Welded Joints

Vedat Temiz
Assistant Professor of Machine Design

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.

Advantages and Disadvantages of Welded Joints over Riveted Joints

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 and Disadvantages of Welded Joints over Riveted Joints

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.

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.*

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.**

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.

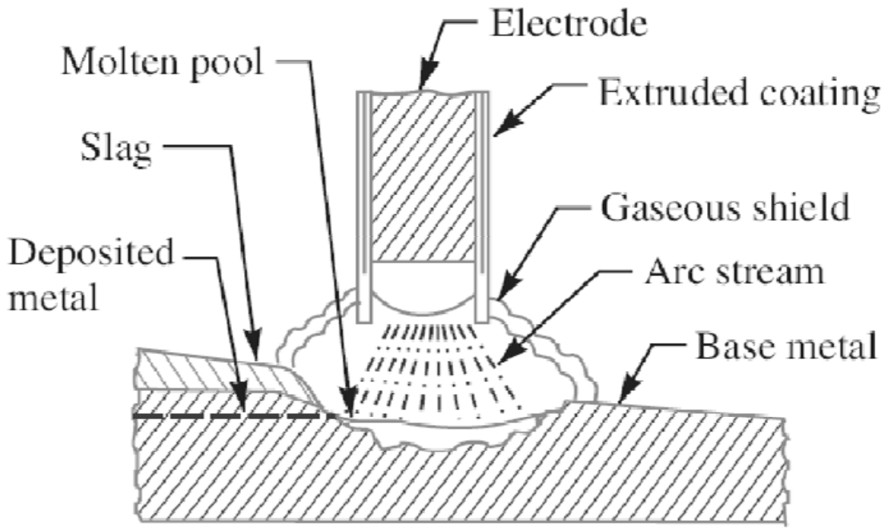
Gas Welding

- 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.

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 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. 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.

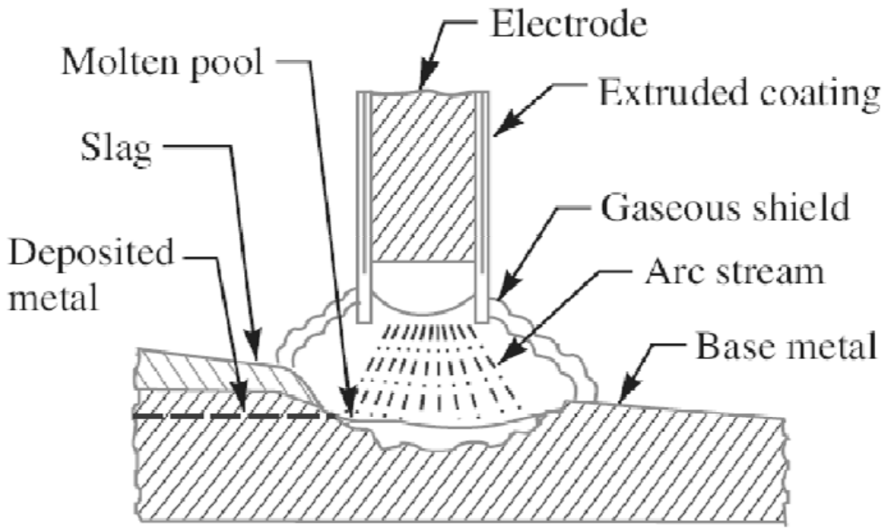
The arc welding does not require the metal to be preheated and since the temperature of the arc is quite high, therefore the fusion of the metal is almost instantaneous.



Electric Arc Welding

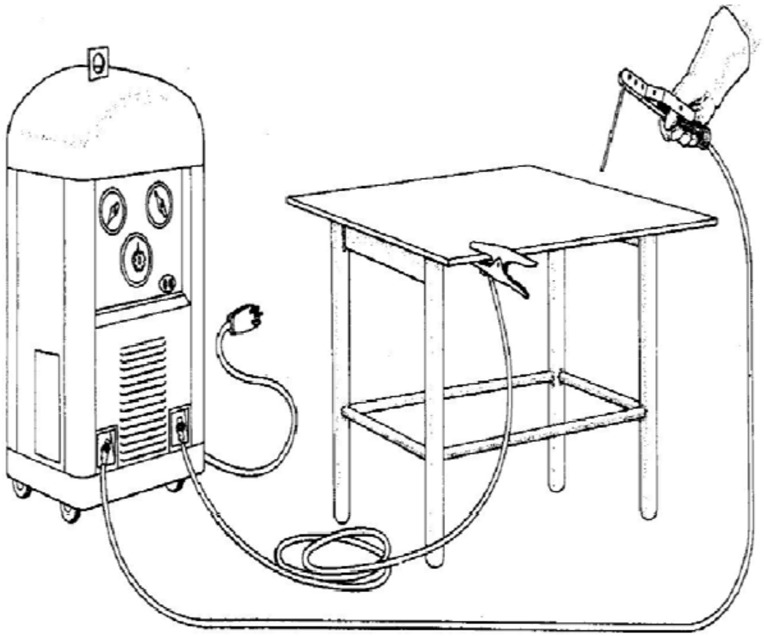
- There are two kinds of arc weldings depending upon the type of electrode.
- **1. Un-shielded arc welding, and**
- **2. Shielded arc welding.**
- When a large electrode or filler rod is used for welding, it is then said to be ***un-shielded arc welding.*** In this case, the deposited weld metal while 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.

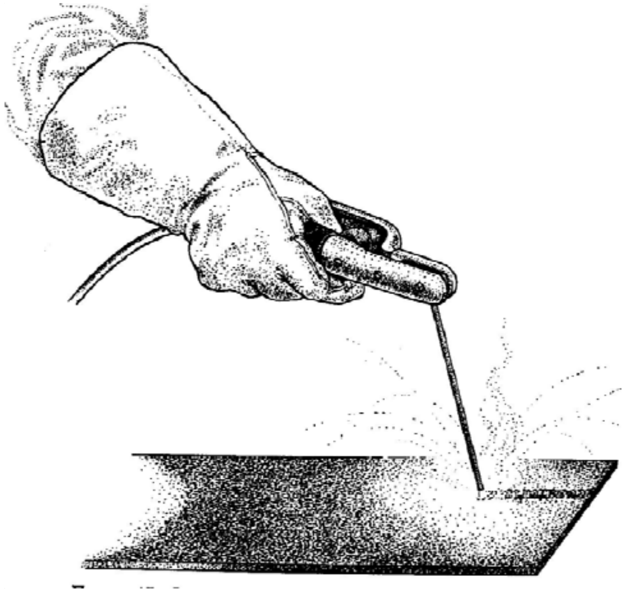
In ***shielded arc welding,*** the welding rods coated with solid material are used, as shown in Fig. The resulting projection of coating focuses a concentrated arc stream, which protects the globules of metal from the air and prevents the absorption of large amounts of harmful oxygen and nitrogen.



Arc Welding

- Electric current flowing through a high resistance air gap generates an intense arc with temperatures ranging from 3,000 to 5,500^{o} C.





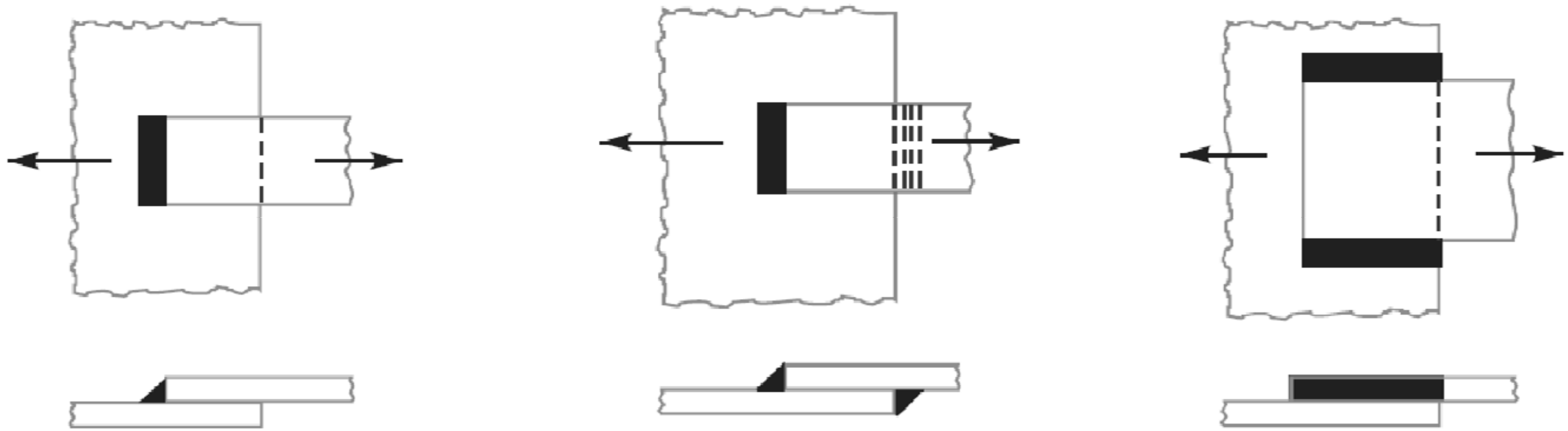
Arc welding is the most common method used with structural steel welding.

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.***

Types of Welded Joints

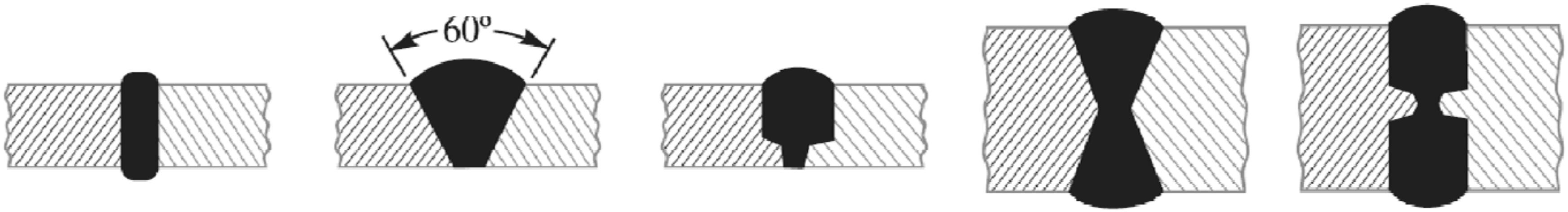
- Lap Joint
- The lap joint or the fillet joint is obtained by overlapping the plates and then welding the edges of the plates. The cross-section of the fillet is approximately triangular. The fillet joints may be
- **1. Single transverse fillet,**
- **2. Double transverse fillet, and**
- **3. Parallel fillet joints.**



(a) Single transverse. (b) Double transverse. (c) Parallel fillet.

Types of Welded Joints

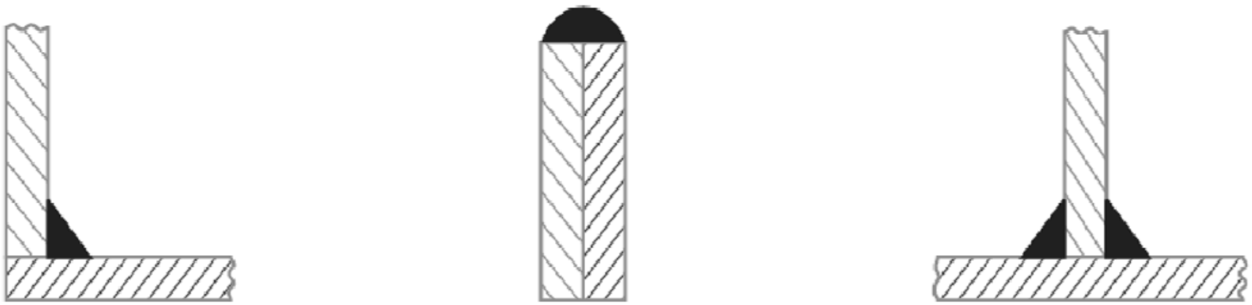
- Butt Joint
- The butt joint is obtained by placing the plates edge to edge. In butt welds, the plate edges do not require bevelling if the thickness of plate is less than 5 mm. On the other hand, if the plate thickness is 5 mm to 12.5 mm, the edges should be bevelled to V or U-groove on both sides.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



(*a*) Square butt joint. (*b*) Single *V*-butt joint. (*c*) Single *U*-butt joint. (*d*) Double *V*-butt joint. (*e*) Double *U*-butt joint.

Types of Welded Joints

- ## Other Joints
- The other type of welded joints are corner joint, edge joint and T-joint as shown in Fig. below.



(a) Corner joint. (b) Edge joint. (c) T-joint.

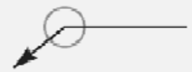
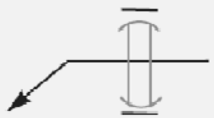
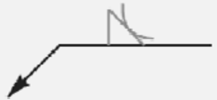
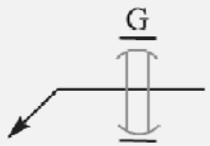
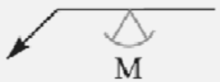
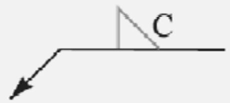
The main considerations involved in the selection of weld type are:

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.

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		
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	Before / After	
17.	Plug		
18.	Backing strip		
19.	Stitch		
20.	Projection	Before / After	
21.	Flash	Rod or bar / Tube	
22.	Butt resistance or pressure (upset)	Rod or bar / Tube	

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

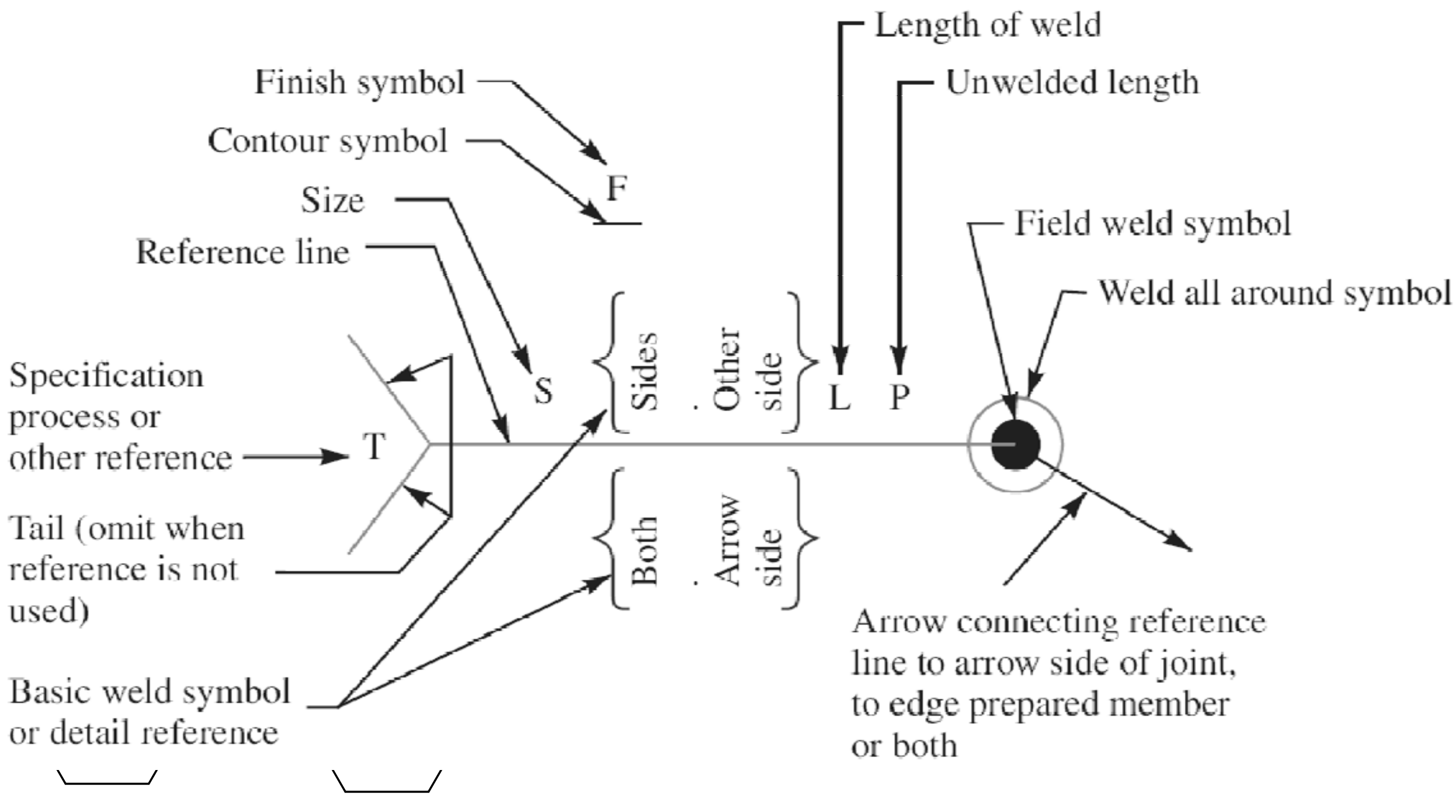
Elements of a Welding Symbol

- A welding symbol consists of the following eight elements:

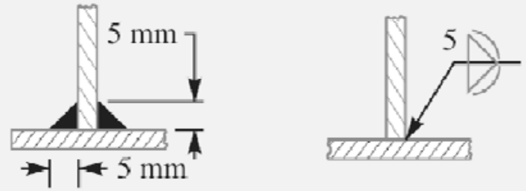
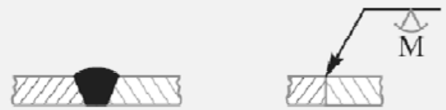
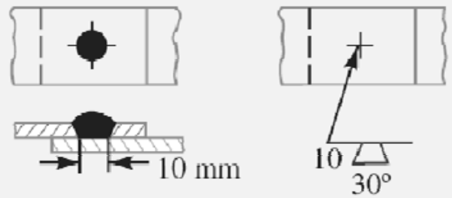
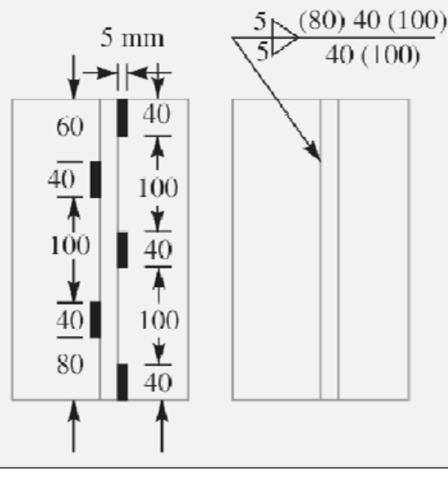
- **1. Reference line, 2. Arrow,**
- **3. Basic weld symbols, 4. Dimensions and other data,**
- **5. Supplementary symbols, 6. Finish symbols,**
- **7. Tail, and 8. Specification, process or other references.**

Standard Location of Elements of a Welding Symbol

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. below shows the standard locations of welding symbols represented on drawing.

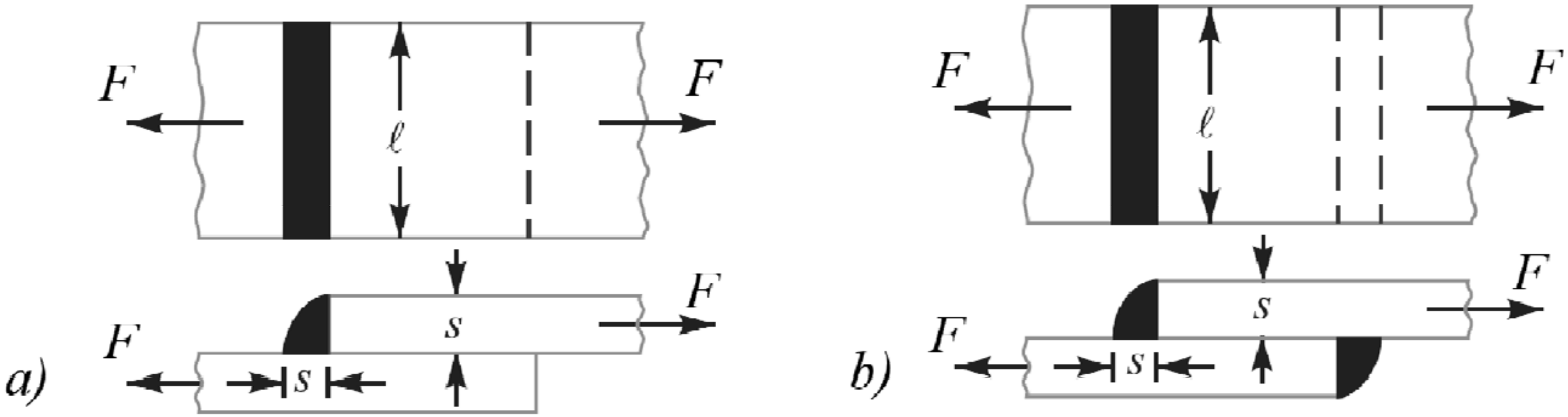


Representation of welding symbols

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	

Strength of Transverse Fillet Welded Joints

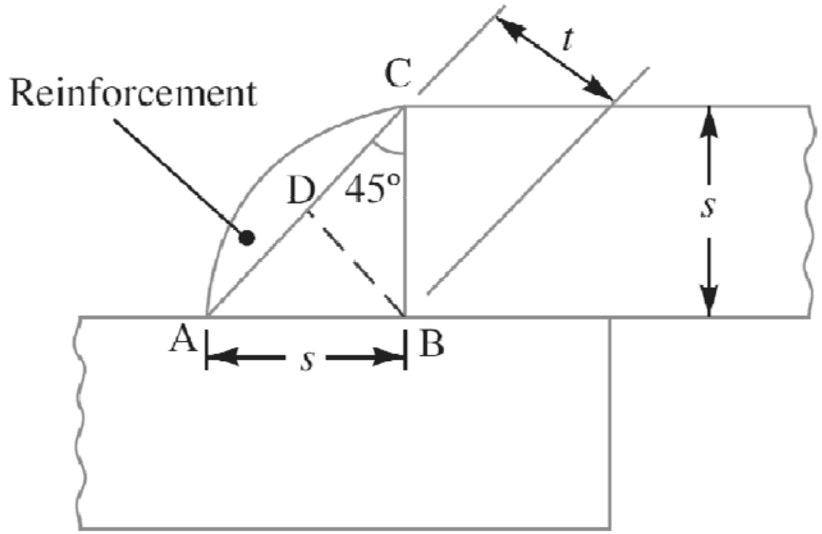
- The transverse fillet welds are designed for tensile strength. Let us consider a single and double transverse fillet welds as shown in Fig. (*a) and (b) respectively.*



Strength of Transverse Fillet Welded Joints

- 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. below 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.

t = Throat thickness (BD),
s = Leg or size of weld,
= Thickness of plate, and
l = Length of weld,



Strength of Transverse Fillet Welded Joints

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

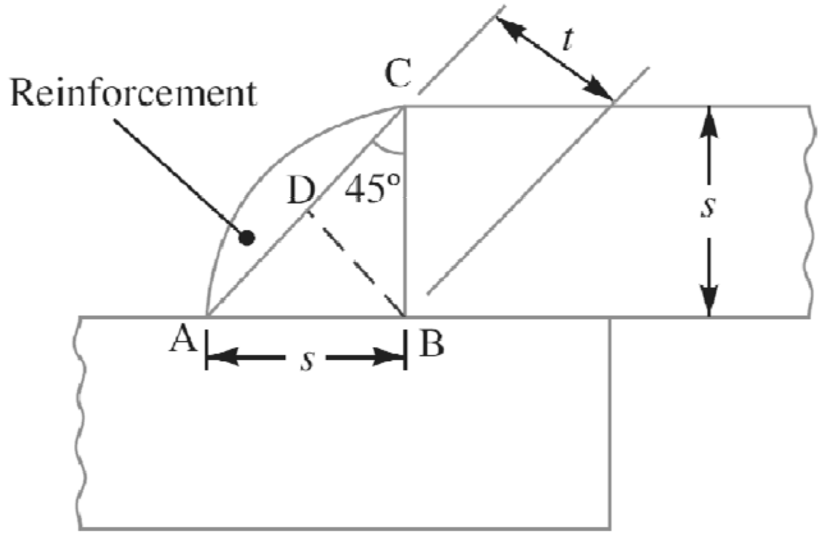
$$t = s \times \sin 45° = 0.707\, s$$

Minimum area of the weld or throat area,

A = *Throat thickness* × Length of weld = $t \times l = 0.707\, s \times l$

If σ_t *is the allowable tensile stress for the weld* metal, then the tensile strength of the joint for single fillet weld,

F = Throat area × Allowable tensile stress = $0.707\, s \times l \times \sigma_t$



and tensile strength of the joint for double fillet weld,

$$F = 2 \times 0.707\, s \times l \times \sigma_t = 1.414\, s \times l \times \sigma_t$$

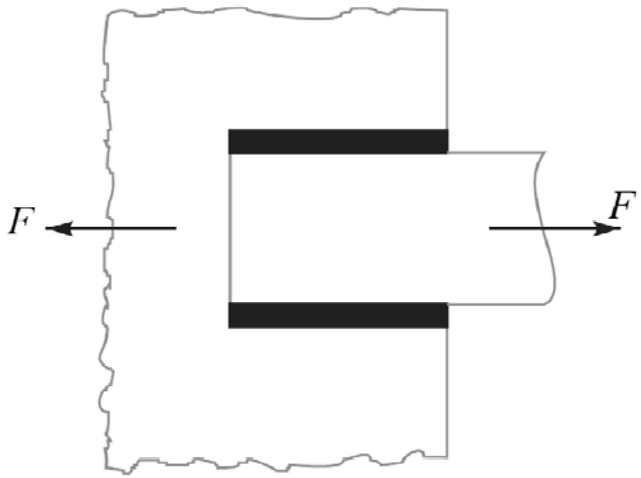
Strength of Parallel Fillet Welded Joints

- The parallel fillet welded joints are designed for shear strength. Consider a double parallel fillet welded joint as shown in Fig. (*a*). *The* minimum area of weld or the throat area, $A = 0.707\, s \times l$
- If τ is the allowable shear stress for the weld metal, then the shear strength of the joint for single parallel fillet weld,

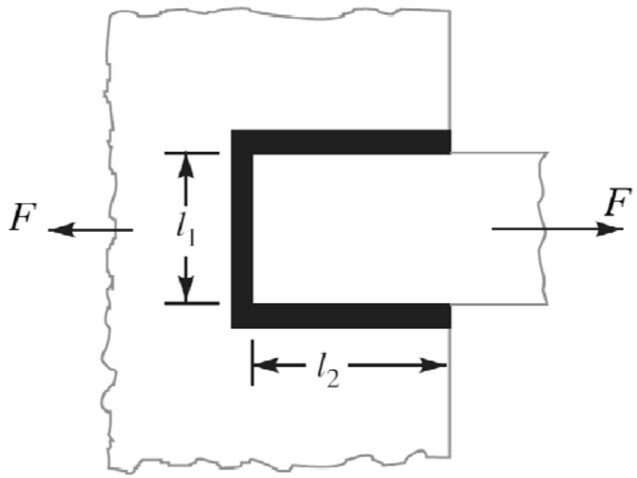
  F = *Throat area* × *Allowable shear stress* $= 0.707\, s \times l \times \tau$

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

$$F = 2 \times 0.707 \times s \times l \times \tau = 1.414\, s \times l \times \tau$$



(*a*) Double parallel fillet weld.



(*b*) Combination of transverse and parallel fillet weld.

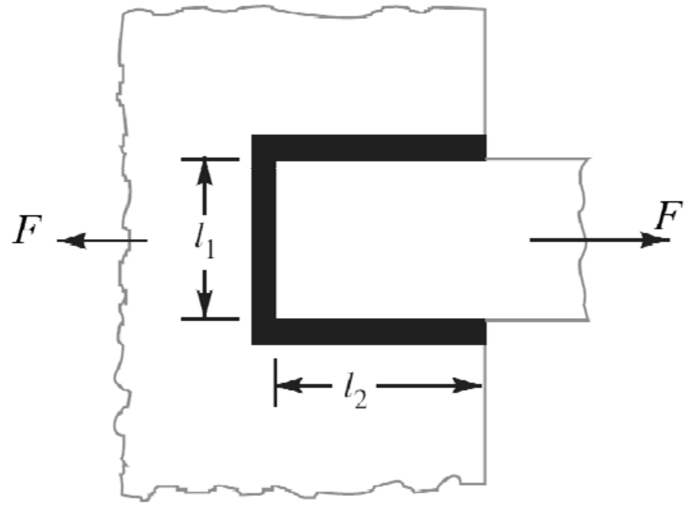
Notes

- 1. If there is a combination of single transverse and double parallel fillet welds as shown in Fig., then the strength of the joint is given by the sum of strengths of single transverse and double parallel fillet welds.
- Mathematically,

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

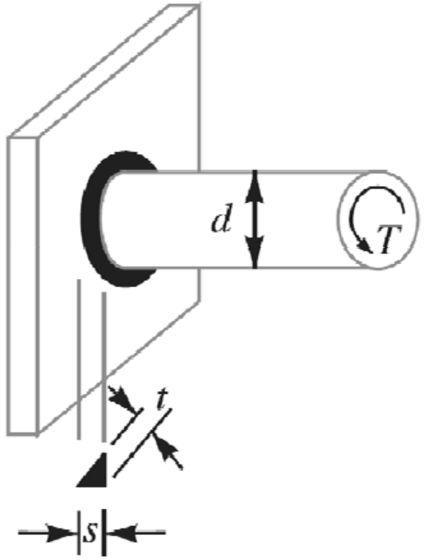
2. In order to allow for starting and stopping of the bead, 12.5 mm should be added to the length of each weld obtained by the above expression.

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



Special Cases of Fillet Welded Joints

- ***Circular fillet weld subjected to torsion.***



We know that shear stress for the material,

$$\tau = \frac{T.r}{J} = \frac{T \times d/2}{J} = \frac{T \times d/2}{\pi t d^3/4} = \frac{2T}{\pi t d^2}$$

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° to the horizontal plane.

Length of throat, $t = s \sin 45° = 0.707\, s$

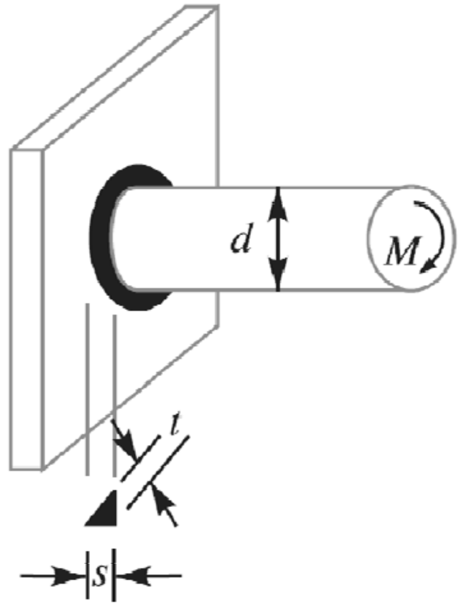
Maximum shear stress

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

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 → $\frac{\pi t d^3}{4}$

Special Cases of Fillet Welded Joints

- ***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° = 0.707 s*

Maximum bending stress

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

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 ⇨ $\frac{\pi t d^2}{4}$

Strength of Butt Joints

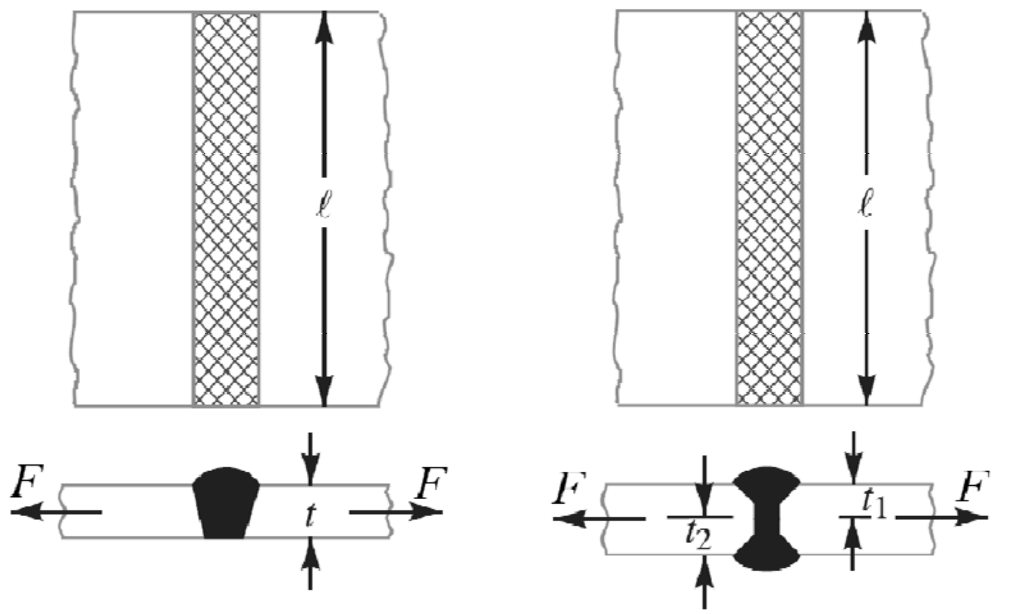
- The butt joints are designed for tension or compression. Consider a single V-butt joint as shown in Fig. *(a).*
- In case of butt joint, the length of leg or size of weld is equal to the throat thickness which is equal to thickness of plates.
- Tensile strength of the butt joint (single-*V or square butt joint),*

$$F = t \times l \times \sigma_t$$

and tensile strength for double-*V butt joint as shown in Fig. (b)*

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

t_1 = Throat thickness at the top, and
t_2 = Throat thickness at the bottom.
l = Length of weld. It is generally equal to the width of plate.



(*a*) Single *V*-butt joint.   (*b*) Double *V*-butt joint.

Stresses for Welded Joints

- The stresses in welded joints are difficult to determine because of the variable and unpredictable parameters like homogenuity 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.

Type of weld	*Bare electrode*		*Coated electrode*	
	Steady load (MPa)	*Fatigue load (MPa)*	*Steady load (MPa)*	Fatigue load *(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

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.

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.

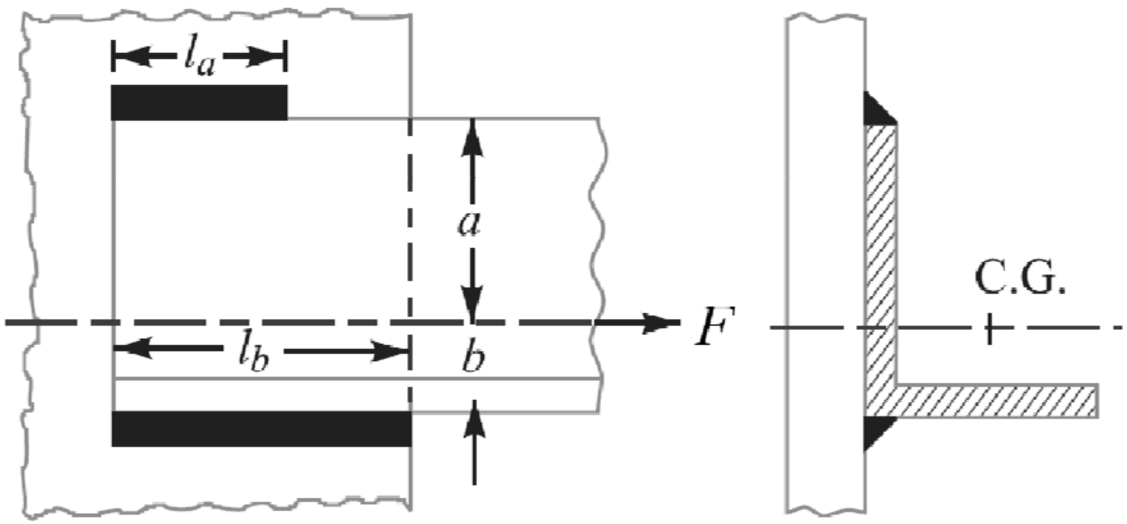
Axially Loaded Unsymmetrical Welded Sections

- Sometimes unsymmetrical sections such as angles, channels, *T-sections etc., welded on the flange edges are loaded* axially as shown in below. 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.

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

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 $l_a \times a = l_b \times b$



We know that $l = l_a + l_b$

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

f = Resistance offered by the weld per unit length.

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,

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

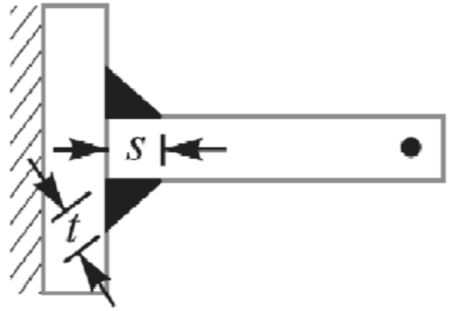
Maximum shear stress

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

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

Eccentrically Loaded Welded Joints

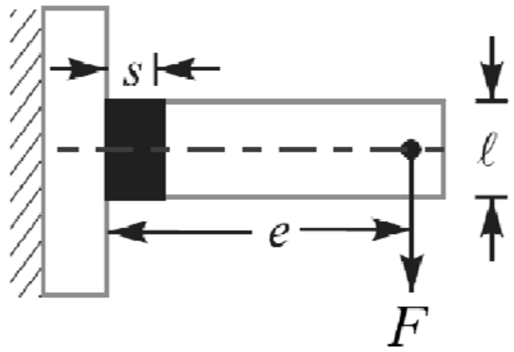
Consider a *T-joint fixed at one end and subjected to an eccentric load P at a distance e as shown* in Fig.



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,*

2. Bending stress due to the bending moment *P × e.*



We know that area at the throat, A= *t × l × 2 = 2 t × l*

= 2 × 0.707 *s × l = 1.414 s × l*

Shear stress in the weld (assuming uniformly distributed),

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

Section modulus of the weld metal through the throat $Z = \frac{t \times l^2}{6} \times 2 = \frac{s \times l^2}{4.242}$

Bending moment, *M = F × e*

Bending stress

$$\sigma_b = \frac{M}{Z} = \frac{F \times e \times 4.242}{s \times l^2} = \frac{4.242\ F \times e}{s \times l^2}$$

We know that the maximum normal stress,

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

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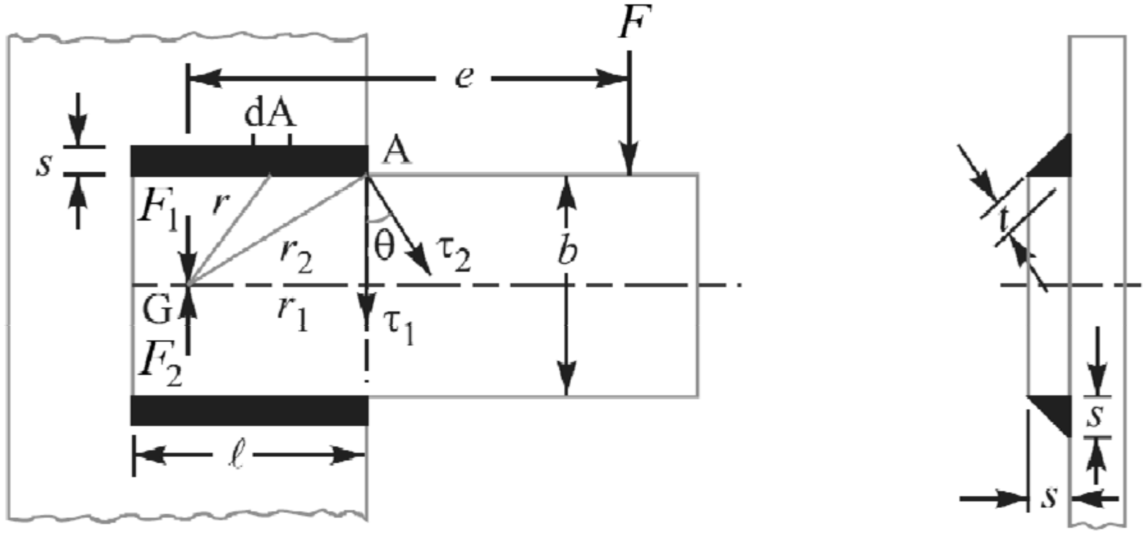
When a welded joint is loaded eccentrically as shown in Fig.



the following two types of the stresses are induced:

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

Let two loads F_1 *and* F_2 *(each equal to F) are introduced at the centre of gravity 'G' of the weld* system. The effect of load $F_1 = F$ *is to produce direct shear stress which is assumed to be uniform over* the entire weld length. The effect of load $F_2 = F$ *is to produce a turning moment of magnitude* $F \times e$ which tends of rotate the joint about the centre of gravity '*G' of the weld system. Due to the turning* moment, secondary shear stress is induced.

We know that the direct or primary shear stress

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