UNIT III
TEMPORARY AND PERMANENT JOINTS
CHAPTER 4

Introduction of Cotter Joint

A cotter is a flat wedge shaped piece of rectangular cross-section and its width is tapered (either on one side or both sides) from one end to another for an easy adjustment. The taper varies from 1 in 48 to 1 in 24 and it may be increased up to 1 in 8, if a locking device is provided. The locking device may be a taper pin or a set screw used on the lower end of the cotter. The cotter is usually made of mild steel or wrought iron. A cotter joint is a temporary fastening and is used to connect rigidly two co-axial rods or bars which are subjected to axial tensile or compressive forces. It is usually used in connecting a piston rod to the crosshead of a reciprocating steam engine, a piston rod and its extension as a tail or pump rod, strap end of connecting rod etc.

Types of Cotter Joints

Following are the three commonly used cotter joints to connect two rods by a cotter:

1. Socket and spigot cotter joint,
2. Sleeve and cotter joint, and
3. Gib and cotter joint.

Socket and Spigot Cotter Joint

In a socket and spigot cotter joint, one end of the rods (say A) is provided with a socket type of end as shown in Fig. 4.1 and the other end of the other rod (say B) is inserted into a socket. The end of the rod which goes into a socket is also called spigot. A rectangular hole is made in the socket and spigot. A cotter is then driven tightly through a hole in order to make the temporary connection between the two rods. The load is usually acting axially, but it changes its direction and hence the cotter joint must be designed to carry both the tensile and compressive loads. The compressive load is taken up by the collar on the spigot.

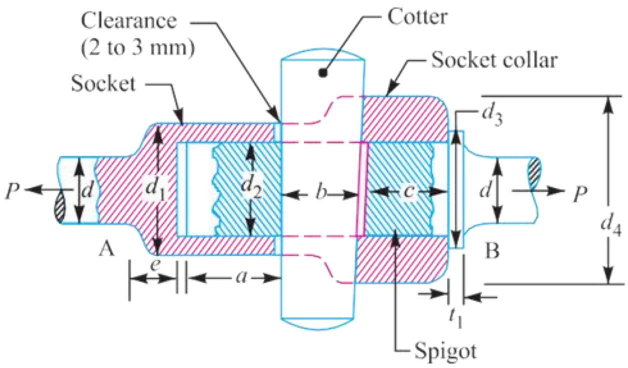

Fig 4.1 Socket and spigot cotter joint.

[Source: "A Textbook of Machine Design by R.S. Khurmi J.K. Gupta, Page: 432]

Design of Socket and Spigot Cotter Joint

The socket and spigot cotter joint is shown in Fig. 4.1.

Let P = Load carried by the rods,

d = Diameter of the rods,

d_1 = Outside diameter of socket,

d_2 = Diameter of spigot or inside diameter of socket,

d_3 = Outside diameter of spigot collar,

t_1 = Thickness of spigot collar,

d_4 = Diameter of socket collar,

c = Thickness of socket collar,

b = Mean width of cotter,

t = Thickness of cotter,

l = Length of cotter,

a = Distance from the end of the slot to the end of rod,

σ_t = Permissible tensile stress for the rods material,

τ = Permissible shear stress for the cotter material, and

σ_c = Permissible crushing stress for the cotter material.

The dimensions for a socket and spigot cotter joint may be obtained by considering the various modes of failure as discussed below:

1. Failure of the rods in tension

The rods may fail in tension due to the tensile load P.

We know that

Area resisting tearing = $\frac{\pi}{4} \times d^2$

∴ Tearing strength of the rods,

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

Equating this to load (P), we have

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

From this equation, diameter of the rods (d) may be determined.

2. Failure of spigot in tension across the weakest section (or slot)

Since the weakest section of the spigot is that section which has a slot in it for the cotter, as shown in Fig. 4.2, therefore

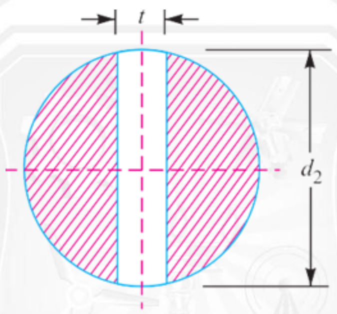

Fig 4.2

[Source: "A Textbook of Machine Design by R.S. Khurmi J.K. Gupta, Page: 433]

Area resisting tearing of the spigot across the slot = $\frac{\pi}{4}(d_2)^2 - d_2 \times t$

and tearing strength of the spigot across the slot = $[\frac{\pi}{4}(d_2)^2 - d_2 \times t]\,\sigma_t$

Equating this to load (P), we have

$$P = [\frac{\pi}{4}(d_2)^2 - d_2 \times t]\,\sigma_t$$

From this equation, the diameter of spigot or inside diameter of socket (d_2) may be determined.

3. Failure of the rod or cotter in crushing

We know that the area that resists crushing of a rod or cotter = $d_2 \times t$

∴ Crushing strength = $d_2 \times t \times \sigma_c$

Equating this to load (P), we have

$$P = d_2 \times t \times \sigma_c$$

From this equation, the induced crushing stress may be checked.

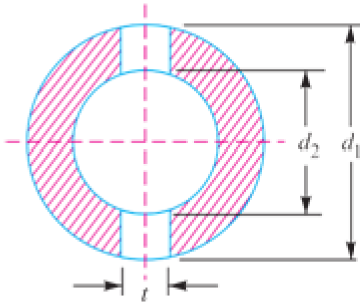

Fig 4.3

[Source: "A Textbook of Machine Design by R.S. Khurmi J.K. Gupta, Page: 433]

4. Failure of the socket in tension across the slot

We know that the resisting area of the socket across the slot, as shown in Fig. 4.3

$$= \frac{\pi}{4}[(d_1)^2 - (d_2)^2]-(d_1-d_2) - t$$

∴ Tearing strength of the socket across the slot $=\{ \frac{\pi}{4}[(d_1)^2 - (d_2)^2]-(d_1-d_2) - t\} \sigma_t$

Equating this to load (P), we have

$$P = \{ \frac{\pi}{4}[(d_1)^2 - (d_2)^2]-(d_1-d_2) - t\} \sigma_t$$

From this equation, outside diameter of socket (d_1) may be determined.

5.Failure of cotter in shear

Considering the failure of cotter in shear as shown in Fig. 4.4. Since the cotter is in double shear, therefore shearing area of the cotter

$$= 2\ b \times t$$

and shearing strength of the cotter

$$=2\ b \times t \times \tau$$

Equating this to load (P), we have

$$P = 2\ b \times t \times \tau$$

From this equation, width of cotter (b) is determined.

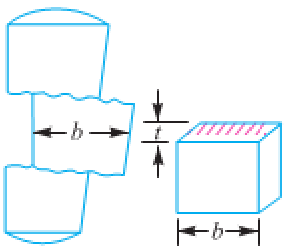

Fig 4.4

[Source: "A Textbook of Machine Design by R.S. Khurmi J.K. Gupta, Page: 434]

6. Failure of the socket collar in crushing

Considering the failure of socket collar in crushing as shown in Fig. 5.5.

We know that area that resists crushing of socket collar = $(d_4 - d_2)\ t$

and crushing strength = $(d_4 - d_2)\ t \times \sigma_c$

Equating this to load (P), we have

$$P = (d_4 - d_2)\ t \times \sigma_c$$

From this equation, the diameter of socket collar (d_4) may be obtained.

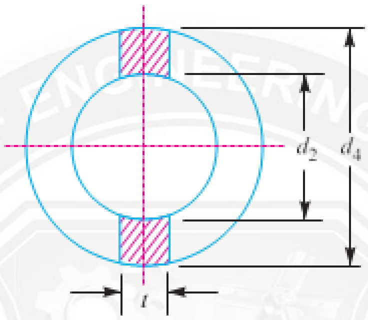

Fig 4.5

[Source: "A Textbook of Machine Design by R.S. Khurmi J.K. Gupta, Page: 434]

8. Failure of rod end in shear

Since the rod end is in double shear, therefore the area resisting shear of the rod end $= 2\ a \times d_2$

and shear strength of the rod end

$$= 2\ a \times d_2 \times \tau$$

Equating this to load (P), we have

$$P = 2\ a \times d_2 \times \tau$$

From this equation, the distance from the end of the slot to the end of the rod (a) may be obtained.

9. Failure of spigot collar in crushing

Considering the failure of the spigot collar in crushing as shown in Fig. 4.6. We know that area that resists crushing of the collar

$$= \frac{\pi}{4}[(d_3)^2 - (d_2)^2]$$

and crushing strength of the collar

$$= \frac{\pi}{4}[(d_3)^2 - (d_2)^2]\sigma_c$$

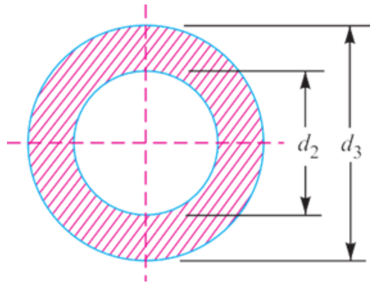

Fig 4.6

[Source: "A Textbook of Machine Design by R.S. Khurmi J.K. Gupta, Page: 435]

Equating this to load (P), we have

$$P = \frac{\pi}{4}[(d_3)^2 - (d_2)^2]\sigma_c$$

From this equation, the diameter of the spigot collar (d_3) may be obtained.

10. Failure of the spigot collar in shearing

Considering the failure of the spigot collar in shearing as shown in Fig. 4.7. We know that area that resists shearing of the collar

$$= \pi\, d_2 \times t_1$$

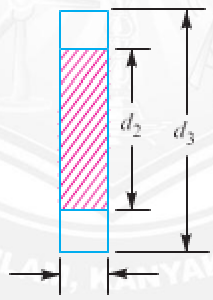

Fig 4.7

[Source: "A Textbook of Machine Design by R.S. Khurmi J.K. Gupta, Page: 435]

and shearing strength of the collar,

$$= \pi\, d_2 \times t_1 \times \tau$$

Equating this to load (P), we have

$$P = \pi\, d_2 \times t_1 \times \tau$$

From this equation, the thickness of spigot collar (t_1) may be obtained.

10.Failure of cotter in bending

In all the above relations, it is assumed that the load is uniformly distributed over the various cross-sections of the joint. But in actual practice, this does not happen and the cotter is subjected to bending. In order to find out the bending stress induced, it is assumed that the load on the cotter in the rod end is uniformly distributed while in the socket end it varies from zero at the outer diameter (d_4) and maximum at the inner diameter (d_2), as shown in Fig. 4.8.

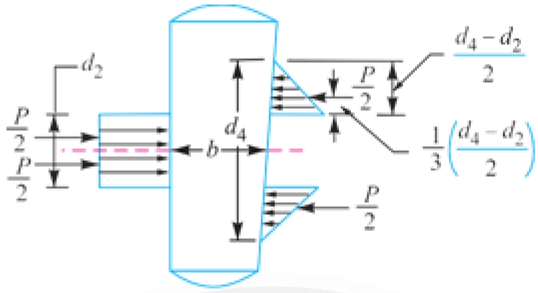

Fig 4.8

[Source: "A Textbook of Machine Design by R.S. Khurmi J.K. Gupta, Page: 435]

The maximum bending moment occurs at the centre of the cotter and is given by

$$M_{max} = \frac{P}{2}\left(\frac{1}{3} \times \frac{d_4 - d_2}{2} + \frac{d_2}{2}\right) - \frac{P}{2} \times \frac{d_2}{4}$$

$$M_{max} = \frac{P}{2}\left(\frac{d_4 - d_2}{6} + \frac{d_2}{2} - \frac{d_2}{4}\right)$$

$$M_{max} = \frac{P}{2}\left(\frac{d_4 - d_2}{6} + \frac{d_2}{4}\right)$$

We know that section modulus of the cotter,

$$Z = t \times \frac{b^2}{6}$$

∴ Bending stress induced in the cotter,

$$\sigma_b = \frac{\frac{P}{2}\left(\frac{d_4 - d_2}{6} + \frac{d_2}{4}\right)}{t \times \frac{b^2}{6}}$$

This bending stress induced in the cotter should be less than the allowable bending stress of the cotter.

12.The length of cotter (l) is taken as 4 d.

13. The taper in cotter should not exceed 1 in 24. In case the greater taper is required, then a locking device must be provided.

14.The draw of cotter is generally taken as 2 to 3 mm.

Notes: 1. When all the parts of the joint are made of steel, the following proportions in terms of diameter of the rod (d) are generally adopted:

$d_1 = 1.75$ d;	$d_2 = 1.21$ d;	$d_3 = 1.5$ d;
$d_4 = 2.4$ d;	a = c = 0.75 d;	b = 1.3 d;

$l = 4\ d$; $t = 0.31\ d$; $t_1 = 0.45\ d$; $e = 1.2\ d$.

Taper of cotter = 1 in 25, and draw of cotter = 2 to 3 mm.

2. If the rod and cotter are made of steel or wrought iron, then $\tau = 0.8\ \sigma_t$ and $\sigma_c = 2\ \sigma_t$ may be taken.

Problem 4.1

Design and draw a cotter joint to support a load varying from 30 kN in compression to 30 kN in tension. The material used is carbon steel for which the following allowable stresses may be used. The load is applied statically. Tensile stress = compressive stress = 50 MPa shear stress = 35 MPa and crushing stress = 90 MPa.

Given Data:

$P = 30\ kN = 30 \times 10^3\ N$

$\sigma_t = 50\ MPa = 50\ N / mm^2$

$\tau = 35\ MPa = 35\ N / mm^2$

$\sigma_c = 90\ MPa = 90\ N/mm^2$

1. Diameter of the rods

Let d = Diameter of the rods.

Considering the failure of the rod in tension. We know that load (P),

$$30 \times 10^3 = \frac{\pi}{4} \times d^2 \times \sigma_t$$

$$30 \times 10^3 = \frac{\pi}{4} \times d^2 \times 50$$

$$30 \times 10^3 = 39.3 d^2$$

$$d^2 = 30 \times 10^3 / 39.3$$

$$d^2 = 763$$

$$d = 27.6 \text{ say } 28\ mm.$$

2. Diameter of spigot and thickness of cotter

Let d_2 = Diameter of spigot or inside diameter of socket, and

t = Thickness of cotter. It may be taken as $d_2 / 4$.

Considering the failure of spigot in tension across the weakest section. We know that load (P),

$$30 \times 10^3 = [\ \frac{\pi}{4} (d_2)^2 - d_2 \times t]\ \sigma_t$$

$$30 \times 10^3 = [\frac{\pi}{4}(d_2)^2 - d_2 \times \frac{d_2}{2}]\ 50$$

$$30 \times 10^3 = 26.8\ d_2^2$$

$$(d_2)^2 = 30 \times 10^3 / 26.8$$

$$(d_2)^2 = 1119.4 \text{ or}$$

$$d_2 = 33.4 \text{ say } 34 \text{ mm}$$

and thickness of cotter, $t = \frac{d_2}{2} = \frac{34}{2}$

$$t = 8.5 \text{ mm}$$

Let us now check the induced crushing stress. We know that load (P),

$$30 \times 10^3 = d_2 \times t \times \sigma_c$$

$$30 \times 10^3 = 34 \times 8.5 \times \sigma_c$$

$$30 \times 10^3 = 289\ \sigma_c$$

$$\sigma_c = 30 \times 10^3 / 289$$

$$\sigma_c = 103.8 \text{ N/mm}^2$$

Since this value of σ_c is more than the given value of σ_c = 90 N/mm^2, therefore the dimensions d_2 = 34 mm and t = 8.5 mm are not safe. Now let us find the values of d_2 and t by substituting the value of σ_c = 90 N/mm2 in the above expression, i.e.

$$30 \times 10^3 = d_2 \times \frac{d_2}{4} \times 90$$

$$30 \times 10^3 = 22.5\ d_2^2$$

$$(d_2)^2 = 30 \times 10^3 / 22.5 = 1333$$

$$d_2 = 36.5 \text{ say } 40 \text{ mm Ans.}$$

and $t = d_2 / 4 = 40 / 4 = 10$ mm.

3. Outside diameter of socket

Let d_1 = Outside diameter of socket.

Considering the failure of the socket in tension across the slot. We know that load (P),

$$30 \times 10^3 = \{ \frac{\pi}{4}[(d_1)^2 - (d_2)^2]-(d_1-d_2) - t\}\ \sigma_t$$

$$30 \times 10^3 = \{ \frac{\pi}{4}[(d_1)^2 - (40)^2]-(d_1-40) - 10\}\ 50$$

$$30 \times 10^3/50 = 0.7854\ (d_1)^2 - 1256.6 - 10\ d_1 + 400$$

$$(d_1)^2 - 12.7\ d_1 - 1854.6 = 0$$

$$d_1 = \frac{12.7 \pm \sqrt{(12.7)^2 + 4 \times 1854.6}}{2}$$

$$d_1 = \frac{12.7 \pm 87.1}{2}$$

d_1 = 49.9 say 50 mm. ... (Taking +ve sign)

4. Width of cotter

Let b = Width of cotter.

Considering the failure of the cotter in shear. Since the cotter is in double shear, therefore load (P),

$30 \times 10^3 = 2\ b \times t \times \tau$

$30 \times 10^3 = 2\ b \times 10 \times 35$

$30 \times 10^3 = 700\ b$

$b = 30 \times 10^3 / 700$

$\therefore b = 43$ mm.

5. Diameter of socket collar

Let d_4 = Diameter of socket collar.

Considering the failure of the socket collar and cotter in crushing. We know that load (P),

$30 \times 10^3 = (d_4 - d_2)\ t \times \sigma_c$

$30 \times 10^3 = (d_4 - 40)10 \times 90$

$30 \times 10^3 = (d4 - 40)\ 900$

$d_4 - 40 = 30 \times 10^3 / 900 = 33.3$

$d_4 = 33.3 + 40$

d_4 = 73.3 say 75 mm.

6. Thickness of socket collar

Let c = Thickness of socket collar.

Considering the failure of the socket end in shearing. Since the socket end is in double shear, therefore load (P),

$30 \times 10^3 = 2(d_4 - d_2)\ c \times \tau$

$30 \times 10^3 = 2\ (75 - 40)\ c \times 35$

$30 \times 10^3 = 2450\ c$

$c = 30 \times 103 / 2450$

c = 12 mm.

7. Distance from the end of the slot to the end of the rod

Let a = Distance from the end of slot to the end of the rod.

Considering the failure of the rod end in shear. Since the rod end is in double shear, therefore load (P),

$$30 \times 10^3 = 2\,a \times d_2 \times \tau$$

$$30 \times 10^3 = 2a \times 40 \times 35$$

$$30 \times 10^3 = 2800\,a$$

$$a = 30 \times 10^3 / 2800$$

$$\therefore a = 10.7 \text{ say } 11 \text{ mm.}$$

8. Diameter of spigot collar

Let d3 = Diameter of spigot collar.

Considering the failure of spigot collar in crushing. We know that load (P),

$$30 \times 10^3 = = \frac{\pi}{4}\left[(d_3)^2 - (d_2)^2\right]\sigma_c$$

$$30 \times 10^3 = = \frac{\pi}{4}\left[(d_3)^2 - (40)^2\right]90$$

$$(d_3)^2 - (40)^2 = \frac{30\times10^3\times 4}{90\times\pi}$$

$$(d_3)^2 = 424 + (40)^2$$

$$(d_3)^2 = 2024$$

$$d_3 = 45 \text{ mm}$$

9. Thickness of spigot collar

Let t_1 = Thickness of spigot collar.

Considering the failure of spigot collar in shearing. We know that load (P),

$$30 \times 10^3 = \pi\, d_2 \times t_1 \times \tau$$

$$30 \times 10^3 = \pi \times 40 \times t_1 \times 35$$

$$30 \times 10^3 = 4400\, t_1$$

$$t_1 = 30 \times 103 / 4400$$

$$\therefore t_1 = 6.8 \text{ say } 8 \text{ mm.}$$

10. The length of cotter (l) is taken as 4 d.

$$l = 4\,d = 4 \times 28$$

$$\therefore l = 112 \text{ mm.}$$

11. The dimension e is taken as 1.2 d.

$e = 1.2 \times 28$

$\therefore e = 33.6$ say 34 mm.