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.

<table>
<thead>
<tr>
<th>Type of weld</th>
<th>Groove</th>
</tr>
</thead>
<tbody>
<tr>
<td>Bead</td>
<td>Plug or slot</td>
</tr>
<tr>
<td>Fillet</td>
<td>Square</td>
</tr>
<tr>
<td>Butt</td>
<td></td>
</tr>
</tbody>
</table>

- 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:

\[
\sigma = \frac{F}{hl}
\]

Where  \( h \): Throat of the weld

*(Does not include the reinforcement)*

\( l \): Length of the weld

➢ The average shear stress is found as:

\[
\tau = \frac{F}{hl}
\]

➢ 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 \( \theta \) there are normal stress “\( \sigma \)” and shear stress “\( \tau \)” where:
  \[ \sigma = \frac{F_n}{A} = \frac{F}{lt} \quad \text{and} \quad \tau = \frac{F_s}{A} = \frac{F}{lt} \]

  - The values of \( \sigma \) & \( \tau \) depend on \( \theta \) and using Von Mises stress, the maximum stress is found to occur at \( \theta = 62.5^\circ \).
  - 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 “\( t \)” @ \( \theta = 45^\circ \)).
  - 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:
  \[ \tau = \frac{F}{lt} = \frac{F}{l(h \cos 45)} = \frac{1.414F}{lh} \]

  - 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:

\[
J = 0.707 \, h \, J_u
\]

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*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)*.
  
  $$
  \tau' = \frac{V}{A}
  $$

  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;

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

  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:

  $$
  I = 0.707\ h \ I_u
  $$
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:
    \[
    S_{ys} = 0.577 \cdot S_y
    \]

- The welding code includes a 1.6 design factor for the allowable shear stress in weldments:
  \[
  \tau_{all} = \left( 0.577 \cdot S_y \right) / 1.6
  \]

- 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:
  \[
  \tau_{all} = 0.4 \cdot S_y \quad \& \quad \sigma_{all} = 0.6 \cdot S_y \quad S_y \text{ of the base material}
  \]

- 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*