Mechanical Engineering

Machine Design

Comprehensive Theory

with **Solved Examples** and **Practice Questions**

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Corporate Office: 44-A/4, Kalu Sarai (Near Hauz Khas Metro Station), New Delhi-110016
E-mail: infomep@madeeasy.in
Contact: 011-45124660, 8860378007
Visit us at: www.madeeasypublications.org

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CHAPTER 02

Cotter and Knuckle Joint

2.1 Cotter

A cotter is a flat wedge-shape piece of rectangular cross-section and its width is tapered from one end to another for an easy adjustment. It is usually made of mild steel or wrought iron.

Use of Cotter Joint

A cotter joint is used to connect two co-axial rods, which are subjected to either axial tensile force or axial compressive force. It is not used for connecting shafts that rotate and transmit torque.

Application of Cotter Joints

- Joints between the piston rod and the cross-head of a steam engine.
- Joint between the piston rod and the tail or pump rod.
- Joint between the slide spindle and the fork of the valve mechanism.
- Foundation Bolt.

Principle of Cotter Joint

- The principle of wedge action is used in a cotter joint.
- The joint is tightened and adjusted by means of a wedge action of the cotter.
- Cotter has uniform thickness and the width dimension has a slight taper.
- The taper is usually 1 in 24. Due to taper shape, it is easy to remove the cotter and dismantle the joint.
- The taper of the cotter as well as slots is on one side because machining a taper on two side is more difficult.
- A clearance of 1.5 mm to 3 mm is provided between the slots and the cotter.

Remember : Draw of Cotter: The amount by which the two rods are drawn together is called the draw of the cotter.

Advantage of Cotter Joint

(a) Assembly and dismantling the parts of the cotter joint is quick and simple.
(b) The wedge action develops a very high tightening force, which prevents loosening of parts in service.
(c) Joint is simple to design and manufacture.

2.2 Construction of a Cotter Joint

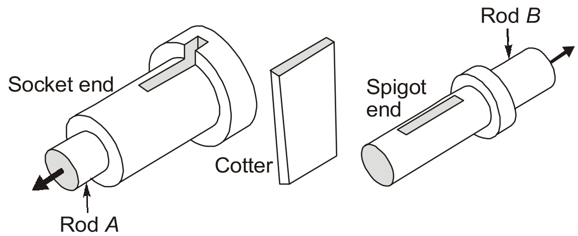


Figure 2.1

The construction of cotter joint used to connect two rods *A* and *B* is shown figure 2.1. Rod-A is provided with a socket and while Rod-B is provided with a spigot end. The socket end of Rod-A fits over the spigot end of Rod-B. The socket as well as the spigot is provided with a narrow rectangular slot. A cotter is tightly fitted in this slot passing through the socket and the spigot.

NOTE : Taper in the cotter is provided to facilitate its removal when its fails due to shear.

2.2.1 Design procedure for Cotter Joint

Assumption for stress analysis:

- The rods size subjected to axial tensile force.
- Effect of stress concentration due to slot is neglected.
- Stress due to initial tightening of the cotter are neglected.

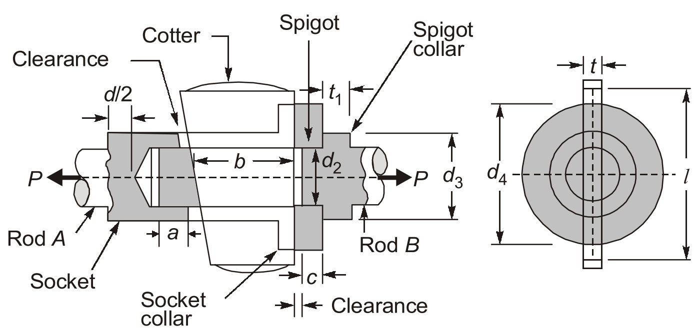


Figure 2.2

Here, P = Tensile force acting on rod
d = Diameter of each rod
d_1 = Outside diameter of socket
d_2 = Diameter of spigot or inside diameter of socket
d_3 = Diameter of spigot collar
d_4 = Diameter of socket collar
a = Distance from end of slot to the end of spigot on Rod-B
b = Mean width of cotter
c = Axial distance from slot to end of socket collar
t = Thickness of cotter
t_1 = Thickness of spigot-collar
l = Length of cotter

(i) Tensile Failure of Rods,

Permissible tensile stress $\sigma_t = \dfrac{P}{\dfrac{\pi}{4}d^2} \Rightarrow d = \sqrt{\dfrac{4P}{\pi\sigma_t}}$

(ii) Tensile Failure of Spigot

The weakest cross-section is at X-X of spigot end, which is subjected to tensile stress.

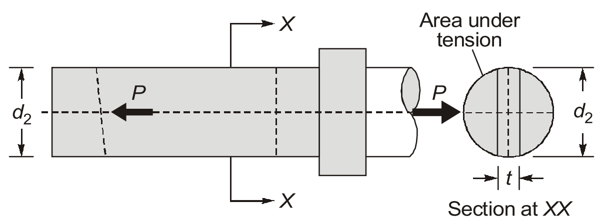


Figure 2.3

$$\text{Area of section at } X\text{-}X = \frac{\pi}{4}d_2^2 - d_2 t$$

$\therefore$ Permissible tensile stress, $\sigma_t = \dfrac{P}{\dfrac{\pi}{4}d_2^2 - d_2 t}$

Thickness of cotter is usually determined by empirical relationships

$$t = 0.31\, d_2$$

So, we can find inner diameter (d_2) of socket.

(iii) Tensile failure of Socket

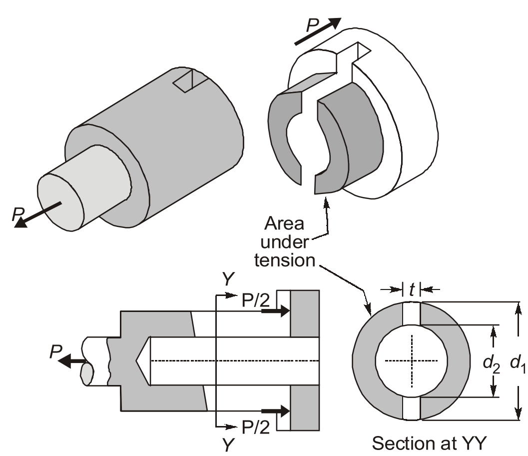


Figure 2.4

From the above figure, weakest section is Y-Y

$$\text{Area of section at } Y\text{-}Y = \left[\frac{\pi}{4}(d_1^2 - d_2^2) - (d_1 - d_2)t\right]$$

$\therefore$ Permissible tensile stress, $\sigma_t = \dfrac{P}{\dfrac{\pi}{4}(d_1^2 - d_2^2) - (d_1 - d_2)t}$

Because 'd_2' and 't' is known, we can find outside diameter of socket (d_1).

(iv) Shear Failure of Cotter

The cotter is subjected to double shear.

$$\text{Area of shear plane} = bt$$

$\therefore$ Permissible shear stress, $\tau = \dfrac{P}{2bt}$

$\therefore$ Mean width of cotter (b) can be calculated.

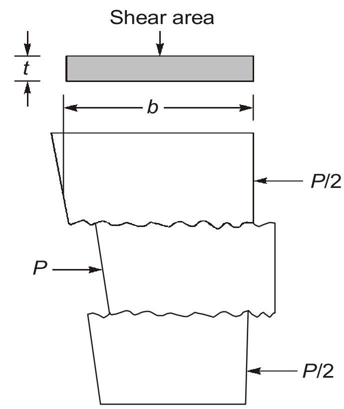


Figure 2.5

(v) Shear failure of Spigot End

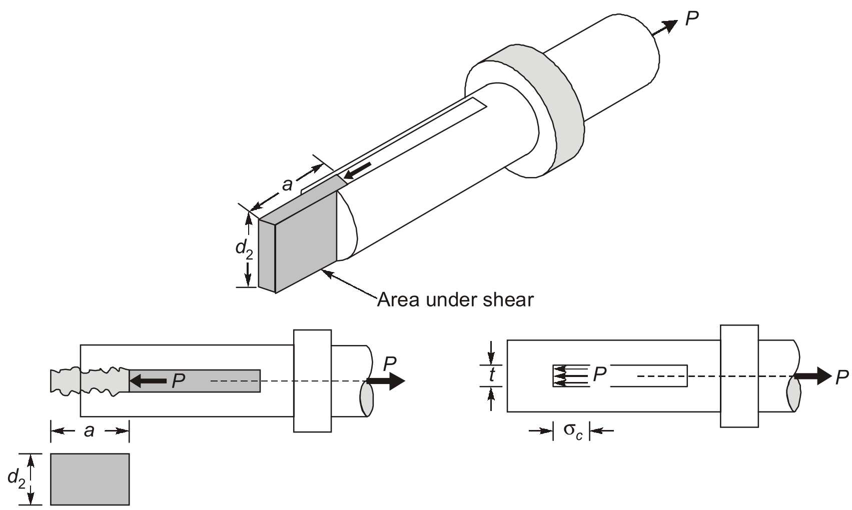


Figure 2.6

Spigot end is subjected to double shear. Area of plane that resist shear failure = $a.d_2$

$\therefore$ Permissible shear stress, $\tau = \dfrac{P}{2(ad_2)}$

Thus, we can calculate 'a' from above equation.

(vi) Shear failure of Socket End

Socket end is subject to double shear.

$$\text{Area subjected to shear} = (d_4 - d_2)C$$

$\therefore$ Permissible shear stress, $\tau = \dfrac{P}{2(d_4 - d_2)C}$

Thus we can find out C.

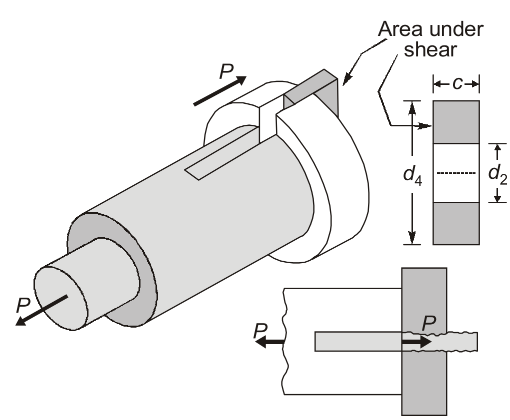


Figure 2.7

(vii) Crushing failure of Spigot End

Area, subjected to compressive stress = $\tau \times d_2$

$\therefore$ Permissible compressive stress, $\sigma_c = \dfrac{P}{t \times d_2}$

(viii) Crushing failure of Socket End

Area subjected to compressive stress = $(d_4 - d_2) \times t$

$\therefore$ Permissible compressive stress = $\sigma_c = \dfrac{P}{(d_4 - d_2) \times t}$

(ix) Calculation of a, c, d_3, d_4, t_1 by empirical relationship

$$d_3 = 1.5\,d \qquad d_4 = 2.4\,d$$
$$a = c = 0.75\,d \qquad t_1 = 0.45$$

(x) If material of Rod is not given

Take material - Plain carbon steel [3068]

$$\sigma_{yt} = 400\ \text{N/mm}^2$$

2.3 Knuckle Joint

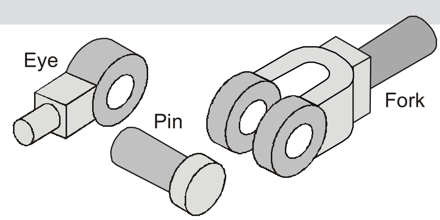
It is used to connect two rods whose axes either coincide or intersects and lie in one plane and used to transmit only axial tensile force. This joint permits limited angular movement between rods, about the axis of the pin. It is not used to connect rods, that rotate and transmit torque.

Application of Knuckle Joint

(i) Joint between tie bar and roof trusses.
(ii) Joint between link of suspension bridge.
(iii) Joints in valve mechanism of reciprocating engine.
(iv) Fulcrum for the levers.
(v) Joint between link of a bicycle chain.

Do You Know?

In rare application, a knuckle joint is used to connect three rods - two with forks and third with eye.



Advantage of Knuckle Joint

(a) Joint is simple to design and manufacture.
(b) Due to few part, cost is less and high reliability.
(c) Assembly and dismantling is quick and simple.

2.3.1 Design procedure of Knuckle Joint

Assumption for stress analysis

(i) Rods are subjected to only axial tensile force.
(ii) The effect of stress concentration due to hole is neglected.
(iii) Force is uniformly distributed in various parts.

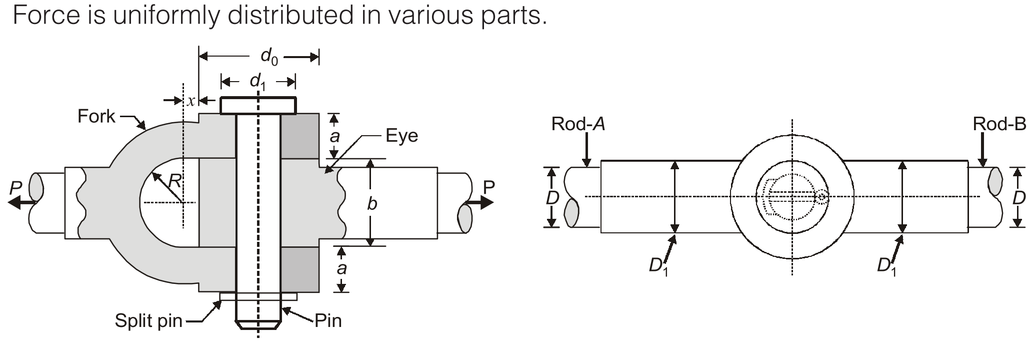


Figure 2.8

Here, D = Diameter of each rod
D_1 = Enlarged diameter of each rod
d = Diameter of knuckle pin/Inside diameter of fork/eye
d_0 = Outside diameter of eye or fork.
a = Thickness of each eye of fork (Rod-A)
b = Thickness of eye of Rod-B
d_1 = Diameter of pin head
x = Distance of centre of fork radius R from the eye.

(i) Tensile Failure of Rod

Permissible tensile stress, $$\sigma_t = \frac{P}{\frac{\pi}{4}.D^2} = \frac{4P}{\pi D^2}$$

For calculation of D_1, use empirical relationship
$$D_1 = 1.1\,D$$

(ii) Shear Failure of Pin

The *pin* is subjected to double shear
Permissible shear stress,
$$\tau = \frac{P}{2 \times \left(\frac{\pi}{4} d^2\right)}$$
$$\Rightarrow \qquad d = \sqrt{\frac{2P}{\pi \tau}}$$
Standard diameter of pin(d) should be
$$d = D$$

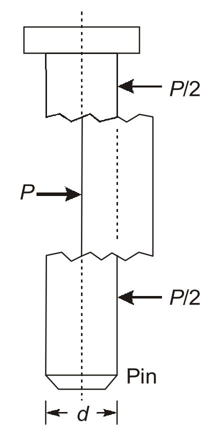


Figure 2.9

(iii) Crushing Failure of Pin in Eye

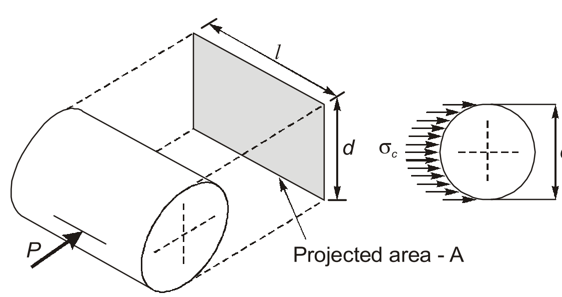


Figure 2.10

When a cylindrical surface is subjected to a force along its periphery, its projected area (not actual area) is taken into consideration.

$\therefore$ Permissible crushing stress, $$\sigma_c = \frac{P}{l \times d}$$

The projected area of the pin in the eye is $b \times d$, thus, permissible crushing stress,
$$\sigma_c = \frac{P}{b \times d}$$

(iv) Crushing Failure of Pin in the Fork

Total projected area of pin in fork = $2ad$

$\therefore$ Permissible crushing stress, $\sigma_c = \dfrac{P}{2ad}$

(v) Tensile Failure of Eye

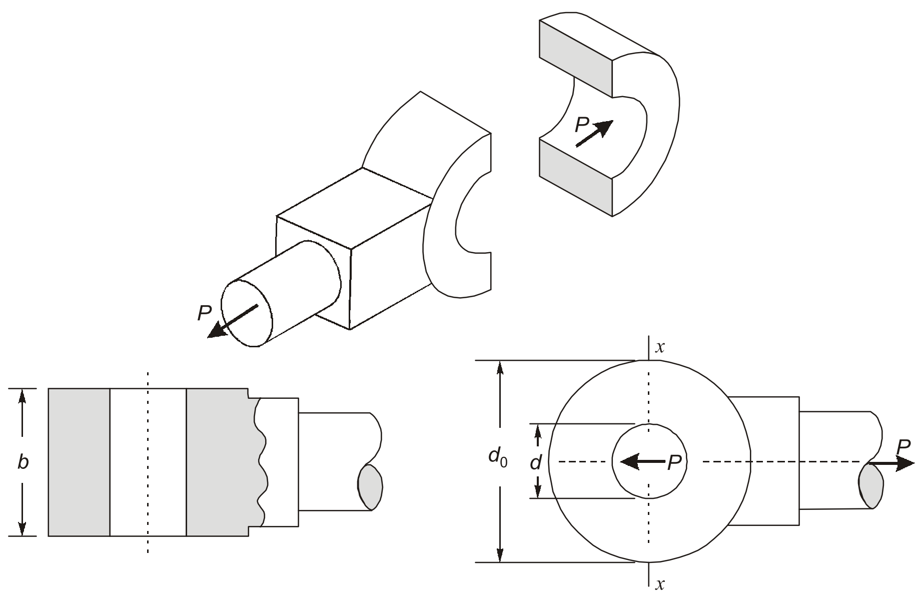


Figure 2.11

In figure, X-X section is the weakest section of the eye.

Area at X-X = $b(d_0 - d)$

$\because$ Permissible tensile stress, $\sigma_t = \dfrac{P}{b(d_0 - d)}$

(vi) Shear Failure of Eye

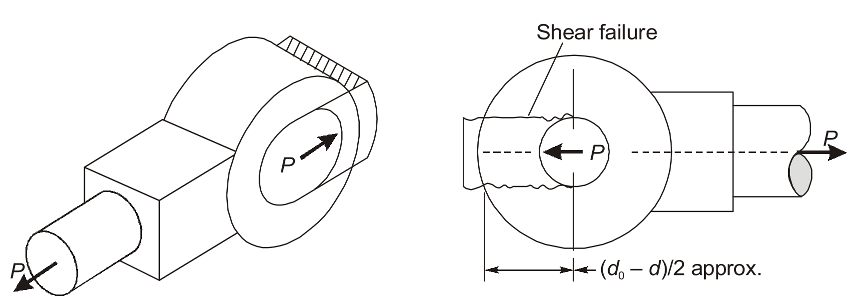


Figure 2.12

Eye is subjected to double shear

$\therefore$ Area of each shear plane $= \dfrac{b(d_0 - d)}{2}$

$\therefore$ Permissible shear stress, $\tau = \dfrac{P}{2\left[\dfrac{b(d_0-d)}{2}\right]} = \dfrac{P}{b(d_0-d)}$

Standard proportion, $d_0 = 2d$

(vii) Tensile Failure of Fork

Fork has a double eye

Area of weakest section $= a(d_0 - d)$

Permissible tensile stress in the fork, $\sigma_t = \dfrac{P}{2a(d_0-d)}$

(viii) Shear Failure of Fork

Each eye of fork subjected to double shear.

$\therefore$ Permissible shear stress, $\tau = \dfrac{P}{2b(d_0-d)}$ [from 6]

Standard proportion for 'a' and 'b' and 'd_1', 'x'

$a = 0.75D$ $\quad b = 1.75D$

$d_1 = 1.5d$ $\quad x = 10$ mm (usually)

(ix) Bending Failure of Pin

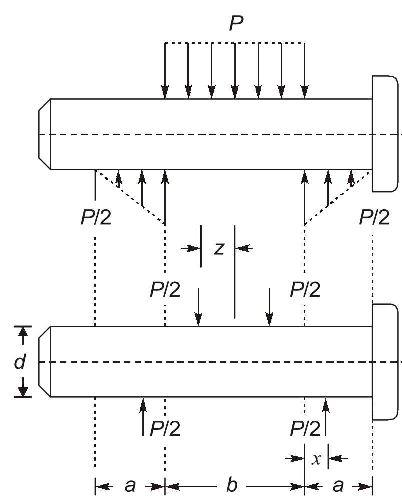


Figure 2.13

- When the pin is tight in the eye and the fork, failure occur due to shear, when the pin is loose failure occur due to bending moment.
- Load acting on the pin is uniformly distributed in the eye, but uniformally varying in the two part of fork.
  $\therefore$ Permissible bending stress

$$\sigma_b = \frac{M_b y}{I} = \frac{\frac{P}{2}\left[\frac{b}{4}+\frac{a}{3}\right]\frac{d}{2}}{\frac{\pi d^4}{64}} = \frac{32}{\pi d^3}\times\frac{P}{2}\left[\frac{b}{4}+\frac{a}{3}\right]$$

Example 2.1 Design a socket and spigot cotter joint for transmission of 25 kN tensile forces for given allowable stress, $\sigma_t = 50$ MPa, $\sigma_c = 80$ MPa, $\tau = 40$ MPa. $P = 25$ kN.

Solution :

Rod:

$$\sigma_t = \frac{P}{\pi/4\times d^2} = 50$$

$$d = 25.23 = 30 \text{ mm}$$

$$t = \frac{d}{4} = \frac{30}{4} = 7.5 \text{ mm}$$

Spigot:

$$\sigma_t = \frac{P}{\left[\frac{\pi}{4}d_1^2 - d_1 t\right]} = 50$$

$$\Rightarrow \quad d_1 = 30.45 \approx 35 \text{ mm}$$

$$\sigma_c = \frac{P}{d_1 t} = 95.23 > 80 \text{ MPa design fails.}$$

$$80 = \frac{25 \times 10^3}{35 \times t} \quad \Rightarrow \quad t = 8.9 \text{ mm} \approx 10 \text{ mm}$$

Socket

$$\sigma_t = \frac{P}{\pi / 4\left(d_2^2 - d_1^2\right) - (d_2 - d_1)t} = 50$$

$$\Rightarrow \quad d_2 = 44.5 \approx 45 \text{ mm}$$

$$\sigma_c = \frac{P}{(d_3 - d_1)t} = 80 \quad \Rightarrow \quad d_3 = 66.25 \approx 70 \text{ mm}$$

Cotter

$$\tau = \frac{P}{2bt} \quad \Rightarrow \quad b = 31.25 \text{ mm} \approx 35 \text{ mm}$$

$$L = (D_3 + 20) = 90 \text{ mm}$$

Example 2.2 Design a gib and cotter joint for 2 rods of square cross-section carrying an axial tensile load of 40 kN. Cotter and rods (same material – σ_t = 60 MPa, σ_c = 125 MPa, τ = 45.

Solution :

Rod

$$\sigma_t = \frac{P}{a(a-t)} = 60$$

$$a = 31.62 \approx 35 \text{ mm}$$

$$\therefore \quad t = \frac{35}{3} = 11.66 \approx 12 \text{ mm}$$

$$\sigma_c = \frac{P}{at} = 95.23 < 125 - \text{design is safe}$$

$$\tau = \frac{P}{2aL_1}$$

$$\Rightarrow \quad L_1 = 12.69 \text{ mm} \approx 15 \text{ mm}$$

Strap

$$\sigma_t = \frac{P}{(a-t)t_1 2} = 60$$

$$\Rightarrow \quad t_1 = 14.49 \approx 15 \text{ mm}$$

$$\sigma_c = \frac{P}{2tt_1} = 11411 < 125 \text{ safe}$$

$$\tau = \frac{P}{4t_1 L_2} = 45$$

$$\Rightarrow \quad L_2 = 14.81 \approx 15 \text{ mm}$$

Cotter and gib

$$t = 12 \text{ mm}$$

$$\tau = 45 = \frac{P}{2(b + b_1)t}$$

$$b = 16.46 \approx 18 \text{ mm}$$

$$\therefore \quad b_1 = 22.5 \approx 24 \text{ mm}$$

and

$$L_3 = 0.79 = 24.5 \text{ mm} \approx 25 \text{ mm}$$

Objective Brain Teasers

Q.1 A cotter joint is used when no relative motion is permitted between the rods joined by the cotter. It is capable of transmitting
(a) twisting moment
(b) an axial tensile as well as compressive load
(c) the bending moment
(d) only compressive axial load

Q.2 In a gib and cotter joint, the gib and cotter are subjected to
(a) Single shear only
(b) Double shear only
(c) Single shear and crushing
(d) Double shear and crushing

Q.3 Permissible shear stress in socket end

(a) $\tau = \dfrac{P}{2(d_o - d_i)C}$

(b) $\tau = \dfrac{P}{(d_o + d_i)C}$

(c) $\tau = \dfrac{2P}{(d_o + d_i)C}$

(d) $\tau = \dfrac{P}{(d_o + d_i)2C}$

where, C = Axial distance from slot to end of socket coller

Q.4 The taper on cotter is usually
(a) 1 in 24 (b) 1 in 8
(c) 1 in 100 (d) 1 in 48

Q.5 A taper is provided for cotter
(a) to ensure tightness in operating condition
(b) to provide wedge action
(c) to ease the removal of cotter during dismantling
(d) for all three reasons

Q.6 The joint between the piston rod and the cross head of steam engine is
(a) Kunckle joint
(b) Universal joint
(c) Cotter joint
(d) Key joint

Q.7 Cotter joint is used for the joint between
(a) piston rod and cross-head of steam engine
(b) slide spindle and fork of valve mechanism
(c) piston rod and tail rod or pump rod
(d) for all three applications

Q.8 A knuckle joint is used to transmit
(a) axial tensile force only
(b) axial tensile or compressive force
(c) axial compressive force only
(d) combined bending and torsional moment

Q.9 The pin in knuckle joint is subjected to
(a) double shear stress
(b) torsional shear stress
(c) axial tensile stress
(d) axial compressive stress

Answers

1. (b)	2. (d)	3. (a)	4. (a)	5. (d)
6. (c)	7. (d)	8. (a)	9. (a)	

Hints and Explanations:

1. **(b)**
Note that cotter joint is not used for connecting two shafts which are rotating and transmitting torque. It is used to transmit axial tensile as well as compressive load.

Student's Assignments

Q.1 Two rods are connected by means of a cotter joint. The inside diameter of the socket and outside diameter of the socket collar are 50 and 100 mm respectively. The rods are subjected to a tensile force of 50 kN. The cotter is made of steel 30C8 (S_{yt} = 400 N/mm^2) and the factor of safety is 4. The width of the cotter is five times of thickness. Calculate:

(i) width and thickness of the cotter on the basis of shear failure; and

(ii) width and thickness of the cotter on the basis of bending failure.

Q.2 A gib and cotter joint is used for strap-type big end of the connecting rod. The rod is subjected to a maximum pull of 50 kN and the diameter of circular part of the rod adjacent to strap end is 60 mm. The strap, gib and cotter are made of plain carbon steel of grade 30C8 (S_{yt} = 400 N/mm^2) and the factor of safety is 10. There are three reason for recommending a rather high factor of safety, namely – (i) Big end of connecting rod is critical part in engine design; (ii) The analysis used for calculating dimensions of the joint is too elementary; and (iii) There is stress concentration due to oil hole in the strap which is neglected. Calculate:

(i) the width of strap;

(ii) the thickness of strap at the thinnest cross-section and at cross-section passing through the slot; and

(iii) thickness and widths of gib and cotter at mid section.

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