(1) — (11) KIMBOFA GROUP

WELDING

Introduction:

Welding is a process of joining together two or more metal parts permanently. The contacting surfaces are raised to a plastic or molten condition by the application of heat with or without the addition of a molten metal and with or without the application of pressure.

Welding has greatly replaced riveting in ship building and structural works.

1. Advantages, Disadvantages, Application

Advantages:

(i) Cheap and more efficient. Takes less time and low material cost.

(ii) Compact joints and lighter structures. No additional plates as in rivets., hence less weight.

(iii) Strong joint. The joint has the strength of the parent metal.

(iv) High corrosion resistance compared to bolted or riveted joints.

(V) The joint is fluid tight. (as required in tanks and pressure vessels).

(Vi) Many different types of joints are possible. (e.g. circular pipes, Large sections, irregular broken sections are easily welded than riveted)

(vii) Additions and alterations can be easily made in existing structures.

(viii) Welded structures are smooth in appearance. Hence it is easier and economical to paint.

(ix) Possible to weld any part of a structure at any point. Riveting requires enough clearance.

(x) Welded joint is very rigid.

(xi) Less noise in welding operation than riveting

Disadvantages:

(i) Members may either crack or get distorted due to uneven heating and cooling. Residual stresses may develop.

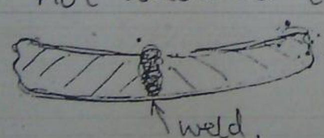
(ii) Requires highly skilled labour and supervision.

(iii) Welded joints are rigid.

(iv) Inspection of welding work is more difficult than riveting work.

(v) Welding cannot be applied to parts which are difficult to weld together.

Note: ① Residual (additional) stresses will be induced in the structure if the components are not allowed to deform freely (e.g. clamping)



Warping (distortion) due to non-uniform heating up.

② Stress-relieving – is the procedure of taking out (not completely) the residual stresses (thermal) induced during welding. Thermal stresses depend on the skill of a welder.

Generally mechanical blows to the surface of the structure and annealing (applying heat) reduce the thermal stresses.

Application:

Welding is used in many areas e.g. automobile, aircraft, structural works, tanks, machine repair, ship-building, pipe-line fabrication, thermal power plants, refineries etc. Probably there is no industry which is not using welding process in the fabrication of its parts in some form or the other.

2. Welding processes

Covers a wide range of bonding techniques. Welding processes could be classified as

(i) Fusion welding

(ii) Pressure welding (Solid-phase welding).

(i) Fusion welding

Is the process of joining two pieces of metal by application of heat. The two parts to be joined together are heated up in the localised area of the joint to the molten state and often a third (filler) material also molten is added. The process is over when the melt has fused and solidified on cooling. Heat may be developed in several ways.

Fusion processes are such as:

Oxy-acetylene gas welding,

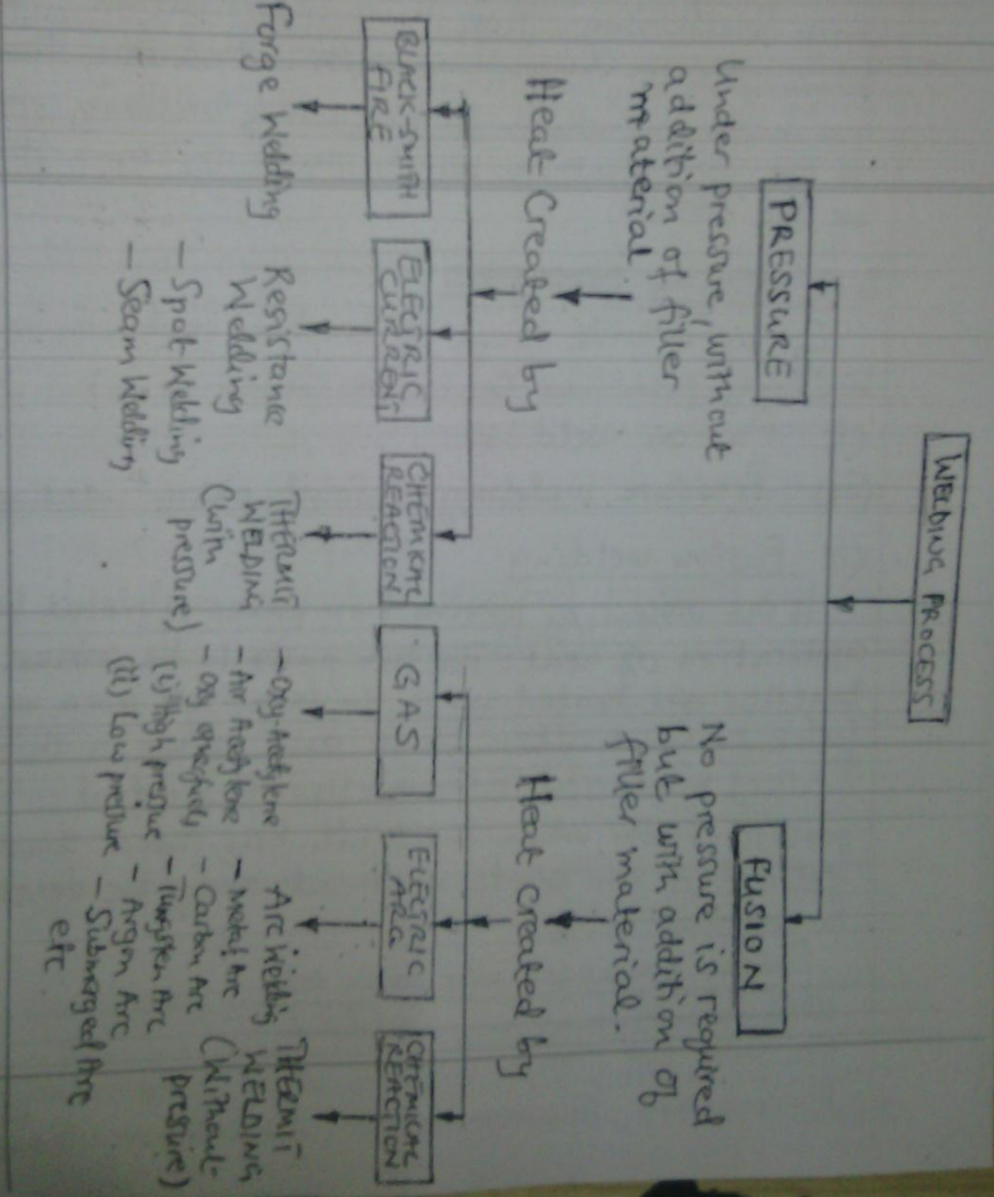
Electric arc (metal Inert Gas - MIG, Tungsten Inert Gas - TIG etc),

Plasma arc, Electron beam, Laser beam, Thermit etc.

(ii) Pressure Welding

Two parts to be joined are pressed together so much in the localised area of the joint, that the resulting plastic deformation make the parts to stick together. Heat may be applied. The process is also termed as Cold welding. Plastics can be joined by this method

Chart below is a summary of Welding Processes.



3. Resistance Welding

Heavy electric current is passed through the metals in their localised areas of the joint, thereby heating the areas to a plastic state and the weld completed by the application of pressure. No additional filler material is required.

In this we have Spot-welding and seam-welding. (Figs, below).

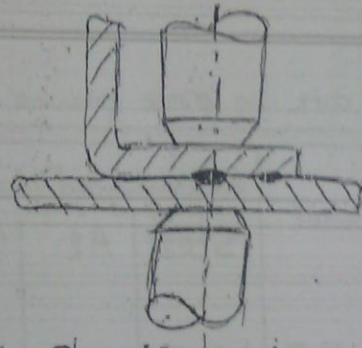


Fig: Spot-welding

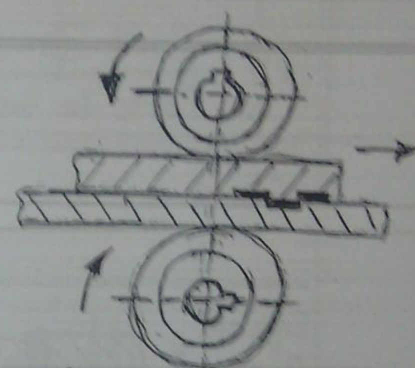


Fig: Seam-Welding (Produce overlaping spots)

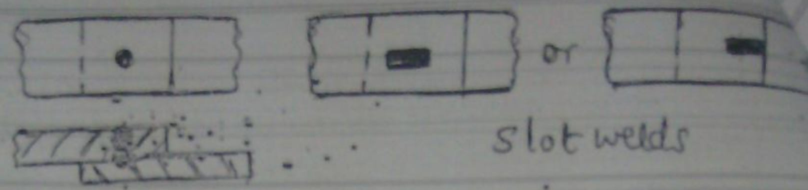
Advantages:

- Speed and uniformity of the weld
- Elimination of filler rods and fluxes (present in Gas and Arc)
- Process easy to automate (Were the first, which led to RAWS - Robotic Arc Welding System)

4. Types of Welded Joints

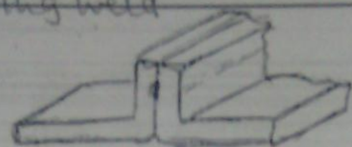
(i) Plug or Slot Weld joint

Lap joints



~~plug weld~~

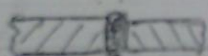
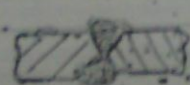
Butt joint



— Areas of spots in resistance welding can be considered as plugs or slots.

(ii) Butt Joints

— Parts to be joined are in one plane.

JOINT DESIGN	Symbol	Recommended plate thickness (mm)			
		Steel	Al	Cu	Ni
Square & Butt-open 	|| or][	1.5–5	—	Upto 3	Upto [illegible]
Single V-groove 	V	5–12	6–12	3–12	3–1[illegible]
Single U-groove 	Y	12–18	—	12–18	12–[illegible]
Double V-groove 	X	18–25	>12	12–25	—
Double U-groove 	Double U symbol	>18	—	>18	>25

Note: Butt weld symbol —||— e.g. ie. weld square butt

presentation of welds

The symbolic representation of a weld has three basic elements: a reference line, an arrow and a weld symbol as shown in fig 8.15.

1 Reference line. These lines are usually horizontal.
2 Arrow.
3 Weld symbol.

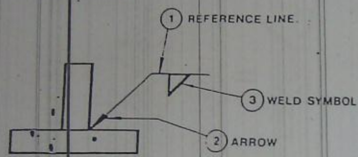


Fig 8.15

There are different ways of inserting the weld symbols on the reference line. They can be inserted below, on the top or on both sides of the reference line, indicating the side the weld is on. See the following examples:

Fillet weld on the right-hand side

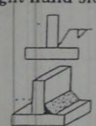


Fig 8.16

Fillet weld on the left-hand side

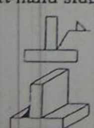


Fig 8.17

Note: weld symbol can go on either side

Fillet weld on both sides

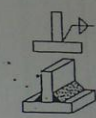


Fig 8.18

Single-V butt weld

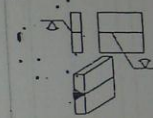


Fig 8.19

Fillet weld on a single lap joint

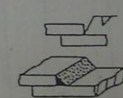


Fig 8.20

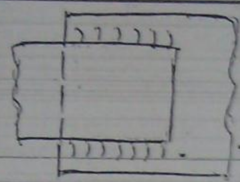
Single-V weld on a corner joint

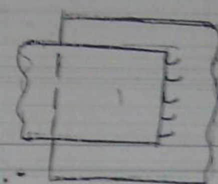
Fig 8.21

(iii) Fillet Joints

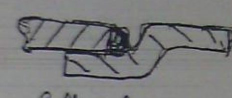
(a) Lap joints

- Parts to be joined overlap.





Double Lap

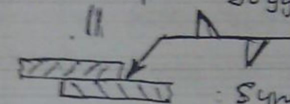


Off-set or Joggled Lap

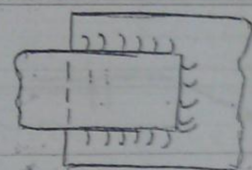
Flank (Side) Seam

End Seam (Single Lap)

||



: Symbol



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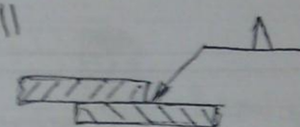


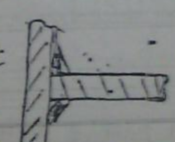
Compound Seam

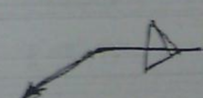
(b) T-Joints

- Parts to be welded meet at right angles to each other.

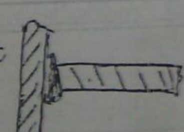
Symbol

Double fillet T-Joint Fillet Seam





Single fillet T-joint V-Seam



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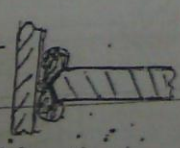
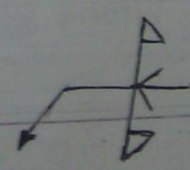
Double fillet T-joint K-seam



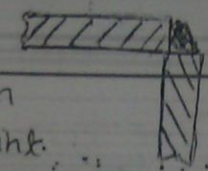
K



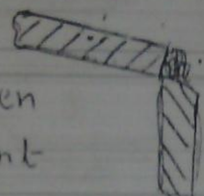
(c) Corner Joints

- Parts meet in L-shape.

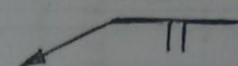
Symbol



Full open Corner joint.



Half open Corner joint



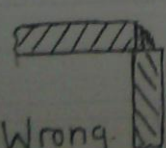
Edge weld

(for sheet metal - Light Loads)

5. General Design rules for Welded joints

Wrong   Right   right

- Also never put weld into a plane where force changes direction or at a places of maximum stress.



Wrong

Right

Wrong

Right (with reinforcing ribs)

6. Terminology

Before taking design calculations for welded joints let us see some of the technical terms in use.

(i) Legs of the weld (with fillet joints)

Ref. fig. below.

∴ The sides containing the right angle are called legs of the weld. In fig. below, 'AB' and 'BC' are legs of the weld.

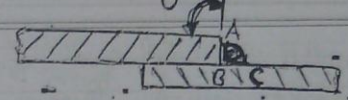


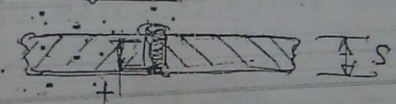
Fig:.

(ii) Size of the weld (S)

The leg with minimum length is called the size of the weld. In fig. above if 'BC' is the minimum leg, then it is called the size of the fillet weld.

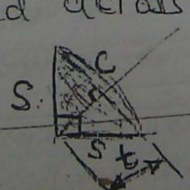
(iii) Throat thickness (t)

(a) In Butt joints the throat thickness $\boxed{t \triangleq s}$



(b) In Fillet - joints

The throat thickness is the perpendicular distance between the corners and the hypotenus of the weld across. (Fig. below)



For $\theta = 90^\circ$

$\therefore C = S\sqrt{2}$

Fig:

$\therefore\ s^2 = t^2 + \left(\frac{1}{2}c\right)^2$

thus $t = s \cdot \frac{\sqrt{2}}{2} \simeq 0.7s$

Hence for fillet welds $\boxed{t = k \cdot s}$

The values of k for different angles between fusion faces is as given below.

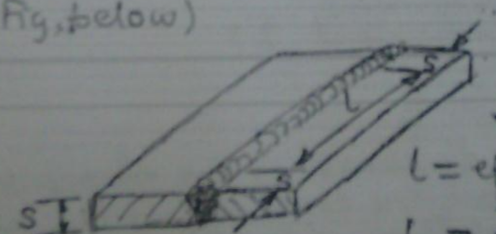
Angle: θ	$60°-90°$	$91°-100°$	$101°-106°$	$107°-113°$	$114°-120°$
k	0.7	0.65	0.60	0.55	0.50

Note:

1) The fillet weld should not be used for connecting parts whose fusion faces make an angle less than 60° or more than 120°.
2) If no angle between fusion faces is given it is taken as 90° and the value of 'k' is taken as 0.7.

(iv) Effective length of the weld

For purposes of design, the effective length of the weld is taken as the actual length of the weld minus twice the size of the weld. (Fig. below)



$\therefore\ \boxed{l = L - 2s}$

l = effective length of seam

L = actual length

s = weld size

Fig:

Note: to take care of workmanship (at start and end of the run).

7. Strength of Welded Joints

(a) Allowable design stresses

For low carbon steels, table below gives the allowable stresses.

Type of Welds	Static Loads [N/mm²]	Dynamic Loads [N/mm²]
BUTT WELDS		
– Tension	110	55
– Compression	124	55
– Shear	67	35
FILLET WELDS		
– Transverse and parallel welds.	97	35

(b) Centric loading

– Loads applied through c.g. of weld.

(i) Plug, Slot or Spot Welds

The strength of the joint is given by

$$\boxed{F_{t,c} = \sigma_A \cdot A} \quad (1) \text{ Tension or Compression}$$

$$\boxed{F_s = \tau_A \cdot A} \quad (2) \text{ Shear}$$

where σ_A = allowable tensile/compressive stress

τ_A = allowable shear stress.

A = Area of weld. (Area of spot, slot(s) or plug).

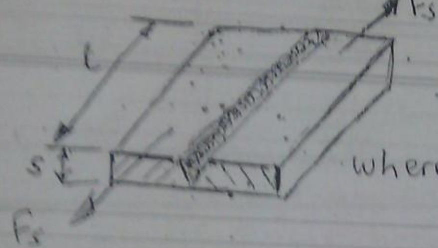
(ii) Butt Joints

— Tension / Compression

$$\boxed{F_t = \sigma_A \cdot A} \quad (1)$$

where σ_A = allowable stress
A = weld area = $s.l$.

— Direct / transverse shear

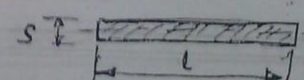


$$\boxed{F_s = \tau_A \cdot A} \quad (2)$$

where τ_A = allowable shear stress
A = area of shear = $s.l$.

— Bending

bending section



$I = \frac{1}{12} l s^3$

$z = s/2$

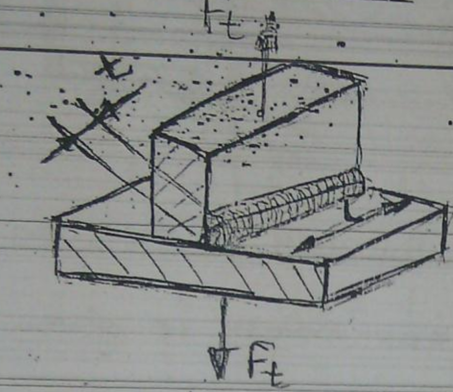
$$\therefore \boxed{\sigma_b = \frac{Mz}{I} = \frac{6M}{ls^2} \le \sigma_A} \quad (3)$$

Where M = bending moment
σ_A = allowable bending stress
σ_b = Weld bending stress.

— Torsion: Butt joint not normally subjected to torsion.

(iii) Fillet Joints

– Tension / Compression



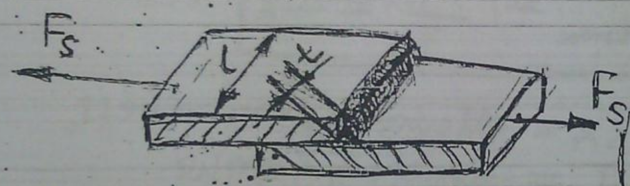
Strength 'F_t' is given by

$$\boxed{F_t = \sigma_A \cdot A} \quad (1)$$

Where σ_A = allowable tensile / compressive stress

A = weld area [redacted]

– Direct / transverse shear



Strength in shear 'F_s' is given by

$$\boxed{F_s = \tau_A \cdot A} \quad (2)$$

Where τ_A = allowable shear stress

A = Area of shear = $t \cdot l$

L = length of weld

t = throat thickness.

For fillet welds fig. below L = total length of the weld

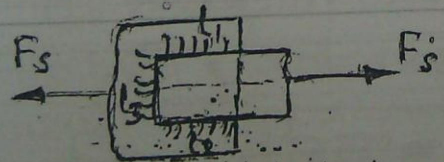


Fig:

$$\therefore \boxed{L = L_1 + L_2 + L_3} \quad (3)$$

– Torsional Shear

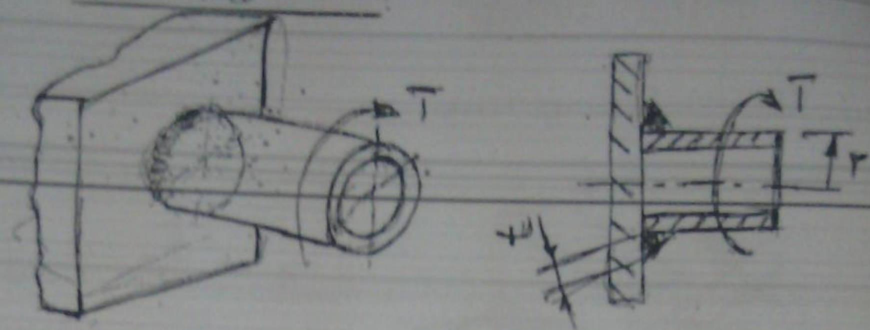


Fig: Weld joint subjected to torsion

The torsional shear stress is given by

$$\boxed{\tau_t = \frac{Tr}{J}}$$

$$\therefore \boxed{\tau_{t_{max}} = \frac{Tr}{J} = \tau_A} \quad (1)$$

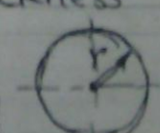
where τ_A = allowable shear stress
T = applied torque
r = radius (outer radius)
J = polar area moment of inertia

$$\boxed{J = J_u \cdot t} \quad (2)$$

where J_u = unit polar moment of inertia
t = throat thickness

Note: 1) Circular section of weld

$$\boxed{J_u = 2\pi r^3}$$



2) Other sections values of J_u can be obtained in tables

* Alternatively this can be taken as follows:

Let dF = differential shear force on element of ring subtending angle $d\theta$

$\therefore dF = \tau_A \cdot dA$

where τ_A = allowable shear stress

$dA = t \cdot r d\theta$ differential area

$\therefore dF = \tau_A \cdot t\, r d\theta$

Differential torque $dT = r dF$

where r = radius of ring

$\therefore$ Total torque $T = \int dT$

$= \int r dF$

$$\therefore T = \int r \cdot \tau_A t \cdot r d\theta$$

$$= \tau_A r^2 t \int_0^{2\pi} d\theta = 2\pi r^2 t \cdot \tau_A$$

$$\therefore \boxed{T = \tau_A \cdot 2\pi r^2 t}$$

where t = throat thickness

(iv) Unsymmetrical sections

Generally designed in such a way to avoid the effect of eccentricity. Fig. below shows an unsymmetrical section e.g. an angle section welded and subjected to a transverse shear load. In order to avoid the effect of eccentricity, the load is applied along the neutral (centroidal) axis of the section. The fillet weld is also applied in such a way that the c.g. of the weld lies in the line of action of the load. That is the c.g. of the weld coincides with the neutral axis of the section.

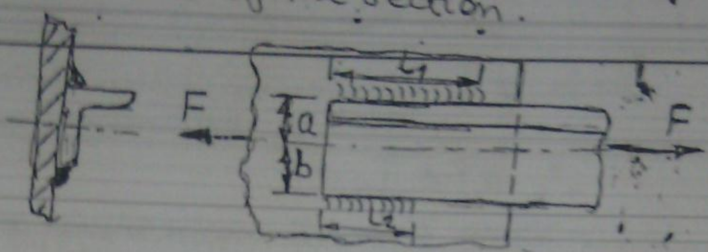
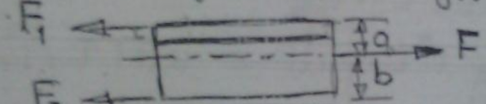


Fig:

Let F = Load acting on the section
τ_A = allowable shear stress of the weld
l_1, l_2 = lengths of side welds.
a, b = distances from neutral axis of the section to edges for l_1, l_2 respectively
s = size of the weld
$t = k.s$ throat thickness.

Then FBD of the weld gives.



$\therefore$ $\boxed{F_1 = \frac{F.b}{(a+b)}}$ and $\boxed{F_2 = \frac{F.a}{(a+b)}}$ (1)

Now $\tau_{max} = \frac{F}{A} = \tau_A$ or $A_{min} = \frac{F}{\tau_A}$

$A_1 = t.L_1$ and $A_2 = t.L_2$ if same size is used.

$\therefore$ Minimum weld lengths are given by

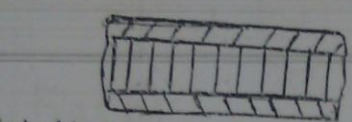
$$\boxed{l_1 = \frac{F_1}{t.\tau_A} = \frac{F.b}{t.\tau_A(a+b)}}$$ (2)

and $$\boxed{l_2 = \frac{F_2}{t.\tau_A} = \frac{F.a}{t.\tau_A(a+b)}}$$

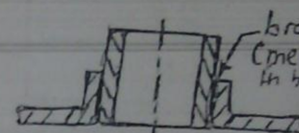
(V) Bonded Joints

When two parts or materials are connected together by a third material different from the base materials; the process is called bonding. Thus brazing (hard soldering), soldering, and cementing (or gluing) are means of bonding parts together.

Figures below show some examples of bonded joints in practice.

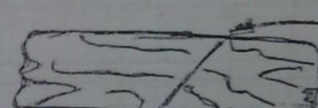


(a) Airplane wing section fabricated by bonding aluminium honeycomb to the skins using resin bonding under heat and pressure.



(b) tubing joined to sheet metal section by brazing metal.

(c) Sheet-metal parts joined by soldering.



(d) Wood parts joined by gluing.

Fig: Bonded joints

General Design Considerations of Bonded Joints

- The joint should be designed so that the bonding material takes only a pure shear load.
- Strength of bonding material is relatively weaker than that of the parts. Therefore enough contact area should be provided in the joint to obtain an adequate margin of safety.
- Properties of bonding agents should be considered (e.g. whether can dissolve in water etc.)
- Strength calculation same as for welding. (Area is that of the bonding material)

Omit 9(b)

(C) Eccentric Loading

If the load is not applied through the c.g. of the weld, then the loading is eccentric.
Consider the two cases in figures below.

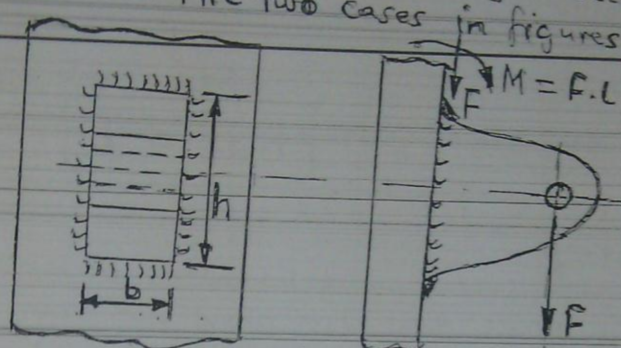


Fig: (i)

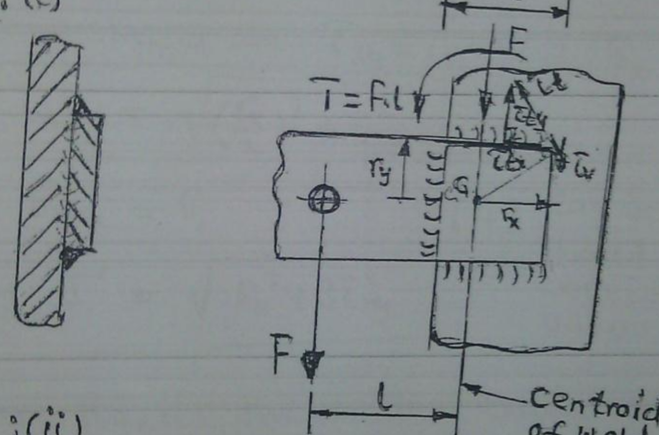


Fig: (ii)

In all cases locate the c.g. of the weld and find the resultant load acting at the c.g. of the weld.

Case fig.(i); the resultant load is a direct (transverse) shear force 'F' and a moment 'M'. Therefore the weld will be subjected to transverse shear and bending.

Hence $\boxed{\tau_v = \frac{F}{A}}$ (1) where A = area of the weld

For bending

$$\boxed{\sigma_b = \frac{M.z}{I}} \quad (2)$$

where $M = F.L$ bending moment

z = distance from weld to centroid.

I = ~~area moment of~~ inertia of weld.

Again for welds

$$\boxed{I = I_u.t} \quad (3)$$

$t = k.s$ throat thickness

I_u = unit area moment of inertia of weld.

I_u can be obtained from tables.

For the various weld sections the bending properties are as listed in table below.

Plane stresses are $\tau_{xy} = \tau_v$ and $\sigma_x = \sigma_b$

$$\therefore \quad \tau_{max} = \sqrt{\left(\frac{\sigma_x}{2}\right)^2 + \tau_{xy}^2} \quad \text{or}$$

$$\sigma_{max} = \sigma_1$$

$$\text{Von Mises} \quad \sigma' = \sqrt{\sigma_x^2 + 3\tau_{xy}^2}$$

(4) Can be applied and should not exceed allowable values

Case fig.(ii), the resultant load is a direct (transverse) shear force 'F' and a torque 'T'. Therefore the weld will be subjected to transverse shear and torsional shear.

Thus $$\boxed{\tau_v = \frac{F}{A}} \quad (1)$$

where $A = L.t$ area of the weld.

$t = k.s$, throat thickness

L = length of the weld

Torsional shear stress 'τ_t' is given by

$$\boxed{\tau_t = \frac{Tr}{J}} \quad (2)$$

where $\bar{T} = F.l$, the torque

r = radius of weld point from c.g.

$\therefore \bar{\tau}_t$ maximum at r_{max}

$\bar{J}$ = polar moment of inertia

$$\boxed{\bar{J} = \bar{J}_u . t}$$

where

$\bar{J}_u$ = unit polar moment of inertia, can be obtained from tables for various sections as listed below.

Note: $$\boxed{\bar{\tau}_t = \sqrt{\bar{\tau}_x^2 + \bar{\tau}_y^2}} \quad (3)$$

Where $$\boxed{\bar{\tau}_{tx} = \frac{\bar{T}.r_y}{\bar{J}}} \quad \text{and} \quad \boxed{\bar{\tau}_{ty} = \frac{\bar{T}.r_x}{\bar{J}}} \quad (4)$$

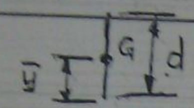
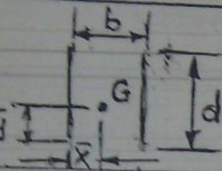
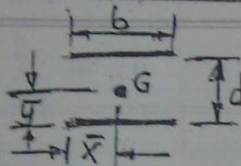
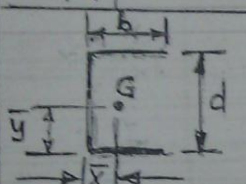
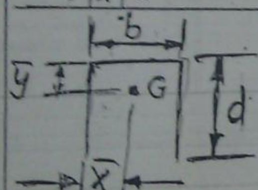
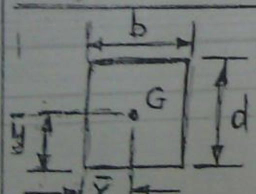
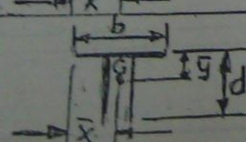
Note: $$\boxed{\bar{\tau}_v = \bar{\tau}_{vy}}$$

$$\therefore \boxed{\bar{\tau}_x = \bar{\tau}_{tx}} \quad \text{and} \quad \boxed{\bar{\tau}_y = \bar{\tau}_v + \bar{\tau}_{ty}} \quad (5)$$

The resultant maximum shear stress '$\bar{\tau}_{max}$' is given by

$$\boxed{\bar{\tau}_{max} = \sqrt{\bar{\tau}_x^2 + \bar{\tau}_y^2}} \quad (6)$$

TABLE: Bending properties of fillet welds. I_u taken about the horizontal axis of the weld.

WELD	THROAT AREA [A]	LOCATION OF G	UNIT MOMENT OF INERTIA I_u
	$A = td$	$\bar{x} = 0$, $\bar{y} = \frac{d}{2}$	$I_u = \frac{d^3}{12}$
	$A = 2td$	$\bar{x} = \frac{b}{2}$, $\bar{y} = d/2$	$I_u = \frac{d^3}{6}$
	$A = 2tb$	$\bar{x} = \frac{b}{2}$, $\bar{y} = d/2$	$I_u = \frac{bd^2}{2}$
	$A = t(2b+d)$	$\bar{x} = \frac{b^2}{2b+d}$, $\bar{y} = \frac{d}{2}$	$I_u = \frac{d^2}{12}(6b+d)$
	$A = t(b+2d)$	$\bar{x} = \frac{b}{2}$, $\bar{y} = \frac{d^2}{b+2d}$	$I_u = \frac{2d^3}{3} - 2d^2\bar{y} + (b+2d)\bar{y}^2$
	$A = 2t(b+d)$	$\bar{x} = \frac{b}{2}$, $\bar{y} = \frac{d}{2}$	$I_u = \frac{d^2}{6}(3b+d)$
	$A = t(b+2d)$	$\bar{x} = \frac{b}{2}$, $\bar{y} = \frac{d^2}{b+2d}$	$I_u = \frac{2d^3}{3} - 2d^2\bar{y} + (b+2d)\bar{y}^2$

(Continued overleaf)

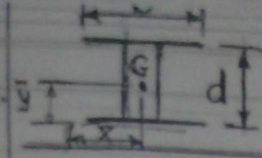
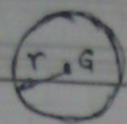
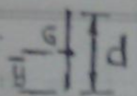
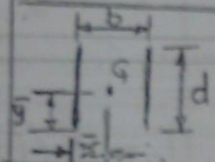
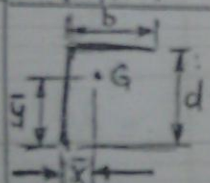
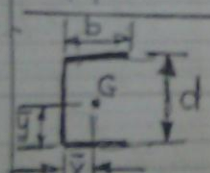
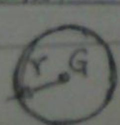
	$A = 2t(b+d)$	$\bar{x} = \frac{b}{2}$ $\bar{y} = \frac{d}{2}$	$J_u = \frac{d^2}{6}(3b$
	$A = 2\pi rt$		$J_u = \pi r^3$

TABLE: Torsional properties for fillet welds.

WELD	THROAT AREA [A]	LOCATION OF G	UNIT POLAR MOMENT OF INERTIA $\bar{J_u}$
	$A = t.d$	$\bar{x} = 0$ $\bar{y} = \frac{d}{2}$	$\bar{J_u} = \frac{d^3}{12}$
	$A = 2td$	$\bar{x} = \frac{b}{2}$ $\bar{y} = \frac{d}{2}$	$\bar{J_u} = \frac{d(3b^2+d^2)}{6}$
	$A = t(b+d)$	$\bar{x} = \frac{b^2}{2(b+d)}$ $\bar{y} = \frac{d^2}{2(b+d)}$	$\bar{J_u} = \frac{(b+d)^4 - 6b^2d^2}{12(b+d)}$
	$A = t(2b+d)$	$\bar{x} = \frac{b^2}{2b+d}$ $\bar{y} = \frac{d}{2}$	$\bar{J_u} = \frac{8b^3+6bd^2+d^3}{12} - \frac{b^4}{3b+d}$
	$A = 2t(b+d)$	$\bar{x} = \frac{b}{2}$ $\bar{y} = \frac{d}{2}$	$\bar{J_u} = \frac{(b+d)^3}{6}$
	$A = 2\pi rt$		$J_u = 2\pi r^3$

Omit