Short Notes for Engineering Materials

Crystal Structure of Materials

- When metals solidify from molten state, the atoms arrange themselves into various crderly configurations called crystal.
- There are seven basic crystal structures, they are

Crystal system	Relation between primitives	Interface Angles	Examples
Cubic	$a = b = c$	$\alpha = \beta = \gamma = 90^\circ$	Fe, Al, Cu
Tetragonal	..	$\alpha = \beta = \gamma = 90^\circ$	Sn, SO_2
Orthogonal	$a \neq b \neq c$	$\alpha = \beta = \gamma = 90^\circ$	$KNO_3, BaSO_4$
Hexagonal	$a = b \neq c$	$\alpha = \beta = 90^\circ\ \gamma = 120^\circ$	$SiO_2, AgCI, Zn$
Rhombohedral	$a = b = c$	$\alpha = \beta = \gamma \neq 90^\circ$	$CaSO_4, CaCO_3$
Monoclinic	$a \neq b \neq c$	$\alpha = \beta = 90^\circ \neq \gamma$	$FeSO_4; NaSO_4$
Friclinic	$a \neq b \neq c$	$\alpha \neq \beta \neq \gamma \neq 90^\circ$	$CuSO_4; K_2Cr_2O_7$

Simple Cubric Cell (SCC)

- The total number of atoms present in crystal structure,

$$n = \frac{1}{8} \times 8 = 1$$

- Atomic Packing Factor (APF)

$$= \frac{\text{Volume of atoms in a cell}}{\text{Volume of unit cell}}$$

$$= \frac{4\pi a^3}{8 \times 3 \times a^3}$$

$$= \frac{\pi}{6} = \frac{3.14}{6}$$

$$= 0.52$$

- Percentage APF = **52%**
- Percentage of voids = 100 – 52 = **48%**

Body Centered Cubic (BCC) Structure

- Total effective number of atoms present in the crystal

$$= 1 + 8 \times \frac{1}{8}$$
$$= 1 + 1 = 2$$

- Atomic Packing Factor (APF)

$$= \frac{\pi\sqrt{3}}{8} = \frac{3.14 \times 1.732}{8} = 0.68 \quad \left(\because r = \frac{\sqrt{3}}{4}a\right)$$

- Percentage APF = **68%**
- Percentage of voids = 100 **–** 68 = **32%**

Face Centred Crystal (FCC)

In this arrangement, each face has an atom and corners are also occupied by atoms.

Total effective number of atoms in cell.

- Atomic Packing Factor (APF)

$$= \frac{n \times \frac{4}{3}\pi r^3}{a^3}$$
$$= \frac{16\pi}{16 \times 3\sqrt{2}}$$
$$= \frac{3.14}{3 \times 1.414}$$
$$= 0.74$$

- Percentage APF = **74%**
- Percentage of voids = 100 **–** 74 = **26%**

Gibbs phase rule :

- F = C **–** P + 2
- Number of external factors = 2 (pressure and temperature).
- For metallurgical system, pressure has no appreciable effect on phase equilibrium and hence,
- F = C **–** P + 1

Engineering and True Stress-Strain Diagrams:

- When we calculate the stress on the basis of the original area, it is called the engineering or nominal stress.
- If we calculate the stress based upon the instantaneous area at any instant of load it is then termed as true stress.
- If we use the original length to calculate the strain, then it is called the engineering strain.

$$\text{True stress}\,(\sigma_T) = \frac{\text{Instantaneous load}}{\text{Instantaneous cross-sectional area}}$$

$$= \frac{P}{A_i}$$

Brittleness:

- It may be defined as the property of a metal by virtue of which it will fracture without any appreciable deformation.
- This property is just opposite to the ductility of a metal.

Toughness:

- It may be defined as the property of a metal by virtue of which it can absorb maximum energy before fracture takes place.
- Toughness is also calculated in terms of area under stress-strain curve.
- Toughness is the property of materials which enables a material to be twisted, bent or stretched under a high stress before rupture.

Resilience:

- This may be defined as the property of a metal by virtue of which it stores energy and resists shocks or impacts.
- It is measured by the amount of energy absorbed per unit volume, in stressing a material up to elastic limit.

Endurance:

- This is defined as the property of a metal by virtue of which it can withstand varying stresses (same or opposite nature).
- The maximum value of stress, which can be applied for indefinite times without causing its failure, is termed as its endurance limit.

Anelastic Behaviour:

- Recoverable deformation that takes place as a function of time is termed an-elastic deformation.
- Due to some relaxation process within the material, the elastic deformation of the material continues even after the application of the load

Isomorphous system.

- **There are 5 invariant reactions occurring in binary phase system:**
- **Eutectic reaction**: When a liquid phase changes into two different solid phases during cooling or two solid phases change into a single liquid phase during heating, this point is known as eutectic point
- **Eutectoid reaction:** When a solid phase changes into two solid phases during cooling and vice-versa that point is known as eutectoid point
- **Peritectic reaction:** A binary system when solid and liquid phases changes solid phase on cooling and vice-versa on heating, then state of system is known as peritectic point
- **Peritectoid reaction**: If a binary phase diagram when two solid phases changes to one solid phase, then state of system is known as peritectoid point.

Normalising

- For this process, the metal is placed in the furnace and heated to just above its 'Upper Critical Temperature'.
- When the new grain structure is formed it is then removed from the furnace and allowed to cool in air as it cools new grains will be formed.
- These grains, although similar to the original ones, will in fact be smaller and more evenly spaced.
- Normalising is used to relieve stresses and to restore the grain structure to normal.

Quenching

- It is a heat treatment when metal at a high temperature is rapidly cooled by immersion in water or oil.
- Quenching makes steel harder and more brittle, with small grains structure

Annealing (Softening)

- Annealing is a heat treatment procedure involving heating the alloy and holding it at a certain temperature (annealing temperature), followed by controlled cooling.
- Annealing results in relief of internal stresses, softening, chemical homogenising and transformation of the grain structure into more stable state.
- The annealing process is carried out in the same way as normalising, except that the component is cooled very slowly. This is usually done by leaving the component to cool down in the furnace for up to 48 hours

Hardening

- Hardening also requires the steel to be heated to its upper critical temperature (plus 50°C) and then quenched.
- The quenching is to hold the grains in their solid solution state called Austenite; cooling at such a rate (called the critical cooling rate) is to prevent the grains forming into ferrite and pearlite.
- Hardening is a process of increasing the metal hardness, strength, toughness, fatigue resistance.

Tempering

- As there are very few applications for very hard and brittle steel, the hardness and brittleness needs to be reduced. The process for reducing hardness and brittleness is called tempering.
- Tempering consists of reheating the previously hardened steel.
- During this heating, small flakes of carbon begin to appear in the needle like structure. (See below) This has the effect of reducing the hardness and brittleness.

Stress Relieving

- When a metal is heated, expansion oc-curs which is more or less proportional to the temperature rise. Upon cooling a metal, the reverse reaction takes place. That is, a contraction is observed.
- When a steel bar or plate is heated at one point more than at another, as in welding or during forging, internal stresses are set up.
- During heating, expansion of the heated area cannot take place unhindered, and it tends to deform.
- On cooling, contraction is prevented from taking place by the unyield-ing cold metal surrounding the heated area.

Casting

- **Solidification Time -** $T_s = k\left(\frac{V}{S.A}\right)^2$

  V=Volume of casting, S.A= Surface area of casting, k=Solidification time (sec/m^2)

- **Caine's Formula-** $X = \frac{a}{Y-b} + c$

  Freezing Ratio(F.R) $X = \frac{\left(\frac{V}{S.A}\right)_R}{\left(\frac{V}{S.A}\right)_C}$ and $Y = \frac{V_R}{V_C}$ a, b and c are constants

- **Shape Factor-** $S.F = \frac{L+W}{T}$

  L- Length of casting, W- Width of the casting and T- Avg. thickness of section

- **Modulus Method -** $M_R = 1.2M_C$

  $M=\left(\frac{V}{S.A}\right)$

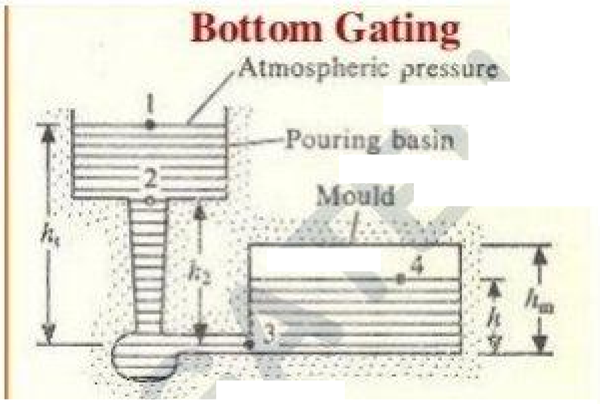
- **Gating Design-**
  1. **Vertical Gating-**

  $$t = \frac{V}{A_g v_g}$$

  where V= Volume of mould, A_g=Cross-section area

  2. **Bottom Gating-**

  $$t = \frac{A_m}{A_g}\frac{1}{\sqrt{2g}}2(\sqrt{h_t} - \sqrt{h_t - h_m})$$



- **Aspiration Effect-**

$$R = \frac{A_2}{A_3} = \sqrt{\frac{h_c}{h_t}}$$

Forging

- **Flow Stress-**

$$\sigma = k\varepsilon^n$$

Rolling

- **Bite Angle-**

$$\text{Cos}\theta = 1 - \frac{\Delta h}{2R}$$

- **Reduction (Draft)-**

$$\Delta h \leq \mu^2 R$$

$$\text{Max Draft}\Delta h = \mu^2 R$$

- **Roll Separating Force-**

$$F_{sep.roll} = LW\left(1 + \frac{\mu L}{2h}\right) \quad L = \sqrt{R\Delta h}, \text{ W=Width}$$

Extrusion and Wire Drawing

$$\sigma_d = K \ln \frac{A_i}{A_f}$$

Where K=Constant, A_i & A_f = Initial and final Area

Bending

Bend Allowance=**θ(R+Kt)** t= Sheet thickness

Θ=angle in radians, K=Stretch factor (0.33 when R<2t and 0.5 when R>2t) R=bend radius

Punching and Blanking

$$\text{Punch load} = \pi Dt \times K' \frac{\text{Penetration}}{\text{Shear on punch}}$$

K′=Yield strength in shear

Deep Drawing

D=Blank Diameter, d=Cup diameter

$$\frac{D}{d} = Draw\ ratio$$

$$\frac{\pi}{4}D^2 = \frac{\pi}{4}d^2 + \pi dh$$

Metal Cutting

- **Cutting Speed in Turning**

$$\mathbf{V = \pi DN}$$

Where D is the diameter of the work piece, m; N is the rotational speed of the work piece, rev/s

- **Economics of Machining**
  1) **Total Minimum Cost**

$$v_{opt} = \frac{C}{\left[\left(\frac{C_e}{C_m} + T_c\right)\left(\frac{1}{n} - 1\right)\right]^n} \Rightarrow t_{opt} = \left[\left(\frac{C_e}{C_n} + T_c\right)\left(\frac{1}{n} - 1\right)\right]$$

where, C_m = Machine cost in /time, T_c = Tool changing time

C = Total cost, C_e = Cost of tool/grind.

2) **Maximum Production Rate**

$$V_{opt} = \frac{C}{\left[\left(\frac{1}{n}-1\right)T_c\right]^n} \qquad T_{opt} = \left(\frac{1}{n}-1\right)T_c$$

3) **Maximum Profit Rate**

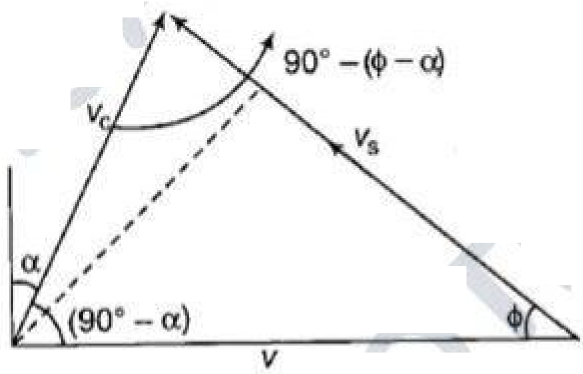
$$\text{Profit rate} = \frac{R - C_0}{T_n + T_n + \frac{T_m}{T} \times T_c} \qquad T_m = \frac{1}{fN}$$

- **Shear angle (β_o)-**

  $\tan \beta_o = r \cos\gamma_o / 1 - r \sin\gamma_o$

Rake angle, γo(in orthogonal plane), r-Chip thickness before and after cut

- **Velocity Ratio**



Velocity ratio diagram

$$\frac{V_s}{\cos\alpha} = \frac{V}{\cos(\phi-\alpha)} = \frac{V_c}{\sin\phi} \qquad \phi = \frac{\pi}{2} + \frac{\alpha}{2} - \frac{\beta}{2}$$

Φ= Shear angle, α=Rake angle, β= Friction angle

- **Shear Strain**

  $\gamma = \tan\phi + \cot(\phi - \alpha)$

- **Tool Life-**

  $VT^n = C$

V = Cutting speed. T = Tool life in minutes, n = A exponent which depends on cutting condition
C = Constant.

$VT^n d^x f^y$ = Constant Where d = Depth of cut, f = Feed rate (in mm/rev) in turning.

- **Yield Shear Strength (τ_s)**

$$\tau_s = \frac{P}{A_s}$$
$$A_s = \frac{tS_o}{Sin\beta_o}$$

t-Thickness, S_0-feed β_o=Shear angle

- **Specific Power Consumption-**

$$U_s = \frac{P_z V_c}{MRR} = \frac{P_z}{tS_o}$$

P_Z=Cutting force, V_c= Cutting Velocity

- **Cutting Force Expression-**

$$F = F_c \sin\alpha + F_t \cos\alpha$$
$$N = F_c \cos\alpha - F_t \sin\alpha$$

The coefficient of friction will be then given as :

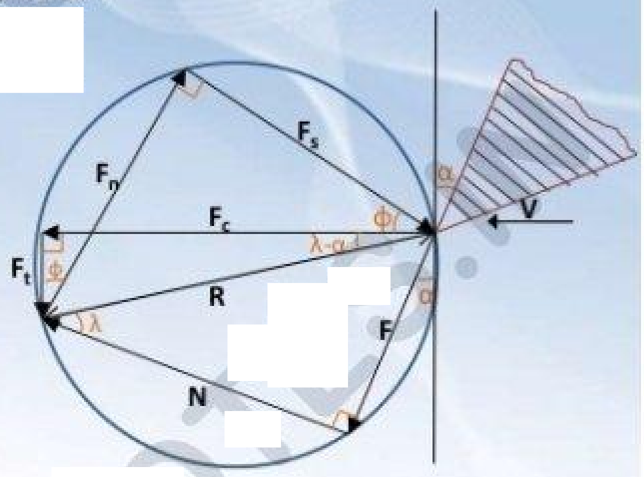
$$\mu = \frac{F}{N} = \frac{F_c \tan\alpha + F_t}{F_c - F_t \tan\alpha}$$
$$\lambda = \tan^{-1}\mu$$

On Shear plane,

$$F_s = F_c \cos\phi - F_t \sin\phi$$
$$F_n = F_c \sin\phi + F_t \cos\phi$$

Now,

$$F_t = F_n \cos\phi - F_s \sin\phi$$
$$F_c = F_n \sin\phi + F_s \cos\phi$$



- **Peak to Valley Height (H_{Max})-**

$$H_{Max} = \frac{f^2}{8R}$$

f- feed, R-Nose radius

$$H_{Max} = \frac{f}{tan\aleph + Cot\aleph_1}$$

$\aleph$=Side Cutting Edge Angle, $\aleph_1$=End Cutting Edge Angle

Non Conventional Machining

- **Electrochemical Machining-**

$$Mass\ removal\ rate\ \dot{m} = \frac{AI}{ZF}$$
$$\text{Volumetric Removal Rate Q} = \frac{AI}{\rho ZF}$$

A=Gram atomic weight of the metallic ions
I=Current (Amps)

P= density of the anode (g/cm^3)
Z= Valency of the cation,
F=mFaraday (96,500 coulombs)

- **Electro Discharge Machining-**

$$V = V_o(1 - e^{-t/RC})$$

V_o=Max. Voltage, t=time, R=Resistance, C= Capacitance

Welding

- **Dilution**

$$= \frac{A_p}{A_P + A_R}$$

A_p=Area of Penetration
A_R= Area of reinforcement

- **Relation in Voltage and Arc Length**

$$V = A + BI$$

l=Arc length, V=Voltage, A&B= Constant

- **Duty Cycle-**

$$I^2 D = Constant$$

D=Duty cycle time, I=current

- **Open Circuit Voltage (OCV) and Short-Circuit Current(SCC) relation-**

$$V_{arc} = OCV - \left[\frac{OCV}{SCC}\right] I$$

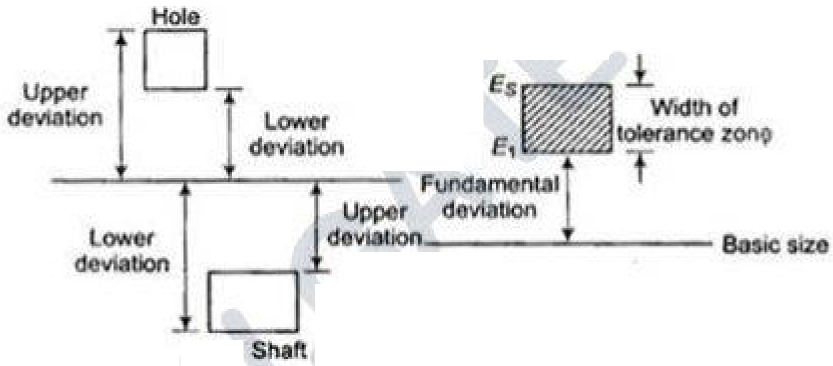
- **Resistance Welding-**

$$H = I^2 Rt$$

For spot welding, diameter of nugget $d_n = 6\sqrt{t}$
Height of the nugget $H_n = 2(t - indentation)/sheet$

Metrology

- **Assembly Representation**



- **Tolerances-**

$$i = 0.45D^{1/3} + 0.001D$$
$$D = \sqrt{D_{max} \times D_{min}}$$

Tolerance Table-

IT01 $0.3 + 0.008D$	IT0 $0.5 + 0.012D$	IT1 $0.8 + 0.02D$ a	IT2 ar
IT3 ar^2	IT4 ar^3	IT5 $\approx 7i = ar^4$	IT6 10i
IT7 $10(10)^{1/5}i = 16i$	IT8 $10(10)^{2/5}i = 25i$	IT9 $10(10)^{3/5}i = 40i$	IT10 $10(10)^{4/5}i = 64i$
IT11 100i	IT12 160i	IT13 250i	IT14 400i
IT15 640i	IT16 1000i		