CH 9: Design of Permanent Joints

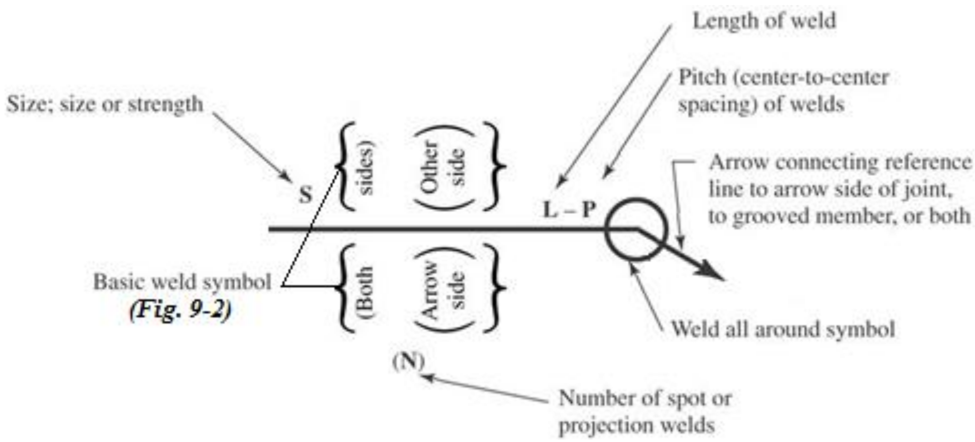
This chapter introduces permanent joining methods which include: welding, soldering, cementing, bonding, etc.

Permanent joining usually leads to significant savings over non-permanent joining (*because of the elimination of fasteners and holes*).

Welding Symbols

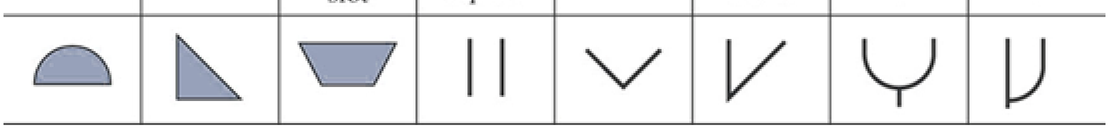
Welding symbols are used on drawings to indicate the type and specifications of the weldments.

- Figure 9-1 shows the *American Welding Society* (*AWS*) standard welding symbol. The most important features of the welding symbol are illustrated below:



- The table below shows the *Basic weld symbol* for the different types of welds.

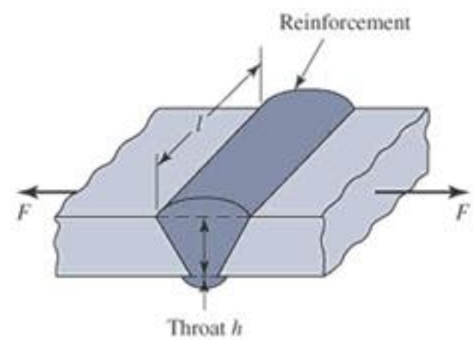
Type of weld							
Bead	Fillet	Plug or slot	Groove				
			Square	V	Bevel	U	J



- Figures 9-3, 4, 5 show some examples for the use of welding symbols.
- In general, there are two types of welds; butt welds and fillet welds.
  - Fillet welds are the most used type for machine elements.
  - Butt welds are usually used for pressure vessels.

- Since welding is associated with a significant increase in temperature, there will be some metallurgical changes in the parent material in the vicinity of the weldments.
  - Thus, when checking for failure of the parent material in the vicinity of the weldments, it is recommended to use the properties of *Hot-Rolled* (*HR*) material even if the material is *Cold-Drawn* (*CD*).
- Also, residual stresses might be introduced during welding because of clamping or sometimes because of the order of welding.

Butt and Fillet Welds



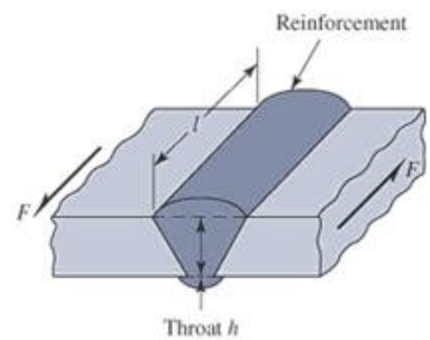
- For a Butt weld subjected to tensile force or shear force;
  - The normal stress is found as:

$$\boxed{\sigma = \frac{F}{hl}}$$

Where h: Throat of the weld

(*Does not include the reinforcement*)

l: Length of the weld

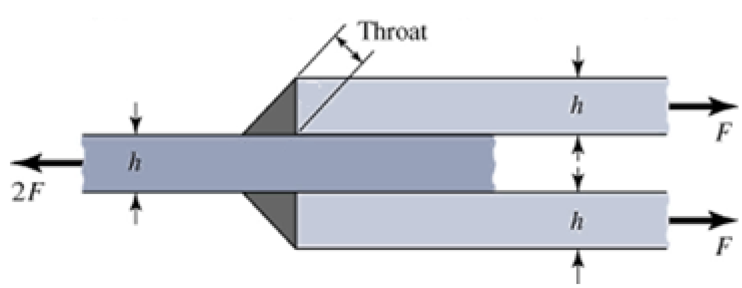


  - The average shear stress is found as:

$$\boxed{\tau = \frac{F}{hl}}$$

- The reinforcement causes stress concentration and therefore it should be removed by grinding or machining if the joint is subjected to fatigue loading.

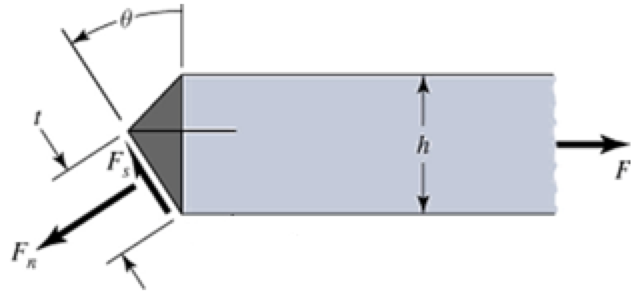
- For a Fillet weld loaded in tension;
  - The forces in each weldment will have two components. *Normal* force "F_n" and *Shear* force "F_s" where their magnitudes change with the angle.



  - From equilibrium the magnitudes are found to be:

$$F_n = F\cos\theta$$

$$F_s = F\sin\theta$$



- From trigonometry the throat "t" is found as:

$$t = \frac{h}{\cos\theta + \sin\theta}$$

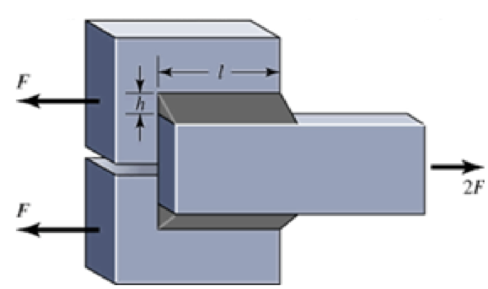
- Therefore, at any angle θ there are normal stress "σ" and shear stress "τ" where;

$$\sigma = \frac{F_n}{A} = \frac{F_n}{lt} \qquad \& \qquad \tau = \frac{F_s}{A} = \frac{F_s}{lt}$$

  - The values of σ & τ depend on θ and using *Von Mises* stress, the maximum stress is found to occur at $\theta = 62.5°$.
  - However this analysis procedure is too complicated and the geometry of weldments is not uniform.

- Instead, a simplified (*conservative*) approach is used for design purposes.
  - The approach ignores the normal stresses and assumes that the external force is carried as shear stress only on the smallest throat area of the weldment (*the smallest value of "t" @ $\theta = 45°$*).
    - Conservative because all the external force is assumed to cause shear stress knowing that the shear strength is almost half of the normal strength.
  - According to this approach, the shear stress is found as:

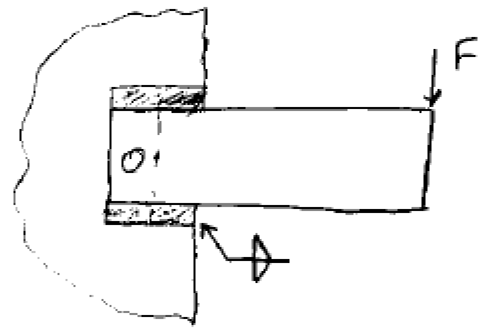
$$\tau = \frac{F}{lt} = \frac{F}{l\,(h\cos 45)} = \boxed{\frac{1.414\,F}{l\,h}}$$



- The same equation is also used to calculate the shear stress when a fillet weld is loaded in shear.

- For a welded joint loaded with eccentric force there will be, in general, more than one shear stress component acting on the weldments where there will be a primary shear due to the force itself and a secondary shear resulting from the moment or torque produced by the force.

Stresses in Welded Joints in Torsion



For a welded shear joint such as the shown there will be two shear stress components in the weldments.

- Primary shear (*due to the shear force*).

$$\tau' = \frac{V}{A}$$

Where A is the *total throat area* of all the welds.

- Secondary shear (*due to the twisting moment "the torque"*).

$$\tau'' = \frac{Mr}{J}$$

Where: r is the distance from the centroid of the weld group to the point of interest.
J is the polar moment of inertia of the weld group (*based on the throat area*) about the centroid of the group.

➢ The centroid can be located as:

$$\bar{x} = \frac{A_1x_1 + A_2x_2 + A_3x_3 + \cdots}{A_1 + A_2 + A_3 + \cdots}$$

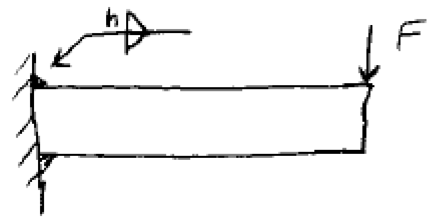
$$\bar{y} = \frac{A_1y_1 + A_2y_2 + A_3y_3 + \cdots}{A_1 + A_2 + A_3 + \cdots}$$

- To make the calculation easier, the polar moment of inertia for some common welding patterns is given in tables.
  - ❖ *Table 9 - 1* gives the location of the centroid and the *unit* polar moment of inertia "J_u" for some common weld shapes.
    - ➢ J_u is the polar moment of inertia for a line (*assuming unit width*).
    - ➢ Since the minimum throat width for a fillet weld is $(0.707\ h)$ then J is found as:

$$J = 0.707\ h\ J_u$$

*See **Example 9-1** from text*

Stresses in Welded Joints in Bending



For the cantilever beam welded to a support using fillet wilds as shown, the welds will be subjected to two components of shear stress.

- Primary shear (*due to the shear force*).

$$\boxed{\tau' = \frac{V}{A}}$$

Where A is the *total throat area* of all the welds.

- Secondary shear (*due to the tensile force produced by the bending moment*).

  The moment will cause a bending stress of magnitude $\sigma = \frac{Mc}{I}$. However, according to the conservative approach we use, all the force acting on fillet weld is assumed to be carried as shear force on the throat area of the weld.

  - Thus we can write;

$$\boxed{\tau'' = \frac{Mc}{I}}$$

Where: c is the distance from the neutral axis of the weld group to the point of interest.
I is the moment of inertia of the weld group (*based on the throat area*) about the neutral axis of the group.

- *Table 9 - 2* gives the location of the centroid and the *unit* moment of inertia "I_u" for some common weld shapes.
  - The moment of the inertia of the throat area is found as:

$$\boxed{I = 0.707\, h\, I_u}$$

The Strength of Welded Joints

The electrode materials (filler material) are standardized and they are usually chosen such that they have higher strength than the parent materials.

- *Table 9 - 3* gives the minimum properties for the *AWS* electrode classes.
  - It should be noted that the table gives the *"tensile" yield strength* of the electrode material.
  - The "shear" yield strength is found using the distortion energy theory as:

$$S_{ys} = 0.577\ S_y$$

- The welding code includes a *1.6 design factor* for the allowable shear stress in weldments: $\tau_{all} = \left(0.577\ S_y\right)/1.6$
  - *Table 9 - 6* gives the allowable shear stress in fillet welds for the different electrode classes (*with 1.6 design factor included*).

- As mentioned earlier, the parent material in the vicinity of the weldment will be subjected to high temperatures and thus its properties might change. Therefore, if the parent material is *Cold-Dawn* it will be heat treated and thus it will have properties similar to a *Hot-Rolled* material (*in the vicinity of the weldment*).
- According to the welding code, the allowable values of shear & normal stresses in the base material are:

$$\tau_{all} = 0.4\ S_y \quad \& \quad \sigma_{all} = 0.6\ S_y$$

S_y of the base material

- The procedure for evaluating the strength of welded joints is as follows:
  - Find the primary shear stress due to external forces.
  - Find the secondary shear stress due torsion *and/or* bending moments.
  - Add the primary and secondary shear stress components using vector summation.
  - Find the strength of weldments, and thus the allowable load.
  - Find the strength of the parent material and thus the allowable load.

*See **Examples 9-2 & 9-4** from text*