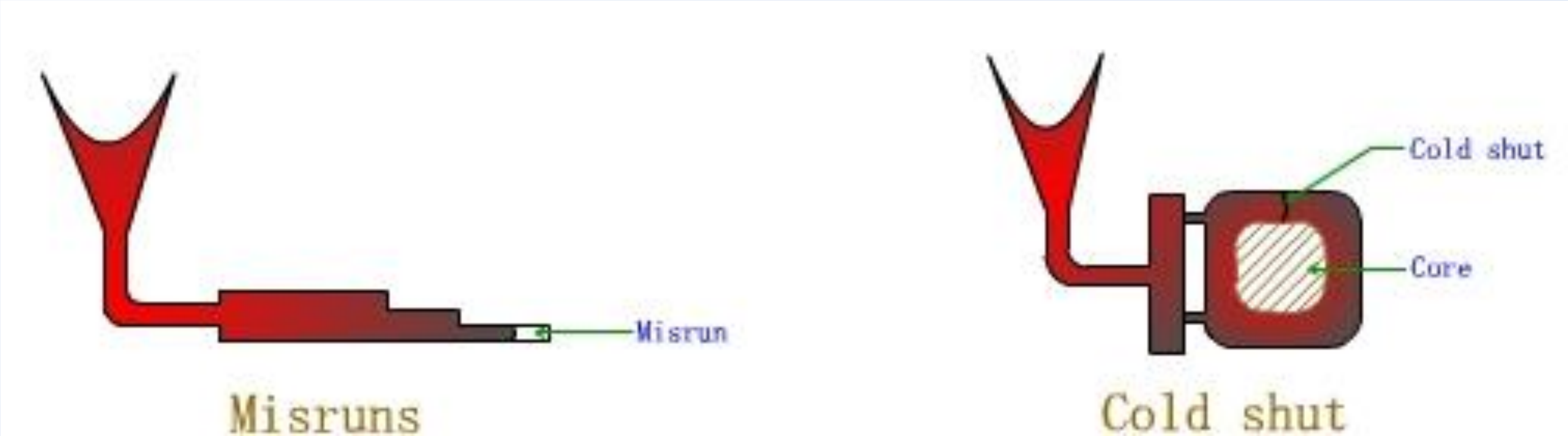




If liquid and solidification shrinkage is not compensated by riser

Proper riser design and placement which drive directional solidification. Chemistry of the liquid metal. Use of chill mold.

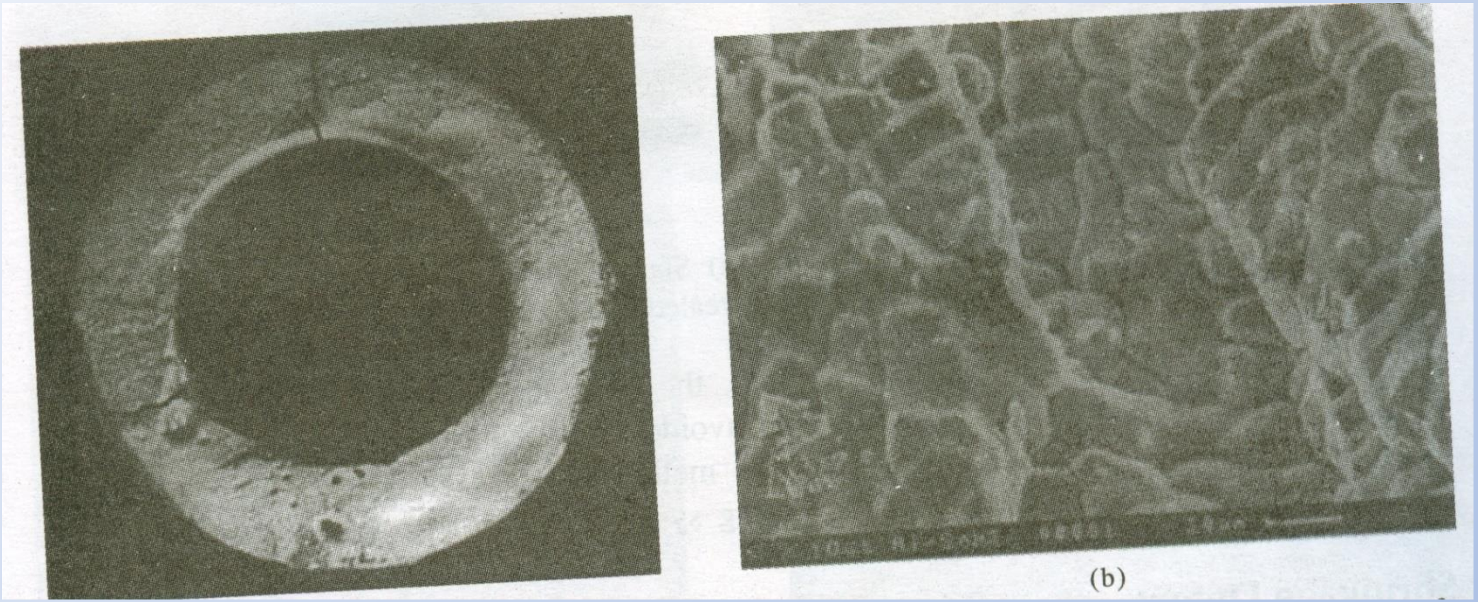
4. Misrun and cold shut



Inefficient fluidity of molten metal

Proper chemistry of the metal with superheat. Design of gating system. Good permeability of mold.

5. Hot tears

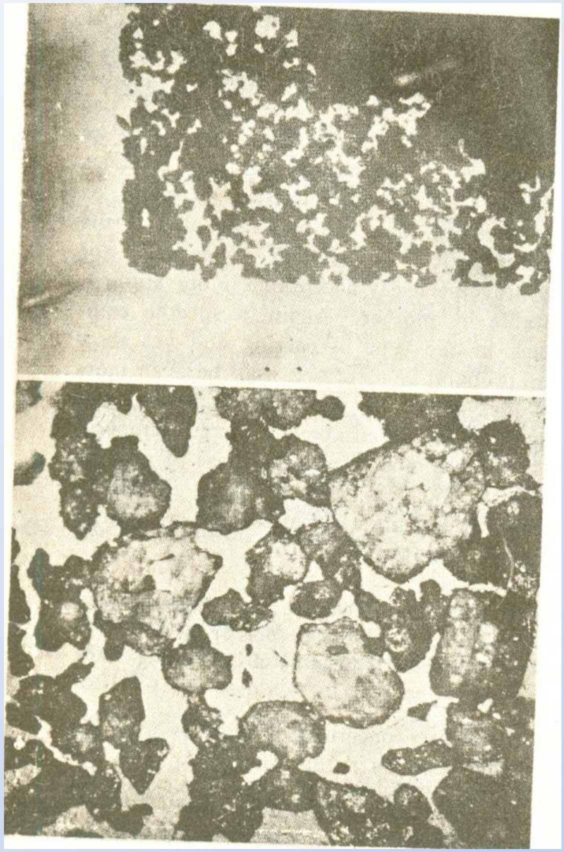


(b)

Tearing of casting at the grain boundaries in the later part of the solidification majorly due to residual stress

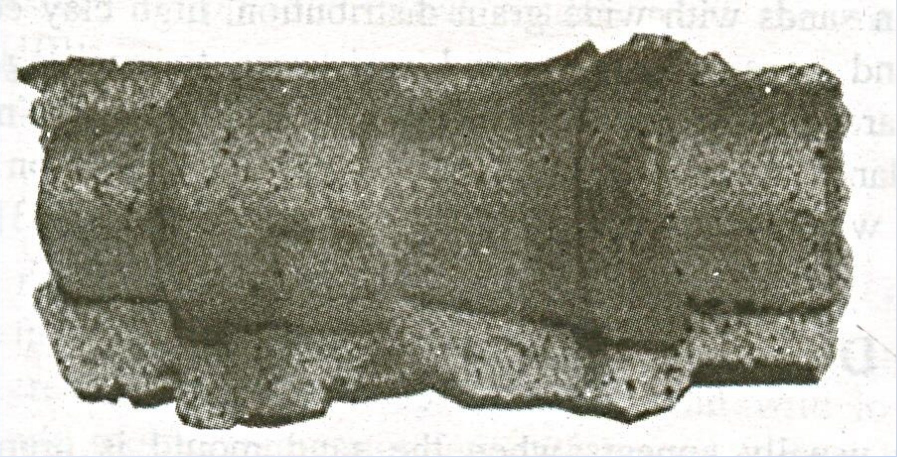
Change of geometry of casting, mold material, alloy composition.

6. Metal penetration and sand burn



Less grain size, sand strength should be sufficient to withstand metalostatic pressure, high refractoriness of sand.

7. Mismatch



Misalignment of pattern and improper handling of mold.

Similarly sand drop/mold break, rat tails etc.

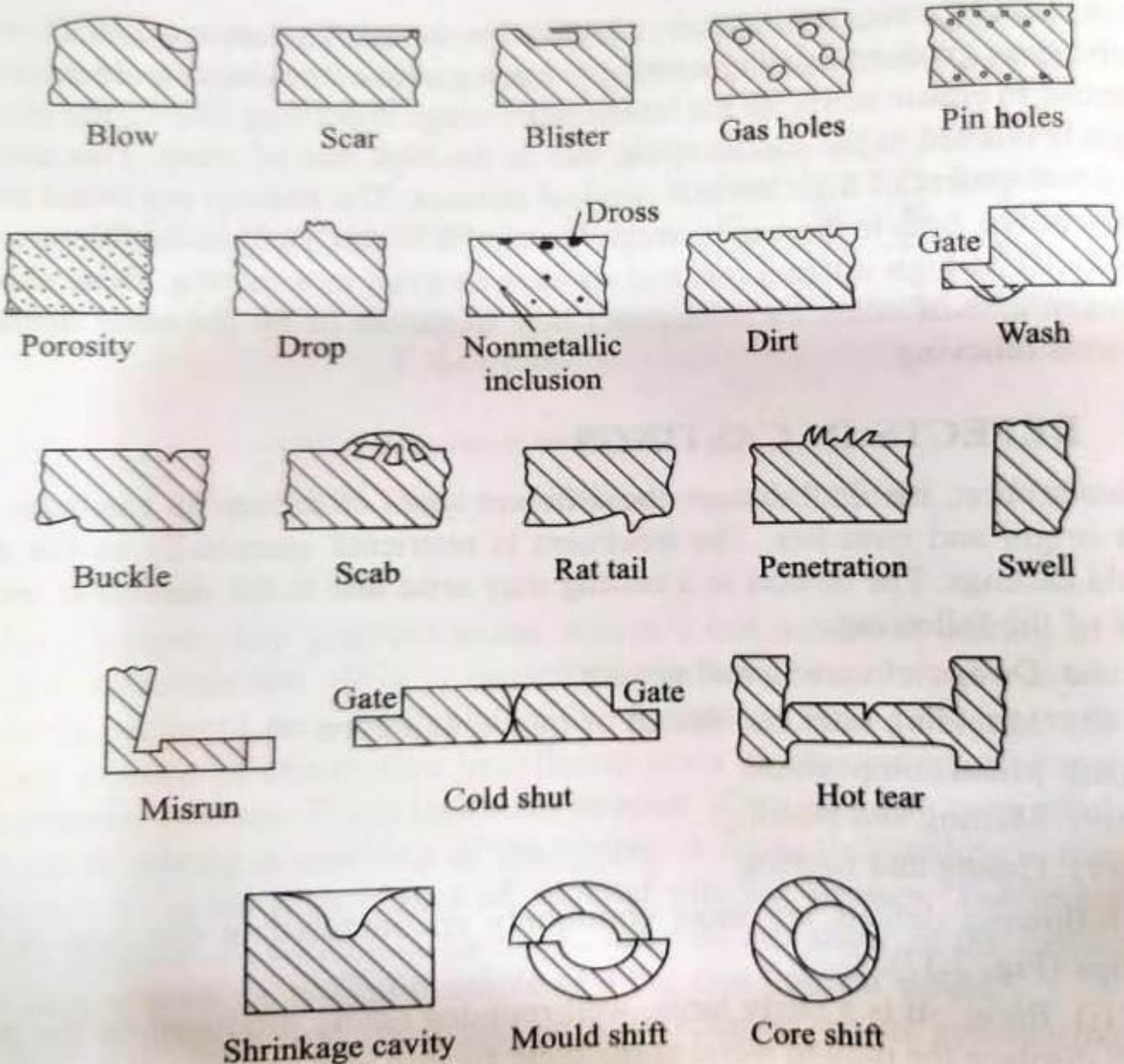
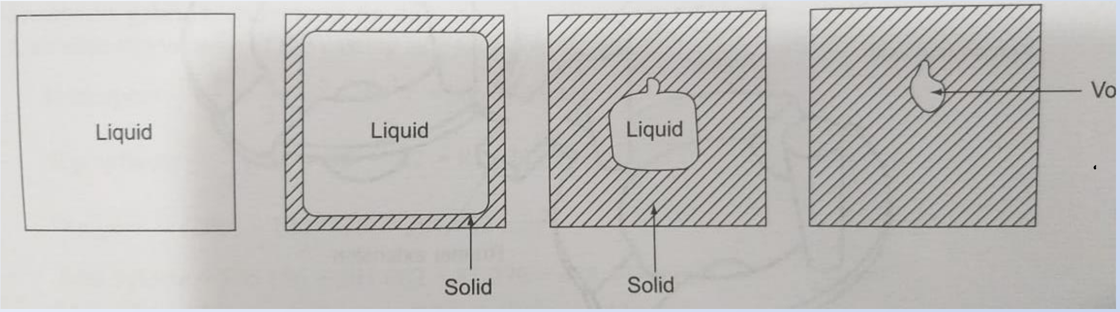
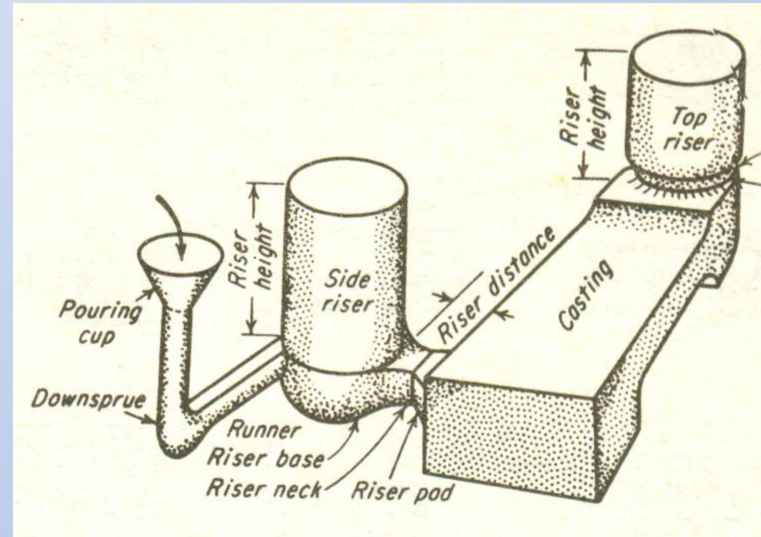


Fig. 2.37 Common casting defects.

Riser





- Feed metal to the casting till it solidifies
- Feeding requirement depends upon the volumetric shrinkage of the material

Few important factor influencing metal feeding during solidification

- Riser shape, size and location
- Use of chills
- Use of insulators and exothermic compound

Material	Volumetric shrinkage, %
Medium carbon steel	2.5–3.0
1% carbon steel	4.0
Pure aluminum	6.60
Pure copper	4.92
Gray cast iron	1.90 to negative depending on graphitization, composition, etc.
White cast iron	4.0–5.50

Riser design

Chvorinov's rule

riser $t_r = K_r\left(\frac{V}{A}\right)^2_r$ casting $t_c = Kc\left(\frac{V}{A}\right)^2_c$

t= solidification time, K=mold constant, V = Volume, A = Surface area and V/A=Modulus

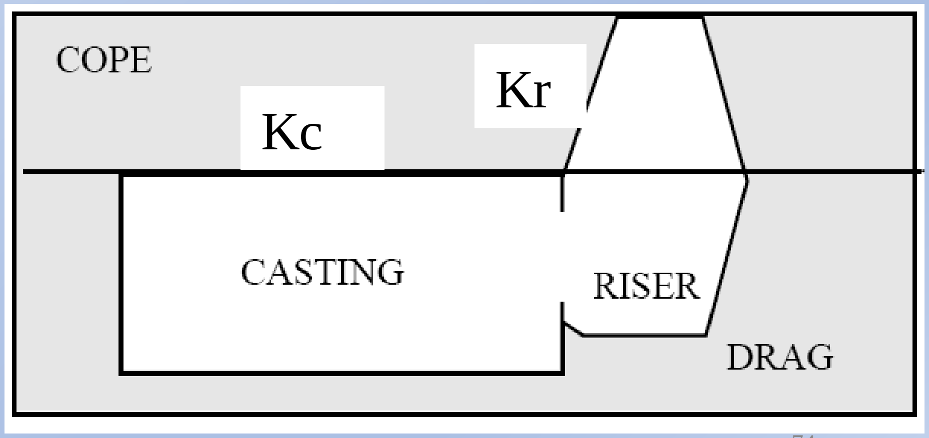
For successful riser design, tr>tc

i.e. $K_r\left(\frac{V}{A}\right)^2_r > Kc\left(\frac{V}{A}\right)^2_c$

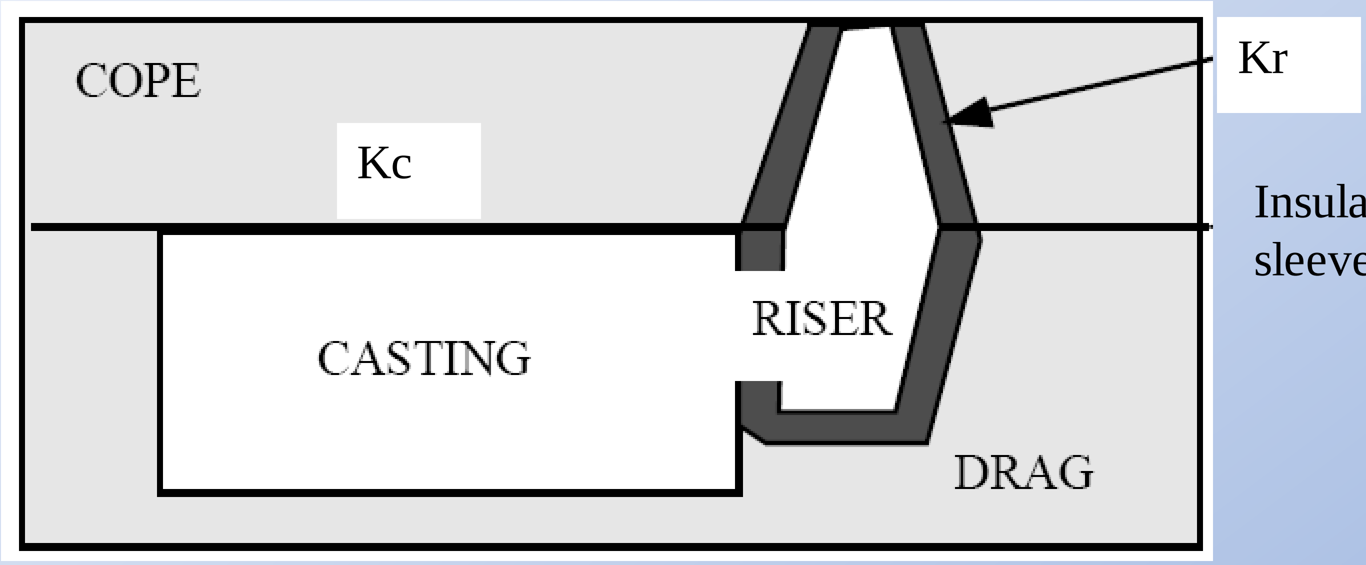
There are two cases

1. Kr=Kc

Mr>1.1Mc

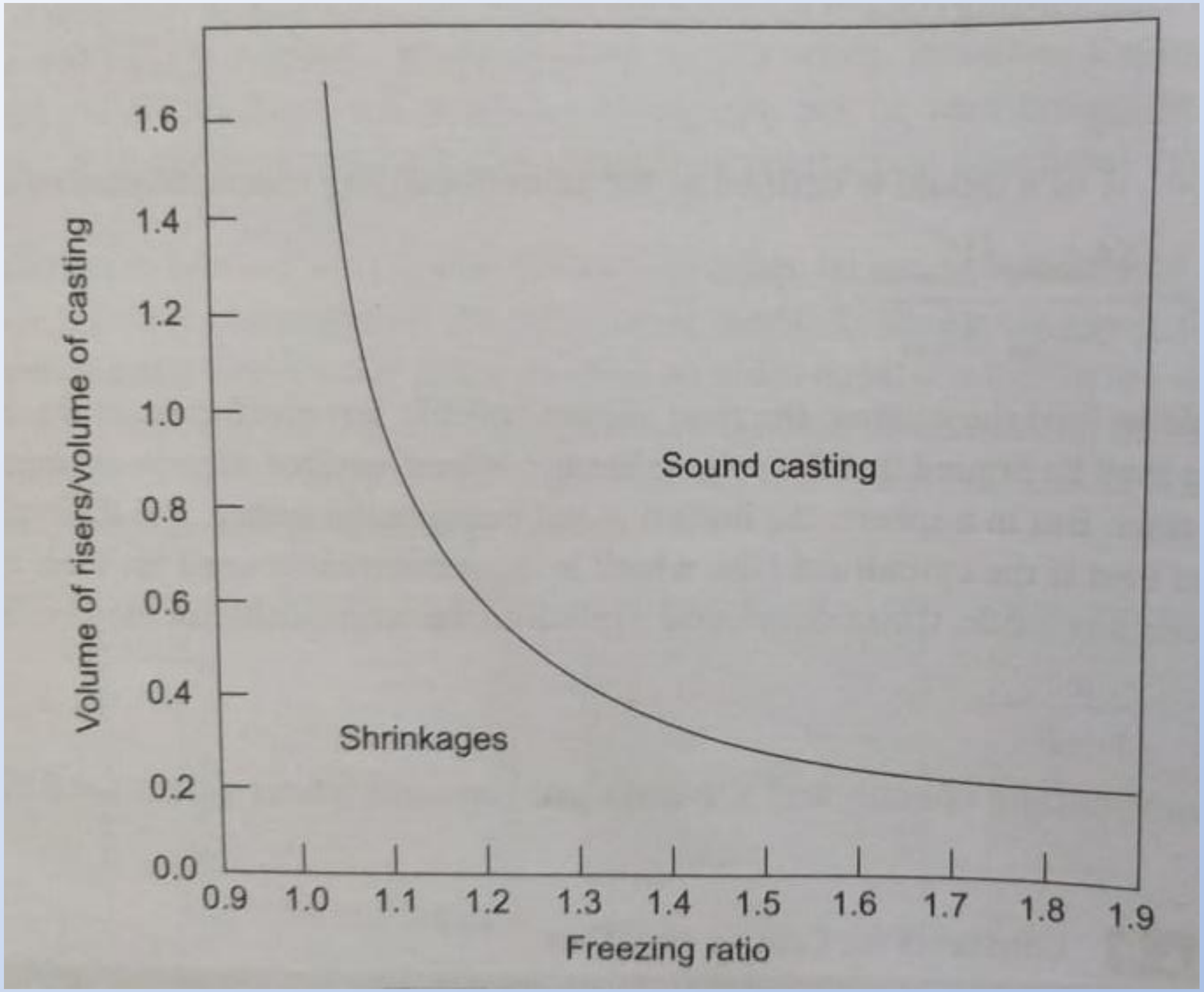


2. Kr>Kc and Mr<Mc, still the inequality tr>tc holds good



Insulating riser sleeve

Caines's relation



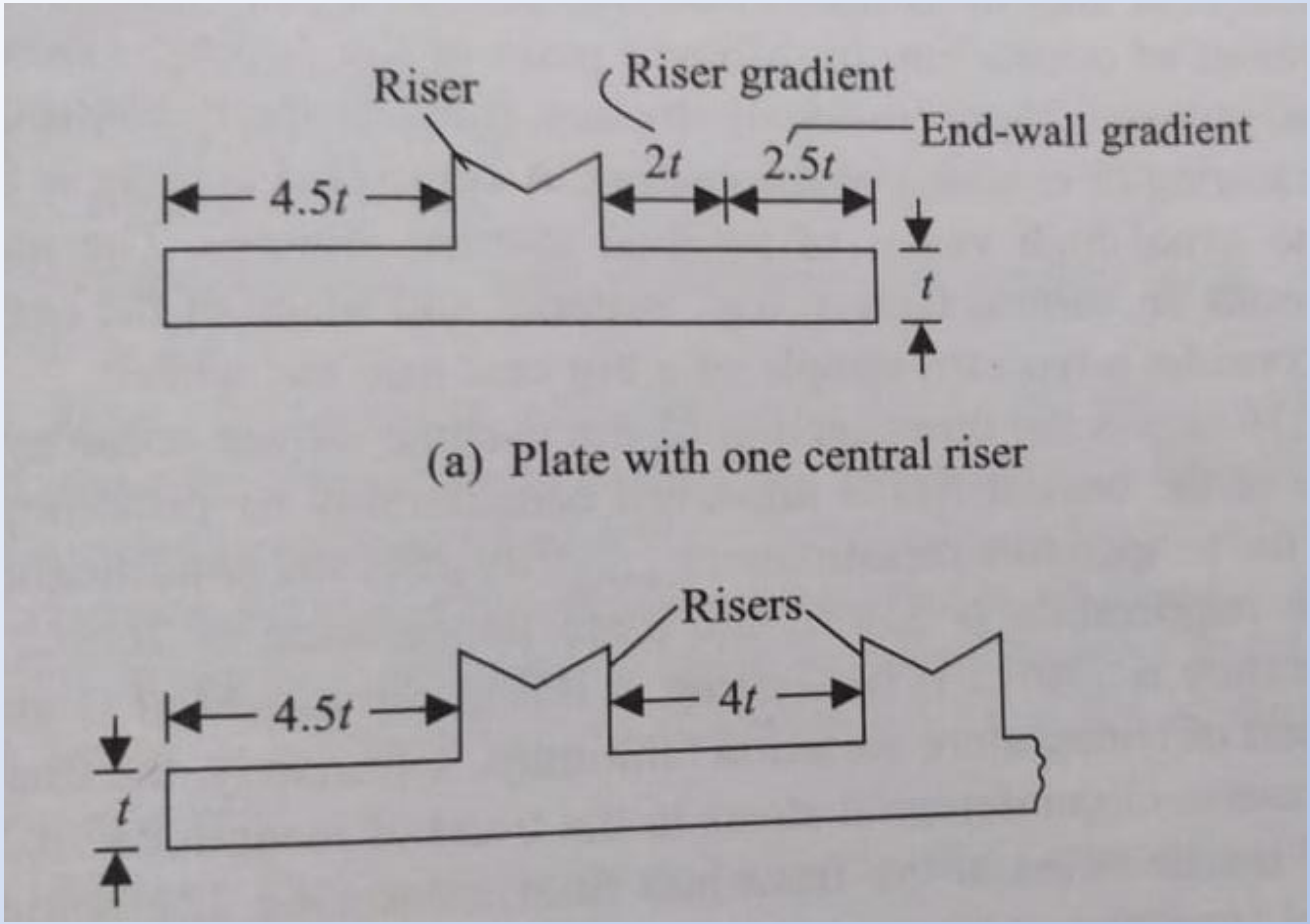
$$X = \frac{a}{Y - b} + c$$

$Y = V_r / V_c$

a, b and c are constant

$$FR = X = \frac{(SA/V)_c}{(SA/V)_r}$$

FR >1

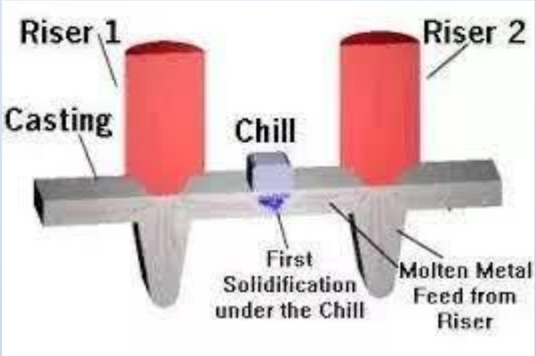


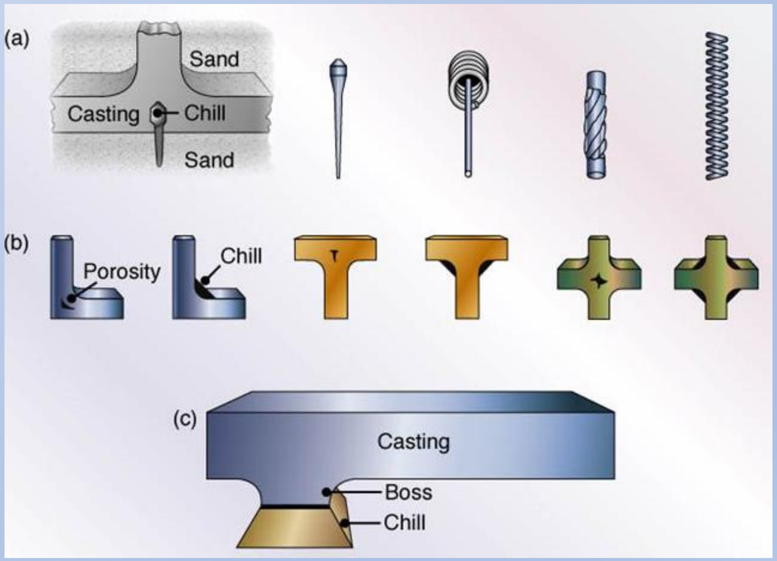
Maximum distance of two consecutive riser

End effect: Thermal gradient created due to the end walls

Chill

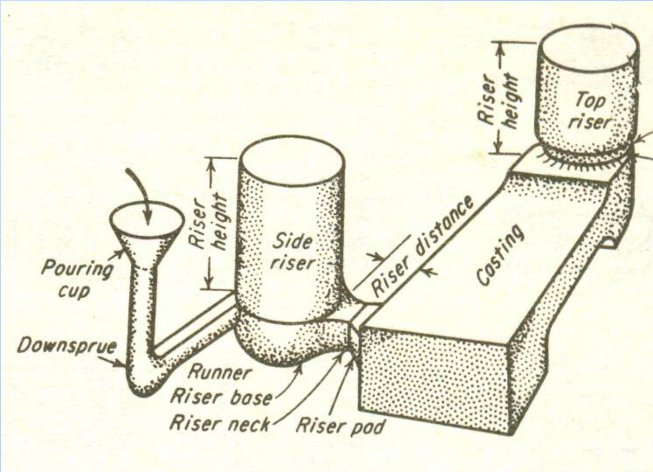
- A metallic piece to promote the directional solidification in the casting
- Increases the cooling rate in that location
- May lead to formation of hard spot at the contact area





Chill useful for eliminating internal voids

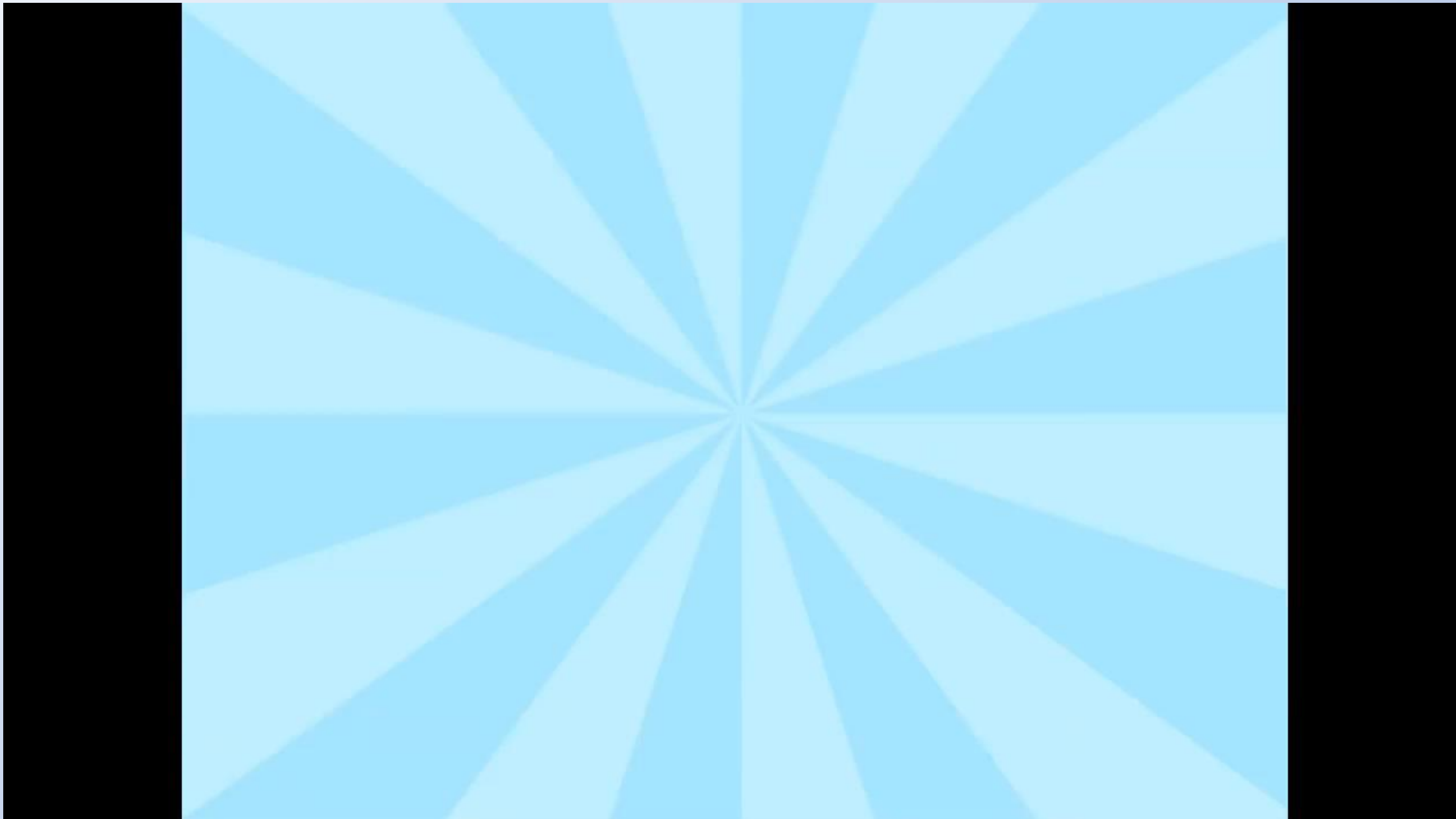
Q1) Find the optimum d/h ratio for the top riser and side riser



Q2) Determine the dimensions of a cylindrical riser to be used for casting as aluminum cube of sides 15 cm. The volume shrinkage of aluminum during solidification is 6.5%. Consider volume of riser to be atleast 3 times higher than required volume

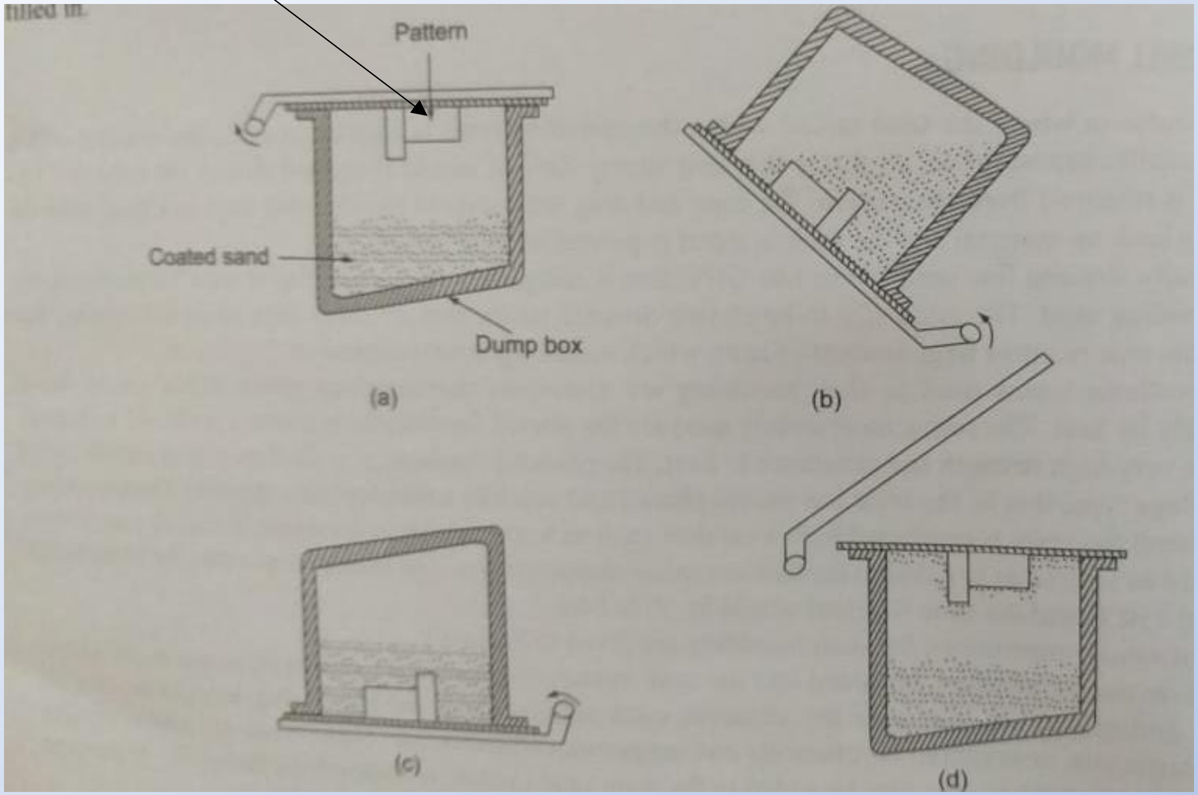
Q3) Calculate the size of a cylindrical riser necessary to feed a steel slab casting of 25*25*5 cm, with a side riser casting. a= 0.1, b=0.03, c =1.0. (assume h=d).

Shell Moulding

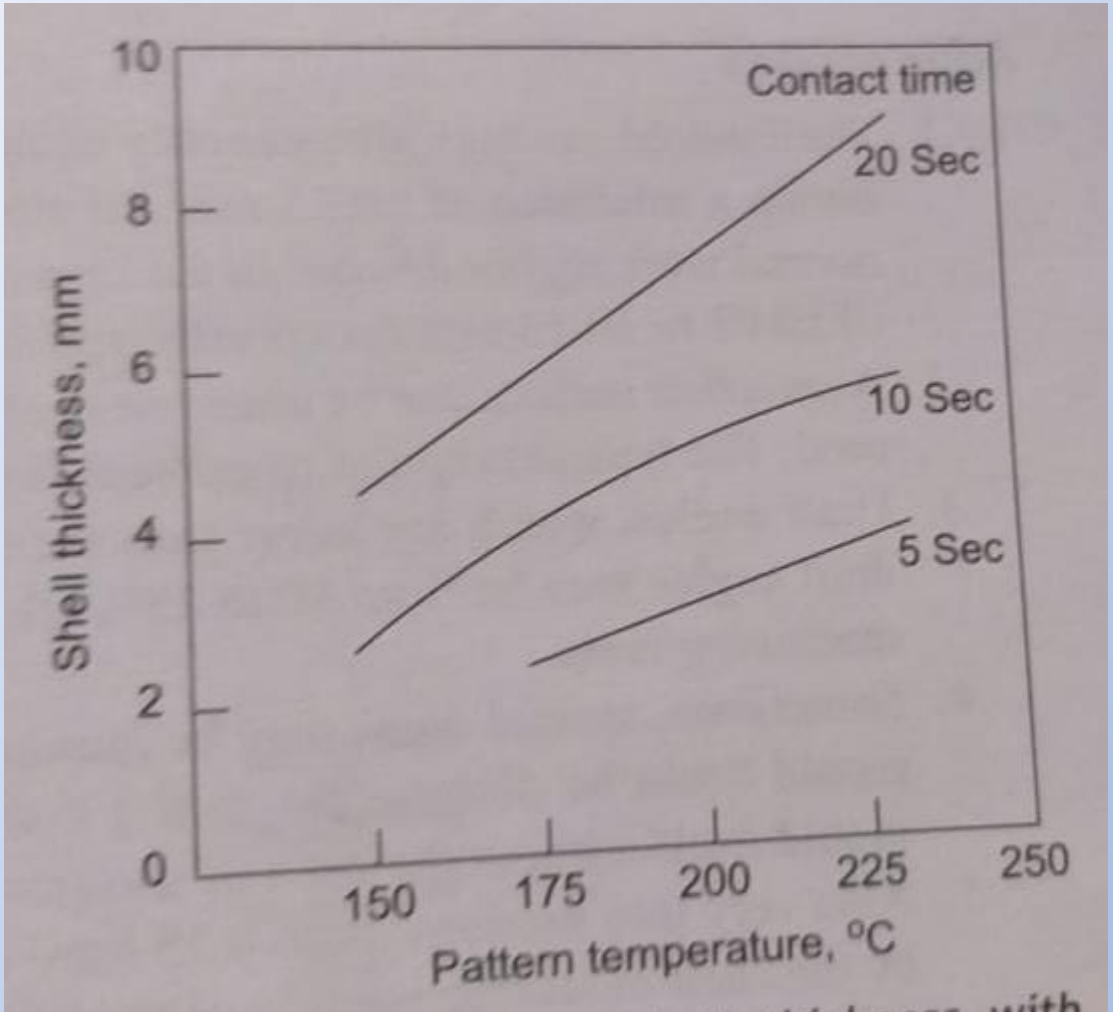


Shell moulding

Heated pattern (150-200^{o}C)



- ✓ Sand mixed with thermosetting resins (phenol formaldehyde) is allowed to come in contact with heated pattern
- ✓ GFN of 90-140 is used that is completely free of clay. Finer sand require more resin
- ✓ Additives: Coal dust, calcium carbonate etc
- ✓ Lubricants to increase flowability, calcium stearate, zinc stearate
- ✓ Metal pattern is used
- ✓ Hexa-methylene-tetramine is used as catalyst to convert thermoplastic resin to thermosetting. Due to excess phenol, the resin initially acts as thermoplastic


Contact time
20 Sec
10 Sec
5 Sec
Shell thickness, mm
10
8
6
4
2
0
150
175
200
225
250
Pattern temperature, °C

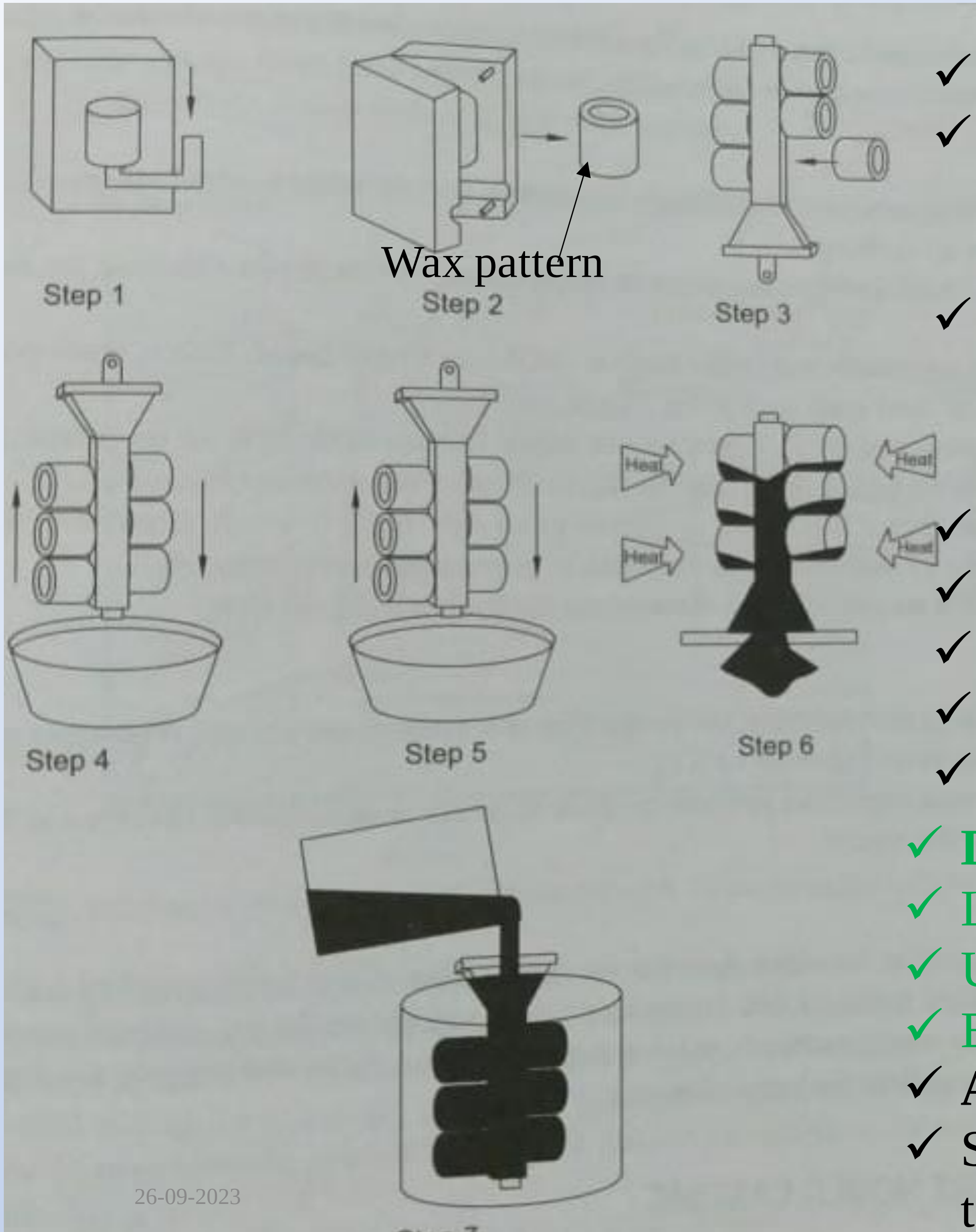
- **Advantages:** Dimensionally accurate, Good surface finish (3-6 micron)
- Thin section upto 0.25 mm of the type of air cooled cylinder heads

Limitations: Expensive pattern, Suitable for large scale production, Complicated sample cannot be made, generally casting upto 200 kg can be manufactured though in small quantity it can upto 450 kg

Applications: Cylinders and cylinder head, brake beam, gear blanks, refrigerator valve plate, small crank shafts

Investment Casting

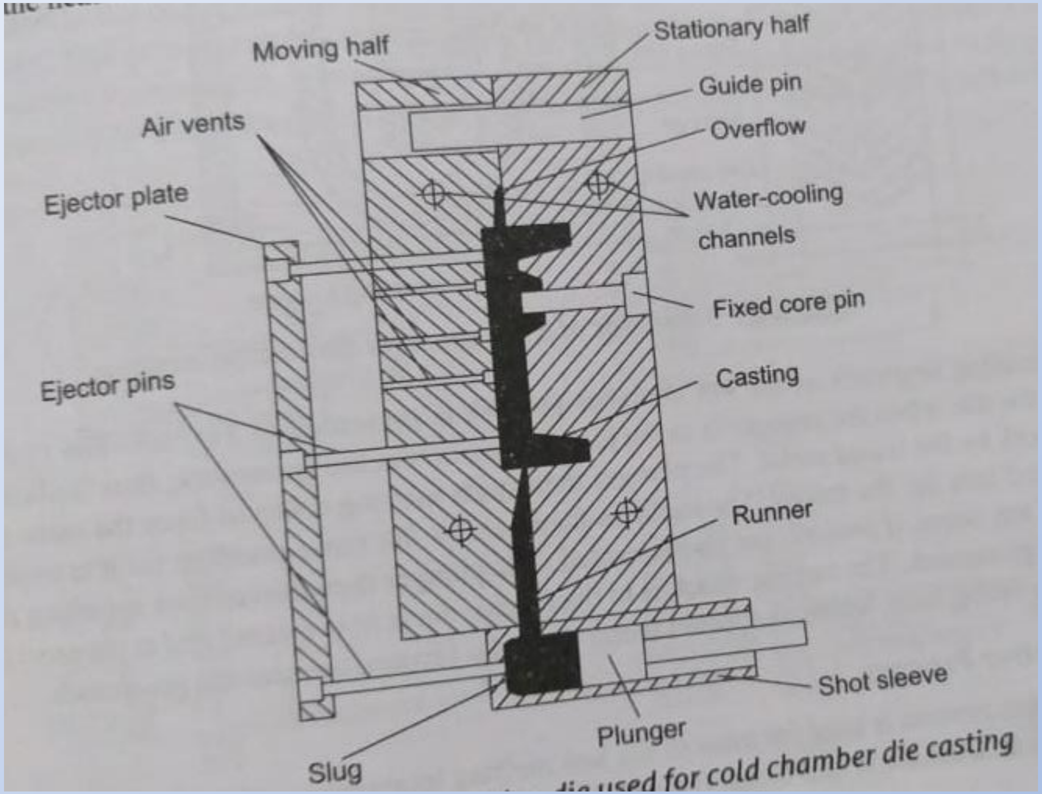
Precision investment casting



- ✓ Expendable pattern is used
- ✓ Slurry made by suspending fine ceramic particle in a liquid such as ethyl silicate or sodium silicate
- ✓ Dry refractory grains like fused silica or zircon are stuccoed on this liquid ceramic coating
- ✓ **Advantages**
- ✓ Complex shape is possible
- ✓ High tolerance and surface finish
- ✓ Little to no machining required
- ✓ Useful for difficult to machine material
- ✓ **Disadvantages**
- ✓ Limited by size and mass of casting
- ✓ Upper limit is 5-100 kg
- ✓ Expensive
- ✓ **Application**
- ✓ Surgical instruments, blades of gas turbine, bolts and triggers of fire arm

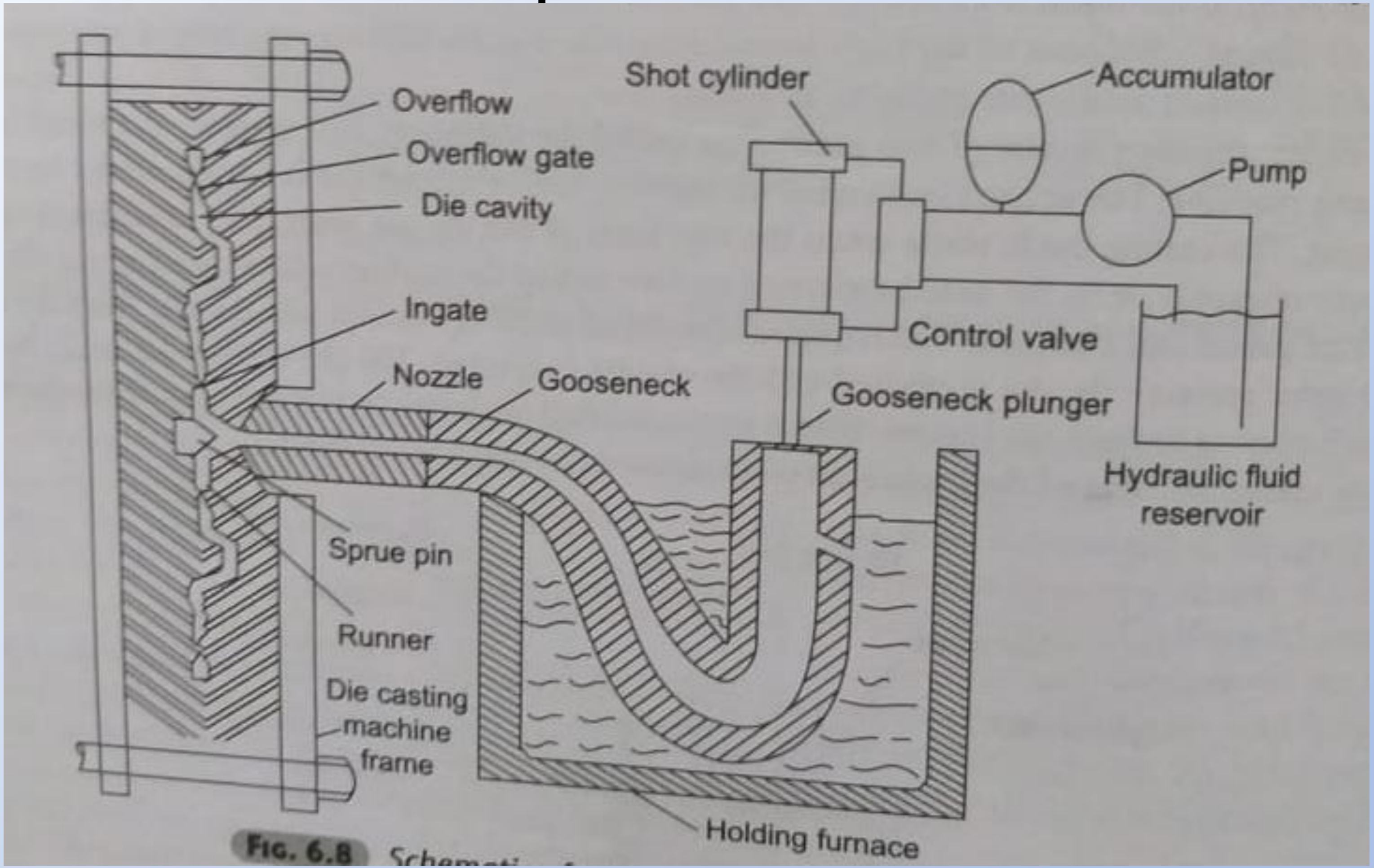
Die Casting

Die casting



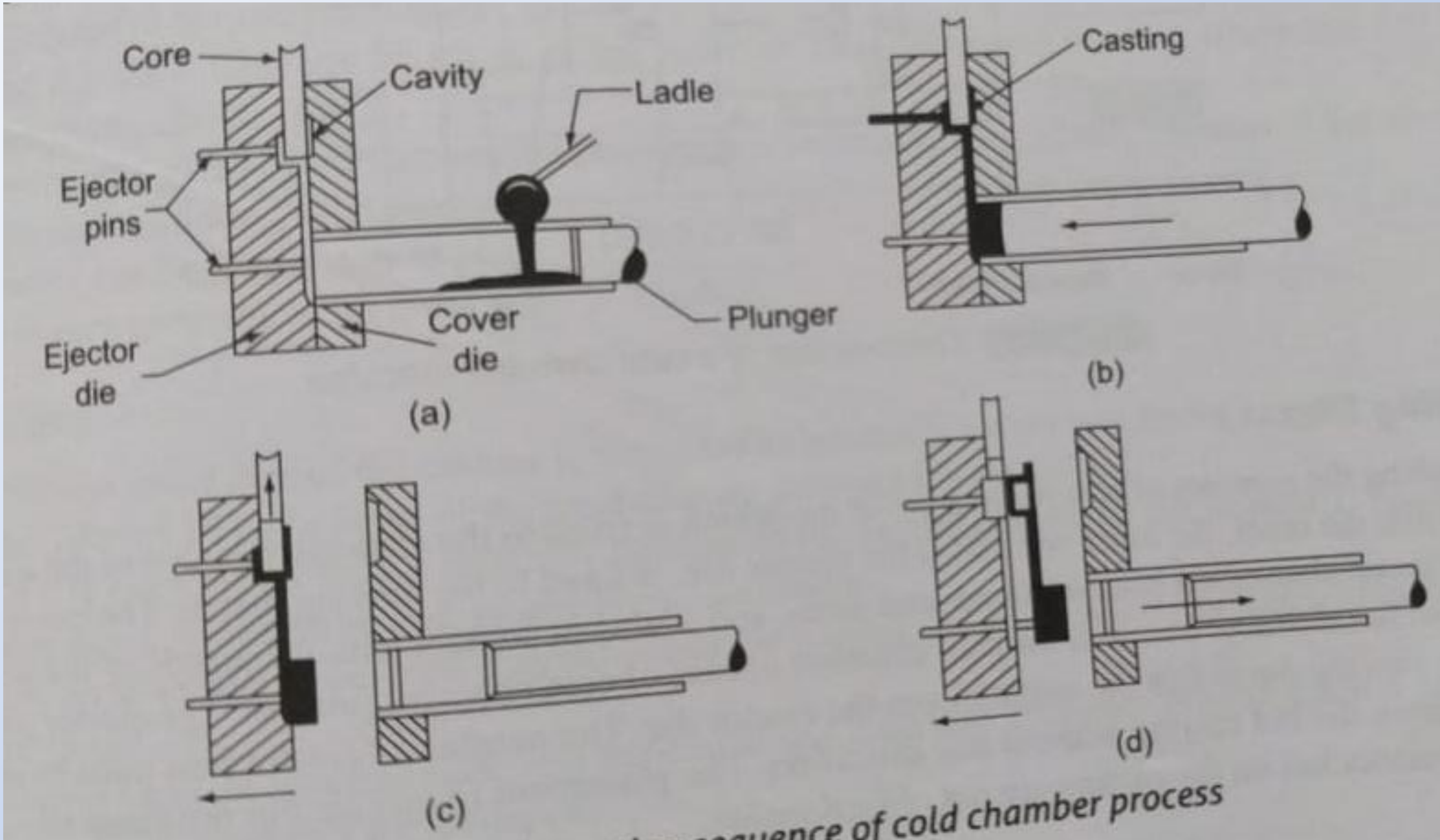
- ✓ Injecting molten metal at high pressure into metallic die
- ✓ Any narrow section, complex shapes and fine details
- ✓ If liquid metal is filled forced in pressure than it is called as pressure die casting
- ✓ Grey cast Iron/alloy steel is used as die material

Hot Chamber process



Used for low melting point temperature alloys such as Zinc, lead and tin
Die material: tool steels

Cold chamber process



Used for high melting temperature alloys

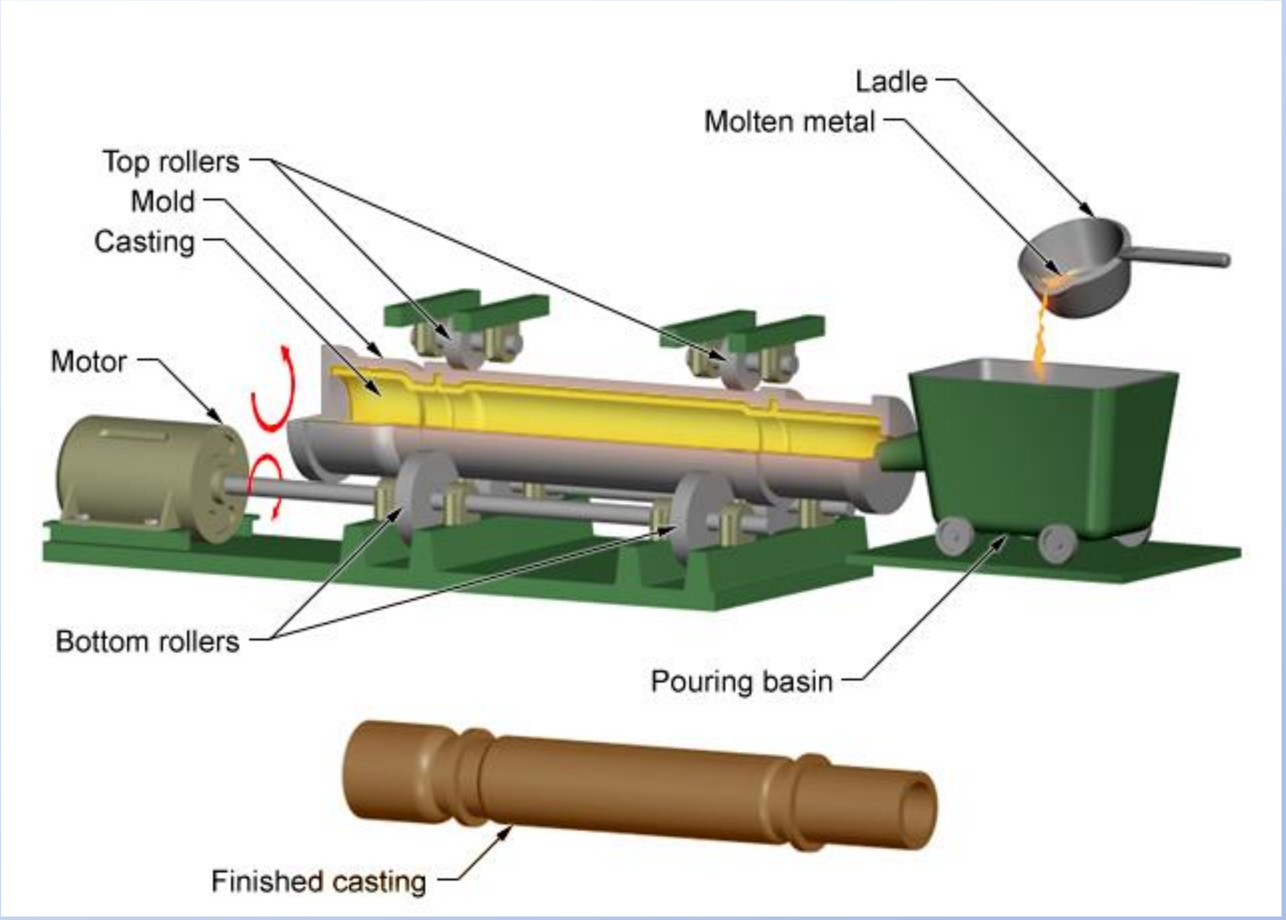
Advantage

- Small thickness can be easily filled
- High production rates and higher surface finish
- Close tolerances of the order of 0.08 mm
- Better mechanical properties as compared with sand casting
- Economical for mass production

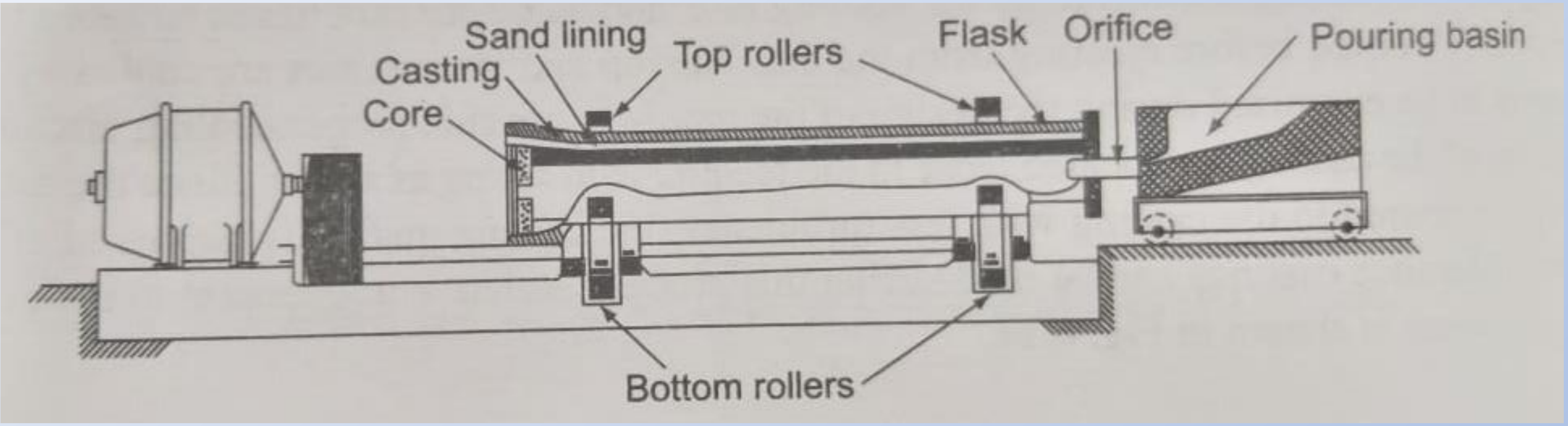
Disadvantage

- Maximum size of casting is limited. Preferably less than 4 kg with a maximum order of 15 kg
- Preferred for Zinc, aluminum, magnesium, and copper alloys
- The dies and machine are very expensive

Centrifugal casting



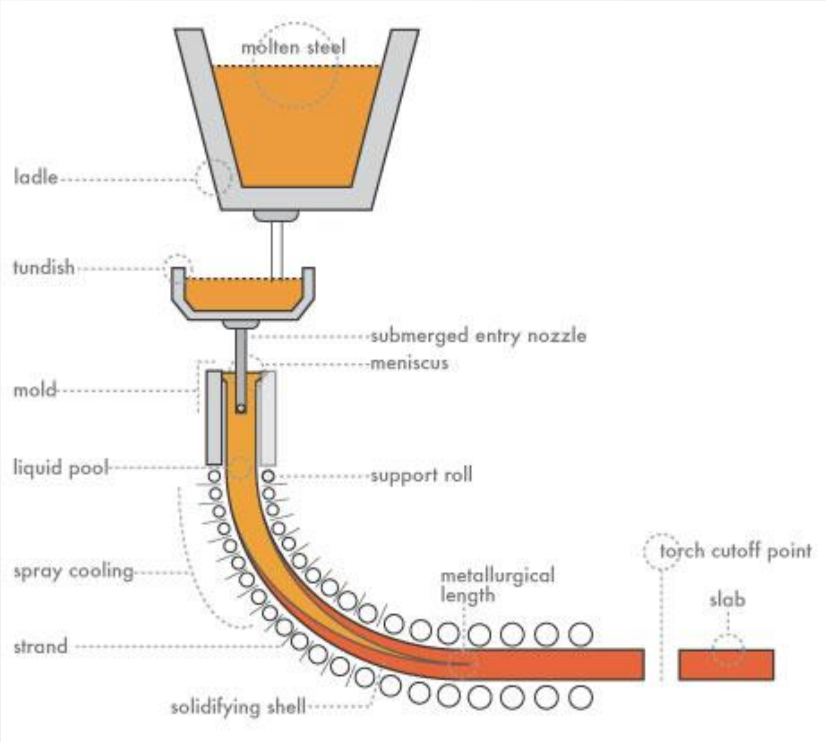
True centrifugal casting

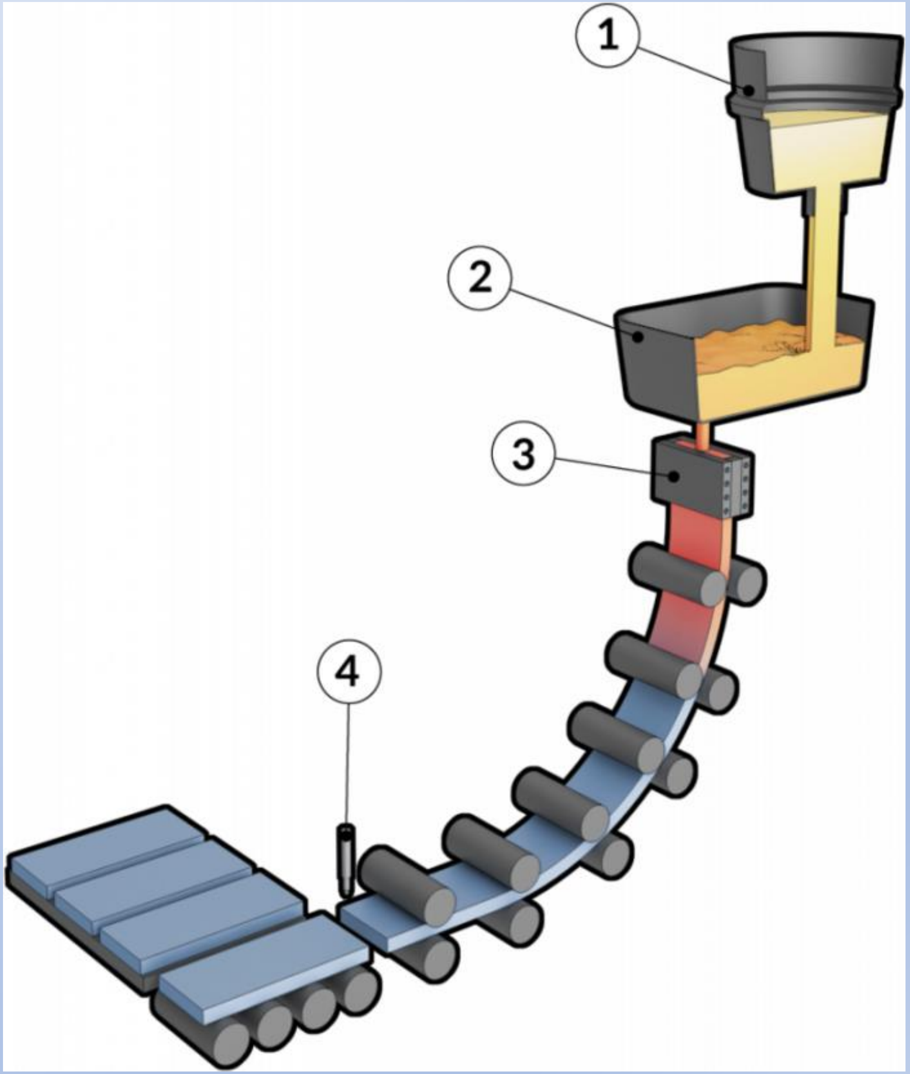


Advantages: Mechanical properties are better, upto certain thickness directional solidification can be attained, No core is required, No need of gate and runner

Disadvantages: Only certain shapes which are axi-symmetric can be manufactured, equipment is expensive

Continuous casting



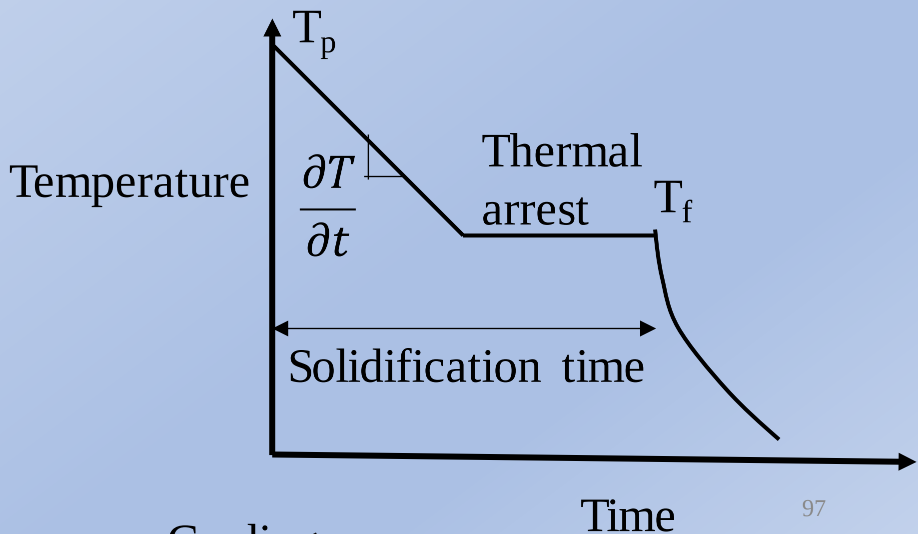


Self study

- Types of casting such as permanent mould, vacuum die casting, types of centrifugal casting, Squeeze casting, slush casting etc
- Types of defects over and above discussed in class

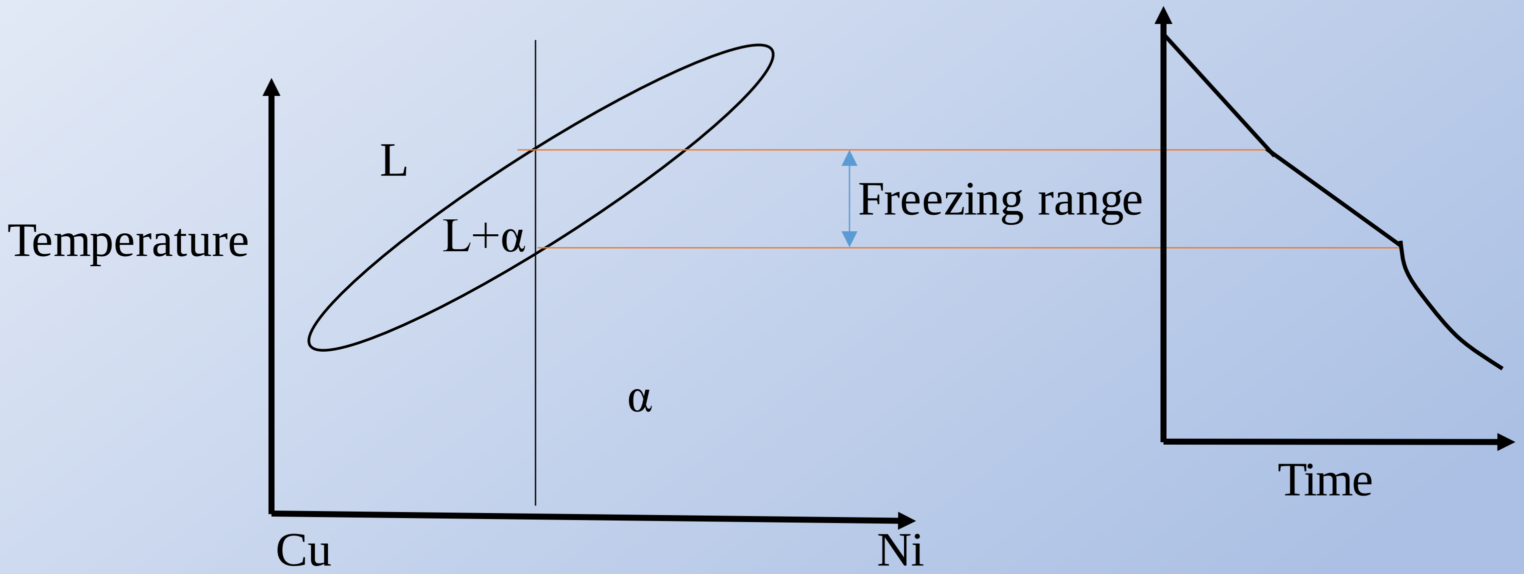
The solidification process

- Molten metal is poured and allowed to freeze
- Many casting defects such as solidification shrinkage, gas porosity are also solidification phenomenon.
- Solidification is two stage process: **nucleation** and **growth**
- Size and character of grains are controlled by composition of alloy and cooling rate
- Nucleation: When a stable particle of solid forms from liquid



Cooling curve

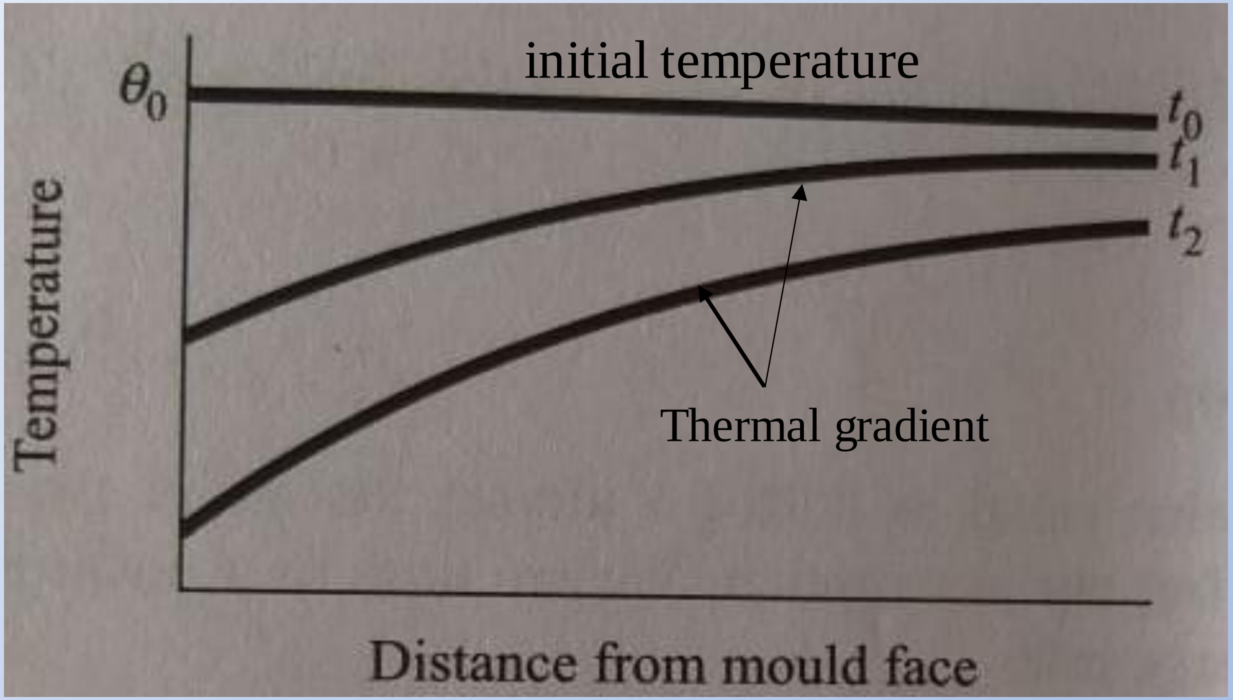
Phase diagram and corresponding cooling curve of an alloy



Phase diagram

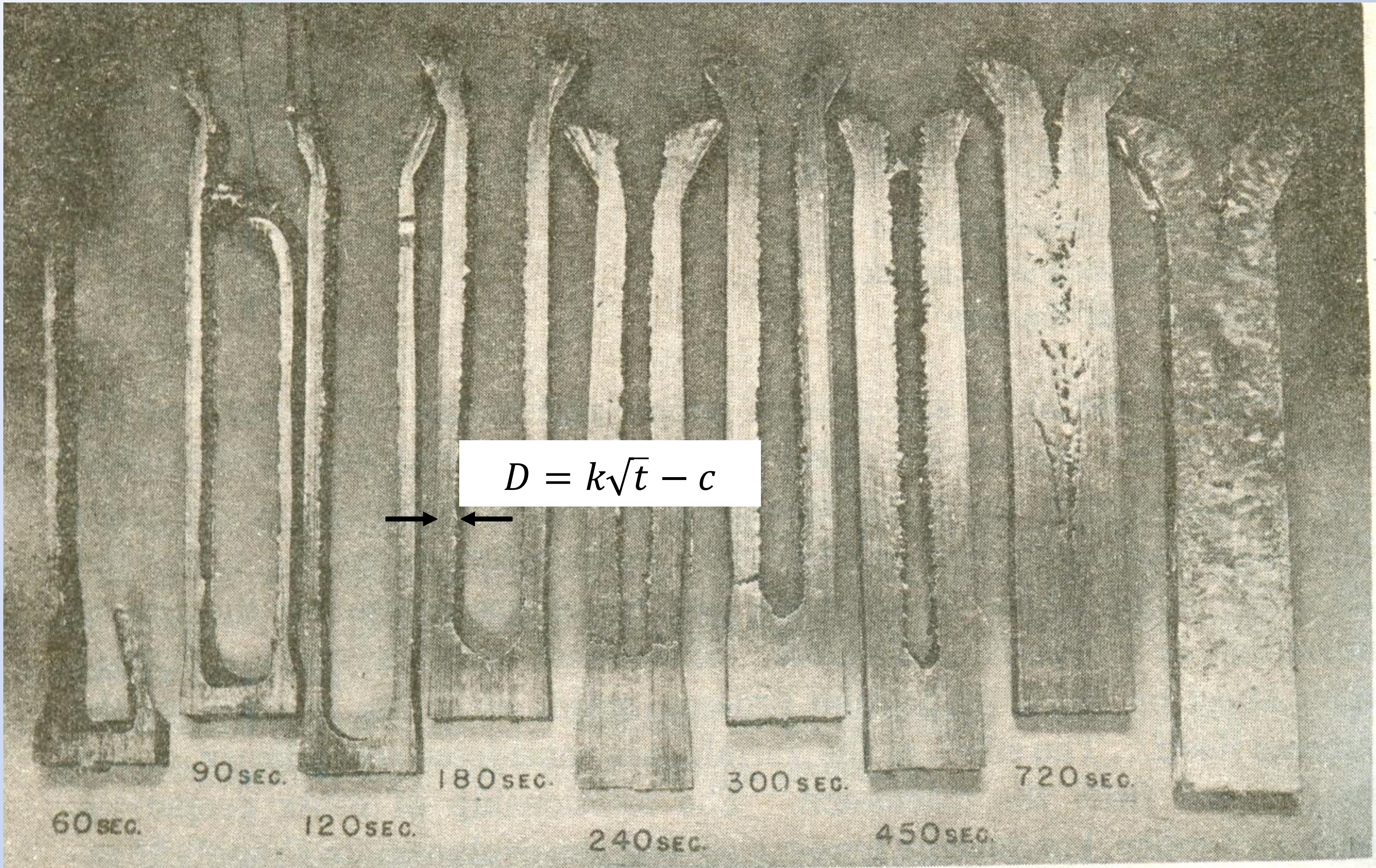
Cooling and solidification

- *Mechanism of solidification: Pure metals*
- Liquid needs to be cooled below the freezing point as it require energy to create surfaces for new crystal
- The required degree of super cooling is reduced by the presence of other surfaces such as particle, which act as initial nuclei



If conductivity of mould is high, randomly-oriented small crystals grow near the mould face

Solidification of pure metal



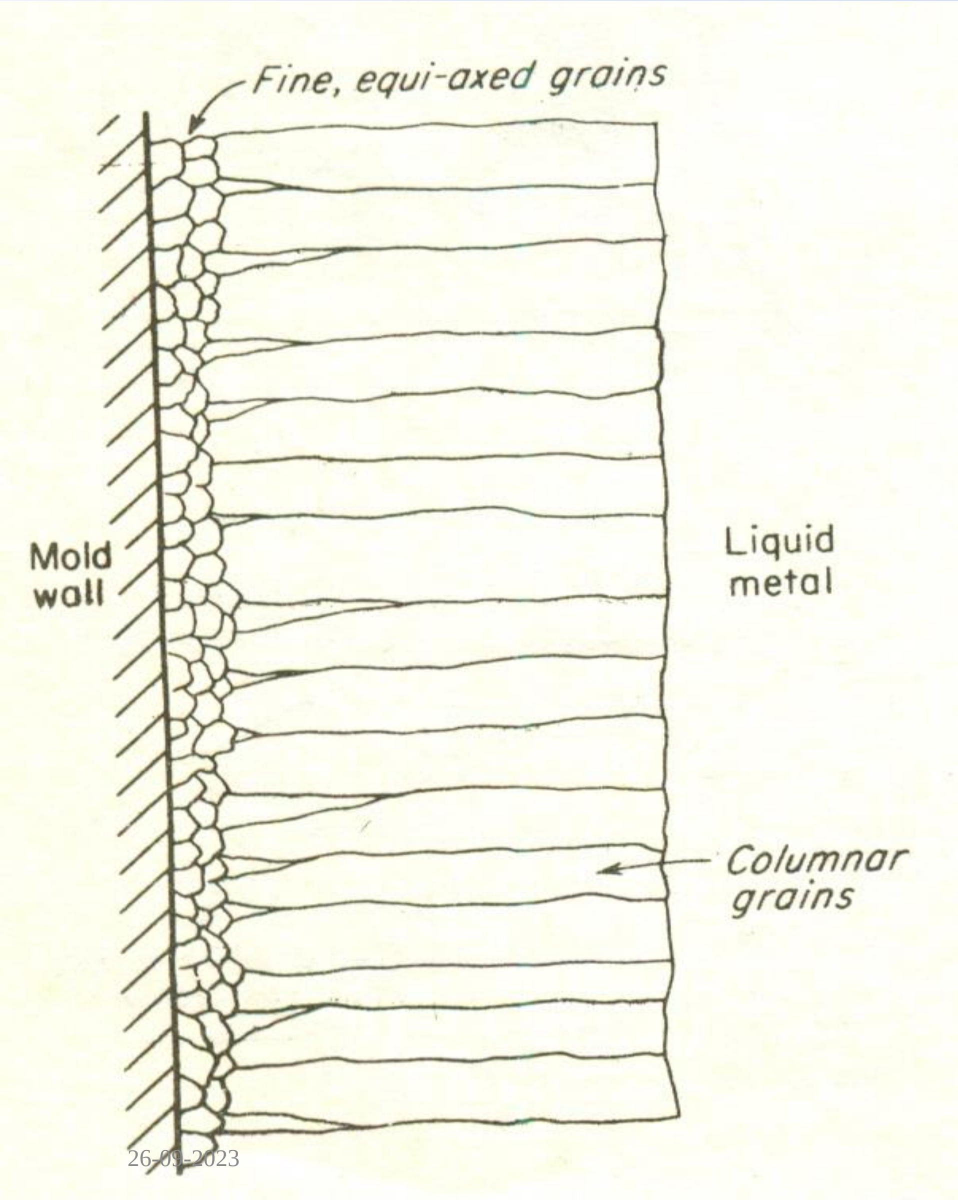
$$D = k\sqrt{t} - c$$

D = Thickness; k,c = constant; t=time

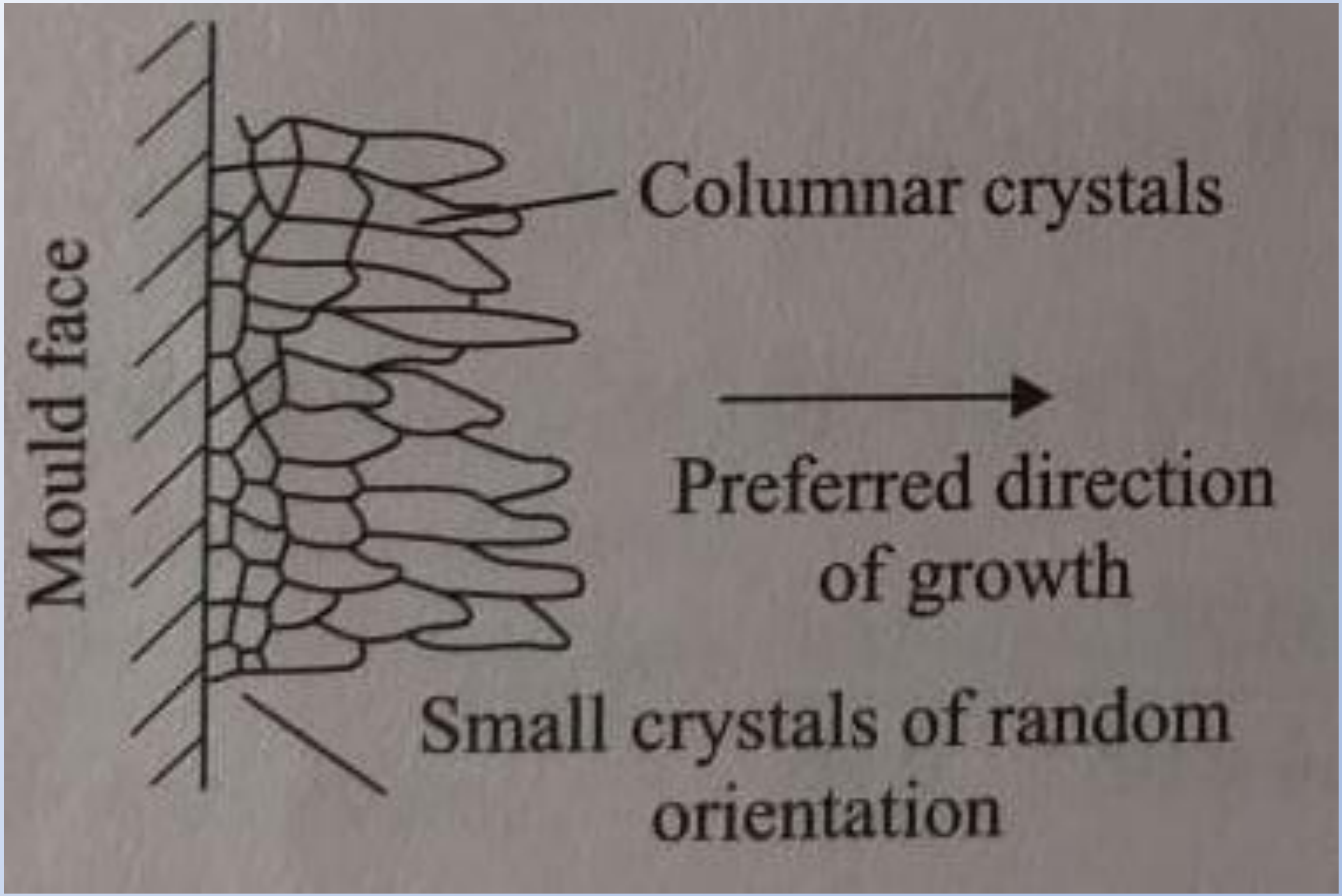
k is determined by the size of the casting and how fast heat can be extracted

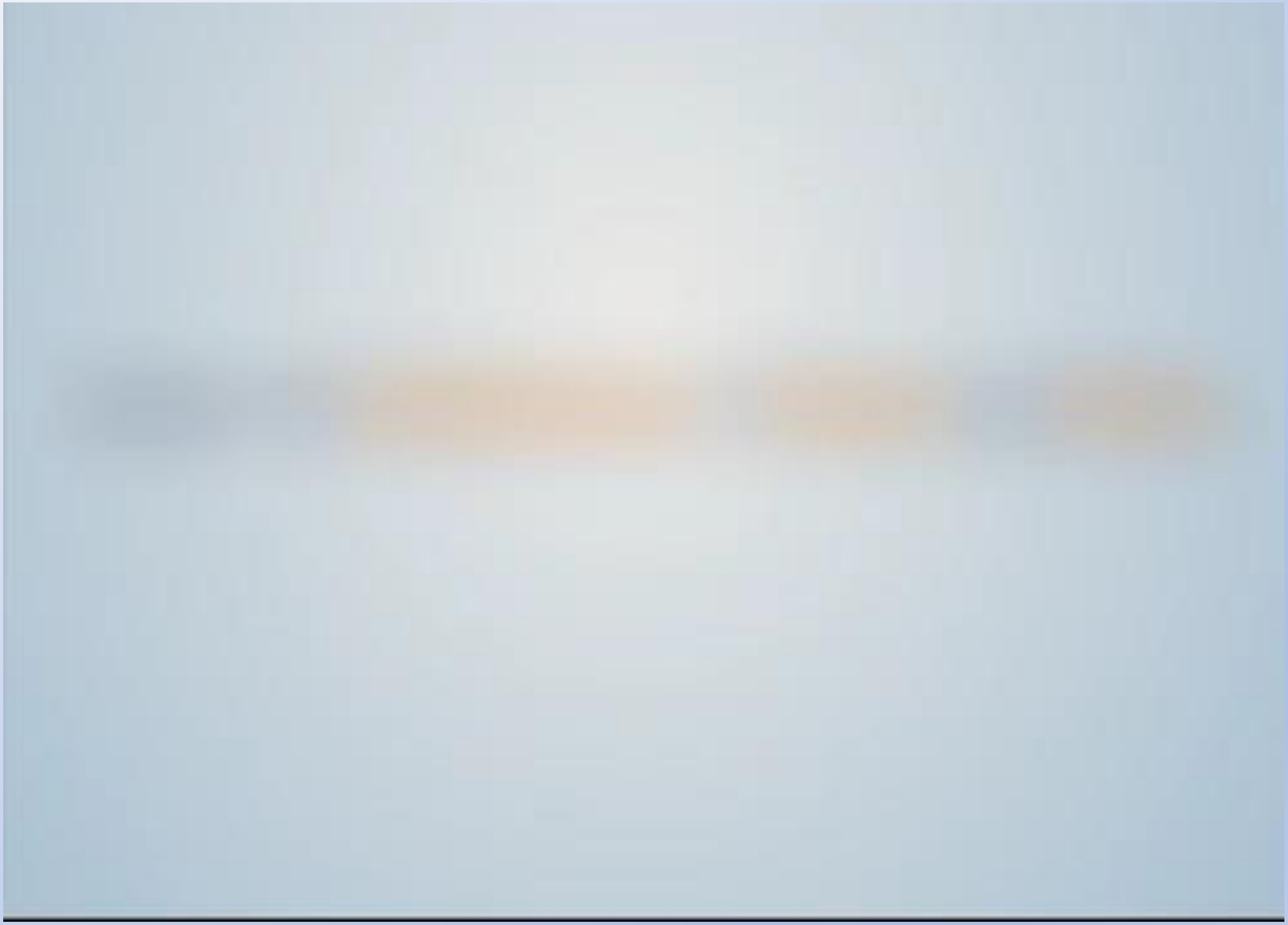
c is determined largely by the degree of superheat

Nucleation and grain growth



- Fine equiaxed grains near the wall due to super cooled mould due to high rate of nucleation
- Latent heat of fusion is released and remaining liquid metal rapidly loses undercooling
- Growth continues from the nucleated grains opposite to the direction of heat flow due to thermal gradient

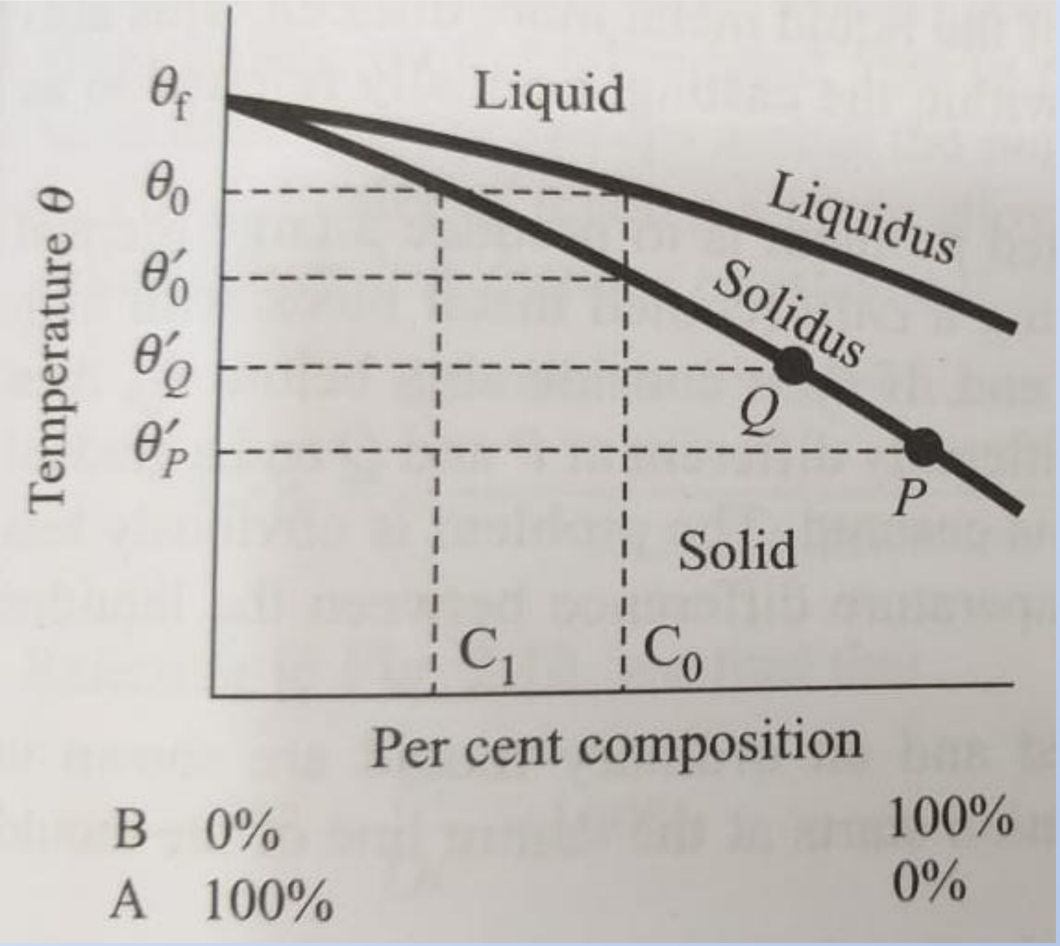

Mould face
Columnar crystals
Preferred direction of growth
Small crystals of random orientation

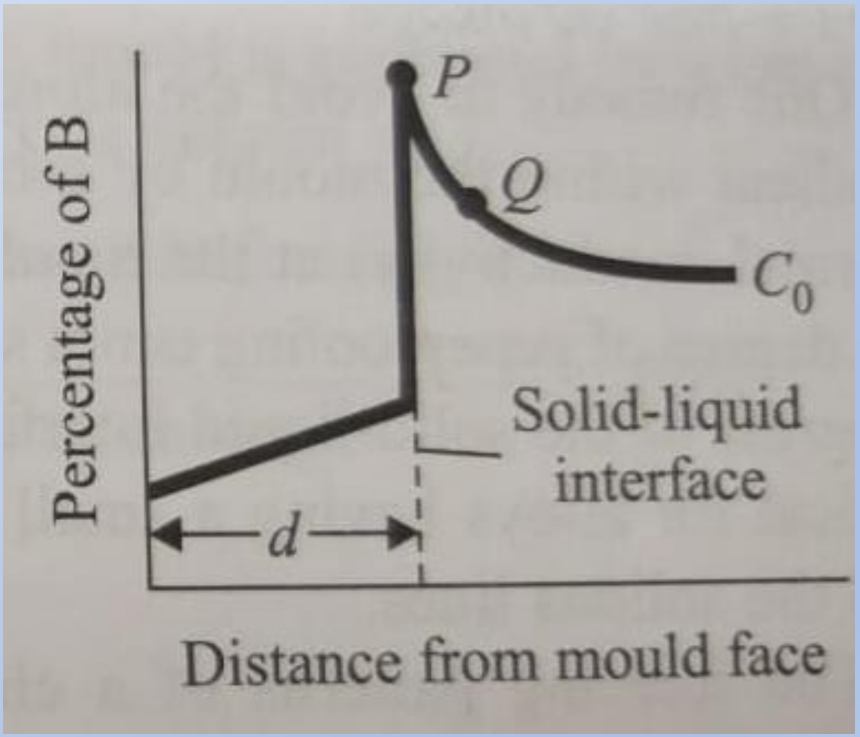


Alloys

- Does not have a sharp freezing point
- The solids separating out at different temperature posses varying compositions.
- Solidification depends on following factor
  - The composition gradient within the casting
  - The variation of solidus temperature with composition
  - The thermal gradient within the mould

Alloys





Θ_f = freezing point of pure metal
Θ_0, Θ_o' = liquidus and solidus temperature

- Co is the composition of liquid alloy (B in A)
- Solid start separating below solidus temperature

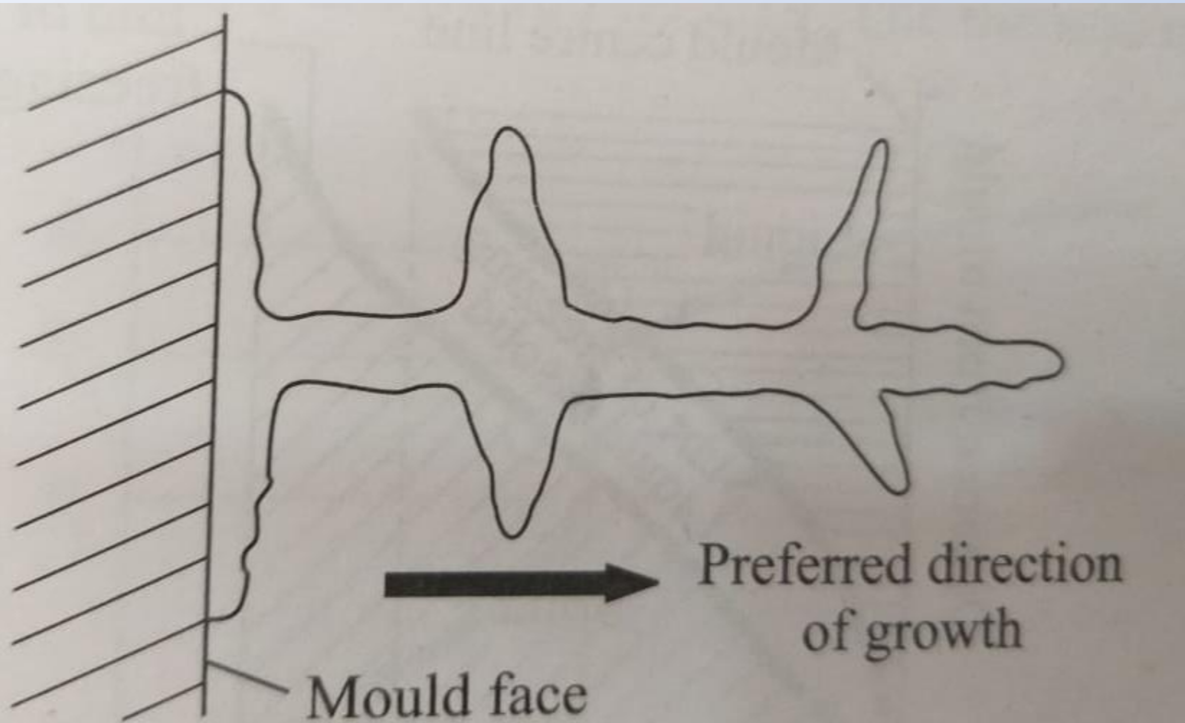
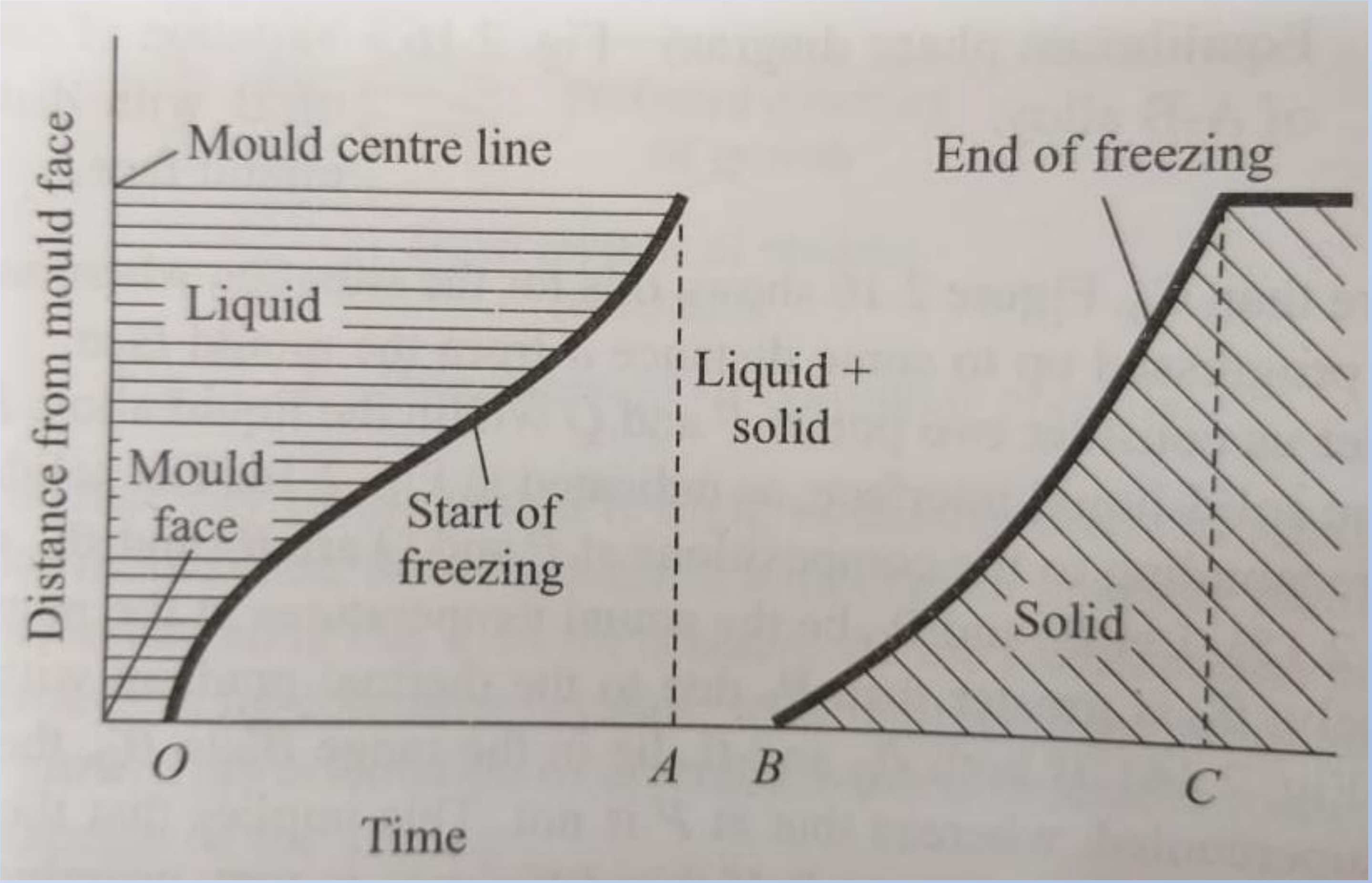


Fig. 2.17 Dendritic crystal growth structure.

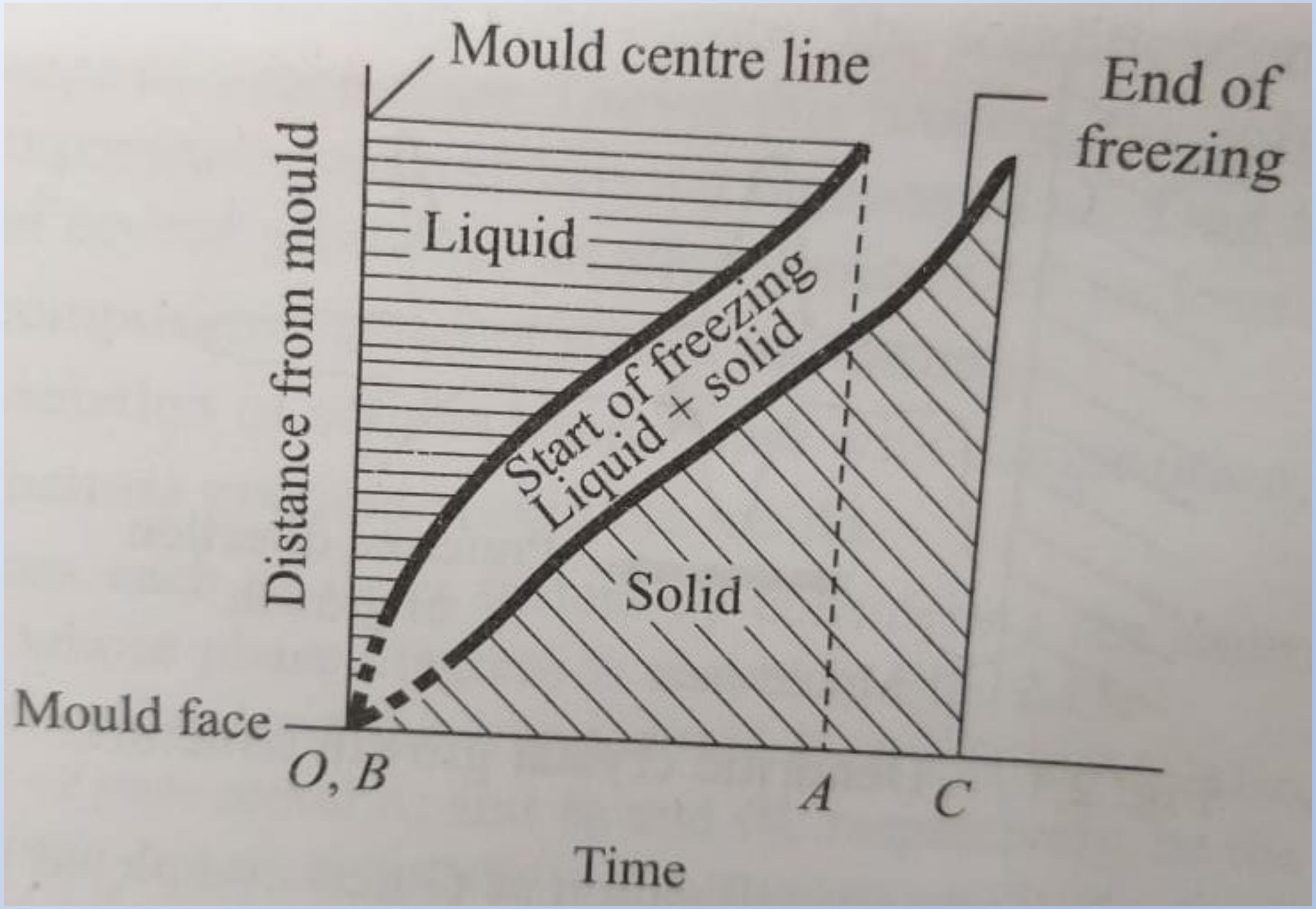
Presence of solid crystal ahead of the solid-liquid interface makes feeding of the liquid Metal more difficult. It is normally called as centre line shrinkage

Centre line feeding resistance (CFR)



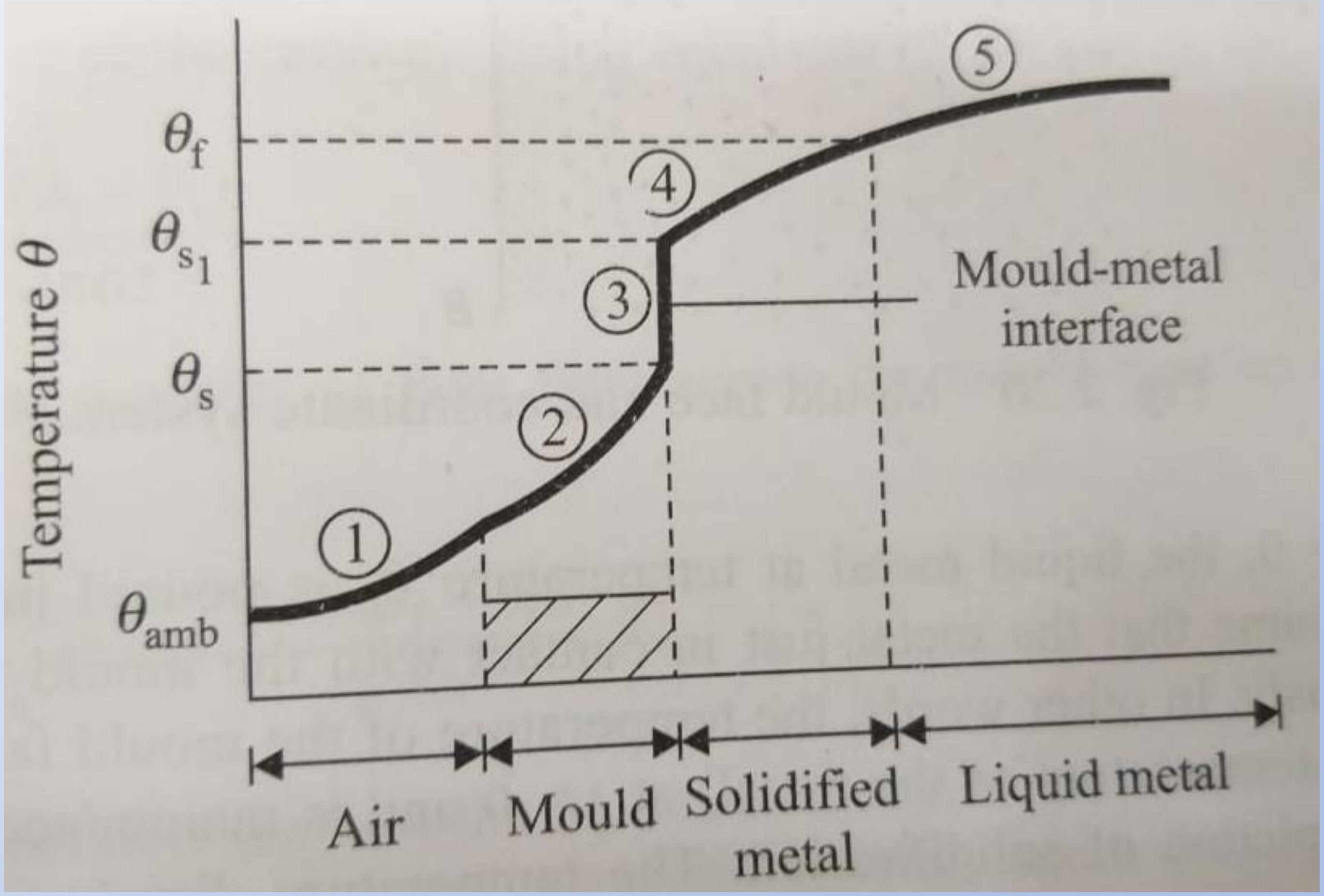
$$CFR = \frac{\text{time interval between start and end of freezing at centerline}}{\text{total solidification time of casting}}$$

$$CFR = \frac{AC}{OC} * 100,$$ CFR<=70 else it is difficult



Freezing diagram for chilled mould

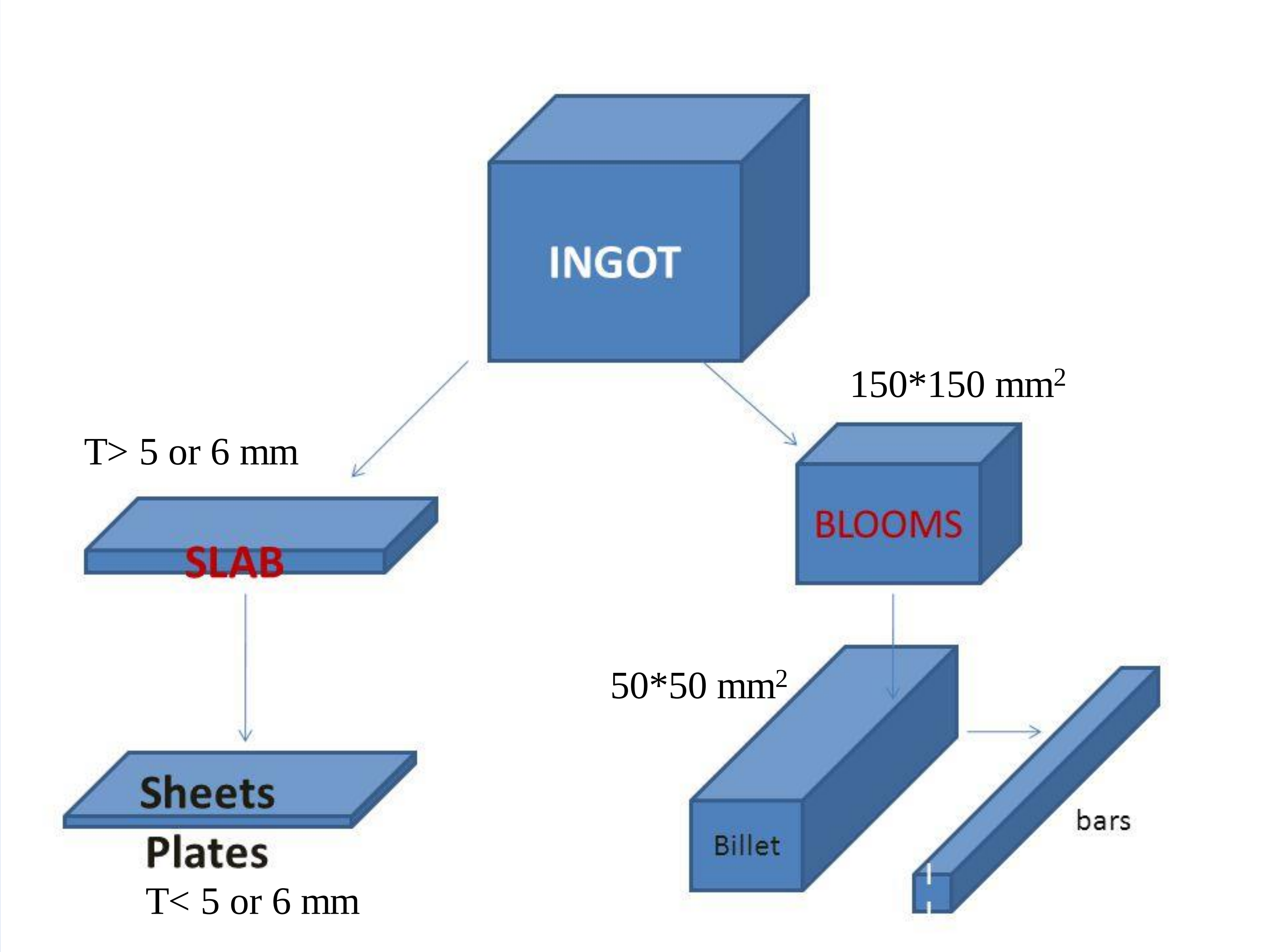
Rate of solidification



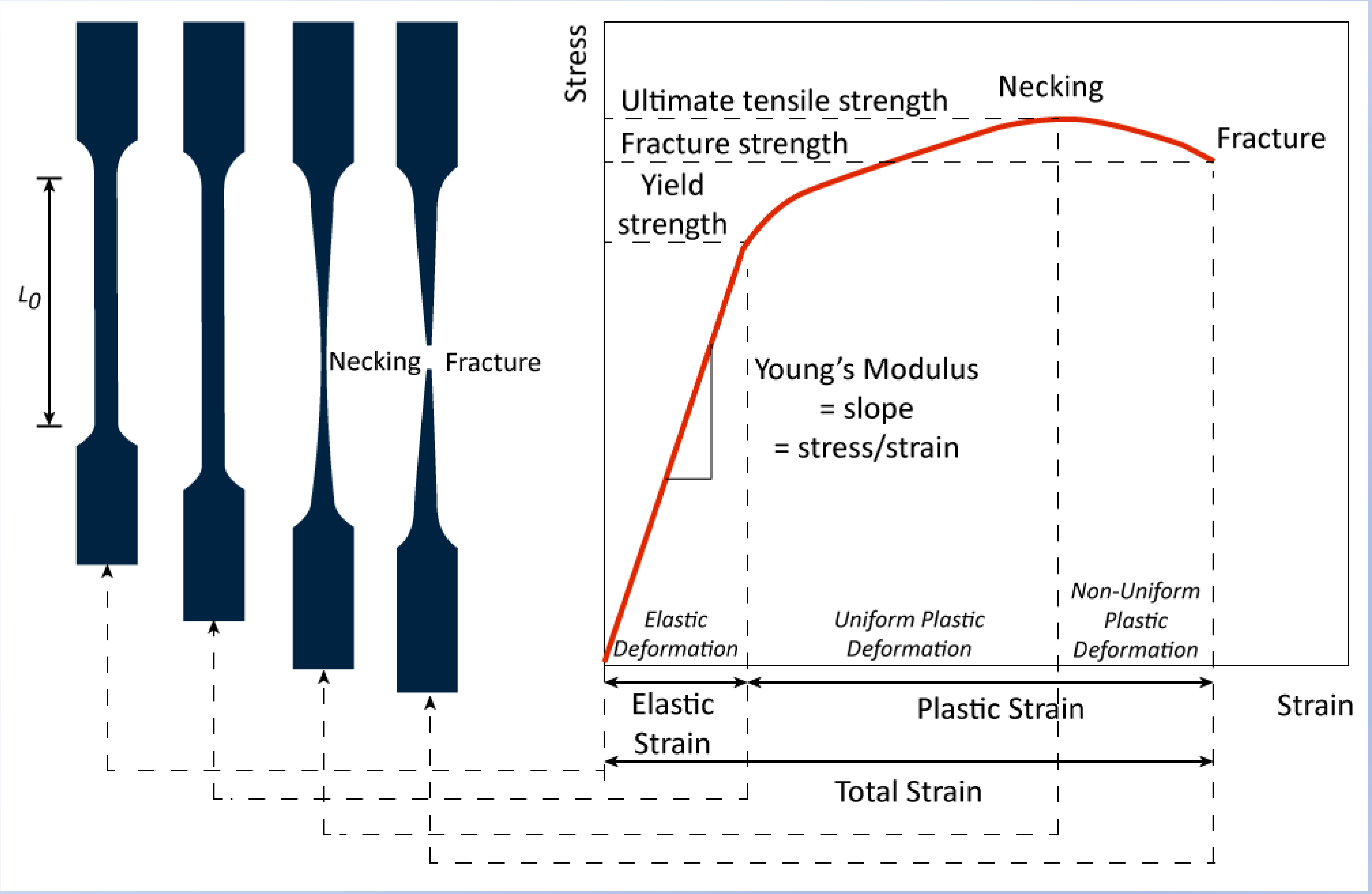
Temperature distribution at different level

Solidification of a large casting in an insulating mould

Metal Forming


INGOT
150*150 mm^2
T> 5 or 6 mm
BLOOMS
SLAB
50*50 mm^2
Sheets
bars
Billet
Plates
T< 5 or 6 mm

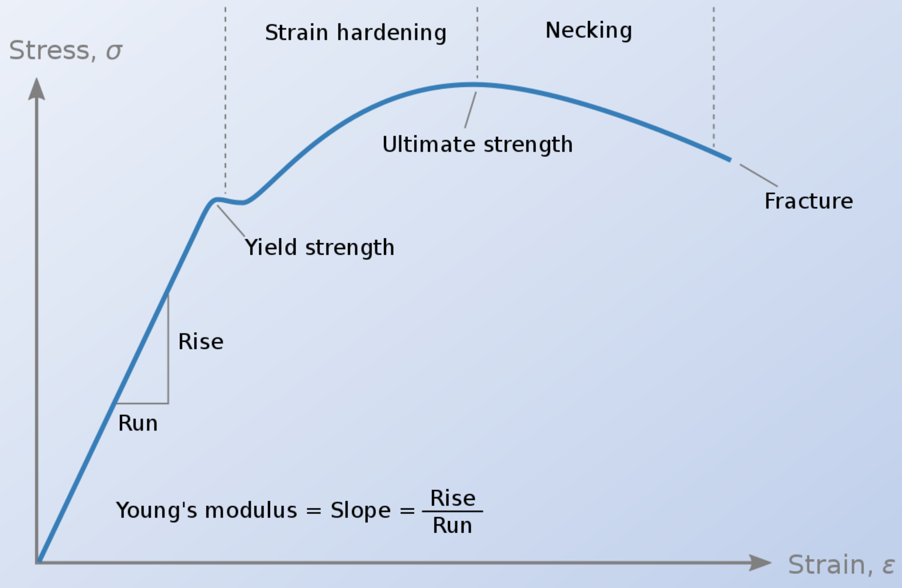
Stress-strain curve

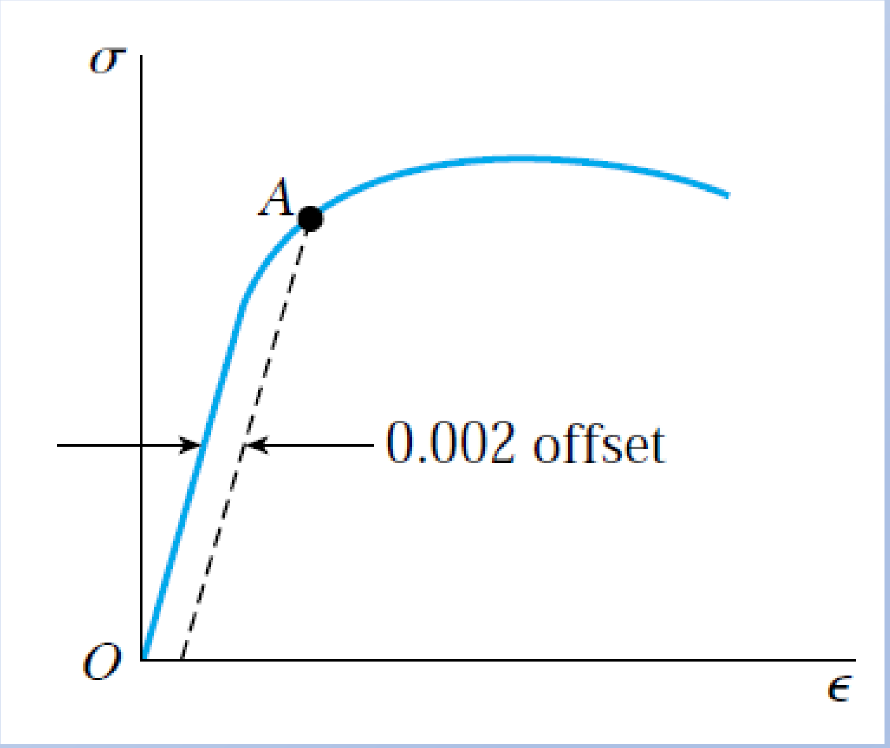


Strain hardening: Plastic deformation increases the dislocation density and this creates difficulty into the movement of dislocation

Clearly defined yield point

If yield point is not clear than offset method





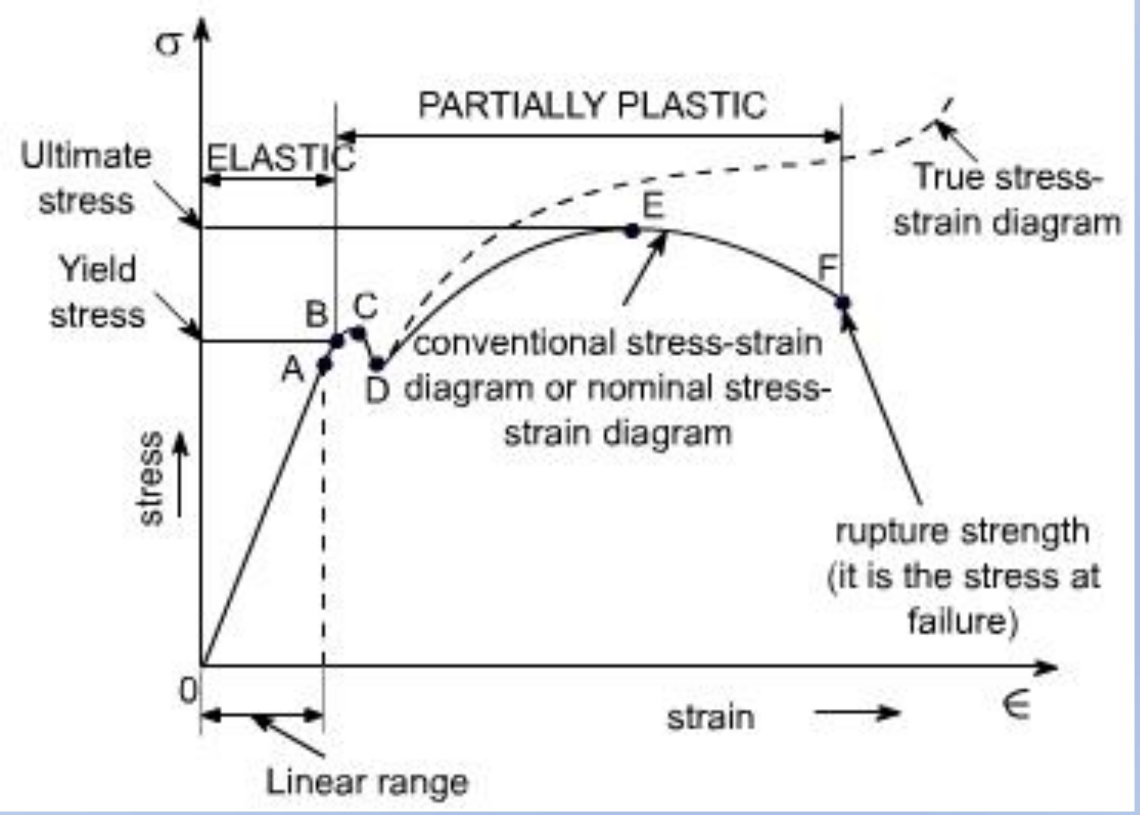
Stress strain curve for mild/low carbon steel

True stress versus Engineering stress

- True stress: Ratio of instantaneous load by instantaneous area

$$\sigma' = \frac{F}{A} = \frac{FL}{A_o L_o} = \frac{F}{A_o}(1+\varepsilon)$$

Volume is constant so $AL = A_o L_o$

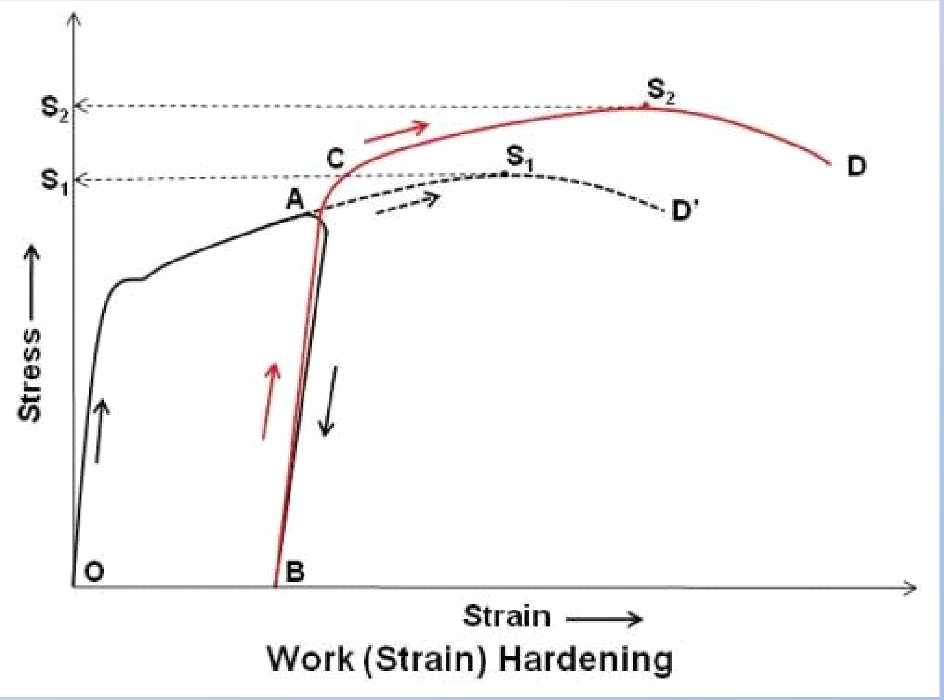


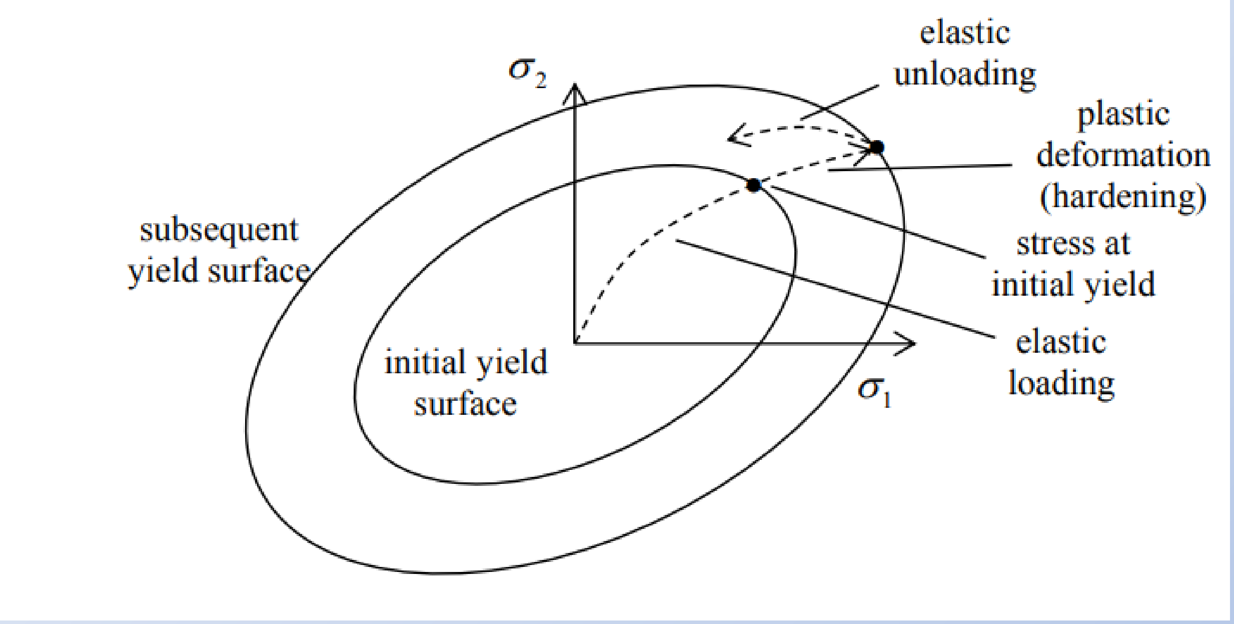
True strain: Rate of instantaneous increase in the instantaneous gauge length

$$\varepsilon' = \int_{L_o}^{L} \frac{dL}{L} = \ln\left(\frac{L}{L_o}\right) = \ln(1+\varepsilon)$$

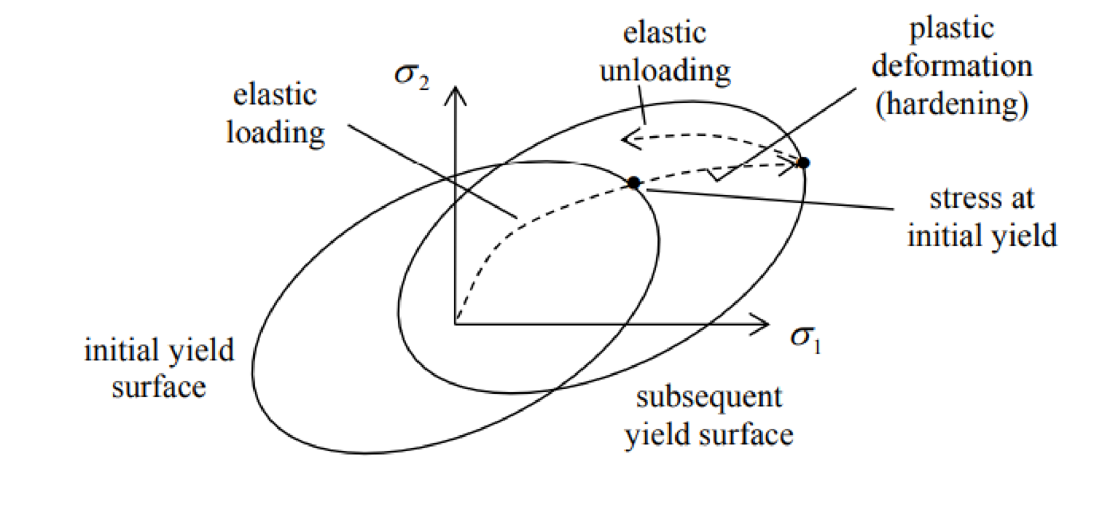
Factors affecting stress-strain curve

Strain hardening





Isotropic hardening



Kinematic hardening: Yield surface remains in same shape, but it only shifts

Effect of strain rate and temperature on stress-strain curve

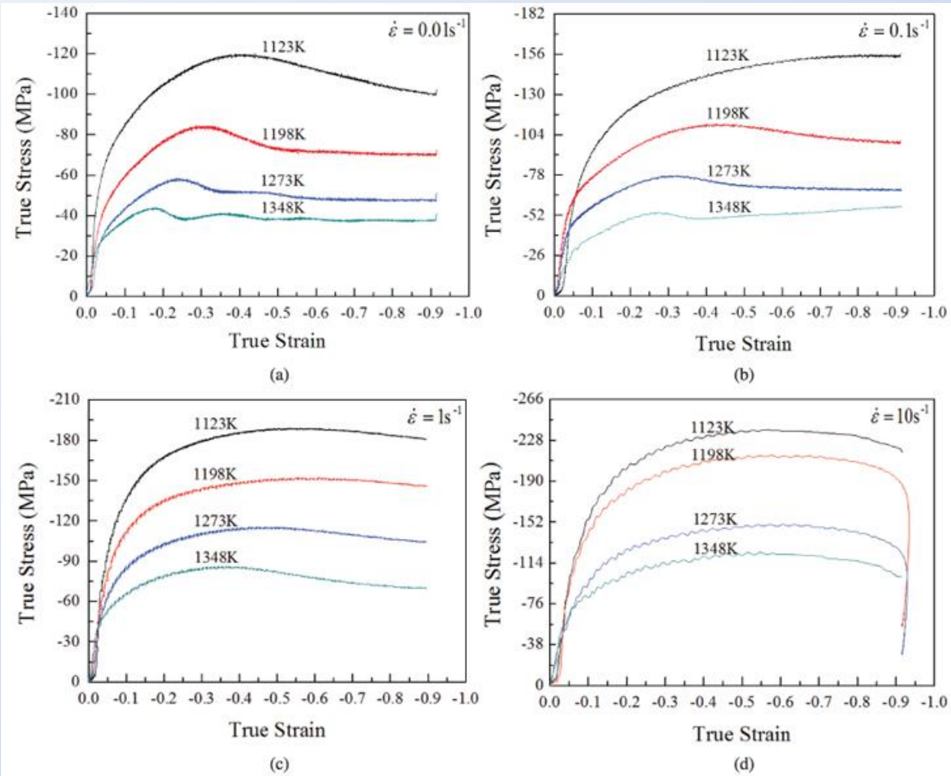
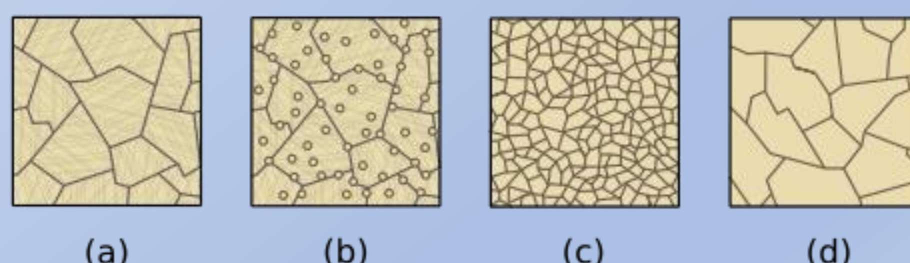


Figure 2. True stress-strain curves of as-extruded 42CrMo high-strength steel obtained by Gleeble 1500 under the different deformation temperatures with strain rates. (a) 0.01 s^{-1}, (b) 0.1 s^{-1}, (c) 1 s^{-1}, (d) 10 s^{-1}.

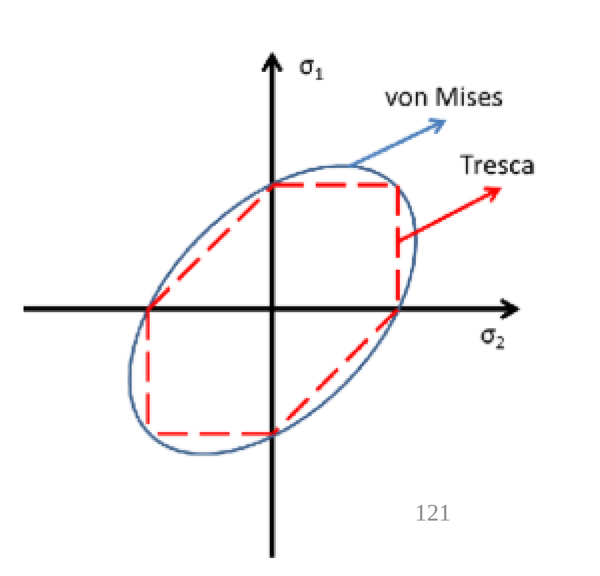


Recrystallization

Yield criteria

- **Tresca’s maxiumum shear stress criteria**: Plastic flow initiates when maximum shear stress reaches a limiting value.
- The limiting value is defined as the shear yield stress, say K.

- Von-Mises Maximum distortion energy criterion:
  - Plastic flow occurs when the shear strain energy reaches a critical value.

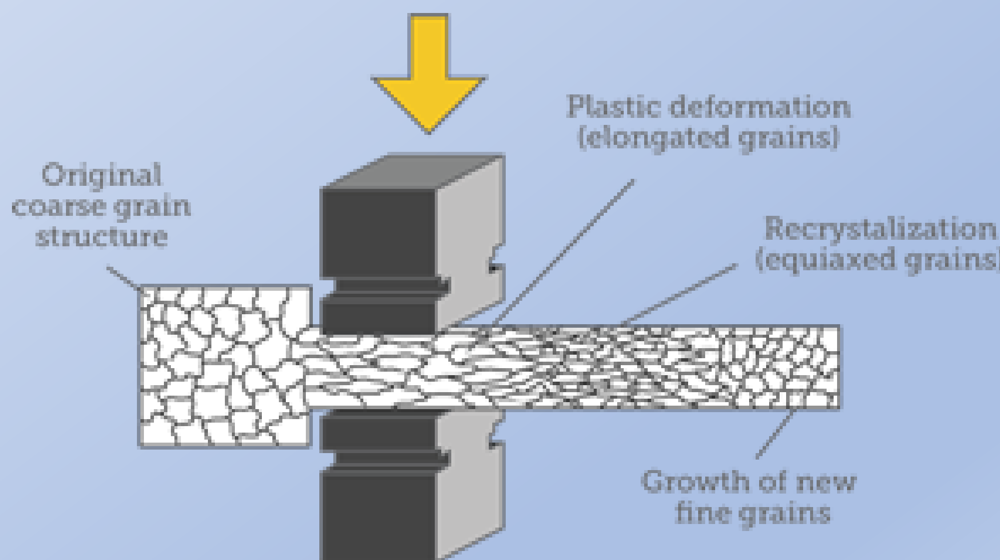


Relation between tensile and shear yield stress

Properties of material for Forming

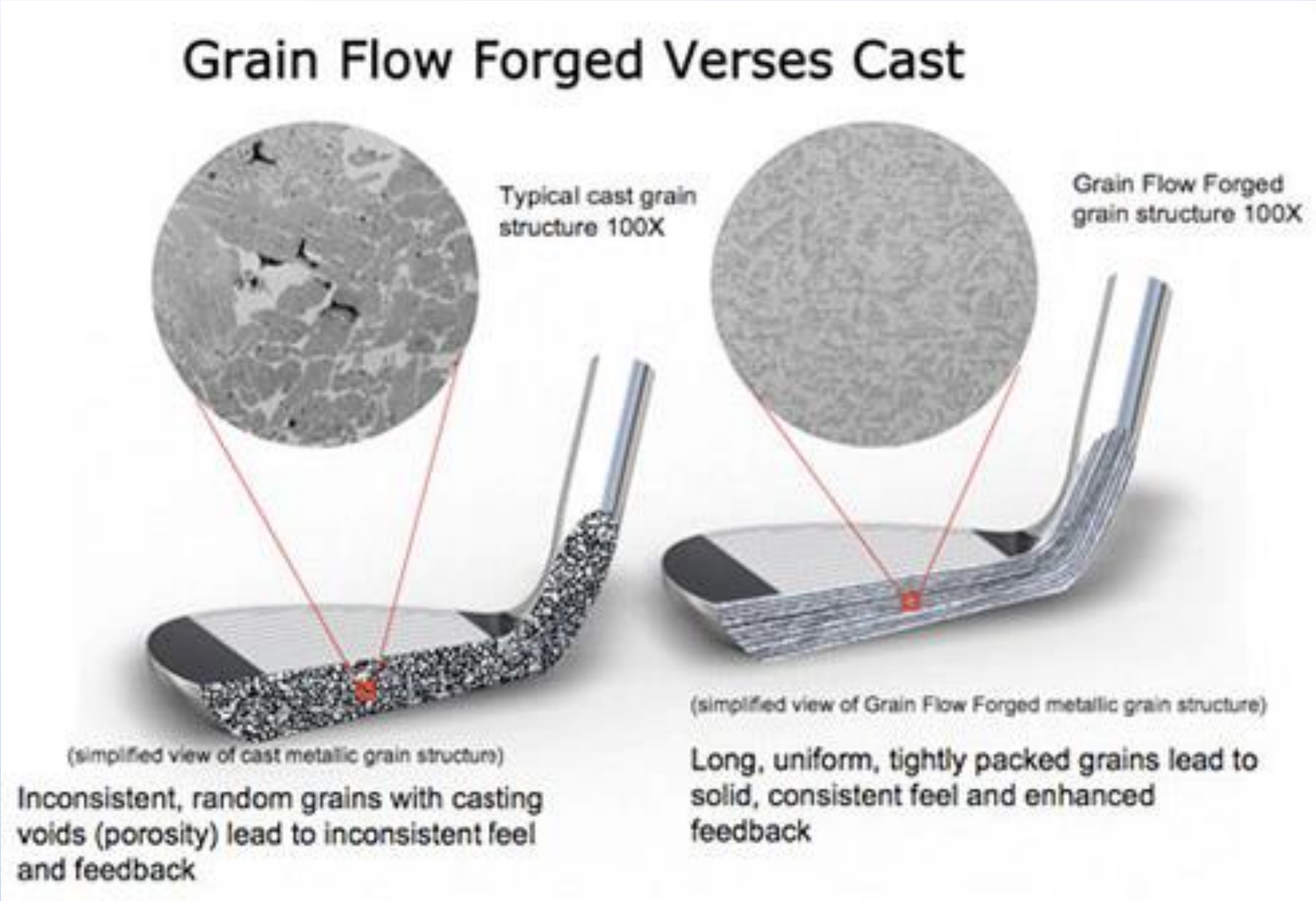
- Yield strength/flow strength
- Ductility
- Strain hardening

Metal Forming



How the open die forging process affects the crystal structure.

Casting versus forging



Hot versus cold working

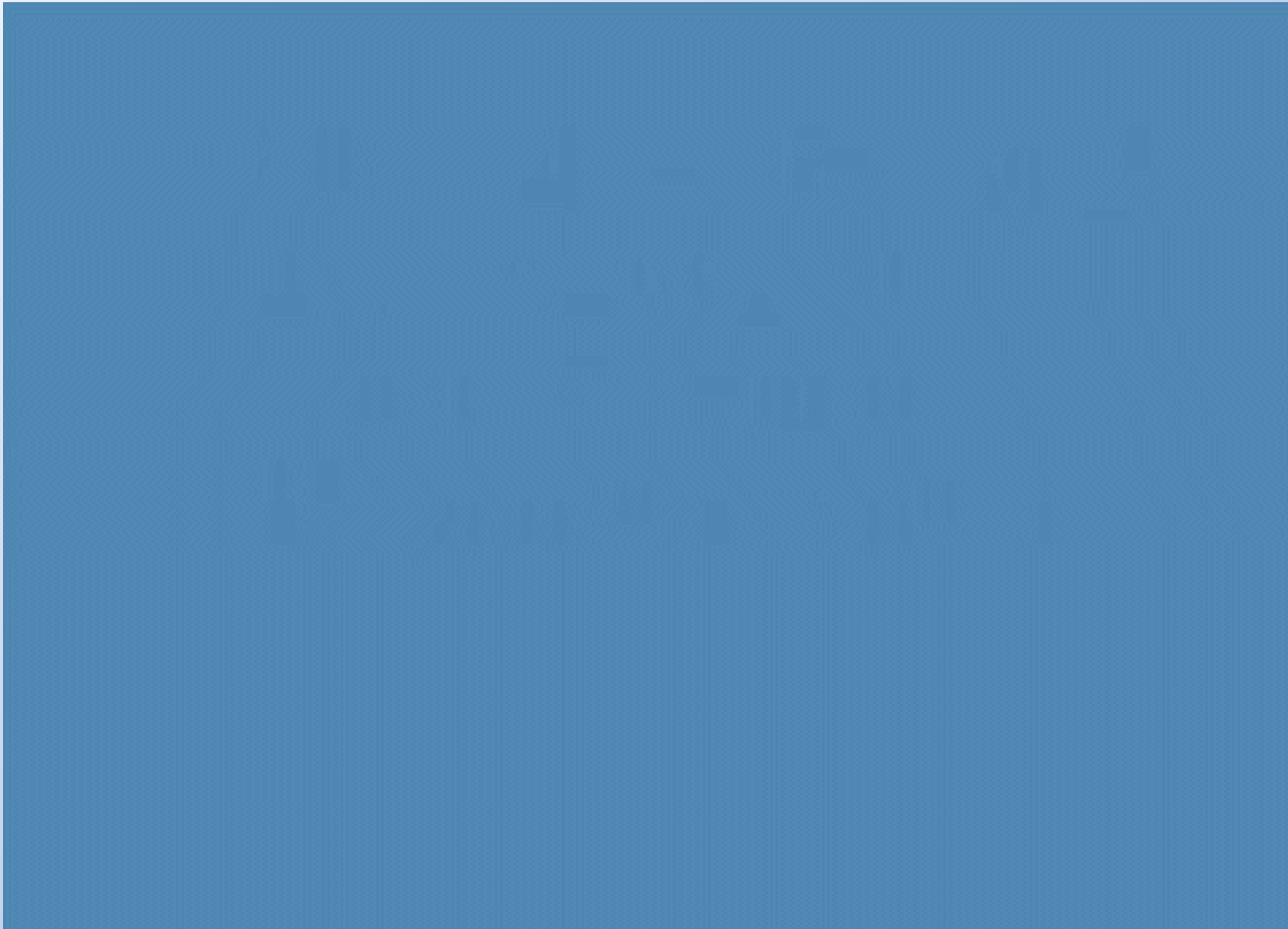
Hot working	Cold working
Working above recrystallization temperature	Working below recrystallization temperature
Formation of new grains	No new grains are formed
Surface finish is not good	Good surface finish
No stress formation	Internal stress develop
Improved mechanical properties such as elongation, impact strength	Strength increases with elongation decreases
Closed dimensional tolerance cannot be achieved	Superior dimension tolerance can be achieved
Scale formation	No scale formation
Low force is required	High force is required

Forging operation

- Drawing out: Metal get elongated with a reduction in the cross-sectional area. Force is applied perpendicular to length axis
- Upsetting: Increase cross-section area for making bolts
- Drop forging: Uses a closed die impression to obtain the desired shape of the component
  - Various stages involved in drop forging are fullering, edging, bending, blocking, finishing and trimming

Forging process

Different types of forging operation



Different methods for solution developed so far for solving metal forming problems

- Slab method: Problem is simplified by approximating the equilibrium equations
- Slip line method: Slip lines are direction of maximum shear stress
- Upper bound theorem
- Lower bound theorem
- Numerical techniques and FEM

Slipping versus sticking friction

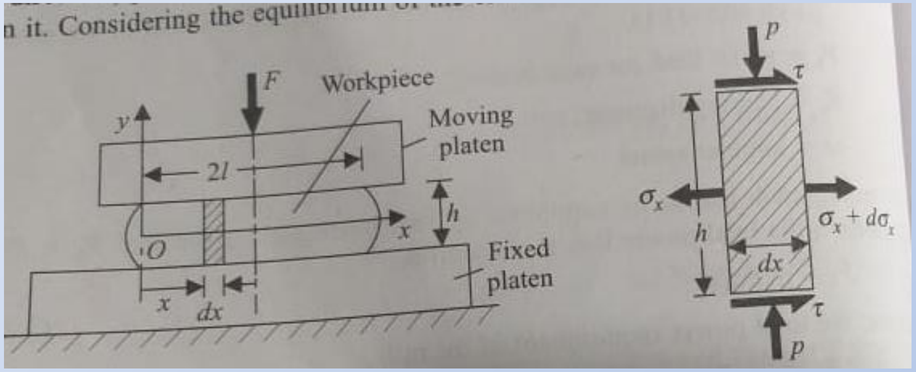
$\tau = \mu p \quad for\ p < K$; μ is COF

$\tau = mk \quad for\ p > K$; m is shear factor

Forging of strip

Assumption:

- Forging force attains its maximum value at the end
- COF between die and workpiece is constant
- Thickness of workpiece is small as compared with other dimensions
- Length of strip is higher than the width
- Elastic deformation is neglected



Details of forging operation   Stresses in element

$\tau = \mu p$

$\sigma_1, \sigma_2, \sigma_3$

$\sigma_x \quad -p$

$(\sigma_x + d\sigma_x)h \cdot b + 2\tau b\, dx - \sigma_x h b = 0$

$h\, d\sigma_x + 2\tau\, dx = 0 \rightarrow (1)$

Let $-p, \sigma_x$ are two principal stresses

Von-Mises yield criteria

$\varepsilon_2 = 0$

$= \frac{1}{E}\left(\sigma_2 - \nu(\sigma_1 + \sigma_3)\right)$

$\sigma_2 = \frac{1}{2}\sigma_1 + \sigma_3$

$\left[\sigma_x - \frac{1}{2}(\sigma_x - p)\right]^2 + \left[\frac{1}{2}(\sigma_x - p) + p\right]^2 + (-p - \sigma_x)^2 = 6K^2$

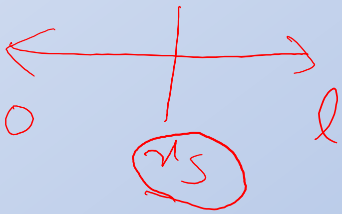
$\frac{1}{4}(\sigma_x + p)^2 + \frac{1}{4}(\sigma_x + p)^2 + (\sigma_x + p)^2 = 6K^2$

$\boxed{p + \sigma_x = 2K}$

$$d\sigma_x = -dP$$

Putting above in eqⁿ (1)

$$dP = \frac{2\tau}{h}\,dx$$



Case I Slipping condition $\tau = \mu P$ $\quad 0 \le x \le x_s$

$$\frac{dP}{P} = \frac{2\mu}{h}\,dx$$

Integrating above

$$\ln P + \frac{2\mu x}{h} + C_1$$

at $x = 0$, $\sigma_x = 0$, $P = 2K$ ($\because P + \sigma_x = 2K$)

$$C_1 = \ln 2K$$

$$\boxed{P = 2K\,e^{2\mu x/h}} \longrightarrow (2) \qquad 0 \le x \le x_s$$

$$\int dP = \int \frac{2K}{h}\,dx$$

$x_s \le x \le l$ $\quad x_s = ?$

$$P_1 = \frac{2Kx}{h} + C_2$$

If for $P = P_s$ at $x = x_s$

$$C_2 = P_s - \frac{2Kx_s}{h}$$

$$P - P_s = \frac{2K}{h}(x - x_s)$$

Using $P_s = 2K\,e^{2\mu x_s/h}$ for $x = x_s$

$$P = 2K\left[\exp\left(\frac{2\mu x_s}{h}\right) + \frac{1}{h}(x - x_s)\right] \rightarrow (3)$$

at $x = x_s$, $\tau = \mu P_s = K$

$$\mu 2K \exp(2\mu x_s/h) = K =$$

$$\frac{2\mu x_s}{h} = \ln\frac{1}{2\mu}$$

$$\boxed{x_s = \frac{h}{2\mu}\ln\left(\frac{1}{2\mu}\right)}$$

Putting value of $x_s = \frac{h}{2\mu} \ln \frac{1}{2a}$ in eqn (3)

$$P_2 = 2K\left[\frac{1}{2\mu}\left\{1 - \ln\left(\frac{1}{2\mu}\right)\right\} + \frac{x}{h}\right] \qquad x_s \le x \le l$$

$$\boxed{F = 2\left[\int_0^{x_s} P_1\,dx + \int_{x_s}^{l} P_2\,dx\right]\phi}$$

- A strip of lead with initial dimensions 24 mm*24 mm*150 mm is forged between two flat dies to a final size of 6 mm* 96 mm* 150 mm, if the coefficient of friction between job and the dies is 0.25, determine the maximum forging force. The average yield stress of lead in tension is 7 N/mm^2 ?

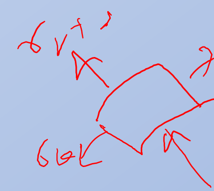
$\mu = 0.08$

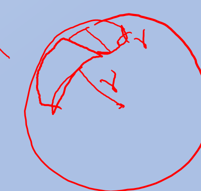
- Solve above example when coefficient of friction is 0.08. 8.3 mm

Soln $x_s = \frac{h}{2\mu}\ln\frac{1}{2\mu} = \frac{6}{2\times 0.25}\ln\frac{1}{2\times 0.25}$

length $\cancel{b} = 96\,mm = 2l \Rightarrow l = 48\,mm$

$K = \frac{\sigma_y}{\sqrt{3}} = 4.04\ N/mm^2$





$F = 2\left[\int_0^{8.3} p_1\,dx + \int_{8.3}^{48} p_2\,dx\right]$

$p_1 = 2K e^{2\mu x/h} = 2\times 4.04\, e^{\frac{2\times 0.25\times x}{6}}$

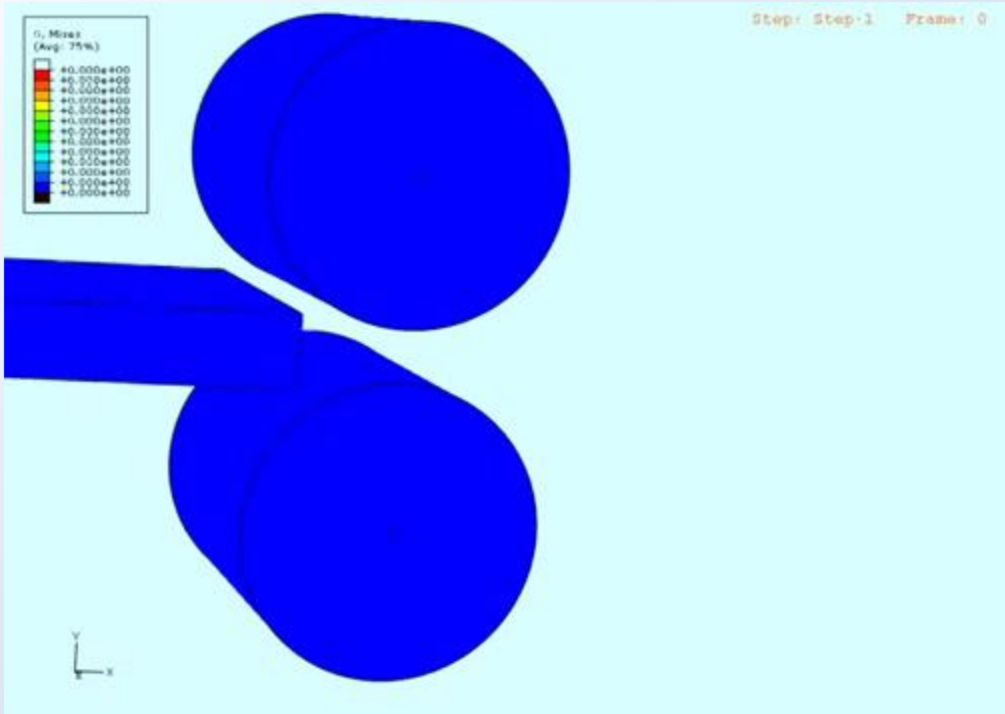
$= 8.08\, e^{0.083x}$

$p_2 = 8.08(0.614 + 0.167x)$ dx

$\boxed{F = 3602.5\ N/mm}$

Self study → Derivation for circular disc

Rolling

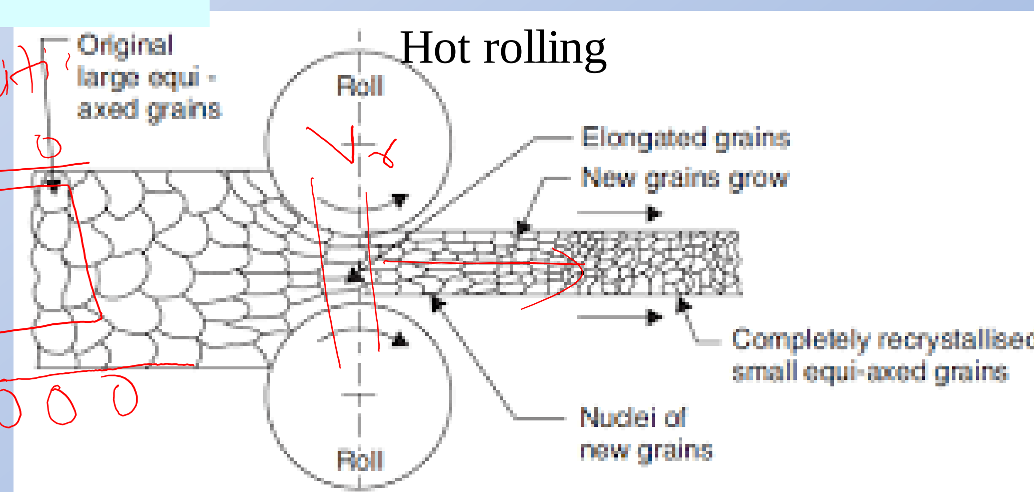


$V_s < V_r \rightarrow$ Entry condition

Neutral plane $V_s = V_r$

$V_s > V_r$

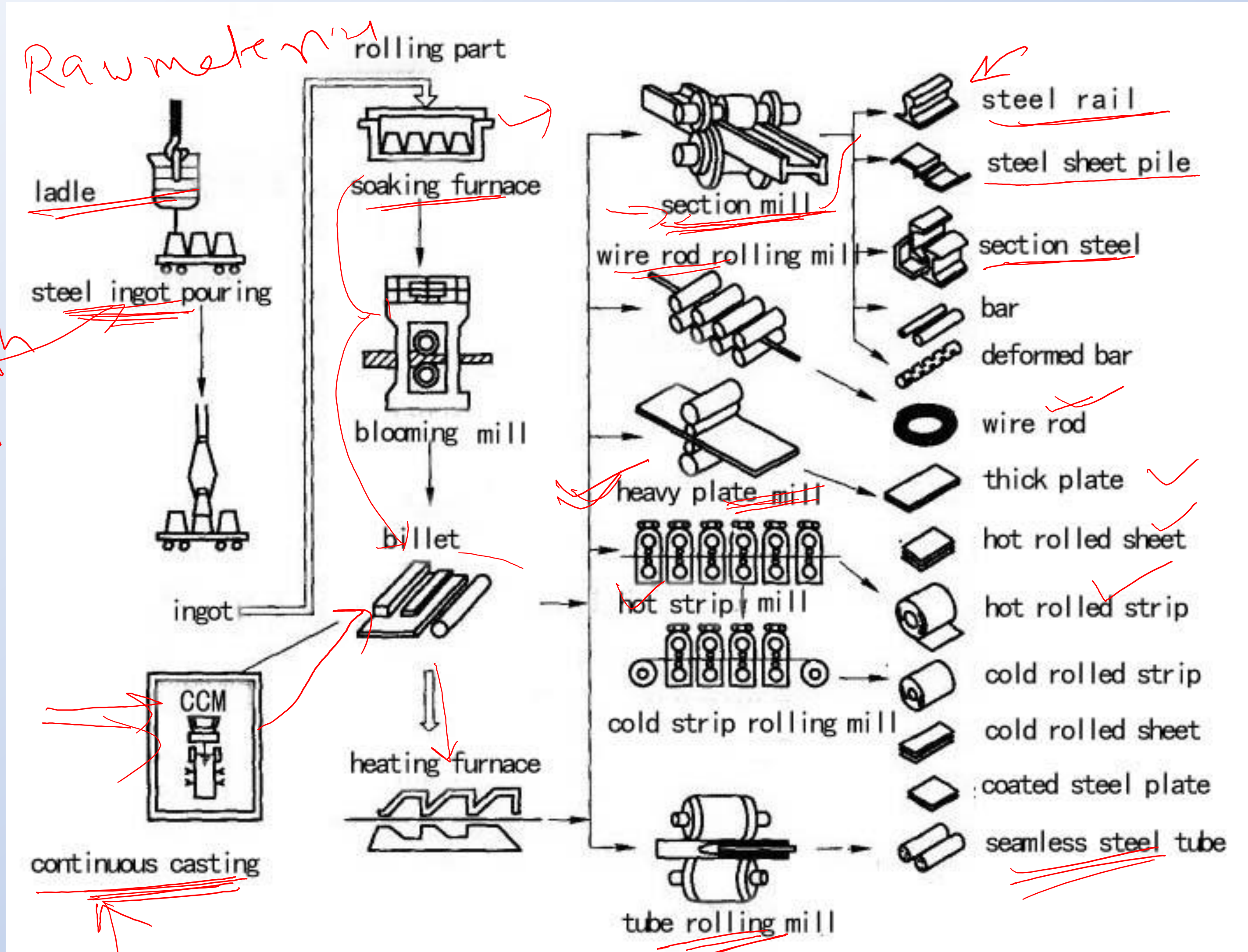
V_s



- To produce components having uniform cross-section throughout its length such as I, T, channel section.
- Metal is taken into the rollers due to friction

Raw material

through Casting



Thread rolling

Schematic of industrial production setup

SMS, Plate mill

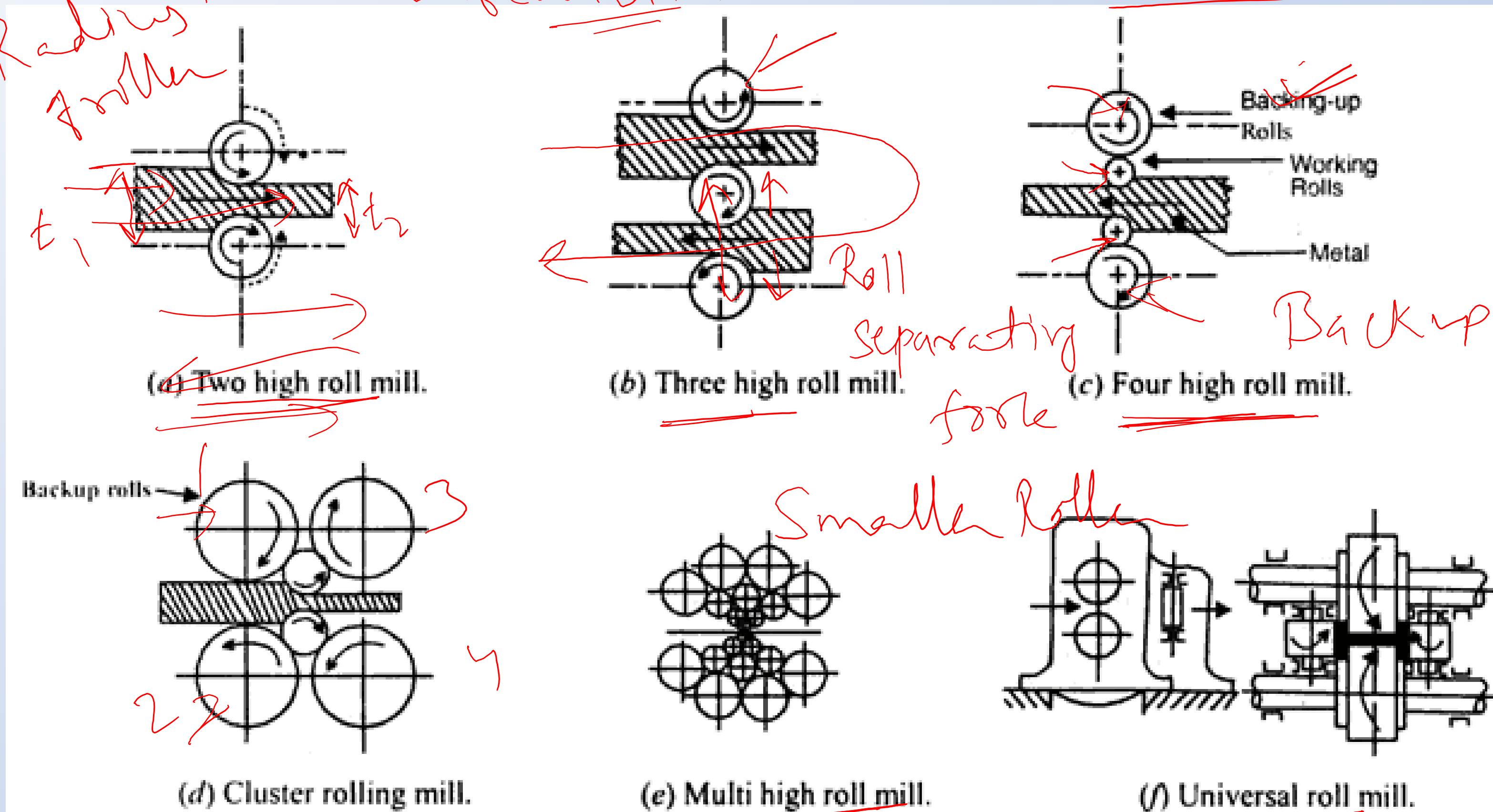
Types of rolling mill

$\Delta t = t_1 - t_2$

$t_1 - t_2$ = draft or reduction

elastic deformation

∝ Radius of roller



(a) Two high roll mill. (b) Three high roll mill. (c) Four high roll mill.

(d) Cluster rolling mill. (e) Multi high roll mill. (f) Universal roll mill.

20 mm → 3 mm

- 4 high roll mill is predominantly used for rolling of thin strip where due to elastic deformation further reduction is difficult

2.5 mm final req.

Roughing mill d_1 d_2 d_3 d_4

Hot rolling mill

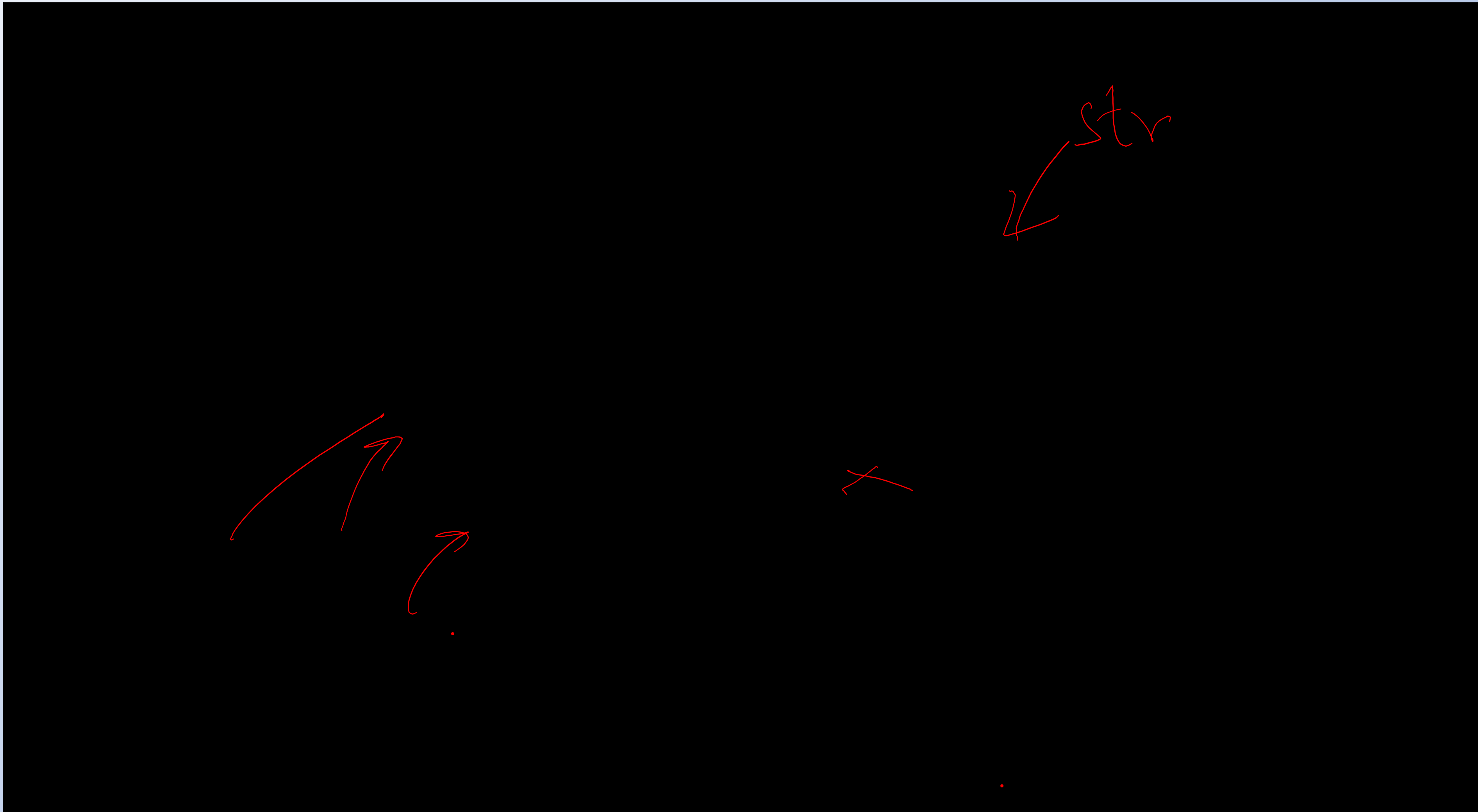
Quenching → Oil Cooling →

Cooling

Water Cooling

Air Cooling | Furnace

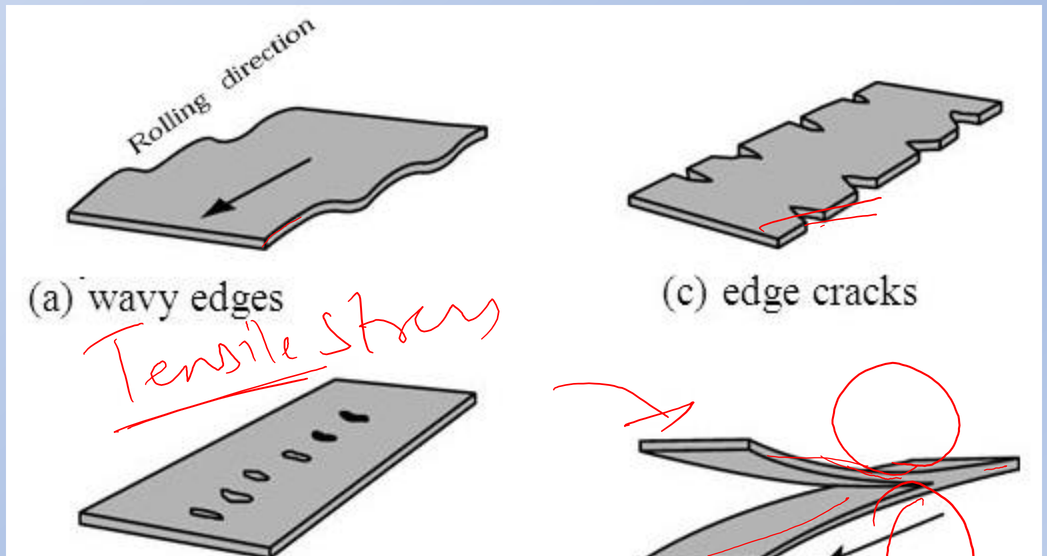
Manufacturing of seamless tubes



Rolling: defects

- Structural defect: Deflection of roller due to uneven loading.
  - Solution: Provide camber
- Wavy edges: due to elastic deflection of the rolls
- Zipper cracks: Due to bending of the rolls under pressure similar to wavy edge. Seen at center due to tensile stress
- Alligatoring: Splitting of the material into two
- Edge crack: Non-homogenous plastic deformation

Self study: other types of rolling, rolling mills and defects



(a) wavy edges

(c) edge cracks

(b) zipper cracks in the center of the flat rolling

(d) alligatoring

Effect of friction on rolling

$\mu \geq \tan\theta$ ①

$\frac{t_f - t_i}{2} = R - R\cos\theta$

$= R(1-\cos\theta)$

for smaller 'θ'

$\theta = \sqrt{\frac{t_f - t_i}{R}}$

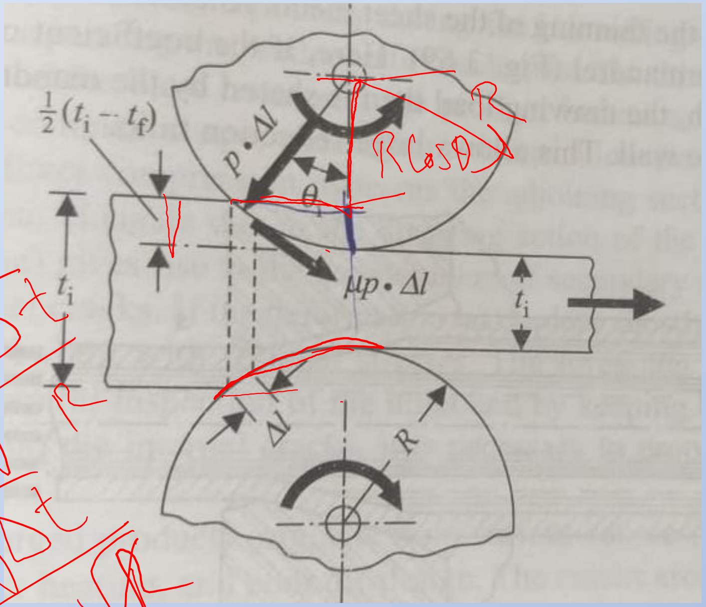
$\frac{l}{R}$

$l = \sqrt{R\Delta t}$

② $\boxed{\mu^2 R = \Delta t_{max}}$

③ Length of Contact $\simeq \sqrt{R\Delta t}$

$L \propto \sqrt{R}$



Role of friction on rolling

4 → 16 mm

2 ← 4 mm

$\mu \geq \tan\theta$

$\mu = \tan\theta$

Smaller θ

$\mu = \theta$

Mechanics of rolling

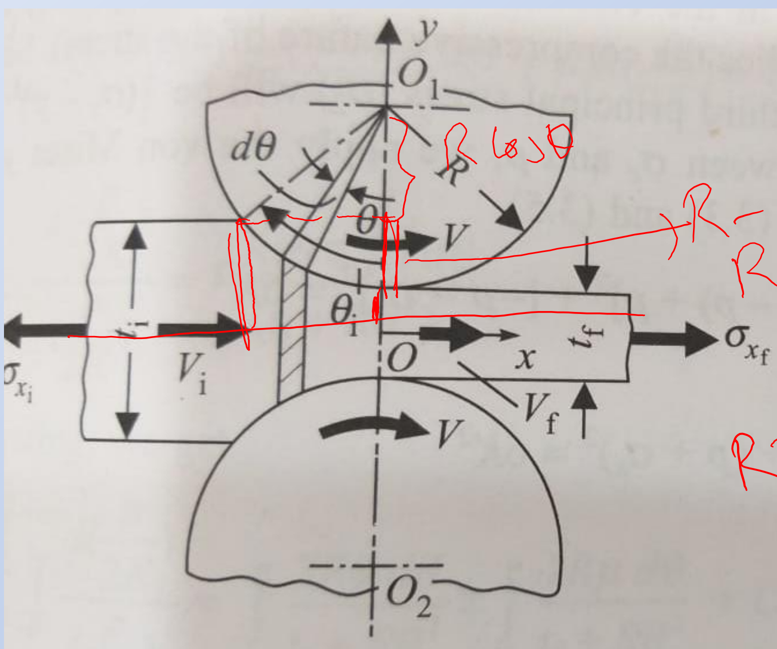
Objective

- Roll separating force
- Torque and power requirement

Assumption

- Rollers are straight and rigid cylinder
- Width of strip is much larger than its thickness and no significant widening takes place i.e. It’s a plain strain problem
- μ is constant and uniform

y



Details of rolling operation

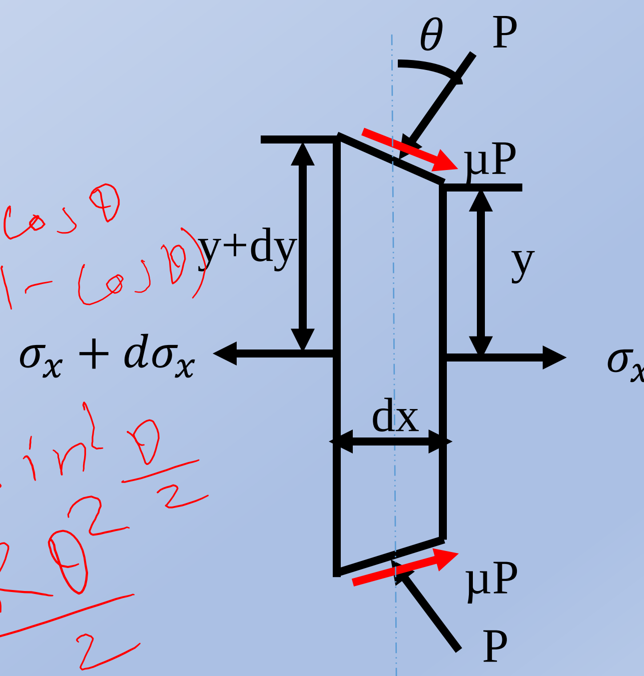
$R\cos\theta$

$R - R\cos\theta$

$R(1-\cos\theta)$

$R\,2\sin^2\frac{\theta}{2}$

$\frac{R\theta^2}{2}$



Stresses on element

for smaller θ

$$\cancel{2}(\sigma_x + d\sigma_x)(y + dy) + \cancel{2}PR\theta\, d\theta - \cancel{2}\sigma_x y - \cancel{2}\mu PR\, d\theta = 0$$

$$= \cancel{2}y\, d\sigma_x + \cancel{2}\sigma_x\, dy - \cancel{2}R\mu P\, d\theta + \cancel{2}RP\theta\, d\theta = 0$$

$$= \frac{d(y\sigma_x)}{\cancel{d\theta}} - RP(\mu - \theta)\frac{\cancel{d\theta}}{d\theta} = 0 \rightarrow (1)$$

=

Let σ_x & $-P$ be principal stresses

$\sigma_x \rightarrow \sigma_1$, $-P \rightarrow \sigma_3$

& $\sigma_2 = \frac{1}{2}(\sigma_x - P)$

$P + \sigma_x = 2K$

or $\sigma_x = 2K - P$

$$\frac{d}{\cancel{d\theta}}\left((2K-P)y\right) - (\pm\mu - \theta)\, d\theta = 0$$

→ Considering the forbe neutr

$Ky = C$ { K = shear yield stress → increases ; y = thickness → decreasing } → strain hardening

−ve → after neutr

$$2Ky\frac{d}{d\theta}\left(1-\frac{p}{2K}\right)+(\theta\mp\mu)Rp=0$$

$$x=R(1-\cos\theta)$$

for small θ

$$y=\frac{t_f}{2}+\frac{R\theta^2}{2}$$

$$x=\frac{R\theta^2}{2}$$

$$y=\frac{t_f}{2}+\frac{R\theta^2}{2}$$

$$-(t_f+R\theta^2)\frac{d}{d\theta}\left(\frac{p}{2K}\right)+2(\theta\mp\mu)R\left(\frac{p}{2K}\right)d\theta=0$$

or

$$\int\frac{d(p/2K)}{p/2K}=\int\frac{2R(\theta\mp\mu)\,d\theta}{(t_f+R\theta^2)}$$

$$\ln(p/2K)=\ln(t_f+R\theta^2)\mp 2\mu\underbrace{\sqrt{\frac{R}{t_f}}\tan^{-1}\sqrt{\frac{R}{t_f}}\,\theta}+\ln\frac{C}{2R}$$

$$\lambda=2\sqrt{\frac{R}{t_f}}\tan^{-1}\left(\sqrt{\frac{R}{t_f}}\,\theta\right)$$

or

$$\frac{p}{2K}=C\frac{y}{R}e^{\mp\mu\lambda} \rightarrow (3)$$

$$\underbrace{P + \sigma_u = 2K}_{\text{at the beginning}} = \frac{P_i}{2K} = 1 - \frac{\sigma_{x_i}}{2K}$$

$\bar{C}$ = Constant before n.p

C^{+} = Constant after N.P

Putting this in eqn ③

$$\frac{P_i}{2K} = 1 - \frac{\sigma_{x_i}}{2K} = \bar{C}\,\frac{t_i}{2R}\,e^{-\mu\lambda_i}$$

$$\bar{C} = \frac{2R}{t_i}\left(1 - \frac{\sigma_{x_i}}{2K}\right) e^{+\mu\lambda_i}$$

After neutral plane $\frac{P}{2K} = C^{+}\frac{y}{R}\,e^{\mu\lambda}$

$$\frac{P_f}{2K} = 1 - \frac{\sigma_{x_f}}{2K} = C^{+}\frac{t_f}{2R}\,e^{\mu\lambda}$$

$$C^{+} = \frac{2R}{t_f}\left(1 - \frac{\sigma_{x_f}}{2K}\right)$$

Putting $\bar{c}$ & c^T in eqn (3)

$$\left(\frac{p}{2k}\right)_{before} = \frac{2y}{t_i}\left(1 - \frac{\sigma_{x_i}}{2k}\right) e^{\mu(\lambda - \lambda_i)} \rightarrow (4)$$

$$\left(\frac{p}{2k}\right)_{after} = \frac{2y}{t_f}\left(1 - \frac{\sigma_{x_f}}{2k}\right) e^{\mu\lambda} \rightarrow (5)$$

Location of neutral plane :: eqn (4) & eqn (5)

$$\lambda_n = \frac{1}{2}\left[\frac{1}{\mu}\ln\left\{\frac{t_f}{t_i}\left(\frac{(1-\sigma_{x_i}/2k)}{1-\frac{\sigma_{x_f}}{2k}}\right)\right\} + \lambda_i\right]$$

$$\lambda = 2\sqrt{\frac{R}{t_f}}\tan^{-1}\left(\sqrt{\frac{R}{t_f}}\,\theta\right)$$

Step 1 - take small element

2 → F.B.D of element

3 → Consider principal stresses
Use relationship between
p, δ & n

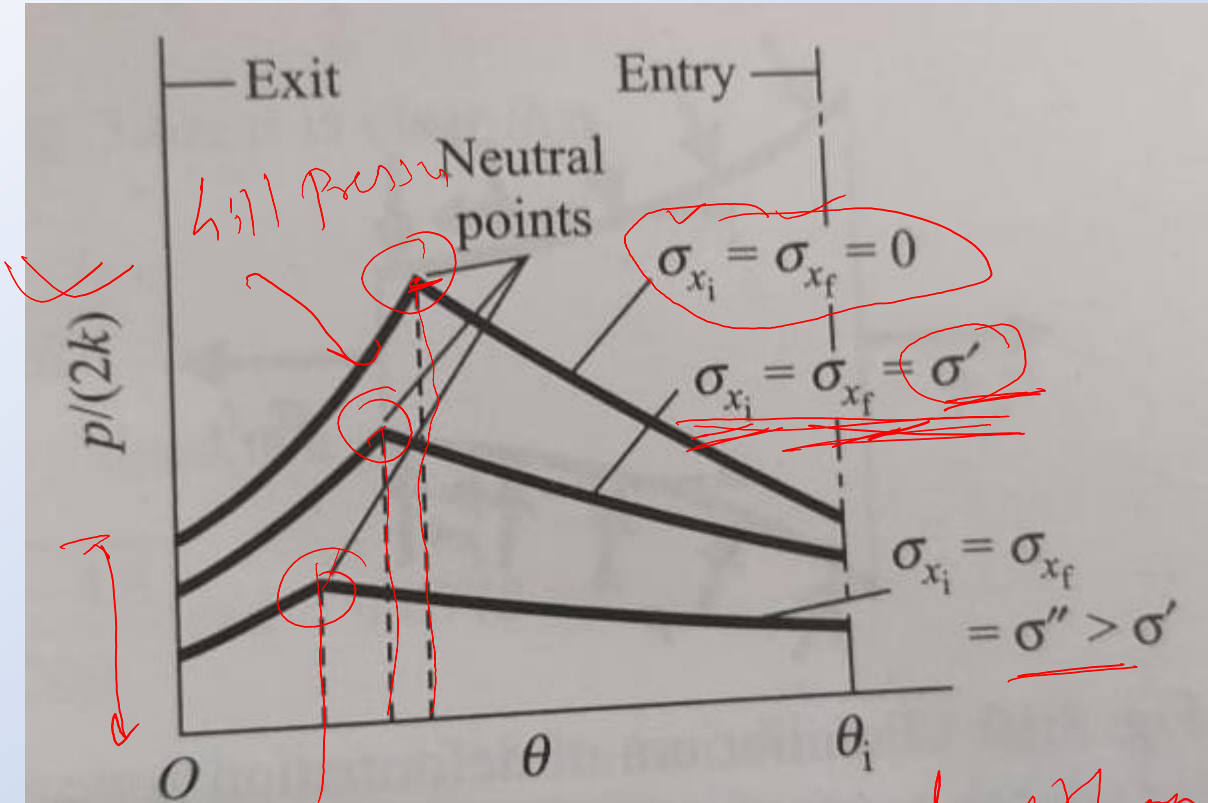
4 → Integration

5 → finding value of constant
Using Boundary terms

6 → Putting the constant value
back to equation

$$F = \int_0^{\theta_i} pR\cos\theta \, d\theta = \int_0^{\theta_n} P_{after}\, R\, d\theta + \int_{\theta_n}^{\theta_i} P_{before}\, R\, d\theta$$

Roll separating force



$\sigma_{x_i} < k$

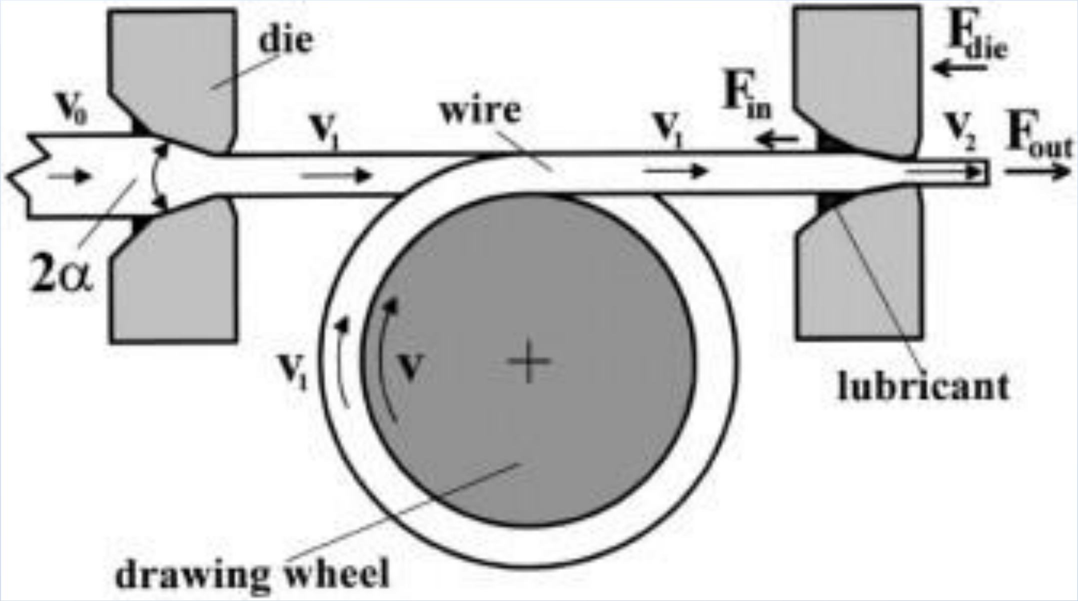
less than k

Pressure distribution during rolling

$$\text{Before} = \frac{2y}{t_i}\left(1 - \frac{\sigma_{x_i}}{2k}\right) e^{\mu(\lambda - \lambda_i)}$$

$$\text{After} = \frac{2y}{t_f}\left(1 - \frac{\sigma_{x_f}}{2k}\right) e^{\mu\lambda}$$

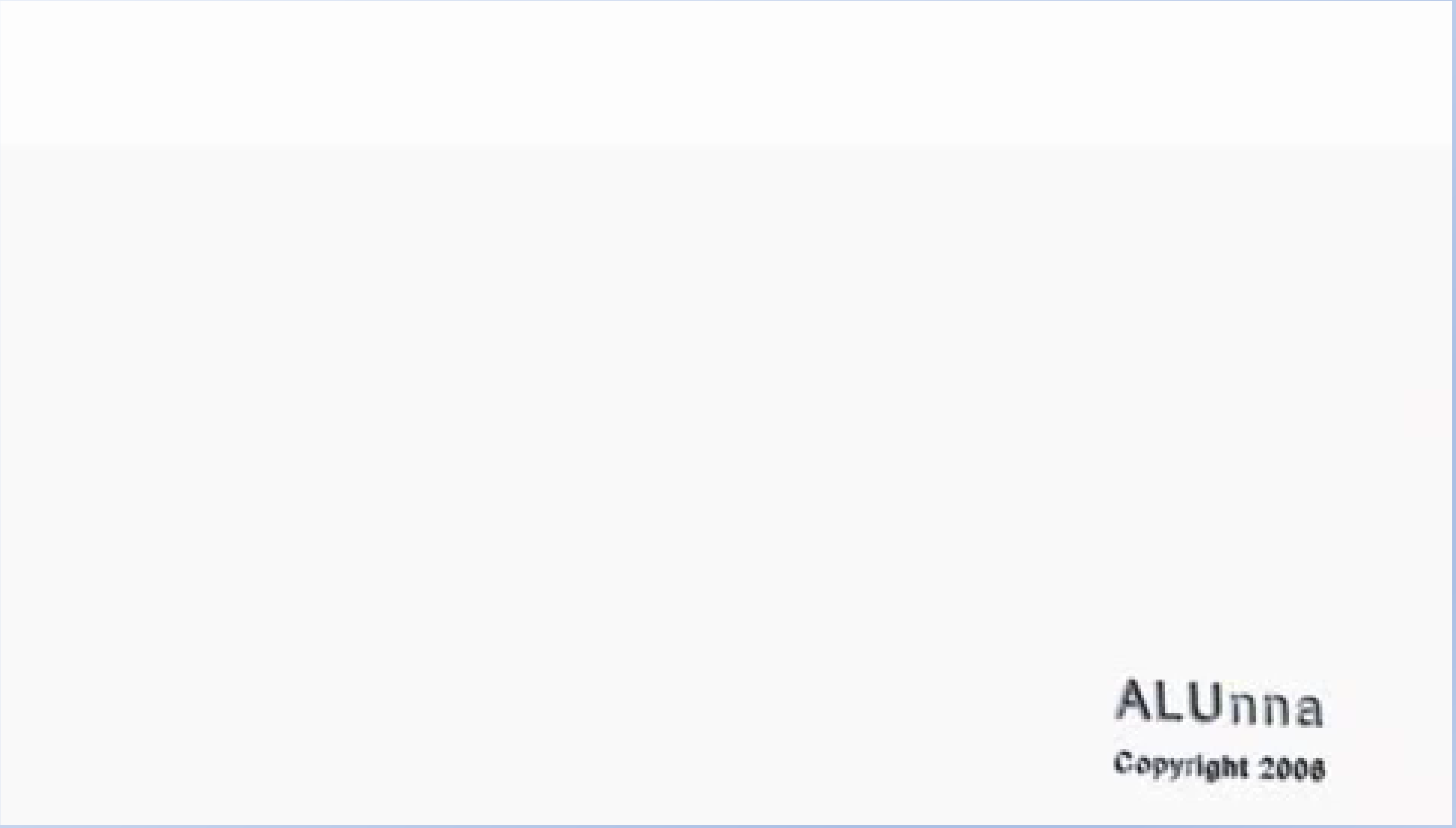
Wire drawing



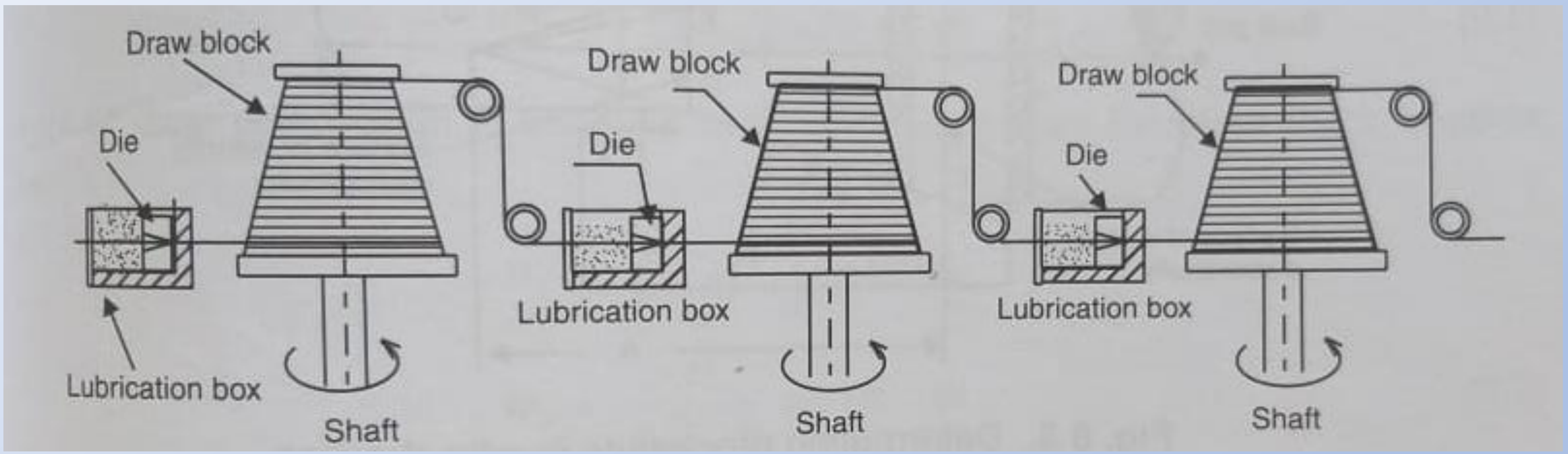
- A wire is circular with small diameters so that it is flexible
- It is always a cold working process
- Material should have sufficient ductility to withstand tensile stress
- Die material is made of hard material, tungsten carbide, ceramic and even diamond
- Dry drawing: when solid lubricants (such as graphite, mixture of soap powder, mixture of solid fat and lime) is used
- Wet drawing: liquid lubricant such as soap solution with 3% oil

Actual setup of wire drawing

Animation of Wire drawing process



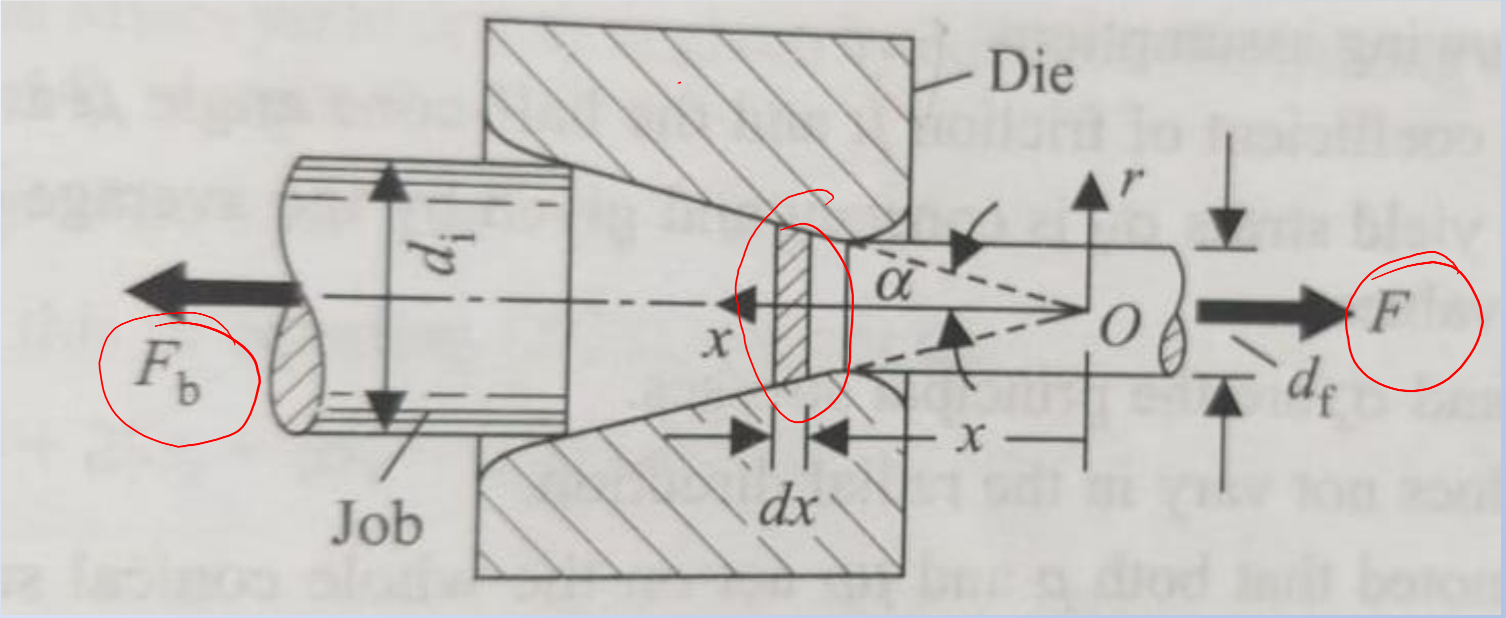
Schematic of wire drawing setup

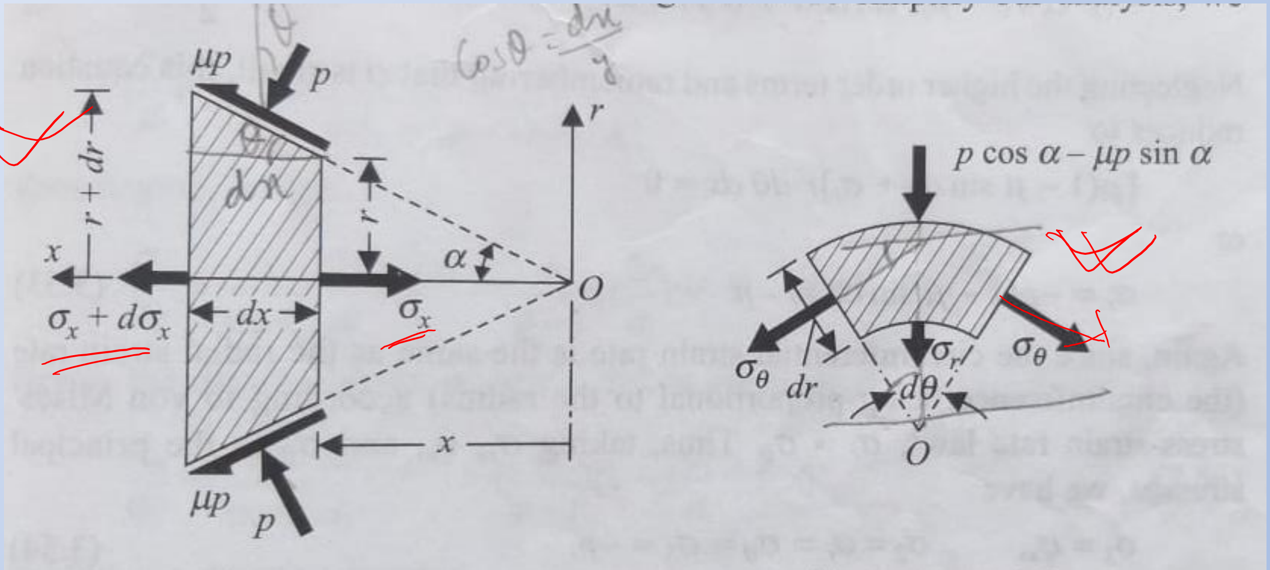


Drawing ratio = D = $(A_i - A_f)/A_i$

True strain = $\ln (A_i/A_f) = \ln(1/1\text{-}D)$

FBD of wire drawing





(a) Complete element

(b) Segment of element

FBD at element level

Self study Derivation of to calculate F?

$$\frac{\sigma_{x_f}}{\sigma_Y} = \frac{F_b}{\sigma_Y A_i}\left(\frac{d_f}{d_i}\right)^{2(\phi-1)} + \left(\frac{\phi}{\phi-1}\right)\left[1 - \left(\frac{d_f}{d_i}\right)^{2(\phi-1)}\right].$$

Finally, the drawing force is

$$F = \sigma_{x_f} A_f,$$

$$\frac{\sigma_{x_f}}{\sigma_Y} = 1.$$

Using this in equation (3.56), the relation we obtain is

$$D_{max} = 1 - \frac{1}{\left[\phi - \frac{F_b(\phi-1)}{\sigma_Y A_i}\right]^{1/(\phi-1)}}.$$

- A steel wire is drawn from an initial diameter of 12.7 mm to a final diameter of 10.2 mm at a speed of 90 m/min. The half cone angle of the die is 6° and the coefficient of at the job-die interface is 0.1. A tensile test on the original steel specimens gives a tensile yield stress 207 N/mm². A similar specimens shows a tensile yield stress of 414 N/mm2 at a strain of 0.5. Assuming a linear relationship for the material determine the drawing power and the maximum possible reduction with the same die. No back tension is applied

Strain hardening

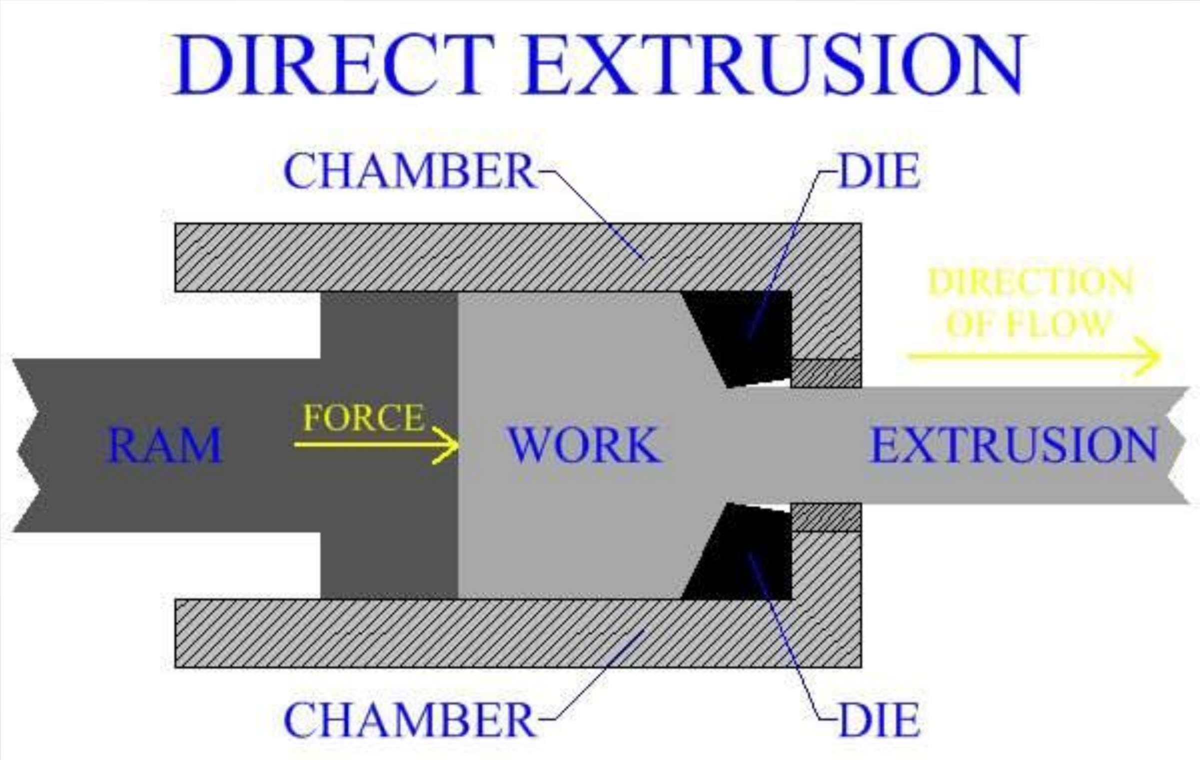
$d_i = 12.7\,mm$

$d_f = 10.2$

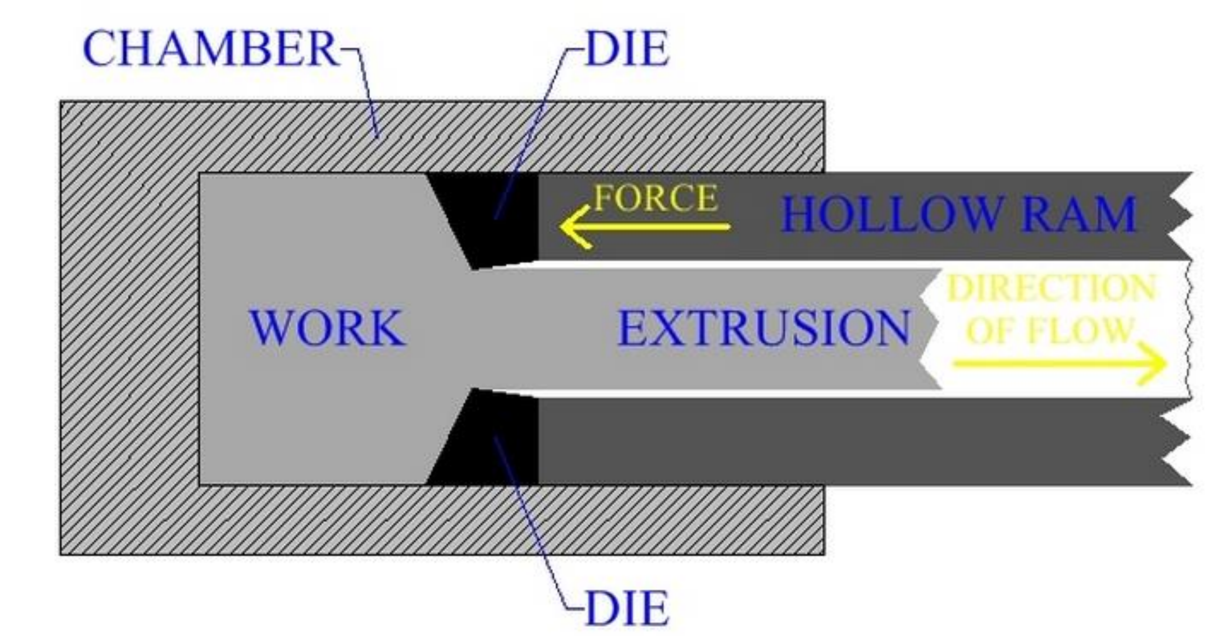
$P = F \times V$

$\sigma_{xf} \times A_f$

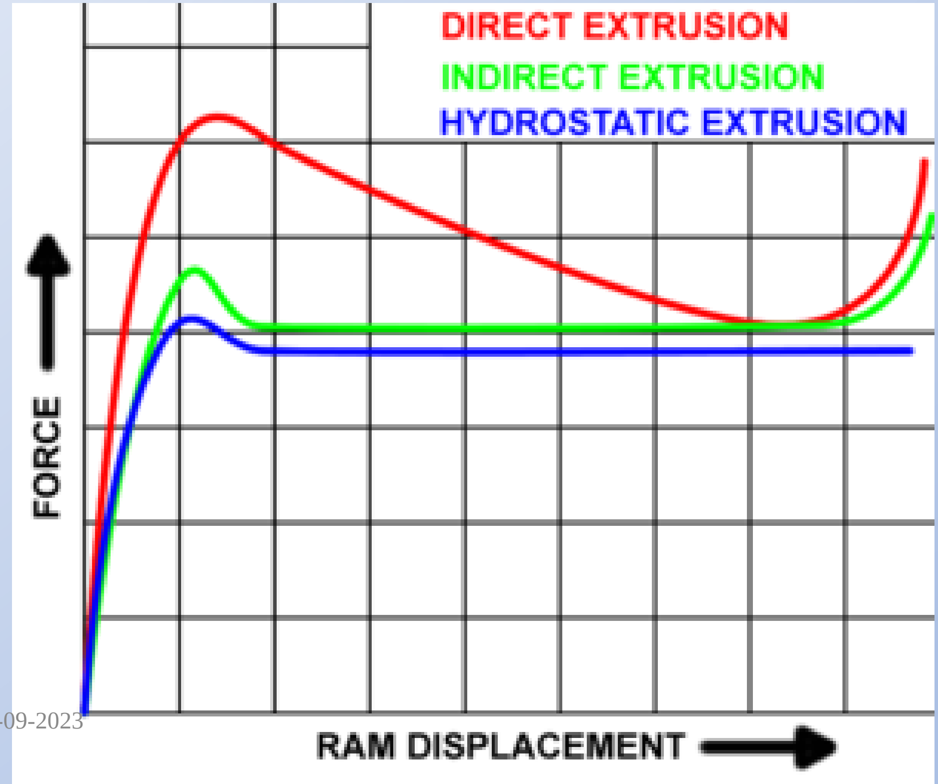
Extrusion



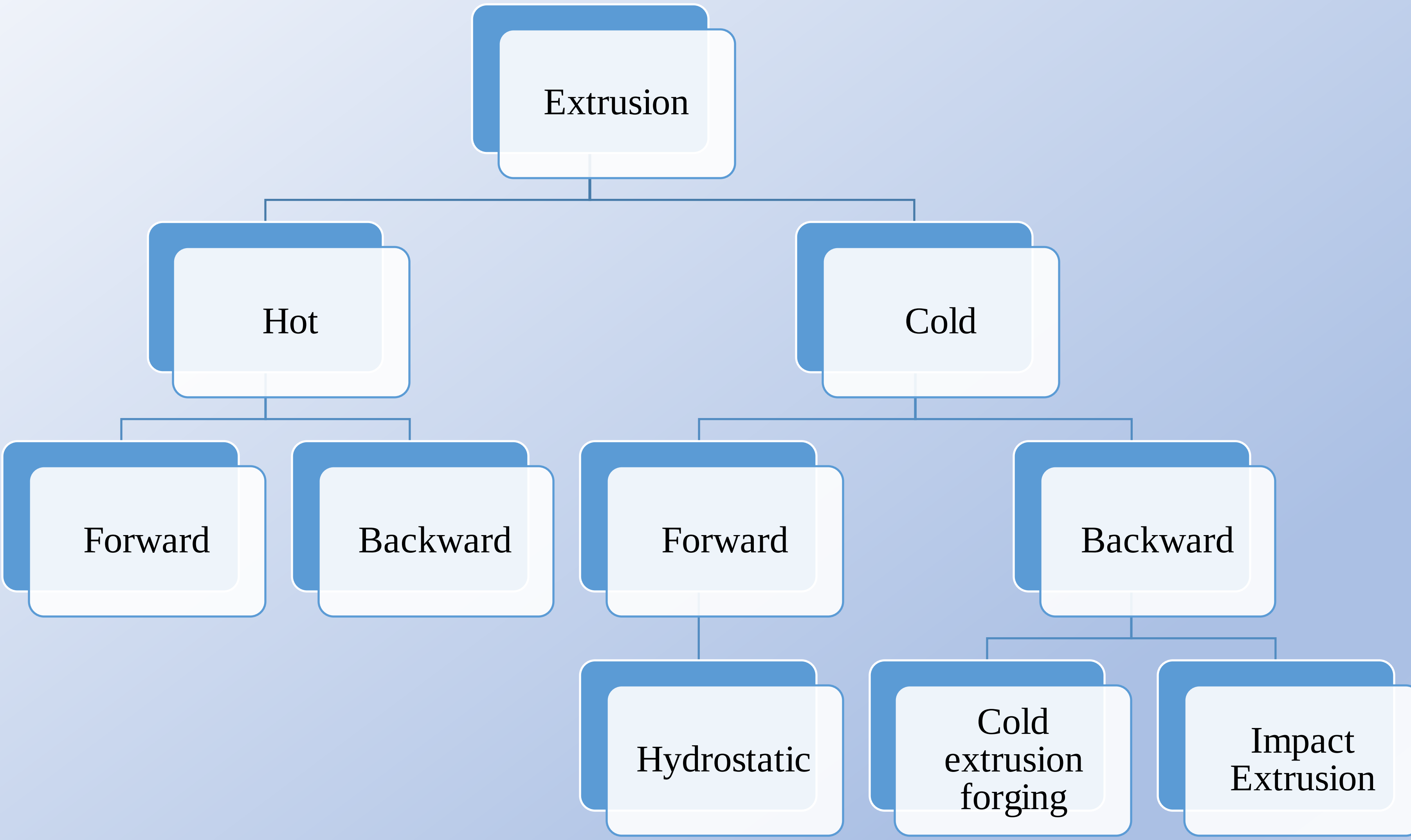
- Possible to manufacture components have a constant cross-section over any length
- Extrusion ratio: Ratio of cross-section area of billet to the extruded product



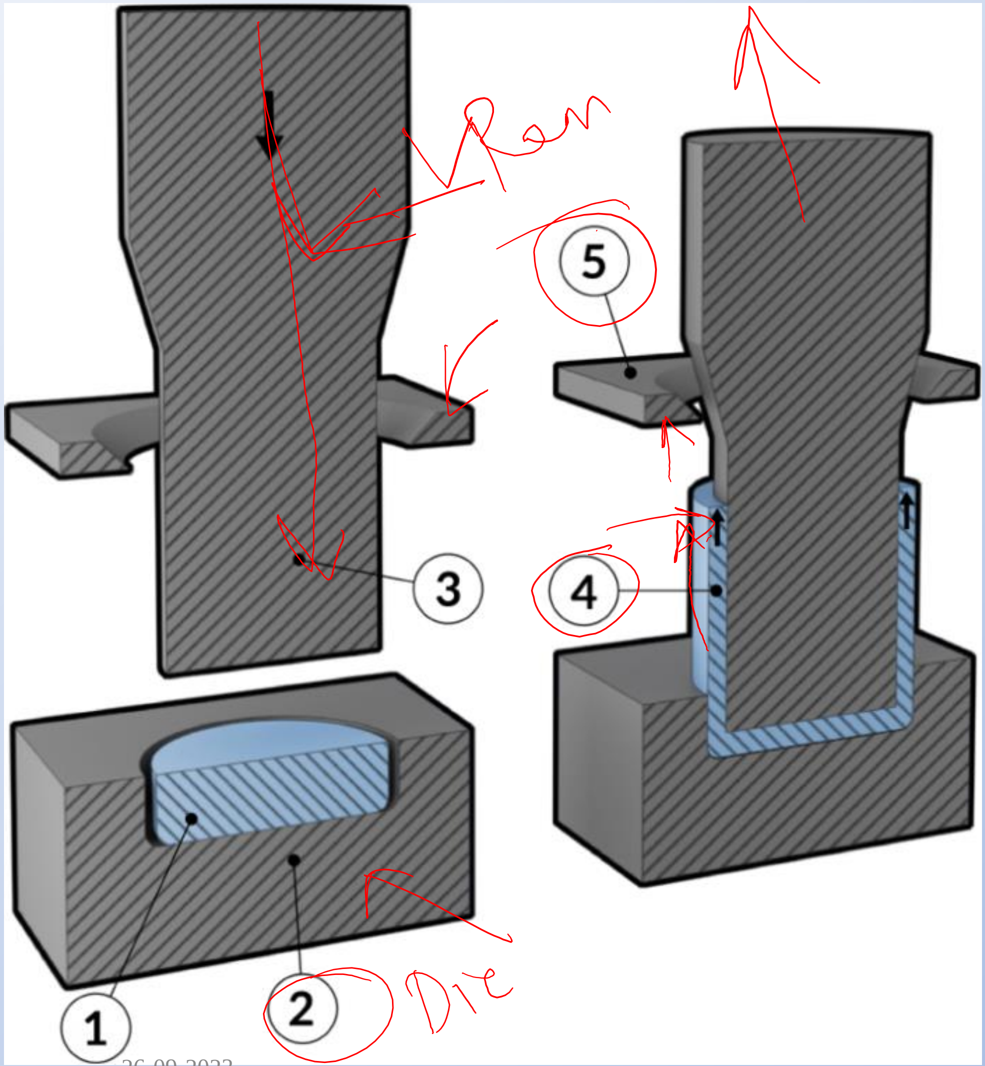
Backward Extrusion



Products made through Extrusion process


Extrusion
Hot
Cold
Forward
Backward
Forward
Backward
Hydrostatic
Cold extrusion forging
Impact Extrusion

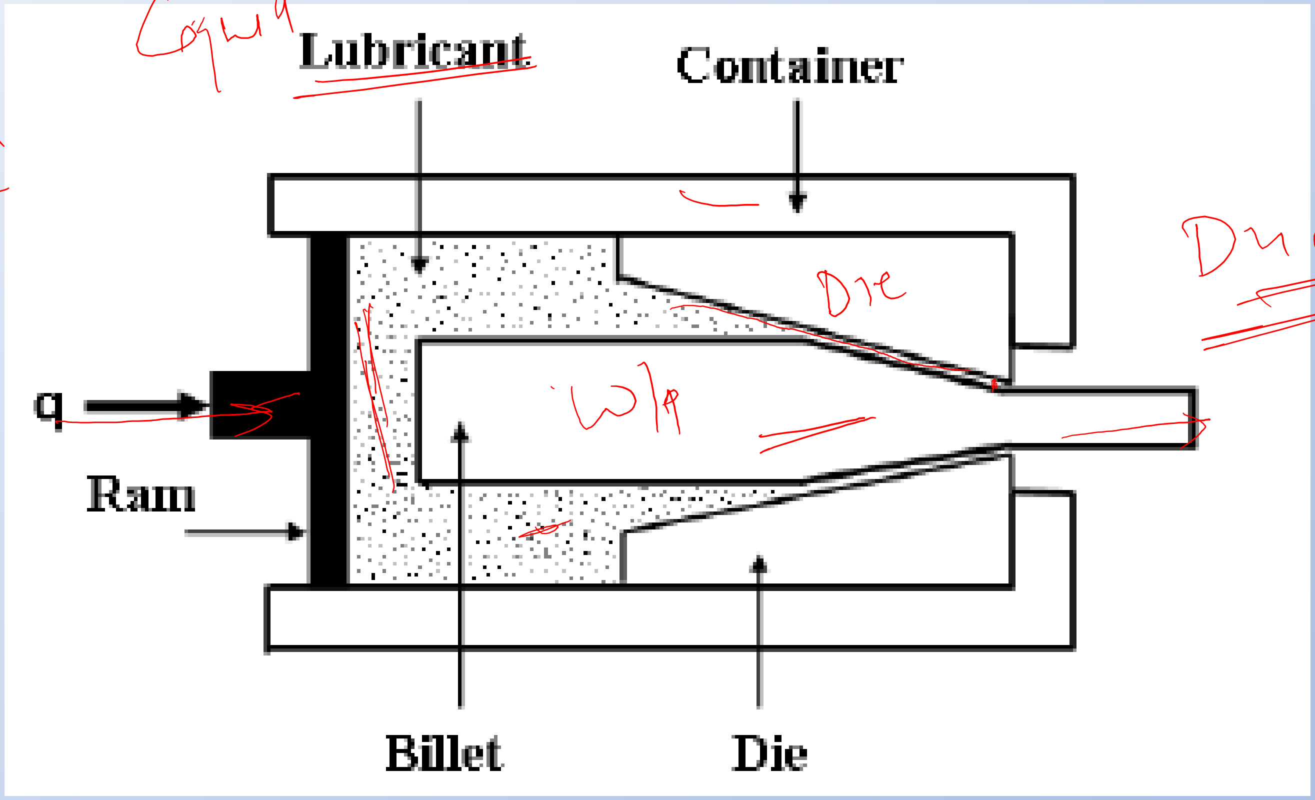
Impact extrusion



- Mostly used for softer material such as Al
- Collapsible tubes for housing pastes, cosmetic packaging

Hydrostatic extrusion

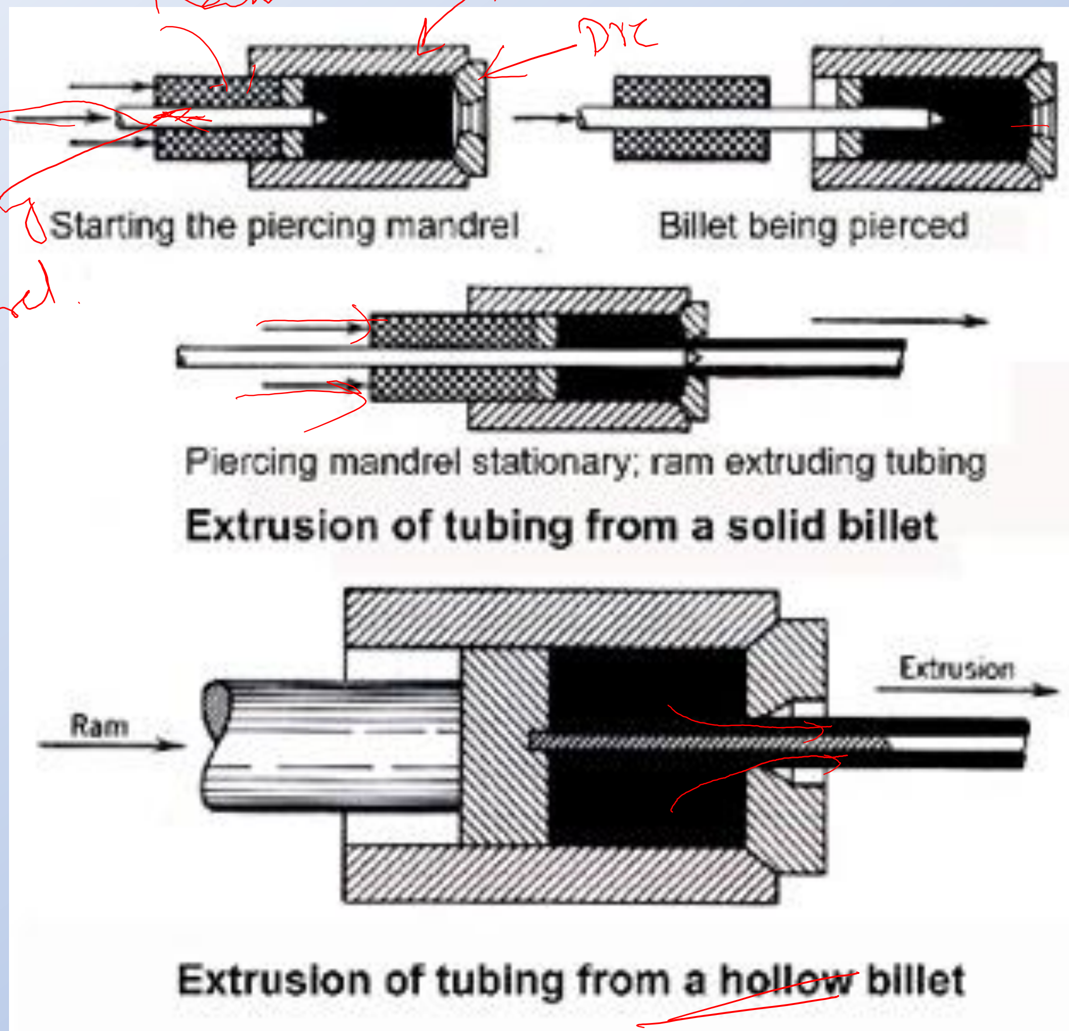
Frictional force



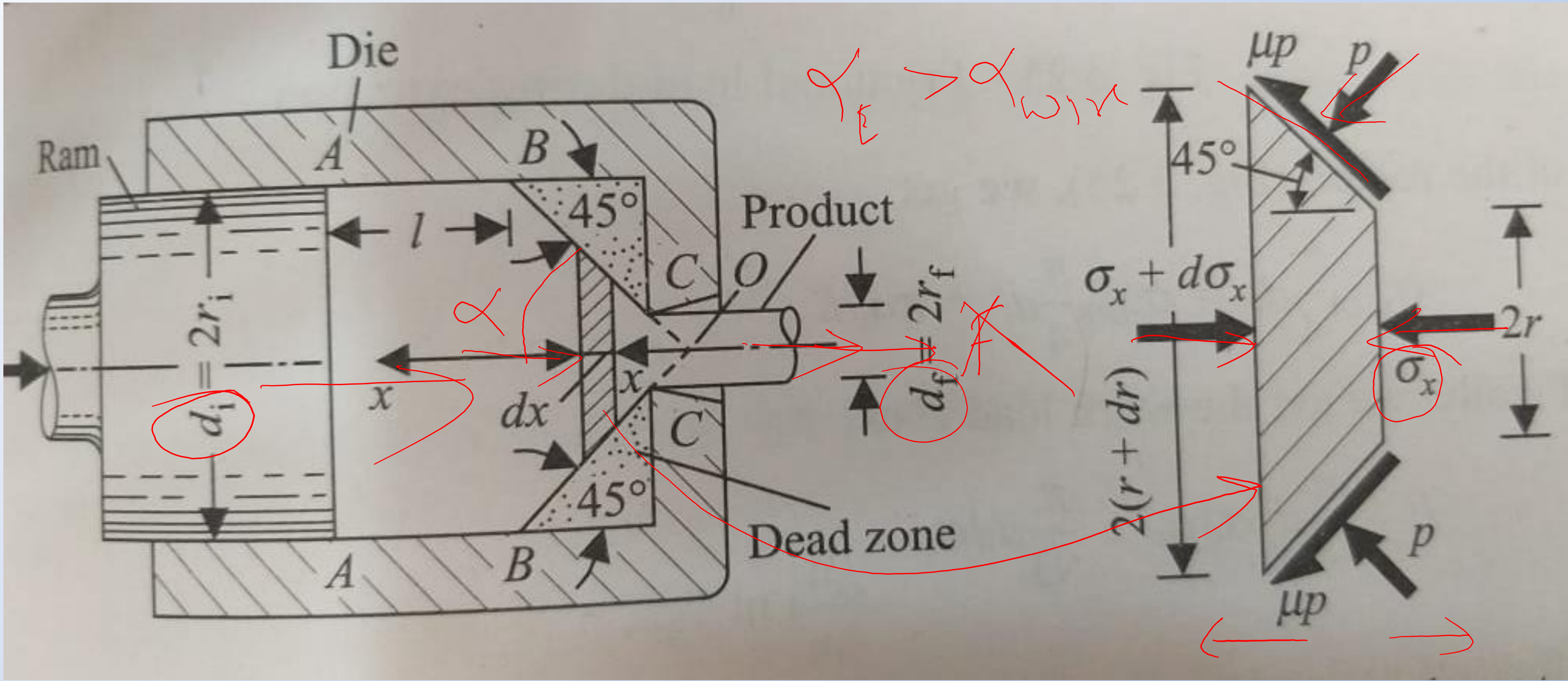
Ductility

- Brittle material can be extruded
- Lubricant: Castor oil with 10% alcohol, glycerine, ethyl glycol
- Application: reactor fuel rods, cladding of metals, and making wires of less ductile material

Extruding tubes



Extruding tube



Details of extrusion process

Stresses on the element

Self: Derivation of workload

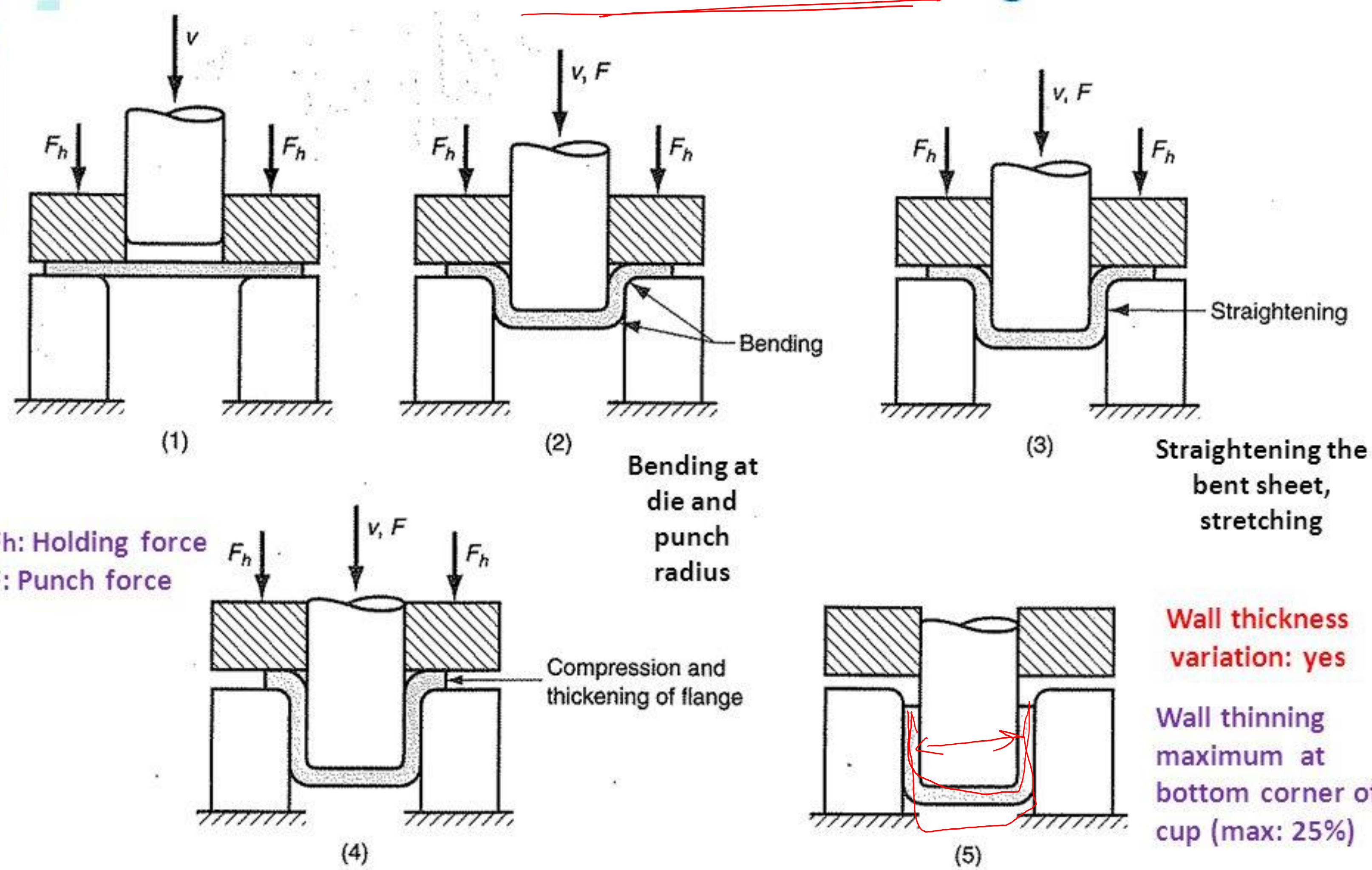
Sheet metal operation

- Deep drawing
- Shearing operation
- Punching operation
- Notching operation
- Bending operation
- Perforating operation
- Bending operation etc.

Stresses induced	Operation
Shearing	Shearing, Blanking, punching, trimming shaving, notching
Tension	Stretch forming
Compression	Coining, Ironing,
Tension and compression	Drawing, Bending, Forming

Sheetmetal operation

Mechanics of Drawing



Bending at die and punch radius

Straightening the bent sheet, stretching

Fh: Holding force
F: Punch force

Wall thickness variation: yes

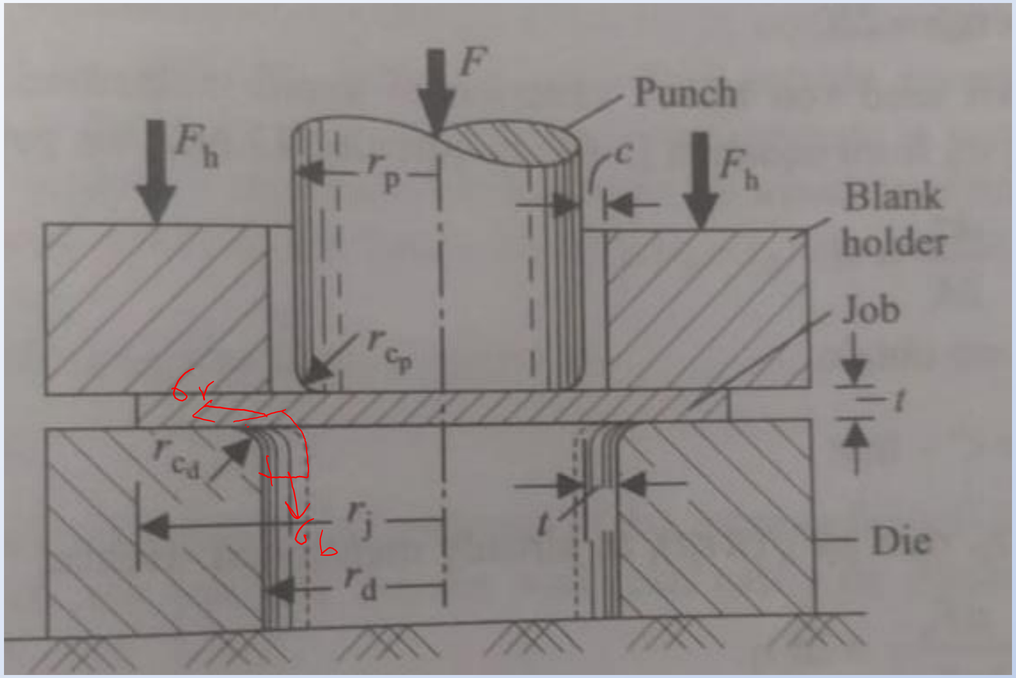
Wall thinning maximum at bottom corner of cup (max: 25%)

FIGURE 20.20 Stages in deformation of the work in deep drawing: (1) punch makes initial contact with work, (2) bending, (3) straightening, (4) friction and compression, and (5) final cup shape showing effects of thinning in the cup walls. Symbols: v = motion of punch, F = punch force, F_h = blankholder force.

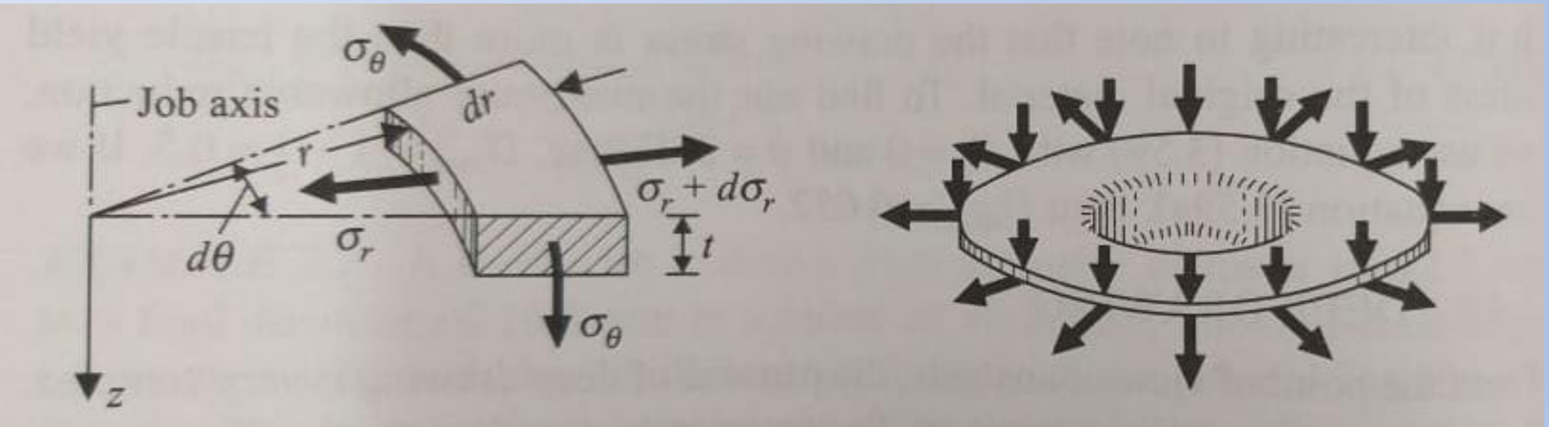
Deep drawing process

PRESSPART

- LDR (limiting diameter ratio) = Maximum diameter of blank that can be drawn/ Inside diameter of cup
- LDR indicates the capability of material to be drawn into cup
- Various factor affecting LDR are
  - Tool geometry of deep drawing setup
  - Lubrication
  - Blank holding pressure
  - Sheet metal properties

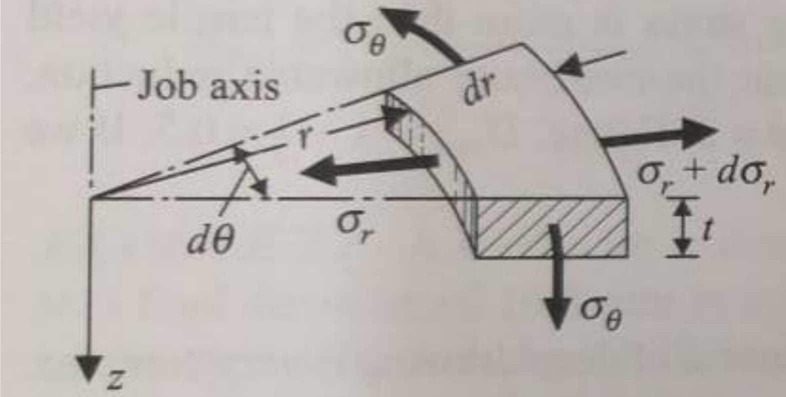


Schematic of deep drawing

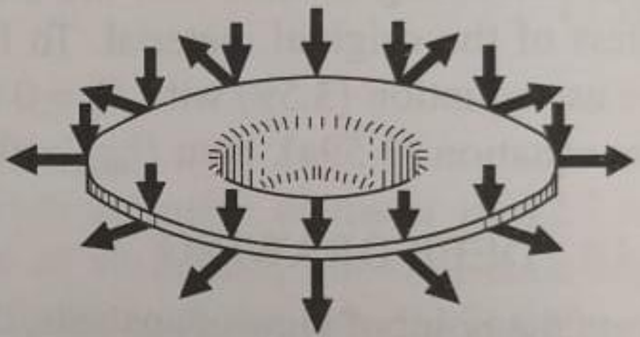


(a) Stresses acting on element during drawing

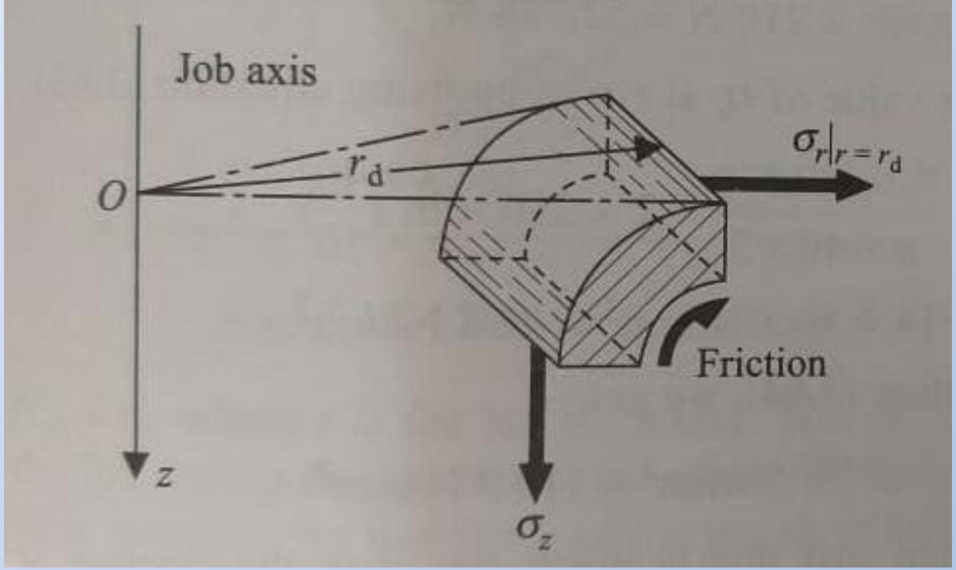
(b) Radial stress due to blank holding pressure



(a) Stresses acting on element during drawing

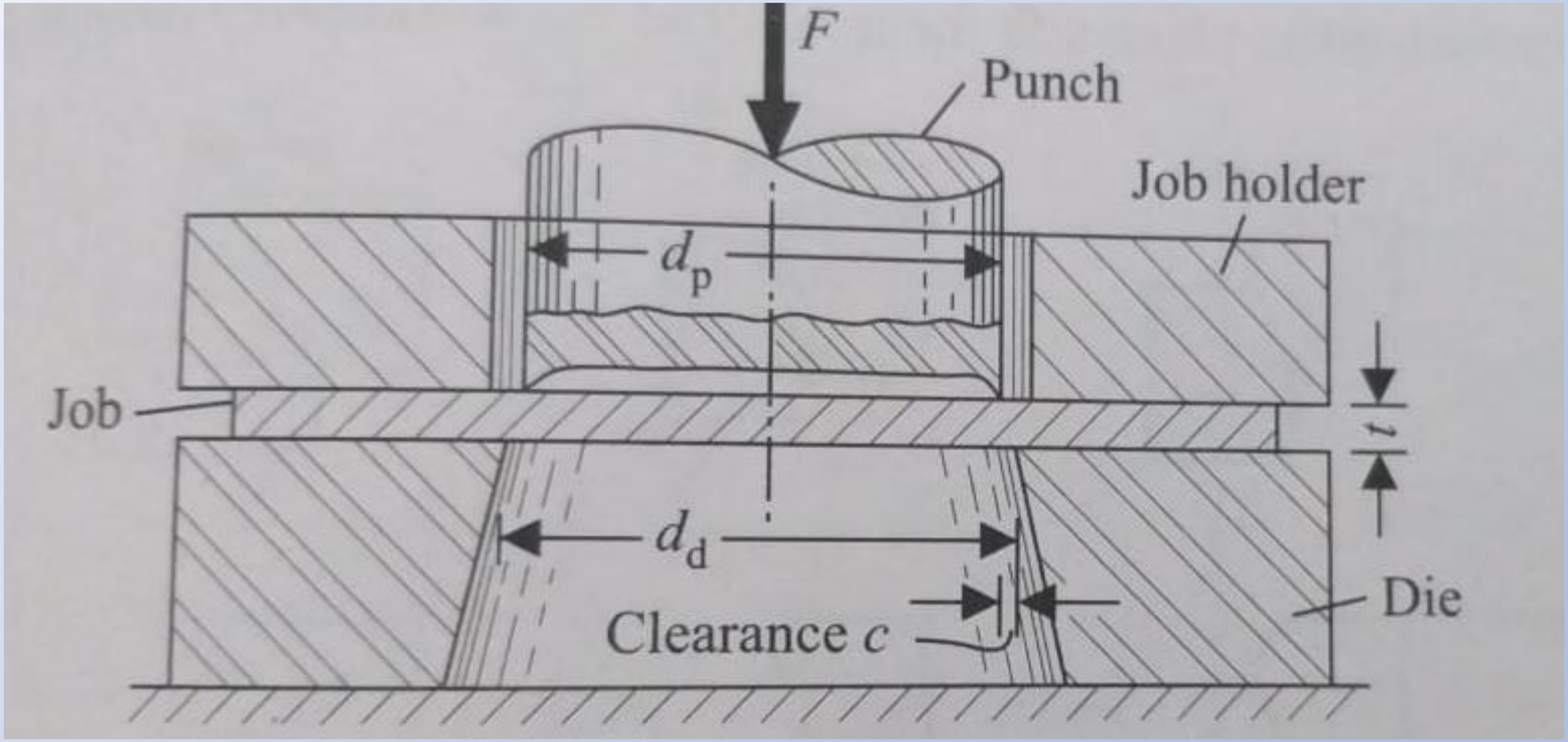


(b) Radial stress due to blank holding pressure


Job axis
O
r_d
$\sigma_r|_{r=r_d}$
Friction
z
σ_z

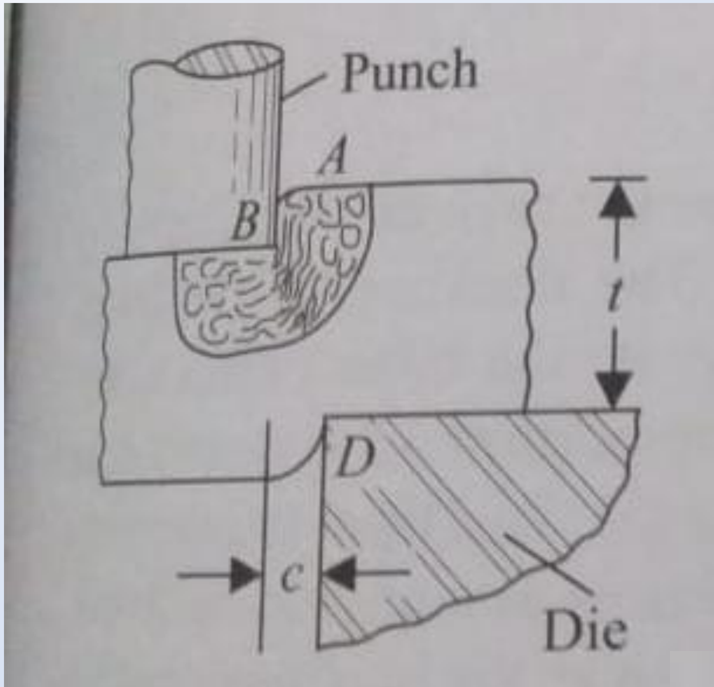
- A cold rolled steel cup with an inside radius 30 mm and a thickness 3 mm is to be drawn from a blank of radius 40 mm. The shear yield stress and the maximum allowable stress of the material can be taken as 210 and 600 Mpa, respectively.
  - Calculate the drawing force, assuming coefficient of friction is 0.1 and beta is 0.05
  - Determine the minimum possible radius of the cup which can be drawn from the given blank without causing a fracture.

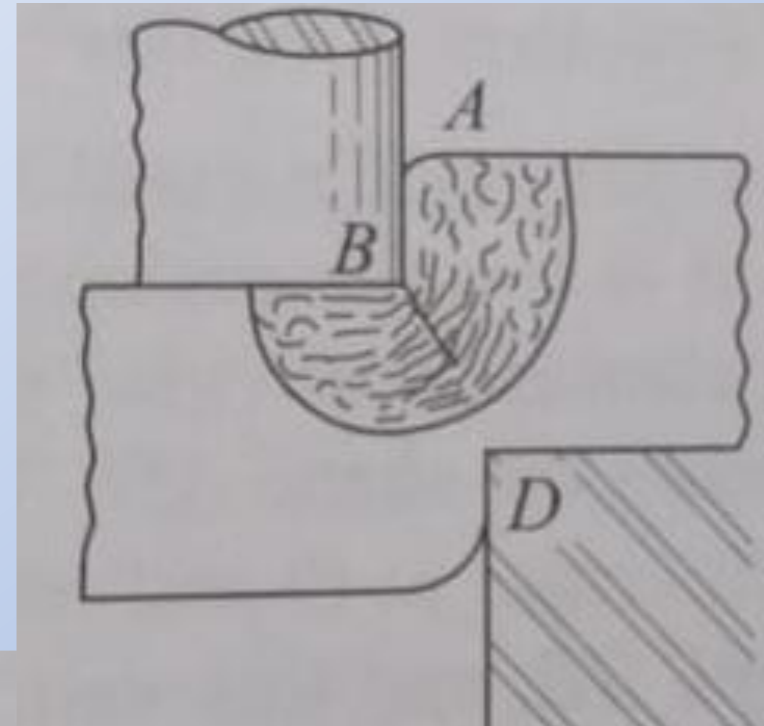
Punching and blanking



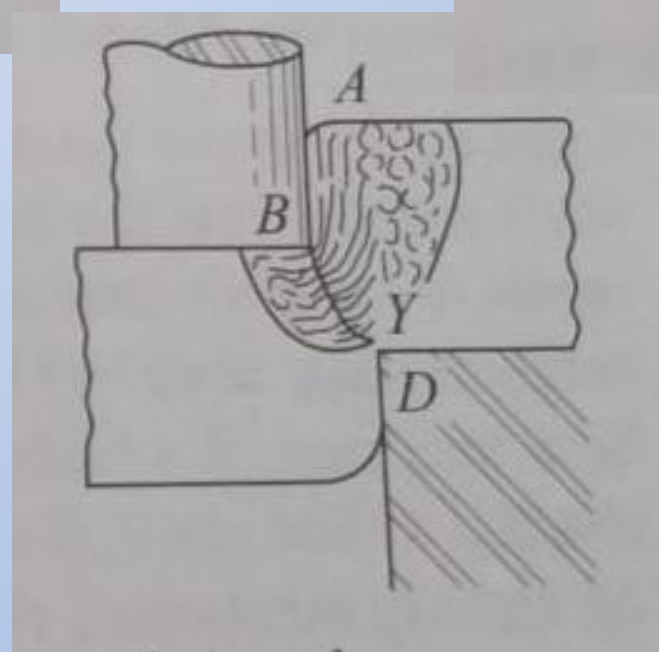
- ✓ If removed material is of interest than process is called as blanking process
- ✓ If hole is of interest than the process is called as punching process
- ✓ Elastic recovery: Size of blank increases while hole shrinks

Mode of metal deformation and failure

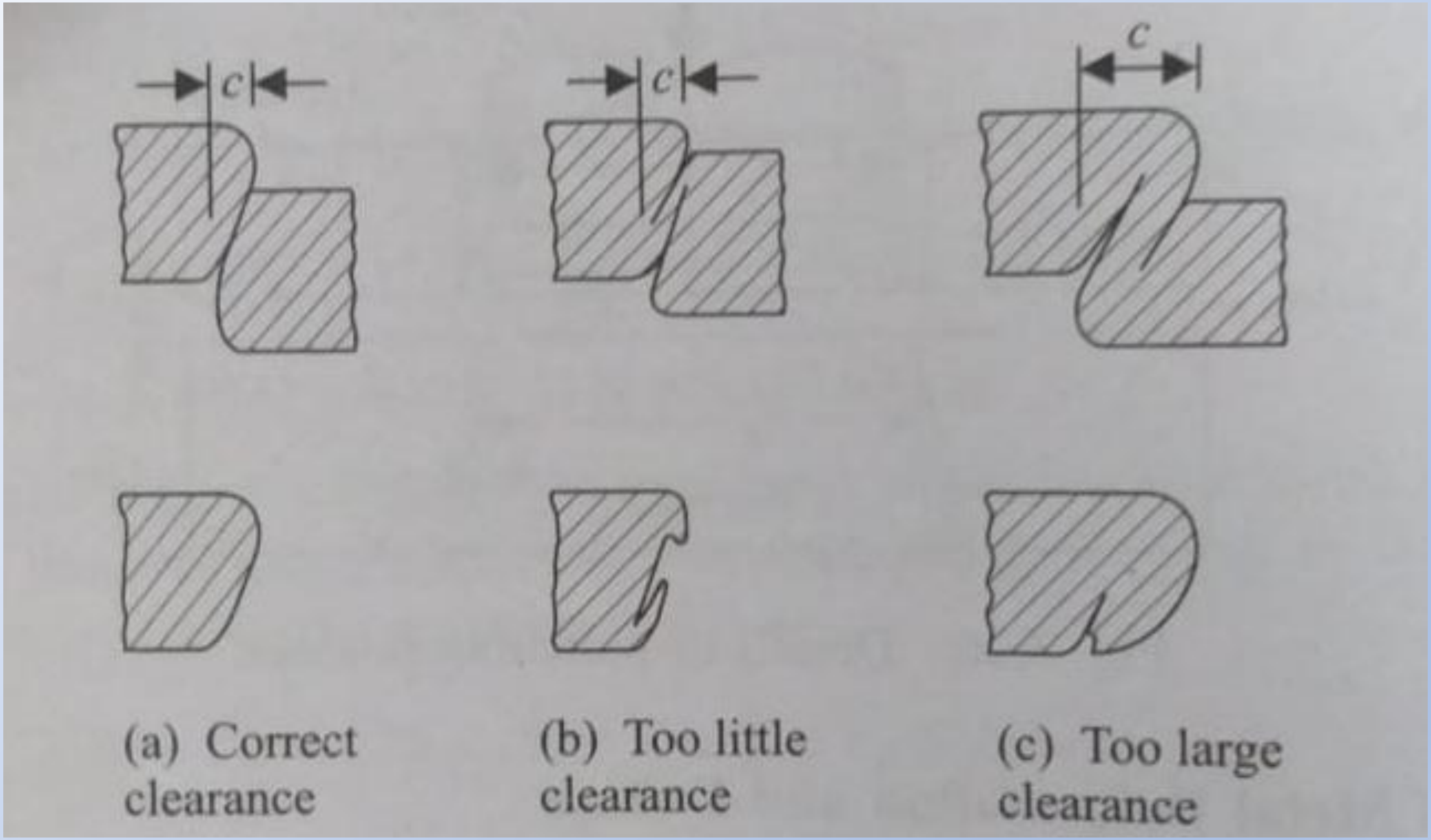




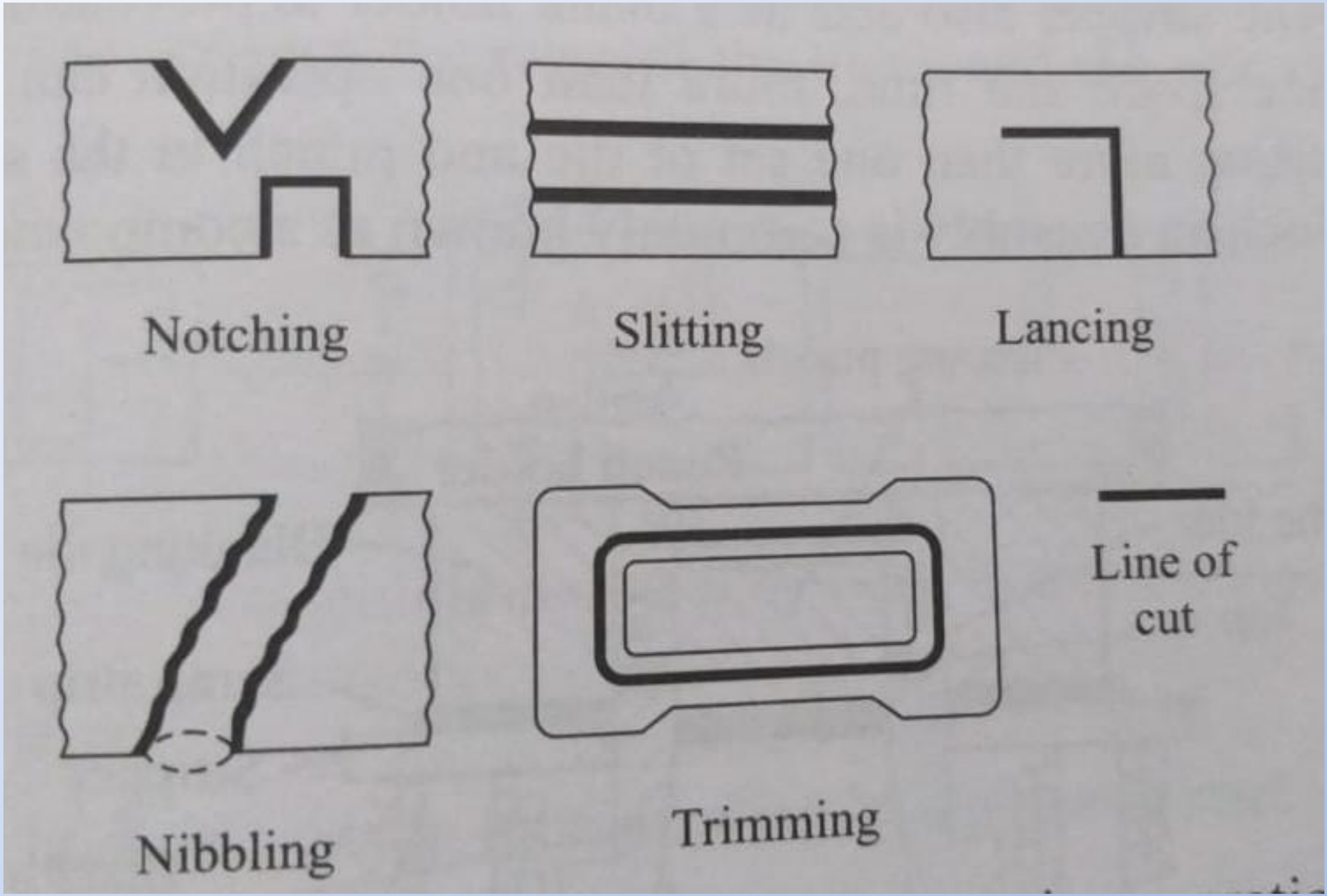
Grain elongate at B and D



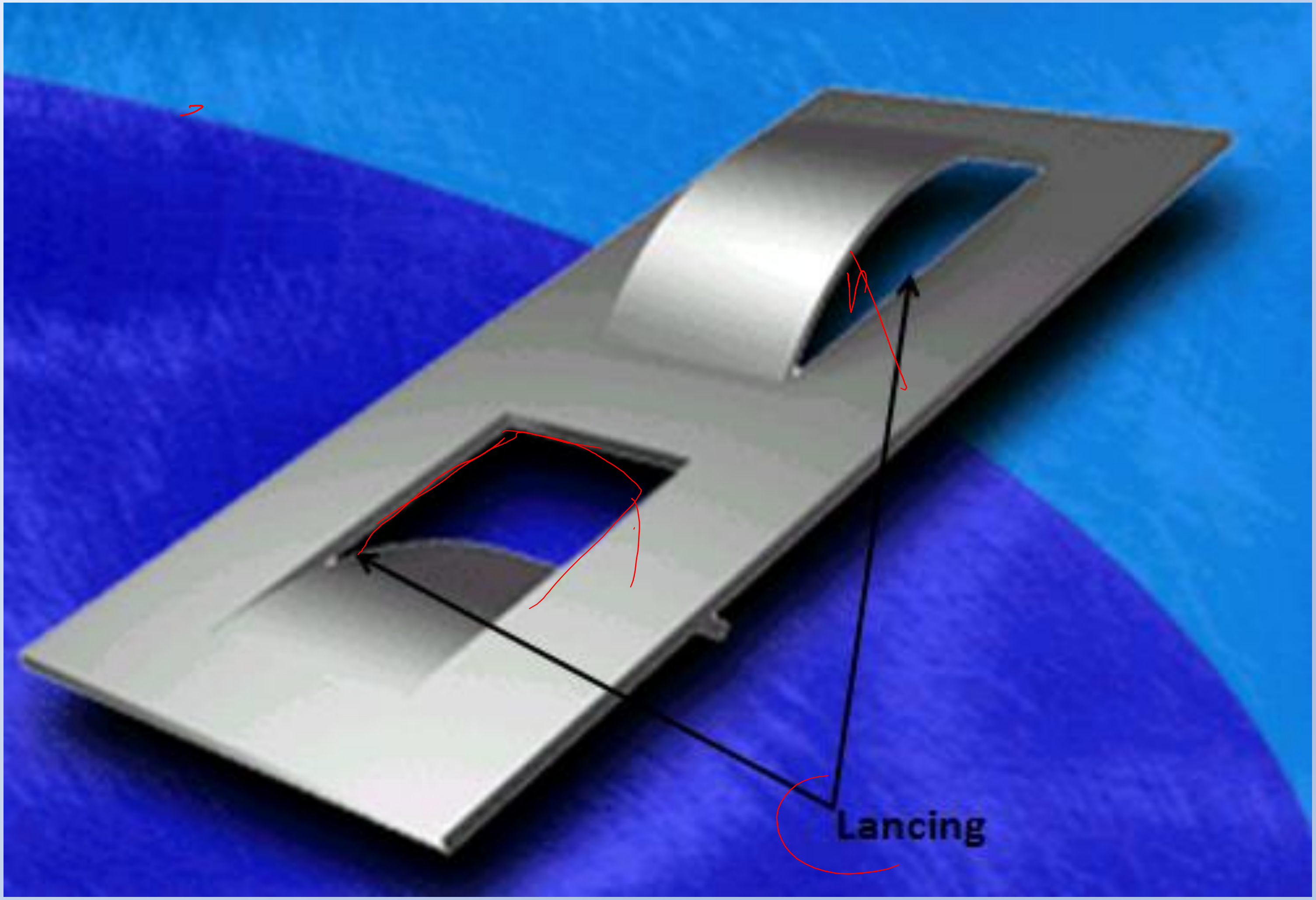
Effect of clearance on fracture of material

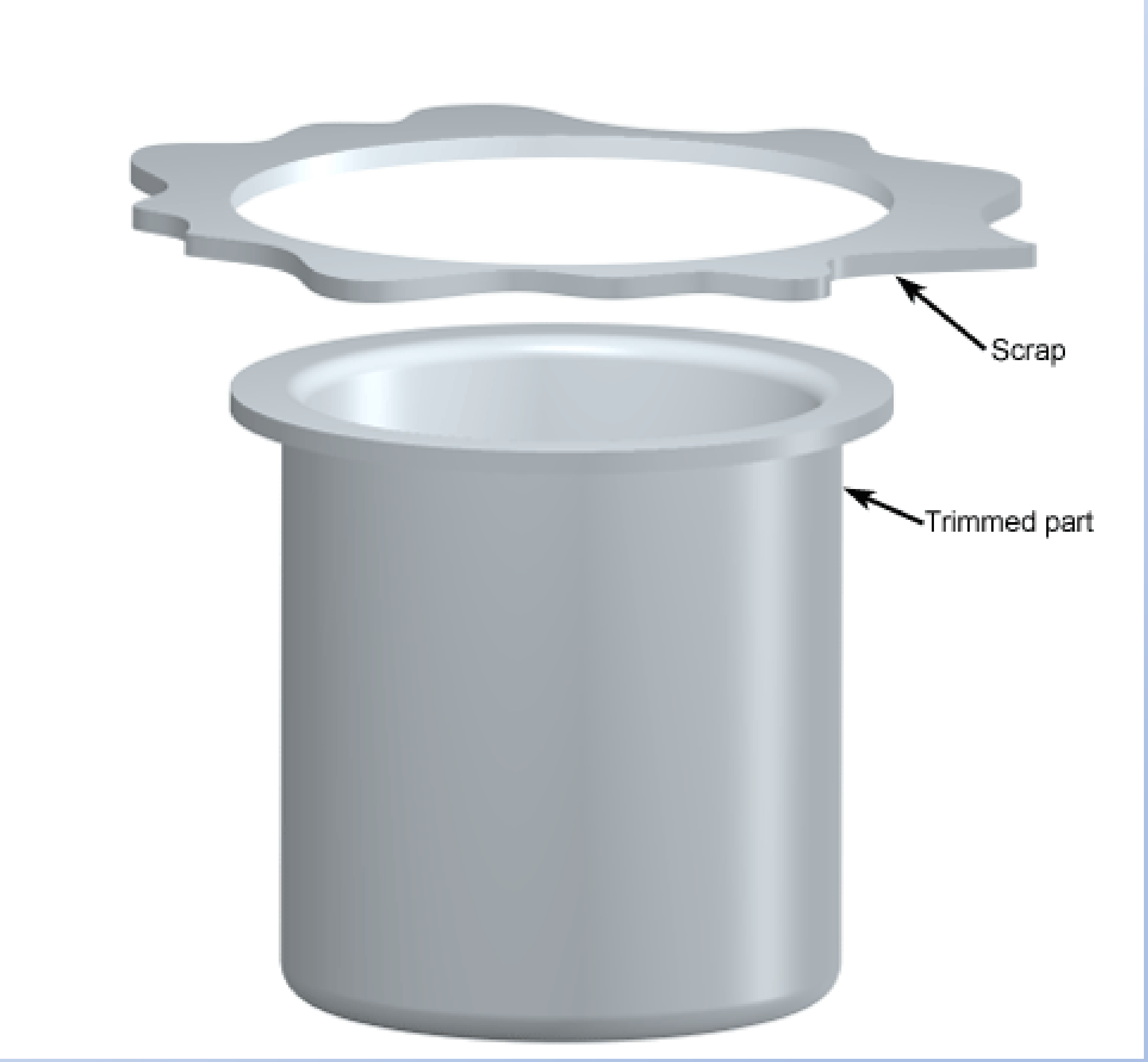


$$C=0.0032*t*(\tau)^{0.5}$$

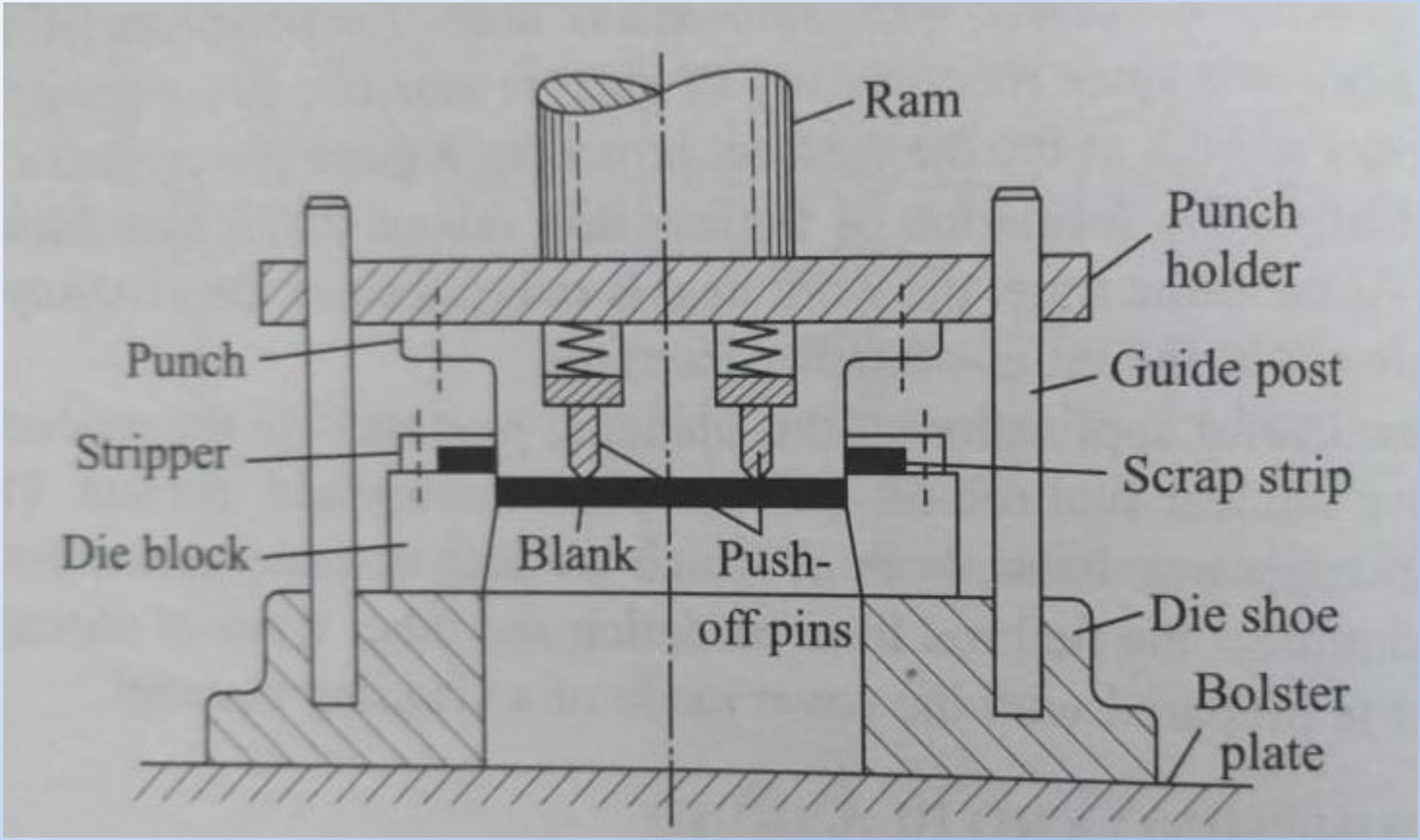

Notching
Slitting
Lancing
Nibbling
Trimming
Line of cut

Slitting operation

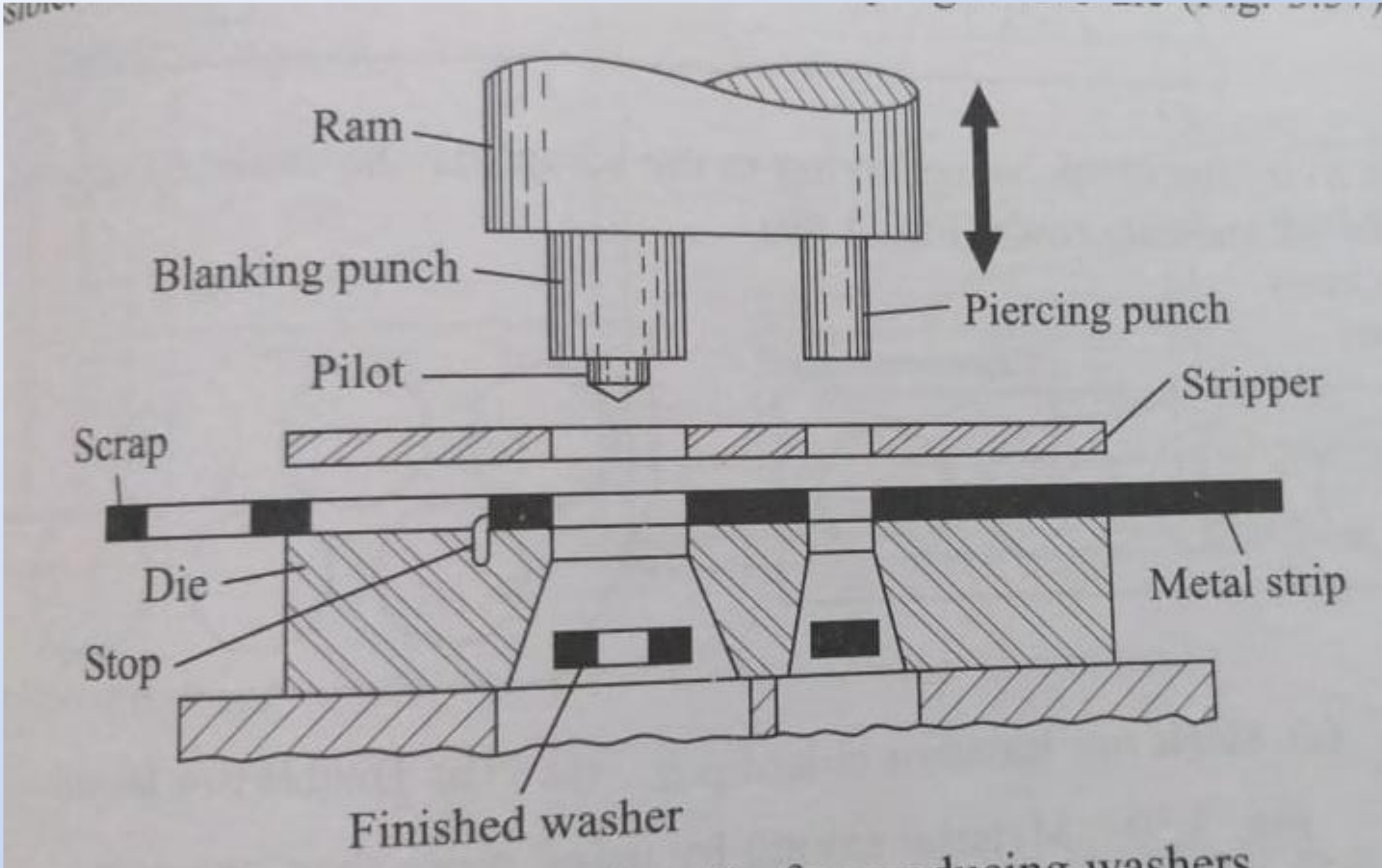

Lancing


Scrap
Trimmed part

Die-punch combination

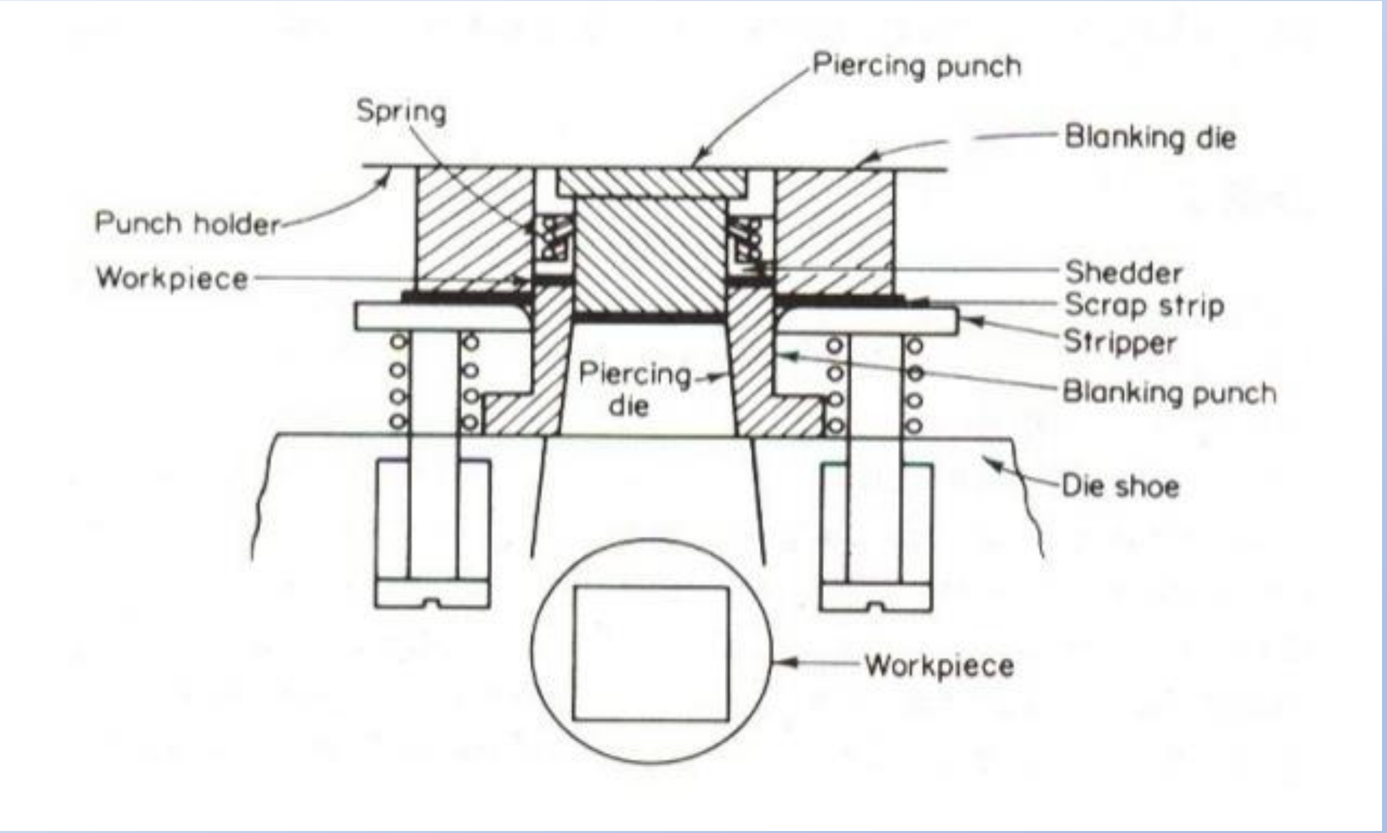


Progressive die

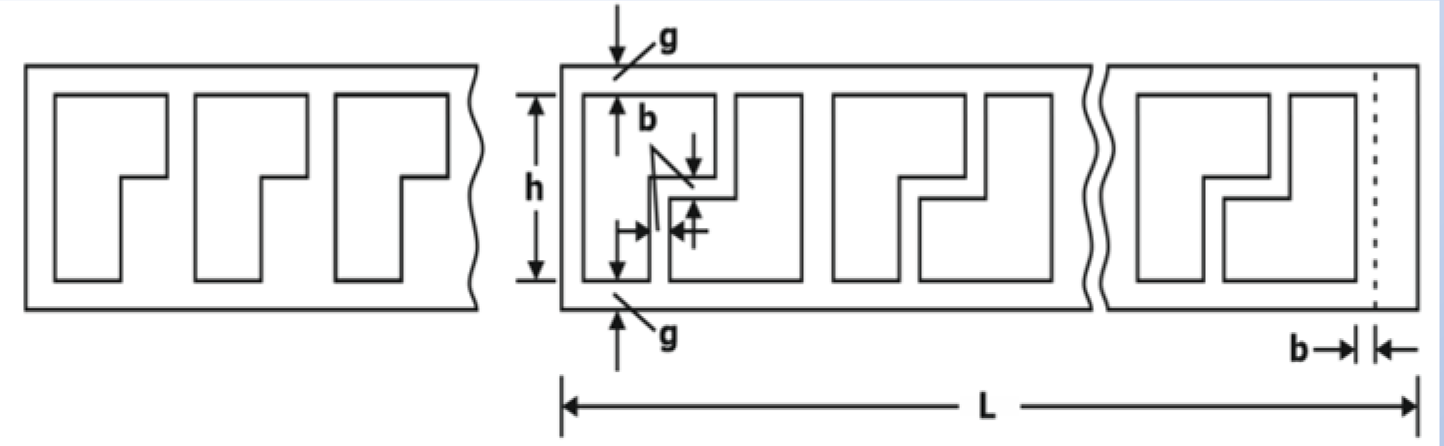


Self: Details study about types of dies such as compound die, progressive die etc

Compound die



Stock strip layout



(a) Improper layout (b) Optimum layout

Some principles:

- Always pierce the piloting hole in the first station. This helps in proper registering of strip for the subsequent substation
- If number of punched holes are very close than distribute them in more than one station so that die block remains stronger
- A complex contour should normally be slit into combination of simple shapes and punched out at different stations

Welding

Outcome: Why to study welding; Types of welding and purpose

What is Welding and its significance

- Welding is a process in which materials of the same fundamental type or class or brought together and caused to join through formation of primary (or occasionally secondary) chemical bonds under combined action of heat and pressure

- <u>American Heritage dictionary</u>: To join by application of heat, sometimes with pressure and sometimes with an intermediate or filler material having higher melting point

- <u>ISO standard</u>: Welding is an operation in which continuity is obtained between parts for assembly, by various means

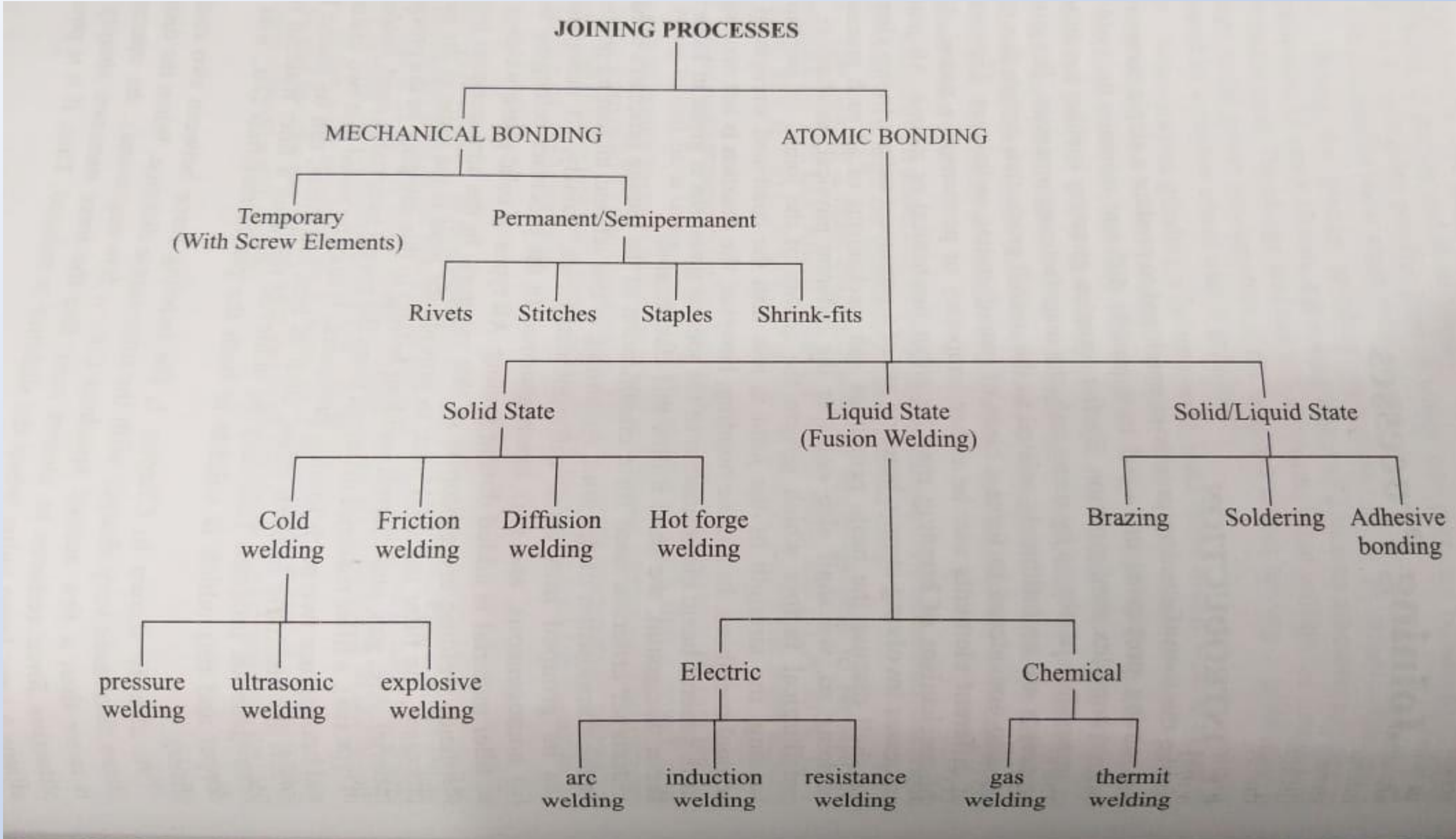
Welding: Key attributes

- Essence: Multiple parts are made one by establishing continuity
  - Continuity means absence of any physical disruption on an atomic scale
- Welding is not only limited to metals. It is equally applicable to thermoplastics, non-oxide ceramics etc
- Welding is a result of combined heat and pressure in most of the cases
- Usage of filler material: Autogenous, homogenous and heterogenous

Purpose of heat and pressure

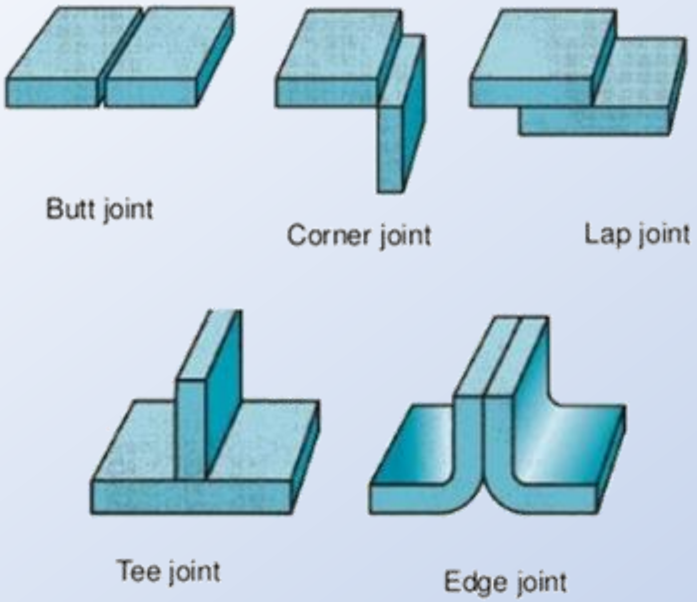
- Heat: Driving off volatile adsorbed layers of gases or moisture
  - Breaking down the brittle oxide due to difference in coefficient of thermal expansion or disrupting the discontinuity
  - Lowering yield strength of the material such that plastic deformation can occur at lower load
  - Melting up the material thereby rearranging of atoms by fluid flow
- Pressure: Disrupting absorbed layers at micro/macro level
  - Fracturing brittle oxide to expose clean surface
  - Plastically deforming asperities to increase the contact area

Welding

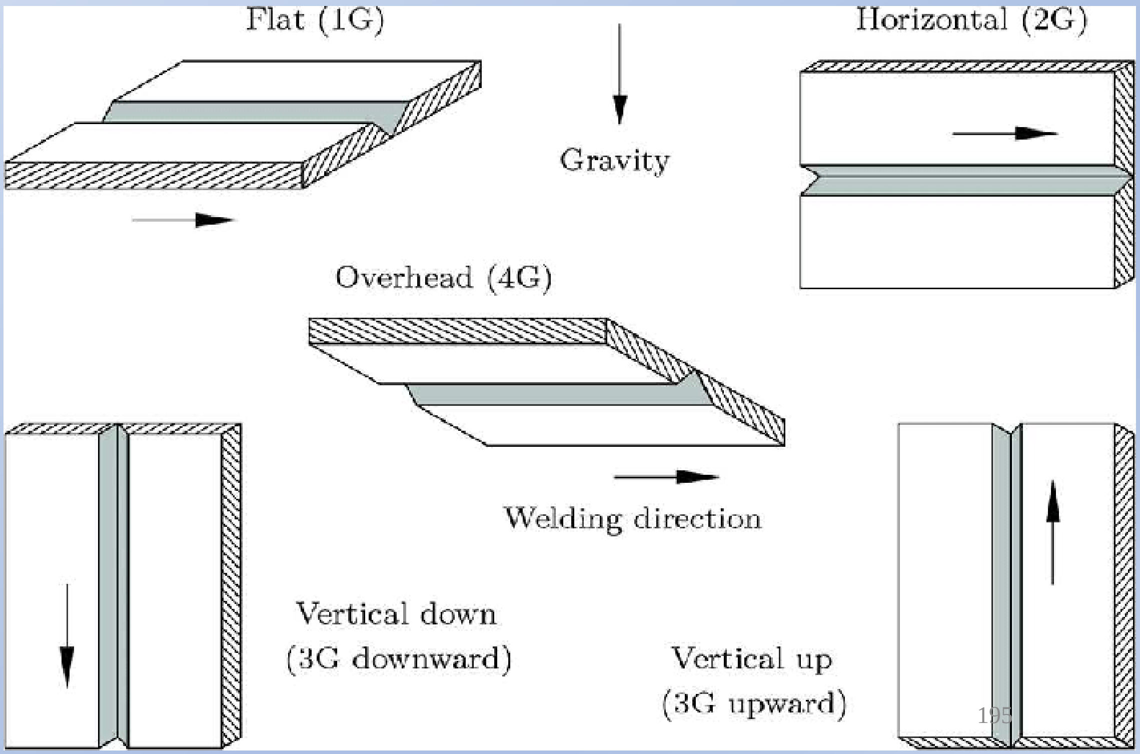


Other classification: Autogeneous, homogeneous, heterogeneous

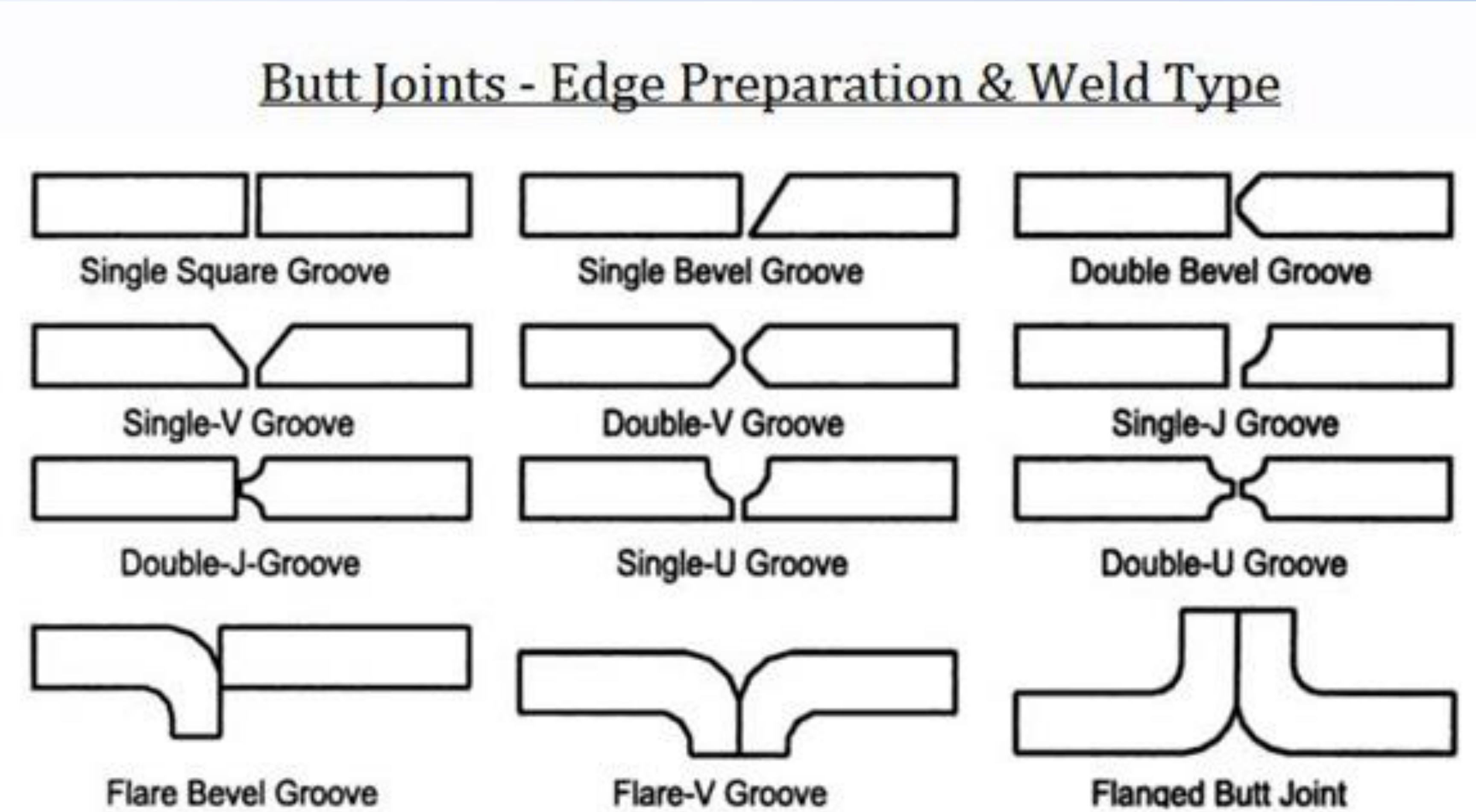
Types of joints in welding



Welding position



Edge preparation



Edge should be clean, free from burrs, oxides etc

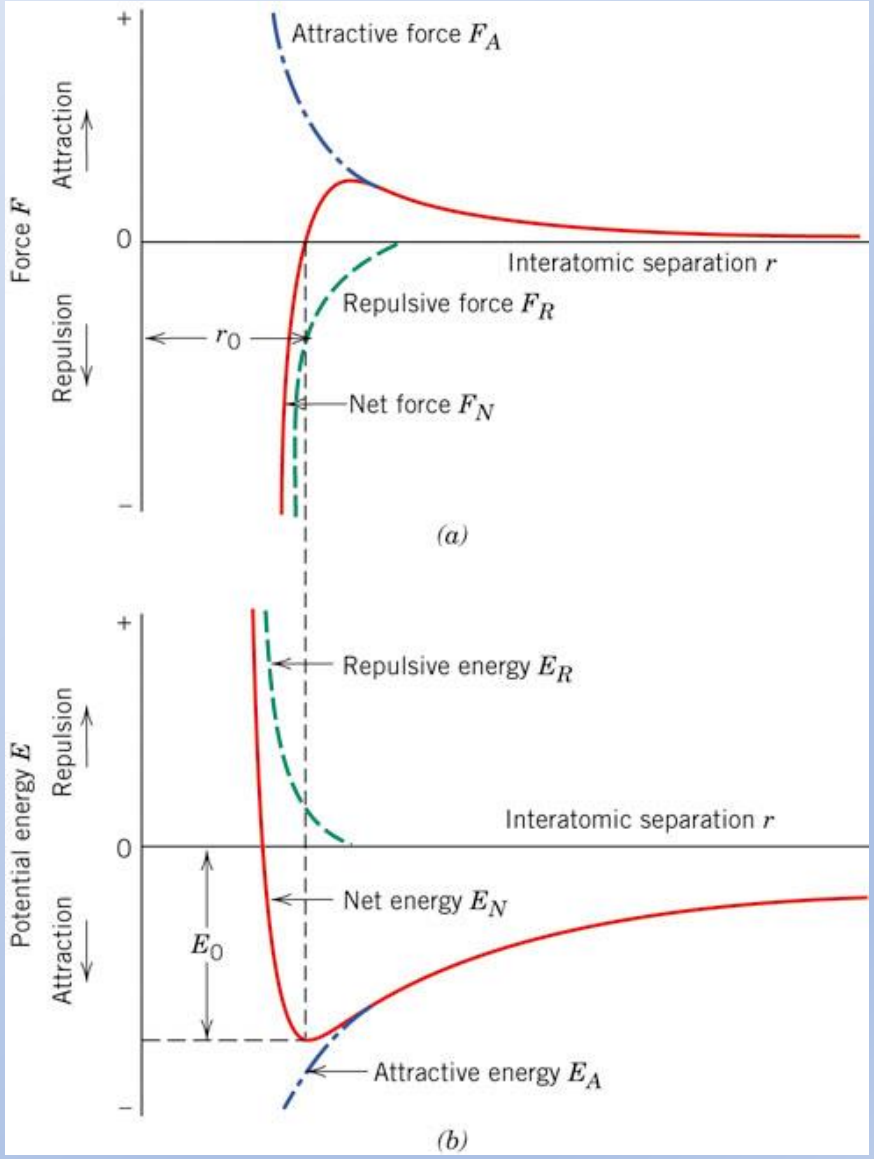
Solid phase welding

✓ When heat is not used

- Atoms are brought together or closer by plastic deformation
- Sufficiently close to ensure that bonds are established at their equilibrium spacing
- Significant lattice deformation

✓ When heat is used

- In hot state strained lattice recover from the distorted shape
- Atomic re-arrangement and re-crystallization
- Grain growth across original interface

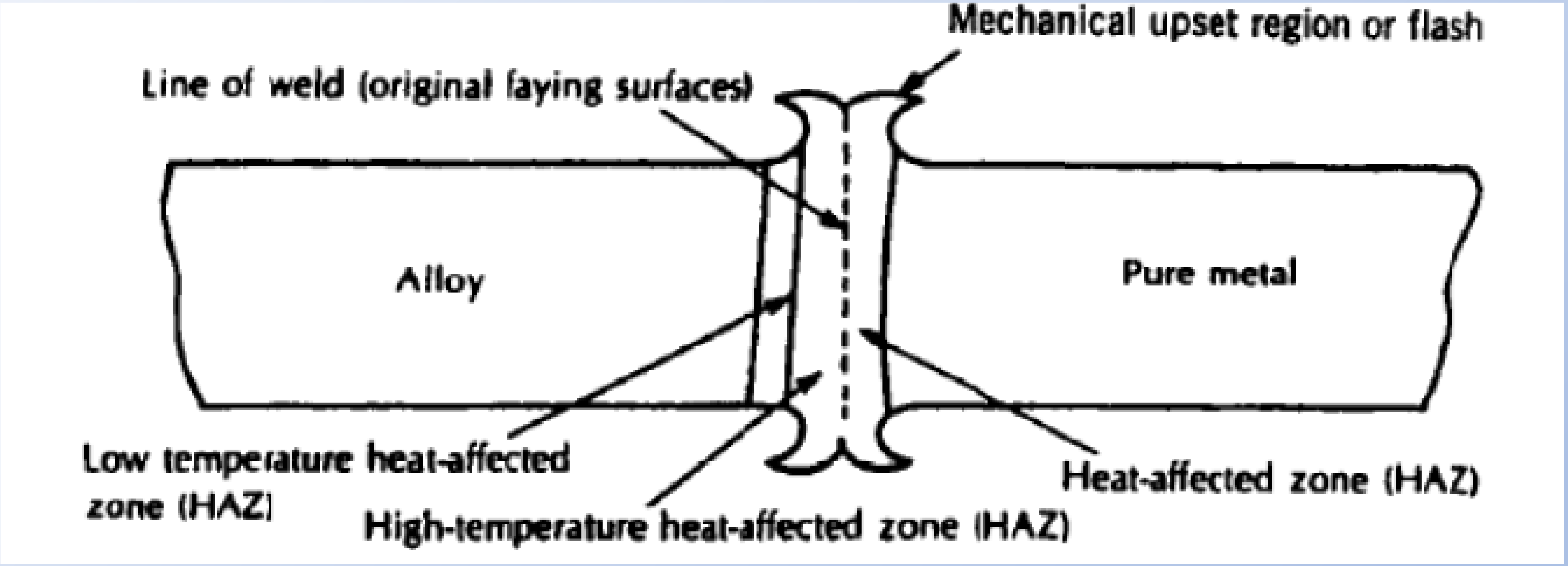


Attractive force F_A
Force F
Attraction
Repulsion
+
0
−
Interatomic separation r
Repulsive force F_R
r_0
Net force F_N
(a)
Potential energy E
Repulsion
Attraction
+
0
−
Repulsive energy E_R
Interatomic separation r
Net energy E_N
E_0
Attractive energy E_A
(b)

Important factors

- Surface deformation:
  - Strength of weld increases with increase in bulk deformation
  - No weld takes place below a critical deformation and it is dependent on temperature
- Surface films
  - Biggest problem is oxide layer and oil films
- Recrystallization
- Diffusion

Microstructural zone in solid state welding

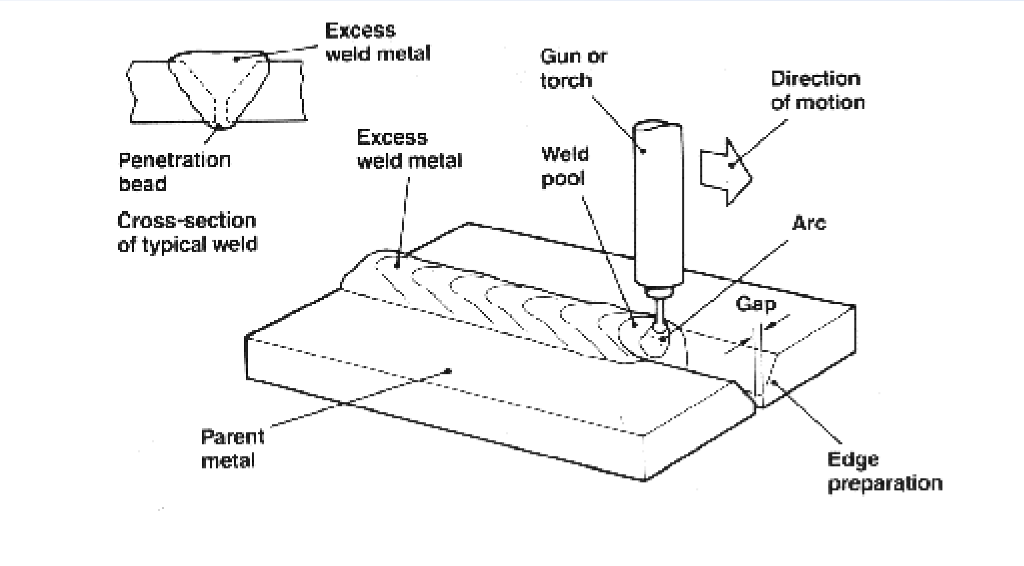


Principle of Fusion welding

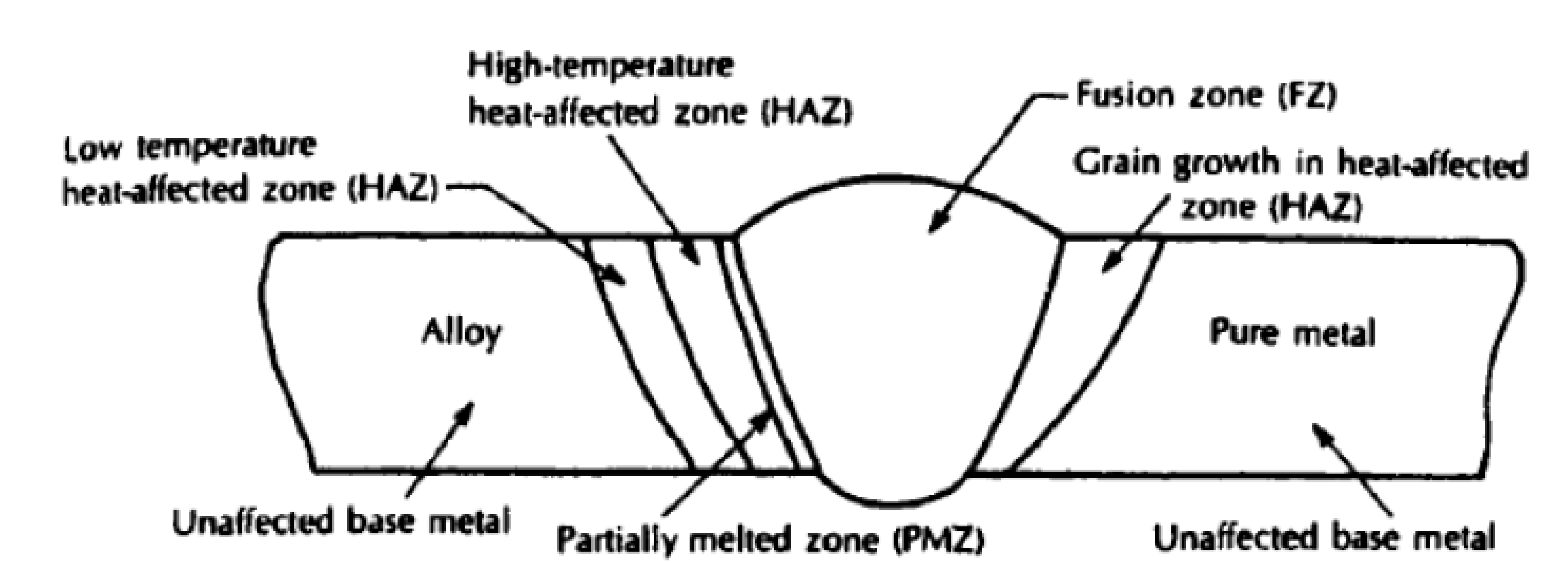
✓ Important factors governing a fusion welding process

- The characteristics of the heat source
- Nature of deposition of the filler material in the filler zone i.e. weld pool
- Shielding gas
- Heat flow characteristics in the joint
- Cooling of the fusion zone with the associated contraction, residual stresses and metallurgical changes

Nomenclature of weld for fusion welding



Microstructural zone in Fusion welding

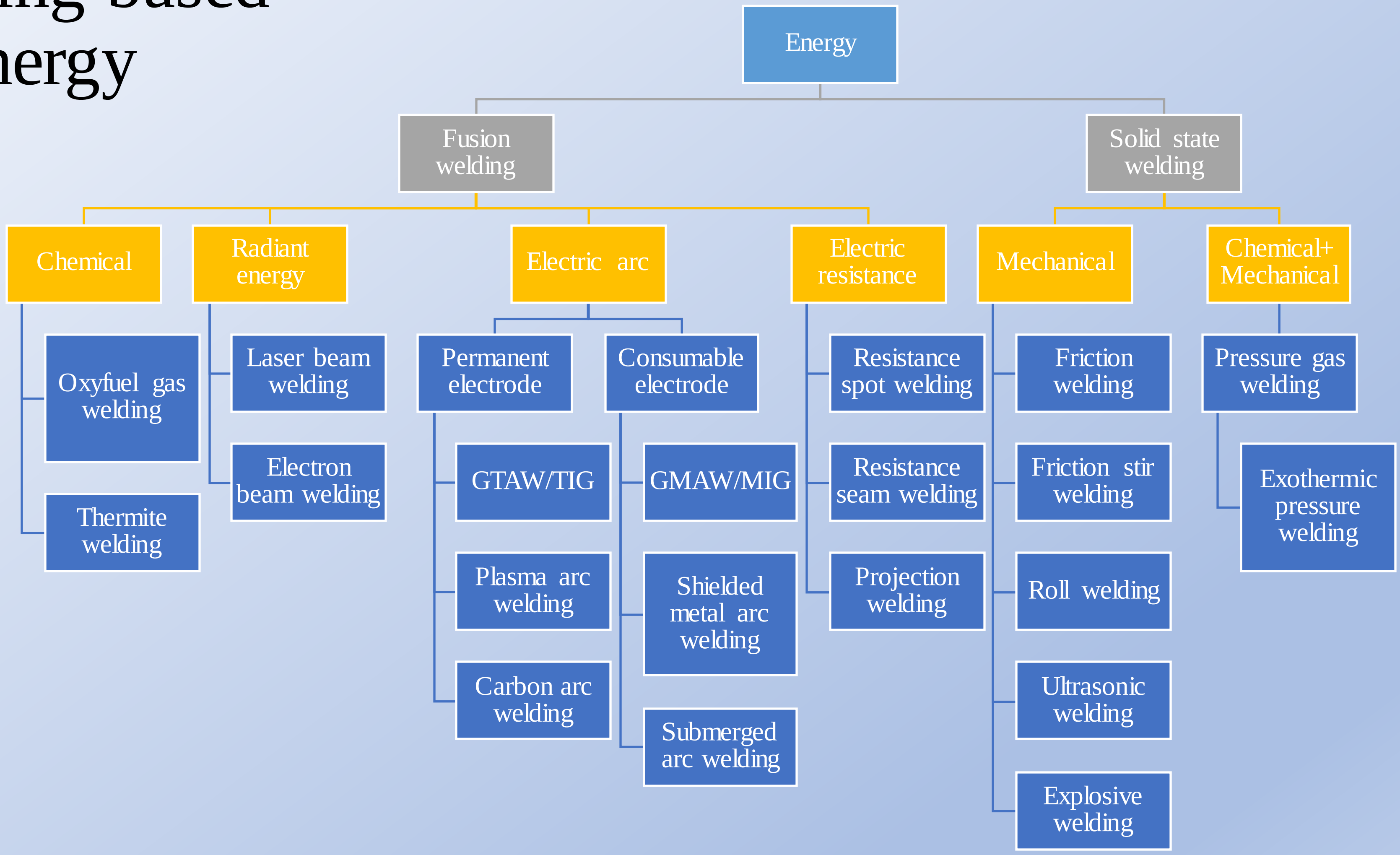


Power density

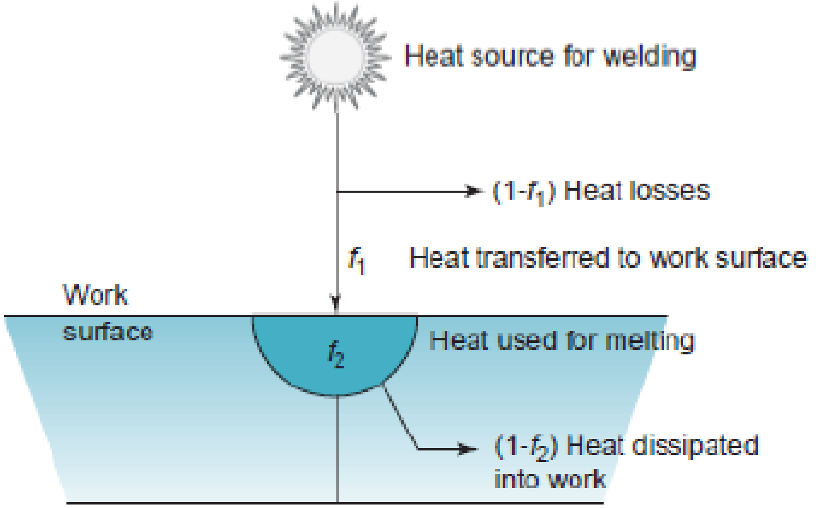
- Defined as the power transferred to work per unit surface area (W/mm^2)
- Time to melt the metal is inversely proportional to power density

Welding Process	Approx. Power density (W/mm^2)
Oxy-fuel welding	10
Arc welding	50
Resistance welding	1000
Laser beam welding	9000
Electron beam welding	10,000

Types of welding based on energy



Heat transfer mechanisms in Fusion Welding



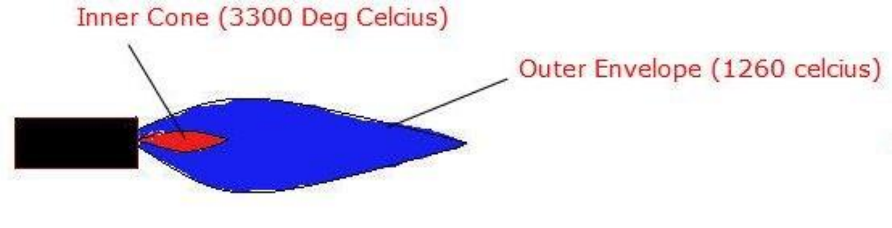
Heat transf. factor f_1= Heat transf. to work / Heat gen. by source

Melting Factor f_2 = Heat used for melting / Heat tranf. to work

Useful heat or energy = $f_1.f_2$

Gas Welding: combustion of fuel gas and O_2

- Oxy-Acetylene gas welding



Chemical reaction takes place in two stages

$C_2H_2 + O_2 = 2CO + H_2 + 448 kJ/mol$

$4CO + 2H_2 + 3O_2 = 4CO_2 + 2H_2O + 812$ kJ/mol (With atmospheric oxygen)

Gas	Primary heat content (MJ/m^3)	Secondary heat content (MJ/m^3)	Total (MJ/m^3)	Flame temperature (^{o}C)
Acetylene	18.97	36.03	55	3100
Propylene	16.38	71.62	88	2500
Propane	9.38	83.62	93	2450
Hydrogen	-	-	10	2390
Natural gas	0.41	36.59	37	2350

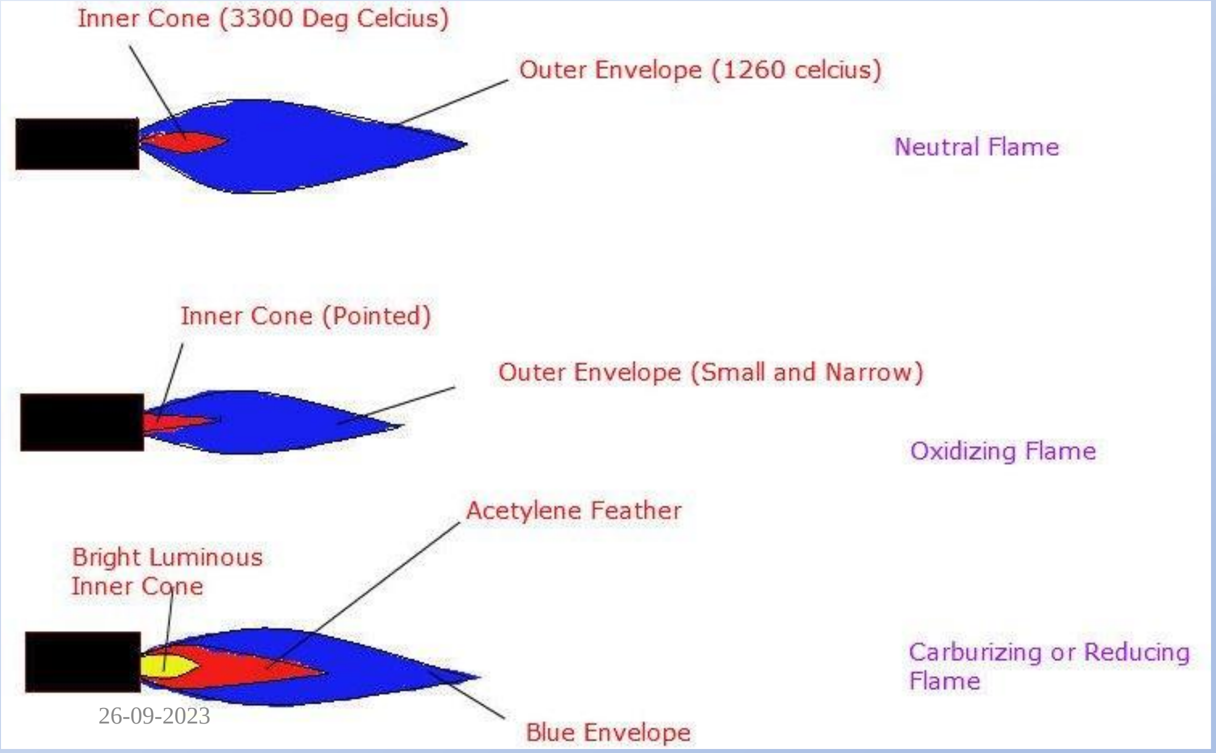
Gas Welding: combustion of fuel gas and O_2

- Oxy-Acetylene gas welding

Chemical reaction takes place in two stages

$C_2H_2 + O_2 = 2CO + H_2 + 448 kJ/mol$

$4CO + 2H_2 + 3O_2 = 4CO_2 + 2H_2O + 812$ kJ/mol (With atmospheric oxygen)

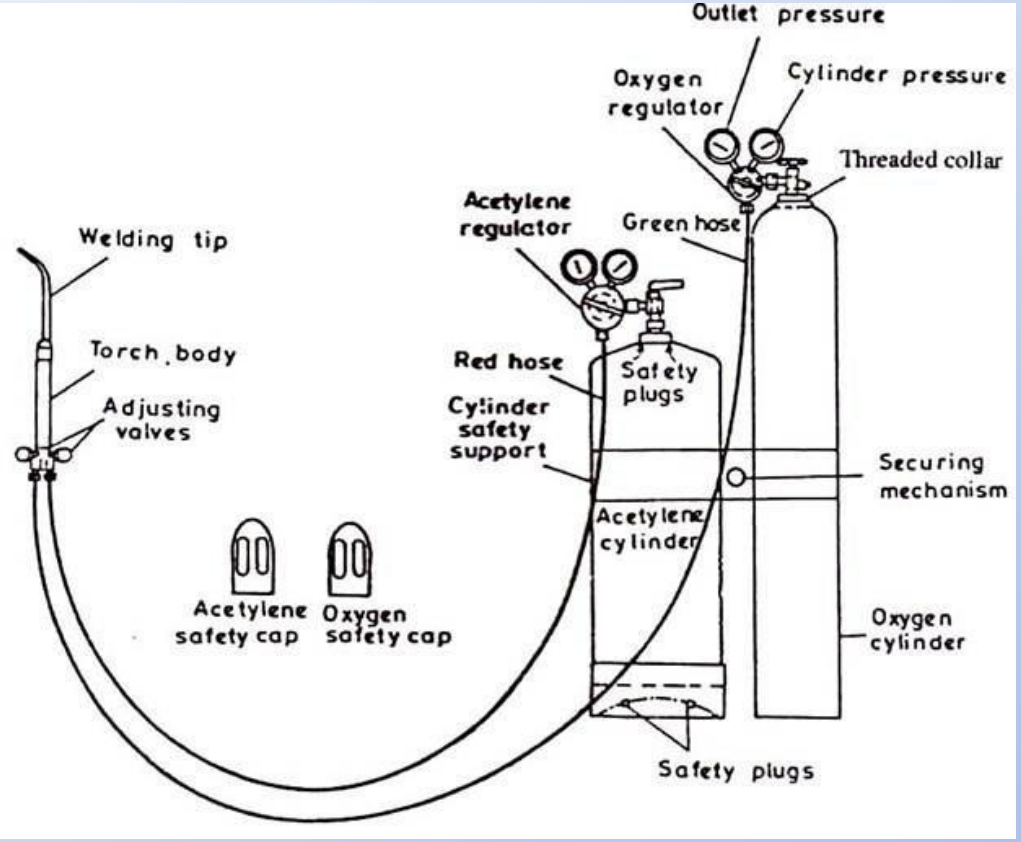


Generally Non-ferrous alloys

Useful for material which readily oxidizes such oxygen free copper, high carbon steel, GCI

Metal	Flame	Metal	Flame
Mild steel	Neutral	Aluminium	Slightly carburising
High carbon steel	Reducing	Brass	Slightly oxidising
Grey cast iron		Copper, Bronze	Neutral, Slightly oxidising
	Neutral, slightly oxidising	Nickel alloys	Slightly carburising
Alloy steel	Neutral	Lead	Neutral

Equipment of Gas welding



Acetylene storage

- Free acetylene is highly explosive, if stored at a pressure more than 200 kPa
- It is stored in a strong cylinder filled with 80-85% of porous material such as calcium silicate and then filled with acetone to absorb acetylene
- Generally acetylene molecules fit in between the acetone molecules and this help in storing acetylene at a higher pressure
- Acetylene would be released from acetone at a slow rate and it depends on the temperature of the gas

Acetylene generator

acetylene generator: $CaC_2 + 2H_2O = C_2H_2 + Ca(OH)_2$

Pros and Cons of gas welding

- Welding of ferrous and non-ferrous material
- No requirement of electricity
- Equipment is portable and low cost
- Does not require high skilled labor

Cons

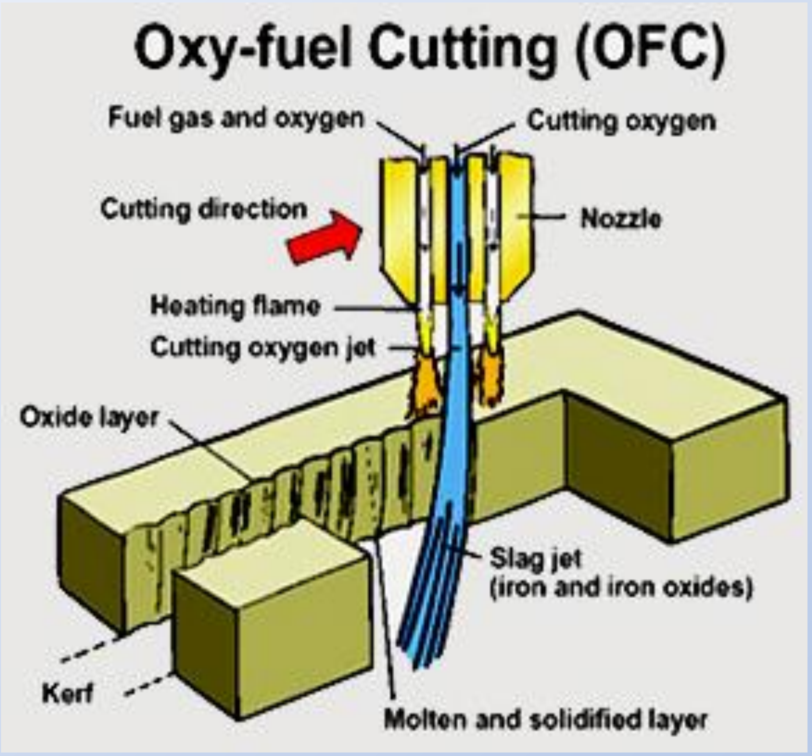
- Not suitable for thick sections
- Less working temperature and hence low heating rate
- Not suitable for reactive material like titanium
- Larger heat affected area

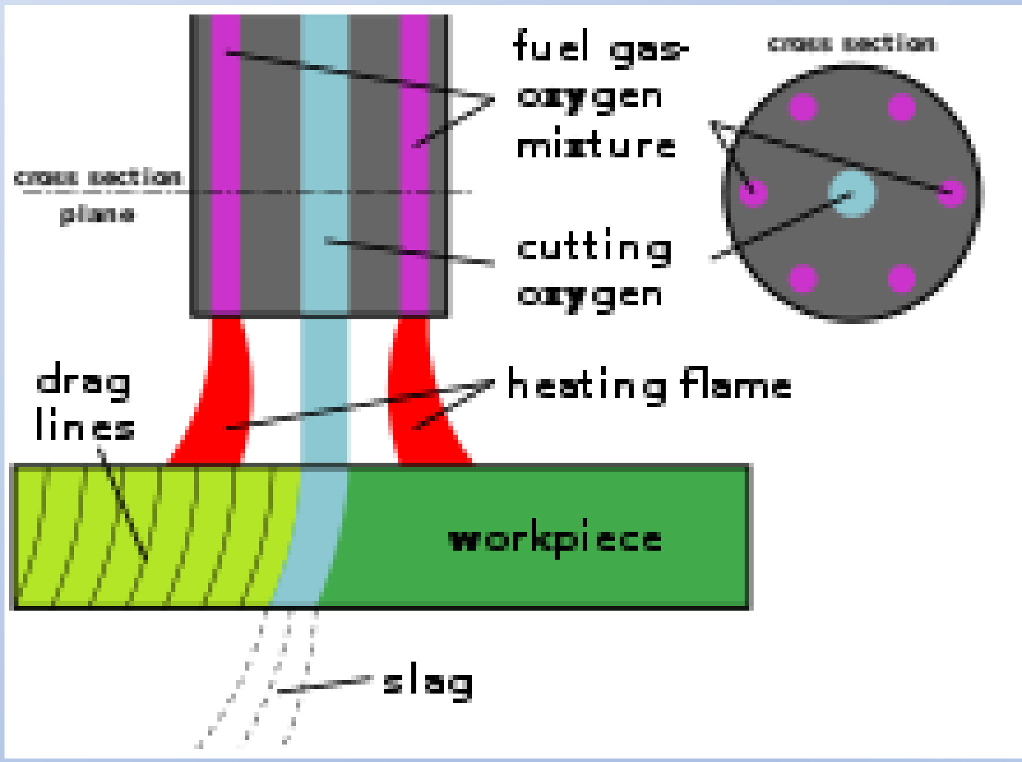
Application

- Repair work
- Fabrication of sheet metal for aerospace and automobile industry

Gas cutting

- It is possible to oxidize iron and steel when it is heated to a temperature between 800-1000^{o}C, when high pressure (300kPa) oxygen jet is directed against it





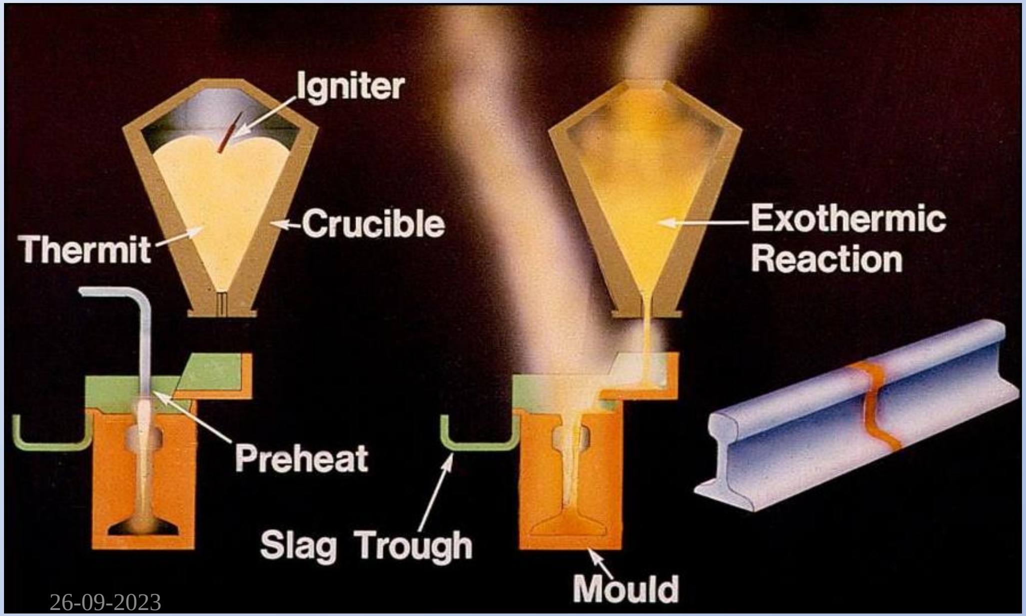
$$3Fe+2O_2 = Fe_2O_3+6.67\ MJ/kg$$

Thermit Welding

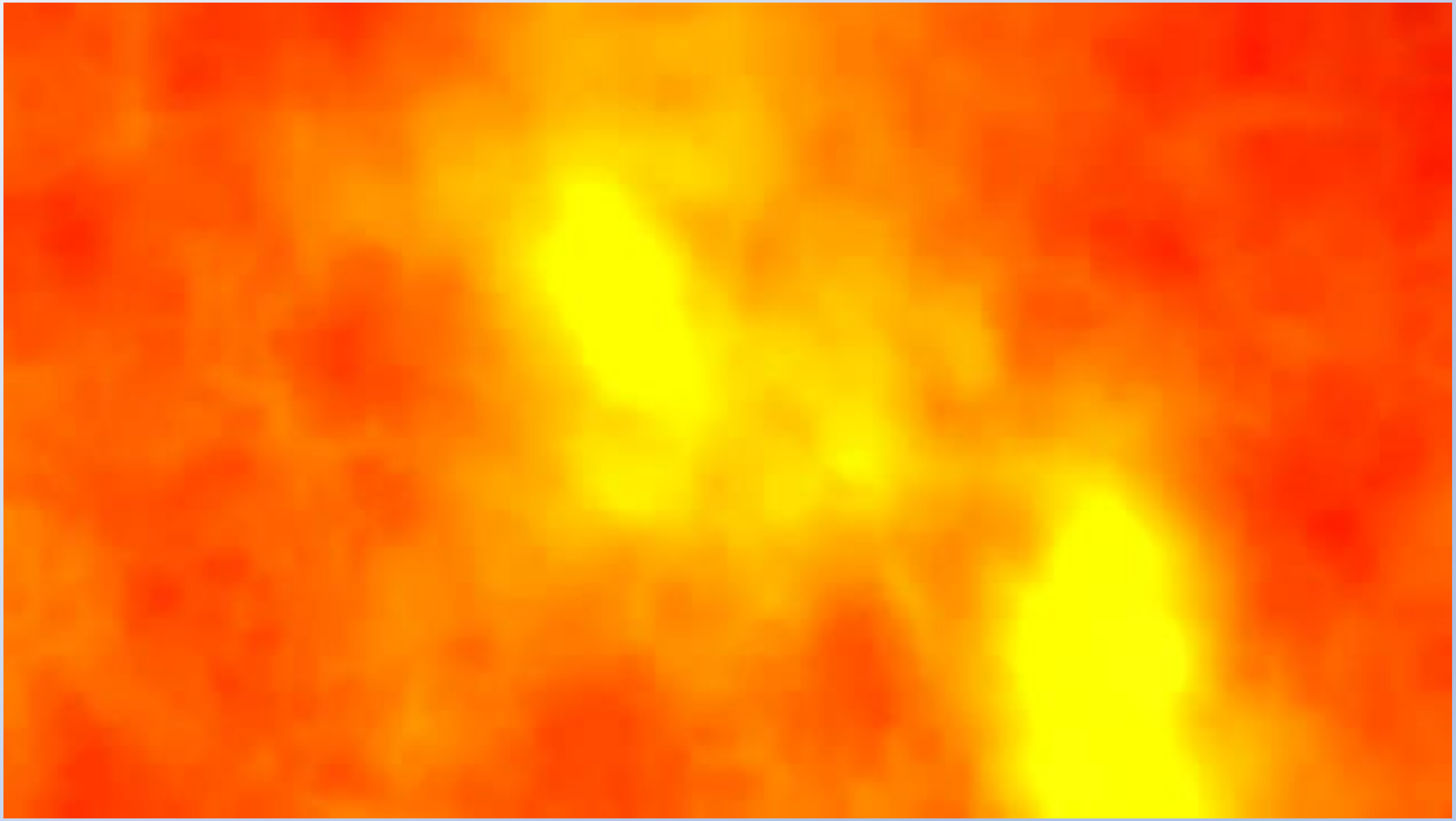
- Used for welding of very thick plates specifically locomotive rails, ships hulls
- Exothermic reaction provides the molten metal, and it is eventually used for welding

$$3Fe_3O_4+8Al = 9Fe +4Al_2O_3+3.01 \text{ MJ/mol}$$

- Above reaction takes place around 1200^{o}C which is ignition temperature.
- After reaction around 3000^{o}C is achieved
- Heat released in the reaction is approximately 35kJ/kg of thermit mixture

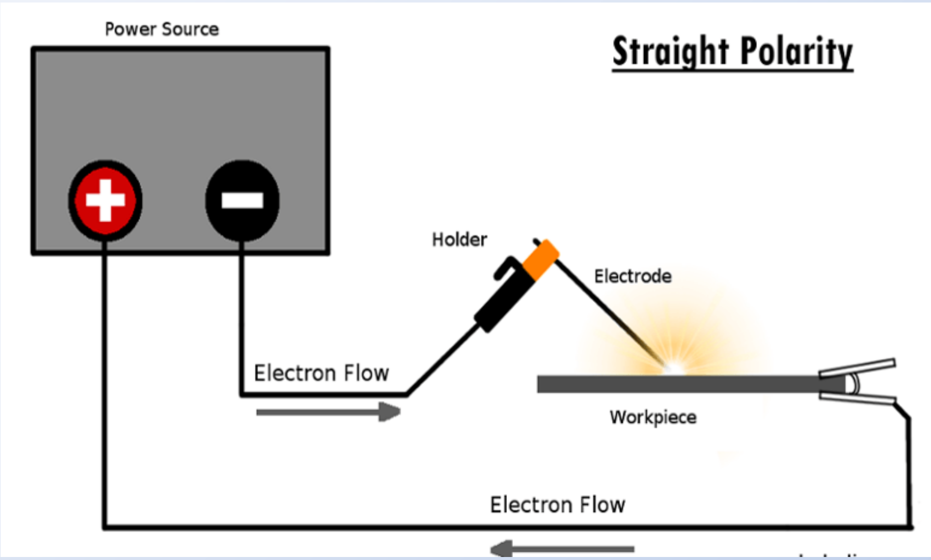


Schematic of thermit welding



Arc Welding

How arc is generated



Schematic of arc welding setup

Rate at which electron is emitted
$I = CT^2 \exp(-\beta/T)$; C is constant

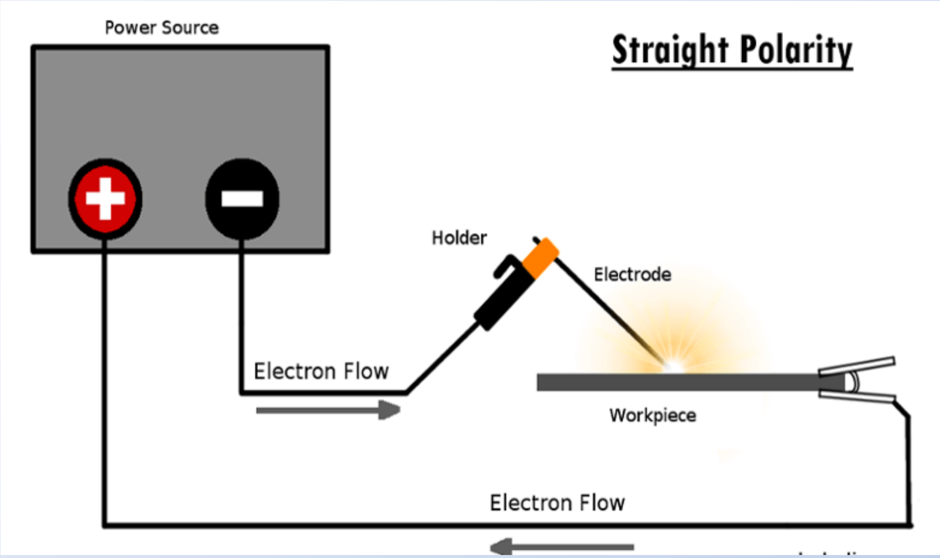
$\beta = \Phi e/(kT)$; e is charge of electron, k is Boltzmann's constant and Φ is thermionic emission

Values of ionization potential and work function

Metal	Ionization potential (V)	ϕ (eV)
Aluminium	6.0	4.1
Copper	7.9	4.4
Iron	7.83	4.4
Tungsten	8.1	4.5
Sodium	5.1	2.3
Potassium	4.3	2.2
Nickel	7.61	5.0

Arc Welding

How arc is generated

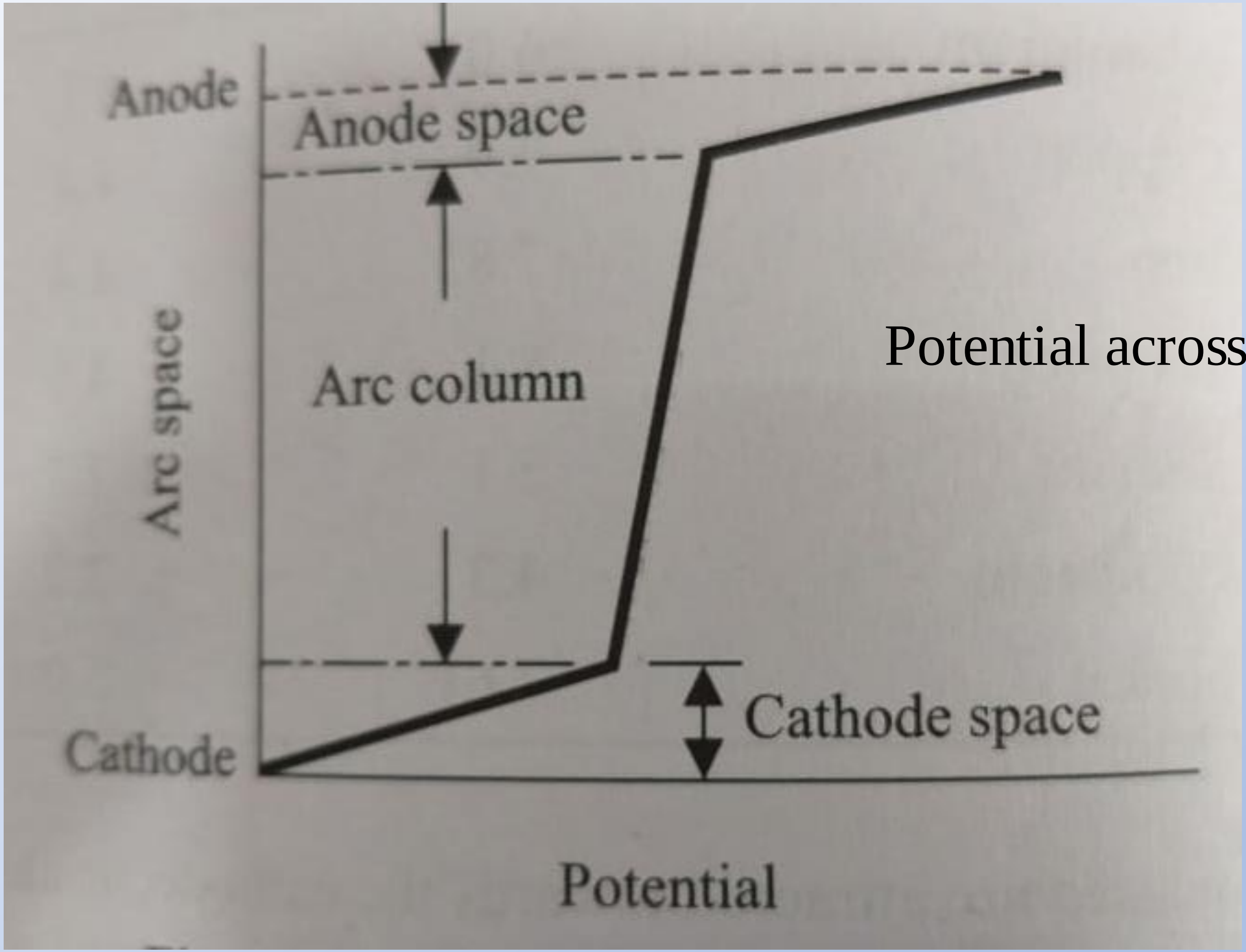


Schematic of arc welding setup

Ionization:

- An electron of charge e is moving in an electric field and experiences a force of eE and resulting in acceleration of eE/m
- It will collide with either electron or neutral atom
- Though mostly the collisions are elastic and both momentum and KE are conserved
- But at times electron may be knocked out from neutral atom

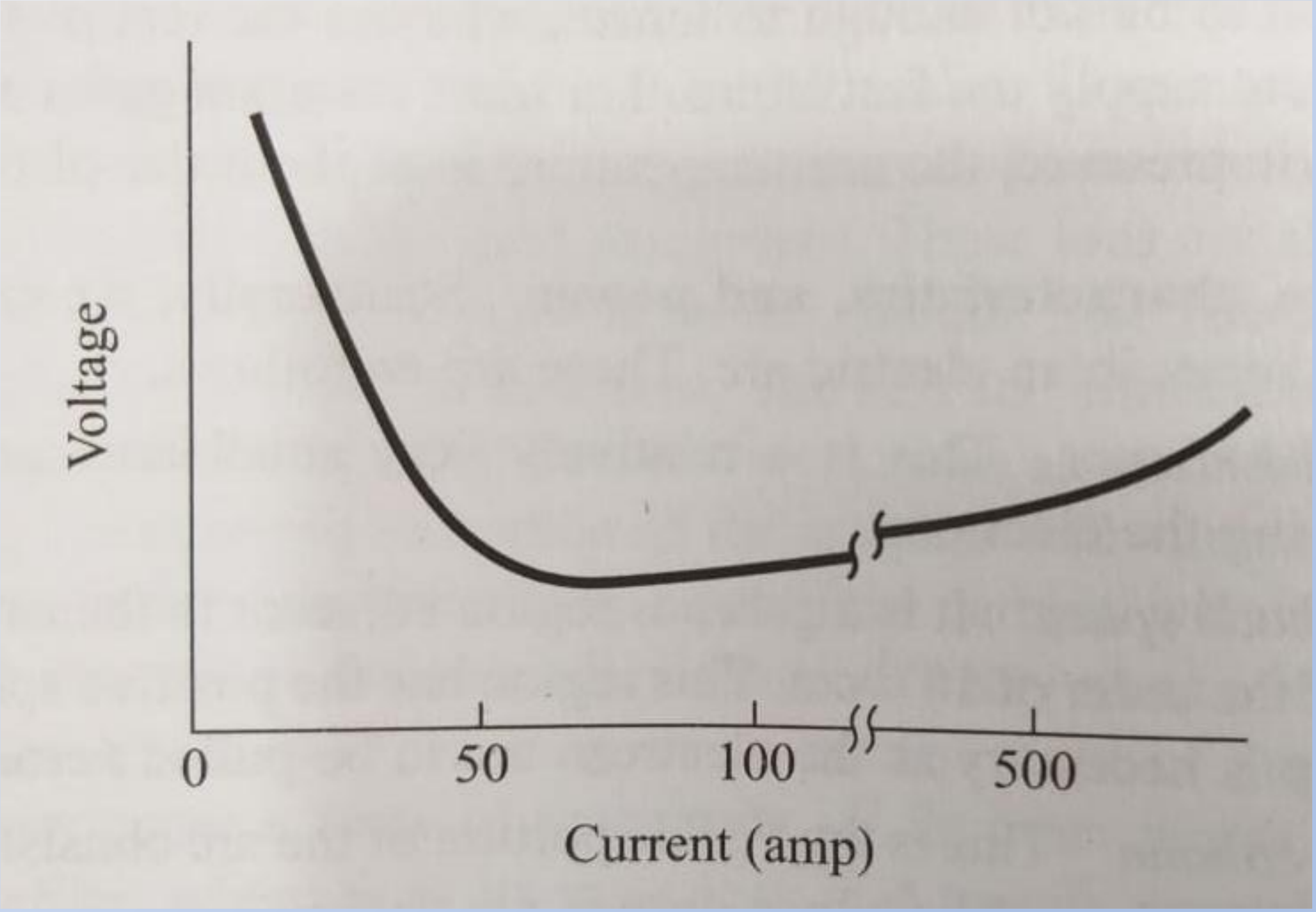
Primary electron carry most of the current for tungsten and carbon while for copper and aluminum it is secondary electron



Potential across arc space

- Cathode spot: Small area on cathode surface, emitting electrons
- Cathode space: Gaseous region in order of 0.1 mm. This space has positive space charge, so some voltage drop
- Arc column: visible portion of arc
- Anode space: Drop in voltage. e- have to penetrate the anode surface after overcoming repulsion from thermionically emitted electrons
- Anode spot: electrons are absorbed.

Current voltage characteristics



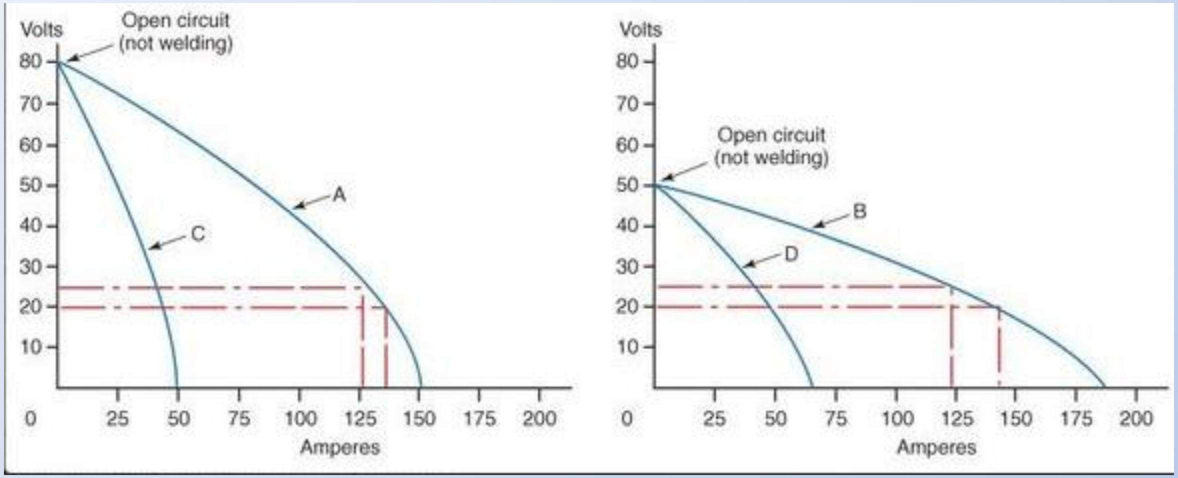
Current Voltage characteristics

Surface to volume ratio decreases with increase in radius

Volt-amperage characteristics

- Arc welding involves low voltage high current between the electrode and workpiece.
- Power generating utility: transformer, electric generator etc
- Effectiveness of voltage-amperage characteristics is determined by **static as well as dynamic characteristics**
- Static characteristics: Measured under static condition using conventional test procedure. A set of output voltage v/s output current describe the characteristics. **Two types: Constant current and constant voltage**
- Dynamics characteristics: determined by measuring for very short duration (0.001 s) transient variation in output voltage and current that appear in arc itself.
- Dynamic condition arises due to change in conditions such as striking of the arc, rapid change in arc length, transfer of molten metal, arc extinction and reignition at each half cycle (For AC only)
- Power supplies must be capable of dealing these by: storing energy in parallel capacitors, using feedback control etc

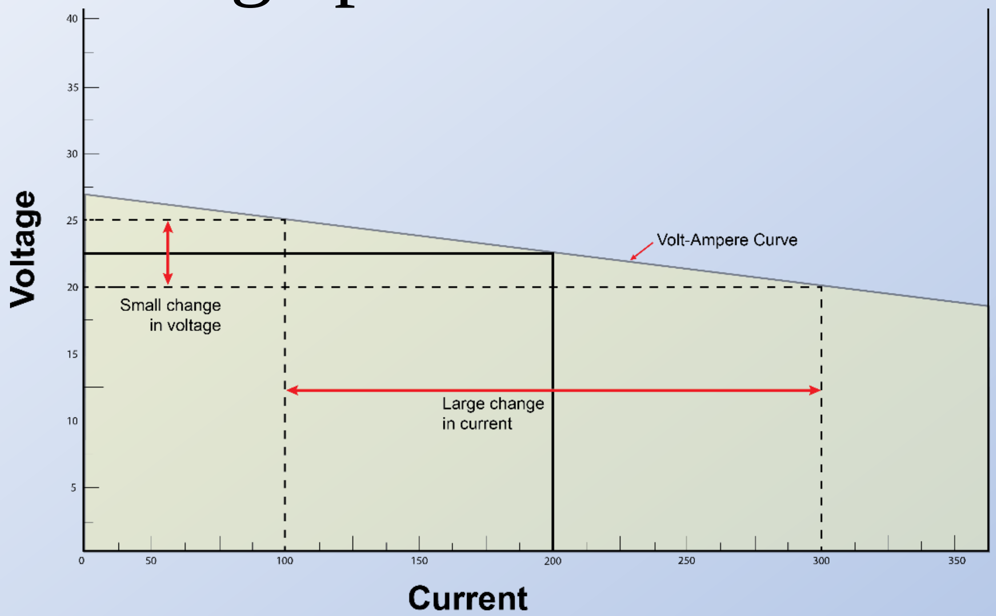
Constant current power source or drooping



Volt-ampere output for CC characteristics

- This is also called as drooping source or droopers
- Change in voltage leads to minimal change in the current
- It is mainly used for manual welding such as SMAW or GTAW

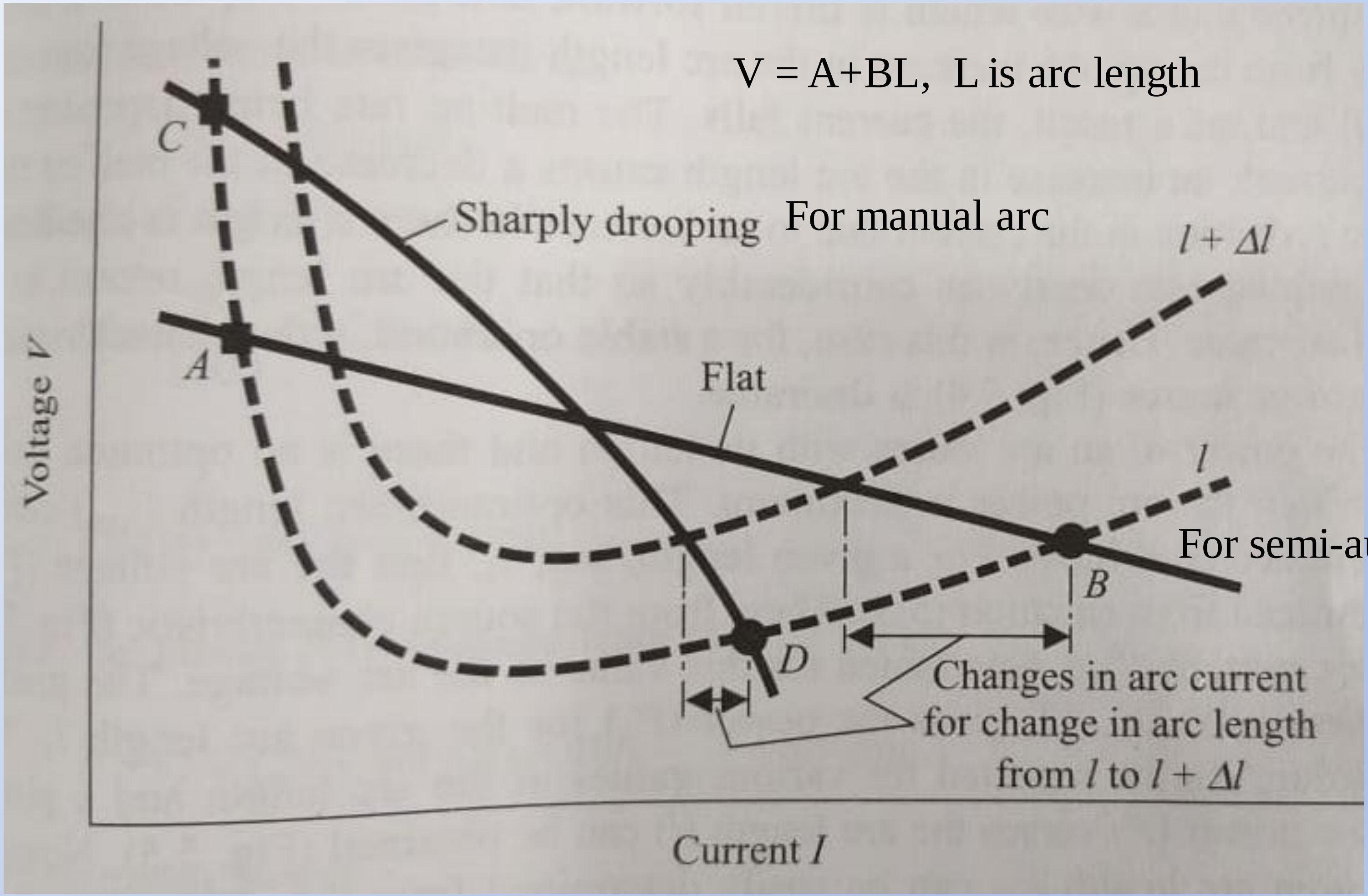
Constant voltage power source or drooping



Volt-ampere output for CV characteristics

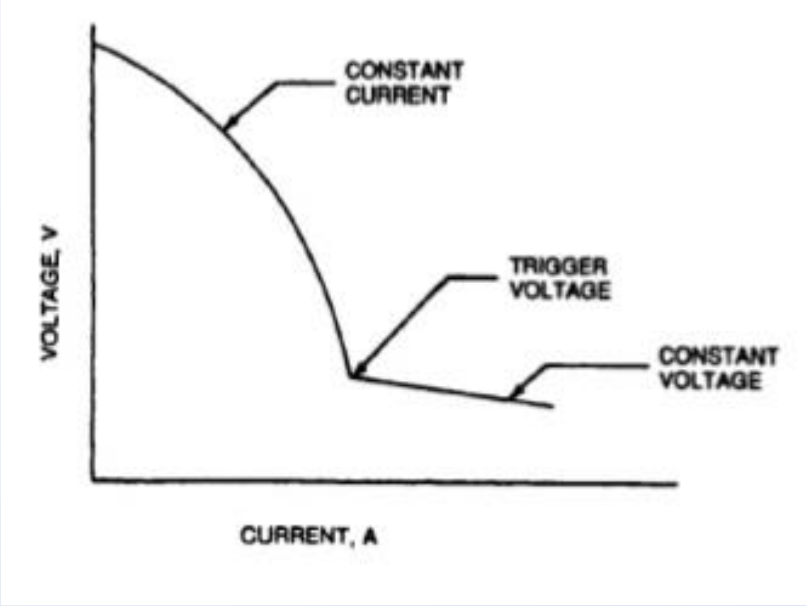
- Minimal variation in the voltage
- It is mainly used for continuous fed electrode such as GMAW, FCAW, SAW to maintain arc length
- A small change in arc length changes a large change in current and hence the melting rate. This is called self-regulation

Change in arc current for a change in arc length



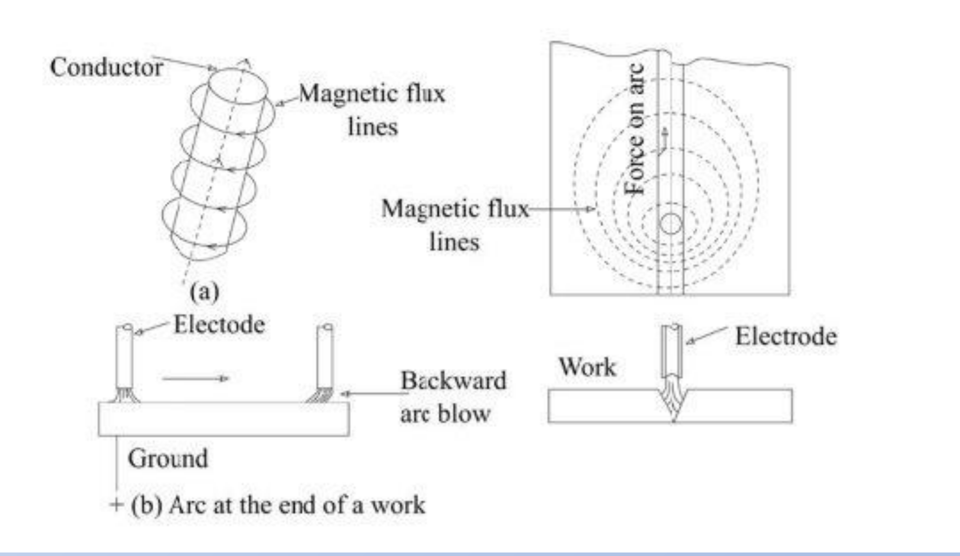
Duty cycle: The percentage of time in a 10 minutes period that a welding machine can be used at its rated output

Combined characteristics



Arc blow

- Deflection of arc by means of the magnetic field setup due to the flow of the welding current

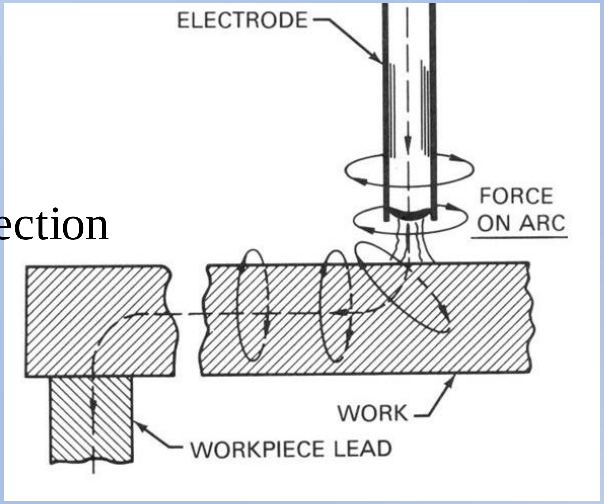


Arc blow arises due to

- Change in direction of current flow as it leaves the arc and enters the workpiece to seek ground
- Asymmetric arrangement of magnetic materials around the arc

Solution:

- Use of AC current instead of DC
- Putting up additional piece of metal block to avoid deflection



Arc blow effect due to ground effect

Molten metal shielding

- It is important to shield molten metal from gas-metal reaction
- Reactiveness is very high with molten metal, but it is also high when it is solid but red hot
- Cleaning and shielding must be accompanied simultaneously
- Shielding approaches:
  - protective/shielding gas,
  - chemical reduction or protective molten slag,
  - protective vacuum
  - Cleansing self-fluxing action

Shielding Gas

- Helium, carbon dioxide, argon and mixture of above gases
- Argon has higher density than air as compared with Helium which has lower density
- Argon reduces spatter and concentrates the arc and hence give higher penetration
- Helium has a better conductivity and hence useful for thicker sheets and for material with higher thermal conductivity
- Arc with CO_2 is unstable therefore shorter arc is used. Generally produces globular metal transfer

- Slags
  - Slag is unwanted material produced during melting of metal ores
  - Flux once reacted is called as slag. Flux is coated on electrode
  - Function:
    - Dry flux melt in the electrode melt in the heat and forms a protective shield on the molten metal pool.
    - Removing nonmetallic impurities from the molten metal in the weld pool by scavenging

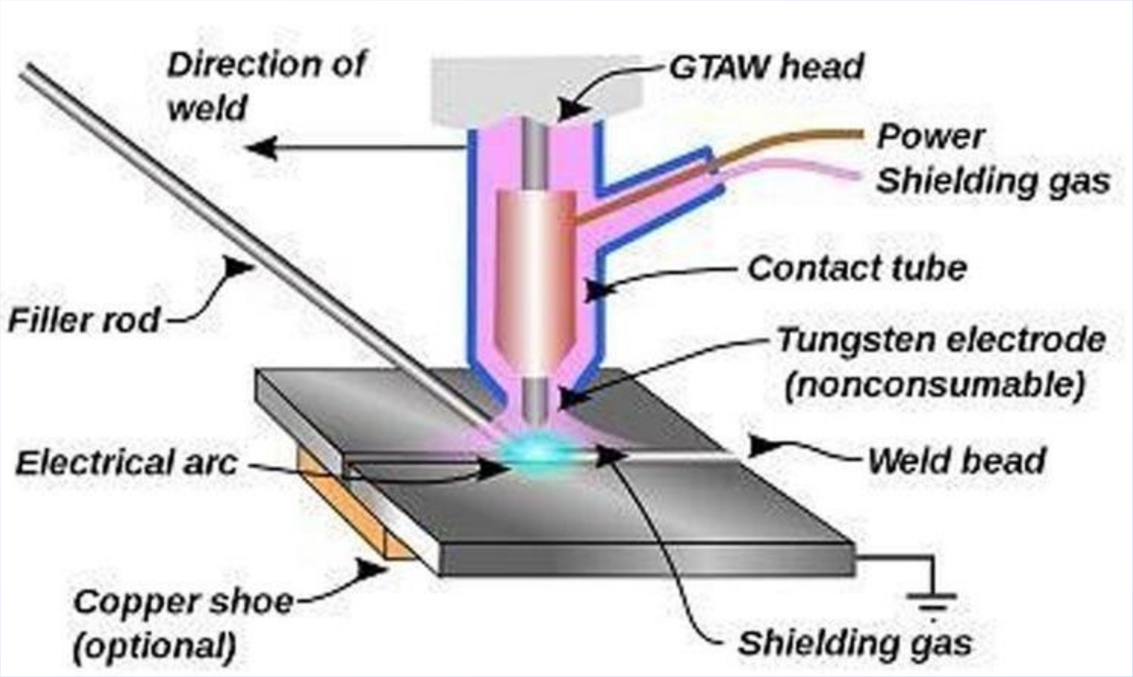
- Vacuum
  - Sure shot way to avoid interaction between gas and weld pool
  - Useful for only handful processes such as EBW

- Self-fluxing action
  - Through wetting between substrate and molten metal
  - Example resistance welding, upset welding etc

Arc welding with non-consumable electrode

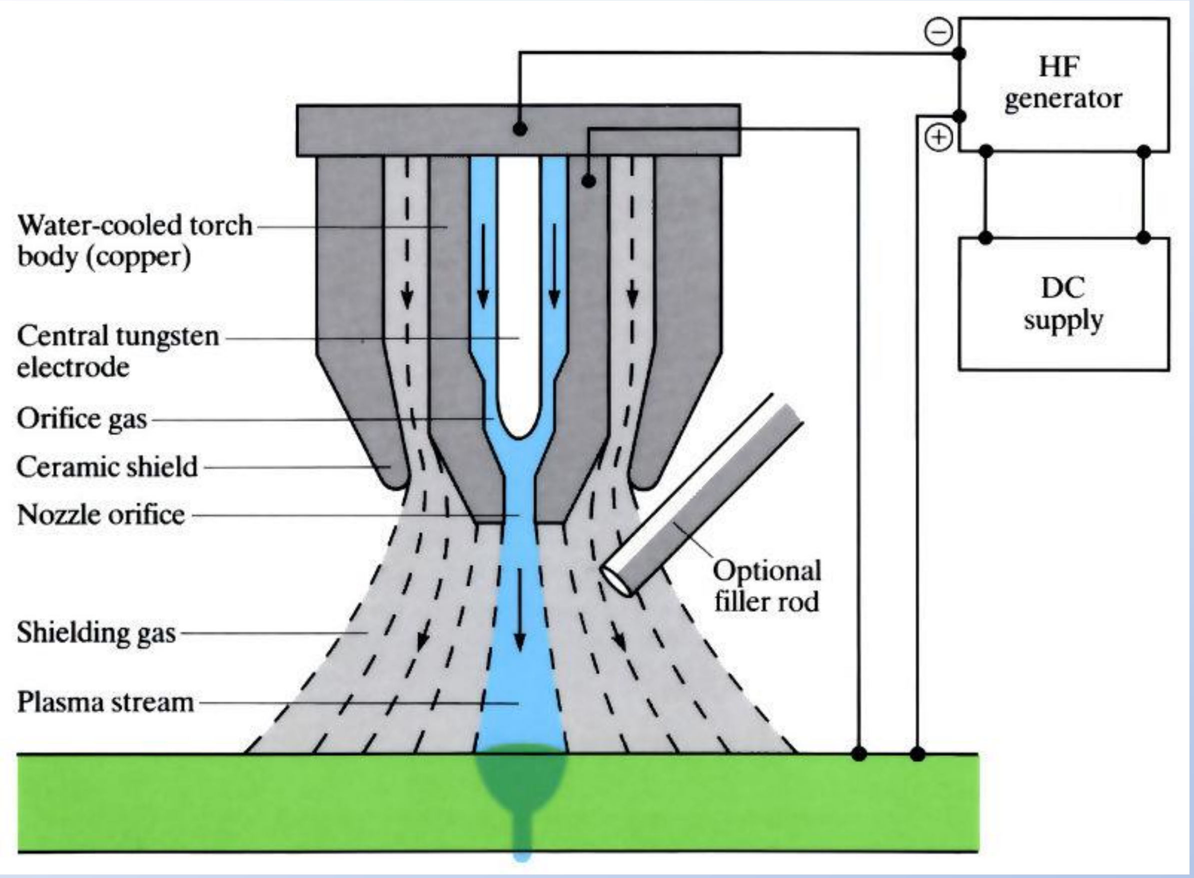
- Gas tungsten arc welding (GTAW) or TIG
- Plasma arc welding
- Carbon arc welding
- Stud arc welding
- Magnetically impelled arc butt welding

TIG Welding



- Non consumable electrode
- Normally DC is used with Tungsten electrode as cathode
- For Al and Mg, AC arc is used
- To increase melting point and current carrying capacity of electrode thorium or zirconium is added to the tungsten electrode
- Ar is used as shielding gas, N_2 is preferred for welding of Copper.
- This process is costly

Plasma arc welding

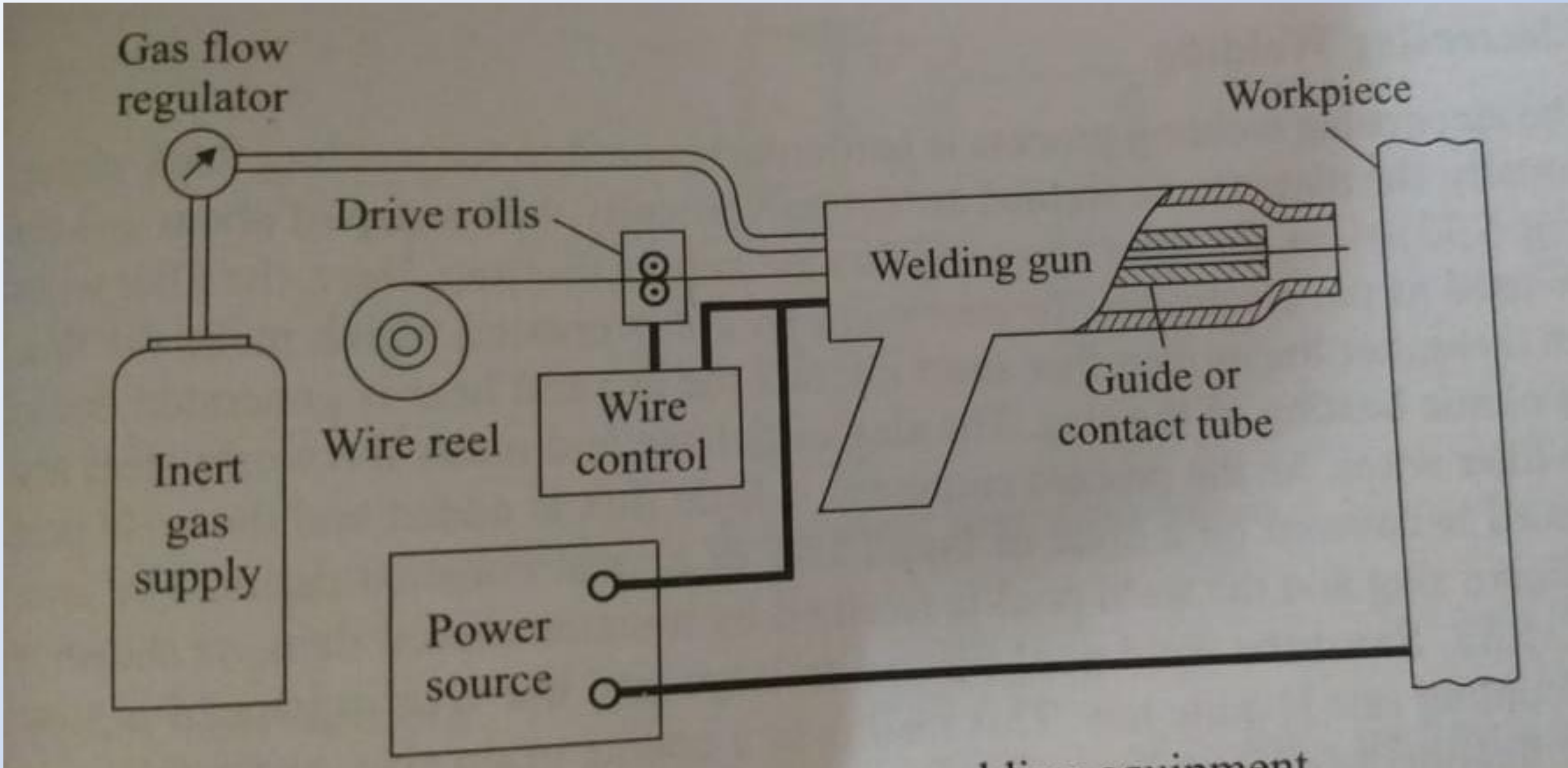


- Similar to TIG with a difference that there is a converging action of inert gas at an orifice of nozzle
- This results in advantages such as higher heat content, deeper penetration, higher welding speed

- Plasma is created by flow of argon through inner orifice and a pilot arc is generated between the electrode and the orifice and this ignites primary arc to the workpiece
- Transferred arc mode: Plasma is drawn toward the workpiece when it is electrically connected
- Modes of welding: melt-in and keyhole

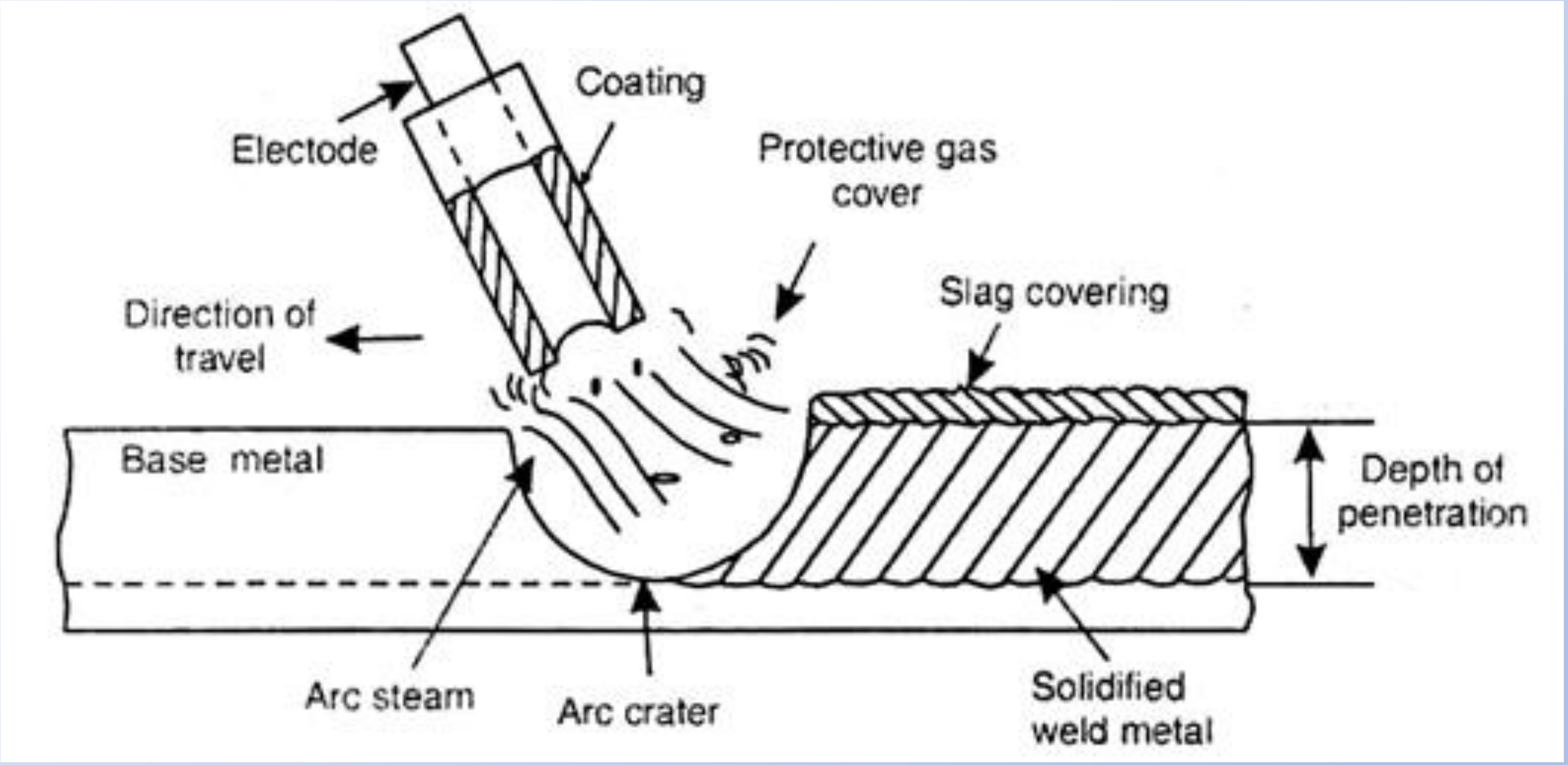
- **Consumable electrode arc welding**
  - Gas metal arc welding (GMAW) or Metal inert gas welding (MIG)
  - Shielded metal arc welding
  - Flux cored arc welding
  - Submerged arc welding

MIG Welding



Consumable electrode, preferred for thick material because of usage of consumable electrode, High deposition rate (5-20 kg per hour)

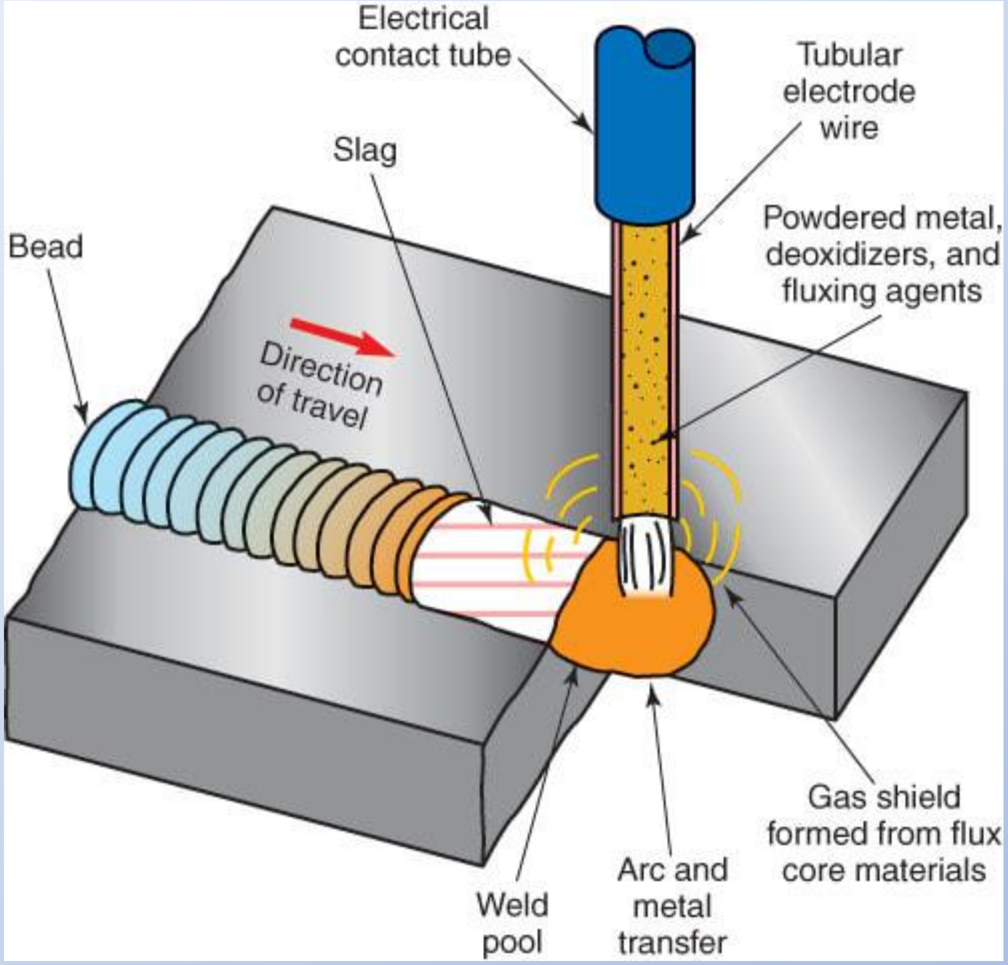
Shielded metal arc welding or stick welding



Type of coating: Cellulosic coating, rutile coating, iron oxide coating and basic or low hydrogen coating ($CaCO_3$ and Caf_2)

In general cellulose, rutile and basic coating lead to short circuit

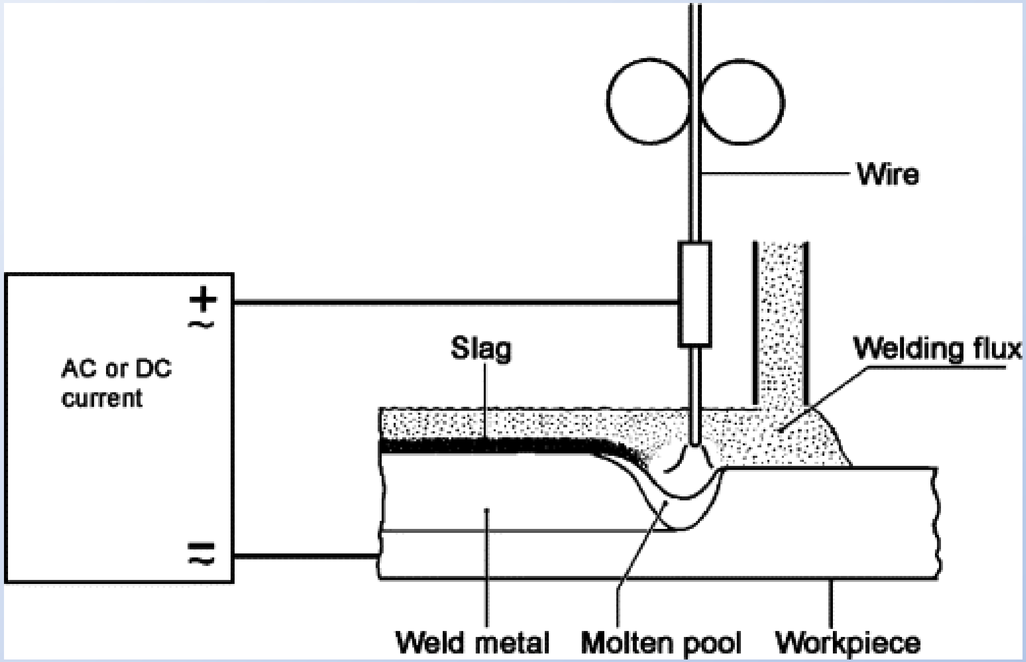
Flux cored arc welding



- Flux is contained in the roll formed and drawn from tubular wire
- Shielding is more effective
- Higher deposition rate of 2-15 kg/hour
- Can be operated at higher current as compared with SMAW

Submerged arc welding

Submerged arc welding

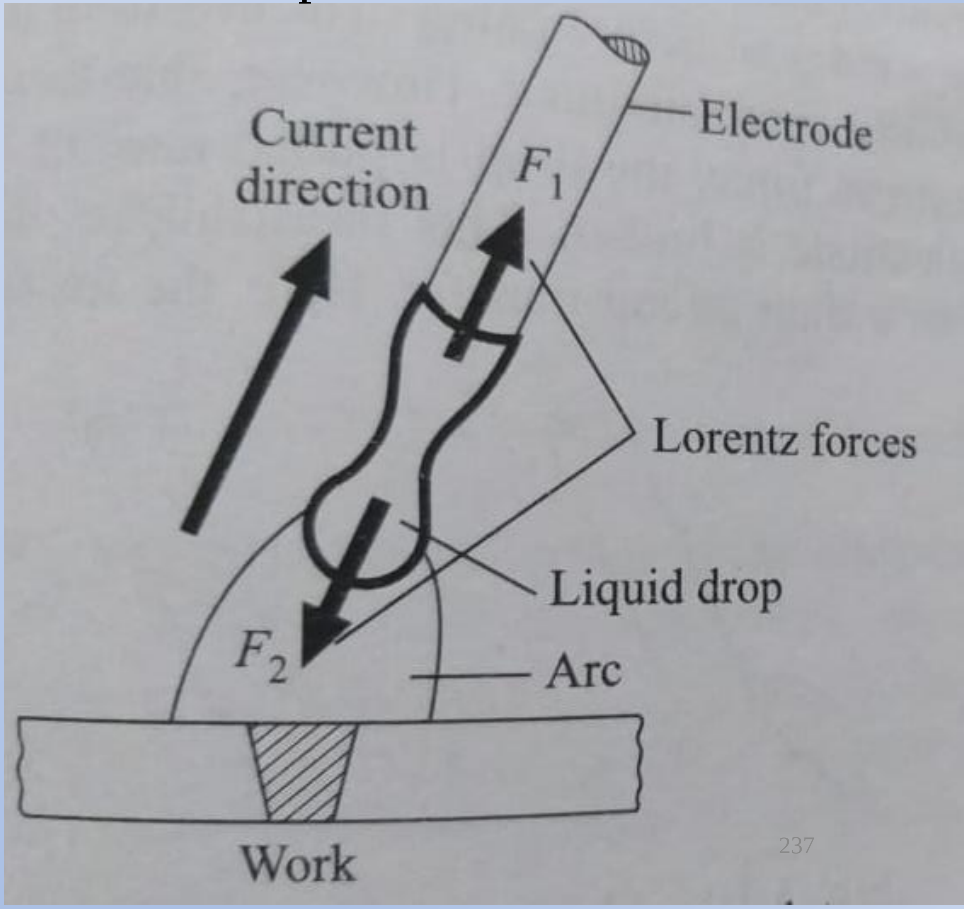


Advantages

- Strong, sound welds are readily made
- Minimal welding fume is emitted
- Less distortion
- Deep weld penetration
- Minimal edge preparation
- High deposition rates are possible upto 27-45 kg/hour
- Thick materials may be welded

Modes of metal transfer in arc welding

- Forces acting on weld pool
  - Pressure generated by evolution of gas at electrode tip
  - Gravity
  - Surface tension
  - Electromagnetic interaction
  - Hydrodynamic action of plasma



Gravity

Gravity is a detaching force when the electrode is pointed downwards as in down-hand welding, and a retaining force when it is pointed upwards as in overhead welding.

$$F_g = m.g$$

$$= \rho.V.g$$

ρ Density of metal

V Volume of metal drop

g Gravitational constant

Surface tension

This force is experienced by drop of the liquid metal hanging at the tip of electrode due to surface tension effect.

Surface tension tends to retain the molten droplet at the tip of the electrode.

$$F_s = 2\pi\gamma r \times f\left(\frac{r}{c}\right)$$

$$c = \sqrt{\frac{2\gamma}{mg\rho}}$$

γ	Surface tension	c	Constant of capillarity
r	Electrode radius	$f\left(\frac{r}{c}\right)$	Complex function

Electromagnetic pinch effect

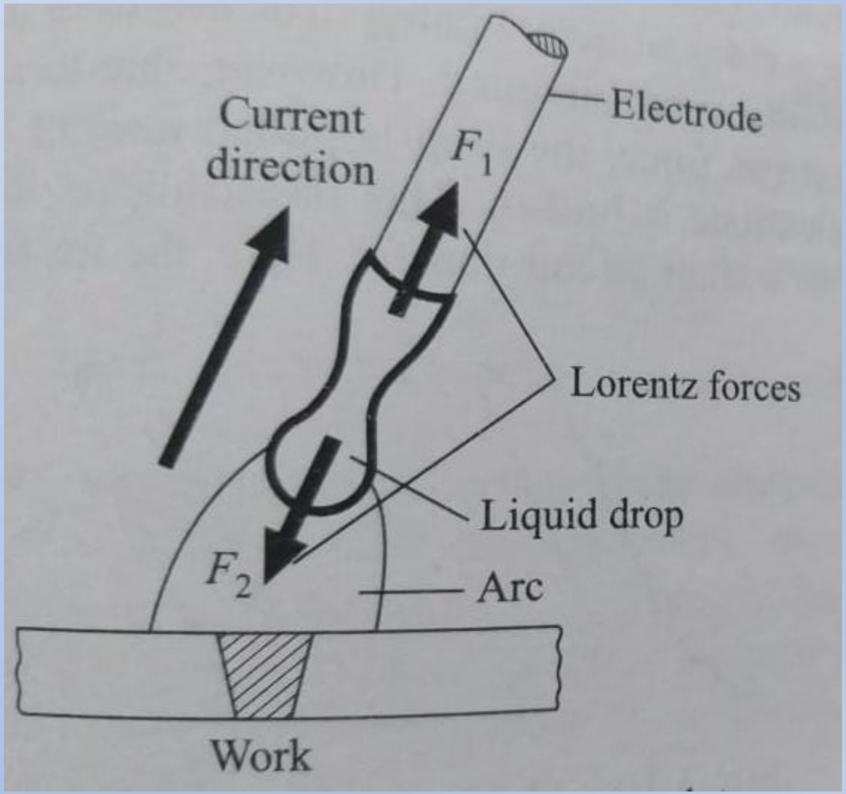
Flow of current through the arc gap develops the electromagnetic field. Interaction of this electromagnetic field with that of charge carriers produces a force which tends to pinch the drop hanging at the tip of the electrode

$$f_p = \frac{100\mu I^2}{8\pi^2 R^2}\left(2 - \frac{r^2}{R^2}\right)$$

μ Magnetic permeability

I Electric current

R Conductor radius



Drag force or gas pressure

A drag force due to the flow of gas around the drop helps in detaching the droplet from the electrode tip.

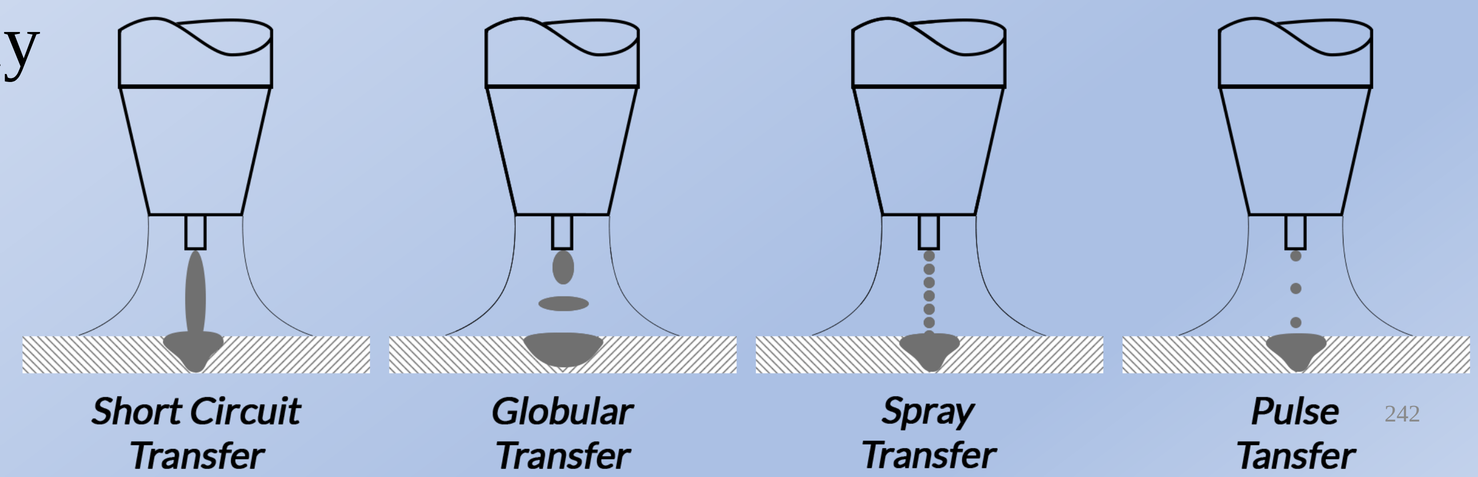
The magnitude of this force may be affected by the amount of gas flow in GMAW.

Metal transfer types

Free-flight transfer: molten metal drop completely detaches from the electrode tip before falling to the weld pool. No physical contact between electrode and weld pool.

Globular transfer, Spray transfer, Pulsed spray transfer

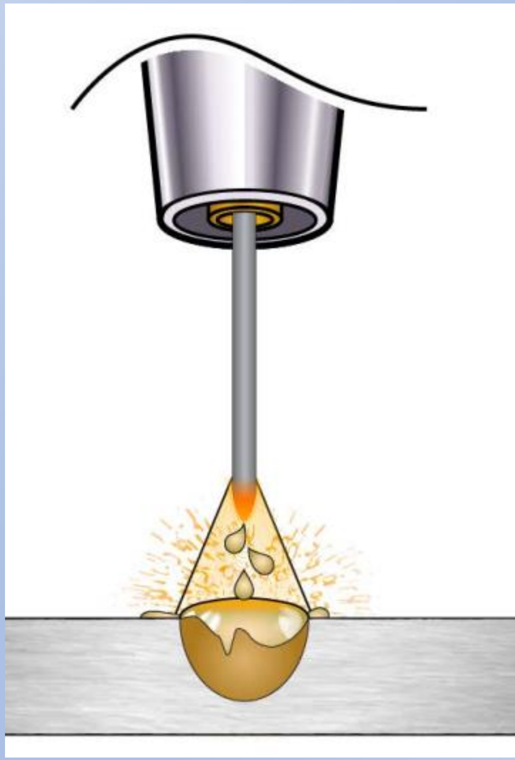
Short circuit transfer: molten metal drops are never completely free; rather they are always attached to the consumable electrode and the work piece, momentarily bridging the two from a material standpoint -and electrically



Metal transfer in welding

Globular transfer

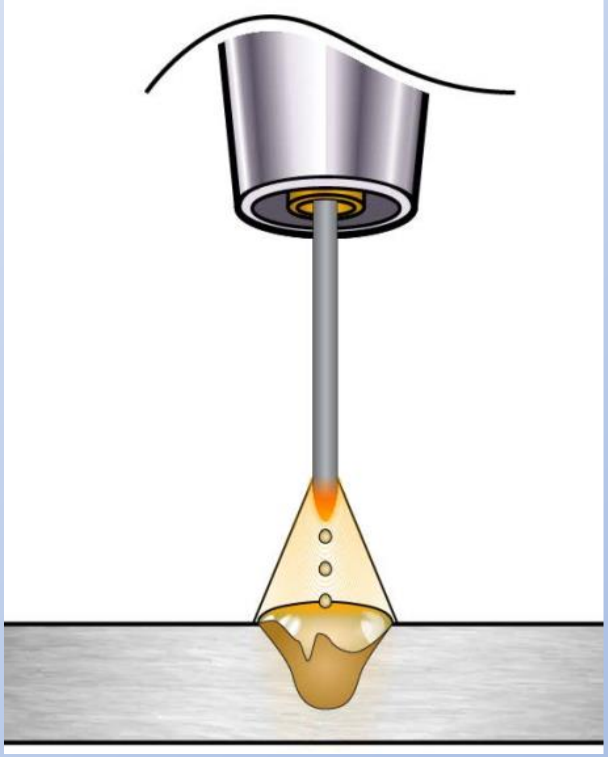
- The weld metal transfers across the arc in gravity-assisted large droplets.
- Globular transfer characteristically gives the appearance of large, irregularly shaped molten droplets that are larger than the diameter of the electrode
- At low welding current (50-170 A) and small diameter electrodes (1-1.3 mm)
- The transfer mode is associated with the use of 100 percent CO_2 shielding, but it has also seen heavy use with argon/CO_2 blends.
- Suitable position is flat and horizontal



Limitation of Globule transfer

- High spatter level reduces electrode efficiency to a range of 87 - 93 percent.
- A less desirable weld appearance than spray or pulsed spray transfers
- Unsuitable for vertical and over head position
- Welding limited to 3 mm or higher metal plate

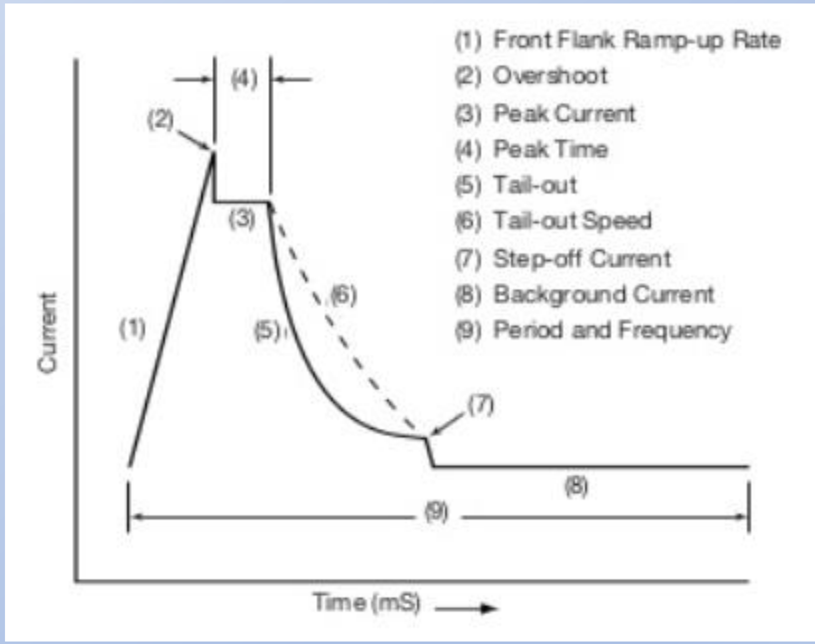
Spray transfer



- When welding current crosses a critical value
- In the spray mode of transfer, filler metal is transferred across the arc in a continuous, directed stream of fine (smaller than the wire diameter) droplets.
- Spray transfer involves hundreds of drops per second.
- High voltage, wire feed speed and amperage compared to globular transfer
- Argon-rich shielding gas is suggested

Pulsed spray transfer

- High peak currents (amperage) which are set at levels which will cause the transfer to go into a spray.
- The background current (amperage) is set at a level that will maintain the arc, but is too low for any metal transfer to occur.
- This mode of transfer can be used to weld out of position on thick sections.



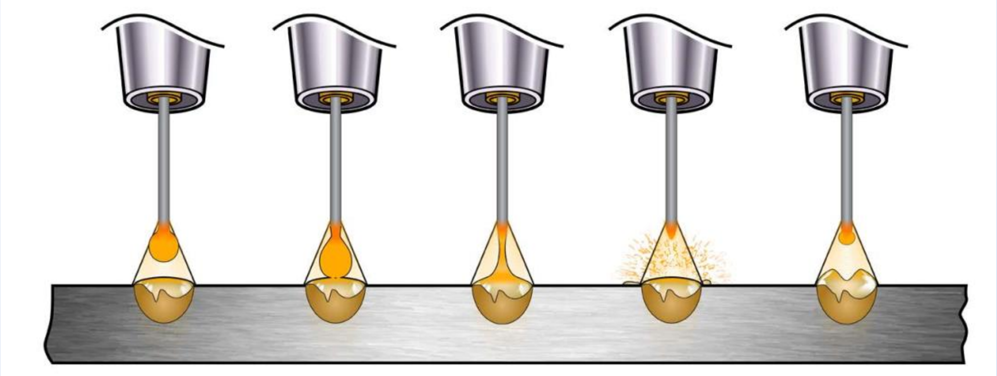
Advantages

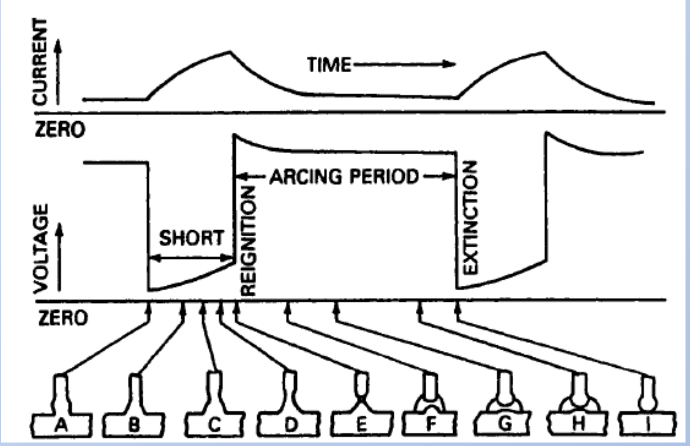
- Negligible spatter
- Excellent weld bead
- Reduced level of heat induced distortion
- Lower tendency of arc blow
- Higher electrode efficiency 98%
- Out of position weld

Limitation

- Expensive equipment
- More cost for shielding gas
- Additional safety requirement for bystander

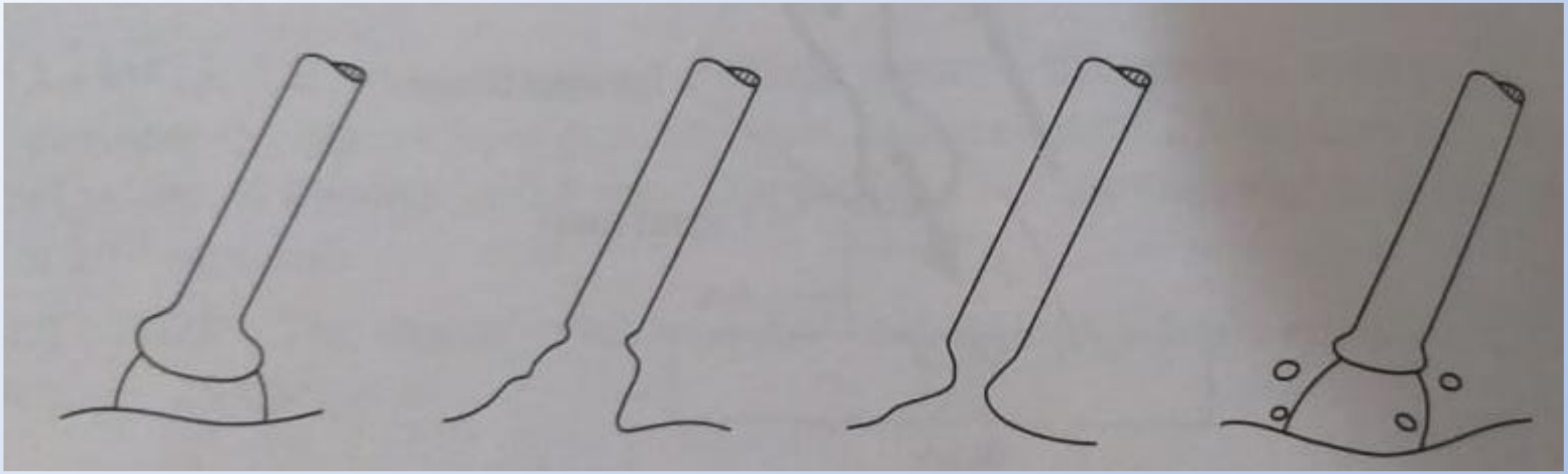
Short circuit transfer





- Periodic bridging of the gap between the electrode and the workpiece resulting in arc getting extinguished.
- Consequently heavy flow of current occurs which results in increased heating of the bridge.
- Decreased viscosity and surface tension, increased electromotive and hydrodynamic forces result in the transfer of molten metal from the electrode to the weld pool.

- Short circuiting transfer



This method is independent of gravity, so preferred for overhead welding but can be Used for all welding positions

Advantages

- All-position capability, including flat, horizontal, vertical-up, vertical-down and overhead
- Handles poor fit-up extremely well, and is capable of root pass work on pipe applications
- Lower heat input reduces weldment distortion
- Higher operator appeal and ease of use
- Higher electrode efficiencies (93 percent or greater)

Parameter setting for GMAW

The machine settings used for GMAW process

Electrode diameter (mm)	Mild steel and low-alloy steels				Aluminium alloys			
	Short-circuit transfer		Spray transfer		Short-circuit		Spray transfer	
	Voltage (V)	Current (A)	Voltage (V)	Current (A)	Voltage (V)	Current (A)	Voltage (V)	Current (A)
0.8	15–21	70–130	24–28	150–265	15–18	45–120	22–28	90–150
0.9	16–22	80–190	24–28	175–290	17–19	50–150	22–28	100–175
1.2	17–22	100–225	24–30	200–315	16–20	60–175	22–28	120–210
1.6	—	—	24–32	275–300	—	—	24–30	160–300
2.4	—	—	24–33	350–600	—	—	24–32	220–450

Variation of temperature with time and distance

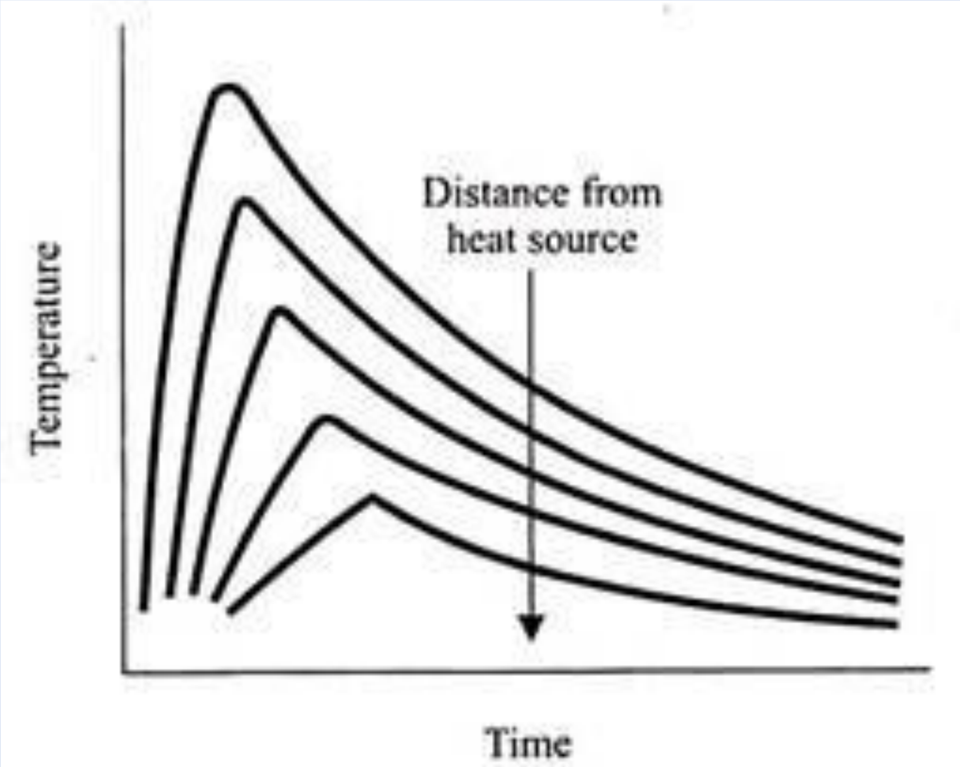
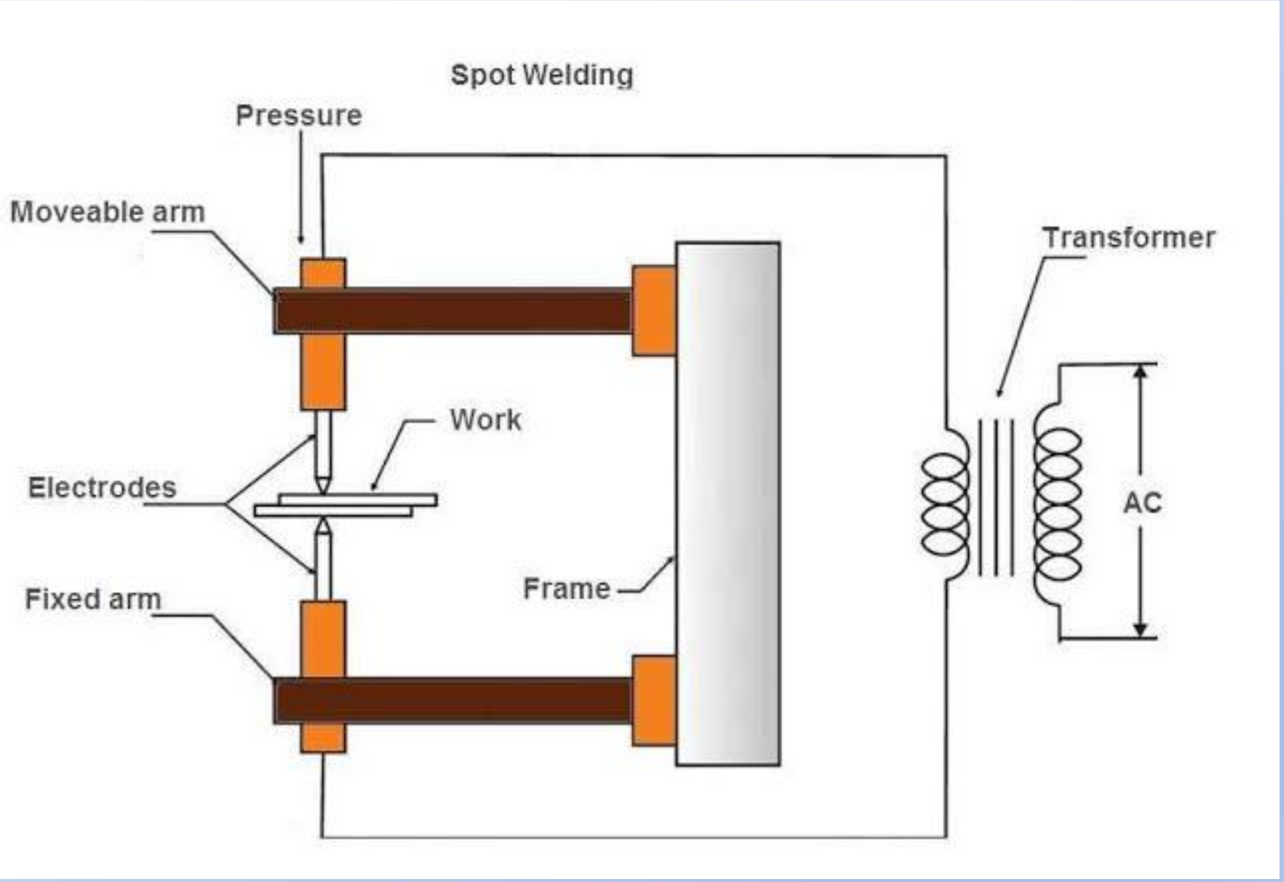


Fig. 5.13 Variation of temperature with time at different distances from source.

Resistance welding

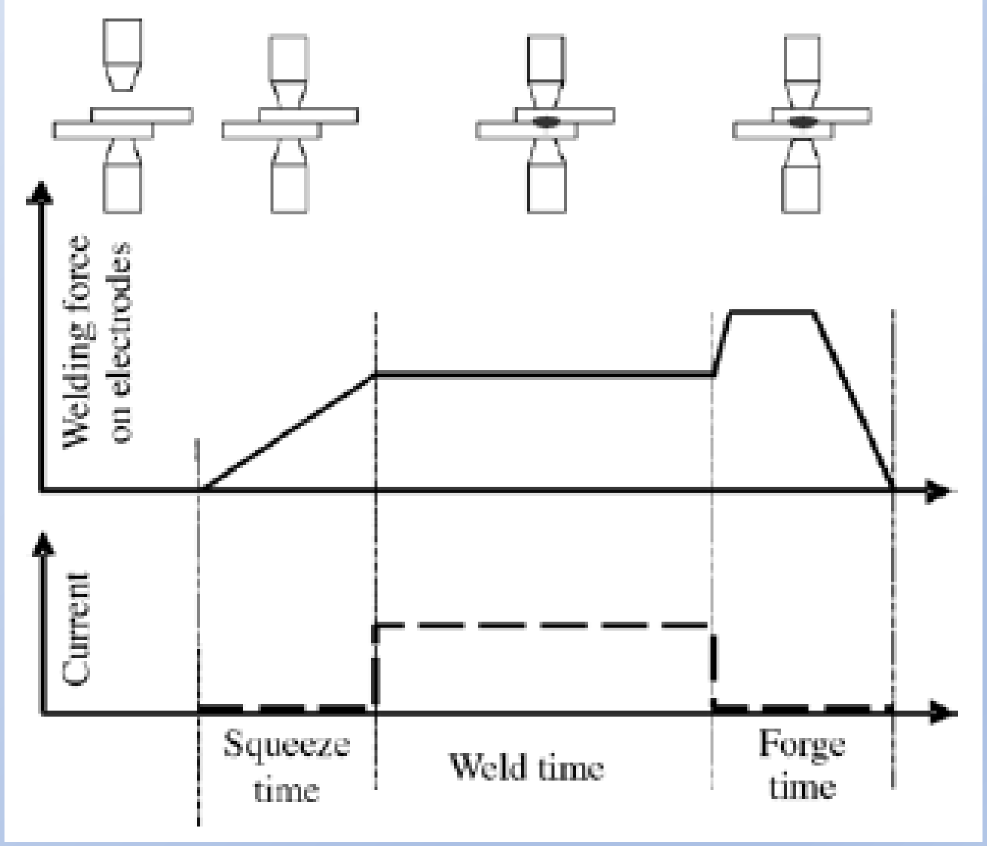
- A very low voltage and high current (typically 15kA) is passed through a joint for short duration.

Spot welding

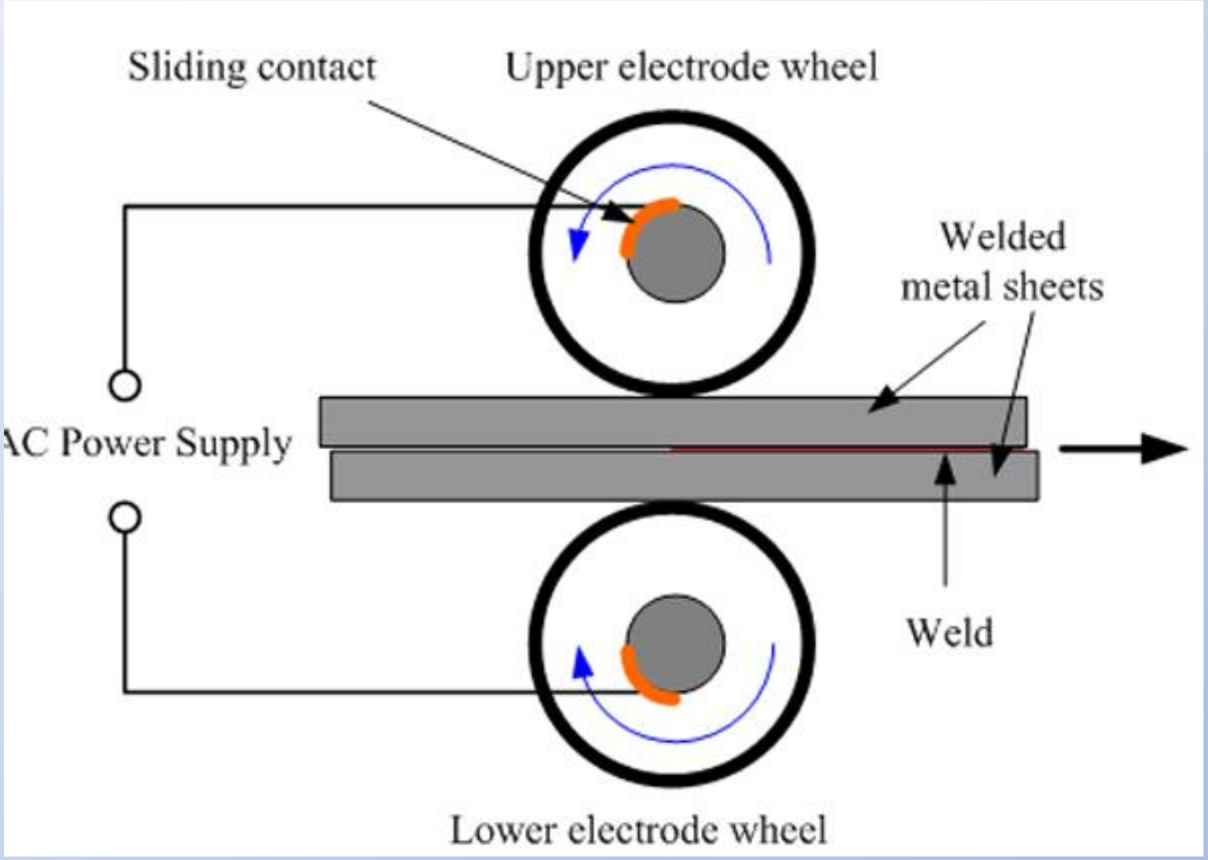


Electrode material: high electrical conductivity and hardness: Generally copper is used

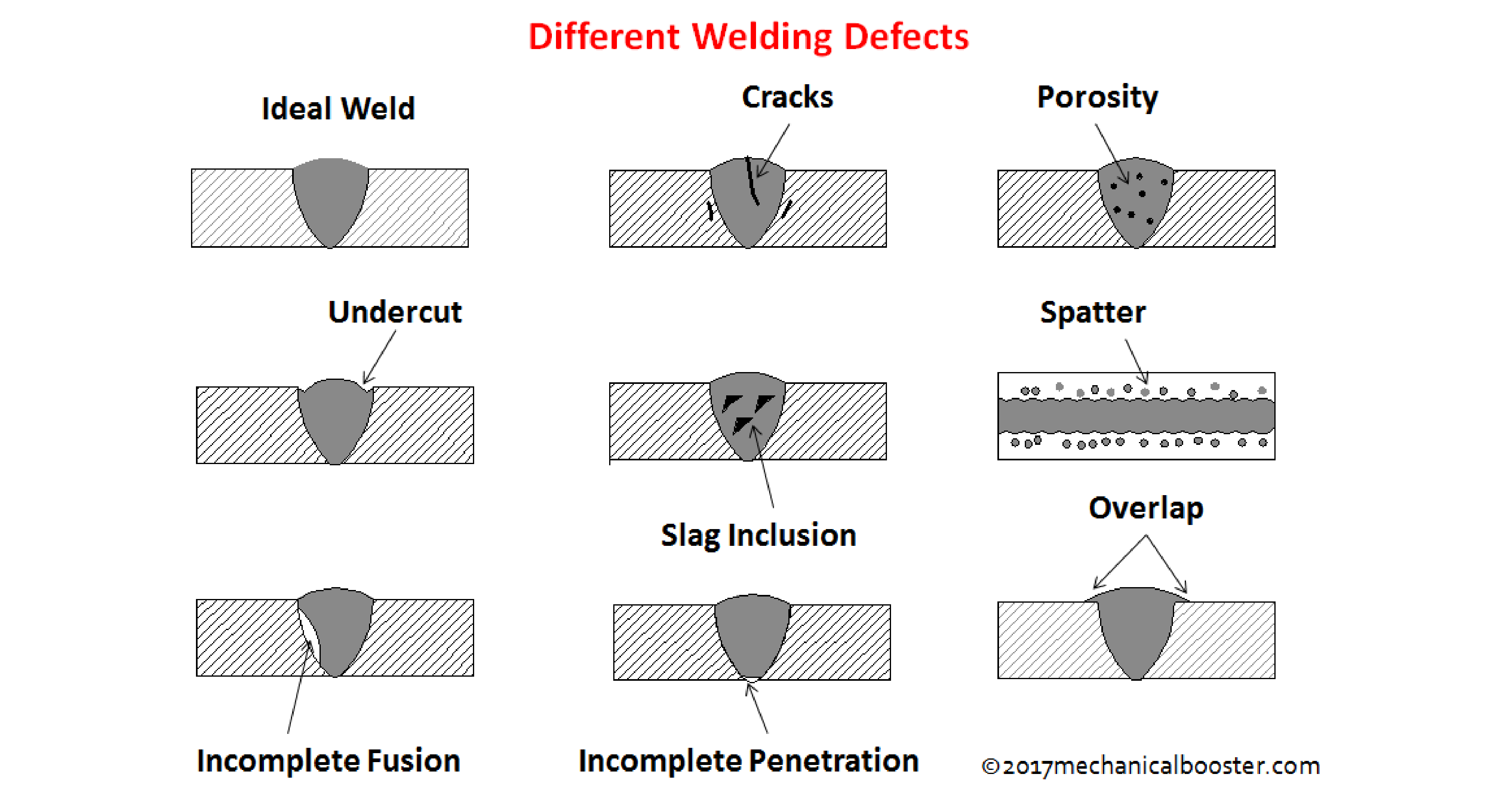
Advantages	Disadvantages
Well suited for mass production	Machine is complicated
Little skill set is required as mostly it is automated	Only lap position is possible
No consumables	Thick material cannot be welded
Localized heating i.e. low distortion	
Weld dissimilar as well as different thickness	



Seam welding



Defects in welding



Solid state welding

- Ultrasonic welding
- Explosive welding
- Friction welding
- Friction stir welding

Ultrasonic welding

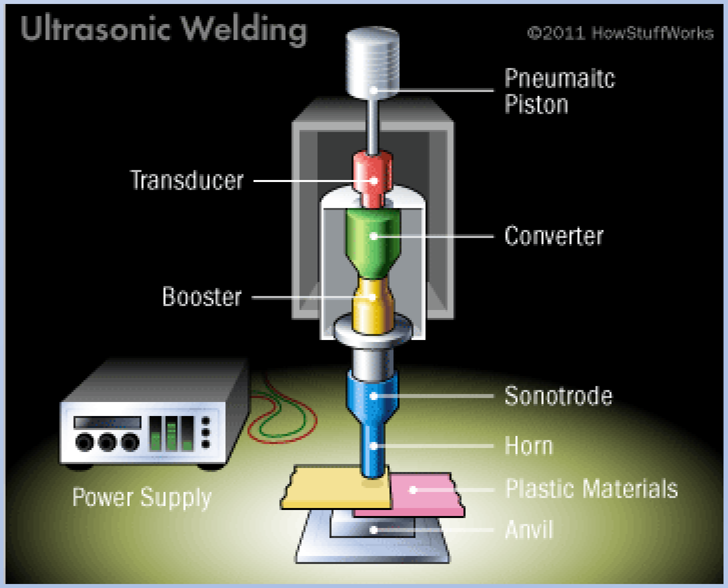
Uses high frequency (20-50 kHz) ultrasonic vibration

Componenets

Transducer: Produces high frequency ultrasonic vibration

Booster: Amplify the received frequency if required

Horn: Increases the amplitude by creating the resonance



Ultrasonic welding

• High frequency current passes through a piezoelectric transducer. This transducer converts high frequency electrical signal into mechanical vibration.

•This vibration further supplied to the booster which amplify its frequency.

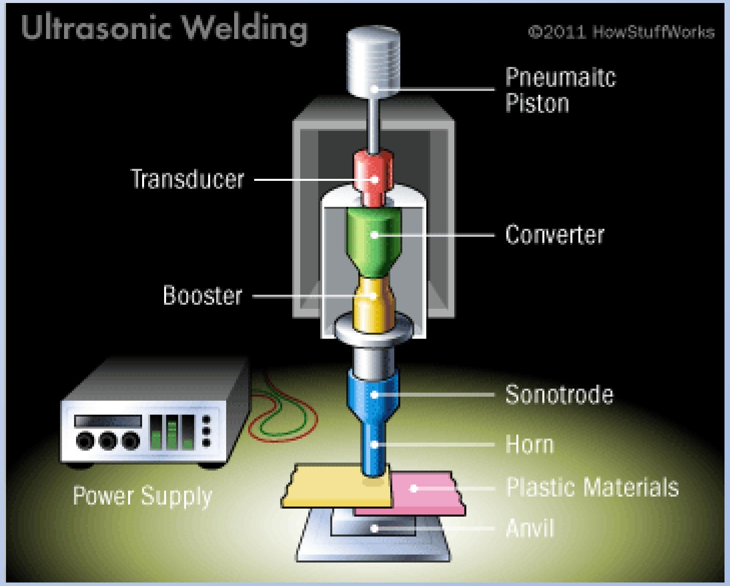
•The amplified high frequency vibration passes through horn which is in contact with welding plate.

•This welding creates lap joint. One plant of the weld is fixed into fixture and other one is in direct contact with horn. These plates are fixed under moderate pressure force.

•The horn supply high frequency mechanical vibration to the welding plate.

•Oscillation shear force act at the interface between welding plates which result elesto-plastic deformation at interface

Local plastic deformation and heat due to friction



Local plastic deformation
and heat generation due to friction

USW

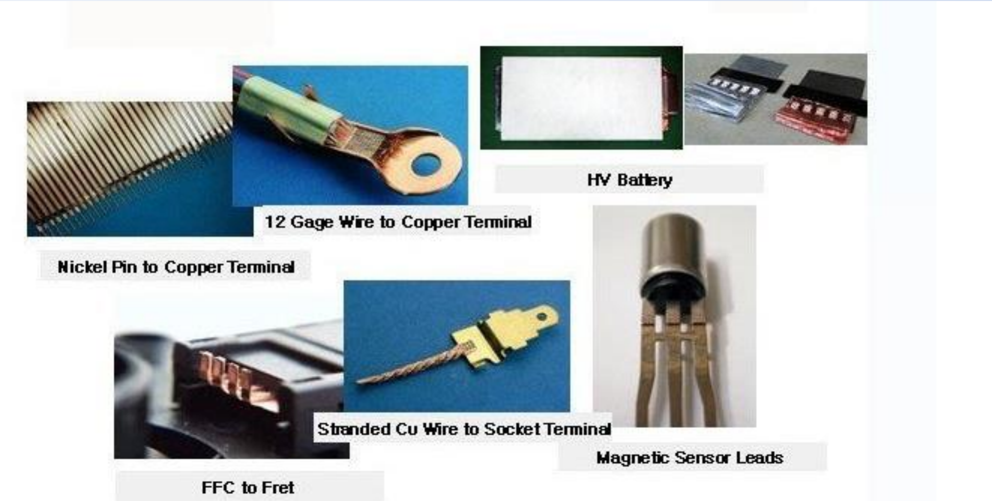
Advantages

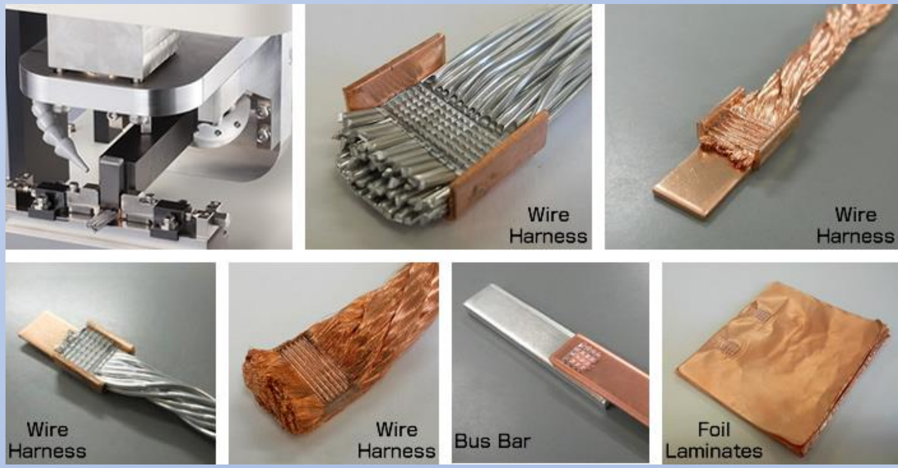
- ✓Very fast process
- ✓Delicate part can be welded
- ✓ Clean, reliable and accurate
- ✓ No consumables are required
- ✓ Lowest energy requirement
- ✓ Lower maintenance

Disadvantage

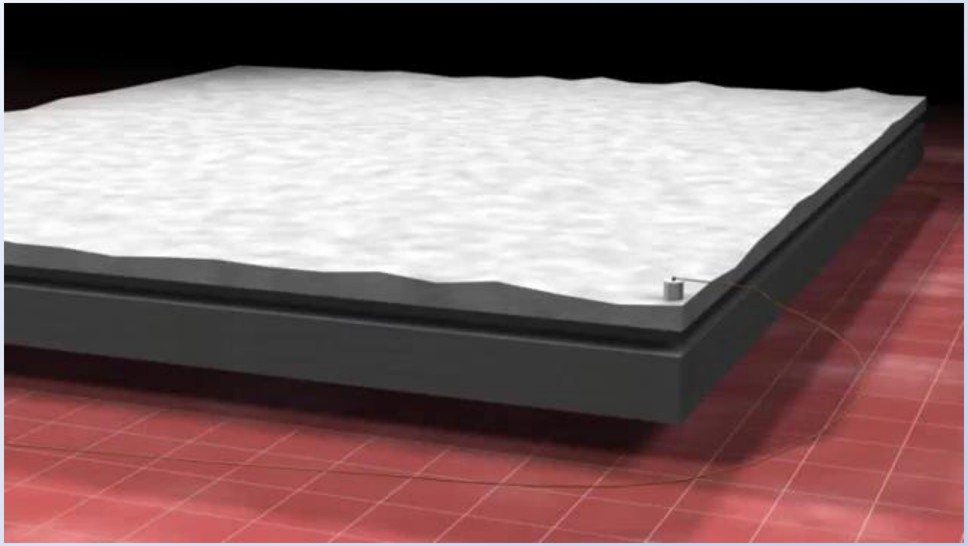
- × Difficult to weld thick harder material
- × Only lap weld can be performed

Application





Explosive welding



It is a solid state metal joining process that uses Explosive force to create electron sharing metallurgical bond.

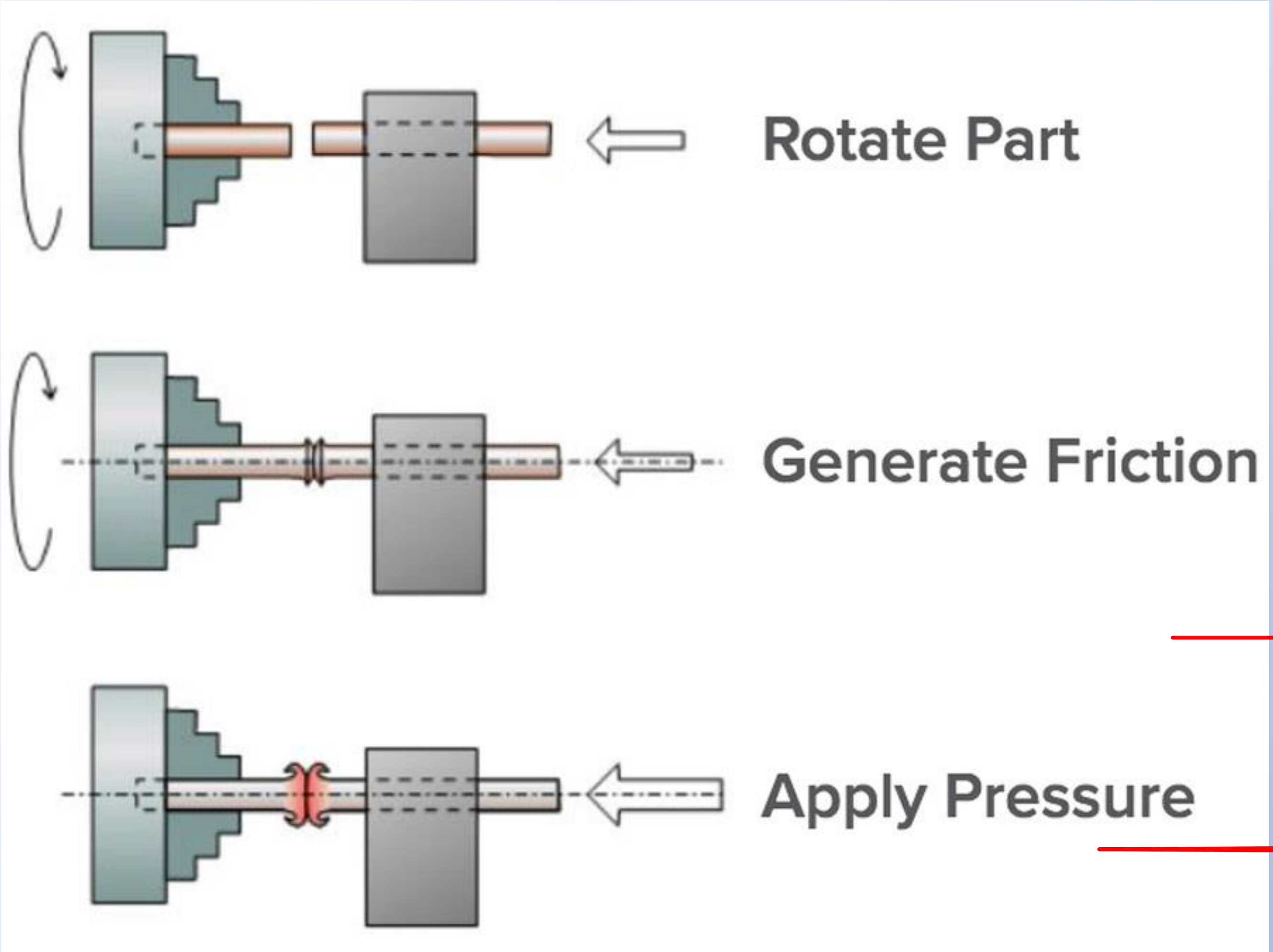
Used for cladding of high corrosion resistant material on low cost material for application such as chemical and petrochemical industries

$$V_d = 1440 + 4020\rho_e$$

Detonation velocity = 2000-5000 m/s for nitroguanidine ($CH_4N_4O_2$)

$$P \propto V_d^2 \rho_e$$

Explosive pressure



Steps in rotary friction welding

Friction stir welding

Necessity is Mother of all Invention

MOTIVATION BEHIND FRICTION STIR WELDING

Human aspiration to curb fuel consumption

↓

Emphasis on weight reduction

↓

Use of lighter material like Aluminum, Magnesium etc

↓

Aluminum is difficult to weld with conventional methods

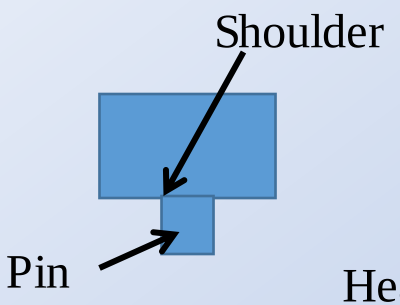
Hurdles in welding Aluminum

- $(H_2 \text{ solubility})_{liquid} > (H_2 \text{ solubility})_{solid} \longrightarrow$ porosity, blow holes
- Formation of aluminum oxide (M.P.-- 1950^{o}C), which is non conductive, brittle and hard
- **High thermal conductivity** leads to rapid heat distribution due to conduction within the material
- **High thermal expansion** (almost twice of steel) and high shrinkage volume (approx 6% of volume) increases distortion and weld crater size

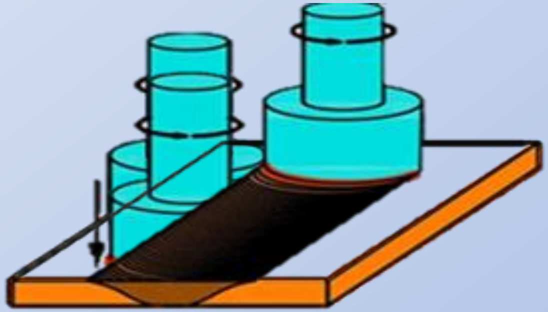
Existing Methods for Welding Aluminum

Welding Technique	Disadvantages
MIG and TIG	•High temperature@ HAZ; •Reduced strength of weld (40-50%) • High distortion
Laser welding	• Low absorption due to high reflectivity of aluminum • High energy input • Low operating efficiency and high initial cost
Friction Welding	•Use for bars of different cross- section • Only bars can be welded

Friction Stir Welding



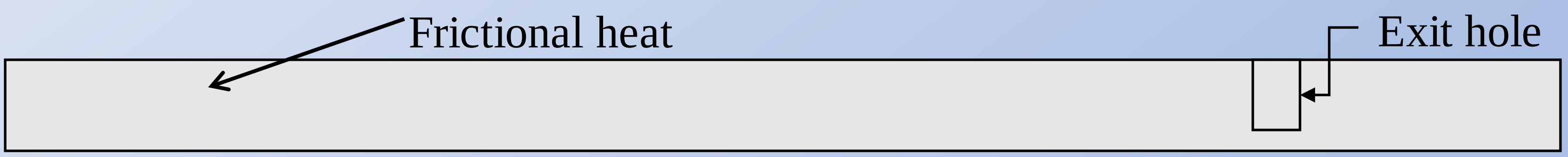
Plunging of tool.
Similar to drilling operation



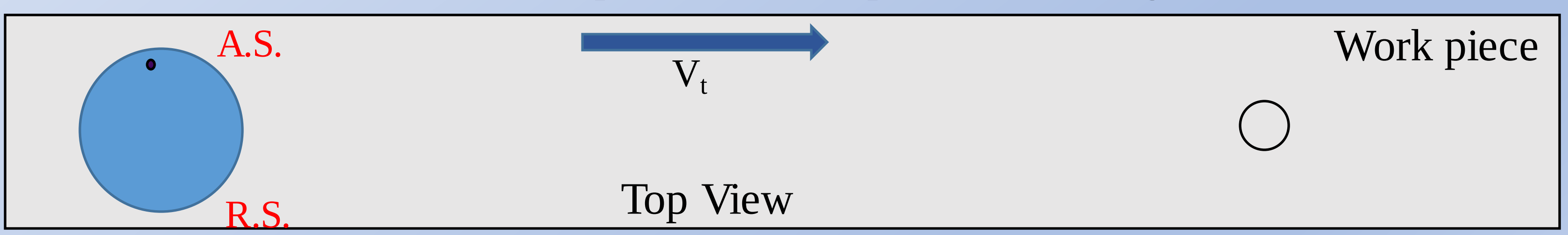
Isometric View

Plunge out

Heat generated = Friction +Plastic deformation of workpiece



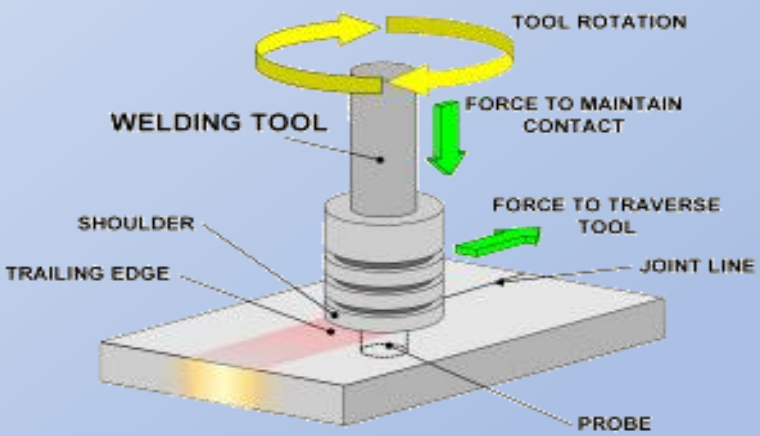
Traverse speed of tool to perform welding



Schematic of FSW

Function of tool

- Tool
  - Shoulder
    - Heat generation due to friction
    - Plasticize material
    - Contain Viscous material
    - Mixing of material on top surface
  - Pin
    - Disrupts faying surface
    - Heat generation on abutting edges



Pros and Cons of FSW

Pros

- Defects related to solidification is eliminated
- Fine equi-axed grains are developed in the stirred region, which improves the mechanical strength of weld
- Dissimilar material can be welded efficiently (Al-steel, Al-Mg, Al-Cu etc)
- **Green technology** and **energy efficient** (only 2% of energy compared to laser welding)
- No addition of filler material
- Less distortion due to reduced heat input
- Small or no heat affected zone

Pros and Cons of FSW

Cons

- Exit hole at the end of the process
- Thinning takes place at the weld region due to formation of ribbon flash

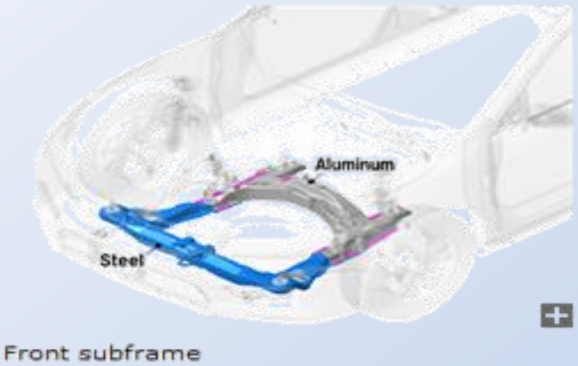
APPLICATION OF FSW (AEROSPACE)

NASA'S Orion space craft

Cargo floor panels for Lockheed Martin´ C-130 Hercules aircraft

Source:
http://www.fpe.co.uk/products/friction-stir-welders

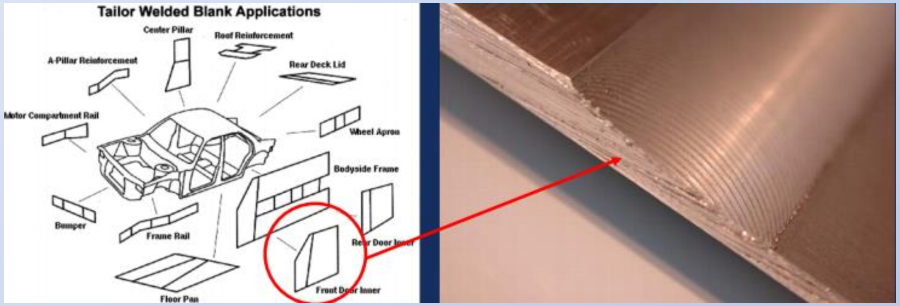
APPLICATION OF FSW (AUTOMOBILE/RAILWAYS)



Weight reduction: 6 kg

HONDA ACCORD

China's high speed railway carriages



Tailor Welded Blanks welded for Renault´ inner door panels

Wheel Assembly

Ref: http://www.holroyd.com/blog/friction-stir-welding-applications/
http://spinoff.nasa.gov/Spinoff2008/ip_4.html

APPLICATION OF FSW (MISCELLANEOUS)

C-arc beams for Philips medical X-ray scanning equipment

The Super liner Ogasawara

Apple iMac

Application of FSW

Soon after the success of the mission, ISRO Chairman K Sivan said, "PSLV-C41 precisely injected the eighth navigation satellite of India of the NavIC constellation into the targeted orbit. The entire ISRO community worked tirelessly to achieve this success. We have adopted a new technology called friction stir welding, which will improve the productivity and enhance the payload capability of the vehicle," he said

Published in The Indian Express on April 13, 2018

ISRO officials said the rocket launched Wednesday was also the first to fly with propellant tanks constructed using a technique called friction stir welding, a more efficient manufacturing method used on SpaceX's Falcon rocket family and NASA's Space Launch System.

The introduction of friction stir welding is "going to improve the productivity and also enhance the payload capability of the vehicle," Sivan said.

Published in spaceflight.com on April 11, 2018

FSW commercial application

- 2001 Volvo V70 (rear seat frame)
- 2003 Lincoln Town Car L (suspension components)
- 2004 Mazda RX-8 (rear doors and hood)
- 2005 Ford GT (part of space frame)
- 2006 Mazda MX-5 Miata (trunk and hood)
- 2007 Audi R8 (parts of space frame)
- 2010 Toyota Plus (rear hatch)
- 2013 Honda Accord (front sub frame)

Brazing

- Brazing is the joining method with the help of filler metal whose liquidus temperature is above 450ºC and below the solidus temperature of base material.
- The filler material is drawn through capillary action. Hence clearance is an important factor
- Surface should be clean, free from oil or grease
- Copper, silver are some of the filler material used

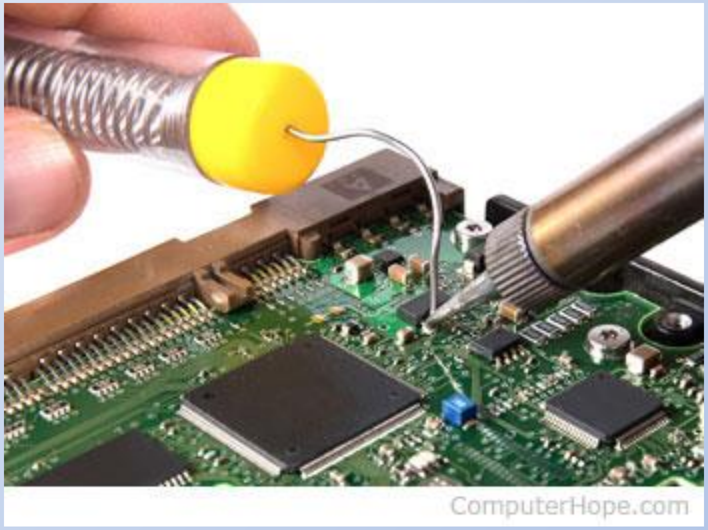
Torch brazing

- Resistance brazing, Induction brazing are the other types of brazing operation

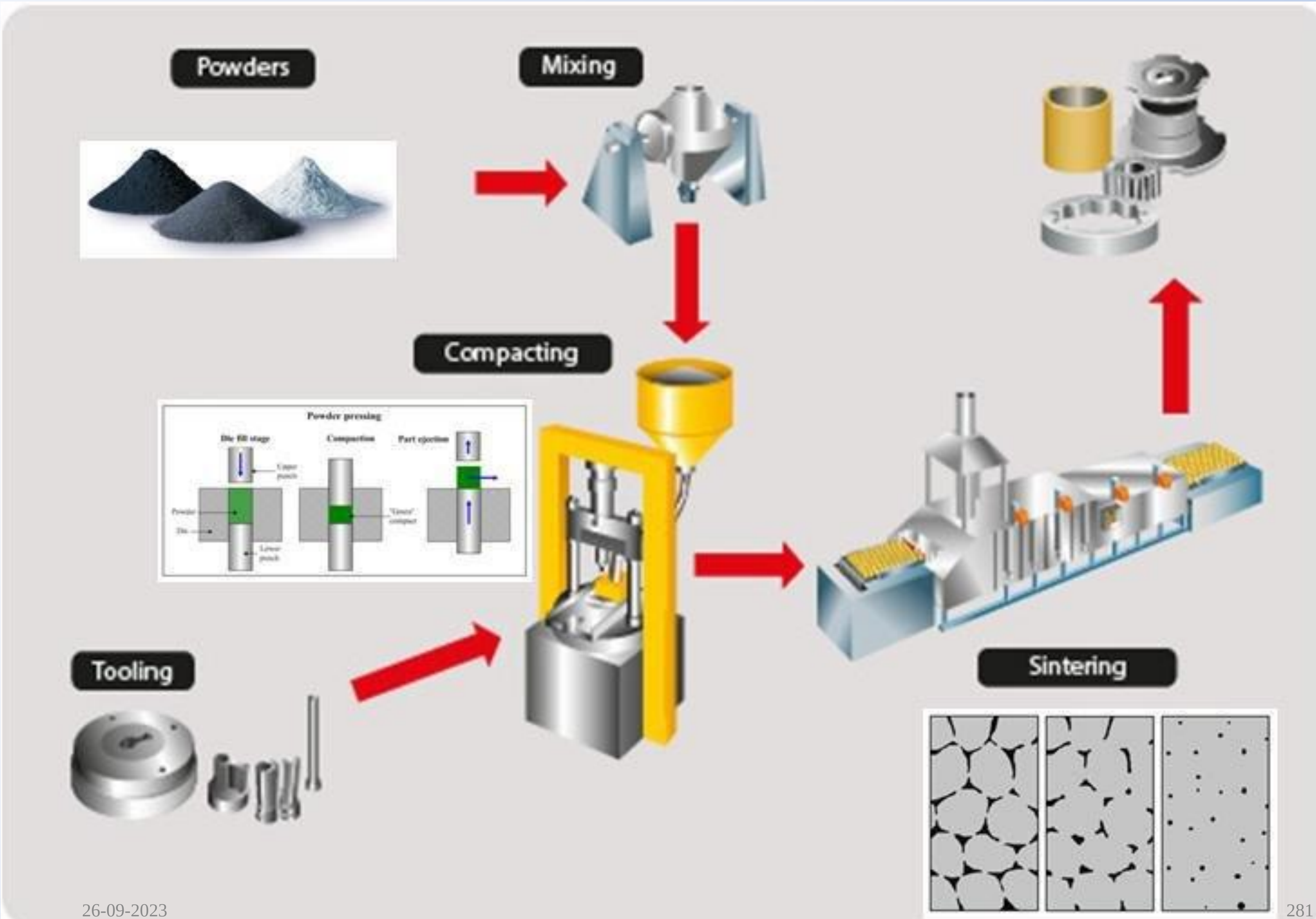
Soldering

- Liquidus temperature of filler material is less than 450^{o}C
- Generally used to get leak proof joints. The joint is weaker than brazing.
- Solders or filler material are generally alloy of lead and tin

- Types: Soldering iron, Dip soldering and Wave soldering



Powder metallurgy



Thank You

Reference

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- Manufacturing Technology By PN Rao