DETAILS EXPLANATIONS

ME: Paper-1 (Paper-1) [Full Syllabus]

[PART : A]

1. The radius of Mohr's circle for strains is given by

$$r = \frac{1000-(-600)}{2}\times 10^{-6} = 800 \times 10^{-6}$$

The maximum shear strain is given by

$$\gamma = 2 \times r = 16 \times 10^{-6}$$

2. Given that, $\tau_1 = 240$ MPa

Maximum shear stress in a solid shaft is

$$\tau = \frac{16T}{\pi d^3}$$

Therefore, the maximum shear stress developed in the shaft is

$$\frac{\tau_2}{\tau_1} = \left(\frac{d_1}{d_2}\right)^3$$

$$\tau_2 = \frac{\tau_1}{8} = \frac{240}{8} = 30 \text{ MPa}$$

3. To avoid the problem of axial thrust in helical gears, double helical gears are made of two helical gears with opposite helix angles, which can be up to 45°C. If the left helix and right helix of a double helical gear meet at a common apex and there is no groove in between two pairs of gears, the gear is called herringbone gear.

4.
- Addendum circle is the outermost profile circle of a gear.
- Dedendum circle is the innermost profile circle.
- Clearance is the radial distance from the top of the tooth to the bottom of the tooth space in the mating gear.

5. Pulleys of flat drives are crowned by producing slightly conical or convex surface on the rim. When the belt slips off the pulley, the crown helps it to adhere to the cone surface due to pull on the belt. Crowning is always done on the driving pulley because tension is on entry side.

6. Uniform Pressure Theory The uniform pressure theory assumes that intensity of pressure on the bearing surface is constant. This can be examined in flat and conical collars/pivots.

Uniform Wear Theory The uniform wear theory assumes the uniform wearing of the bearing surface. For this, the intensity of pressure should be inversely proportional to the elemental areas. In this case, for the two locations at r_1 and r_2 with the same width b, the pressure intensities are given by

$$p_1 \times 2\pi r_1 b = p_2 \times 2\pi r_2 b$$

$$p_1 r_1 = p_2 r_2$$

Hence, $pr = \text{constant}$

7.

	Governor	Flywheel
1.	Provided on prime-movers.	Provided in engine and machines.
2.	Regulates supply of fuel.	Stores mechanical energy.
3.	Takes care of long range variation in load.	Take care of variation in the cycle.
4.	Works only when load changes	Works in each cycle.

8. The equivalent spring constant of the parallel springs is

$$k_e = 2 \times \frac{k}{2} = k$$

Therefore, it constitutes two springs of stiffness k in series, therefore, equivalent spring constant is $\frac{k}{2}$.

Hence, the natural frequency is given by $\omega_n = \sqrt{\frac{k}{2m}}$

9. Notch sensitivity (q) for fatigue loading is defined in terms of actual stress concentration factor kf and the theoretical stress concentration factor kt by the following expression :

$$q = \frac{k_f - 1}{k_t - 1}$$

The value of q is different for different materials and this normally lies between 0 to 0.7. It is small for ductile materials and increases with decrease the ductility.

10. ***Soderberg Line :*** A straight line joining σ_e on the ordinate and σ_y on the abscissa is called the Soderberg line of fatigue failure. Following is the equation for this failure criterion :

$$\frac{\sigma_a}{\sigma_y} + \frac{\sigma_v}{\sigma_e} = 1$$

To consider a factor of safety N, the equation takes the following form :

$$\frac{\sigma_a}{\sigma_y} + \frac{\sigma_v}{\sigma_e} = \frac{1}{N}$$

This indicates that the factor of safety shifts the criterion's line towards origin.

11. To achieve complete tightness, the joints are caulked or fullered. In caulking, the edge of one plate is pressed tightly against the other plate by means of a blunt chisel like tool called caulking tool.

Fullering is similar to caulking except that fullering makes use of tool having thickness at the end equal to that of the plate. There is less risk of the plate being damaged in fullering.

12. A solid with non-crystalline structure is called amorphous, such as silicate glasses, metallic glasses, amorphous carbon, amorphous silicon and many polymers. Many amorphous materials can be crystallized in a controlled fashion. This is the basis for formation of glass–ceramics and strengthening of polyethylene terephthalate (PET) plastics used for manufacturing of containers of beverages and foods.

13. Twinning occurs when a portion of crystal takes up an orientation that is related to the orientation of the rest of the un twinned lattice in a definite, symmetrical way. Twinning results in very small gross plastic deformation, but it causes the changes in plane orientation that facilitate slip. Twinning generally occurs when slip is restricted, because the stress necessary for twinning is usually higher than that for slip.

14.
- Cores are provided to form additional part of pattern for hollow castings, for example, in pipe fittings.
- Core prints are provided on the patterns for proper seating of cores.
- Chaplets are used to support cores inside the mold cavity against the weight and hydraulic forces.
- Risers are provided in gating systems to compensate liquid shrinkage of poured metal.

15. Press forging is performed by using hydraulic press to obtain slow and squeezing action instead of a series of blows as in drop forging. This enables uniform deformation throughout the entire depth of the workpiece. Press forgings generally need smaller draft than drop forgings and have greater dimensional accuracy. Dies are generally heated during press forging to reduce heat loss, promote more uniform metal flow and production of finer details.

16. Oxydized flame uses excess oxygen and produces a loud noise. It is composed of only two cones: inner (3300°C, maximum overall) and outer. This flame is less luminous as compared to carburized flame. Since oxygen is a rapid supporter of combustion, therefore, oxidizing flame is never used for general purpose welding, specially of ferrous alloys. However, oxidized flame is some times used for welding of copper and zinc base alloys where oxide film is necessary to check vaporization of zinc and also to reduce further oxidation.

17. Honing is an abrasive machining process that produces a precision surface on a metal workpiece by scrubbing an abrasive stone against it along a controlled path.

Typical applications are the finishing of cylinders for internal combustion engines, air bearing spindles and gears.

18. The Delphi technique1 is a group process used to survey and collect the opinions of experts on a particular subject. Delphi technique in forecasting is based on a panel of experts in a way that eliminates the potential dominance of the most prestigious, the most verbal and best salespeople. The expert opinion is consensus instead of a compromise; the experts review each others' ideas.

19. Given that

$$\mu = 0.4$$
$$D_1 = 95$$
$$D_2 = 82$$
$$D_3 = 68$$
$$D_4 = 70$$

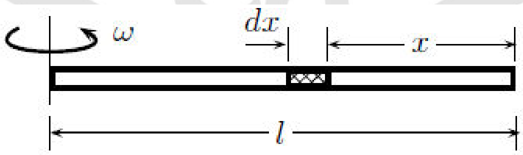
Forecast for the fifth month is given by

$$F_5 = \mu D_1 + \mu(1-\mu)D_2 + \mu(1-\mu)^2 D_3 + \mu(1-\mu)^3 D_4$$
$$= 73.52$$

20. Product layout is generally used in systems where a product has to be manufactured or assembled in large quantities. Machining equipments, and work centers are arranged in the order in which they have to be used.

[PART : B]

21. The condition presented in the problem is depicted in the following figure.



The extension of a small element of length dx at distance x from the free end is given by

$$\delta = \int_0^l \frac{1}{AE}\left(l - \frac{x}{2}\right)\omega^2 \frac{w}{g} x dx = \frac{w\omega^2}{gAE}\left[l\frac{x^2}{2} - \frac{x^3}{6}\right]_0^l$$

$$= \frac{w\omega^2 l^3}{gAE}\left(\frac{1}{2} - \frac{1}{6}\right) = \frac{w\omega^2 l^3}{3gAE}$$

22. Strain energy (per unit volume) is determined as :

$$\frac{\sigma_y^2}{2E} = \frac{u}{\pi d^2 \times (l/4)}$$

$$s_y = \sqrt{\frac{8uE}{\pi d^2 \times l}} = \sqrt{\frac{8 \times 15 \times 200 \times 10^9}{\pi 0.02^2 \times 2}} = 97.72 \text{ MPa}$$

23. If s is cost of stock-ut cost, then the safety level of stock is determined as

$$Q_s = Q^* \times \sqrt{\frac{s}{s+h}}$$

Given that

D = 1000 units
A = ₹100/order
h = ₹100/unit-year
s = ₹400

Therefore,

$$Q_s = \sqrt{\frac{2AD}{h}} \times \sqrt{\frac{s}{s+h}} = \sqrt{\frac{2\times100\times1000}{100}} \times \sqrt{\frac{400}{400+100}} = 40$$

24. Shortest processing time (SPT) rule is based on the principle that the shortest job is handled first and completed. It orders the jobs in the order of increasing processing times. Whenever a machine is free, the shortest job ready at the time will begin processing. This algorithm is optimal for finding the minimum total completion time and weighted completion time. The flow time is the cumulative sum of processing time each job by each job. In the given case, first the jobs are reordered in the ascending order of processing time as follows :

Job	Processing Time (Days)	Cumulative Time(Days)
I	4	4
III	5	9
V	6	15
VI	8	23
II	9	32
IV	10	42
	Sum	125

The average flow time is given by

$$AFT = \frac{125}{6} = 20.8333.$$

25. Based on the following equation, $t_e = \frac{t_o + 4t_m + t_p}{6}$

The expected time of all the activities t_e is calculated as follows :

Activity	t_o	t_m	t_p	t
1-2	1	2	3	2
1-3	5	6	7	6
1-4	3	5	7	5
2-5	5	7	9	7
3-5	2	4	6	4
5-6	4	5	6	5
4-7	4	6	8	6
6-7	2	3	4	3

Only three paths are possible, and their duration is found as.

- Path 1 - 3 - 5 - 6 - 7 $T_e = 6 + 4 + 5 + 3 = 18$
- Path 1- 2 - 5 - 6 - 7 $T_e = 2 + 7 + 5 + 3 = 17$
- Path 1 - 4 - 7 $T_e = 5 + 6 = 11$

The longest duration path (d) is the critical path whose duration is 18 days.

26. ***Routing*** is to determine and ensure the best and cheapest route or sequence of operations to be followed by the raw material in acquiring the shape of the finished product. Thus, routing involves two elements: operations, and their sequence. Routing is performed through route sheets for different manufacturing orders. Route sheet of a product defines each step of the production operation and lays down the precise route of operations. It includes important details, such as product identification number, symbol for identification of parts, number of pieces in each lot, operation data, production rate. An assembly of a number of component parts, like a printer or a laptop, requires separate route sheets for each of its parts, sub-assemblies and final assembly.

Scheduling is deciding the priorities for each job and planning the time-table of production through considerate allocation of start and finishing time for each operation and entire series as routed. Objective of scheduling is to prevent unbalanced use of time among work centers and to utilize resources within established cycle time. Scheduling is closely related to routing because routing cannot be done without scheduling. Therefore, routing and scheduling are generally done by the same team or person of an enterprise. Routing and scheduling need immediate change in the event of contingencies, such as machine breakdowns, delays in supply of raw materials.

27. Basic Hole System Basic hole system is a system of fits in which design size of the hole is the basic size from which allowance is subtracted to obtain the diameter of the shaft. The system is preferred because standard tooling (e.g. drills, reamers, broaches, plug gauges) whose size is not adjustable, and shaft can then easily be machined to fit.

Basic Shaft System Basic shaft system is a system of fits in which the design size of the shaft is the basic size to which allowance is added to obtain the diameter of the hole.

28. Tapping is a machining process that uses a multi-point cutting tool (tap) to produce uniform, internal, helical threads. A tap is simply a hardened tool steel screw with length wise groves called fleets, milled or ground across the threads. The leading end is tapered to facilitate entry of the tool into the work material. Once started, the tap is automatically drawn into the hole by threads. Hence, it is not be forced in but to be rotated only. The feed per revolution of the tap is equal to the lead of the thread. Taps with long chamfer can be run at higher speeds because long chamfer reduces chip load per tooth

29. Sintering involves heating of the green compact in a protective atmosphere furnace to a suitable temperature below the melting point of the metal. Typical sintering atmospheres are endothermic gas, exothermic gas, dissociated ammonia, hydrogen, and nitrogen. Sintering is responsible for producing physical and mechanical properties by developing metallurgical bond among the powder particles. It also serves to remove the lubricant from the powder, prevents oxidation, and controls carbon content in the part.

30. (i) The maximum permissible load P to avoid crushing of the rivets is determined as :

$$F = n \times dt\sigma_c = 3 \times 10 \times 5 \times 150 = 22500 \text{ N} = 22.5 \text{ kN}$$

(ii) The maximum permissible load P to avoid tearing of the plates is determined as

$$F = (w - nd_h)t\sigma_t = (200 - 3 \times 11) \times 5 \times 200$$
$$= 167000 \text{ N} = 167 \text{ kN}$$

31. Given, that $C = 25$ kN; $N = 540$ rpm; $L_h = 2500$ hours

Life of bearing in million revolutions (L) is

$$L = \frac{60 \times 540 \times 2500}{10^6} = 81$$

The designation indicates a ball bearing, thus

$$C = PL^{1/3}$$

$$P = \frac{C}{L^{1/3}} = \frac{25}{81^{1/3}} = 5.77 \text{ kN}$$

32. Worm gears are used to connect skewed shafts (i.e. non-parallel and nonintersecting), but not necessarily at right angles. Teeth on worm gear are cut continuously like the threads on a screw. The gear meshing with the worm gear is known as worm wheel and the combination is known as worm and worm wheel. At least one teeth of the worm must make a complete turn around the pitch cylinder, and thus forms screw thread. Unlike with ordinary gear trains, the direction of transmission in worm drive is not reversible when using large reduction ratios. Due to the greater friction involved between the worm and worm-wheel, usually a single start (one spiral) worm is used. If a multi-start worm (multiple spirals) is used then the ratio reduces accordingly and the braking effect of a worm and worm-gear would need to be discounted as the gear will be able to drive the worm.

[PART : C]

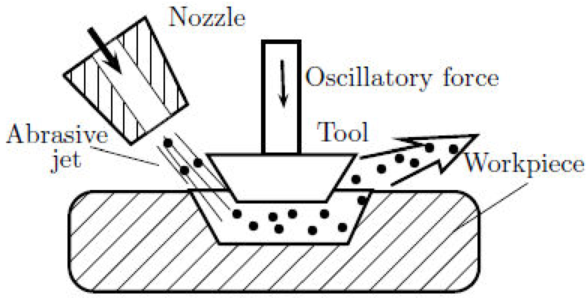
33. Ceramics are inorganic and non-metallic materials, which are hard, abrasion resistant, brittle, chemically inert, and poor conductors of heat.

Types of Ceramics

Important types of ceramics are discussed as follows :

- Glasses Glasses are non-crystalline silicates containing oxides, usually CaO, Na_2O, K_2O and Al_2O_3. Typical property of glasses that is important in engineering applications is their optical transparency and ease in fabrication. Glasses are mainly used in containers, windows, mirrors, etc.
- Clay Products Clay is an inexpensive ingredient, found naturally in great abundance. Clay products are mainly of two kinds: structural products (bricks, tiles, sewer pipes) and white-wares (porcelain, chinaware, pottery, etc.).
- Refractories Refractories are described by their capacity to withstand high temperatures without melting or decomposing; and their inertness in severe environments. Thermal insulation is also an important functionality of refractories.
- Abrasive Ceramics Abrasive ceramics are used to grind, wear, or cut away other softer material. Diamond, silicon carbide, tungsten carbide, silica sand and corundum (crystalline form of aluminium oxide) are some typical examples of abrasive ceramic materials.
- Cements Cement, plaster of Paris and lime come under this cement group of ceramics. Upon mixing with water, these materials form slurry, whichsets subsequently and hardens. The cementituous bond develops at room temperature.
- Advanced Ceramics These are newly developedand manufactured in limited range for specific applications. Usually their electrical, magnetic andoptical properties and combination of properties are exploited. Their typical applications includeheat engines, ceramic armors, electronic packaging, optical fiber communication, etc.

34. The term ultrasonic refers to the frequency above the audible range of human ear (more than 16 kHz). Basic Principle The basic ultrasonic machining (USM) involves a tool (made of ductile and tough material) vibrating with a very high frequency and a continuous flow of abrasive grains carried in a liquid between the small gap between the tool and the work surface. The tool is gradually fed with a uniform speed. The slurry of abrasive grains suspended in a liquid is fed into the cutting zone under pressure. The abrasive particles are driven into the work surface by the oscillating tool. This action gradually chips away minute particles of material in a pattern controlled by the tool shape and contour



Small wear particle are carried away by the abrasive slurry. The tool material, being tough and ductile, wears out a much slower rate.

Basic Elements USM consists of the following elements :

- Transducer The transducer is utilized to convert the electrical energy into high frequency vibratory motion of the tool by using piezoelectric materials, such as quartz, lead zirconate titanate (PZT). The tool vibrations are in the order of 15 – 30 kHz with amplitudes of the order of 10 – 100 ìm.
- Tool cone amplifies the mechanical energy produced by the transducer to give the required force-amplitude ratio. Titanium, Monel, and stainless steels are generally used as tool cone materials.
- The tip of the tool, called sonotrode, is attached to the cone by means of silver brazing or by screws. Tools are made of tough and ductile materials, such as brass, low carbon steel, stainless steel. Length of the tool should be short since massive tools absorb the vibration energy reducing the efficiency of machining. Long tools also cause over stressing to the tool at brazed point.
- Typical abrasives used are alumina (Al_2O_3), silicon carbide (SiC), and boron carbide (B4C). Alumina abrasives wear fast but are good for glass and ceramics. Boron carbide is harder than SiC but is more expensive. It shows faster MRR and can be used with higher frequencies. It is best for machining of tungsten carbide (WC), tool steel and precision stones. Diamond dust is sometimes used for good accuracy, surface finish and cutting rate in diamonds and rubies.
- Liquid for Abrasive Abrasive grains are suspended in liquid with 20–60% concentration by volume.

The liquid serves following purposes :

(a) An acoustic bond between the tool and the workpiece.

(b) A coolant on the tool face.

(c) Carrier for abrasive and debris both. Water is the most commonly used liquid, although benzene and glycerol are also used.

Merits : Ultrasonic machining is best suited for hard and brittle materials. It is the only way to produce economically complex cavities without breaking the workpiece. Tooling cost of the the process is low. It does not involve thermal stresses.

Demerits Major limitations of this process are

- Low MRR.
- Limited depth of hole produced.
- High tool wear.
- Unable to produce sharp corners.

Applications USM is suitable for machining shallow die cavities and forms in hard and brittle materials, such as hardened steel and sintered carbides. The process is also used for thread cutting in ceramics by rotating the workpiece in a controlled manner.

35. Given :

$$T_A = 12,\ T_B = 30,\ T = 14$$

$$N_A = 1 \text{ r.p.s.},\ N_D = 5 \text{ r.p.s.}$$

Number of teeth on wheels D and E

Let T_D and T_E be the number of teeth on wheels D and E respectively. Let d_A, d_B, d_C, d_D and d_E be the pitch circle diameters of wheels A, B, C, D and E respectively. from the geometry of the figure,

$$d_E = d_A + 2d_B \text{ and } d_D = d_E - (d_B - d_C)$$

Since the number of teetl are proportioual to tleir pitch circle diameters for tle same module, therefore

$$T_E = T_A + 2T_B = 12 + 2 \times 30 = 72 \text{ Ans.}$$

aud $$T_D = T_E - (T_B - T_C) = 72 - (30 - 14) = 56 \text{ Ans.}$$

Magnitude and direction of angular velocities of arm OP and wheel E

The table of motions is drawn as follows :

Table of Motions

Step No.	Conditions of motion	Revolutions of elements				
		Arm	Wheel A	Compound wheel B-C	Wheel D	Wheel E
1.	Arm fixed *A* rotated through – 1 revolution (*i.e.* 1 revolution clockwise)	0	– 1	$+\frac{T_A}{T_B}$	$+\frac{T_A}{T_B}\times\frac{T_C}{T_D}$	$+\frac{T_A}{T_B}\times\frac{T_B}{T_E}$ $=+\frac{T_A}{T_E}$
2.	Arm fixed-wheel *A* rotated through – *x* revolutions	0	$-x$	$+x\times\frac{T_A}{T_B}$	$+x\times\frac{T_A}{T_B}\times\frac{T_C}{T_D}$	$+x\times\frac{T_A}{T_E}$
3.	Add – *y* revolutions to all elements	$-y$	$-y$	$-y$	$-y$	$-y$
4.	Total motion	$-y$	$-x-y$	$x\times\frac{T_A}{T_B}-y$	$x\times\frac{T_A}{T_B}\times\frac{T_C}{T_D}-y$	$x\times\frac{T_A}{T_E}-y$

Since tle wheel A makes 1 r.p.s. clockwise, therefore from tle fourth row of tle table,

$$-x - y = -1 \text{ or } x + y = 1 \quad ...(i)$$

Also, the wleel D makes 5 r.p.s. counter clockwise, tlerefore

$$x \times \frac{T_A}{T_B}\times\frac{T_C}{T_D} - y = 5 \text{ or } x \times \frac{12}{30}\times\frac{14}{56} - y = 5$$

$\therefore$ $$0.1x - y = 5 \quad ...(ii)$$

From equations (i) aud (ii), $x = 5.45$ and $y = -4.45$

$\therefore$ Angular velocity of arm OP

$= -y = -(-4.45) = 4.45$ r.p.s

$= 4.45 \times 2\pi = 27.964$ rad/s (couuter clockwise) ***Ans.***

and angular velocity of wheel $E = x \times \frac{T_A}{T_E} - y = 5.45 \times \frac{12}{72} - (-4.45) = 5.36$ r.p.s.

$= 5.36 \times 2\pi = 33.68$ rad/s (couuter clockwise) ***Ans.***

36. Given: $\alpha = 98°$

Let θ = Angle turned through by the driving shaft.

When the velocity ratio is maximum

We know that velocity ratio,

$$\frac{\omega_1}{\omega} = \frac{\cos\alpha}{1-\cos^2\theta.\sin^2\alpha}$$

The velocity ratio will be maximum when $\cos^2 0$ is minimum, *i.e.* when

$$\cos^2 \theta = 1$$

or when $\theta = 0°$ or $180°$ ***Ans.***

When the velocity ratio is unity

The velocity ratio $\frac{\omega}{\omega_1}$ will be unity, when

$$1 - \cos^2 8 \,.\, \sin^2 \alpha = \cos \alpha$$

or

$$\cos^2\theta = \frac{1-\cos\alpha}{\sin^2\alpha}$$

$\therefore$

$$\cos\theta = \pm\sqrt{\frac{1-\cos\alpha}{\sin^2\alpha}} = \pm\sqrt{\frac{1-\cos\alpha}{1-\cos^2\alpha}} = \pm\sqrt{\frac{1}{1+-\cos\alpha}}$$

$$= \pm\sqrt{\frac{1}{1+\cos 18^o}} = \pm\sqrt{\frac{1}{1+0.9510}} = \pm 0.7159$$

$$q = 44.3^o \text{ or } 135.7^o \textbf{\textit{ Ans.}}$$

37. Given :

$$P = 20 \text{ kW} = 20 \times 10^3 \text{ W}$$

$$N_P = 300 \text{ r.p.m.}$$

$$\text{V.R.} = T_G / T_p = 3$$

$$\sigma_{OP} = 120 \text{ MPa} = 120 \text{ N/mm}^2$$

$$\sigma_{OG} = 100 \text{ MPa} = 100 \text{ N/mm}^2$$

$$T_p = 15 \;;\; b = 14 \text{ module} = 14 \text{ m}$$

I. Module : Let, m = Module in mm,

and D_p = Pitch circle diameter of the pinion in mm.

We know that pitch line velocity.

$$v = \frac{\pi D_P N_P}{60} = \frac{\pi m.T_P.N_P}{60} \qquad (\because D_P = m.T_P)$$

$$= \frac{\pi m \times 15 \times 300}{60} = 236 \text{ m mm/s} = = 0.236 \text{ m m/s}$$

Assuming steady load conditions and 8 - 10 hours of service per day, the service factor (C_3) from Table 28.10 is given by

$$C_s = 1$$

We know that design tangential tooth load.

$$W_T = \frac{P}{v} \times C_S = \frac{20\times10^3}{0.236m}\times 1 = \frac{84.746}{m} N$$

and velocity factor

$$C_v = \frac{3}{3+v} = \frac{3}{3+0.236m}$$

We know that tooth form factor for the pinion.

$$y_P = 0.154 - \frac{0.912}{T_P} = 0.154 - \frac{0.912}{15}$$

$$= 0.154 - 0.0608 = 0.0932$$

and tooth form factor for the gear. $y_G = 0.154 - \frac{0.912}{T_G} = 0.154 - \frac{0.912}{3\times15}$

$= 0.154 - 0.203 = 0.1337$ $(\because T_G = 3T_P)$

$\therefore$ $\sigma_{OP} \times y_P = 120 \times 0.0932 = 11.184$

and $\sigma_{OG} \times y_G = 100 \times 0.1337 = 13.37$

Since ($\sigma_{OP} \times y_P$) is less tlian ($\sigma_{OG} \times y_G$), therefore tlie pinion is weaker. Now using the Lewis equation to the pinion, we have

$$W_T = \sigma_{wP}.b.\pi.m.y_P = (\sigma_{OP} \times C_v)b.\pi.m.y_P$$

$$\therefore \quad \frac{84.476}{m} = 120\left(\frac{3}{3+0.236m}\right) 14\ m \times \pi m \times 0.0932 = \frac{1476m^2}{3+0.236m}$$

or $3 + 0.236\ m = 0.0174\ m^3$

Solving this equation by hit and trial method, we find that m = 6.4 mm

The standard module is 8 mm. Therefore let us take m = 8 mm ***Ans.***

II. Face width

We know that the face width,

$$b = 14\ m = 14 \times 8 = 112 \text{ mm } \textit{Ans.}$$

III. Pitch circle diameter of the pinion and gear

We know that pitch circle diameter of the pinion,

$$D_P = m.T_P = 8 \times 15 = 120 \text{ mm } \textit{Ans.}$$

and pitch circle diameter of the gear,

$$D_G = m.T_G = 8 \times 45 = 360 \text{ mm } \textit{Ans.}$$

38. Given, $a + b = 200$ mm

$P = 200$ kN $= 200 \times 10^3$ N

$\tau = 75$ MPa $= 75$ N/mm^2

Let, l_a = Length of weld at the top

l_b = Length of weld at the bottom

and l = Total length of the weld = $l_a + l_b$

Since the thickness of the angle is 10 mm. therefore size of weld,

$s = 10$ mm

We know that for a single parallel fillet weld, the maximum load (P),

$$200 \times 10^3 = 0.707\ s \times l \times \tau = 0.707 \times 10 \times l \times 75 = 530.25\ l$$

$\therefore$ $l = 200 \times 10^3 / 530.25 = 377$ mm

or $l_a + l_b = 377$ mm

Now let us find out the position of the centroidal axis.

Let b = Distance of centroidal axis from the bottom of the angle.

$$\therefore \quad b = \frac{(200-10)\ 10 \times 95 + 150 \times 10 \times 5}{190 \times 10 + 150 \times 10}\ 55.3 \text{ mm}$$

and $a = 200 - 55.3 = 144.7$ mm

We know that $l_a = \frac{l\times b}{a+b} = \frac{377\times55.3}{200} = 104.2$ mm ***Ans.***

and $l_h = 1 - l_a = 377 - 104.2 = 272.8$ mm ***Ans.***

39. The term heat treatment may be defined as an operation or a combination of operations, involving the heating and cooling of a metal or an alloy in the solid state for the purpose of obtaining certain desirable conditions or properties without change in chemical composition. The aim of heat treatment is to achieve one or more of the following objects :

(i) To increase the hardness of metals.

(ii) To relieve the stresses set up in the material after hot or cold working.

(iii) To improve machinability.

(iv) To soften the metal.

(v) To modify the structure of the material to improve its electrical and magnetic properties.

(vi) To change the grain size.

(vii) To increase the qualities of a metal to provide better resistance to heat, corrosion and wear.

Following are the various heat treatment processes commonly employed in engineering practice :

- ***Normalising :*** The main objects of normalising are :

(i) To refine the grain structure of the steel to improve machinability, tensile strength and structure of weld.

(ii) To remove strains caused by cold working processes like hammering, rolling, bending, etc., which makes the metal brittle and unreliable.

(iii) To remove dislocations caused in the internal structure of the steel due to hot working.

(iv) To improve certain mechanical and electrical properties.

The process of normalising consists of heating the steel from 30 to 50°C above its upper critical temperature (for hypoeutectoid steels) or Acme line (for hypereutectoid steels). It is held at this temperature for about fifteen minutes and then allowed to cool down in still air.

This process provides a homogeneous structure consisting of ferrite and pearlite for hypoeutectoid steels, and pearlite and cementite for hypereutectoid steels. The homogeneous structure provides a higher yield point, ultimate tensile strength and impact strength with lower ductility to steels. The process of normalising is frequently applied to castings and forgings, etc. The alloy steels may also be normalised but they should be held for two hours at a specified temperature and then cooling in the furnace.

Notes: *(a) The upper critical temperature for a steel depends upon its carbon content. It is 900°C for pure iron, 860°C for steels with 2.2% carbon, 723°C for steel with 0.8% carbon and 1130°C for steel with 1.8% carbon.*

(b) Steel containing 0.8% carbon is known as eutectoid steel, steel containing less than 0.8% carbon is called hypoeutectoid steel and steel containing above 0.8% carbon is called hypereutectoid steel.

- ***Annealing :*** The main objects of annealing are :

(i) To soften the steel so that it may be easily machined or cold worked.

(ii) To refine the grain size and structure to improve mechanical properties like strength and ductility.

(iii) To relieve internal stresses which may have been caused by hot or cold working or by unequal contraction in casting.

(iv) To alter electrical, magnetic or other physical properties.

(v) To remove gases trapped in the metal during initial casting.

The annealing process is of the following two types :

(a) Full annealing : The purpose of full annealing is to soften the metal to refine the grain (i) heating the steel from 30 to 50°C above the upper critical temperature for hypoeutectoid steel and by the same temperature above the lower critical temperature i.e. 723°C for hypereutectoid stee (ii) holding it at this temperature for sometime to enable the internal changes to take place. The time allowed is approximately 3 to 4 minutes for each millimetre of thickness of the largest section, (iii) cooling slowly in the furnace. The rate of cooling varies from 30 to 200°C per hour depending upon the composition of steel.

In order to avoid decarburisation of the steel during annealing, the steel is packed in a cast iron box containing a mixture of cast iron borings, charcoal, lime, sand or ground mica. The box along with its contents is allowed to cool slowly in the furnace after proper heating has been completed.

(b) Process annealing : The process annealing is used for relieving the internal stresses previously set up in the metal and for increasing the machinability of the steel. In this process, steel is heated to a temperature below or close to the lower critical temperature, held at this temperature for sometime and then cooled slowly. This causes complete recrystallisation in steels which have been severely cold worked and a new grain structure is formed. The process annealing is commonly used in the sheet and wire industries.

- ***Spheroidising :*** It is another form of annealing in which cementite in the granular form is produced in the structure of steel. This is usually applied to high carbon tool steels which are difficult to machine. The operation consists of heating the steel to a temperature slightly above the lower critical temperature (730 to 770°C). It is held at this temperature for some time and then cooled slowly to a temperature of 600°C. The rate of cooling is from 25 to 30°C per hour.

  The spheroidising improves the machinability of steels, but lowers the hardness and tensile strength. These steels have better elongation properties than the normally annealed steel.

- ***Hardening :*** The main objects of hardening are :

  (i) To increase the hardness of the metal so that it can resist wear.

  (ii) To enable it to cut other metals i.e. to make it suitable for cutting tools

  The process of hardening consists of (a) heating the metal to a temperature from 30 to 50°C above the upper critical point for hypoeutectoid steels and by the same temperature above the lower critical point for hypereutectoid steels. (b) keeping the metal at this temperature for a considerable time, depending upon its thickness. (c) quenching (cooling suddenly) in a suitable cooling medium like water, oil or brine.

  It may be noted that the low carbon steels cannot be hardened appreciably, because of the presence of ferrite which is soft and is not changed by the treatment. As the carbon content goes on increasing, the possible obtainable hardness also increases.

Notes:*(a) The greater the rate of quenching, the harder is the resulting structure of steel.*

(b) For hardening alloy steels and high speed steels, they are heated from 1100°C to 1300°C followed by cooling in a current of air.

- ***Tempering :*** The steel hardened by rapid quenching is very hard and brittle. It also contains internal stresses which are severe and unequally distributed to cause cracks or even rupture of hardened steel. The tempering (also known as drawing) is, therefore, done for the following reasons :

  (i) To reduce brittleness of the hardened steel and thus to increase ductility.

  (ii) To remove the internal stresses caused by rapid cooling of steel.

  (iii) To make steel tough to resist shock and fatigue.

  The tempering process consists of reheating the hardened steel to some temperature below the lower critical temperature, followed by any desired rate of cooling. The exact tempering temperature depends upon the purpose for which the article or tool is to be used.

- ***Surface hardening or case hardening :*** In many engineering applications, it is desirable that a steel being used should have a hardened surface to resist wear and tear. At the same time, it should have soft and tough interior or core so that it is able to absorb any shocks, etc. This is achieved by hardening the surface layers of the article while the rest of it is left as such. This type of treatment is applied to gears, ball bearings, railway wheels, etc.

  Following are the various *surface or case hardening processes by means of which the surface layer is hardened :

  (i) Carburising, (ii) Cyaniding,

  (iii) Nitriding, (iv) Induction hardening

  (v) Flame hardening.

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