

## Welded Joints

1. Introduction.
2. Advantages and Disadvantages of Welded Joints over Riveted Joints.
3. Welding Processes.
4. Fusion Welding.
5. Thermit Welding.
6. Gas Welding.
7. Electric Arc Welding.
8. Forge Welding.
9. Types of Welded Joints.
10. Lap Joint.
11. Butt Joint.
12. Basic Weld Symbols.
13. Supplementary Weld Symbols.
14. Elements of a Weld Symbol.
15. Standard Location of Elements of a Welding Symbol.
16. Strength of Transverse Fillet Welded Joints.
17. Strength of Parallel Fillet Welded Joints.
18. Special Cases of Fillet Welded Joints.
19. Strength of Butt Joints.
20. Stresses for Welded Joints.
21. Stress Concentration Factor for Welded Joints.
22. Axially Loaded Unsymmetrical Welded Sections.
23. Eccentrically Loaded Welded Joints.
24. Polar Moment of Inertia and Section Modulus of Welds.



### 10.1 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.

## 10.2 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.

## 10.3 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.

### 10.4 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



*Fusion welding at 245°C produces permanent molecular bonds between sections.*

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.

### 10.5 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.

### 10.6 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.

### 10.7 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. 10.1. 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. 10.1. 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.

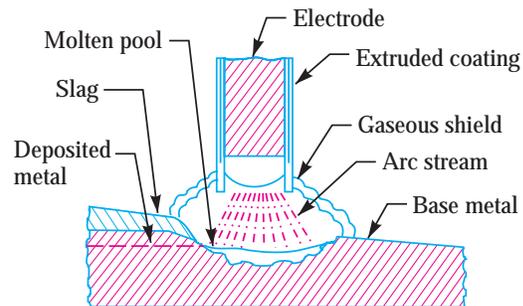


Fig. 10.1. Shielded electric arc welding.

### 10.8 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 joined 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*.



Forge welding.

### 10.9 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.

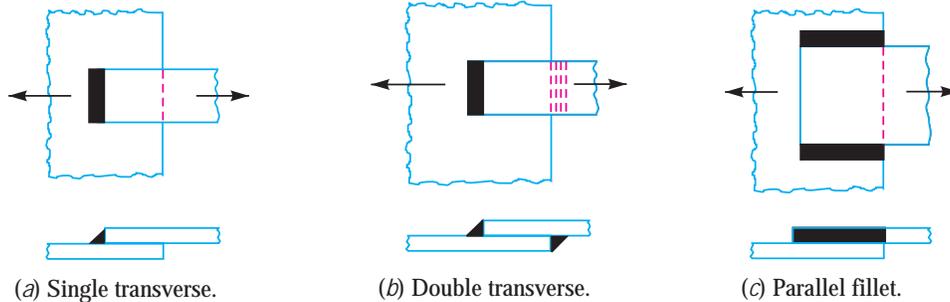


Fig. 10.2. Types of lap or fillet joints.

### 10.10 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. 10.2. 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.

### 10.11 Butt Joint

The butt joint is obtained by placing the plates edge to edge as shown in Fig. 10.3. 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.

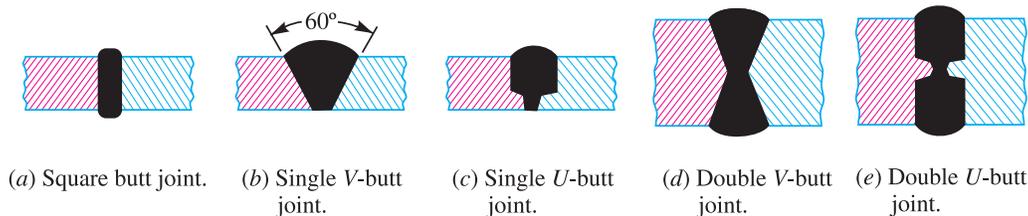


Fig. 10.3. Types of butt joints.

\* For further details, refer author's popular book 'A Textbook of Workshop Technology'.

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. 10.3.

The other type of welded joints are corner joint, edge joint and T-joint as shown in Fig. 10.4.

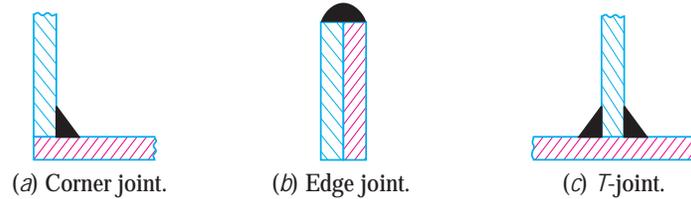


Fig. 10.4. Other types of welded joints.

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

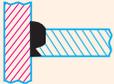
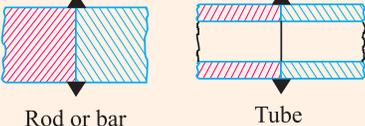
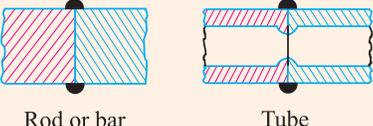
1. The shape of the welded component required,
2. The thickness of the plates to be welded, and
3. The direction of the forces applied.

### 10.12 Basic Weld Symbols

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

Table 10.1. Basic weld symbols.

| S. No. | Form of weld      | Sectional representation | Symbol |
|--------|-------------------|--------------------------|--------|
| 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-J butt                       |     |    |
| 10.    | Double-J 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) |  |  |

### 10.13 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 10.2. 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      |

### 10.14 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.

### 10.15 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. 10.5 shows the standard locations of welding symbols represented on drawing.

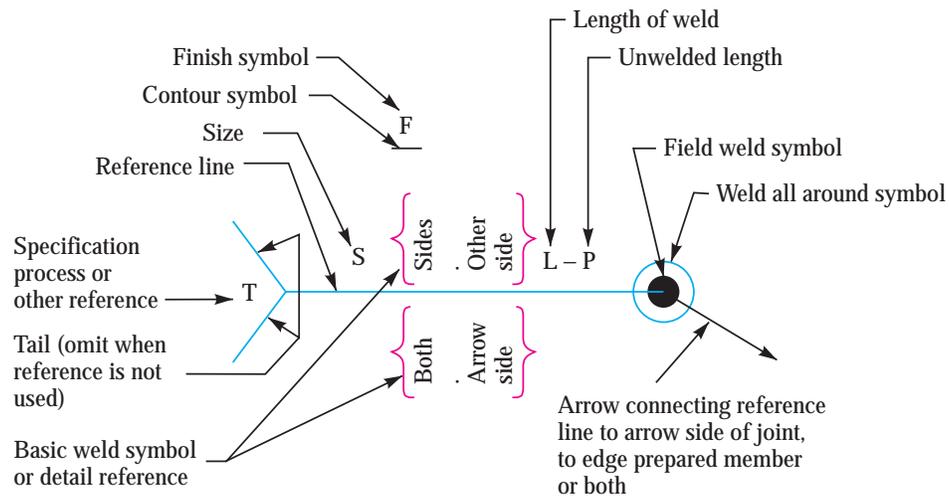


Fig. 10.5. Standard location of welding symbols.

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

Table 10.3. 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         |                           |

### 10.16 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. 10.6 (a) and (b) respectively.

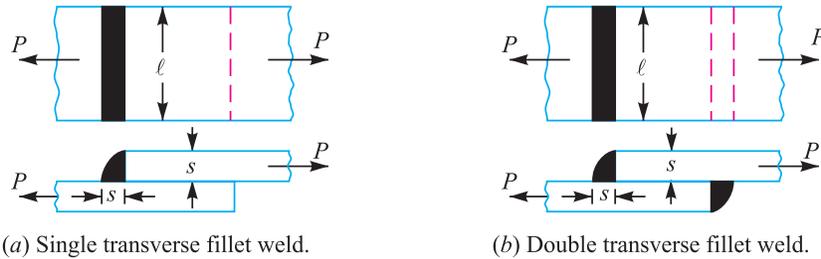


Fig. 10.6. Transverse fillet welds.

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. 10.7. 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,
  - = Thickness of plate, and
  - $l$  = Length of weld,

From Fig. 10.7, we find that the throat thickness,

$$t = s \times \sin 45^\circ = 0.707 s$$

∴ \*Minimum area of the weld or throat area,

$$A = \text{Throat thickness} \times \text{Length of weld} \\ = t \times l = 0.707 s \times l$$

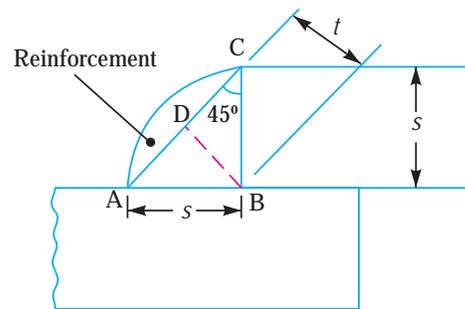


Fig. 10.7. Enlarged view of a fillet weld.

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,

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

**Note:** Since the weld is weaker than the plate due to slag and blow holes, therefore the weld is given a reinforcement which may be taken as 10% of the plate thickness.

### 10.17 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. 10.8 (a). We have already discussed in the previous article, that the minimum area of weld or the throat area,

$$A = 0.707 s \times l$$

\* The minimum area of the weld is taken because the stress is maximum at the minimum area.

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,

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

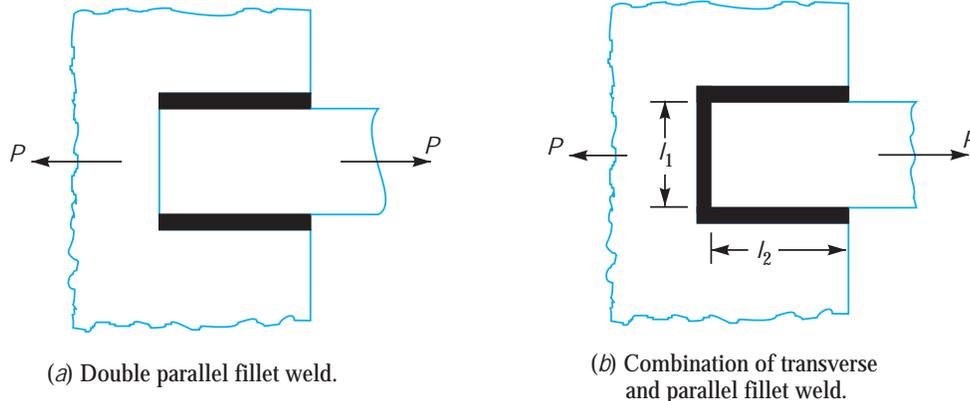


Fig. 10.8

**Notes:** 1. If there is a combination of single transverse and double parallel fillet welds as shown in Fig. 10.8 (b), then the strength of the joint is given by the sum of strengths of single transverse and double parallel fillet welds. Mathematically,

$$P = 0.707s \times l_1 \times \sigma_t + 1.414 s \times l_2 \times \tau$$

where  $l_1$  is normally the width of the plate.

2. In order to allow for starting and stopping of the bead, 12.5 mm should be added to the length of each weld obtained by the above expression.

3. For reinforced fillet welds, the throat dimension may be taken as  $0.85 t$ .

**Example 10.1.** 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

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



Electric arc welding

\* Superfluous data.

### 10.18 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. 10.9.

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

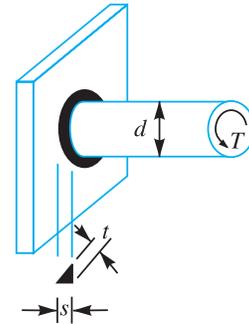


Fig. 10.9. Circular fillet weld subjected to torsion.

We know that shear stress for the material,

$$\begin{aligned} \tau &= \frac{T.r}{J} = \frac{T \times d/2}{J} \\ &= \frac{T \times d/2}{\pi t d^3/4} = \frac{2T}{\pi t d^2} \end{aligned} \quad \dots \left( \because \frac{T}{J} = \frac{\tau}{r} \right)$$

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

∴ 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. 10.10.

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

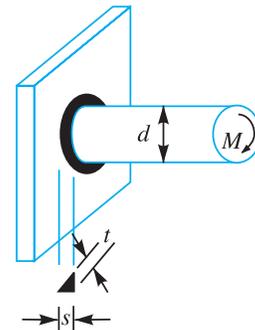


Fig. 10.10. Circular fillet weld subjected to bending moment.

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° to the horizontal plane.

∴ Length of throat,  $t = s \sin 45^\circ = 0.707 s$   
and maximum bending stress,

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

\* See Art, 10.24.

\*\* See Art, 10.24.

**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. 10.11.

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

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

( $\therefore$  of both sides weld)

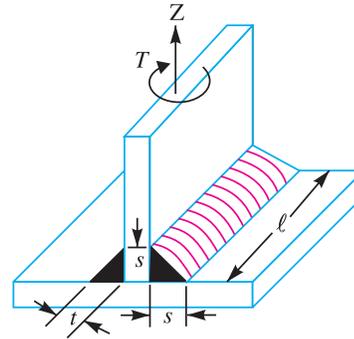


Fig. 10.11. Long fillet weld subjected to torsion.

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.

$\therefore$  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

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

**Example 10.2.** A 50 mm diameter solid shaft is welded to a flat plate by 10 mm fillet weld as shown in Fig. 10.12. 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.

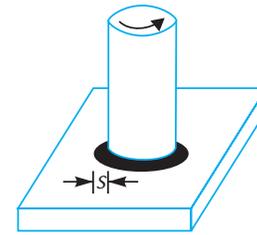


Fig. 10.12

**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 ( $\tau_{max}$ ),

$$80 = \frac{2.83 T}{\pi s \times d^2} = \frac{2.83 T}{\pi \times 10 (50)^2} = \frac{2.83 T}{78550}$$

$\therefore$   $T = 80 \times 78550 / 2.83$   
 $= 2.22 \times 10^6 \text{ N-mm} = 2.22 \text{ kN-m}$  **Ans.**

**Example 10.3.** 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. 10.13. 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.

**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.

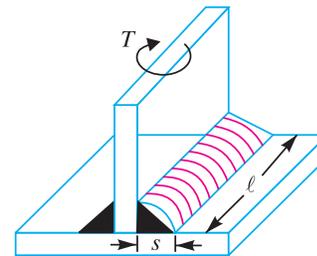


Fig. 10.13

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

$$80 = \frac{4.242 T}{s \times l^2} = \frac{4.242 T}{15 (1000)^2} = \frac{0.283 T}{10^6}$$

∴  $T = 80 \times 10^6 / 0.283 = 283 \times 10^6 \text{ N-mm} = 283 \text{ kN-m}$  **Ans.**

### 10.19 Strength of Butt Joints

The butt joints are designed for tension or compression. Consider a single V-butt joint as shown in Fig. 10.14 (a).

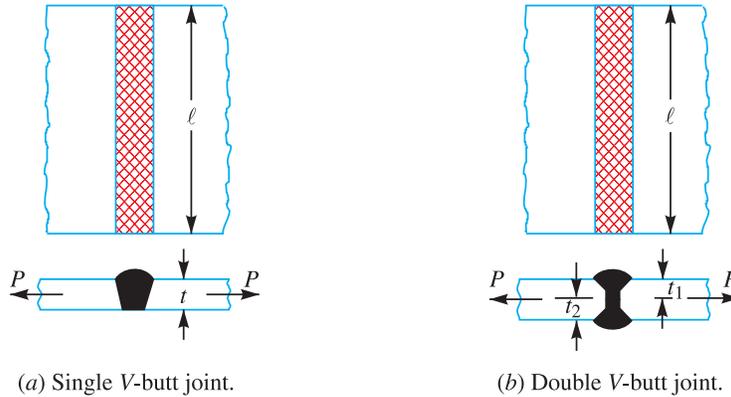


Fig. 10.14. Butt joints.

In case of butt joint, the length of leg or size of weld is equal to the throat thickness which is equal to thickness of plates.

∴ Tensile strength of the butt joint (single-V or square butt joint),

$$P = t \times l \times \sigma_t$$

where

$l$  = Length of weld. It is generally equal to the width of plate.

and tensile strength for double-V butt joint as shown in Fig. 10.14 (b) is given by

$$P = (t_1 + t_2) l \times \sigma_t$$

where

$t_1$  = Throat thickness at the top, and

$t_2$  = Throat thickness at the bottom.

It may be noted that size of the weld should be greater than the thickness of the plate, but it may be less. The following table shows recommended minimum size of the welds.

Table 10.4. Recommended minimum size of welds.

| Thickness of plate (mm)   | 3 – 5 | 6 – 8 | 10 – 16 | 18 – 24 | 26 – 55 | Over 58 |
|---------------------------|-------|-------|---------|---------|---------|---------|
| Minimum size of weld (mm) | 3     | 5     | 6       | 10      | 14      | 20      |

### 10.20 Stresses for Welded Joints

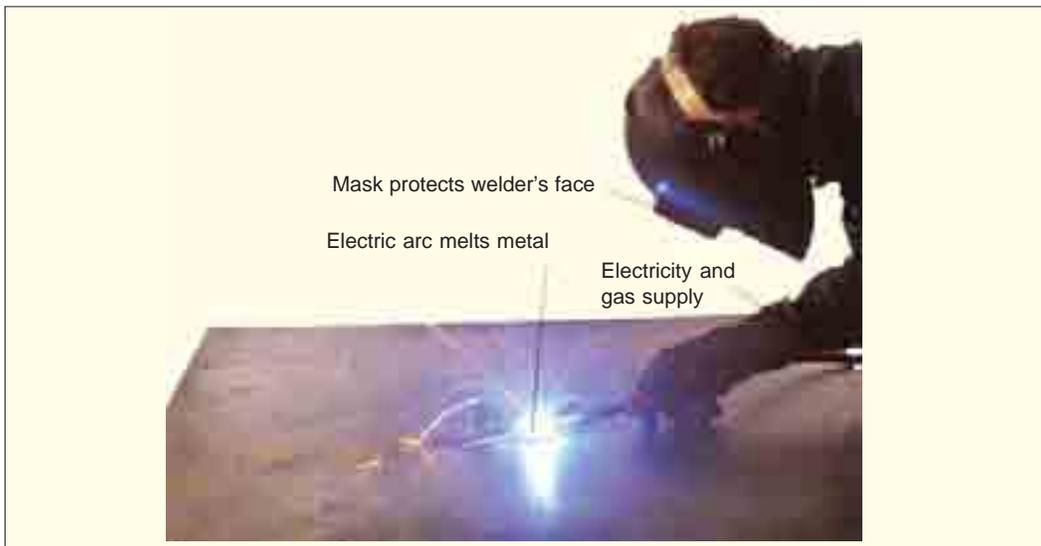
The stresses in welded joints are difficult to determine because of the variable and unpredictable parameters like homogeneity of the weld metal, thermal stresses in the welds, changes of physical properties due to high rate of cooling etc. The stresses are obtained, on the following assumptions:

1. The load is distributed uniformly along the entire length of the weld, and
2. The stress is spread uniformly over its effective section.

The following table shows the stresses for welded joints for joining ferrous metals with mild steel electrode under steady and fatigue or reversed load.

**Table 10.5. Stresses for welded joints.**

| Type of weld                | Bare electrode       |                       | Coated electrode     |                       |
|-----------------------------|----------------------|-----------------------|----------------------|-----------------------|
|                             | Steady load<br>(MPa) | Fatigue load<br>(MPa) | Steady load<br>(MPa) | Fatigue load<br>(MPa) |
| 1. Fillet welds (All types) | 80                   | 21                    | 98                   | 35                    |
| 2. Butt welds               |                      |                       |                      |                       |
| Tension                     | 90                   | 35                    | 110                  | 55                    |
| Compression                 | 100                  | 35                    | 125                  | 55                    |
| Shear                       | 55                   | 21                    | 70                   | 35                    |



In TIG (Tungsten Inert Gas) and MIG (Metal Inert Gas) welding processes, the formation of oxide is prevented by shielding the metal with a blast of gas containing no oxygen.

### 10.21 Stress Concentration Factor for Welded Joints

The reinforcement provided to the weld produces stress concentration at the junction of the weld and the parent metal. When the parts are subjected to fatigue loading, the stress concentration factor as given in the following table should be taken into account.

**Table 10.6. Stress concentration factor for welded joints.**

| Type of joint                     | Stress concentration factor |
|-----------------------------------|-----------------------------|
| 1. Reinforced butt welds          | 1.2                         |
| 2. Toe of transverse fillet welds | 1.5                         |
| 3. End of parallel fillet weld    | 2.7                         |
| 4. T-butt joint with sharp corner | 2.0                         |

**Note :** For static loading and any type of joint, stress concentration factor is 1.0.

**Example 10.4.** A plate 100 mm wide and 12.5 mm thick is to be welded to another plate by means of parallel fillet welds. The plates are subjected to a load of 50 kN. Find the length of the weld so that the maximum stress does not exceed 56 MPa. Consider the joint first under static loading and then under fatigue loading.

**Solution.** Given: \*Width = 100 mm ; Thickness = 12.5 mm ;  $P = 50 \text{ kN} = 50 \times 10^3 \text{ N}$  ;  $\tau = 56 \text{ MPa} = 56 \text{ N/mm}^2$

**Length of weld for static loading**

Let  $l$  = Length of weld, and  
 $s$  = Size of weld = Plate thickness  
 = 12.5 mm ... (Given)

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

$$50 \times 10^3 = 1.414 s \times l \times \tau$$

$$= 1.414 \times 12.5 \times l \times 56 = 990 l$$

$$\therefore l = 50 \times 10^3 / 990 = 50.5 \text{ mm}$$

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

$$l = 50.5 + 12.5 = 63 \text{ mm Ans.}$$

**Length of weld for fatigue loading**

From Table 10.6, we find that the stress concentration factor for parallel fillet welding is 2.7.

$\therefore$  Permissible shear stress,

$$\tau = 56 / 2.7 = 20.74 \text{ N/mm}^2$$

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

$$50 \times 10^3 = 1.414 s \times l \times \tau = 1.414 \times 12.5 \times l \times 20.74 = 367 l$$

$$\therefore l = 50 \times 10^3 / 367 = 136.2 \text{ mm}$$

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

$$l = 136.2 + 12.5 = 148.7 \text{ mm Ans.}$$

**Example 10.5.** A plate 75 mm wide and 12.5 mm thick is joined with another plate by a single transverse weld and a double parallel fillet weld as shown in Fig. 10.15. The maximum tensile and shear stresses are 70 MPa and 56 MPa respectively.

Find the length of each parallel fillet weld, if the joint is subjected to both static and fatigue loading.

**Solution.** Given : Width = 75 mm ; Thickness = 12.5 mm ;  $\sigma_t = 70 \text{ MPa} = 70 \text{ N/mm}^2$  ;  $\tau = 56 \text{ MPa} = 56 \text{ N/mm}^2$ .

The effective length of weld ( $l_1$ ) for the transverse weld may be obtained by subtracting 12.5 mm from the width of the plate.

$$\therefore l_1 = 75 - 12.5 = 62.5 \text{ mm}$$

**Length of each parallel fillet for static loading**

Let  $l_2$  = Length of each parallel fillet.

We know that the maximum load which the plate can carry is

$$P = \text{Area} \times \text{Stress} = 75 \times 12.5 \times 70 = 65\,625 \text{ N}$$

Load carried by single transverse weld,

$$P_1 = 0.707 s \times l_1 \times \sigma_t = 0.707 \times 12.5 \times 62.5 \times 70 = 38\,664 \text{ N}$$

and the load carried by double parallel fillet weld,

$$P_2 = 1.414 s \times l_2 \times \tau = 1.414 \times 12.5 \times l_2 \times 56 = 990 l_2 \text{ N}$$

\* Superfluous data.



TIG (Tungsten Inert Gas) welding Machine

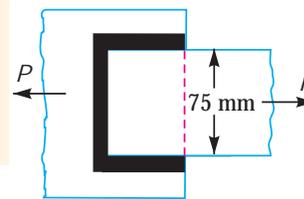


Fig. 10.15

### 356 ■ A Textbook of Machine Design

∴ Load carried by the joint ( $P$ ),

$$65\,625 = P_1 + P_2 = 38\,664 + 990 l_2 \quad \text{or} \quad l_2 = 27.2 \text{ mm}$$

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

$$l_2 = 27.2 + 12.5 = 39.7 \text{ say } 40 \text{ mm} \quad \text{Ans.}$$

#### Length of each parallel fillet for fatigue loading

From Table 10.6, we find that the stress concentration factor for transverse welds is 1.5 and for parallel fillet welds is 2.7.

∴ Permissible tensile stress,

$$\sigma_t = 70 / 1.5 = 46.7 \text{ N/mm}^2$$

and permissible shear stress,

$$\tau = 56 / 2.7 = 20.74 \text{ N/mm}^2$$

Load carried by single transverse weld,

$$P_1 = 0.707 s \times l_1 \times \sigma_t = 0.707 \times 12.5 \times 62.5 \times 46.7 = 25\,795 \text{ N}$$

and load carried by double parallel fillet weld,

$$P_2 = 1.414 s \times l_2 \times \tau = 1.414 \times 12.5 l_2 \times 20.74 = 366 l_2 \text{ N}$$

∴ Load carried by the joint ( $P$ ),

$$65\,625 = P_1 + P_2 = 25\,795 + 366 l_2 \quad \text{or} \quad l_2 = 108.8 \text{ mm}$$

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

$$l_2 = 108.8 + 12.5 = 121.3 \text{ mm} \quad \text{Ans.}$$

**Example 10.6.** Determine the length of the weld run for a plate of size 120 mm wide and 15 mm thick to be welded to another plate by means of

1. A single transverse weld; and
2. Double parallel fillet welds when the joint is subjected to variable loads.

**Solution.** Given : Width = 120 mm ; Thickness = 15 mm

In Fig. 10.16,  $AB$  represents the single transverse weld and  $AC$  and  $BD$  represents double parallel fillet welds.

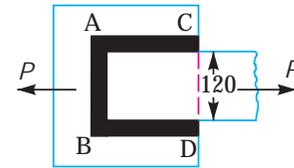


Fig. 10.16

#### 1. Length of the weld run for a single transverse weld

The effective length of the weld run ( $l_1$ ) for a single transverse weld may be obtained by subtracting 12.5 mm from the width of the plate.

$$\therefore l_1 = 120 - 12.5 = 107.5 \text{ mm} \quad \text{Ans.}$$

#### 2. Length of the weld run for a double parallel fillet weld subjected to variable loads

Let  $l_2$  = Length of weld run for each parallel fillet, and  
 $s$  = Size of weld = Thickness of plate = 15 mm

Assuming the tensile stress as 70 MPa or N/mm<sup>2</sup> and shear stress as 56 MPa or N/mm<sup>2</sup> for static loading. We know that the maximum load which the plate can carry is

$$P = \text{Area} \times \text{Stress} = 120 \times 15 \times 70 = 126 \times 10^3 \text{ N}$$

From Table 10.6, we find that the stress concentration factor for transverse weld is 1.5 and for parallel fillet welds is 2.7.

∴ Permissible tensile stress,

$$\sigma_t = 70 / 1.5 = 46.7 \text{ N/mm}^2$$

and permissible shear stress,

$$\tau = 56 / 2.7 = 20.74 \text{ N/mm}^2$$

∴ Load carried by single transverse weld,

$$P_1 = 0.707 s \times l_1 \times \sigma_t = 0.707 \times 15 \times 107.5 \times 46.7 = 53\,240 \text{ N}$$

and load carried by double parallel fillet weld,

$$P_2 = 1.414 s \times l_2 \times \tau = 1.414 \times 15 \times l_2 \times 20.74 = 440 l_2 \text{ N}$$

∴ Load carried by the joint ( $P$ ),

$$126 \times 10^3 = P_1 + P_2 = 53\,240 + 440 l_2 \text{ or } l_2 = 165.4 \text{ mm}$$

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

$$l_2 = 165.4 + 12.5 = 177.9 \text{ say } 178 \text{ mm} \quad \text{Ans.}$$

**Example 10.7.** The fillet welds of equal legs are used to fabricate a 'T' as shown in Fig. 10.17 (a) and (b), where  $s$  is the leg size and  $l$  is the length of weld.

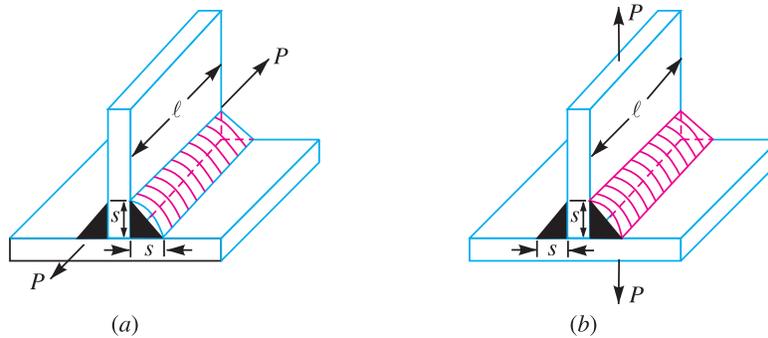


Fig. 10.17

Locate the plane of maximum shear stress in each of the following loading patterns:

1. Load parallel to the weld (neglect eccentricity), and
2. Load at right angles to the weld (transverse load).

Find the ratio of these limiting loads.

**Solution.** Given : Leg size =  $s$  ; Length of weld =  $l$

**1. Plane of maximum shear stress when load acts parallel to the weld (neglecting eccentricity)**

Let  $\theta$  = Angle of plane of maximum shear stress, and

$t$  = Throat thickness  $BD$ .

From the geometry of Fig. 10.18, we find that

$$\begin{aligned} BC &= BE + EC \\ &= BE + DE \quad \dots(\because EC = DE) \end{aligned}$$

or

$$\begin{aligned} s &= BD \cos \theta + BD \sin \theta \\ &= t \cos \theta + t \sin \theta \\ &= t (\cos \theta + \sin \theta) \end{aligned}$$

$$\therefore t = \frac{s}{\cos \theta + \sin \theta}$$

We know that the minimum area of the weld or throat area,

$$A = 2 t \times l = \frac{2 s \times l}{(\cos \theta + \sin \theta)} \quad \dots(\because \text{ of double fillet weld})$$

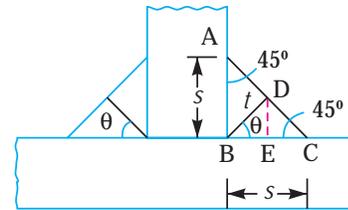


Fig. 10.18

and shear stress, 
$$\tau = \frac{P}{A} = \frac{P(\cos \theta + \sin \theta)}{2s \times l} \quad \dots(i)$$

For maximum shear stress, differentiate the above expression with respect to  $\theta$  and equate to zero.

$$\therefore \frac{d\tau}{d\theta} = \frac{P}{2s \times l} (-\sin \theta + \cos \theta) = 0$$

or 
$$\sin \theta = \cos \theta \text{ or } \theta = 45^\circ$$

Substituting the value of  $\theta = 45^\circ$  in equation (i), we have maximum shear stress,

$$\tau_{max} = \frac{P (\cos 45^\circ + \sin 45^\circ)}{2s \times l} = \frac{1.414 P}{2s \times l}$$

or 
$$P = \frac{2s \times l \times \tau_{max}}{1.414} = 1.414 s \times l \times \tau_{max} \text{ Ans.}$$

**2. Plane of maximum shear stress when load acts at right angles to the weld**

When the load acts at right angles to the weld (transverse load), then the shear force and the normal force will act on each weld. Assuming that the two welds share the load equally, therefore summing up the vertical components, we have from Fig. 10.19,

$$P = \frac{P_s}{2} \sin \theta + \frac{P_n}{2} \cos \theta + \frac{P_s}{2} \sin \theta + \frac{P_n}{2} \cos \theta$$

$$= P_s \sin \theta + P_n \cos \theta \quad \dots(ii)$$

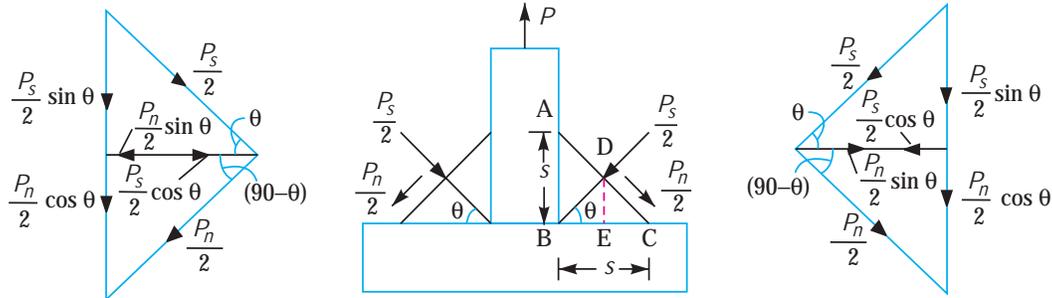


Fig. 10.19

Assuming that the resultant of  $\frac{P_s}{2}$  and  $\frac{P_n}{2}$  is vertical, then the horizontal components are equal and opposite. We know that

Horizontal component of  $\frac{P_s}{2} = \frac{P_s}{2} \cos \theta$

and horizontal component of  $\frac{P_n}{2} = \frac{P_n}{2} \sin \theta$

$$\therefore \frac{P_s}{2} \cos \theta = \frac{P_n}{2} \sin \theta \text{ or } P_n = \frac{P_s \cos \theta}{\sin \theta}$$

Substituting the value of  $P_n$  in equation (i), we have

$$P = P_s \sin \theta + \frac{P_s \cos \theta \times \cos \theta}{\sin \theta}$$

Multiplying throughout by  $\sin \theta$ , we have

$$P \sin \theta = P_s \sin^2 \theta + P_s \cos^2 \theta$$

$$= P_s (\sin^2 \theta + \cos^2 \theta) = P_s \quad \dots(ii)$$

From the geometry of Fig. 10.19, we have

$$BC = BE + EC = BE + DE \quad \dots (\because EC = DE)$$

or  $s = t \cos \theta + t \sin \theta = t (\cos \theta + \sin \theta)$

$\therefore$  Throat thickness,  $t = \frac{s}{\cos \theta + \sin \theta}$

and minimum area of the weld or throat area,

$$A = 2t \times l \quad \dots (\because \text{of double fillet weld})$$

$$= 2 \times \frac{s}{\cos \theta + \sin \theta} \times l = \frac{2s \times l}{\cos \theta + \sin \theta}$$

$\therefore$  Shear stress,  $\tau = \frac{P_s}{A} = \frac{P \sin \theta (\cos \theta + \sin \theta)}{2s \times l}$  ...[From equation (ii)] ... (iii)

For maximum shear stress, differentiate the above expression with respect to  $\theta$  and equate to zero.

$$\therefore \frac{d\tau}{d\theta} = \frac{P}{2s \times l} [\sin \theta (-\sin \theta + \cos \theta) + (\cos \theta + \sin \theta) \cos \theta] = 0$$

$$\dots \left( \because \frac{d(u.v)}{d\theta} = u \frac{dv}{d\theta} + v \frac{du}{d\theta} \right)$$

or  $-\sin^2 \theta + \sin \theta \cos \theta + \cos^2 \theta + \sin \theta \cos \theta = 0$   
 $\cos^2 \theta - \sin^2 \theta + 2\sin \theta \cos \theta = 0$

Since  $\cos^2 \theta - \sin^2 \theta = \cos 2\theta$  and  $2 \sin \theta \cos \theta = \sin 2\theta$ , therefore,  
 $\cos 2\theta + \sin 2\theta = 0$

or  $\frac{\sin 2\theta}{\cos 2\theta} = -1$  or  $\tan 2\theta = -1$

$\therefore 2\theta = 135^\circ$  or  $\theta = 67.5^\circ$  **Ans.**

Substituting the value of  $\theta = 67.5^\circ$  in equation (iii), we have maximum shear stress,

$$\tau_{max} = \frac{P \sin 67.5^\circ (\cos 67.5^\circ + \sin 67.5^\circ)}{2s \times l}$$

$$= \frac{P \times 0.9239 (0.3827 + 0.9229)}{2s \times l} = \frac{1.21 P}{2s \times l}$$

and  $P = \frac{2s \times l \times \tau_{max}}{1.21} = 1.65 s \times l \times \tau_{max}$  **Ans.**

**Ratio of the limiting loads**

We know that the ratio of the limiting (or maximum) loads

$$= \frac{1.414 s \times l \times \tau_{max}}{1.65 s \times l \times \tau_{max}} = 0.857$$
 **Ans.**

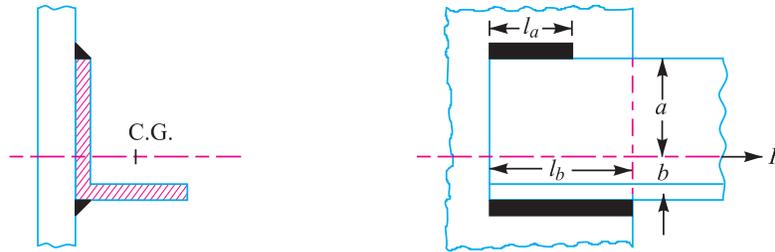
**10.22 Axially Loaded Unsymmetrical Welded Sections**

Sometimes unsymmetrical sections such as angles, channels, T-sections etc., welded on the flange edges are loaded axially as shown in Fig. 10.20. In such cases, the lengths of weld should be proportioned in such a way that the sum of resisting moments of the welds about the gravity axis is zero. Consider an angle section as shown in Fig. 10.20.



Plasma arc welding

- Let
- $l_a$  = Length of weld at the top,
  - $l_b$  = Length of weld at the bottom,
  - $l$  = Total length of weld =  $l_a + l_b$
  - $P$  = Axial load,
  - $a$  = Distance of top weld from gravity axis,
  - $b$  = Distance of bottom weld from gravity axis, and
  - $f$  = Resistance offered by the weld per unit length.



**Fig. 10.20.** Axially loaded unsymmetrical welded section.

∴ Moment of the top weld about gravity axis  
 $= l_a \times f \times a$

and moment of the bottom weld about gravity axis  
 $= l_b \times f \times b$

Since the sum of the moments of the weld about the gravity axis must be zero, therefore,

$$l_a \times f \times a - l_b \times f \times b = 0$$

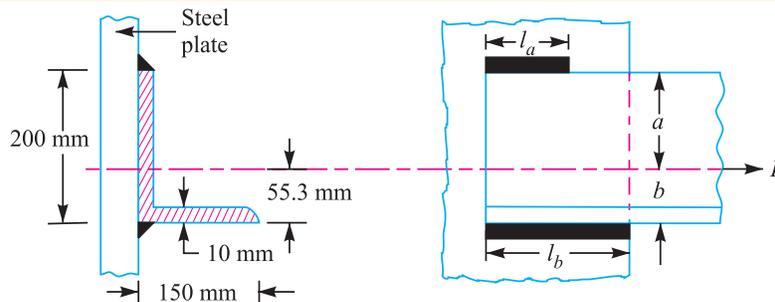
or  $l_a \times a = l_b \times b$  ...**(i)**

We know that  $l = l_a + l_b$  ...**(ii)**

∴ From equations **(i)** and **(ii)**, we have

$$l_a = \frac{l \times b}{a + b}, \quad \text{and} \quad l_b = \frac{l \times a}{a + b}$$

**Example 10.8.** A  $200 \times 150 \times 10$  mm angle is to be welded to a steel plate by fillet welds as shown in Fig. 10.21. If the angle is subjected to a static load of 200 kN, find the length of weld at the top and bottom. The allowable shear stress for static loading may be taken as 75 MPa.



**Fig. 10.21**

**Solution.** Given :  $a + b = 200$  mm ;  $P = 200$  kN =  $200 \times 10^3$  N ;  $\tau = 75$  MPa =  $75$  N/mm<sup>2</sup>

- 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,

$$s = 10 \text{ mm}$$

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

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

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

or  $l_a + l_b = 377 \text{ mm}$

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

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

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

and  $a = 200 - 55.3 = 144.7 \text{ mm}$

We know that  $l_a = \frac{l \times b}{a + b} = \frac{377 \times 55.3}{200} = 104.2 \text{ mm}$  **Ans.**

and  $l_b = l - l_a = 377 - 104.2 = 272.8 \text{ mm}$  **Ans.**

### 10.23 Eccentrically Loaded Welded Joints

An eccentric load may be imposed on welded joints in many ways. The stresses induced on the joint may be of different nature or of the same nature. The induced stresses are combined depending upon the nature of stresses. When the shear and bending stresses are simultaneously present in a joint (see case 1), then maximum stresses are as follows:

Maximum normal stress,

$$\sigma_{t(max)} = \frac{\sigma_b}{2} + \frac{1}{2} \sqrt{(\sigma_b)^2 + 4 \tau^2}$$

and maximum shear stress,

$$\tau_{max} = \frac{1}{2} \sqrt{(\sigma_b)^2 + 4 \tau^2}$$

where

$\sigma_b$  = Bending stress, and

$\tau$  = Shear stress.

When the stresses are of the same nature, these may be combined vectorially (see case 2).

We shall now discuss the two cases of eccentric loading as follows:

#### Case 1

Consider a T-joint fixed at one end and subjected to an eccentric load  $P$  at a distance  $e$  as shown in Fig. 10.22.

- Let
- $s$  = Size of weld,
  - $l$  = Length of weld, and
  - $t$  = Throat thickness.

The joint will be subjected to the following two types of stresses:

1. Direct shear stress due to the shear force  $P$  acting at the welds, and
2. Bending stress due to the bending moment  $P \times e$ .

We know that area at the throat,

$$A = \text{Throat thickness} \times \text{Length of weld}$$

$$= t \times l \times 2 = 2 t \times l \quad \dots \text{(For double fillet weld)}$$

$$= 2 \times 0.707 s \times l = 1.414 s \times l \quad \dots (\because t = s \cos 45^\circ = 0.707 s)$$

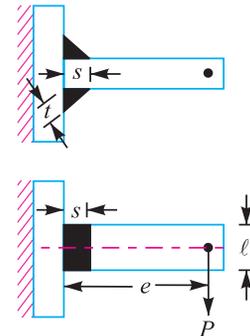


Fig. 10.22. Eccentrically loaded welded joint.

∴ Shear stress in the weld (assuming uniformly distributed),

$$\tau = \frac{P}{A} = \frac{P}{1.414 s \times l}$$

Section modulus of the weld metal through the throat,

$$Z = \frac{t \times l^2}{6} \times 2 \quad \dots(\text{For both sides weld})$$

$$= \frac{0.707 s \times l^2}{6} \times 2 = \frac{s \times l^2}{4.242}$$

Bending moment,  $M = P \times e$

$$\therefore \text{Bending stress, } \sigma_b = \frac{M}{Z} = \frac{P \times e \times 4.242}{s \times l^2} = \frac{4.242 P \times e}{s \times l^2}$$

We know that the maximum normal stress,

$$\sigma_{t(max)} = \frac{1}{2} \sigma_b + \frac{1}{2} \sqrt{(\sigma_b)^2 + 4 \tau^2}$$

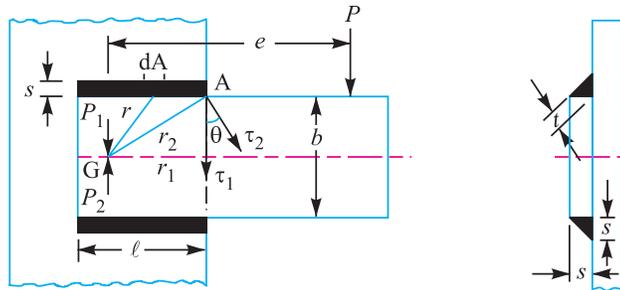
and maximum shear stress,

$$\tau_{max} = \frac{1}{2} \sqrt{(\sigma_b)^2 + 4 \tau^2}$$

**Case 2**

When a welded joint is loaded eccentrically as shown in Fig. 10.23, the following two types of the stresses are induced:

1. Direct or primary shear stress, and
2. Shear stress due to turning moment.



**Fig. 10.23.** Eccentrically loaded welded joint.

- Let
- $P$  = Eccentric load,
  - $e$  = Eccentricity *i.e.* perpendicular distance between the line of action of load and centre of gravity ( $G$ ) of the throat section or fillets,
  - $l$  = Length of single weld,
  - $s$  = Size or leg of weld, and
  - $t$  = Throat thickness.

Let two loads  $P_1$  and  $P_2$  (each equal to  $P$ ) are introduced at the centre of gravity ' $G$ ' of the weld system. The effect of load  $P_1 = P$  is to produce direct shear stress which is assumed to be uniform over the entire weld length. The effect of load  $P_2 = P$  is to produce a turning moment of magnitude  $P \times e$  which tends to rotate the joint about the centre of gravity ' $G$ ' of the weld system. Due to the turning moment, secondary shear stress is induced.



Soldering is done by melting a metal which melts at a lower temperature than the metal that is soldered.

We know that the direct or primary shear stress,

$$\begin{aligned}\tau_1 &= \frac{\text{Load}}{\text{Throat area}} = \frac{P}{A} = \frac{P}{2t \times l} \\ &= \frac{P}{2 \times 0.707s \times l} = \frac{P}{1.414s \times l}\end{aligned}$$

... ( $\because$  Throat area for single fillet weld  $= t \times l = 0.707s \times l$ )

Since the shear stress produced due to the turning moment ( $T = P \times e$ ) at any section is proportional to its radial distance from  $G$ , therefore stress due to  $P \times e$  at the point  $A$  is proportional to  $AG$  ( $r_2$ ) and is in a direction at right angles to  $AG$ . In other words,

$$\frac{\tau_2}{r_2} = \frac{\tau}{r} = \text{Constant}$$

or 
$$\tau = \frac{\tau_2}{r_2} \times r \quad \dots (i)$$

where  $\tau_2$  is the shear stress at the maximum distance ( $r_2$ ) and  $\tau$  is the shear stress at any distance  $r$ .

Consider a small section of the weld having area  $dA$  at a distance  $r$  from  $G$ .

$\therefore$  Shear force on this small section  
 $= \tau \times dA$

and turning moment of this shear force about  $G$ ,

$$dT = \tau \times dA \times r = \frac{\tau_2}{r_2} \times dA \times r^2 \quad \dots \text{ [ From equation (i) ]}$$

$\therefore$  Total turning moment over the whole weld area,

$$\begin{aligned}T &= P \times e = \int \frac{\tau_2}{r_2} \times dA \times r^2 = \frac{\tau_2}{r_2} \int dA \times r^2 \\ &= \frac{\tau_2}{r_2} \times J \quad \left( \because J = \int dA \times r^2 \right)\end{aligned}$$

where  $J =$  Polar moment of inertia of the throat area about  $G$ .

$\therefore$  Shear stress due to the turning moment *i.e.* secondary shear stress,

$$\tau_2 = \frac{T \times r_2}{J} = \frac{P \times e \times r_2}{J}$$

In order to find the resultant stress, the primary and secondary shear stresses are combined vectorially.

$\therefore$  Resultant shear stress at  $A$ ,

$$\tau_A = \sqrt{(\tau_1)^2 + (\tau_2)^2 + 2\tau_1 \times \tau_2 \times \cos \theta}$$

where  $\theta =$  Angle between  $\tau_1$  and  $\tau_2$ , and

$$\cos \theta = r_1 / r_2$$

**Note:** The polar moment of inertia of the throat area ( $A$ ) about the centre of gravity ( $G$ ) is obtained by the parallel axis theorem, *i.e.*

$$J = 2 [I_{xx} + A \times x^2] \quad \dots (\because \text{ of double fillet weld})$$

$$= 2 \left[ \frac{A \times l^2}{12} + A \times x^2 \right] = 2A \left( \frac{l^2}{12} + x^2 \right)$$

where  $A =$  Throat area  $= t \times l = 0.707s \times l$ ,

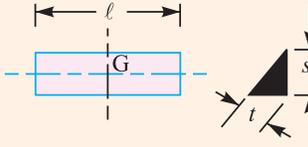
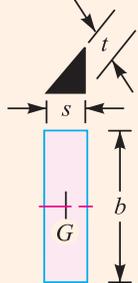
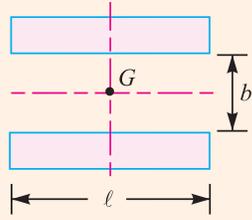
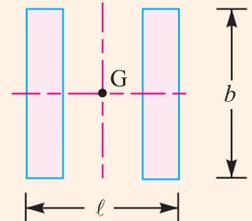
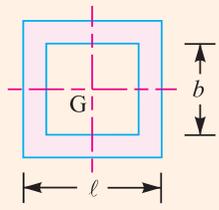
$l =$  Length of weld, and

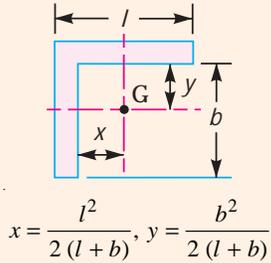
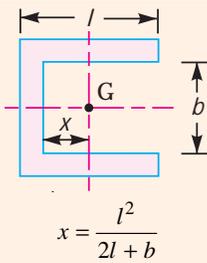
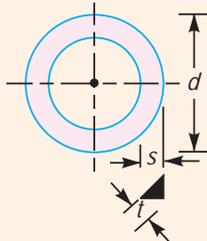
$x =$  Perpendicular distance between the two parallel axes.

10.24 Polar Moment of Inertia and Section Modulus of Welds

The following table shows the values of polar moment of inertia of the throat area about the centre of gravity 'G' and section modulus for some important types of welds which may be used for eccentric loading.

Table 10.7. Polar moment of inertia and section modulus of welds.

| S.No | Type of weld  | Polar moment of inertia (J) | Section modulus (Z)                    |
|------|---|-----------------------------|--|
| 1.   |    | $\frac{t.l^3}{12}$          | —                                      |
| 2.   |   | $\frac{t.b^3}{12}$          | $\frac{t.b^2}{6}$                      |
| 3.   |  | $\frac{t.l(3b^2 + l^2)}{6}$ | $t.b.l$                                |
| 4.   |  | $\frac{t.b(b^2 + 3l^2)}{6}$ | $\frac{t.b^2}{3}$                      |
| 5.   |  | $\frac{t(b+l)^3}{6}$        | $t \left( b.l + \frac{b^2}{3} \right)$ |

| S.No | Type of weld   | Polar moment of inertia (J)                                      | Section modulus (Z)  |
|------|--|--|--|
| 6.   |  $x = \frac{l^2}{2(l+b)}, y = \frac{b^2}{2(l+b)}$ | $t \left[ \frac{(b+l)^4 - 6b^2l^2}{12(l+b)} \right]$             | $t \left( \frac{4lb + b^2}{6} \right) \text{ (Top)}$ $t \left[ \frac{b^2 (4lb + b)}{6(2l + b)} \right] \text{ (Bottom)}$ |
| 7.   |  $x = \frac{l^2}{2l + b}$                         | $t \left[ \frac{(b+2l)^3}{12} - \frac{l^2(b+l)^2}{b+2l} \right]$ | $t \left( lb + \frac{b^2}{6} \right)$  |
| 8.   |    | $\frac{\pi t d^3}{4}$  | $\frac{\pi t d^2}{4}$  |

**Note:** In the above expressions,  $t$  is the throat thickness and  $s$  is the size of weld. It has already been discussed that  $t = 0.707 s$ .

**Example 10.9.** A welded joint as shown in Fig. 10.24, is subjected to an eccentric load of 2 kN. Find the size of weld, if the maximum shear stress in the weld is 25 MPa.

**Solution.** Given:  $P = 2\text{ kN} = 2000\text{ N}$ ;  $e = 120\text{ mm}$ ;  $l = 40\text{ mm}$ ;  $\tau_{max} = 25\text{ MPa} = 25\text{ N/mm}^2$

Let  $s =$  Size of weld in mm, and  
 $t =$  Throat thickness.

The joint, as shown in Fig. 10.24, will be subjected to direct shear stress due to the shear force,  $P = 2000\text{ N}$  and bending stress due to the bending moment of  $P \times e$ .

We know that area at the throat,

$$\begin{aligned} A &= 2t \times l = 2 \times 0.707 s \times l \\ &= 1.414 s \times l \\ &= 1.414 s \times 40 = 56.56 \times s \text{ mm}^2 \end{aligned}$$

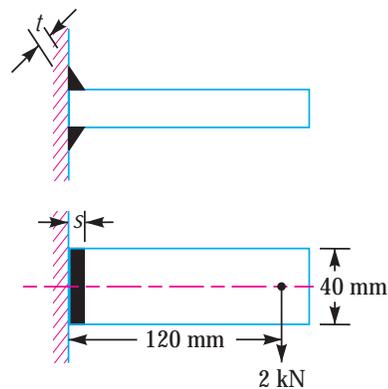


Fig. 10.24

$$\therefore \text{Shear stress, } \tau = \frac{P}{A} = \frac{2000}{56.56 \times s} = \frac{35.4}{s} \text{ N/mm}^2$$

$$\text{Bending moment, } M = P \times e = 2000 \times 120 = 240 \times 10^3 \text{ N-mm}$$

Section modulus of the weld through the throat,

$$Z = \frac{s \times l^2}{4.242} = \frac{s (40)^2}{4.242} = 377 \times s \text{ mm}^3$$

$$\therefore \text{Bending stress, } \sigma_b = \frac{M}{Z} = \frac{240 \times 10^3}{377 \times s} = \frac{636.6}{s} \text{ N/mm}^2$$

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

$$25 = \frac{1}{2} \sqrt{(\sigma_b)^2 + 4 \tau^2} = \frac{1}{2} \sqrt{\left(\frac{636.6}{s}\right)^2 + 4 \left(\frac{35.4}{s}\right)^2} = \frac{320.3}{s}$$

$$\therefore s = 320.3 / 25 = 12.8 \text{ mm Ans.}$$

**Example 10.10.** A 50 mm diameter solid shaft is welded to a flat plate as shown in Fig. 10.25. If the size of the weld is 15 mm, find the maximum normal and shear stress in the weld.

**Solution.** Given :  $D = 50 \text{ mm}$  ;  $s = 15 \text{ mm}$  ;  $P = 10 \text{ kN}$   
 $= 10\,000 \text{ N}$  ;  $e = 200 \text{ mm}$

Let  $t =$  Throat thickness.

The joint, as shown in Fig. 10.25, is subjected to direct shear stress and the bending stress. We know that the throat area for a circular fillet weld,

$$\begin{aligned} A &= t \times \pi D = 0.707 s \times \pi D \\ &= 0.707 \times 15 \times \pi \times 50 \\ &= 1666 \text{ mm}^2 \end{aligned}$$

$\therefore$  Direct shear stress,

$$\tau = \frac{P}{A} = \frac{10000}{1666} = 6 \text{ N/mm}^2 = 6 \text{ MPa}$$

We know that bending moment,

$$M = P \times e = 10\,000 \times 200 = 2 \times 10^6 \text{ N-mm}$$

From Table 10.7, we find that for a circular section, section modulus,

$$Z = \frac{\pi t D^2}{4} = \frac{\pi \times 0.707 s \times D^2}{4} = \frac{\pi \times 0.707 \times 15 (50)^2}{4} = 20\,825 \text{ mm}^3$$

$\therefore$  Bending stress,

$$\sigma_b = \frac{M}{Z} = \frac{2 \times 10^6}{20\,825} = 96 \text{ N/mm}^2 = 96 \text{ MPa}$$

**Maximum normal stress**

We know that the maximum normal stress,

$$\begin{aligned} \sigma_{t(max)} &= \frac{1}{2} \sigma_b + \frac{1}{2} \sqrt{(\sigma_b)^2 + 4 \tau^2} = \frac{1}{2} \times 96 + \frac{1}{2} \sqrt{(96)^2 + 4 \times 6^2} \\ &= 48 + 48.4 = 96.4 \text{ MPa Ans.} \end{aligned}$$

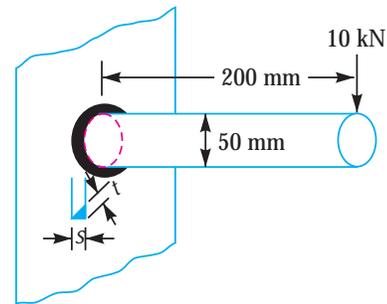


Fig. 10.25

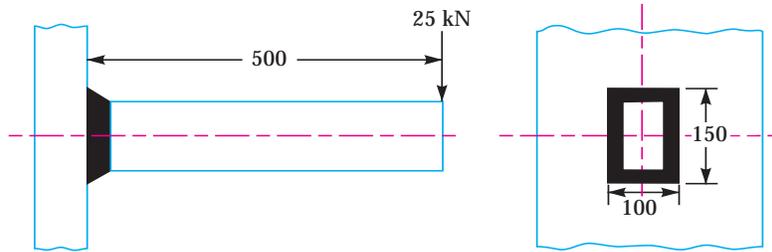
**Maximum shear stress**

We know that the maximum shear stress,

$$\tau_{max} = \frac{1}{2} \sqrt{(\sigma_b)^2 + 4 \tau^2} = \frac{1}{2} \sqrt{(96)^2 + 4 \times 6^2} = 48.4 \text{ MPa} \quad \text{Ans.}$$

**Example 10.11.** A rectangular cross-section bar is welded to a support by means of fillet welds as shown in Fig. 10.26.

Determine the size of the welds, if the permissible shear stress in the weld is limited to 75 MPa.



All dimensions in mm

**Fig. 10.26**

**Solution.** Given :  $P = 25 \text{ kN} = 25 \times 10^3 \text{ N}$  ;  $\tau_{max} = 75 \text{ MPa} = 75 \text{ N/mm}^2$  ;  $l = 100 \text{ mm}$  ;  $b = 150 \text{ mm}$  ;  $e = 500 \text{ mm}$

Let  $s =$  Size of the weld, and  
 $t =$  Throat thickness.

The joint, as shown in Fig. 10.26, is subjected to direct shear stress and the bending stress. We know that the throat area for a rectangular fillet weld,

$$A = t(2b + 2l) = 0.707 s(2b + 2l) \\ = 0.707 s(2 \times 150 + 2 \times 100) = 353.5 s \text{ mm}^2 \quad \dots (\because t = 0.707s)$$

$$\therefore \text{Direct shear stress, } \tau = \frac{P}{A} = \frac{25 \times 10^3}{353.5 s} = \frac{70.72}{s} \text{ N/mm}^2$$

We know that bending moment,

$$M = P \times e = 25 \times 10^3 \times 500 = 12.5 \times 10^6 \text{ N-mm}$$

From Table 10.7, we find that for a rectangular section, section modulus,

$$Z = t \left( bl + \frac{b^2}{3} \right) = 0.707 s \left[ 150 \times 100 + \frac{(150)^2}{3} \right] = 15\,907.5 s \text{ mm}^3$$

$$\therefore \text{Bending stress, } \sigma_b = \frac{M}{Z} = \frac{12.5 \times 10^6}{15\,907.5 s} = \frac{785.8}{s} \text{ N/mm}^2$$

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

$$75 = \frac{1}{2} \sqrt{(\sigma_b)^2 + 4 \tau^2} = \frac{1}{2} \sqrt{\left(\frac{785.8}{s}\right)^2 + 4 \left(\frac{70.72}{s}\right)^2} = \frac{399.2}{s}$$

$$\therefore s = 399.2 / 75 = 5.32 \text{ mm} \quad \text{Ans.}$$

**Example 10.12.** An arm A is welded to a hollow shaft at section '1'. The hollow shaft is welded to a plate C at section '2'. The arrangement is shown in Fig. 10.27, along with dimensions. A force  $P = 15 \text{ kN}$  acts at arm A perpendicular to the axis of the arm.

Calculate the size of weld at section '1' and '2'. The permissible shear stress in the weld is 120 MPa.

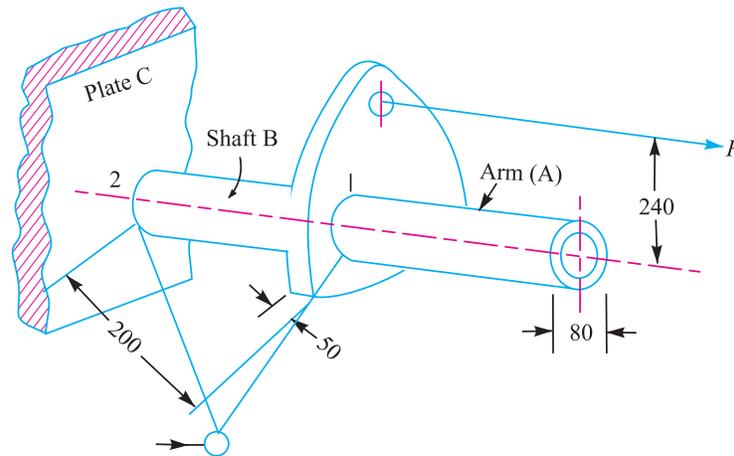


Fig. 10.27. All dimensions in mm.

**Solution.** Given :  $P = 15 \text{ kN} = 15 \times 10^3 \text{ N}$ ;  $\tau_{max} = 120 \text{ MPa} = 120 \text{ N/mm}^2$ ;  $d = 80 \text{ mm}$   
 Let  $s =$  Size of the weld.

The welded joint, as shown in Fig. 10.27, is subjected to twisting moment or torque ( $T$ ) as well as bending moment ( $M$ ).

We know that the torque acting on the shaft,

$$T = 15 \times 10^3 \times 240 = 3600 \times 10^3 \text{ N-mm}$$

$$\therefore \text{Shear stress, } \tau = \frac{2.83 T}{\pi s d^2} = \frac{2.83 \times 3600 \times 10^3}{\pi \times s (80)^2} = \frac{506.6}{s} \text{ N/mm}^2$$

$$\text{Bending moment, } M = 15 \times 10^3 \left( 200 - \frac{50}{2} \right) = 2625 \times 10^3 \text{ N-mm}$$

$$\therefore \text{Bending stress, } \sigma_b = \frac{5.66 M}{\pi s d^2} = \frac{5.66 \times 26.25 \times 10^3}{\pi s (80)^2} = \frac{738.8}{s} \text{ N/mm}^2$$

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

$$120 = \frac{1}{2} \sqrt{(\sigma_b)^2 + 4 \tau^2} = \frac{1}{2} \sqrt{\left( \frac{738.8}{s} \right)^2 + 4 \left( \frac{506.6}{s} \right)^2} = \frac{627}{s}$$

$$\therefore s = 627/120 = 5.2 \text{ mm} \quad \text{Ans.}$$

**Example 10.13.** A bracket carrying a load of 15 kN is to be welded as shown in Fig. 10.28. Find the size of weld required if the allowable shear stress is not to exceed 80 MPa.

**Solution.** Given :  $P = 15 \text{ kN} = 15 \times 10^3 \text{ N}$ ;  $\tau = 80 \text{ MPa} = 80 \text{ N/mm}^2$ ;  $b = 80 \text{ mm}$ ;  $l = 50 \text{ mm}$ ;  $e = 125 \text{ mm}$

Let  $s =$  Size of weld in mm, and  
 $t =$  Throat thickness.

We know that the throat area,

$$\begin{aligned} A &= 2 \times t \times l = 2 \times 0.707 s \times l \\ &= 1.414 s \times l = 1.414 \times s \times 50 = 70.7 s \text{ mm}^2 \end{aligned}$$

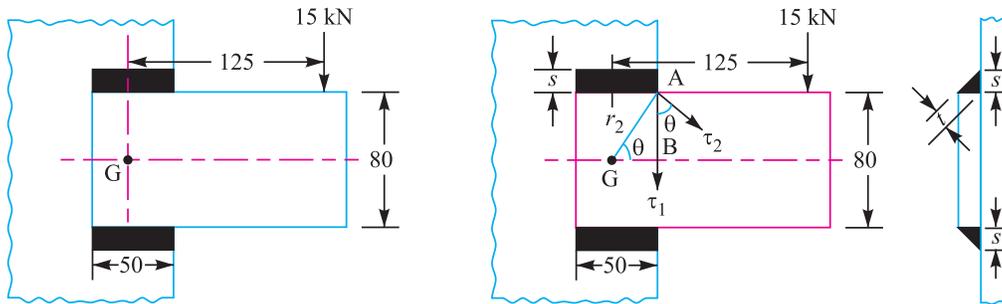
$\therefore$  Direct or primary shear stress,

$$\tau_1 = \frac{P}{A} = \frac{15 \times 10^3}{70.7 s} = \frac{212}{s} \text{ N/mm}^2$$

From Table 10.7, we find that for such a section, the polar moment of inertia of the throat area of the weld about  $G$  is

$$J = \frac{t.l(3b^2 + l^2)}{6} = \frac{0.707 s \times 50 [3(80)^2 + (50)^2]}{6} \text{ mm}^4$$

$$= 127\,850 s \text{ mm}^4 \quad \dots (\because t = 0.707 s)$$



All dimensions in mm.

Fig. 10.28

Fig. 10.29

From Fig. 10.29, we find that  $AB = 40 \text{ mm}$  and  $BG = r_1 = 25 \text{ mm}$ .

$\therefore$  Maximum radius of the weld,

$$r_2 = \sqrt{(AB)^2 + (BG)^2} = \sqrt{(40)^2 + (25)^2} = 47 \text{ mm}$$

Shear stress due to the turning moment *i.e.* secondary shear stress,

$$\tau_2 = \frac{P \times e \times r_2}{J} = \frac{15 \times 10^3 \times 125 \times 47}{127\,850 s} = \frac{689.3}{s} \text{ N/mm}^2$$

and

$$\cos \theta = \frac{r_1}{r_2} = \frac{25}{47} = 0.532$$

We know that resultant shear stress,

$$\tau = \sqrt{(\tau_1)^2 + (\tau_2)^2 + 2 \tau_1 \times \tau_2 \cos \theta}$$

$$80 = \sqrt{\left(\frac{212}{s}\right)^2 + \left(\frac{689.3}{s}\right)^2 + 2 \times \frac{212}{s} \times \frac{689.3}{s} \times 0.532} = \frac{822}{s}$$

$$\therefore s = 822 / 80 = 10.3 \text{ mm} \quad \text{Ans.}$$

**Example 10.14.** A rectangular steel plate is welded as a cantilever to a vertical column and supports a single concentrated load  $P$ , as shown in Fig. 10.30.

Determine the weld size if shear stress in the same is not to exceed 140 MPa.

**Solution.** Given :  $P = 60 \text{ kN} = 60 \times 10^3 \text{ N}$  ;  $b = 100 \text{ mm}$  ;  $l = 50 \text{ mm}$  ;  $\tau = 140 \text{ MPa} = 140 \text{ N/mm}^2$

Let  $s =$  Weld size, and

$t =$  Throat thickness.

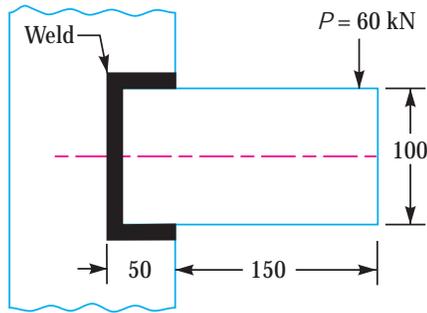


Fig. 10.30

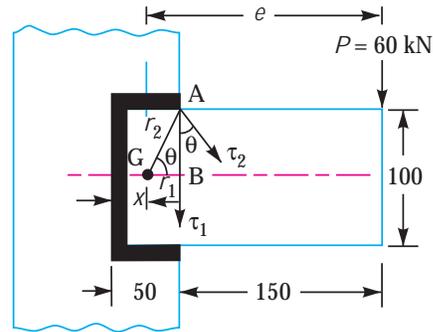


Fig. 10.31

All dimensions in mm.

First of all, let us find the centre of gravity ( $G$ ) of the weld system, as shown in Fig. 10.31.

Let  $x$  be the distance of centre of gravity ( $G$ ) from the left hand edge of the weld system. From Table 10.7, we find that for a section as shown in Fig. 10.31,

$$x = \frac{l^2}{2l + b} = \frac{(50)^2}{2 \times 50 + 100} = 12.5 \text{ mm}$$

and polar moment of inertia of the throat area of the weld system about  $G$ ,

$$\begin{aligned} J &= t \left[ \frac{(b + 2l)^3}{12} - \frac{l^2 (b + l)^2}{b + 2l} \right] \\ &= 0.707s \left[ \frac{(100 + 2 \times 50)^3}{12} - \frac{(50)^2 (100 + 50)^2}{100 + 2 \times 50} \right] \dots (\because t = 0.707s) \\ &= 0.707s [670 \times 10^3 - 281 \times 10^3] = 275 \times 10^3 s \text{ mm}^4 \end{aligned}$$

Distance of load from the centre of gravity ( $G$ ) i.e. eccentricity,

$$e = 150 + 50 - 12.5 = 187.5 \text{ mm}$$

$$r_1 = BG = 50 - x = 50 - 12.5 = 37.5 \text{ mm}$$

$$AB = 100 / 2 = 50 \text{ mm}$$

We know that maximum radius of the weld,

$$r_2 = \sqrt{(AB)^2 + (BG)^2} = \sqrt{(50)^2 + (37.5)^2} = 62.5 \text{ mm}$$

$$\therefore \cos \theta = \frac{r_1}{r_2} = \frac{37.5}{62.5} = 0.6$$

We know that throat area of the weld system,

$$\begin{aligned} A &= 2 \times 0.707s \times l + 0.707s \times b = 0.707s (2l + b) \\ &= 0.707s (2 \times 50 + 100) = 141.4 s \text{ mm}^2 \end{aligned}$$

$\therefore$  Direct or primary shear stress,

$$\tau_1 = \frac{P}{A} = \frac{60 \times 10^3}{141.4s} = \frac{424}{s} \text{ N/mm}^2$$

and shear stress due to the turning moment or secondary shear stress,

$$\tau_2 = \frac{P \times e \times r_2}{J} = \frac{60 \times 10^3 \times 187.5 \times 62.5}{275 \times 10^3 s} = \frac{2557}{s} \text{ N/mm}^2$$

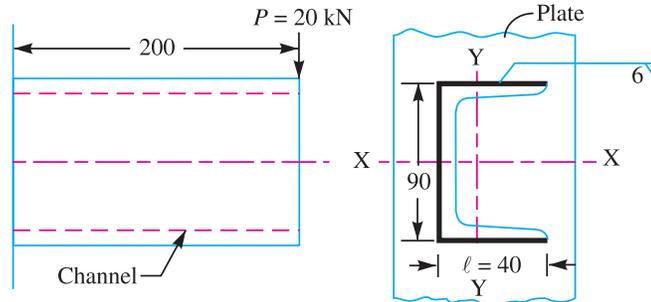
We know that the resultant shear stress,

$$\tau = \sqrt{(\tau_1)^2 + (\tau_2)^2 + 2 \tau_1 \times \tau_2 \times \cos \theta}$$

$$140 = \sqrt{\left(\frac{424}{s}\right)^2 + \left(\frac{2557}{s}\right)^2 + 2 \times \frac{424}{s} \times \frac{2557}{s} \times 0.6} = \frac{2832}{s}$$

∴  $s = 2832 / 140 = 20.23 \text{ mm}$  **Ans.**

**Example 10.15.** Find the maximum shear stress induced in the weld of 6 mm size when a channel, as shown in Fig. 10.32, is welded to a plate and loaded with 20 kN force at a distance of 200 mm.



All dimensions in mm.

Fig. 10.32

**Solution.** Given :  $s = 6 \text{ mm}$  ;  $P = 20 \text{ kN} = 20 \times 10^3 \text{ N}$  ;  $l = 40 \text{ mm}$  ;  $b = 90 \text{ mm}$

Let  $t =$  Throat thickness.

First of all, let us find the centre of gravity ( $G$ ) of the weld system as shown in Fig. 10.33. Let  $x$  be the distance of centre of gravity from the left hand edge of the weld system. From Table 10.7, we find that for a section as shown in Fig. 10.33,

$$x = \frac{l^2}{2l + b} = \frac{(40)^2}{2 \times 40 + 90} = 9.4 \text{ mm}$$

and polar moment of inertia of the throat area of the weld system about  $G$ ,

$$J = t \left[ \frac{(b + 2l)^3}{12} - \frac{l^2 (b + l)^2}{b + 2l} \right]$$

$$= 0.707 s \left[ \frac{(90 + 2 \times 40)^3}{12} - \frac{(40)^2 (90 + 40)^2}{90 + 2 \times 40} \right] \dots (\because t = 0.707 s)$$

$$= 0.707 \times 6 [409.4 \times 10^3 - 159 \times 10^3] = 1062.2 \times 10^3 \text{ mm}^4$$

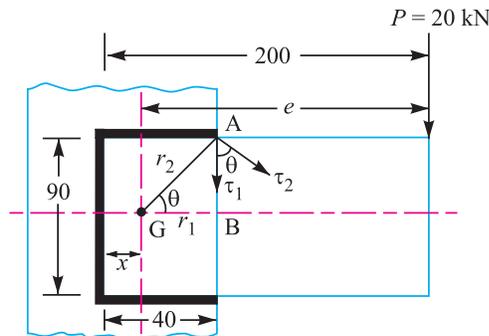


Fig. 10.33

### 372 ■ A Textbook of Machine Design

Distance of load from the centre of gravity ( $G$ ), i.e. eccentricity,

$$e = 200 - x = 200 - 9.4 = 190.6 \text{ mm}$$

$$r_1 = BG = 40 - x = 40 - 9.4 = 30.6 \text{ mm}$$

$$AB = 90 / 2 = 45 \text{ mm}$$

We know that maximum radius of the weld,

$$r_2 = \sqrt{(AB)^2 + (BG)^2} = \sqrt{(45)^2 + (30.6)^2} = 54.4 \text{ mm}$$

$$\therefore \cos \theta = \frac{r_1}{r_2} = \frac{30.6}{54.4} = 0.5625$$

We know that throat area of the weld system,

$$A = 2 \times 0.707s \times l + 0.707s \times b = 0.707s(2l + b)$$

$$= 0.707 \times 6(2 \times 40 + 90) = 721.14 \text{ mm}^2$$

$\therefore$  Direct or primary shear stress,

$$\tau_1 = \frac{P}{A} = \frac{20 \times 10^3}{721.14} = 27.7 \text{ N/mm}^2$$

and shear stress due to the turning moment or secondary shear stress,

$$\tau_2 = \frac{P \times e \times r_2}{J} = \frac{20 \times 10^3 \times 190.6 \times 54.4}{1062.2 \times 10^3} = 195.2 \text{ N/mm}^2$$

We know that resultant or maximum shear stress,

$$\tau = \sqrt{(\tau_1)^2 + (\tau_2)^2 + 2\tau_1 \times \tau_2 \times \cos \theta}$$

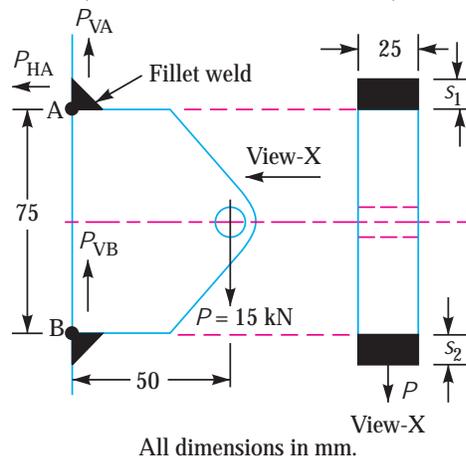
$$= \sqrt{(27.7)^2 + (195.2)^2 + 2 \times 27.7 \times 195.2 \times 0.5625}$$

$$= 212 \text{ N/mm}^2 = 212 \text{ MPa} \text{ Ans.}$$

**Example 10.16.** The bracket, as shown in Fig. 10.34, is designed to carry a dead weight of  $P = 15 \text{ kN}$ .

What sizes of the fillet welds are required at the top and bottom of the bracket? Assume the forces act through the points A and B. The welds are produced by shielded arc welding process with a permissible strength of 150 MPa.

**Solution.** Given :  $P = 15 \text{ kN}$  ;  $\tau = 150 \text{ MPa} = 150 \text{ N/mm}^2$  ;  $l = 25 \text{ mm}$



**Fig. 10.34**

In the joint, as shown in Fig. 10.34, the weld at A is subjected to a vertical force  $P_{VA}$  and a horizontal force  $P_{HA}$ , whereas the weld at B is subjected only to a vertical force  $P_{VB}$ . We know that

$$P_{VA} + P_{VB} = P \quad \text{and} \quad P_{VA} = P_{VB}$$

∴ Vertical force at A and B,

$$P_{VA} = P_{VB} = P / 2 = 15 / 2 = 7.5 \text{ kN} = 7500 \text{ N}$$

The horizontal force at A may be obtained by taking moments about point B.

$$\therefore P_{HA} \times 75 = 15 \times 50 = 750$$

or

$$P_{HA} = 750 / 75 = 10 \text{ kN}$$

**Size of the fillet weld at the top of the bracket**

Let  $s_1$  = Size of the fillet weld at the top of the bracket in mm.

We know that the resultant force at A,

$$P_A = \sqrt{(P_{VA})^2 + (P_{HA})^2} = \sqrt{(7.5)^2 + (10)^2} = 12.5 \text{ kN} = 12\,500 \text{ N} \quad \dots(i)$$

We also know that the resultant force at A,

$$\begin{aligned} P_A &= \text{Throat area} \times \text{Permissible stress} \\ &= 0.707 s_1 \times l \times \tau = 0.707 s_1 \times 25 \times 150 = 2650 s_1 \quad \dots(ii) \end{aligned}$$

From equations (i) and (ii), we get

$$s_1 = 12\,500 / 2650 = 4.7 \text{ mm} \quad \text{Ans.}$$

**Size of fillet weld at the bottom of the bracket**

Let  $s_2$  = Size of the fillet weld at the bottom of the bracket.

The fillet weld at the bottom of the bracket is designed for the vertical force ( $P_{VB}$ ) only. We know that

$$P_{VB} = 0.707 s_2 \times l \times \tau$$

$$7500 = 0.707 s_2 \times 25 \times 150 = 2650 s_2$$

$$\therefore s_2 = 7500 / 2650 = 2.83 \text{ mm} \quad \text{Ans.}$$

## EXERCISES

1. A plate 100 mm wide and 10 mm thick is to be welded with another plate by means of transverse welds at the ends. If the plates are subjected to a load of 70 kN, find the size of weld for static as well as fatigue load. The permissible tensile stress should not exceed 70 MPa. **[Ans. 83.2 mm; 118.5 mm]**
2. If the plates in Ex. 1, are joined by double parallel fillets and the shear stress is not to exceed 56 MPa, find the length of weld for (a) Static loading, and (b) Dynamic loading. **[Ans. 91 mm; 259 mm]**
3. A 125 × 95 × 10 mm angle is joined to a frame by two parallel fillet welds along the edges of 150 mm leg. The angle is subjected to a tensile load of 180 kN. Find the lengths of weld if the permissible static load per mm weld length is 430 N. **[Ans. 137 mm and 307 mm]**
4. A circular steel bar 50 mm diameter and 200 mm long is welded perpendicularly to a steel plate to form a cantilever to be loaded with 5 kN at the free end. Determine the size of the weld, assuming the allowable stress in the weld as 100 MPa. **[Ans. 7.2 mm]**

$$\left[ \text{Hint : } \sigma_{b(max)} = \frac{5.66 M}{\pi s d^2} \right]$$

5. A 65 mm diameter solid shaft is to be welded to a flat plate by a fillet weld around the circumference of the shaft. Determine the size of the weld if the torque on the shaft is 3 kN-m. The allowable shear stress in the weld is 70 MPa. **[Ans. 10 mm]**

$$\left[ \text{Hint : } \tau_{(max)} = \frac{2.83 T}{\pi s d^2} \right]$$

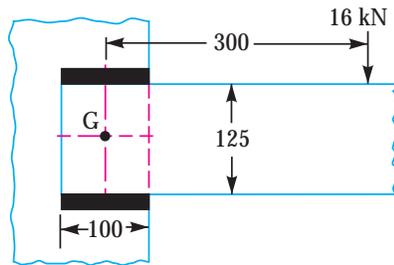
### 374 ■ A Textbook of Machine Design

6. A solid rectangular shaft of cross-section 80 mm × 50 mm is welded by a 5 mm fillet weld on all sides to a flat plate with axis perpendicular to the plate surface. Find the maximum torque that can be applied to the shaft, if the shear stress in the weld is not to exceed 85 MPa.

$$\left[ \text{Hint : } \tau_{(max)} = \frac{4.242 T}{s \times l^2} \right]$$

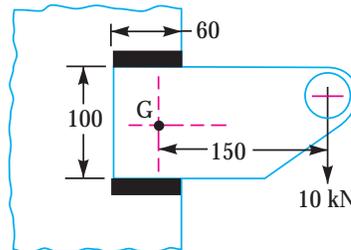
[Ans. 32.07 kN-m]

7. A low carbon steel plate of 0.7 m width welded to a structure of similar material by means of two parallel fillet welds of 0.112 m length (each) is subjected to an eccentric load of 4000 N, the line of action of which has a distance of 1.5 m from the centre of gravity of the weld group. Design the required thickness of the plate when the allowable stress of the weld metal is 60 MPa and that of the plate is 40 MPa. [Ans. 2 mm]
8. A 125 × 95 × 10 mm angle is welded to a frame by two 10 mm fillet welds, as shown in Fig. 10.35. A load of 16 kN is applied normal to the gravity axis at a distance of 300 mm from the centre of gravity of welds. Find maximum shear stress in the welds, assuming each weld to be 100 mm long and parallel to the axis of the angle. [Ans. 45.5 MPa]



All dimensions in mm.

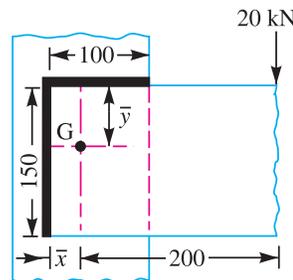
Fig. 10.35



All dimensions in mm.

Fig. 10.36

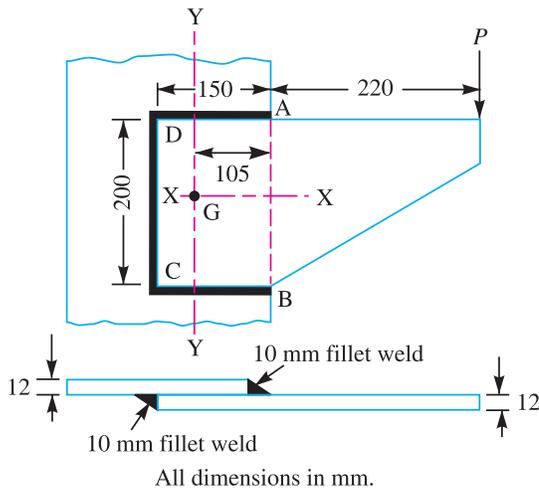
9. A bracket, as shown in Fig. 10.36, carries a load of 10 kN. Find the size of the weld if the allowable shear stress is not to exceed 80 MPa. [Ans. 10.83 mm]



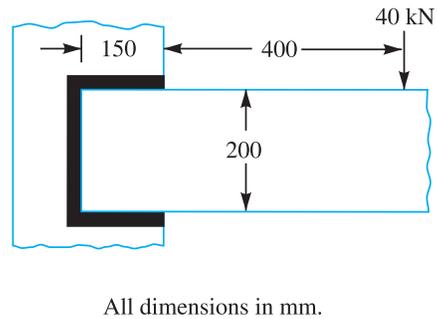
All dimensions in mm.

Fig. 10.37

10. Fig. 10.37 shows a welded joint subjected to an eccentric load of 20 kN. The welding is only on one side. Determine the uniform size of the weld on the entire length of two legs. Take permissible shear stress for the weld material as 80 MPa. [Ans. 8.9 mm]
11. A bracket is welded to the side of a column and carries a vertical load  $P$ , as shown in Fig. 10.38. Evaluate  $P$  so that the maximum shear stress in the 10 mm fillet welds is 80 MPa. [Ans. 50.7 kN]



**Fig. 10.38**



**Fig. 10.39**

12. A bracket, as shown in Fig. 10.39, carries a load of 40 kN. Calculate the size of weld, if the allowable shear stress is not to exceed 80 MPa. [Ans. 7 mm]

### QUESTIONS

1. What do you understand by the term welded joint? How it differs from riveted joint?
2. Sketch and discuss the various types of welded joints used in pressure vessels. What are the considerations involved?
3. State the basic difference between manual welding, semi-automatic welding and automatic welding.
4. What are the assumptions made in the design of welded joint?
5. Explain joint preparation with particular reference to butt welding of plates by arc welding.
6. Discuss the standard location of elements of a welding symbol.
7. Explain the procedure for designing an axially loaded unsymmetrical welded section.
8. What is an eccentric loaded welded joint? Discuss the procedure for designing such a joint.
9. Show that the normal stress in case of an annular fillet weld subjected to bending is given by

$$\sigma = \frac{5.66 M}{\pi s d^2}$$

where  $M$  = Bending moment;  $s$  = Weld size and  $d$  = Diameter of cylindrical element welded to flat surface.

### OBJECTIVE TYPE QUESTIONS

1. In a fusion welding process,
 

|  |                           |
|--|---------------------------|
| (a) only heat is used                        | (b) only pressure is used |
| (c) combination of heat and pressure is used | (d) none of these         |
2. The electric arc welding is a type of ..... welding.
 

|           |            |
|-----------|------------|
| (a) forge | (b) fusion |
|-----------|------------|
3. The principle of applying heat and pressure is widely used in
 

|                        |                  |
|------------------------|------------------|
| (a) spot welding       | (b) seam welding |
| (c) projection welding | (d) all of these |

**376 ■ A Textbook of Machine Design**

4. In transverse fillet welded joint, the size of weld is equal to  
(a)  $0.5 \times$  Throat of weld (b) Throat of weld  
(c)  $\sqrt{2} \times$  Throat of weld (d)  $2 \times$  Throat of weld
5. The transverse fillet welded joints are designed for  
(a) tensile strength (b) compressive strength  
(c) bending strength (d) shear strength
6. The parallel fillet welded joint is designed for  
(a) tensile strength (b) compressive strength  
(c) bending strength (d) shear strength
7. The size of the weld in butt welded joint is equal to  
(a)  $0.5 \times$  Throat of weld (b) Throat of weld  
(c)  $\sqrt{2} \times$  Throat of weld (d)  $2 \times$  Throat of weld
8. A double fillet welded joint with parallel fillet weld of length  $l$  and leg  $s$  is subjected to a tensile force  $P$ . Assuming uniform stress distribution, the shear stress in the weld is given by  
(a)  $\frac{\sqrt{2} P}{s.l}$  (b)  $\frac{P}{2s.l}$   
(c)  $\frac{P}{\sqrt{2} s.l}$  (d)  $\frac{2P}{s.l}$
9. When a circular rod welded to a rigid plate by a circular fillet weld is subjected to a twisting moment  $T$ , then the maximum shear stress is given by  
(a)  $\frac{2.83 T}{\pi s d^2}$  (b)  $\frac{4.242 T}{\pi s d^2}$   
(c)  $\frac{5.66 T}{\pi s d^2}$  (d) none of these
10. For a parallel load on a fillet weld of equal legs, the plane of maximum shear occurs at  
(a)  $22.5^\circ$  (b)  $30^\circ$   
(c)  $45^\circ$  (d)  $60^\circ$

**ANSWERS**

1. (a)                      2. (b)                      3. (d)                      4. (c)                      5. (a)  
6. (d)                      7. (b)                      8. (c)                      9. (a)                      10. (c)