

## 3.2 WELDED JOINTS

### 3.3.1 Introduction

A welded joint is a permanent joint which is obtained by the fusion of the edges of the two parts to be joined together, with or without the application of pressure and a filler material. The heat required for the fusion of the material may be obtained by burning of gas (in case of gas welding) or by an electric arc (in case of electric arc welding). The latter method is extensively used because of greater speed of welding. Welding is extensively used in fabrication as an alternative method for casting or forging and as a replacement for bolted and riveted joints. It is also used as a repair medium *e.g.* to reunite metal at a crack, to build up a small part that has broken off such as gear tooth or to repair a worn surface such as a bearing surface.

### 3.3.2 Advantages and Disadvantages of Welded Joints over Riveted Joints

Following are the advantages and disadvantages of welded joints over riveted joints.

#### *Advantages*

1. The welded structures are usually lighter than riveted structures. This is due to the reason, that in welding, gussets or other connecting components are not used.
2. The welded joints provide maximum efficiency (may be 100%) which is not possible in case of riveted joints.
3. Alterations and additions can be easily made in the existing structures.
4. As the welded structure is smooth in appearance, therefore it looks pleasing.
5. In welded connections, the tension members are not weakened as in the case of riveted joints.
6. A welded joint has a great strength. Often a welded joint has the strength of the parent metal itself.
7. Sometimes, the members are of such a shape (*i.e.* circular steel pipes) that they afford difficulty for riveting. But they can be easily welded.
8. The welding provides very rigid joints. This is in line with the modern trend of providing rigid frames.
9. It is possible to weld any part of a structure at any point. But riveting requires enough clearance.
10. The process of welding takes less time than the riveting.

#### *Disadvantages*

1. Since there is an uneven heating and cooling during fabrication, therefore the members may get distorted or additional stresses may develop.
2. It requires a highly skilled labour and supervision.
3. Since no provision is kept for expansion and contraction in the frame, therefore there is a possibility of cracks developing in it.
4. The inspection of welding work is more difficult than riveting work.

### 3.3.3 Welding Processes

The welding processes may be broadly classified into the following two groups:

1. Welding processes that use heat alone *e.g.* fusion welding.
2. Welding processes that use a combination of heat and pressure  
*e.g.* forge welding.

These processes are discussed in detail, in the following pages

### 3.3.4 Fusion Welding

In case of fusion welding, the parts to be jointed are held in position while the molten metal is supplied to the joint. The molten metal may come from the parts themselves (*i.e.* parent metal) or filler metal which normally have the composition of the parent metal. The joint surface become

plastic or even molten because of the heat from the molten filler metal or other source. Thus, when the molten metal solidifies or fuses, the joint is formed. The fusion welding, according to the method of heat generated, may be classified as:

1. Thermit welding, 2. Gas welding, and 3. Electric arc welding.

### 3.3.5 Thermit Welding

In thermit welding, a mixture of iron oxide and aluminium called *thermit* is ignited and the iron oxide is reduced to molten iron. The molten iron is poured into a mould made around the joint and fuses with the parts to be welded. A major advantage of the thermit welding is that all parts of weld section are molten at the same time and the weld cools almost uniformly. This results in a minimum problem with residual stresses. It is fundamentally a melting and casting process. The thermit welding is often used in joining iron and steel parts that are too large to be manufactured in one piece, such as rails, truck frames, locomotive frames, other large sections used on steam and rail roads, for stern frames, rudder frames etc. In steel mills, thermit electric welding is employed to replace broken gear teeth, to weld new necks on rolls and pinions, and to repair broken shears

### 3.3.6 Gas Welding

A gas welding is made by applying the flame of an oxy-acetylene or hydrogen gas from a welding torch upon the surfaces of the prepared joint. The intense heat at the white cone of the flame heats up the local surfaces to fusion point while the operator manipulates a welding rod to supply the metal for the weld. A flux is being used to remove the slag. Since the heating rate in gas welding is slow, therefore it can be used on thinner materials.

### 3.3.7 Electric Arc Welding

In electric arc welding, the work is prepared in the same manner as for gas welding. In this case the filler metal is supplied by metal welding electrode. The operator, with his eyes and face protected, strikes an arc by touching the work of base metal with the electrode. The base metal in the path of the arc stream is melted, forming a pool of molten metal, which seems to be forced out of the pool by the blast from the arc, as shown in Fig. 3.45. A small depression is formed in the base metal and the molten metal is deposited around the edge of this depression, which is called the *arc crater*. The slag is brushed off after the joint has cooled. The arc welding does not require the metal to be preheated and since the temperature of the arc is quite high, therefore the fusion of the metal is almost instantaneous. There are two kinds of arc weldings depending upon the type of electrode.

1. Un-shielded arc welding, and
2. Shielded arc welding.

When a large electrode or filler rod is used for welding, it is then said to be *un-shielded arc welding*. In this case, the deposited weld metal while it is hot will absorb oxygen and nitrogen from the atmosphere. This decreases the strength of weld metal and lower its ductility and resistance to corrosion. In *shielded arc welding*, the welding rods coated with solid material are used, as shown in Fig. 3.45. The resulting projection of coating focuses a concentrated arc stream, which protects the globules of metal from the air and prevents the absorption of large amounts of harmful oxygen and nitrogen.

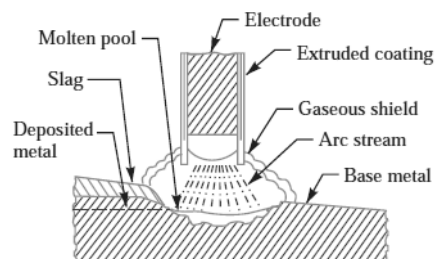


Fig. 3.45. Shielded electric arc welding

### 3.3.8 Forge Welding

In forge welding, the parts to be jointed are first heated to a proper temperature in a furnace or forge and then hammered. This method of welding is rarely used now-a-days. An *electric-resistance welding* is an example of forge welding. In this case, the parts to be jointed are pressed together and an electric current is passed from one part to the other until the metal is heated to the fusion temperature of the joint. The principle of applying heat and pressure, either sequentially or simultaneously, is widely used in the processes known as *spot, seam, projection, upset and flash welding*.

### 3.3.9 Types of Welded Joints

Following two types of welded joints are important from the subject point of view:

1. Lap joint or fillet joint, and
2. Butt joint.

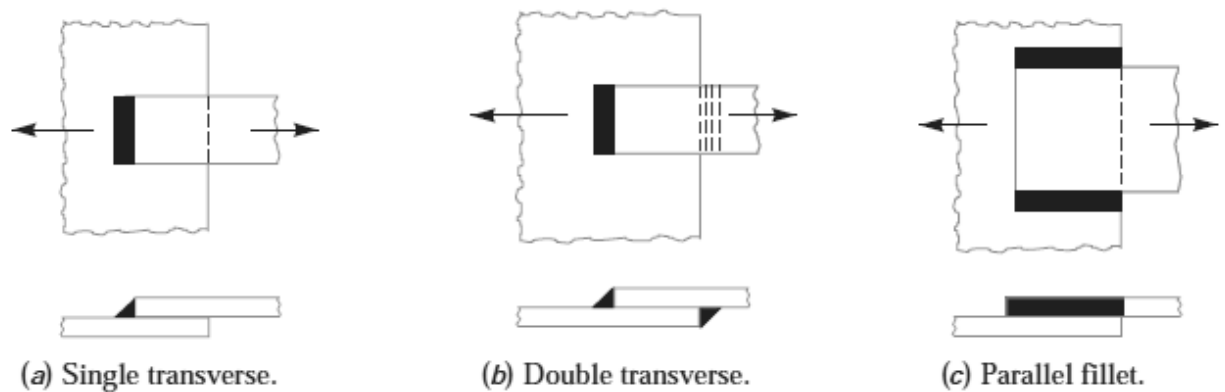


Fig. 3.46. Types of lap or fillet joints.

#### Lap Joint

The lap joint or the fillet joint is obtained by overlapping the plates and then welding the edges of the plates. The cross-section of the fillet is approximately triangular. The fillet joints may be

1. Single transverse fillet,
2. Double transverse fillet,
- and 3. Parallel fillet joints.

The fillet joints are shown in Fig. 3.46. A single transverse fillet joint has the disadvantage that the edge of the plate which is not welded can buckle or warp out of shape.

#### Butt Joint

The butt joint is obtained by placing the plates edge to edge as shown in Fig. 3.47. In butt welds, the plate edges do not require bevelling if the thickness of plate is less than 5 mm. On the other hand, if the plate thickness is 5 mm to 12.5 mm, the edges should be bevelled to V or U-groove on both sides.

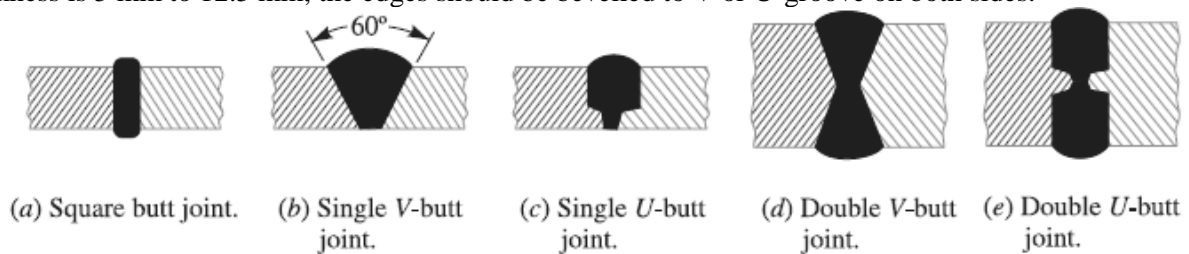


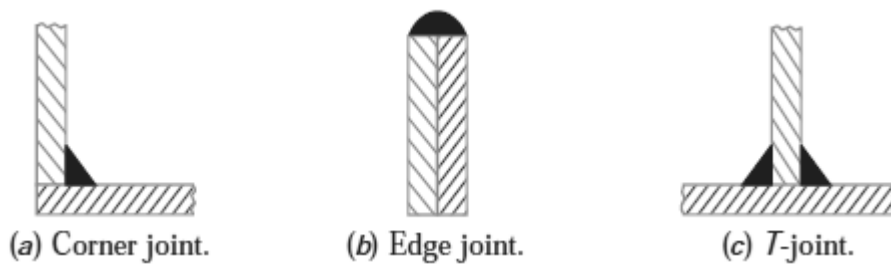
Fig. 3.47. Types of butt joints.

The butt joints may be

1. Square butt joint,
2. Single V-butt joint,
3. Single U-butt joint,
4. Double V-butt joint,
- and 5. Double U-butt joint.

These joints are shown in Fig. 3.48.

The other type of welded joints are corner joint, edge joint and T-joint as shown in Fig. 3.48.



**Fig. 3.48.** Other types of welded joints.

The main considerations involved in the selection of weld type are:

1. The shape of the welded component required,
2. The thickness of the plates to be welded, and
3. The direction of the forces applied.

### 3.3.10 Basic Weld Symbols

The basic weld symbols according to IS : 813 – 1961 (Reaffirmed 1991) are shown in the following table.

**Table 3.2. Basic weld symbols.**

<i>S. No.</i>	<i>Form of weld</i>	<i>Sectional representation</i>	<i>Symbol</i>
1.	Fillet		
2.	Square butt		
3.	Single-V butt		
4.	Double-V butt		
5.	Single-U butt		
6.	Double-U butt		
7.	Single bevel butt		
8.	Double bevel butt		

S. No.	Form of weld	Sectional representation	Symbol
9.	Single-V butt		
10.	Double-V butt		
11.	Bead (edge or seal)		
12.	Stud		
13.	Sealing run		
14.	Spot		
15.	Seam		
16.	Mashed seam		
17.	Plug		
18.	Backing strip		
19.	Stitch		
20.	Projection		
21.	Flash		
22.	Butt resistance or pressure (upset)		

### 3.3.11 Supplementary Weld Symbols

In addition to the above symbols, some supplementary symbols, according to IS:813 – 1961 (Reaffirmed 1991), are also used as shown in the following table.

**Table 3.3. Supplementary weld symbols.**

S. No.	Particulars	Drawing representation	Symbol
1.	Weld all round		○
2.	Field weld		●
3.	Flush contour		—
4.	Convex contour		⌒
5.	Concave contour		⌒
6.	Grinding finish		G
7.	Machining finish		M
8.	Chipping finish		C

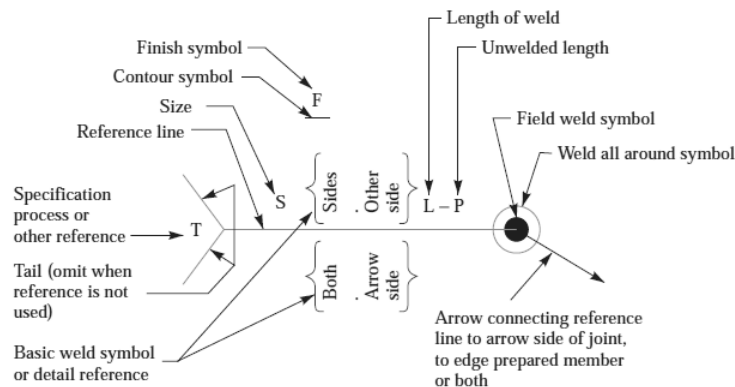
**3.3.12 Elements of a Welding Symbol**

A welding symbol consists of the following eight elements:

1. Reference line,
2. Arrow,
3. Basic weld symbols,
4. Dimensions and other data,
5. Supplementary symbols,
6. Finish symbols,
7. Tail, and
8. Specification, process or other references.

**3.3.13 Standard Location of Elements of a Welding Symbol**

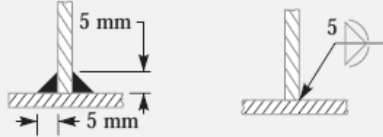


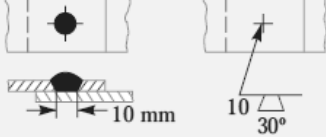
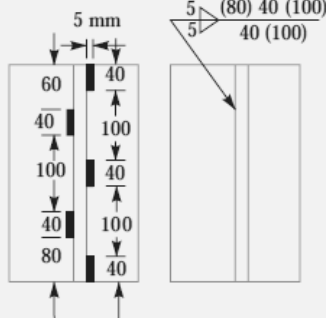
According to Indian Standards, IS: 813 – 1961 (Reaffirmed 1991), the elements of a welding symbol shall have standard locations with respect to each other. The arrow points to the location of weld, the basic symbols with dimensions are located on one or both sides of reference line. The specification if any is placed in the tail of arrow. Fig. 3.49 shows the standard locations of welding symbols represented on drawing.



**Fig. 3.49.** Standard location of welding symbols.

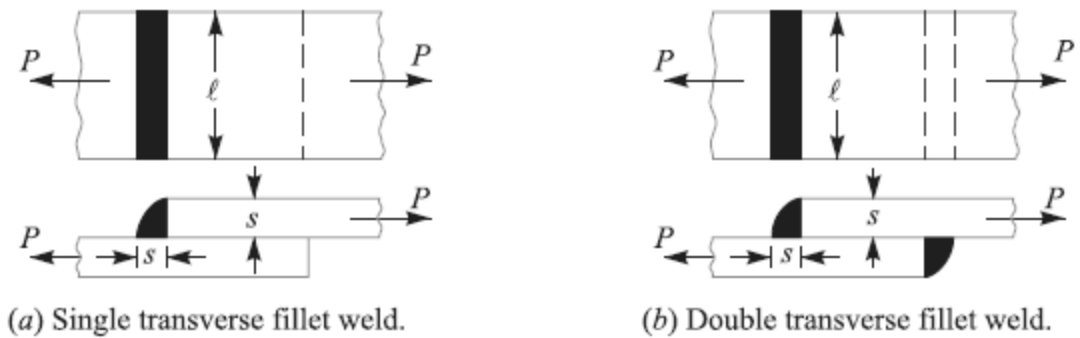
Some of the examples of welding symbols represented on drawing are shown in the following table.

**Table 3.4. Representation of welding symbols.**

S. No.	Desired weld	Representation on drawing
1.	Fillet-weld each side of Tee- convex contour	
2.	Single V-butt weld -machining finish	
3.	Double V- butt weld	
4.	Plug weld - 30° Groove-angle-flush contour	
5.	Staggered intermittent fillet welds	

**3.3.14 Strength of Transverse Fillet Welded Joints**

We have already discussed that the fillet or lap joint is obtained by overlapping the plates and then welding the edges of the plates. The transverse fillet welds are designed for tensile strength. Let us consider a single and double transverse fillet welds as shown in Fig. 3.50 (a) and (b) respectively.



**Fig. 3.50.** Transverse fillet welds.

In order to determine the strength of the fillet joint, it is assumed that the section of fillet is a right angled triangle  $ABC$  with hypotenuse  $AC$  making equal angles with other two sides  $AB$  and  $BC$ . The enlarged view of the fillet is shown in Fig. 3.50. The length of each side is known as **leg** or **size of the weld** and the perpendicular distance of the hypotenuse from the intersection of legs (*i.e.*  $BD$ ) is known as **throat thickness**. The minimum area of the weld is obtained at the throat  $BD$ , which is given by the product of the throat thickness and length of weld.

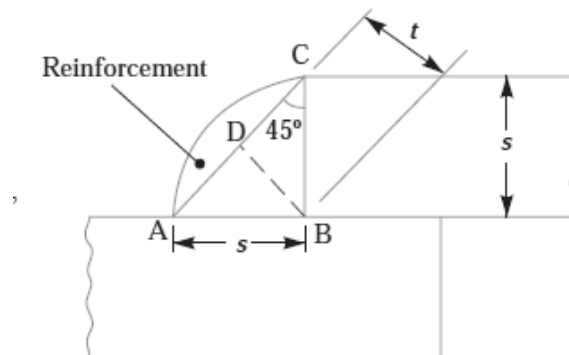
Let  $t$  = Throat thickness ( $BD$ ),  
 $s$  = Leg or size of weld,  
 $\delta$  = Thickness of plate, and  
 $l$  = Length of weld,  
 From Fig. 3.50, we find that the throat thickness,  
 $t = s \times \sin 45^\circ = 0.707 s$   
 $\therefore$  Minimum area of the weld or throat area,  
 $A = \text{Throat thickness} \times \text{Length of weld}$   
 $= t \times l = 0.707 s \times l$

If  $\sigma_t$  is the allowable tensile stress for the weld metal, then the tensile strength of the joint for single fillet weld,

$$P = \text{Throat area} \times \text{Allowable tensile stress} = 0.707 s \times l \times \sigma_t$$

and tensile strength of the joint for double fillet weld,

$$P = 2 \times 0.707 s \times l \times \sigma_t = 1.414 s \times l \times \sigma_t$$



**Fig. 3.51.** Enlarged view of a fillet weld.

### 3.3.15 Strength of Parallel Fillet Welded Joints

The parallel fillet welded joints are designed for shear strength. Consider a double parallel fillet welded joint as shown in Fig. 3.52 (a). We have already discussed in the previous article, that the minimum area of weld or the throat area,

$$A = 0.707 s \times l$$



If  $\tau$  is the allowable shear stress for the weld metal, then the shear strength of the joint for single parallel fillet weld,

$$P = \text{Throat area} \times \text{Allowable shear stress} = 0.707 s \times l \times \tau$$

and shear strength of the joint for double parallel fillet weld,

$$P = 2 \times 0.707 \times s \times l \times \tau = 1.414 s \times l \times \tau$$

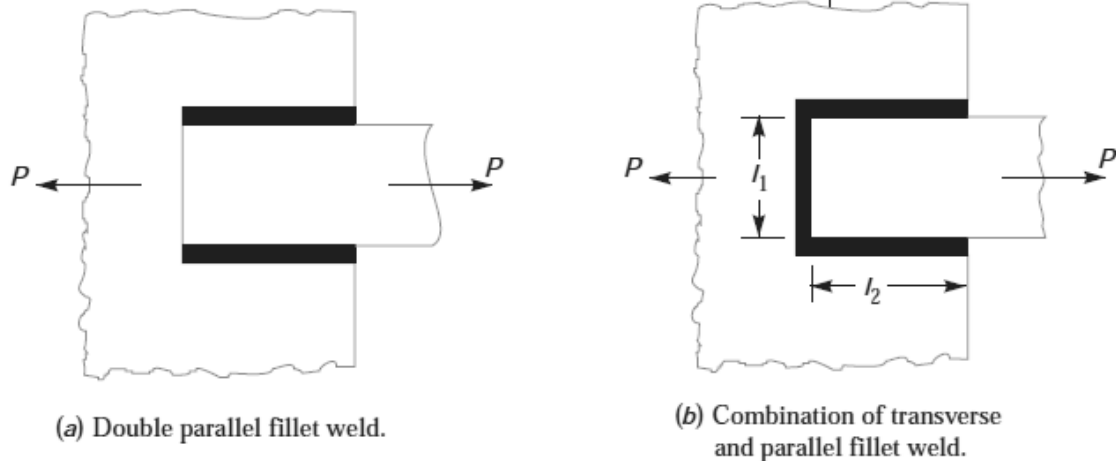


Fig. 3.52

**Example 3.11.** A plate 100 mm wide and 10 mm thick is to be welded to another plate by means of double parallel fillets. The plates are subjected to a static load of 80 kN. Find the length of weld if the permissible shear stress in the weld does not exceed 55 MPa.

**Solution.** Given:

Width = 100 mm

Thickness = 10 mm

$P = 80 \text{ kN} = 80 \times 10^3 \text{ N}$

$\tau = 55 \text{ MPa} = 55 \text{ N/mm}^2$

Let  $l$  = Length of weld, and

$s$  = Size of weld = Plate thickness = 10 mm ... (Given)

We know that maximum load which the plates can carry for double parallel fillet weld ( $P$ ),

$$80 \times 10^3 = 1.414 \times s \times l \times \tau = 1.414 \times 10 \times l \times 55 = 778 l$$

$$\therefore l = 80 \times 10^3 / 778 = 103 \text{ mm}$$

Adding 12.5 mm for starting and stopping of weld run, we have

$$l = 103 + 12.5 = 115.5 \text{ mm Ans.}$$

### 3.3.16 Special Cases of Fillet Welded Joints

The following cases of fillet welded joints are important from the subject point of view.

**1. Circular fillet weld subjected to torsion.** Consider a circular rod connected to a rigid plate by a fillet weld as shown in Fig. 3.53.

Let  $d$  = Diameter of rod,

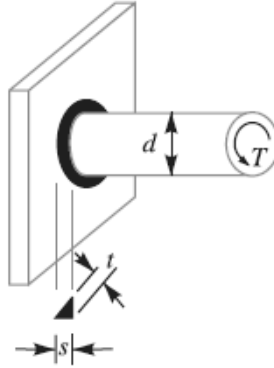
$r$  = Radius of rod,

$T$  = Torque acting on the rod,

$s$  = Size (or leg) of weld,

$t$  = Throat thickness,

$J$  = Polar moment of inertia of the



**Fig. 3.53.** Circular fillet weld subjected to torsion.

$$\text{weld section} = \frac{\pi t d^3}{4}$$

We know that shear stress for the material,

$$\begin{aligned} \tau &= \frac{Tr}{J} = \frac{T \times d/2}{J} \\ &= \frac{T \times d/2}{\pi t d^3 / 4} = \frac{2T}{\pi t d^2} \end{aligned}$$

This shear stress occurs in a horizontal plane along a leg of the fillet weld. The maximum shear occurs on the throat of weld which is inclined at  $45^\circ$  to the horizontal plane.

$\therefore$  Length of throat,  $t = s \sin 45^\circ = 0.707 s$

and maximum shear stress,

$$\tau_{max} = \frac{2T}{\pi \times 0.707 s \times d^2} = \frac{2.83 T}{\pi s d^2}$$

**2. Circular fillet weld subjected to bending moment.** Consider a circular rod connected to a rigid plate by a fillet weld as shown in Fig. 3.54.

Let  $d$  = Diameter of rod,  
 $M$  = Bending moment acting on the rod,  
 $s$  = Size (or leg) of weld,  
 $t$  = Throat thickness,  
 $Z$  = Section modulus of the weld section

$$= \frac{\pi t d^2}{4}$$

We know that the bending stress,

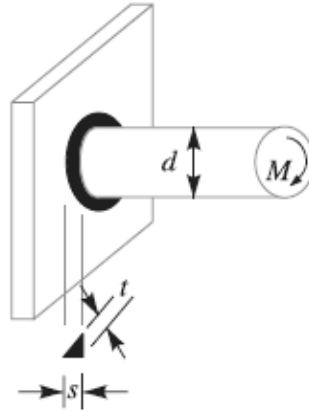
$$\sigma_b = \frac{M}{Z} = \frac{M}{\pi t d^2 / 4} = \frac{4M}{\pi t d^2}$$

This bending stress occurs in a horizontal plane along a leg of the fillet weld. The maximum bending stress occurs on the throat of the weld which is inclined at  $45^\circ$  to the horizontal plane.

$\therefore$  Length of throat,  $t = s \sin 45^\circ = 0.707 s$

and maximum bending stress,

$$\sigma_{b(max)} = \frac{4 M}{\pi \times 0.707 s \times d^2} = \frac{5.66 M}{\pi s d^2}$$



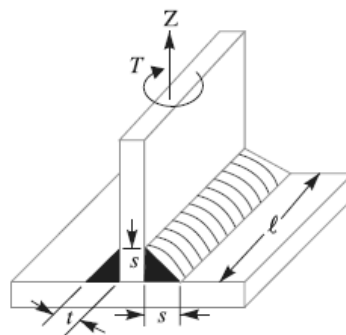
**Fig. 3.54.** Circular fillet weld subjected to bending moment.

**3. Long fillet weld subjected to torsion.** Consider a vertical plate attached to a horizontal plate by two identical fillet welds as shown in Fig. 3.55.

- Let  $T$  = Torque acting on the vertical plate,  
 $l$  = Length of weld,  
 $s$  = Size (or leg) of weld,  
 $t$  = Throat thickness, and  
 $J$  = Polar moment of inertia of the weld section

$$= 2 \times \frac{t \times l^3}{12} = \frac{t \times l^3}{6} \dots$$

( $\because$  of both sides weld)



**Fig. 3.55.** Long fillet weld subjected to torsion.

It may be noted that the effect of the applied torque is to rotate the vertical plate about the Z-axis through its mid point. This rotation is resisted by shearing stresses developed between two fillet welds and the horizontal plate. It is assumed that these horizontal shearing stresses vary from zero at the Z-axis and maximum at the ends of the plate. This variation of shearing stress is analogous to the variation of normal stress over the depth ( $l$ ) of a beam subjected to pure bending.

$$\therefore \text{Shear stress, } \tau = \frac{T \times l/2}{t \times l^3/6} = \frac{3T}{t \times l^2}$$

The maximum shear stress occurs at the throat and is given by

$$\tau_{max} = \frac{3T}{0.707s \times l^2} = \frac{4.242T}{s \times l^2}$$

**Example 3.12.** A 50 mm diameter solid shaft is welded to a flat plate by 10 mm fillet weld as shown in Fig. 3.56. Find the maximum torque that the welded joint can sustain if the maximum shear stress intensity in the weld material is not to exceed 80 MPa.

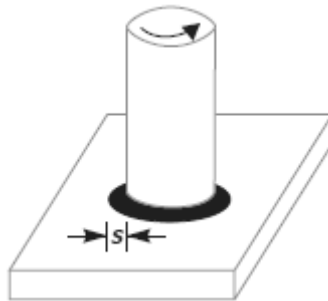


Fig. 3.56

**Solution.**

Given :  $d = 50 \text{ mm}$

$s = 10 \text{ mm}$

$\tau_{max} = 80 \text{ MPa} = 80 \text{ N/mm}^2$

Let  $T =$  Maximum torque that the welded joint can sustain.

We know that the maximum shear stress ( $\tau_{max}$ ),

$$\begin{aligned} 80 &= \frac{2.83T}{\pi s \times d^2} = \frac{2.83T}{\pi \times 10 (50)^2} = \frac{2.83T}{78550} \\ T &= 80 \times 78550 / 2.83 \\ &= 2.22 \times 10^6 \text{ N-mm} = 2.22 \text{ kN-m Ans.} \end{aligned}$$

**Example 3.13.** A plate 1 m long, 60 mm thick is welded to another plate at right angles to each other by 15 mm fillet weld, as shown in Fig. 3.57. Find the maximum torque that the welded joint can sustain if the permissible shear stress intensity in the weld material is not to exceed 80 MPa.

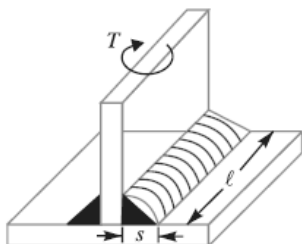


Fig. 3.57

**Solution.** Given:  $l = 1 \text{ m} = 1000 \text{ mm}$

Thickness = 60 mm

$s = 15 \text{ mm}$

$\tau_{max} = 80 \text{ MPa} = 80 \text{ N/mm}^2$

Let  $T =$  Maximum torque that the welded joint can sustain.

We know that the maximum shear stress ( $\tau_{max}$ ),

$$\begin{aligned} 80 &= \frac{4.242T}{s \times l^2} = \frac{4.242T}{15 (1000)^2} = \frac{0.283T}{10^6} \\ \therefore T &= 80 \times 10^6 / 0.283 = 283 \times 10^6 \text{ N-mm} = 283 \text{ kN-m Ans.} \end{aligned}$$